APPENDIX L

Derivation of Remedial Goals and Tissue Monitoring Endpoints

Remedial goals (RGs) are media-specific cleanup goals for a selected remedial action that set targets for meeting primary ecological endpoints. The Baseline Ecological Risk Assessment (BERA) (Arcadis 2012) concluded that risks in the lower Emory and Clinch Rivers to benthic invertebrate communities, and birds that consume these invertebrates, are sufficient to warrant risk management in the Engineering Evaluation/Cost Analysis. Arsenic and selenium were identified as the constituents of ecological concern (COECs) associated with these risks.

The data in the BERA provide a reasonable basis for development of sediment RGs for the benthic invertebrate community. Risk characterization was based on multiple lines of evidence, including surveys of benthic invertebrate communities, toxicity tests of site sediment, and physical and chemical analyses of site sediment and sediment porewater. The best evidence of adverse effects was provided by the paired toxicity tests and chemical analyses of sediment from the Emory and Clinch Rivers. These data also provide the best basis for development sediment RGs for arsenic and selenium, as described below.

Risks to invertebrate-feeding birds were based on reproduction data from nest box surveys (tree swallow), tissue concentrations of constituents (e.g., tree swallow eggs and nestlings), and modeled dietary exposures (killdeer and tree swallow). The nest box surveys and tissue samples provide site-specific data, but cannot be adequately linked with site sediment concentrations to derive sediment RGs. Dietary exposure models could be used to back-calculate sediment concentrations of COECs associated with adverse effects. However, this approach is not appropriate for selenium, is not based on site-specific effects data, and has substantial inherent uncertainties. More specifically:

- The bioaccumulative properties of selenium make it difficult to measure in sediment or water at biologically relevant concentrations (EPA 2004). This is reflected in the relatively low frequency of detection in sediment.
- Arsenic is a COEC for killdeer only and comparison with literature-derived effects values is the only available line of evidence.
- The site data relating concentrations in sediment to concentrations in prey are not tightly correlated spatially. Paired sediment and tissue samples are not available for invertebrates (i.e., mayfly nymphs), making it necessary to calculate biota-sediment accumulation factors from reach-wide averages.

Given these factors, sediment RGs are not provided for protection of invertebrate-feeding birds (killdeer). However, as a heuristic exercise the dietary exposure model was used to estimate the arsenic sediment concentrations that would correspond with the literature-derived effects values used in the BERA for killdeer. The results of this exercise are briefly described below.

Invertebrate tissue monitoring endpoints (TME) also were derived for the representative bird species (i.e., killdeer and tree swallow). TME is a concentration in dietary items that, when consumed by these species, is estimated to be protective of the population. TME is based on literature-derived effects data and modeled dietary exposures, and is also compared with concentrations in tissues of prey items collected at the site (e.g., mayfly nymphs and adults). This avoids the inherent uncertainty associated with using biota-sediment accumulation factors. The derivation of TMEs for killdeer and tree swallow are described below.

1. Remedial Goals

Site-specific sediment toxicity test data provide strong support for RGs for arsenic and selenium in sediments. Long-term sediment toxicity testing was conducted on laboratory raised amphipods and midges using Emory River sediment samples from Emory River Mile (ERM) 0.5 (midge only), ERM 1.0, ERM 2.5, ERM 3.5, and ERM 5.5 (amphipod only). These four locations for each organism were chosen based on results from shorter term, 10-day tests where 8 samples were tested. Each of the sediments from the four locations were diluted in a 100, 80, 60, 40, 20, and 10% site sediment-to-reference ratio in order to provide necessary data to generate useful measurement endpoints to assess effects.

Sediment toxicity labs provided toxicity endpoints as percent site sediment. This percent site sediment represents portions of both the reference and the site sample. Arsenic and selenium concentrations were measured by analytical laboratories in both the reference and site sediment samples. Total arsenic and selenium concentrations associated with the toxicity test endpoints was calculated for both midge and amphipod tests and presented in Table L-1.

The long-term tests for the amphipods ran for 28 days and generated concentrations that inhibited 25% of test organisms (IC_{25}) for survival and biomass. Biomass incorporates both survival and growth data, because it is calculated as the dry weight of surviving organisms divided by the number of original organisms at the start of the tests.

Long-term partial life cycle tests for midges ran until no emergence occurred for 3 consecutive days in each treatment sample (>50 days). These tests also generated IC_{25} endpoints for survival, but instead of biomass, emergence was measured at the termination of the test.

The IC_{25} endpoints used in the BERA to identify arsenic and selenium as COECs provide a reasonably conservative range of concentrations for use as sediment RGs. The use of IC_{25} endpoints takes full advantage of the wealth of data generated via dilution-series testing protocols. This is also consistent with recommendations in the scientific literature for appropriate reporting of toxicity test results, which advocate against the use of no observed effects concentrations and lowest observed effects concentrations when more robust endpoints such as an IC_{25} are available (Warne & van Dam 2008). IC_{25} concentrations are presented and discussed further in the BERA (Arcadis 2012).

The average IC_{25} for each of the tested species was selected as the endpoints that define the RG range for each COEC. The amphipod and midge are widely accepted as sediment test organisms because they are recognized as being more sensitive to chemical exposures than most other tested species. That is, they are at the lower end of the species sensitivity distribution for a variety of COECs. Selecting two points from the lower end of the assumed species sensitivity distribution is reasonably conservative, because the RGs are intended to be protective of the benthic invertebrate community as a whole, rather than any one given species.

1.1. Arsenic

The BERA (Arcadis 2012) concluded that, more than any other constituent, arsenic co-varied with ash, other ash-related constituents, and effects in both the short- and long-term tests for both organisms. Arsenic was also found at higher than reference area concentrations in many organisms (benthic invertebrates, fish, birds, mammals, and turtles), and it was identified as a COEC for benthic invertebrates and birds (killdeer).

The sediment RGs based on the average IC_{25} for survival and sublethal (emergence and biomass) endpoints were 29 milligrams per kilogram (mg/kg) for the midge and 41 mg/kg for the amphipod (Figure L-1). This range brackets the consensus-based probable effect concentration of 33 mg/kg for arsenic in sediment (MacDonald, Ingersoll, & Berger 2000).

This range also brackets the low end of the range of sediment concentrations protective of killdeer, which were estimated at 33 mg/kg and 45 mg/kg. As noted above, these concentrations are for comparative purposes only and are not appropriate for use as sediment RGs. They were back-calculated using the dietary exposure model and literature-derived effects values presented in the BERA. Bioaccumulation of arsenic in prey items was modeled using submerged sediment data (both bulk and vibracore samples) and whole body nymph mayfly data. An exponential function ($y = 3.316e^{0.0705x}$) was fit to the data with a resulting R squared value of 0.66. Although not sufficient for deriving of sediment RGs, this exercise does suggest that the arsenic RG range for benthic invertebrates is reasonably protective of killdeer.

1.2. Selenium

The BERA (Arcadis 2012) concluded that selenium also co-varied with ash, the long-term toxicity tests, and to a lesser extent the short-term toxicity tests. Selenium was also found at higher than reference area concentrations in many organisms (benthic invertebrates, fish, birds, amphibians, and turtles), and was identified as a COEC for benthic invertebrates and birds (killdeer, tree swallow).

The sediment RGs based on the average IC_{25} for survival and sublethal (emergence and biomass) endpoints were 2.8 mg/kg for the midge and 3.2 mg/kg for the amphipod (Figure L-2). There is no known consensus-based probable effect concentration for selenium at this time.

2. Tissue Monitoring Endpoints

The dietary exposure models developed in the BERA were used to derive TMEs for riparian- and aerial-feeding insectivorous bird populations. TMEs are risk-based concentrations in tissue of prey items that result in hazard quotients (HQs) equal to one. The HQ is defined as the dietary exposure dose divided by the effects dose (i.e., toxicity reference value [TRV]). TMEs were calculated for the "surrogate" species used in the BERA to represent riparian- and aerial-feeding insectivorous bird populations (i.e., killdeer and tree swallow). TMEs are developed by re-arranging the refined dietary exposure model in the BERA (Arcadis 2012) to solve for tissue concentration when HQ = 1. Inputs used in the TMEs calculation include receptor exposure parameters (i.e., body weight [BW] and food ingestion rate [IR]) and TRVs.

Receptor assumptions for the killdeer and the tree swallow (i.e., BW, IR) were based on those used in the BERA (Arcadis 2012). It was assumed that 100% of the diet is made up of invertebrates from the site for the calculation of TMEs. It was also assumed that constituents detected in the tissue are 100% bioavailable. Further, since intake through ingestion of surface water contributed <1% to the dose in the BERA dietary exposure model, surface water intake was considered negligible in the calculation of TMEs.

Like the receptor assumption, the refined avian TRVs used in the BERA were used to calculate the TMEs. A TRV is defined as a daily dose of a chemical expressed in milligram per kilogram body weight per day (mg/kg per day) and represents a dose associated with no effect or lowest effect at the population level of ecological organization. TRVs based on the no observed adverse effect level (NOAEL) and/or the lowest observed adverse effect level (LOAEL) values of the refined TRVs selected in the BERA were used to estimate a range of TMEs for each receptor.

The following equation was used to calculate the TMEs:

$$TME = \frac{(THQ \times TRV \times BW) - (Csed \times IRsed \times SUF)}{IRfd \times SUF}$$

TME = tissue monitoring endpoint (mg/kg dry weight)
THQ = target hazard quotient (unitless); set at 1
TRV = toxicity reference value (mg/kg per day)
Csed = sediment concentration (mg/kg)
IRsed = sediment ingestion rate (kilograms per day)
BW = body weight of receptor (kilograms)
IRfd = food ingestion rate (kilograms dry tissue per day)
SUF = site use factor (unitless); represents the fraction of the exposure area for the receptor represented by the area of contamination generally calculated by dividing the area of contamination by the home or foraging range of the receptor; assumed to be 1

Note: For the tree swallow, the IRsed was zero and therefore the second portion of the numerator in above equation was not needed to calculate the TME.

The calculation of the TMEs for the protection of the killdeer and the tree swallow as a representative of riparian- and aerial-feeding insectivores birds are presented in Tables L-2 and L-3, respectively. TMEs were calculated on a dry-weight basis.

For arsenic, the TME range is 34 to 81 mg/kg for dietary exposures of killdeer.

For selenium, the TME ranges are 2.3 to 5.0 mg/kg for dietary exposures of killdeer and 1.6 to 2.8 mg/kg for dietary exposures of tree swallow.

References

Arcadis 2012. *Kingston Ash Recovery Project Non-Time Critical Removal Action River System Baseline Ecological Risk Assessment*. Document No. EPA-EO-050. August 3, 2012.

EPA 2004. *Draft Aquatic Life Water Quality Criteria for Selenium - 2004*. EPA-822-D-04-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. November.

MacDonald, D.D., Ingersollm, C.G., and Berger, T.A. 2000. “Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems.” *Arc. Environ. Contam. Toxicol.* 39:20-31.

Warne, M.S. and van Dam, R. 2008. “NOEC and LOEC Data Should No Longer Be Generated or Used.” *Australasian Journal of Ecotoxicology*. 14:1-5.

Attachments

Table L-1 Arsenic and Selenium IC_{23} Concentrations for Chironomid and Amphipod Sediment Toxicity Test Endpoints

Table L-2 Calculation of Diet Tissue Monitoring Endpoints for the Kildeer

Table L-3 Calculation of Diet Tissue Monitoring Endpoints for the Tree Swallow

Figure L-1 Average Emory River IC_{25} from Sediment Toxicity Tests Using Amphipods and Chironomids – Arsenic

Figure L-2 Average Emory River IC_{25} from Sediment Toxicity Tests Using Amphipods and Chironomids – Selenium

Table L-1. Arsenic and Selenium IC25 Concentrations for Chironomid and Amphipod Sediment Toxicity Test Endpoints

Chironomid

	ERM 0.5		ERM 1.0		ERM 2.5		ERM 3.5		Average	
	IC_{25}		IC_{25}		IC_{25}		IC_{25}		IC_{25}	
	Arsenic	Selenium	Arsenic	Selenium	Arsenic	Selenium	Arsenic	Selenium	Arsenic	Selenium
PLC Survival	15.72	2.55	19.98	2.91	42.77	3.06	37.97	2.81	29.11	2.83
PLC Emergence	14.44	2.43	19.65	2.88	42.32	3.04	37.01	2.77	28.35	2.78

Amphipod

	ERM 1.0		ERM 2.5		ERM 3.5		ERM 5.5		Average	
	IC_{25}		IC_{25}		IC_{25}		IC_{25}		IC_{25}	
	Arsenic	Selenium	Arsenic	Selenium	Arsenic	Selenium	Arsenic	Selenium	Arsenic	Selenium
28d Survival	>100%	>100%	68.98	4.19	>100%	>100%	>100%	>100%	68.98	4.19
28d Biomass	22.90	3.18	40.25	2.96	57.31	3.61	16.65	1.86	34.28	2.90

Overall average:	Arsenic	Selenium
Chironomid	29	2.8
Amphipod	41	3.2
Midpoint	35	3.0

Notes: Table uses only IC_{25} values and excludes those samples with an IC25 > 100% site sediment (i.e. no effect)

Selenium concentrations are based on the assumption that the reference concentration is equal to the reporting limit (1.33 mg/kg)

Concentrations are in mg/kg dry weight of sediment for arsenic and selenium

IC25- Concentrationg inhibiting 25% test ogranisms. PLC- Partial Life Cycle

Table L-2
Calculation of Diet Tissue Monitoring Endpoints for the Killdeer
Kingston Fossil Plant
Tennesse Valley Authority

Constituent	Sediment Concentration (Csed) [a] (mg/kg)	Refined Toxicity Reference Value (TRV) Range [b] (mg/kg-BW-day)		Calculated Diet Tissue Monitoring Endpoint (TME) [c] (mg/kg)	
		NOAEL	LOAEL	low	high
Inorganics					
Arsenic	41	5.8	13	34	81
Selenium	3	0.4	0.8	2.3	5.0

LOAEL	Lowest Observed Adverse Effect Level
mg/kg	milligrams per kilogram.
mg/kg-BW-day	milligrams per kilogram of body weight per day.
NOAEL	No Observed Adverse Effect Level

[a] Maximum sediment remedial goals (RGs) based on effects to benthic invertebrates.
[b] TRVs are from the Baseline Ecological Risk Assessment (ARCADIS 2012).
[c] TME = [(THQ x TRV x BW) - (Cs x IRsed x SUF)] / (IRfd x SUF)
Assuming 100% of diet is invertebrates from source.
Receptor exposure parameters are from the Baseline Ecological Risk Assessment (ARCADIS 2012) and are presented below.

Exposure Assumptions			
Body Weight	BW	kg	0.095
Food Ingestion Rate	IRfd	kg/day	0.014
Soil/Sed Ingestion Rate	IRsed	kg/day	0.002
Site Use Factor	SUF	--	1
Target Hazard Quotient	THQ	--	1

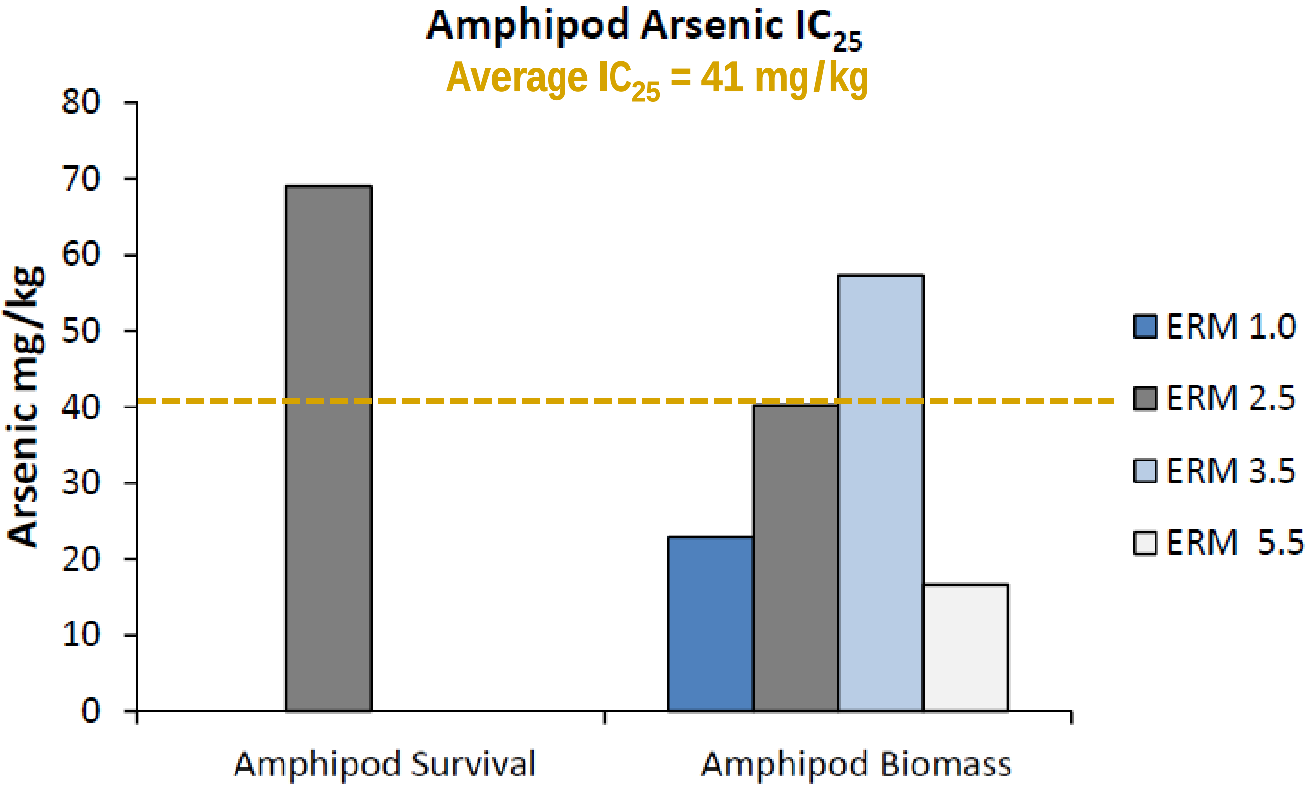
Table L-3
Calculation of Diet Tissue Monitoring Endpoints for the Tree Swallow
Kingston Fossil Plant
Tennesse Valley Authority

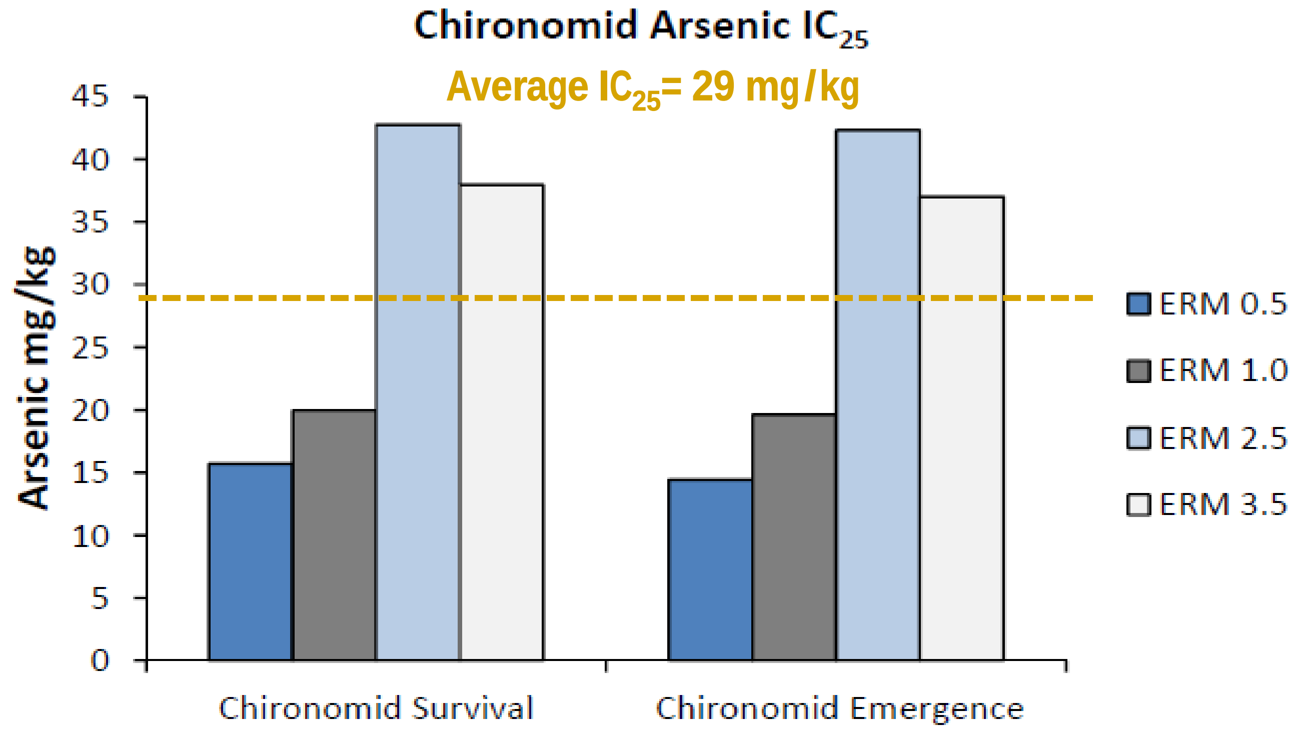
	Refined Toxicity Reference Value (TRV) Range [a]		Calculated Diet Tissue Monitoring Endpoint (TME) [b]	
	NOAEL	LOAEL	low	high
Constituent	(mg/kg-BW-day)		(mg/kg)	
Inorganics				
Selenium	0.4	0.7	1.6	2.8

LOAEL	Lowest Observed Adverse Effect Level
mg/kg	Milligrams per kilogram.
mg/kg-BW-day	Milligrams per kilogram of body weight per day.
NOAEL	No Observed Adverse Effect Level

[a] TRVs are from the Baseline Ecolgoical Risk Assessment (ARCADIS 2012) .
[b] TME = (THQ x TRV x BW) / (IRfd x SUF)
Assuming 100% of diet is invertebartes from source.
Receptor exposure parameters are from the Baseline Ecological Risk Assessment (ARCADIS 2012) and are presented below.

Exposure Assumptions			
Body Weight	BW	kg	0.020
Food Ingestion Rate	IRfd	kg/day	0.005
Site Use Factor	SUF	--	1
Target Hazard Quotient	THQ	--	1



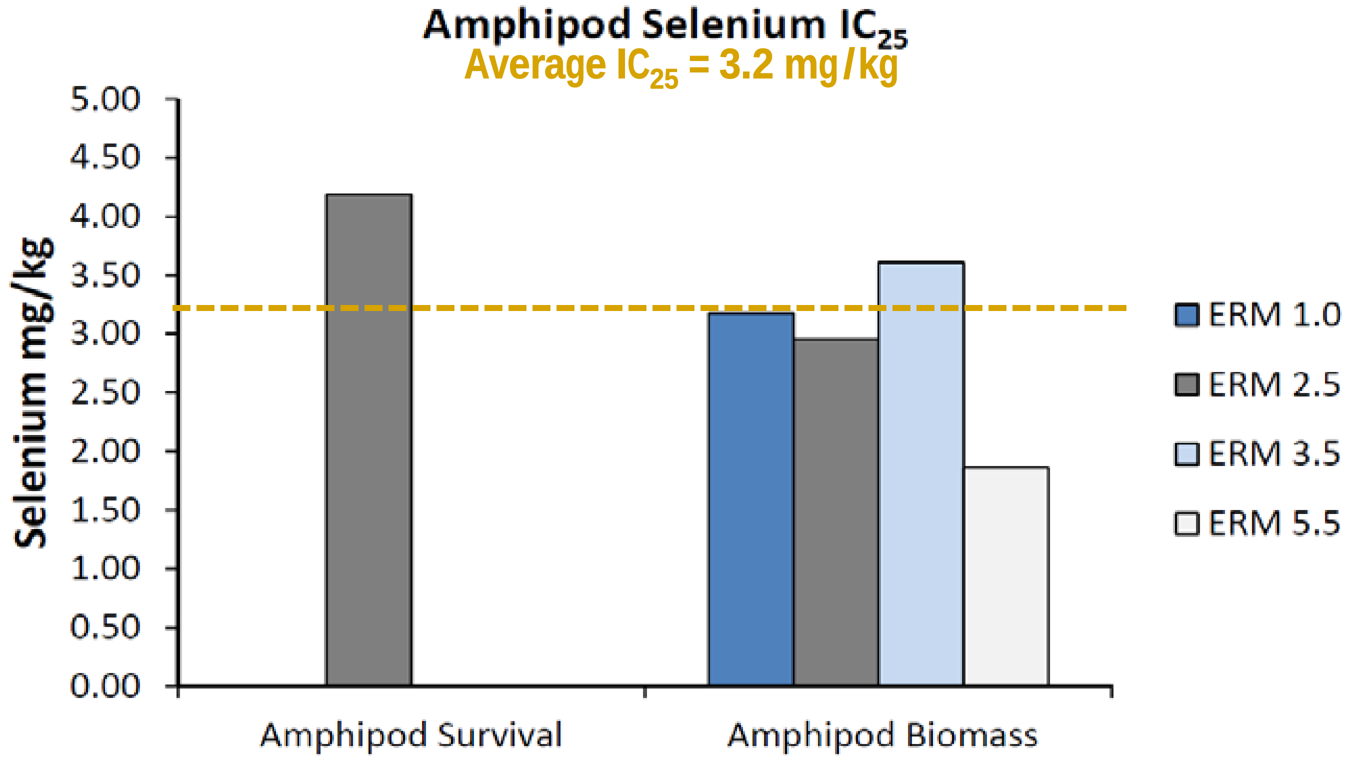


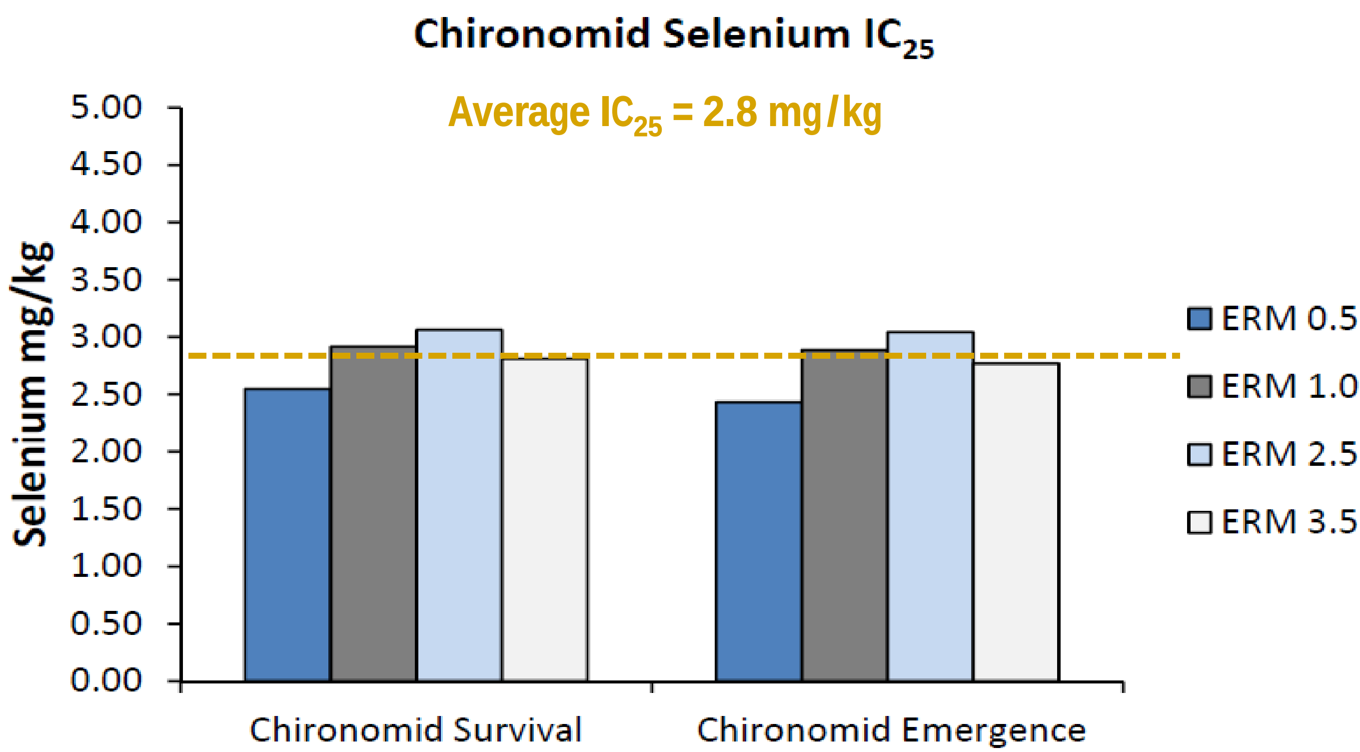
Note only ERM 2.5 had a measurable effect on amphipod survival.
ERM – Emory River Mile; mg/kg – milligram per kilogram;
IC_{25} – Concentration where 25% of organisms are inhibited.
IC_{25} endpoints for each location tested were averaged (except for ERM 0.5 and 5.5 where only one organism was tested) and an overall average for survival and sublethal (emergence and biomass) endpoints was generated.
This range is 29 – 41 mg/kg arsenic.

ARCADIS

Average Emory River IC_{25} from Sediment Toxicity Tests Using Amphipods and Chironomids

FIGURE
L-1





Note only ERM 2.5 had a measurable effect on amphipod survival.
ERM – Emory River Mile; mg/kg – milligram per kilogram;
IC_{25} – Concentration where 25% of organisms are inhibited.
IC_{25} endpoints for each location tested were averaged (except for ERM 0.5 and 5.5 where only one organism was tested) and an overall average for survival and sublethal (emergence and biomass) endpoints was generated.
This range is 2.8 – 3.2 mg/kg selenium.

ARCADIS

Average Emory River IC_{25} from Sediment Toxicity Tests Using Amphipods and Chironomids

FIGURE
L-2