RISK MANAGEMENT CRITERIA FOR METALS AT BLM MINING SITES

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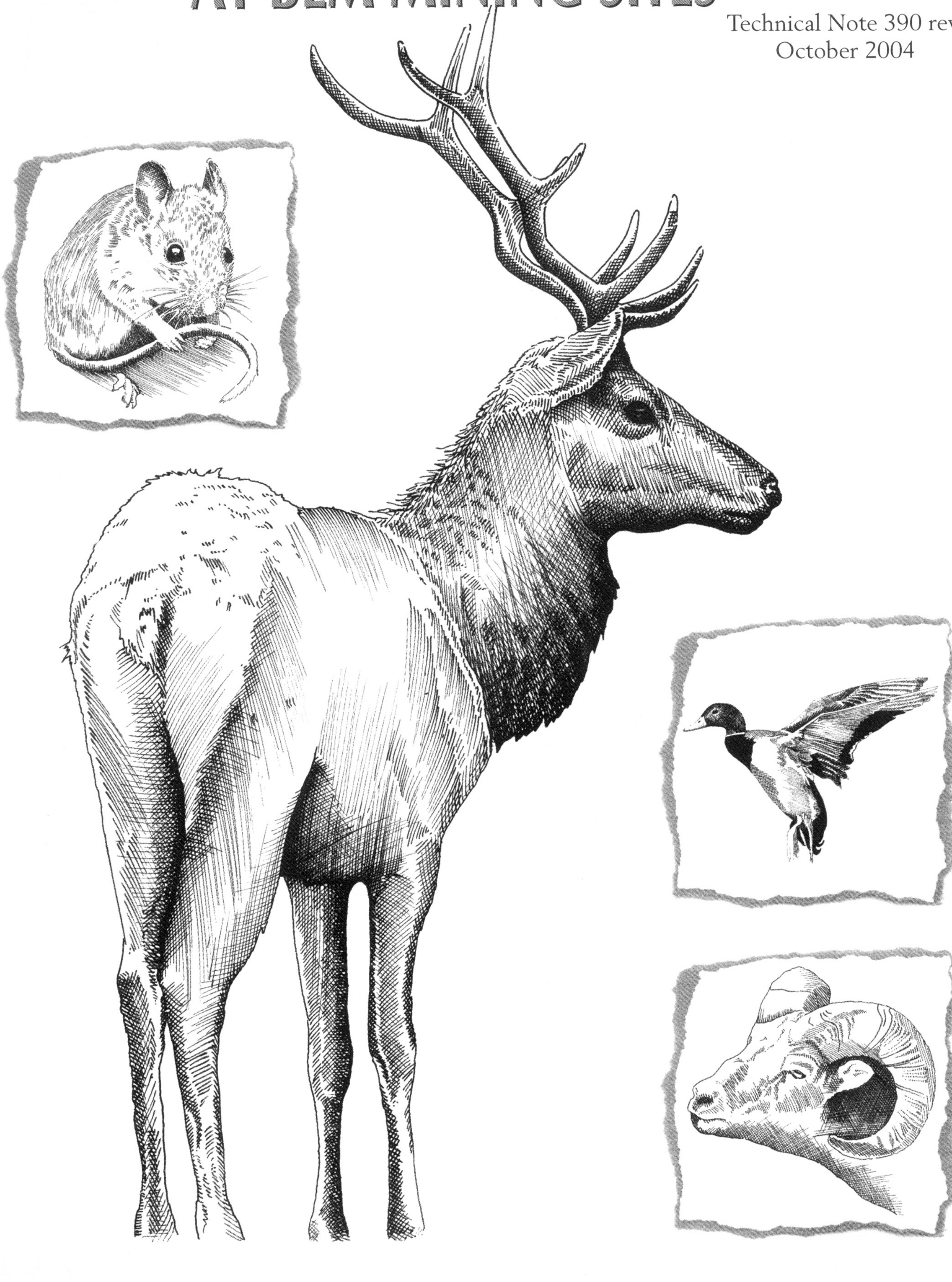

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United States Department of the Interior
Bureau of Land Management

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HUMAN HEALTH RISK MANAGEMENT CRITERIA

RISK MANAGEMENT CRITERIA FOR METALS AT BLM MINING SITES

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INTRODUCTION

Mining activities have influenced the environment of Public Lands throughout the West. Tailings from ore mills have contributed large amounts of heavy metals into air, water, stream sediments, and soils. Uncontrolled migration of metal-laden mine tailings via dust entrainment and erosion continues to present potentially adverse risks to human health and wildlife. Recreational demands are increasing on areas where acute and prolonged exposure to relatively high metal concentrations in soils, sediments, and surface waters is occurring. In some locations, avian and aquatic kills have been reported.

To address these issues, BLM has developed acceptable multimedia criteria for the chemicals of concern (heavy metals) as they relate to recreational use and wildlife habitat on BLM lands. The primary objective of this report is to establish risk management criteria (RMC) for human health and wildlife. Risk management criteria provide numerical action levels for metals in environmental media. RMC are designed (1) to assist land managers in making natural resource decisions and (2) to support ecosystem management. Ecosystem management is defined as the skillful use of ecological, economic, social, and managerial principles in managing ecosystems to produce, restore, or sustain ecosystem integrity and desired conditions, uses, products, or values and services over the long term.

RMC designed to protect human receptors for the metals of concern were developed using available toxicity data and standard U.S. Environmental Protection Agency (EPA) exposure assumptions. RMC designed to protect wildlife receptors for the metals of concern were developed using toxicity values and wildlife intake assumptions reported in the current ecotoxicology literature. Ingestion of soil, sediment, and plants is assumed to be the predominant source of metal exposure for wildlife receptors.

The contaminants of concern and metal contamination migration pathways were identified from historical information and site visits. Potential receptors, receptor exposure routes, and exposure scenarios were identified from on-site visits and discussions with BLM personnel. Representative wildlife receptors at risk were chosen using a number of criteria, including likelihood of inhabitation and availability of data.

Risk management criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are indicated. Furthermore, these criteria may be used as target cleanup levels if remedial action is undertaken.

HUMAN HEALTH RISK MANAGEMENT CRITERIA

A wide range of possible exposure scenarios was examined to represent potential human exposures that might occur on BLM lands. A conceptual site model was developed for abandoned mining sites on BLM lands, Figure 1. This model shows the relationships of waste sources, release mechanisms, and migration pathways to human and ecological receptors. Table 1 provides an overview of the potential human receptors considered and the media to which they are assumed to be exposed. All exposure factors are presented in Appendix A. For the most part, the exposure assumptions used in the calculation of human health RMC are those provided in EPA guidance documents.

The equations for the calculations of the human RMC in soil, sediment, groundwater, surface water, and fish are presented in Appendix A. The RMC correspond to a generally recognized acceptable level of health risk, specifically an excess cancer risk of 1.0E-05 or a noncancer hazard index of 1.0. An excess cancer risk of 1.0E-05 means that for an individual exposed at these RMC under the described exposure conditions, there is only a 1 in 100,000 chance that they would develop any type of cancer in a lifetime as a result of contact with the metals of concern on BLM lands. A hazard index of 1.0 means that the dose of noncancer metals assumed to be received on BLM lands by any of the receptors in a medium is lower than, or the same as, a dose that would not result in any adverse noncancer health effects.

The risk and hazard levels are consistent with EPA guidance. The concept behind the RMC is that people will not experience adverse health effects from metal contamination on BLM lands during their lifetimes if exposure is limited to soil, sediments, and waters with concentrations at or less than the RMC. To calculate this chance, EPA's conservative interpretations of cancer data have been used; therefore, the likelihood that this risk has been underestimated is very low.

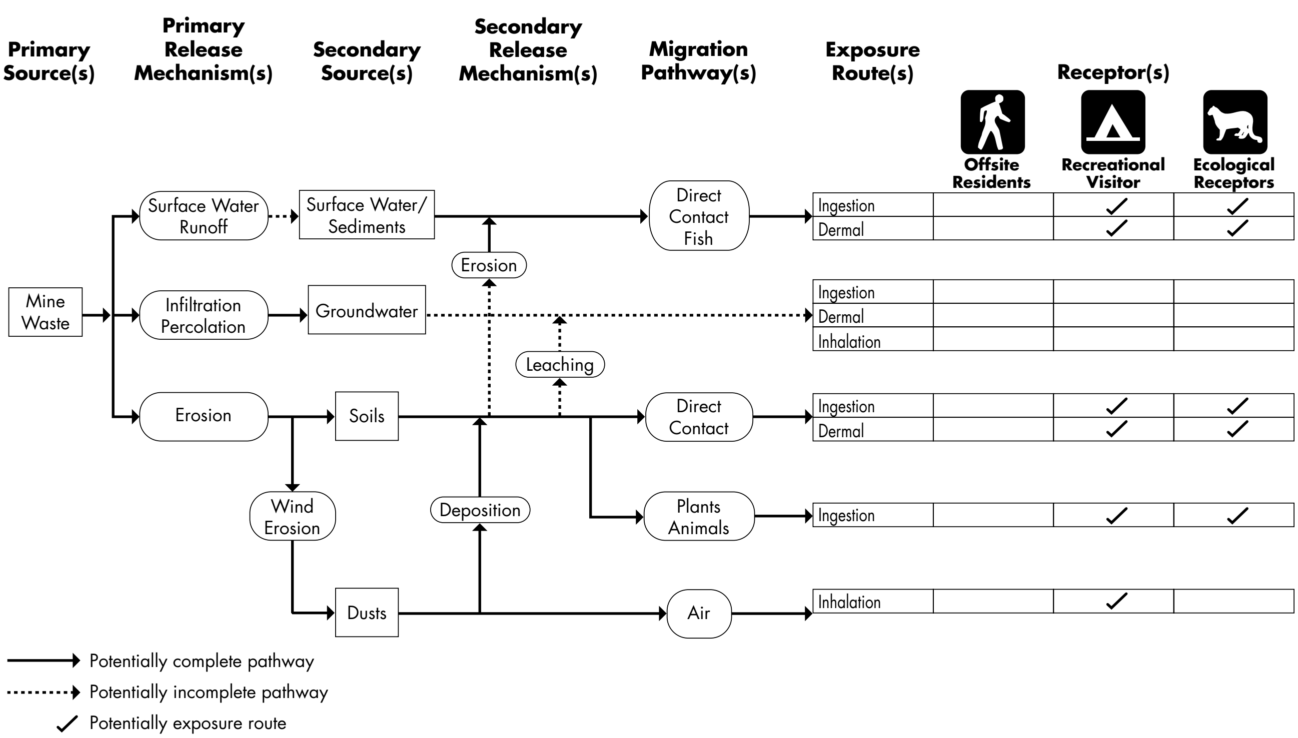

FIGURE 1. Mine Waste Conceptual Site Model for Human and Ecological Risk.

TABLE 1. Human Health Receptors, Media and Exposure Routes

RECEPTOR	Medium/Exposure Routes					
	Groundwater	Surface Water	Sediments	Surface Soils		Fish
	ingestion	ingestion	ingestion	ingestion	inhalation	ingestion
Resident	◘			◘	◘	◘
Camper	◘	◘	◘	◘	◘	◘
Boater		◘	◘			
Swimmer		◘	◘			
ATV Driver				◘	◘	
Worker	◘			◘	◘	
Surveyor	◘			◘	◘	

Contaminant of Concern Selection

The contaminant of concern (COC) selection processes utilized previous work at mining sites. The selection processes in these investigations were scientifically rigorous and in accordance with EPA risk assessment guidance. Therefore, the COCs for these investigations were combined to form the COC list for this effort. The COCs for the human health RMC are antimony, arsenic, cadmium, copper, lead, manganese, mercury, nickel, selenium, silver, and zinc. In determining COCs for a given site, the RMC may be compared with the mean metals concentrations. Metals exceeding the human or ecological RMC should be evaluated as COCs.

Lead RMC for the resident were determined from EPA's Integrated Exposure Uptake Biokinetic Model. This model calculates acceptable lead exposure via ingestion of soil, drinking water, and food, and via inhalation of air, using 10 ug Pb/dl as an acceptable blood lead concentration for 95% of the exposed child population. Lead criteria for other human receptors were based on available EPA regulation and guidance.

Exposure Scenarios

The human exposure scenarios were developed to provide realistic estimates of the types and extent of exposure which individuals might experience to the COCs in the water, soils, and sediments on BLM property. Such exposures might occur to individuals living on properties adjacent to BLM lands; to individuals who use BLM lands for camping, boating, or all-terrain-vehicle (ATV) driving; or to individuals who work on BLM lands. EPA has published a number of standard exposure assumptions that are consistently used to estimate those factors which have been empirically determined, such as the number of liters of water an adult drinks in a day, the average rate of inhalation of dust, or the average number of years spent in one residence. However, several site-specific exposure assumptions have been developed in this report, in addition to the standard EPA assumptions, to provide estimates as closely resembling probable exposures on BLM property as possible.

The residential scenario was developed because there are residential properties adjacent to BLM land. Contamination may migrate from the BLM tracts to adjoining residential property. All residential scenario exposure assumptions were obtained directly from EPA guidance. A variety of recreational exposure scenarios on BLM lands were also considered, including camping, swimming, boating, and ATV driving. The BLM-specific assumptions were made for the recreational exposure scenarios in consultation with BLM field offices. Table 2 presents the human health RMC. In the case of metals posing both cancer and noncancer threats to health, the lower (more protective) concentration was selected as the risk management criterion.

The RMC have been divided by 11 metals and by "n" media that receptors are exposed to (Table 1) to account for multiple chemical and media exposures. This ensures that the cumulative effects of all the metals and all of the media are considered. Therefore, as long as people are not exposed to metals concentrations exceeding the RMC, they are not expected to experience adverse effects.

TABLE 2. Human Risk Management Criteria

Medium	Resident	Camper	ATV Driver	Worker	Surveyor	Boater	Swimmer
SOILS (mg/kg)							
Antimony	3	50	750	100	600	NA	NA
Arsenic	1	20	300	12	100	NA	NA
Cadmium	3	70	950	100	800	NA	NA
Copper	250	5000	70000	7400	59000	NA	NA
Lead	400	1000	1000	2000	2000	NA	NA
Manganese	960	19000	250000	28000	220000	NA	NA
Mercury	2	40	550	60	480	NA	NA
Nickel	135	2700	38000	4000	32000	NA	NA
Selenium	35	700	9600	1000	8000	NA	NA
Silver	35	700	9600	1000	8000	NA	NA
Zinc	2000	40000	550000	60000	480000	NA	NA
SEDIMENTS (mg/kg)							
Antimony	NA	62	NA	NA	NA	221	96
Arsenic	NA	46	NA	NA	NA	166	72
Cadmium	NA	155	NA	NA	NA	553	239
Copper	NA	5745	NA	NA	NA	20517	8884
Lead	NA	1000	NA	NA	NA	1000	1000
Manganese	NA	21679	NA	NA	NA	77424	33525
Mercury	NA	46	NA	NA	NA	166	72
Nickel	NA	3094	NA	NA	NA	11061	4789
Selenium	NA	774	NA	NA	NA	2765	1197
Silver	NA	774	NA	NA	NA	2765	1197
Zinc	NA	46455	NA	NA	NA	165909	71839
SURFACE WATER (ug/l)							
Antimony	NA	124	NA	NA	NA	442	192
Arsenic	NA	93	NA	NA	NA	81	144
Cadmium	NA	155	NA	NA	NA	553	239
Copper	NA	11490	NA	NA	NA	41035	17768
Lead	NA	50	NA	NA	NA	50	50
Manganese	NA	1548	NA	NA	NA	5530	2395
Mercury	NA	93	NA	NA	NA	332	144
Nickel	NA	6194	NA	NA	NA	22121	9578
Selenium	NA	1548	NA	NA	NA	5530	2395
Silver	NA	1548	NA	NA	NA	5530	2395
Zinc	NA	92909	NA	NA	NA	331818	143677

TABLE 2. Human Risk Management Criteria (continued)

Medium	Resident	Camper	ATV Driver	Worker	Surveyor	Boater	Swimmer
GROUND WATER (ug/l)							
Antimony	0.2	1	NA	3	31	NA	NA
Arsenic	0.1	1	NA	0.7	7	NA	NA
Cadmium	0.2	2	NA	4	39	NA	NA
Copper	18	137	NA	287	2872	NA	NA
Lead	15	15	NA	15	15	NA	NA
Manganese	2	18	NA	39	387	NA	NA
Mercury	0.1	1	NA	2	23	NA	NA
Nickel	9	74	NA	155	1548	NA	NA
Selenium	2	18	NA	39	387	NA	NA
Silver	2	18	NA	39	387	NA	NA
Zinc	142	1106	NA	2323	23227	NA	NA
FISH (ug/kg)							
Antimony	31	65	NA	NA	NA	NA	NA
Arsenic	24	48	NA	NA	NA	NA	NA
Cadmium	78	161	NA	NA	NA	NA	NA
Copper	2907	5984	NA	NA	NA	NA	NA
Lead	200	200	NA	NA	NA	NA	NA
Manganese	10969	22582	NA	NA	NA	NA	NA
Mercury	24	48	NA	NA	NA	NA	NA
Nickel	1567	3226	NA	NA	NA	NA	NA
Selenium	392	807	NA	NA	NA	NA	NA
Silver	392	807	NA	NA	NA	NA	NA
Zinc	23505	48390	NA	NA	NA	NA	NA

(1) Alternatives include defaulting to local background or evaluating bioavailable fraction.
NA - not applicable

Wildlife on the BLM lands may be exposed to metal contamination via several environmental pathways. The potential exposure pathways include soil and sediment ingestion, vegetation ingestion, surface water ingestion, and airborne dust inhalation. This report establishes ecological RMC for metals in soil and sediments. This has been accomplished using the best data available for the calculations, including ecotoxicological effects data for the metals of concern, soil-plant uptake factors, representative wildlife receptors, body weights, and soil and plant ingestion rates for each receptor.

After careful consideration of regional scientific literature, and on the basis of field observations, several wildlife receptors have been selected to represent a range of the types, sizes, and habitats of birds and mammals representative of temperate BLM lands. The selected wildlife receptors are the deer mouse, mountain cottontail, bighorn sheep, white-tailed deer, mule deer, cattle, elk, mallard, Canada goose, and trumpeter swan.

The literature was surveyed for toxicity data relevant either to wildlife receptors at the site or to closely related species. In the absence of available toxicity data for any receptor, data were selected on the basis of phylogenetic similarity between ecological receptors and the test species for which toxicity data were reported. For example, while no data on metal toxicity were found in the literature for trumpeter swans, there were data available on metal toxicity to Canada geese and mallard ducks. Accordingly, the goose and duck data were used, and the toxicity values were adjusted to account for the differences in body weight and food ingestion rate between the species. Uncertainty factors were applied to protect against underestimation of risks to trumpeter swans that might result from metabolic differences between ducks, geese, and swans. The COCs for the ecological assessment included arsenic, cadmium, copper, lead, mercury, and zinc.

Soil ingestion rates and exposure factors for each receptor were obtained from the U.S. Fish and Wildlife Service (Beyer, 1994) and unpublished data. Soil-plant uptake factors were obtained from Baes (1984). Where no dietary soil intake data were available for a particular receptor, the soil intake was assumed to be equal to that of an animal with similar diets and habits.

RMC were calculated for each chemical of concern in soil based upon assumed exposure factors for the selected receptors, along with species- and chemical-specific toxicity reference values (TRVs). TRVs were computed by chemical of concern for each wildlife receptor/metal combination, using the method of Ford, et al. (1992), shown in Appendix A. Table 3 displays the TRVs.

TRVs represent daily doses of the metals for each wildlife receptor that will not result in adverse chronic toxic effects. Wildlife RMC have been calculated from the TRVs and the assumed intake of soil/sediment and plants that each receptor will receive. Therefore, as long as wildlife are not exposed to soils/sediments with concentrations of metals exceeding the RMC, they are not expected to experience adverse toxic effects. Table 4 shows the RMC.

TABLE 3. Toxicity Reference Values (mg/kg/d)

SPECIES	As TRV mg/kg/d	SOURCE	UF	Cu TRV mg/kg/d	SOURCE	UF	Cd TRV mg/kg/d	SOURCE	UF	Pb TRV mg/kg/d	SOURCE	UF
mouse	1.25	Schroeder	2	17.00	CRC	2	0.30	Eisler 85	2	3.000	Schroeder	2
cottontail	0.86	NRC-Rabbit	4	3.44	NRC-Rabbit	4	0.09	NRC-Rabbit	4	0.515	NRC-Rabbit	4
bighorn	0.70	NRC-Sheep	2	0.35	NRC-Sheep	2	0.07	NRC-Sheep	2	0.420	NRC-Sheep	2
WT. Deer	0.24	NRC-Cow	6	0.47	NRC-Cow	6	0.02	NRC-Cow	6	0.142	NRC-Cow	6
M. Deer	0.24	NRC-Cow	6	0.47	NRC-Cow	6	0.02	NRC-Cow	6	0.142	NRC-Cow	6
Elk	0.24	NRC-Cow	8	0.47	NRC-Cow	8	0.02	NRC-Cow	8	0.142	NRC-Cow	8
Robin	0.63	NRC-Poultry	8	3.75	NRC-Poultry	8	0.06	NRC-Poultry	8	0.375	NRC-Poultry	8
Mallard	0.63	NRC-Poultry	8	3.75	NRC-Poultry	8	0.06	NRC-Poultry	8	0.375	NRC-Poultry	8
C. Goose	0.63	NRC-Poultry	8	3.75	NRC-Poultry	8	0.06	NRC-Poultry	8	0.375	NRC-Poultry	8
T. Swan	0.63	NRC-Poultry	8	3.75	NRC-Poultry	8	0.06	NRC-Poultry	8	0.375	NRC-Poultry	8
Cattle	0.70	NRC-Cow	2	1.41	NRC-Cow	2	0.07	NRC-Cow	2	0.425	NRC-Cow	2
Sheep	0.70	NRC-Sheep	2	0.35	NRC-Sheep	2	0.07	NRC-Sheep	2	0.425	NRC-Sheep	2

SPECIES	Hg TRV mg/kg/d	SOURCE	UF	Zn TRV mg/kg/d	SOURCE	UF
mouse	0.15	CRC	2	26.70	Eisler 93	2
cottontail	0.34	NRC-Rabbit	4	8.60	NRC-Rabbit	4
bighorn	0.07	NRC-Sheep	2	4.20	NRC-Sheep	2
WT. Deer	0.09	NRC-Cow	6	2.36	NRC-Cow	6
M. Deer	0.09	NRC-Cow	6	2.36	NRC-Cow	6
Elk	0.09	NRC-Cow	8	2.36	NRC-Cow	8
Robin	0.25	NRC-Poultry	8	12.50	NRC-Poultry	8
Mallard	0.25	NRC-Poultry	8	12.50	NRC-Poultry	8
C. Goose	0.25	NRC-Poultry	8	12.50	NRC-Poultry	8
T. Swan	0.25	NRC-Poultry	8	12.50	NRC-Poultry	8
Cattle	0.28	NRC-Cow	2	7.00	NRC-Cow	2
Sheep	0.28	NRC-Sheep	2	4.20	NRC-Sheep	2

Abbreviations:

crc p._ : Handbook of Chemical Toxicity Profiles of Biological Species. Ramamoorthy, et al., 1995. Lewis Publishers.
nrc : National Research Council, 1980. Mineral Tolerance of Domestic Animals.
Eisler p._ : Eisler, Fish and Wildlife Service Synoptic Reviews, various dates.
UF : Total uncertainty factor.
Note : nrc TRVs were calculated as the product of the dietary concentration times the kg plant ingestion divided by the body weight. Uncertainty factors were applied according to the extrapolation approach above.

TABLE 4. Wildlife and Livestock Risk Management Criteria for Metals in Soils (mg/kg)

	Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Deer Mouse	230	7	640	142	2	419
Cottontail	438	6	358	172	15	373
Bighorn Sheep	387	9	64	152	6	369
White-Tailed Deer	319	3	128	124	11	267
Mule Deer	200	3	102	106	9	222
Elk	328	3	131	127	11	275
Cattle	419	15	413	244	45	1082
Sheep	352	12	86	203	38	545
Mallard	116	1	141	59	4	196
Canada Goose	61	2	161	34	6	271
Trumpeter Swan	76	2	201	43	7	340
Robin	4	0.3	7	6	1	43
Median	275	3	136	125	8	307

Aquatic Plant Ingestion

Aquatic plants such as Arrowhead (*Sagitarria sp.*) appear to accumulate metals and store them in their tubers. Arrowhead tubers are eaten by swan and other waterfowl. Of these consumers, swans reportedly eat the most; the plant constitutes 5-10% of the diet of trumpeter swans and muskrats.

Elevated lead levels in *Sagitarria* have been reported (Krieger, 1990). The mean value detected in tubers was 159 ppm. The trumpeter swan body weight is approximately 8.17 kg, and the daily ingestion rate is 386 grams/day. Assuming the *Sagitarria* is 10% of the swan's diet, a swan's lead intake might be 0.75 mg/kg/day. As shown in Table 3, the swan TRV is 0.125 mg/kg/day. Thus, it can be seen that the lead intake by waterfowl from *Sagitarria* alone may represent a chronic (or possibly acute) lead poisoning hazard for waterfowl.

Aquatic Life Protection

Surface waters are often contaminated by mining sites. Table 5 presents EPA ambient water criteria for metals and cyanide for the protection of aquatic life and humans ingesting water and fish (EPA, 1986). States may have other criteria.

TABLE 5. Selected EPA Ambient Water Quality Criteria (micrograms/liter). Note: States may have other criteria.

Metal	Freshwater Aquatic Life Acute Exposure	Freshwater Aquatic Life Chronic Exposure	Human Water+Fish Ingestion
Antimony	NA	NA	5.6
Arsenic (V)	340	150	0.018
Barium	NA	NA	1000
Cadmium+	2	0.25	NA
Chromium (III)	570	74	NA
Copper+	13	9	NA
Cyanide (free)	22	5.2	700
Iron	NA	1000	300
Lead+	65	2.5	NA
Manganese	NA	NA	50
Mercury	1.4	0.77	0.3*
Nickel+	470	52	610
Selenium	NA	5	170
Silver+	3.2	NA	NA
Thallium	NA	NA	1.7
Zinc+	120+	120	7400

+ Computed from hardness; (100 mg/l used. See reference equation for other hardnesses).
Source: EPA, 2002.
* Fish tissue (ppm), methyl mercury
NA - Not available

DISCUSSION

It is anticipated that the RMC will be used as a benchmark concentration to which environmental concentrations may be compared, assisting land managers in protecting humans and wildlife on BLM lands. These criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are indicated. It is suggested that exceedances of the criteria be interpreted as follows:

- less than criteria: low risk
- 1-10 times the criteria: moderate risk
- 10-100 times the criteria: high risk
- >100 times the criteria: extremely high risk

Given the uncertainties associated with the ecological RMC and the values inherent in ecosystem management, moderate risk may be addressed by management and or institutional controls, whereas high risk may require remediation. Additionally, the criteria may be used as target cleanup levels if remedial action is undertaken. The human RMC may be modified to be less stringent if the number of metals present are fewer or if background concentrations are locally elevated.

Data from this study indicate the importance of plant accumulation of metals. Some authors believe that copper and zinc are self-regulated; however, there is evidence that copper and zinc can be accumulated in target organs such as the kidneys and liver and can cause toxicity. Cadmium and mercury can be bioaccumulated in tissue from one trophic level to the next, resulting in the so-called "secondary poisoning" of top consumers in a food web. The wildlife criteria also protect soil macrofauna such as earthworms and insects that are important parts of terrestrial food chains and detritivores important to nutrient cycling in ecosystems.

Wildlife RMC are consistent with no-effect metal concentrations found for plants (Kabata-Pendias, 1992), for aquatic life associated with stream sediment (EPA, 1977), and for soil organisms responsible for fertility and nutrient cycling (Will and Suter, 1994). For wildlife, this model indicates that the majority of the intake for copper, cadmium, mercury, and zinc derives from ingestion of plants; the majority of intake of arsenic and lead derives from soil ingestion.

Various approaches have been suggested for selecting a criterion suitable for protecting groups of species, communities, or ecosystems; however, none have been widely accepted. For the purposes of this Technical Note, the median (Table 4) is recommended at the present time.

In summary, there are numerous applications of the RMC, depending on the medium and the type of exposure considered. Based on comparisons to available sampling data from mining sites, it is likely that humans are occasionally and wildlife receptors are frequently at risk from adverse toxic effects associated with metal contamination in soils and sediments. In order to ensure proper interpretation of the significance of these results, all of the RMC in this paper must be considered in light of the assumptions used in their development. The contributions of the assumptions used in this report to the degree of uncertainty are described below.

UNCERTAINTY ANALYSIS

Numerous toxicological interactions are known among the metals of concern. Some are protective (e.g., zinc, copper, and calcium protect against cadmium and lead), while others are synergistic (i.e., toxic effects are cumulative). These effects can be concentration dependent and species dependent. The COCs on BLM lands may have synergistic effects on human or wildlife receptors. Cumulative effects were quantitatively dealt with for the human assessment, but not for the ecological assessment. Because species-specific toxicity data were not available for each wildlife receptor and each metal, the ecological RMC for each metal were calculated as though each was the only metal present. As a result, the current ecological RMC for each receptor/metal combination may be numerically larger than if the synergistic effect of simultaneous exposure to all the metals could be estimated.

After careful research into the current wildlife management literature, toxicity data were selected from test species that were phylogenetically similar as possible to likely receptors. The highest potential for uncertainty in the wildlife calculations is associated with the protection against a greater toxic response to any metal by wildlife, as compared to the toxic response to the same metal by laboratory animals. The amount of uncertainty in such cases would be directly proportional to the extent of phylogenetic difference between test and receptor organisms. To minimize this uncertainty, test species data were selected from animals as closely related to the ecological receptors for the region as possible. Most values selected for use in the wildlife risk management calculations are for test species from the same biological order as the ecological receptor, except for the use of poultry (*Galliformes*) test species to estimate effects of cadmium, manganese, and zinc on waterfowl (*Anseriformes*). To account for phylogenetic differences, uncertainty factors were used (Ford, et al., 1992).

Phylogenetic and intraspecies differences between test species and ecological receptors have been taken into account by the application of uncertainty factors in derivation of critical toxicity values. These uncertainty factors were applied to protect wildlife receptors which might be more sensitive to the toxic effects of a metal than the test species. The uncertainty factors were applied to the test species toxicity data in accordance with a method developed by BLM. In accordance with this system, a divisor of two (2) was applied to the toxicity reference dose for each level of phylogenetic difference between the test and wildlife species, (e.g., individual, species, genus, and family). Reasonable uncertainty factors have also been applied to account for the differences between test administration conditions (length of exposure) and conditions in the wild.

Toxic doses for each metal were selected from the literature without regard to the specific metal compound administered in the toxicity test. Metal toxicity varies greatly with the solubility of the metallic compound, which determines the ease of passage through biological membranes. This bioavailability factor results in a tendency to overestimate actual human and wildlife RMC because the geochemical species present in soils, sediments, or waters of mining sites are expected to be of lower solubility. Collection of bioaccessibility or mineralogical data on a site may permit an upward adjustment of the RMC (Ruby et al., 1993).

The process of calculating human health RMC using a target hazard index and target excess lifetime cancer risk has a number of inherent sources of uncertainty. There is statistical quantitative uncertainty associated with the estimates of exposure used in the calculation of the human health RMC. Furthermore, EPA applies uncertainty factors when establishing reference doses and cancer potency slope factors by using animal data to develop human toxicity criteria. The degree of uncertainty in the human health RMC cannot be completely quantified; however, due to the conservative assumptions incorporated in the standard EPA default exposure factors and EPA toxicity criteria used, and due to the conservative nature of the exposure assumptions used for this report, the human health RMC are unlikely to underestimate the true criteria.

For some metal-wildlife combinations, there was a dearth of chronic toxicity data available. Uncertainty exists with the extrapolation process used for wildlife; however, it is conservative and consistent with other work performed with plants and domestic animals (Kabata-Pendias, 1992; National Academy of Sciences, 1980) and soil organisms (Will and Suter, 1994).

SUMMARY

Interpretation of the significance of the human health RMC depends on the current and future land uses envisioned and the potential exposures that could occur. An in-depth comparison between the human health RMC and the actual concentrations of metals on BLM lands is beyond the scope of this paper. A high degree of confidence can be placed in the RMC, because they have been calculated using verifiable scientific data and valid exposure assumptions. Furthermore, a comparison between the risk management calculations and background concentrations shows that, for the most part, all of the calculated wildlife and human RMC are higher than reported background concentrations.

The wildlife RMC are also protective of plants. As would be expected, the wildlife risk management criteria are generally numerically larger than the published soil and sediment background concentrations in the western U.S. (Table 4). However, the increment is often only a few ppm to 50 ppm, suggesting that only slightly elevated concentrations may indicate risk. Based on the size of the exceedances of the risk management criteria routinely found at mining sites, it appears that soil/sediment and plant ingestion may currently be causing metal toxicity in wildlife receptors on Public Lands. Furthermore, there are additional sources of metals for regional wildlife, including contaminated surface water and contaminated airborne dust. Consideration of wildlife exposure to metals in plants indicates that plant ingestion may be a significant exposure route that should be considered when making risk management decisions.

The RMC developed in this paper are conservative and are designed specifically to protect against underestimation of risks to wildlife or human receptors. Therefore, it may be concluded that for any area where environmental metal concentrations are lower than the RMC, such media are not likely to pose a risk of adverse effects to wildlife or humans. Given the uncertainties associated with the ecological RMC and the values inherent in ecosystem management, moderate risk may be addressed by management and or institutional controls, whereas high risk may require remediation.

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APPENDIX A

EQUATION 1: Risk management criteria calculation based upon the noncarcinogenic hazards from exposure to groundwater: residential, campground host, camper, recreation maintenance worker, and surveyor receptors

$$C_W\,(mg/L) = \frac{THI * RfD_o * BW * NCAT}{IR * EF * ED * N_{NCO}}$$

Where:

C_W = Chemical Risk Management Criteria in Water (mg/L)
THI = Target Hazard Index (unitless)
RfD_O = Oral Chronic Reference Dose (mg/kg-day)
BW = Body Weight (kg)
NCAT = Noncarcinogenic Averaging Time (period over which exposure resulting in noncarcinogenic effects is averaged - days)
IR = Ingestion Rate (L/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
N_{NCO} = Number of COCs with an Oral Chronic Reference Dose (unitless)

EQUATION 2: Risk management criteria calculation based upon the carcinogenic risks from the exposure to groundwater: residential, campground host, camper, recreation maintenance worker, and surveyor receptors

$$C_W\,(mg/L) = \frac{TR * CAT}{CPS_o * EF * N_{CO}} * \left[\frac{BW_A}{IR_A * ED_A} + \frac{BW_C}{IR_C * ED_C}\right]$$

Where:

C_W = Chemical Risk Management Criteria in Water (mg/L)
TR = Target Excess Individual Lifetime Cancer Risk (unitless)
CAT = Carcinogenic Averaging Time (period over which exposure resulting in carcinogenic effects is averaged - days)
CPS_O = Oral Carcinogenic Potency Slope $(mg/kg\text{-}day)^{-1}$
EF = Exposure Frequency (days/year)
N_{CO} = Number of COCs with an Oral Carcinogenic Potency Slope (unitless)

BW_A =	Body Weight, Adult (kg)	BW_C =	Body Weight, Child (kg)
IR_A =	Ingestion Rate, Adult (L/day)	IR_C =	Ingestion Rate, Child (L/day)
ED_A =	Exposure Duration, Adult (years)	ED_C =	Exposure Duration, Child (years)

EQUATION 3: Risk management criteria calculation based upon the noncarcinogenic hazards from exposure to surface water: campground host, camper, boater, and swimmer receptors

$$C_W\,(mg/L) = \frac{THI * RfD_o * BW * NCAT}{CR * ET * EF * ED * N_{NCO}}$$

Where:

C_W = Chemical Risk Management Criteria in Surface Water (mg/L)
THI = Target Hazard Index (unitless)
RfD_O = Oral Chronic Reference Dose (mg/kg-day)
BW = Body Weight (kg)
NCAT = Noncarcinogenic Averaging Time (period over which exposure resulting in noncarcinogenic effects is averaged - days)
CR = Contact Rate (L/hour)
ET = Exposure Time (hours/event)
EF = Exposure Frequency (events/year)
ED = Exposure Duration (years)
N_{NCO} = Number of COCs with an Oral Chronic Reference Dose

EQUATION 4: Risk management criteria calculation based upon the carcinogenic risks from exposure to chemicals in surface water: campground host, camper, boater, and swimmer receptors

$$C_W\,(mg/L) = \frac{TR * CAT}{CPS_o * CR * ET * EF * N_{CO}} * \left[\frac{BW_A}{ED_A} + \frac{BW_C}{ED_C}\right]$$

Where:

C_W = Chemical Risk Management Criteria in Surface Water (mg/L)
TR = Target Excess Individual Lifetime Cancer Risk (unitless)
CAT = Carcinogenic Averaging Time (period over which exposure resulting in carcinogenic effects is averaged - days)
CPS_O = Oral Carcinogenic Potency Slope $(mg/kg\text{-}day)^{-1}$
CR = Contact Rate (L/hour)
ET = Exposure Time (hours/event)
EF = Exposure Frequency (events/year)
N_{CO} = Number of COCs with an Oral Carcinogenic Potency Slope (unitless)
BW_A = Body Weight, Adult (kg) BW_C = Body Weight, Child (kg)
ED_A = Exposure Duration, Adult (years) ED_C = Exposure Duration, Child

EQUATION 5: Risk management criteria calculation based upon the noncarcinogenic hazards from exposure to sediments: campground host, camper, boater, and swimmer receptors

$$C_S\,(mg/kg) = \frac{THI * RfD_o * BW * NCAT}{IR * CF * EF * ED * N_{NCO}}$$

Where:

C_S = Chemical Risk Management Criteria in Sediments (mg/kg)
THI = Target Hazard Index (unitless)
RfD_O = Oral Chronic Reference Dose (mg/kg-day)
BW = Body Weight (kg)
NCAT = Noncarcinogenic Averaging Time (period over which exposure resulting in noncarcinogenic effects is averaged - days)
IR = Ingestion Rate (mg/day)
CF = Conversion Factor (kg/mg)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
N_{NCO} = Number of COCs with an Oral Chronic Reference Dose (unitless)

EQUATION 6: Risk management criteria calculation based upon the carcinogenic risks from exposure to sediments: campground host, camper, boater, and swimmer receptors

$$C_S\,(mg/kg) = \frac{TR * CAT}{CPS_o * CF * EF * N_{CO}} * \left(\frac{BW_A}{IR_A * ED_A} + \frac{BW_C}{IR_C * ED_C}\right)$$

Where:

C_S = Chemical Risk Management Criteria in Sediments (mg/kg)
TR = Target Excess Individual Lifetime Cancer Risk (unitless)
CAT = Carcinogenic Averaging Time (period over which exposure resulting in carcinogenic effects is averaged - days)
CPS_o = Oral Carcinogenic Potency Slope $(mg/kg\text{-}day)^{-1}$
CF = Conversion Factor (kg/mg)
EF = Exposure Frequency (days/year)
N_{CO} = Number of COCs with an Oral Carcinogenic Potency Slope (unitless)
BW_A = Body Weight, Adult (kg)
IR_A = Ingestion Rate, Adult (mg/day)
ED_A = Exposure Duration, Adult (years)
BW_C = Body Weight, Child (kg)
IR_C = Ingestion Rate, Child (mg/day)
ED_C = Exposure Duration, Child (years)

EQUATION 7: Risk management criteria calculation based upon the noncarcinogenic hazards from exposure to soil: residential, campground host, camper, ATV driver, recreation maintenance worker, and surveyor receptors

$$C_S\ (mg/kg) = \frac{THI * 365 * NCAT}{EF * M_N} * \left[\left(\frac{RfD_o}{IR_S * CF * N_{NCO}}\right) + \left(\frac{RfD_i}{IHR * 1/PEF * N_{NCI}}\right)\right]$$

Where:

C_S = Chemical Risk Management Criteria in Soil (mg/kg)
THI = Target Hazard Index (unitless)
NCAT = Noncarcinogenic Averaging Time (period over which exposure resulting in noncarcinogenic effects is averaged - years)
EF = Exposure Frequency (days/year)
RfDo = Oral Chronic Reference Dose (mg/kg-day)
IR_S = Age Ajusted Soil Ingestion Rate (mg-yr/kg-day)
CF = Conversion Factor (kg/mg)
N_{NCO} = Number of COCs with an Oral Chronic Reference Dose (unitless)
RfDi = Inhalation Chronic Reference Dose (mg/kg-day)
IHR = Inhalation Rate (m^3/hr)
PEF = Particulate Emission Factor (m^3/kg)
N_{NCI} = Number of COCs with an Inhalation Chronic Reference Dose (unitless)
M_N = Number of Media

EQUATION 8: Risk management criteria calculation based upon the carcinogenic risks from exposure to soil: residential, campground host, camper, ATV driver, recreation maintenance worker, and surveyor receptors

$$C_S\ (mg/kg) = TR * AT * 365/ \left[EF * M_N * \left[\left(SF_o * CF * IR_S\right) + \left(SF_I/N \quad * IR * \left(1/PEF\right)\right)\right]\right]$$

Where:

C_S = Chemical Risk Management Criteria in Soil (mg/kg)
TR = Target Excess Individual Lifetime Cancer Risk (unitless)
AT = Carcinogenic Averaging Time (period over which exposure resulting in carcinogenic effects is averaged - years)
EF = Exposure Frequency (days/year)
SFo = Oral Carcinogenic Potency Slope $(mg/kg\text{-}day)^{-1}$
CF = Conversion Factor (kg/mg)
N_{CO} = Number of COCs with an Oral Carcinogenic Potency Slope (unitless)
M_N = Number of Media
IR_S = Age Ajusted Soil Ingestion Rate (mg-yr/kg-day)
SFi = Inhalation Carcinogenic Potency Slope $(mg/kg\text{-}day)^{-1}$
N_{CI} = Number of COCs with an Inhalation Carcinogenic Potency Slope (unitless)
IR = Inhalation Rate (m^3/hr)

EQUATION 9: Risk management criteria calculation based upon the noncarcinogenic hazards from the ingestion of chemicals in fish tissue: residential, campground host, and camper receptors

$$C_F\ (mg/kg) = \frac{THI * RfD_o * BW * NCAT}{IR * EF * ED * N_{NCO}}$$

Where:

C_F = Chemical Criteria in Fish (mg/kg)
THI = Target Hazard Index (unitless)
RfD_O = Oral Chronic Reference Dose (mg/kg-day)
BW = Body Weight (kg)
NCAT = Noncarcinogenic Averaging Time (period over which exposure resulting in noncarcinogenic effects is averaged - days)
IR = Ingestion Rate (kg/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
N_{NCO} = Number of COCs with an Oral Chronic Reference Dose (unitless)

EQUATION 10: Risk management criteria calculation based upon the carcinogenic risks from the ingestion of chemicals in fish tissue: residential, campground host, and camper receptors

$$C_F\ (mg/kg) = \frac{TR * CAT}{CPS_o * EF * N_{CO}} * \left[\frac{BW_A}{IR_A * ED_A} + \frac{BW_C}{IR_C * ED_C}\right]$$

Where:

C_F = Chemical Criteria in Fish (mg/kg)
TR = Target Excess Individual Lifetime Cancer Risk (unitless)
CAT = Carcinogenic Averaging Time (period over which exposure resulting in carcinogenic effects is averaged - days)
CPS_O = Oral Carcinogenic Potency Slope (mg/kg-day)- 1
EF = Exposure Frequency (days/year)
N_{CO} = Number of COCs with an Oral Carcinogenic Potency Slope (unitless)
BW_A = Body Weight, Adult (kg) BW_C = Body Weight, Child (kg)
IR_A = Ingestion Rate, Adult (kg/day)
IR_C = Ingestion Rate, Child (kg/day)
ED_A = Exposure Duration, Adult (years) ED_C = Exposure Duration, Child (years)

EQUATION 11: Risk management criteria calculation based upon ecological receptor exposure to soil and plants

$$C_S\,(mg/kg) = \frac{TRV * BW}{(IR_S * CF) + (B_r * IR_p * CF * PDW)}$$

Where:

C_S = Dry Weight Soil Concentration
TRV = Toxicity Reference Value (mg/kg-day)
BW = Body Weight (kg)
IRS = Soil Ingestion Rate (g/day)
B_r = Soil-Plant Uptake Factor (unitless)
IR_p = Plant Ingestion Rate (g/day)
CF = Conversion Factor (kg/g)
PDW = Plant Fraction Dry:Fresh Weight (unitless: 0.65)

Variable Values:

TRV: chemical- and species-specific (See Table 3)
BW: species-specific
IRS: species-specific (Beyer, 1992)
B_r: chemical-specific: arsenic .006; cadmium 0.14; copper 0.08; lead .009; manganese .05; mercury 0.2; zinc 0.21
CF: 1E-03 kg/g

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This report sets forth acceptable soil and sediment criteria for heavy metals released from abandoned hard rock mining sites as they relate to ecosystem management and protection of human health and wildlife. The USDI Bureau of Land Management (BLM) manages approximately 270 million acres of public lands, primarily in the Western U.S. These lands include several hundred thousand abandoned mining sites, some of which may be releasing heavy metals into the environment at levels toxic to wildlife.

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