Navajo Nation

Water Quality Standards for Metals and Protection of Crops, Livestock, and Humans

Submitted To:

Navajo Nation Environmental Protection Agency
NPDES Water Quality Program
Window Rock, AZ 86515

Prepared by:

Tetra Tech, Inc.
10711 Red Run Blvd.
Suite 105
Owings Mills, MD 21117

April 2020

Table of Contents

Executive Summary.......... x

1. Introduction.......... 1

   1.1 Potential Exposure Pathways and Conceptual Site Model.......... 2

   1.2 Report Organization.......... 6

2. Recommended Numeric Water Quality Metal Standards for Protection of Crops.......... 7

   2.1 Rationale and Research Used to Derive Recommended Water Quality Standards for Crop Protection.......... 9

   2.2 Calculation of Water Quality Standards for Plants Based on Accumulation in Soil.......... 9

   2.3 Assumptions and Limitations.......... 17

   2.4 Applicability to San Juan River Basin.......... 18

      2.4.1 Soil Samples and Toxicity Assessment.......... 18

   2.5 Other Considerations: Factors Affecting Metals Bioaccumulation in Plants.......... 25

3. Recommended Numeric Water Quality Metal Standards for Protection of Livestock.......... 28

   3.1 Rationale for Recommended Metal Water Quality Standards for Protection of Livestock.......... 30

   3.2 Calculation of Protective Metal Thresholds for Livestock.......... 32

      3.2.1 Method.......... 33

      3.2.2 Exposure to Livestock Through Drinking Water.......... 34

      3.2.3 Risk Based AWQC for Livestock.......... 35

   3.3 Assumptions and Limitations.......... 39

4. Human Exposure to Metals from Crops, Livestock, and Water.......... 40

   4.1 Rationale for AWQC.......... 41

      4.1.1 Exposure Evaluation: Exposure parameters and chemical-specific inputs.......... 43

      4.1.2 Toxicity Assessment.......... 45

   4.2 Human Health Risk Based Ambient Water Quality Standards.......... 54

   4.3 Risk-Based Combined AWQC for Humans.......... 59

   4.4 Assumptions and Uncertainties.......... 61

5. Summary and Conclusions.......... 62

Literature Cited.......... 67

Appendix A.......... A-1

   A.1. State Agricultural Standards.......... A-1

   A.2. Agricultural Water Standards Used by Tribes.......... A-26

Appendix B: Metal Toxicity to Plants: Description of Information from NAE and NAS 1972 and other Published Literature.......... B-1

   B.1. Aluminum (Al).......... B-1

B.2. Arsenic (As) ... B-1
B.3. Beryllium (Be) ... B-2
B.4. Cadmium ... B-2
B.5. Chromium (Cr) ... B-3
B.6. Cobalt (Co) ... B-3
B.7. Copper (Cu) ... B-3
B.8. *Iron (Fe)* ... B-4
B.9. *Lead (Pb)* ... B-5
B.10. Manganese (Mn) ... B-5
B.11. Mercury (Hg) ... B-5
B.12. Molybdenum (Mo) ... B-5
B.13. Nickel (Ni) ... B-6
B.14. Selenium (Se) ... B-6
B.15. Vanadium (V) ... B-6
B.16. Zinc (Zn) ... B-7
B.17. Factors Affecting Metals Bioaccumulations in Plants ... B-10
Appendix C: Toxicity of Metals to Livestock ... C-1
C.1. Arsenic (As) ... C-1
C.2. Cadmium (Cd) ... C-2
C.3. Copper (Cu) ... C-3
C.4. Iron (Fe) ... C-3
C.5. Lead (Pb) ... C-4
C.6. Nickel (Ni) ... C-5
C.7. Zinc (Zn) ... C-5
C.8. Other Metals ... C-6
C.8.1. Aluminum (Al) ... C-6
C.8.2. Beryllium (Be) ... C-6
C.8.3. Chromium (Cr) ... C-6
C.8.4. Cobalt (Co) ... C-7
C.8.5. Manganese (Mn) ... C-7
C.8.6. Mercury (Mn) ... C-7
C.8.7. Molybdenum (Mo) ... C-7
C.8.8. Selenium (Se) ... C-7
C.8.9. Vanadium (V) ... C-8
C.9. Other Information: Toxicity Thresholds in Feed for Protection of Livestock ... C-8

C.9.1. Arsenic (As): In Feed (or direct consumption) C-8
C.9.2. Cadmium (Cd): In Feed (or direct consumption) C-13
C.9.3. Copper (Cu): In Feed (or direct consumption) C-16
C.9.4. Iron (Fe): In Feed (or direct consumption) C-18
C.9.5. Lead (Pb): In Feed (or direct consumption) C-20
C.9.6. Nickel (Ni): In Feed (or direct consumption) C-22
C.9.7. Zinc (Zn): In Feed (or direct consumption) C-24
C.10. Toxicity Summary C-27
Appendix D: Summary of Assessment Performed for San Juan River in Utah D-1
Appendix E: Sediment Toxicity and Aquatic Receptors E-1
E.1. Sediment Toxicity Study E-1
E.2. Navajo Fish Tissue Study E-6
E.3. Other Relevant Fish Tissue Information from the Literature E-7

List of Tables

Table ES-1. Summary of risk-based water quality standards (mg/L) for crops and livestock. Note: Risk-based standards are based on total metal. U.S. EPA 1972 criteria are based on dissolved metal. xiii
Table ES-2. Summary of risk-based metal water quality standards for protection of human health. All standards are expressed as total metal. xiv
Table 1-1. Exposure pathways evaluated. 5
Table 2-1. Recommended Water Quality Criteria Based on Toxicity to Crops 8
Table 2-2. Calculation of Soil Concentration from Use of Unfiltered Irrigation Water and Estimate 12
Table 2-3. Water Concentration that would Result in a Soil Concentration that poses toxicity to plants. 15
Table 2-4. Plant Concentrations derived from Ambient Water Quality Standards based on toxicity to crops. 16
Table 2-5. Summary of soils collected by Navajo Nation personnel and used in soil toxicity evaluations. 19
Table 2-6. Summary of results of general chemistry on Navajo Nation soils. 20
Table 2-7. Summary of metals analysis on Navajo Nation soils. Bolded values indicate the maximum measured value across all soils. Shaded cells indicate measured value above the Soil Screening Level for plants (Efroymson et al. 1997). 21
Table 2-8. Summary of Zea mays L. (corn) survival and growth endpoints for soils. Shaded cells are significantly less than controls ($p < 0.05$). 23
Table 2-9. Summary of Cucumis melo (melon) survival and growth endpoints for Navajo Nation soils. Shaded cells are significantly less than controls ($p < 0.05$). 23
Table 2-10. Summary of Medicago sativa (alfalfa) survival and growth endpoints for soils. Shaded cells are significantly less than controls ($p < 0.05$). 24
Table 2-11. Summary of Cucurbita pepo (squash) survival and growth endpoints for soils. Shaded cells are significantly less than controls ($p < 0.05$). 24
Table 3-1. Summary of recommended AWQC for livestock 29
Table 3-2. Toxicity reference values and screening levels for agricultural receptors in calculating AWQC 31
Table 3-3. Equations and Parameters Used to Develop Risk-Based Concentrations Protective of Livestock 33
Table 3-4. Ingestion-to-Beef Transfer Factor 35
Table 3-5. AWQC for cattle from water ingestion alone and for combined water, soil, and crop ingestion for cattle 36
Table 3-6. AWQC for sheep from water ingestion alone and for combined water, soil, and crop ingestion 38
Table 4-1. Summary of Risk-based AWQC for Humans. 41
Table 4-2. Exposure Equations and Parameters used in Human Health-Based Water Quality Standards Assessment. 44
Table 4-3. Bioaccumulation values 45
Table 4-4. Toxicity values for the human health risk-based AWQC. 46
Table 4-5. AWQC for Humans based on Domestic Water Use. 54
Table 4-6. AWQC based on human ingestion of homegrown produce. 56
Table 4-7. AWQC for ingestion of homegrown meat products, including the adjustment to a hazard index of 1.0 and risk of 1E-6. 58
Table 4-8. Combined AWQC for human health. 60
Table 5-1. Summary of risk-based water quality standards (mg/L) for crops, livestock, and human health. 64

Table 5-2. AWQC Comparisons. 65

Table A-1. States with numeric agricultural water quality standards for metals A-1
Table A-2. Compilation of State Agricultural Water Quality Standards A-4
Table A-3. Tribes with numeric agricultural standards for metals A-26
Table A-4. Compilation of Tribes Agricultural Water Quality Standards A-30
Table A-5. Livestock Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards. A-48
Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards A-51

Table B-1. Additional Information Identified regarding Metal Toxicity to Plants B-8
Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means). B-11

Table C-1. Arsenic toxicity in water to livestock. C-1
Table C-2. Cadmium compound toxicity in water C-2
Table C-3. Copper compounds toxicity in water. C-3
Table C-4. Lead compound toxicity in water. C-4
Table C-5. Nickel compound toxicity in water. C-5
Table C-6. Zinc compounds toxicity in water. C-6
Table C-7. Arsenic toxicity to sheep. C-9
Table C-8. Toxicity of Arsenic compounds to Cattle. C-10
Table C-9. Arsenic compounds toxicity, other animals. C-11
Table C-10. Arsenic compounds toxicity in soil C-12
Table C-11. Cadmium compounds toxicity to sheep. C-13
Table C-12. Cadmium compounds toxicity to cattle. C-14
Table C-13. Cadmium compounds toxicity, other animals. C-15
Table C-14. Cadmium compounds toxicity in soil. C-16
Table C-15. Copper compound toxicity to sheep C-16
Table C-16. Copper compound toxicity to cattle. C-17
Table C-17. Copper compound toxicity, other animals. C-18
Table C-18. Copper compounds toxicity in soil. C-18
Table C-19. Iron compound toxicity to cattle. C-19
Table C-20. Iron compound toxicity, other animals C-19
Table C-21. Lead compound toxicity to sheep. C-20
Table C-22. Lead compound toxicity to cattle. C-21
Table C-23. Lead compound toxicity, other animals. C-22
Table C-24. Lead compound toxicity in soil. C-22
Table C-25. Nickel compound toxicity to cattle. C-23
Table C-26. Nickel compound toxicity, other animals. C-23
Table C-27. Zinc compound toxicity to sheep. C-24
Table C-28. Zinc compounds toxicity to cattle. C-25
Table C-29. Zinc compound toxicity, other animals C-26
Table C-30. Zinc compounds toxicity in soil. C-26
Table C-31. Summary of identified thresholds of concern for 7 metals in feed, water and soils, across a range of livestock and wildlife. C-27

Table E-1. Summary of sediments collected by Navajo Nation personnel and used in sediment toxicity evaluations. E-1
Table E-2. Summary of general chemistry and metals analysis on Navajo Nation sediments. Bolded values indicate the maximum measured value across all sediments. Shaded cells indicate measured value above the Sediment Screening Level (Buchman, 2008). Shaded cells indicate measured value above the Soil Screening Level of plants (Efoymson et al. 1997). E-3
Table E-3. Summary of Hyalella azteca survival, growth and reproduction endpoints for San Juan River sediments. Shaded cells are significantly less than controls (p < 0.05). E-5
Table E-4. Summary of literature fish tissue concentrations observed for several metals of concern in fish species that are relevant to the San Juan River and Lake Powell. dw = dry weight, ww = wet weight. E-7
Table E-5. Trophic levels and main dietary items for select fish species relevant to the San Juan River and Lake Powell. E-9
Table E-6. San Juan River Upstream (New Mexico) Reach fillet tissue concentrations (mg/Kg, wet weight) E-10
Table E-7. San Juan River Upstream (New Mexico) Reach fillet tissue concentrations (mg/Kg, wet weight) (continued) E-11
Table E-8. San Juan River Downstream (Utah) Reach fillet tissue E-12

List of Figures

Figure 1-1. Conceptual Model – Use of surface water for crop irrigation, livestock watering, and domestic use 2
Figure 1-2. Conceptual Site Model (CSM) illustrating potential exposure pathways by which metals in river water or sediment may affect crops, livestock, and people. 4
Figure 2-1: Cadmium concentrations in various plants (from Derrick 2006) 25

Acronyms/Abbreviations

Acronym/Abbreviation	Definition
Ag	silver
Al	aluminum
As	Arsenic
ATP	adenosine triphosphate
AVS	acid volatile sulfides
AWQC	ambient water quality criteria
Ba	barium
BAF	Bioaccumulation factor
BAR	bioaccumulation ratio
Be	beryllium
BW	Body weight
Ca	Calcium
Cd	Cadmium
Co	cobalt
CO_2	Carbon dioxide
COPC	constituents of potential concern
Cr	Chromium
CSM	conceptual site model
Cu	Copper
CWA	Clean Water Act
d	Day
DI	drinking water intake
dw	dry weight
EMEG	environmental media evaluation guides
ESV	Ecological Screening Value
EPA	Environmental Protection Agency
Eqs.	equations
ERA	ecological risk assessment
Fe	Iron
FRC	fish consumption rate
g	gram
GKM	Gold King Mine
Hg	Mercury
IR	ingestion rate
IRIS	Integrated Risk Information System
K	potassium
kg	kilogram

Continued

Acronym/Abbreviation	Definition
L	liter
LOAEL	Lowest observed adverse effects level
mg	milligram
Mg	magnesium
mM	milli-molar
mm	milli-meters
Mn	manganese
Mo	molybdenum
Na	sodium
ND	not detected
NOAEL	no observed adverse effects level
Ni	nickel
NNEPA	Navajo Nation Environmental Protection Agency
P	phosphate
Pb	lead
ppm	parts per million
RfD	reference dose
RMC	risk management criteria
RSC	relative source contribution
Sb	antimony
Se	selenium
SJR	San Juan River
SLERA	screening level ecological risk assessment
SLRA	screening level risk assessment
Sr	strontium
Tl	thallium
TL	trophic level
TOC	total organic carbon
µg	micro-gram
µM	micro-molar
U.S. EPA	United States Environmental Protection Agency
V	vanadium
WQC	water quality criteria
WSC	Wildlife Soil Criteria
wt	weight
ww	wet weight
Zn	zinc

Executive Summary

The Navajo Nation contracted Tetra Tech, Inc. to evaluate current water quality metal standards for protection of crops, livestock, and humans consuming crops and livestock, the rationale behind those standards, and development of science-based standards where feasible. This Report presents and discusses these objectives for metals of concern that were discharged during the Gold King Mine spill in August 2015 into the Animas River, Colorado. That spill, which contained elevated concentrations of arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), zinc (Zn), and other metals, continued down the San Juan River, through Navajo Nation lands, and into Lake Powell downstream. Using comprehensive literature reviews and a human health risk assessment framework, this Report derives potential water quality metal standards for protection of crops, livestock, and humans that consume crop and livestock products, where sufficient information exists.

The science behind developing appropriate water quality standards for crop and livestock protection is complex for metals that may bioaccumulate and be transferred through the food chain. Uptake of water is only one of the potential pathways by which livestock may accumulate metals; ingestion of crops that have been exposed to metals is another pathway. When considering human consumption of crops or livestock products that have been exposed to elevated concentrations of metals, multiple pathways need to be considered including ingestion of water, crops, and livestock, all of which may be exposed to elevated metals.

Most states and tribes include general agricultural uses, livestock watering, or irrigation as designated uses. All states have numerical metals standards; however, most of these are aquatic life or human health ambient water quality standards. Eleven states and two Water Quality Control Boards in California list numeric metals standards for agricultural uses in their water quality standards. Two states (Idaho and Washington) reference agricultural water quality standards for metals but do not provide specific values for these uses in their standards. Most states and tribes that have numeric standards for agricultural designated uses cite or use U.S. Environmental Protection Agency's (U.S. EPA's) 1972 Water Quality Criteria, however, calculations were not provided in U.S. EPA's 1972 criteria for livestock watering or crop irrigation and in most cases, clear rationale for state and tribal numeric standards are lacking.

Published literature indicates that metal toxicity to livestock and wildlife is greater than it is for plants or crops. Recent information suggests that for some of the metals examined, the toxicity may be greater than was assumed in setting the 1972 U.S. EPA criteria for protection of livestock.

Laboratory testing of soil samples from Navajo lands and sediment samples from the San Juan River indicated some toxicity potential using *Hyalella* (amphipod) in sediment testing (presented in Appendix E) and several crop plant species in soil testing (alfalfa, melon, corn, and squash). Soil samples did not exceed screening values used by U.S. EPA for most metals except Cd, molybdenum (Mo), selenium (Se), vanadium (V), and Zn. Statistical comparisons of plant growth effects with soil metal concentrations did not indicate significant relationships, however, in general the range of metal concentrations was limited in the soil samples tested.

To develop risk-based metal criteria to protect human health, the assessment included sources, transport mechanisms, points of exposure, exposure pathways, and intermediate receptors. Water can be used for domestic purposes, and exposure routes to humans can also occur through ingestion of plants and animals that utilize the same water source. Agriculture exposure pathways included livestock and plants, both as receptors and as an additional exposure pathway to humans who ingest homegrown products. Dietary

exposure pathways represent a major exposure route for metals and these pathways were assessed as part of the agricultural risk-based assessment, in which it is assumed that surface water will be used to irrigate crops and pasture lands as well as to water livestock. Further, the crops are assumed to be food for livestock. Homegrown produce was assessed as well, in a manner separate from pasture and agricultural crop irrigation to more accurately assess the potential exposure route of homegrown produce. The agricultural risk assessment therefore includes livestock that have been fed crops grown on irrigated lands, and direct exposure to water and soils irrigated with surface water for livestock. Estimated tissue concentrations from livestock were calculated in this evaluation and used to refine human health water quality standards by estimated contribution of livestock ingestion to total human exposure. The calculated results are based on total metal content of water (not just dissolved concentrations). While water quality standards are often based on dissolved concentrations of metals, total metal content represents a more likely exposure through agricultural use of water to account for the possibility of unfiltered water being used for irrigation and livestock watering. Ambient water quality criteria (AWQC) presented here address toxicity to crops through irrigation, toxicity to livestock through water ingestion and crop/pasture consumption, and toxicity to humans through ingestion of water and consumption of homegrown produce and meat products.

The risk-based criteria for water developed and recommended for crops and livestock in this study are presented in Table ES-1. The first column of values represents values of metals in water that may pose a direct toxicity to crops if all metals are present in a dissolved state. The second column represents the concentration of metals in water that could pose toxicity to crops through accumulation in soil. It is recommended that water samples be compared to both values, especially if water analyses provide both dissolved and total metals results. As toxicity to crops is realized from the dissolved fraction of metals in water, the values in the first two columns represent a range of concentrations: the first column represents the lowest value of concern; if both total and dissolved fractions are at or below this value, then water itself is unlikely to impact crops. The values in the second column are the upper bound values for total metals in water; measured concentrations of metals in water that are below these values are unlikely to accumulate in soil at concentrations that would impact crops. The remaining columns present water quality criteria for cattle and sheep; results of this study indicate that criteria for cattle and sheep are driven primarily by water ingestion rather than pasture or feed irrigated with water.

As shown on Table ES-2, U.S. EPA's 1972 criteria for metals and crop and livestock protection are generally below those calculated using a risk-based approach and realistic exposure information for metals. This is due in part to the fact that the 1972 criteria were apparently based on maximum concentrations reported for soils as well as conservative assumptions regarding exposure. Note, though, that the 1972 values for crops are based on dissolved metals concentration in water while the risk-based calculations are based on total metal concentrations. However, as total metals concentrations encompass dissolved metal concentrations, the dissolved concentrations were adopted as the most conservative measure for total metals as well.

Water ingestion by humans was evaluated in this study as ingestion of crops and home-grown meat products, as shown in Table ES-2. The direct exposure pathway of water ingestion was the dominant exposure pathway for risk-based water criteria for humans. Ingestion of crops irrigated with water and ingestion of homegrown meat products did not significantly contribute to the final AWQC.

Overall, the water ingestion pathway was the dominant exposure pathway for humans and livestock. The combined human health-based AWQC are presented Table ES-2. Two results are presented for As; the

AWQC values associated with carcinogenic effect of As are lower than those based on noncarcinogenic hazard. Carcinogenic endpoints were assessed only for humans.

Several uncertainties are identified regarding the water quality standards estimated in Tables ES-1 and ES-2. The human health and agricultural WQC were based on domestic and agricultural water uses for the Navajo Nation, and upper-bound exposure parameters were chosen. This was a necessary assumption to address the uncertainty in the range of exposures. This assumption is associated with uncertainty that is intended to be protective of all ages. There is uncertainty in the estimate of soil concentrations from the use of water for irrigation. Deeper tillage may act to decrease concentrations, as deposited metals would be dispersed through a larger soil column. Further, decreases in metals through runoff, plant uptake, addition of soil amendments, or other means were not factored into the estimates. In addition, the water usage may be over- or underestimated and could be better assessed if surface water withdrawal rates are known, as well as the acreage that is irrigated by surface water drawn from the river.

The toxicity reference values were based on tolerable levels in feed for cattle and sheep (defined as the dietary level that, when fed for a defined period of time, will not impair animal health and performance). The body weight and feed intake rates used to assess exposures are based on generally accepted values for sheep and cattle. However, these may not be representative exposure parameters for cattle or sheep in New Mexico due to different ranching practices, or temperature and climate conditions, as well as breed size and water/feed intake rates.

Rates for human consumption of homegrown produce and meat are also associated with uncertainty. U.S. EPA consumption rates for homegrown meat and produce were used, and consumption may be less than this if other sources of food items are more commonly used. Conversely, if all food consumed is homegrown, then these intake rates may not fully capture Navajo exposures and they may lead to an underestimate of risk.

Table ES-1. Summary of risk-based water quality standards (mg/L) for crops and livestock. Bolded values are the recommended values for total metals.

Note: Risk-based standards are based on total metal. U.S. EPA 1972 criteria are based on dissolved metal.

Metal	Crops- (Recommended toxicity-based water concentration, total)[1]	Crops - calculated water concentration based on accumulation in soil and toxicity to crops (total) [2]	Cattle (calculated risk-based value, total)[3]	Sheep (Calculated risk-based value, total)[4]	U.S. EPA 1972 Criteria livestock (dissolved)[5]
Aluminum	***5***	**472**	**190**	**170**	--
Antimony	**0.5**	**45**	**1.8**	**1.6**	--
Arsenic	***0.1***	**84**	**7.2**	**4.5**	0.2
Barium	**50**	**1,640**	**75**	**6.5**	--
Beryllium	***0.1***	**89**	**2.8**	**2.5**	--
Cadmium	***0.01***	**290**	**2.3**	**1.5**	50
Chromium	***0.1***	**10**	**24**	**15**	--
Cobalt	***1***	**67**	**6**	**3.8**	--
Copper	***0.2***	**500**	**9.8**	**2.2**	0.5
Iron	***5***	**1,900**	**120**	**75**	2.0
Lead	***5***	**829**	**23**	**150**	0.05
Manganese	***0.2***	**2,050**	**490**	**300**	--
Mercury	**0.03**	**3**	**0.45**	**0.3**	--
Molybdenum	***0.01***	**13**	**1.2**	**0.75**	--
Nickel	***0.2***	**42**	**24**	**15**	--
Selenium	***0.02***	**5**	**1.2**	**0.75**	--
Silver	**56**	**7**	**1100**	**1000**	--
Thallium	**0.1**	**5**	**9**	**8**	--
Vanadium	***0.1***	**19**	**12**	**7.5**	--
Zinc	***2***	**777**	**120**	**45**	25.0

Bolded values are recommended standards for total metals concentration in water.
Italicized values are recommended in NAS&NAE 1972 for dissolved metals.

1. As described in Section 2.
2. Based on continuous use of water for 20 years, shown in Table 2-3.
3. As calculated in Section 3, Table 3-5
4. As calculated in Section 3, Table 3-6
5. NAS & NAE 1972

Table ES-2. Summary of risk-based metal water quality standards for protection of human health. All standards are expressed as total metal. Bolded values are recommended.

	Direct Ingestion AWQC (mg/L)	Risk-based AWQC from Human Exposure Pathways		Combined AWQC (mg/L)
		Ingestion of Plants - AWQC (mg/L)	Ingestion of Homegrown Meat Products - Adjusted AWQC (mg/L)[3]	
Aluminum	**15**	**43000**	**864000**	15
Antimony	**0.006**	**0.37**	**579.3**	0.0059
Arsenic (non-cancer)	**0.005**	**1.4**	**217**	0.0045
Arsenic (cancer)[1]	**0.00002**	**0.000026**	**0.483**	0.0000113
Barium	**3**	**370**	**1930000**	2.98
Beryllium	**0.03**	**37**	**2900**	0.03
Cadmium	**0.008**	**0.185**	**2630**	0.0072
Chromium	**22.5**	**9200**	**395000**	22.4
Cobalt	**0.005**	**1.2**	**21.7**	0.0045
Copper	**0.6**	**4.4**	**5790**	0.53
Iron	**10.5**	**19500**	**50700**	10.5
Lead	**0.015**	**0.015**	**0.015**	0.005
Manganese	**2.1**	**77**	**507000**	2.04
Mercury	**0.005**	**0.042**	**1740**	0.0041
Molybdenum	**0.075**	**2.3**	**1210**	0.073
Nickel	**0.3**	**9.25**	**4830**	0.29
Selenium	**0.075**	**5.5**	**483**	0.074
Silver	**0.075**	**1.4**	**2410**	0.0712
Thallium[2]	**0.00015**	**0.690**	**0.362**	0.00015
Vanadium	**0.075**	**46**	**2900**	0.075
Zinc	**4.5**	**9.2**	**4340**	3.02

Shaded results indicate that screening level is based on carcinogenic risk.

1. AWQC for ingestion of homegrown meat products for arsenic (carcinogenic) was adjusted downward by a factor of 32000 to account for risk above 1E-6.
2. AWQC for ingestion of homegrown meat products for thallium was adjusted downward by a factor of 25.1 to account for hazard index above 1
3. All AWQC for livestock ingestion adjusted upwards except for arsenic and thallium

1. Introduction

The Clear Water Act specifies two broad classes of waterbody uses: those that directly conform to the main goals of the Act – "fishable and swimmable" uses (under section 304(a) of the Act) - and those that are not directly related to ecological integrity and human safety. The latter include waterbody uses such as water supply for crops livestock, industrial consumption, and navigation.

United States Environmental Protection Agency (U.S. EPA) is required by the Act to develop water quality standards to protect 304(a) uses such as aquatic life, drinking water, and recreation (primary contact such as swimming). U.S. EPA is not required to develop water quality standards for the protection of crops and livestock. Therefore, many States and Tribes have identified their own water quality standards for certain types of common pollutants to protect crops and livestock from waterborne pollutants.

The science behind development of safe thresholds of pollutants to protect crops and livestock has mostly resided with the United States Department of Agriculture (USDA). This Department has, as part of their mission, provided information to farmers and others regarding safe levels of certain constituents, including some metals, in water and soil for the continued production of crops and livestock for eventual human use. This information generally addressed acute potential effects of constituents that have been encountered in various regions of the U.S. due to natural geologic or soil conditions. Constituents such as salts or dissolved solids, for example, have been included by states and Tribes in their water quality standards for agricultural uses due to their prevalence in surface waters in many areas of the United States. Some constituents, such as metals, have been less studied and represent a data gap in terms of having science–based standards that are appropriate for the protection of crops and livestock.

Development of appropriate ambient water quality criteria (AWQC) for crop and livestock protection becomes more complex when considering constituents, including metals, that may bioaccumulate and be transported through the food chain. In these instances, uptake of water is only one of the potential pathways by which livestock may accumulate metals; ingestion of crops that have been exposed to metals is another pathway by which livestock can be exposed to elevated metal concentrations in water or soil. AWQC typically do not account for multiple exposure pathways and this can result in a recommended concentration that does not adequately protect human health. The definition of "criteria" as used in this Report is consistent with U.S. EPA *Water Quality Criteria 1972* (NAS & NAE 1972) and is defined as "the scientific data evaluated to derive recommendations for characteristics of water for specific uses." As a first step in the development of standards, it is essential to establish scientifically based recommendations for protection of crops, protection of livestock, and protection of human health. Note that the term "standard" is used in this Report to indicate regulatory directives on allowable concentrations of metals in water.

The Navajo Nation contracted Tetra Tech, Inc. to evaluate current water quality metal standards for protection of crops, livestock, and humans consuming crops and livestock, the rationale behind those standards and development of science-based standards where feasible. This Report presents and discusses these objectives for several metals of concern that were discharged during the Gold King Mine spill in August 2015 into the Animas River, Colorado. That spill, which contained elevated concentrations of primarily arsenic, copper, iron, lead, nickel, and zinc, continued down the San Juan River, through Navajo Nation lands, and into Lake Powell downstream. Using comprehensive literature reviews and a human health risk assessment framework, this Report derives potential water quality standards for metals for protection of crops, livestock, and humans, where sufficient information exists. This Report is based on an exposure assessment and conceptual model to document the potentially complete pathways.

1.1 Potential Exposure Pathways and Conceptual Site Model

Exposure to constituents can only occur if there is a complete pathway by which humans can be exposed to the affected food, soil, or water. Risk-based water quality standards include all potentially complete exposure pathways. A fundamental principle in risk-based evaluations is that a risk can only occur if there are links between sources of chemicals and human or, as in this case, agricultural receptors (crops and livestock). Therefore, determination of complete exposure pathways and development of the Conceptual Site Model (CSM) form the basis of the exposure assessment upon which AWQC calculations are based (Figure 1-2). The CSM for the risk-based standards includes sources, transport mechanisms, points of exposure, exposure pathways, and receptors. Water can be used for domestic purposes, and exposure routes to humans can also occur through ingestion of plants and animals that utilize the same water source. Agriculture exposure pathways include livestock and plants, both as receptors and as an additional exposure pathway to humans who ingest homegrown products. In rural areas, all of these pathways can be complete for people.

Figure 1-1 shows pictorially the potential exposure pathways in the CSM for metals originating in water that may affect crops, livestock and people. Figure 1-2 presents a more detailed CSM that considers all potential pathways. Water can be used for domestic purposes, and exposure routes to humans can also occur through ingestion of plants and animals that utilize the same water source. Agriculture exposure pathways include livestock and plants, both as receptors and as an additional exposure pathway to humans who ingest homegrown products. In rural areas, all of these pathways can be complete for people.

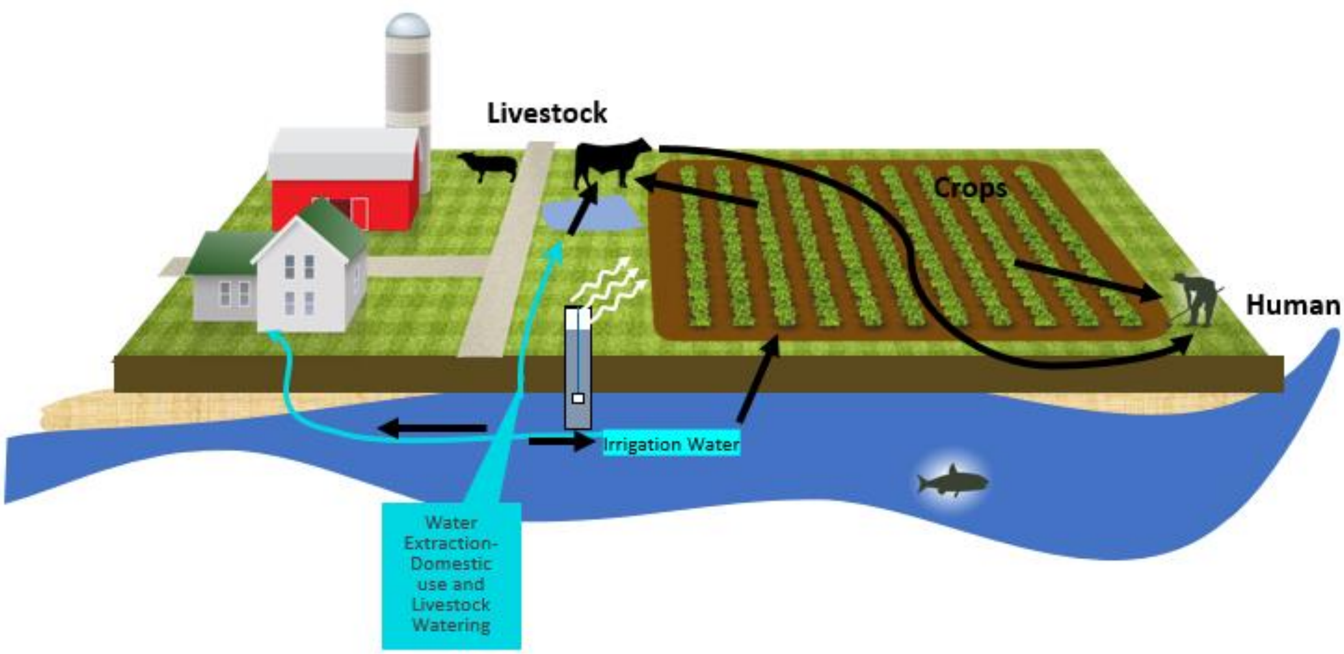

Figure 1-1. Conceptual Model – Use of surface water for crop irrigation, livestock watering, and domestic use

Dietary exposure pathways can represent a major exposure route to metals (U.S. EPA 2007); these are included as part of the livestock and human risk-based assessments. In the livestock risk-based assessment, it is assumed that surface water will be used to irrigate crops and pasture lands as well as to water livestock. Further, the crops are assumed to be food for livestock. The human risk-based assessment includes exposures of water ingestion, ingestion of homegrown produce, and ingestion of homegrown meat products. AWQC based toxicity to plants is presented in Section 2 and those based on toxicity to livestock are presented in Section 3. Homegrown produce is assessed as well, in a manner separate from pasture and agricultural crop irrigation, to more accurately assess the potential human exposure route of consumption of homegrown produce. Estimated tissue concentrations from livestock were calculated in this evaluation and used to refine the human water quality standards by estimated contribution of consumption of homegrown meat products to total human exposure. The calculated results are based on total metal content of water (not just dissolved concentrations). While regulatory water quality standards for aquatic life uses are often based on dissolved concentrations of metals (U.S. EPA 1993), total metal content represents a more likely exposure through agricultural use of water as well as direct exposure to surface water. It is possible that irrigation may occur with water that contains particulates and livestock may have direct access to unfiltered water. Table 1-1 presents the exposure pathways included in the AWQC development.

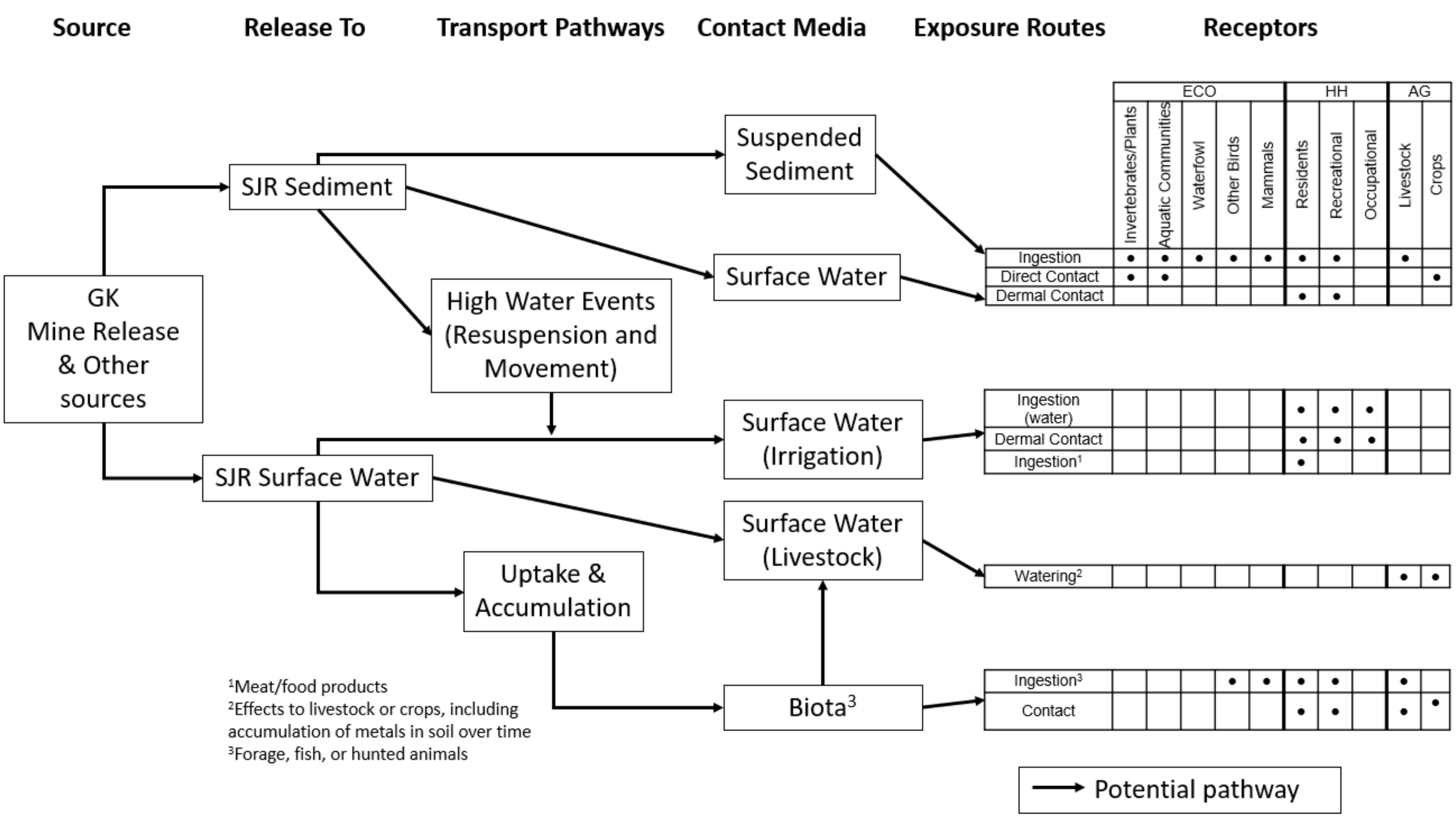

Figure 1-2. Conceptual Site Model (CSM) illustrating potential exposure pathways by which metals in river water or sediment may affect crops, livestock, and people.

Table 1-1. Exposure pathways evaluated.

Receptor	Pathway Evaluated
Crops	Crops irrigated with water – direct toxicity to crop plant (see Section 2)
Livestock	Ingestion of Water (direct exposure of livestock) Ingestion of Soil/Pasture/Crops Irrigated with Water (indirect exposure of livestock) (Section 3)
Humans	Consumption of Homegrown Produce (indirect exposure to metals from surface water) (Section 4) Consumption of Homegrown Meat (indirect exposure to metals from surface water) (Section 4) Ingestion of Water (direct exposure of humans to water) (Section 4)

1.2 Report Organization

Section 2 discusses recommended water quality standards for protection of crops including both published standards and risk-based calculations, their rationale and limitations/uncertainties, application to the San Juan River Basin, and other relevant information regarding metal effects on crops that were compiled in this analysis.

Section 3 discusses recommended water quality standards for protection of livestock including both published standards and risk-based calculations, their rationale and limitations/uncertainties, application to the San Juan River Basin, and other relevant information regarding metal effects on crops that were compiled in this analysis.

Section 4 discusses the toxicological information regarding metals of concern and human health and, respectively, calculates risk to human health from consumption of water, plants, and livestock products exposed to metals. Information compiled in Sections 2 and 3 are used along with Navajo Nation-specific exposure factors to determine acceptable levels of different metals in water based on potential hazard to human, livestock, or crop health. Where sufficient data were available, safe thresholds are presented for each metal as a maximum criterion or a range of concentrations depending on the quality and extent of toxicological information.

Section 5 provides a summary and conclusions of this Report.

2. Recommended Numeric Water Quality Metal Standards for Protection of Crops

This section presents recommended water quality standards for protection of plants, the rationale and research used in deriving these standards, assumptions and limitations regarding the recommended standards and their use, and applicability of these standards to the San Juan River Basin. In this section, the term "crops" is used to refer to plants grown as food for either humans or livestock, and is the focus of this report. The term "plant" refers to terrestrial vegetation and may include crops; it is the term used in many publications to include both crop and non-crop vegetation that may have been the subject of toxicity testing.

After reviewing peer reviewed literature and other sources of information, very few relevant studies were found regarding potential metal toxicological thresholds for crops species. Most of the more recent literature relies on the NAS&NAE standards published in 1972 (NAS & NAE 1972), which were later adopted by U.S. EPA in their water quality criteria. A review of current state and tribal water quality standards (summarized in Appendix A) indicated that many states and tribes have adopted the 1972 NAS &NAE water quality criteria for protection of crops, which includes standards for several metals, depending on the state or tribe.

Appendix A presents current state and tribal agricultural water quality standards (which includes water quality standards for protection of crops) for metals along with the rationale provided if given. As can be seen from Table A-1 through Table A-4 in Appendix A, many states and tribes have adopted somewhat different water quality standards for protection of crops and do not present a rationale as to how they derived their standards.

Table 2-1 presents recommended water quality standards for select metals for the protection of crops. While many of the recommended water quality standards are those published by U.S. EPA due to a lack of more recent relevant data, for a few metals, more current information was available which was used to derive recommended water quality standards. As explained in the "limitations" section (Section 2.2) and in the "other relevant information" section (Section 2.4), relationships between metals in water, resulting metal concentrations in soils, and metal uptake and effects in crops are complex, involving many physicochemical interactions that are not readily extrapolated to soil and climate conditions universally. Currently, published reports appear to contain more information regarding crop toxicological thresholds for metals in soils rather than in water. Other relevant information regarding metals and their effects on crops, including information used by US EPA previously, are also included in this section of the Report and in Appendix B.

Section 2.1 summarizes the rationale and research relied on to derive the standards in Table 2-1 and Section 2.2 presents assumptions and limitations of the recommended standards. Section 2.3 discusses applicability of the crop water quality standards to the San Juan River Basin and Section 2.4 presents additional relevant information that was compiled in this project.

Table 2-1. Recommended Water Quality Criteria Based on Toxicity to Crops

Metals	Criteria Based Primarily on Water Toxicity to Crops			Risk-based AWQC from Accumulation of Metals in Soil and Toxicity to Crops (Total metals in water)	
	NAS and NAE 1972 (mg/L) and USDA 2011 (dissolved)	New Mexico – Irrigation (mg/L dissolved)	Arizona - Irrigation (mg/L)	Based on Accumulation of Metals in Soil, adjusted for Ambient Soil Concentration (mg/L)	Based on 20 years Accumulation, and adjusted for Ambient Soil Concentrations (mg/L)
Aluminum	5	5		9,430	**472**
Antimony	0.1			905	**45**
Arsenic	0.1	0.1	2 (total)	1,685	**84**
Barium	NA			32,800	**1,640**
Beryllium	0.1			1,770	**89**
Cadmium	0.01	0.01	0.05 (hardness dependent)	5,790	**290**
Chromium	0.1	0.1	1 (hardness dependent)	190	**10**
Cobalt	0.05	0.05		1,342	**67**
Copper	0.2	0.2	5 (total)	10,000	**50**
Iron	5			38,000	**1,900**
Lead	5	5	10 (total)	16,580	**829**
Manganese	0.2			41,000	**2,050**
Mercury	NA			54	**3**
Molybdenum	0.01	1		380	**13**
Nickel	0.2			840	**42**
Selenium	0.02	0.13*	0.02 (total)	98	**5**
Silver	NA			135	**7**
Thallium	NA			100	**5**
Vanadium	0.1	0.1		380	**19**
Zinc	2.0	25	1 (total)	15,530	**777**

*In the presence of SO_4 < 500 mg/L

Bolded = derived and recommended in this study

2.1 Rationale and Research Used to Derive Recommended Water Quality Standards for Crop Protection

In researching potential water quality recommendations, preference was given to peer reviewed published information and controlled experimental studies in which the effects of a single metal were clearly demonstrated. Uncontrolled field studies were generally not used to derive recommended water quality standards because effects could not be definitively related to a particular metal. Preference was also given to studies that enabled a direct calculation of water quality standards based on the metal exposure concentration in water. Many studies report soil concentrations of metals that may be toxic to crops or other plants but do not link observed soil metal concentrations with irrigation water concentrations. In addition, many factors affect the concentration of metals in soil including the geological and lithological origin of the soil, the pH of the soil, cation-exchange capacity, organic carbon content, and many other soil and water properties (Khan et al. 2015). Therefore, studies were preferred in which the water metal concentration could be linked to metal effects in plants even with soil present in the study. In general, most information could be traced back to NAS & NAE 1972, which formed the basis for the recommended values in Table 2-1. A brief summary of the rationale for each metal water quality standard from NAS and NAE 1972 is found in Appendix B. In addition, information identified from other sources regarding toxicity of metals to plants is presented in Appendix B.

Another complexity in deriving metal toxicity thresholds for crops is that metals may interact in various ways depending on the combination and concentration (see Appendix B for a discussion on a metal-specific basis). For example, one metal may be more or less toxic in the presence of another as uptake is enhanced or diminished by specific soil chemistry. This was not accounted for in either the NAS &NAE 1972 values nor in the risk-based calculated values. However, existing concentrations of metals in soil was taken into account in deriving the risk-based concentrations as described in Section 2.2.

2.2 Calculation of Water Quality Standards for Plants Based on Accumulation in Soil

Water quality standards presented in NAS &NAE 1972 are based on dissolved concentrations of metals in water. To address issues of suspended sediment and surface water that is not necessarily filtered before its use for irrigation of fields, an evaluation of accumulation of metals in soil from irrigation was conducted. The calculated results are based on total metal content of water (not just dissolved concentrations). While water quality standards are often based on dissolved concentrations of metals, total metal content represents a more likely exposure through agricultural use of water as well as direct exposure to surface water, and accumulation of metals in soil over time can be estimated. Further, total metal content should always be equal to or higher than dissolved metal content for a water sample. The total metal concentration should encompass the amount of dissolved metal plus some potential additional sources of metal attached to sediment or organic material. However, estimation of dissolved metal concentration from total metal concentration in water may not be reliable due to the complexity of water chemistry parameters that influence metal solubility . This issue is beyond the scope of this report and is not discussed further here. As a conservative approach we adopted the simplifying assumption that total metal concentration will be equal to or greater than dissolved metal concentration for this assessment, and that dissolved metal concentrations generally represent the more bioavailable form of metals as noted by U.S. EPA (USEPA 2002, 2007).

The estimate of water concentration that could pose potential toxicity to crops was calculated using the following approach:

(1) Toxicity-based metal concentrations in water identified in literature (these were found to be exclusively dissolved metals concentrations)
(2) When a metal did not have water toxicity-based information, relative toxicity from soil studies was used to determine an acceptable water concentration. Specifically, this approach was used for antimony, barium, silver, thallium, and mercury as noted in Table 2-3. The toxicity of each metal in soil was compared to that of metals with soil and water toxicity-based concentrations, and a water toxicity-based concentration was estimated using the relative toxicity information.
(3) Toxicity-based soil concentrations, from which concentrations in water (total recoverable metals) were calculated, were used to determine a water concentration that could result in toxicity through accumulation in soil.

The toxicity-based water concentrations for dissolved metals were used as a conservative surrogate for total metals concentrations as noted above, and represent a lower-bound value that is protective of toxicity to crops through water. The upper-bound recommended total metals concentrations, based on toxicity through soil, assume that the dissolved concentrations of metals will not exceed the toxicity-based water concentrations. It is recommended that both total and dissolved metals concentrations be obtained for water samples when possible. If that is not possible, then the lower value is more protective of potential toxicity to crops and is recommended for comparison to total metal concentrations in water. The two values represent a range in which compliance with risk-based standards can be gauged: a total metals concentration that is between the upper-bound and lower-bound recommended value may be evaluated using a dissolved concentration. If the dissolved concentration is at or below the lower-bound value, then there is little likelihood of toxicity to crops.

To evaluate the accumulation of metals in soil and subsequent potential toxicity to crops, soil concentrations that represent an upper limit of tolerance for plants (including crops) were used as a not-to-exceed standard. The concentration of each metal in water that would result in the tolerable level of each metal in soil over the course of one year was estimated, predicated on the amount of water used to irrigate crops. The tolerable levels were first adjusted for background by subtracting the maximum concentration measured in the soil samples collected from Navajo lands for each metal (Section 2.4). Ambient metal concentrations in soil for Al, Cr, Fe, Mn, Mo, Se, and V are higher than the tolerable levels and therefore, no adjustment for background was made for these metals.

The amount of water applied to an acre of crop/pasture land was determined from USGS 2015 data for San Juan County, New Mexico (USGS 2019). Per USGS information, 10.81 thousand acre-feet per year of water was used for surface irrigation. This may not capture all surface water irrigation uses, as it excludes sprinkler-supplied water; however, sprinkler-supplied water may be filtered before use. This analysis provides estimates of total metal concentration in water and does not consider filtration. This is to address the possibility of unrestricted access to surface water by livestock for watering, and to address the use of water for irrigating crops or pasture land that are subsequently fed to livestock. The amount of water applied to one acre was determined using the estimated acreage of farmland in San Juan County NM in 2012 (USDA 2012) of 2,580,319 acres.

Potential soil concentrations were estimated by using the conservative assumption that all metals contained in the water applied over a time period of 1 year would remain in the irrigated soil. The depth of the potentially impacted soil was set to 6 inches (0.15 m) to approximate a tillage depth for crops, and this value was used as a mixing zone depth for the metals in irrigation water that would accumulate in soils. Note that some metals in soil already exceeded the toxicity reference levels (Al, Cr, Fe, Mn, Mo, Se, and Va). For these metals, the toxicity reference level unadjusted for background was used; these values are designated in italics.

Estimate of Metal Concentration in Soil

This water usage and acreage were converted to 0.00013 L/cm2 per year, then multiplied by the amount of each metal in water (mg/L) and divided by 15 cm (6 inches) to estimate the average amount of the metal in surface soil, accounting for the tillage depth. The value was converted to units of mg/kg by multiplying by the soil density (g/cm3). Soils were assumed to be sandy-loam based on the samples obtained from Navajo staff and summarized in Section 4.2.3 of this Report. For the purposes of modeling a concentration in soil from use of irrigation water, a soil density of 1.6 g/cm3 was used (USDA 2003). The equation is as follows:

Soil Concentration (mg/kg) = Cw x WC/D x SD

Where:

Cw = Concentration in water (mg/L)

WC = Water Consumption (average annual irrigation rate) (0.00013 L/cm^2)

D = Depth of tillage (15 cm)

SD = Soil Density (1.6 g/cm^3)

The calculated amount of metal residual in soil was used to estimate the amount that may be taken up into crops. This amount was also used to estimate incidental ingestion of metals in soil by livestock while foraging. Estimates were based on 1 year and 20 years of irrigation, and do not include any loss of metals from soil due to soil erosion, uptake, or other factors. Uptake to plants was calculated as the product of the calculated soil concentrations multiplied by the bioaccumulation factor listed in Table 2-2 for use in the livestock and human risk-based assessments.

Table 2-2. Calculation of Soil Concentration from Use of Unfiltered Irrigation Water and Estimate

Equations	**Soil concentration:** AWQC x Water use (L/m^2) /tillage depth* soil bulk density Soil bulk density = 1.6 g/cm^3 Water use = 0.00013 L/cm^2 Tillage depth = 15 cm	**Crop concentration**: Soil concentration estimate x BAF_{veg} BAF_{veg} = chemical specific, below
Metal	**Bv (Bioaccumulation Vegetative)[1]**	**Br (Bioaccumulation Fruit/Vegetable Plant)[1]**
Aluminum	0.001	0.000650
Antimony	0.05	0.03
Arsenic	0.01	0.006
Barium	0.0375	0.015
Beryllium	0.0025	0.00150
Cadmium	0.1375	0.15
Chromium	0.001875	0.0045
Cobalt	0.005	0.007
Copper	0.1	0.25
Iron	0.001	0.001
Lead	0.01125	0.009
Manganese	0.0625	0.05
Mercury	0.225	0.2
Molybdenum	0.0625	0.06
Nickel	0.015	0.06
Selenium	0.00625	0.025
Silver	0.1	0.1
Thallium	0.001	0.0004
Vanadium	0.001375	0.003
Zinc	0.264	0.9

1. From Baes et al. 1984

Estimate AWQC for Crops/Pasture

Accumulation of metals in soils was estimated and evaluated for potential toxicity to crops. The maximum tolerable water concentration was determined when the ratio of the maximum calculated soil concentrations to plant soil screening levels was 1.0. The following equation was used; the ratio of soil concentration to screening level is called the hazard and is acceptable at values of 1.0 and below.

$$Hazard = C_{media} / SL$$

Where

C_{media} = Calculated Concentration in Soil (mg/kg)

SL = Screening Level (mg/kg)

The maximum calculated water concentration for plant toxicity is shown in Table 2-3 reflects the water concentration that would produce a soil concentration with a ratio of 1 to the plant soil screening level. Note that this value is an incremental amount to soil and is based on one year of accumulation to the maximum screening level (adjusted for background where possible). When the plant toxicity screening level was lower than the existing soil concentrations, the screening level was used without any adjustment as a not-to-exceed value for accumulation. The calculated WQ values can be divided by an exposure duration (in years) to estimate an allowable water concentration that will not exceed plant screening level for soil over the desired number of years. The calculated WQ value that would be applicable to 20 years of irrigation are shown, also adjusted for the measured concentrations of metals known to be present in area soils (see Section 2.4). These calculated values are based on total metals in water and are intended to show the accumulation potential of metals to soils, and the subsequent toxicity to crops. As noted previously, some metals in soil already exceeded the toxicity reference levels (Al, Cr, Fe, Mn, Mo, Se, and V). For these metals, the toxicity reference level unadjusted for background was used; these values are designated in italics in Table 2-3.

Table 2-4 presents the toxicity-based water concentrations without regard to soil concentration. These values were first selected from NAS& NAE 1972 and USDA 2011 when available. A literature search was conducted to determine if other values have been developed; the results of the search are presented in Appendix B, but no additional relevant information was found. For those metals without a toxicity-based irrigation water value in NAS&NAE 1972 or USDA 2011, a water value was estimated based on toxicity information from soil. Specifically, there are no irrigation water values based on toxicity to terrestrial plants for antimony, barium, silver, thallium, and mercury. For these metals, it was noted that the toxicity-based soil concentration for antimony was 10 (ten) times lower than that of aluminum; therefore, the AWQC for aluminum was divided by 10 as a surrogate measure of a toxicity-based water value for antimony. Similarly, the toxicity-based soil concentration for barium and silver were 10 (ten) times higher than that of aluminum; therefore, the AWQC for aluminum was multiplied by 10 as a surrogate measure of toxicity-based water value for barium and silver. Likewise, the toxicity-based soil concentration for thallium was equal to that of chromium, therefore the toxicity-based water value for chromium was adopted for thallium as a surrogate. For mercury, the toxicity-based soil concentration was one-third that of chromium; therefore, the AWQC for chromium was multiplied by 0.3 as a surrogate measure of a toxicity-based water value for mercury. It is recognized that this is a simplifying assumption, based on dissolved concentrations of metals in water forming the bioavailable portion of metals from soil.

In all cases, the AWQC values were lower than those estimated for the soil accumulation pathway. As a conservative measure, the AWQC values (including surrogates) were recommended for all metals. Although the AWQC were developed as a dissolved concentration, they represent the most conservative total metals concentration as well. The values estimated for the soil accumulation pathway represent an upper bound concentration for total metals concentration in water.

Table 2-3. Water Concentration that would Result in a Soil Concentration that poses toxicity to crops.

Chemical	Target Soil Concentrations		Calculated Water Concentration (mg/L) for 1 year	Accumulation of Metals in Soil Based on Water Concentration		Water Concentration based on Accumulation in Soil over 20 years[d]
	Plant Toxicity-based Screening Concentration for Soil (mg/kg)	Plant Toxicity-based Screening Concentration Adjusted for Existing Soil Concentrations (mg/kg) [e]		Amount Applied to 1 cm2 x 15 cm depth of Soil in 1 Year (mg/cm3)	Soil Concentration 1 Year through 15 cm depth (mg/kg)	
Aluminum	50[a]	*50*	9,430	0.08	49.5	472
Antimony	5[a]	4.76	905	0.008	4.95	45
Arsenic	18[b]	8.86	1,685	0.029	17.9	84
Barium	500[a]	172	32,800	0.8	494	1,640
Beryllium	10[a]	9.3	1,770	0.016	9.98	89
Cadmium	32	30.46	5,790	0.051	31.5	290
Chromium	1	*1*	190	0.002	1.0	10
Cobalt	13[b]	7.05	1,342	0.021	12.9	67
Copper	70[b]	52.5	10,000	0.111	68.3	500
Iron	200[c]	*200*	38,000	0.015	9	1,900
Lead	120[b]	87.1	16,580	0.192	118	829
Manganese	220[b]	*220*	41,000	0.349	215	2,050
Mercury	0.30[a]	0.28	54	0.0005	0.294	3
Molybdenum	2[a]	*2*	380	0.003	2	13
Nickel	30[a]	4.4	840	0.061	37.8	42
Selenium	0.52[b]	*0.52*	98	0.001	0.52	5
Silver	2[a]	0.71	135	0.894	552	7
Thallium	1[a]	0.53	100	0.002	1.0	5
Vanadium	2[a]	*2*	380	0.003	2	19
Zinc	160[b]	81.6	15,530	0.255	158	777

Water Screening Values from U.S. EPA 1972 (NAS & NAE 1972) with the following exceptions: AWQC values for Sb, Ba, and Ag were derived from the criteria for Al based on relative toxicity in soil; AWQC values for Tl and Hg were derived from Cr based on relative toxicity in soil.

a. From Efroymson et al 1997. It was assumed that the recommended toxicity-based screening levels for plants were applicable to crops.
b. From EPA Eco SSLs for Plants (US EPA, various dates). It was assumed that the recommended toxicity-based screening levels for plants were applicable to crops.
c. EPA Region 4 soil screening value
d. Calculated as total metals concentration in water that would result in soil concentration exceeding plant toxicity values if water is used for 20 years, adjusted for existing concentration in soil with the exception of Al, Cr, Fe, Mn, Mo, Se and V, whose soil concentrations already exceed toxicity-based soil concentrations. For those metals, the unadjusted toxicity value was used as the not-to-exceed standard.
e. See Table 2-7 for Ambient Metals Concentrations for Soil

To determine the uptake of metals to crops based on the AWQC listed in NAS & NAE 1972 and USDA 2011 (listed as toxicity-based values to plants in those documents), the same equation was used to estimate soil concentration and crop concentrations. The results, shown below in Table 2-4, are used in Section 3 of this Report to determine uptake of metals by livestock from pasture and feed, and in Section 4 to estimate uptake of metals by humans who ingest homegrown crops. Note that the 1972 NAS & NAE AWQC result in soil concentrations well below those known to be toxic to crops; this evaluation shows that the AWQC would be protective if applied to total metals concentration in water.

Table 2-4. Predicted Crop Concentrations derived from Ambient Water Quality Standards based on toxicity to crops.

Metals	Maximum Predicted Soil Concentrations from Irrigation					
	AWQC (mg/L) [1]	Amount Applied to 1 cm2 of Soil in 1 Year (mg/cm³)	Amount contained in 1 cm2 x 15 cm depth of Soil in 1 Year (mg/cm³)	Soil Concentration 1 Year (mg/kg)	Plant BAF	Concentration in Crops (mg/kg)
Metals						
Aluminum	5	6.38E-04	4.26E-05	0.0266	0.001	2.66E-05
Antimony	0.5	6.38E-05	4.26E-06	0.0027	0.05	1.33E-04
Arsenic	0.1	1.28E-05	8.51E-07	0.0005	0.01	5.32E-06
Barium	50	6.38E-03	4.26E-04	0.2660	0.0375	9.98E-03
Beryllium	0.1	1.28E-05	8.51E-07	0.0005	0.0025	1.33E-06
Cadmium	0.01	1.28E-06	8.51E-08	0.0001	0.1375	7.32E-06
Chromium	0.1	1.28E-05	8.51E-07	0.0005	0.001875	9.98E-07
Cobalt	0.05	6.38E-06	4.26E-07	0.0003	0.005	1.33E-06
Copper	0.2	2.55E-05	1.70E-06	0.0011	0.1	1.06E-04
Iron	5	6.38E-04	4.26E-05	0.0266	0.001	2.66E-05
Lead	5	6.38E-04	4.26E-05	0.0266	0.01125	2.99E-04
Manganese	0.2	2.55E-05	1.70E-06	0.0011	0.0625	6.65E-05
Mercury	0.03	3.83E-06	2.55E-07	0.0002	0.225	3.59E-05
Molybdenum	0.01	1.28E-06	8.51E-08	0.0001	0.0625	3.33E-06
Nickel	0.2	2.55E-05	1.70E-06	0.0011	0.015	1.60E-05
Selenium	0.02	2.55E-06	1.70E-07	0.0001	0.00625	6.65E-07
Silver	56	7.15E-03	4.77E-04	0.2979	0.1	2.98E-02
Thallium	0.1	1.28E-05	8.51E-07	0.0005	0.001	5.32E-07
Vanadium	0.1	1.28E-05	8.51E-07	0.0005	0.001375	7.32E-07
Zinc	2	2.55E-04	1.70E-05	0.0106	0.264	2.81E-03

ND = Not Detected
NA = Not Available
BAFs are for wet-weight plants (ORNL 2018) for vegetative part of plant
Plant concentration (mg/k) = Soil Concentration * BAF (wet weight)
Screening concentrations are from Efroymson et al. 1997 and U.S. EPA Ecological Screening Levels (2005-2007)

1. NAS and NAE 1972 for all except the following due to a lack of chemical specific information. Relative toxicity to the plant was determined from a ratio of soil toxicity concentrations and used to adjust the water toxicity values were missing.
    a. For Antimony, the AWQC is the toxicity criteria for Aluminum divided by 10
    b. For Barium, AWQC is 10 x the water toxicity criteria for Aluminum
    c. For Silver, AWQC is 10 x the water toxicity criteria for Barium
    d. For Thallium, the AWQC is equivalent to the water toxicity criteria for Chromium
    e. For Mercury, the AWQC is 0.3 x the water toxicity criteria for Chromium

2.3 Assumptions and Limitations

Several assumptions and limitations should be noted regarding the standards suggested for crop protection for the metals listed in Table 2-1 and Table 2-2. Both concentration of metals in soil and water, and metal bioavailability from these media, factor into the development of a protective criteria.

Uptake of metals by plants is influenced by many factors. Both leafy and non-leafy vegetables potentially accumulate metals from their surrounding environment (Khan et al. 2015). Metal accumulation in plant materials results in a range of possible adverse effects: (1) direct and indirect toxic effects to the plants themselves; (2) altered nutritional value of the plants and; (3) foodchain transfer to animals and humans, resulting in potentially toxic effects to the consumer (Khan et al. 2015).

The toxicity of heavy metals to plants is due to direct or indirect interference with metabolism or other active processes (Sharma and Dietz 2006), largely through effects on enzymes (Das et al. 1997). Toxic effects of metals on plants, particularly those that cause reduction in growth, can be attributed to reduced photosynthetic activities, impaired plant mineral nutrition, and reduced activity of some enzymes (Kabata-Pendias 2001). The effect of toxic metals on plants is often discussed in terms of: (1) cellular and physiological-level effects, such as the inhibition of cytoplasmic enzymes, damage to cell structures due to oxidative stress, and chlorosis (loss of chlorophyll in the leaves) and (2) organism-level effects such as decreases in root or stem growth, decreases in production of phyto-biomass, and water stress (Asati et al. 2016, Rucinska-Sobkowiak 2016, Bhalerao et al. 2015, Vijayarengan and Mahalakshmi 2013, John et al. 2009). Heavy metals can interfere with (e.g., substitute for) other essential elements in various physiological processes. For example, arsenic can substitute for phosphate in phosphorylation reactions, including ATP synthesis. Also, cadmium is chemically similar to zinc, calcium and iron and can replace these elements in proteins (Verbruggen et al. 2009).

Section 2.4 below ("Other Relevant Information") discusses metal bioaccumulation for different crop species and presents available data provided in peer-reviewed publications. This information is used in part to assess potential effects of crops on livestock and to derive protective standards for livestock (see Section 3 of this Report).

Specific crop species are not often mentioned so it is not clear whether the criteria recommended in NAS & NAE 1972 are appropriate for certain crops. Many of the crop species of interest to the Navajo (e.g., squash, melons, alfalfa) did not have relevant information. However, some existing soil concentrations exceed the toxicity-based screening levels, indicating that crops of interest may be more tolerant of metals in soil.

Interactions observed between the metals in the water, the soil, and the plants in studies used to derive the NAS&NAE 1972 criteria are assumed by U.S. EPA to be applicable to all crops and all regions, given the soil characteristics if identified in the 1972 criteria rationale. For some metals the type of soil identified may not be relevant to a given region (e.g., San Juan River Basin).

The calculated water quality concentrations based on accumulation in soil account for existing soil concentrations as measured in the soil samples provided. If the existing soil concentrations are higher than these levels, the water concentrations based on soil accumulation should be lowered to prevent accumulation of metals in soil to concentrations that will exceed tolerable levels. Further, unless substantial removal of metals from soil is expected to occur, accumulation over time should be considered as well and concentrations adjusted downward to account for long-term use of unfiltered irrigation water.

Dilution of or removal of metals from soil (such as runoff or soil amendments) has not been included in these values. However, the AWQC recommended in NAS & NAE 1972 will not result in soil concentration that could cause plant toxicity and will result in minimal metal accumulation in crops.

The assumptions used for assessing soil accumulation of metals are associated with some uncertainty. The use of a soil density of 1.6 g/cm^3 corresponding to sandy loam provides a reasonable estimate of soil density based on soil samples evaluated in this study (see Section 2.4.1). However, the representativeness of this soil density for other areas of the Navajo Nation is unknown and pH can also influence availability of metals for uptake by plants. It is also recommended that estimation of metal accumulation in soil be further evaluated.

Site-specific bioaccumulation factors for homegrown plants could be developed by growing species of interest in soil from a representative area. Soil concentration, vegetative plant parts, and non-vegetative plant parts (such as melons, squash, and corn) could be analyzed to determine a more site-specific uptake factor.

2.4 Applicability to San Juan River Basin

The standards presented in Table 2-1 are generally applicable to the San Juan River basin but some considerations must be taken into account. As noted in Section 2.3, except for maize and beans, other common crops in the region such as alfalfa, squash, and melons were not generally tested to the metals evaluated in this Report. Also, the soils often used in those studies to derive water quality standards may not be indicative of all soils in the San Juan River Basin. In some cases, sandy soils or manure were used to assess metal effects on certain crop species, neither of which may be appropriate for soils in the San Juan River Basin.

Tetra Tech conducted U.S. EPA-approved sediment and soil toxicity tests for the Navajo Nation to help inform the water quality standards process and provide current information regarding potential toxicity of different soil and sediment samples. These soils and sediments were selected as part of the assessment of the San Juan River (SJR) using samples from the SJR and surrounding tributaries that are representative of sediments and soils that are affected by water used for agricultural crops. Terrestrial plants and freshwater amphipods were exposed to terrestrial soils and sediments, respectively, for the assessment of lethal (i.e., survival or germination) and sub-lethal (i.e., length, weight, and/or reproduction) effects. Results for soil are discussed below, while information on sediments can be found in Appendix E.

2.4.1 Soil Samples and Toxicity Assessment

Soil samples were collected by Navajo personnel and consisted of various soils farmed. Table 2-5 summarizes the soils used in this study.

Table 2-5. Summary of soils collected by Navajo Nation personnel and used in soil toxicity evaluations.

Area	Soil Unit	Unit Name	Sample Label
Upper Fruitland-San Juan Area	As	Apishapa clay	Soil-AS-01
	Tp/Tt	Turley clay loam/Turley clay loam, wet	Soil-TP-01
	Fu/Fr	Fruitland loam/Fruitland sandy loam	Soil-FR-01
Hogback-Lower Shiprock	200	Tocito silt loam	Soil-200-01 Soil-200-02
	270	Fruitland sandy clay loam	Soil-270-01
	295/290	Mesa sandy clay loam, wet/Mesa clay loam, wet	Soil-295-01 Soil-295-02
Cudei	157	Werjo, saline-Werjo loams	Soil-157-01
Utah	AV	Aquic Ustifluvents-Typic Fluvaquents association	Soil-AV-01

Overall, the soils samples consisted of >89% solids, pH between 7.89 and 8.18, and a range of particle sizes (Table 2-6). Soil-200-02 had the highest percentage of larger particles including medium gravel, fine gravel, and very coarse sand while Soil-295-02 had the highest percentage of clay.

Total metal concentrations in soil samples evaluated exceeded some metal soil screening values for plants (Table 2-7) based on Efromyson et al. (1997). These screening values are commonly used by US EPA and others in site ecological risk assessments. Manganese and vanadium most frequently exceeded their respective screening values for soil samples. Some metals such as aluminum, chromium, manganese, and zinc exceeded their respective screening values by an order of magnitude or more (Table 2-7). It is not known to what degree these metals concentrations are natural or have been affected by human activities (e.g. mine spills).

Soil Chemistry

Fully-homogenized soil subsamples were sent to ALS Environmental in Kelso, WA for the analysis of total solids (EPA 160.3), acid-volatile sulfides (EPA 821/R-91-100), total organic carbon (EPA 9060), metals (EPA 6020A), and Hg (EPA 7471B).

The analysis of total metals in the soils indicated that there were no exceedances of soil screening values for plant toxicity (Efroymson et al. 1997) for Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Hg, Ni, silver (Ag), and thallium (Tl) and zinc (Zn) (Table 2-7). All soils had concentrations of V higher than the screening value and many had higher concentrations of Mn as well. Mo and Se were about screening levels in 1 sample and 4 samples, respectively. Soil-200-01 had the most metals with concentrations in exceedance of screening values including Mo, Se, V, and Zn. The measured concentrations of Cd, Mo, Se, and V in Soil-200-01 were also the highest measured in all sampled soils (Table 2-7).

Table 2-6. Summary of results of general chemistry on Navajo Nation soils.

Parameter	Units	Surface Soils									
		Soil-295-01	Soil-200-02	Soil-200-01	Soil-TP-01	Soil-FR-01	Soil-AS-01	Soil-295-02	Soil-AV-01	Soil-270-01	Soil-157-01
Total Solids	**%**	94.2	91.3	94	94.2	**96.4**	93.1	89.6	**96.4**	95.3	95
pH	**su**	8.13	8.05	7.93	8.04	7.98	7.93	8.13	7.89	**8.18**	8.11
Gravel, Medium	**%**	0	**0.39**	0	0	0	0	0	0	0	0
Gravel, Fine	**%**	0.02	**4.62**	1.98	0.13	0.19	0.32	1.07	0.02	0.21	0.16
Sand, Very Coarse	**%**	0.33	**6.32**	3.29	3.37	0.7	1.51	1.48	0.18	0.81	0.43
Sand, Coarse	**%**	6.1	6.39	3.68	6.26	6.12	3.26	6.17	1.13	**11.73**	1.99
Sand, Medium	**%**	12.06	5.58	3.93	6.84	13.15	5.39	11.78	3.45	**22.17**	3.93
Sand, Fine	**%**	23.76	9.37	11.38	23.79	**31.55**	26.84	21.21	14.33	28.75	12.17
Sand, Very Fine	**%**	11.35	5.77	7.21	12.64	10.41	**15.29**	9.15	10.04	6.36	8.35
Silt	**%**	42.58	54.7	64.74	44.29	34.75	41.38	37.41	**66.6**	25.07	64.06
Clay	**%**	4.59	6.94	2.31	2.3	2.99	6.64	**11.72**	5.55	5	4.95

Table 2-7. Summary of metals analysis on Navajo Nation soils. Bolded values indicate the maximum measured value across all soils. Shaded cells indicate measured value above the Soil Screening Level for plants (Efroymson et al. 1997).

Parameter	Units	Surface Soils										
		Soil Screening Level	Soil-295-01	Soil-200-02	Soil-200-01	Soil-TP-01	Soil-FR-01	Soil-AS-01	Soil-295-02	Soil-AV-01	Soil-270-01	Soil-157-01
Aluminum	**mg/Kg**	50	6910	**7570**	5140	5900	5620	8230	6010	6860	4550	6380
Antimony	**mg/Kg**	5	0.084	0.101	**0.24**	0.087	0.072	0.121	0.099	0.095	0.103	0.074
Arsenic	**mg/Kg**	18	4.52	4.54	**9.14**	3.94	3.16	4.58	3.9	4.14	3.56	4
Barium	**mg/Kg**	500	251	143	68.5	231	141	213	**328**	248	89.7	120
Beryllium	**mg/Kg**	10	0.491	0.621	0.46	0.603	0.445	**0.697**	0.432	0.579	0.35	0.505
Cadmium	**mg/Kg**	32	0.193	0.457	**1.54**	0.276	0.236	0.273	0.216	0.384	0.491	0.355
Chromium	**mg/Kg**	1	5.62	**8.95**	8.8	6.53	5	7.19	5.47	7.78	5.84	8.27
Cobalt	**mg/Kg**	13	4.6	4.74	4.74	**5.95**	4.2	6	4.22	4.53	3.29	3.93
Copper	**mg/Kg**	70	10.9	16.3	16	**17.5**	11.8	16.7	9.69	12.4	8.45	10.9
Iron	**mg/Kg**	--	11400	12500	13500	9340	8810	**13700**	11700	10300	8560	11000
Lead	**mg/Kg**	120	11.4	23.6	11.3	21.5	17.1	**32.9**	9.86	19.3	8.45	11
Manganese	**mg/Kg**	220	259	300	162	387	297	**392**	324	342	200	197
Mercury	**mg/Kg**	0.3	0.013 J	0.017 J	0.019 J	0.012 J	0.011 J	0.018 J	0.015 J	0.011 J	0.006 J	0.013 J
Molybdenum	**mg/Kg**	2	0.517	0.863	**7.77**	0.47	0.333	0.479	0.531	0.464	1.34	1.15
Nickel	**mg/Kg**	30	7.61	10.5	**25.6**	7.68	6.09	8.82	7.01	7.27	8.6	11.5
Selenium	**mg/Kg**	0.52	0.3 J	0.63 J	**3.62**	0.3 J	0.23 J	0.35 J	0.3 J	0.28 J	0.64 J	0.69 J
Silver	**mg/Kg**	2	0.067	0.155	0.117	0.113	0.091	0.17	**1.29**	0.082	0.055	0.073
Thallium	**mg/Kg**	1	0.11	0.144	**0.47**	0.153	0.09	0.141	0.103	0.132	0.164	0.171
Vanadium	**mg/Kg**	2	21.1	18.8	**41.4**	20.1	14.8	20.6	18.7	15.7	23.3	16.8
Zinc	**mg/Kg**	160	36.6	78.5	77.5	79.3	60.4	**78.4**	34.4	54.7	41.9	50.2

Soil toxicity tests were conducted on soil samples to determine whether metal concentrations measured cause significant effects on plant growth. Toxicity tests were conducted using four different plant species including corn (*Zea mays*), squash (*Curcurbita pepo*), alfalfa (*Medicago sativa*), and melon (*Cucumis melo*) following methods in ASTM (2014). Seeds were obtained from Navajo staff. Targeted test duration was twice the time allotted for control germination or 15 days. According to USDA germination standards, (http://www.webgrower.com/information/seed_germ_standards.html) the percent germination for corn and squash is 75% and for alfalfa and melon is 70%. These were the target germination rates that dictated the length of the test. Corn and melon reached the required percent germination in 5 and 7 days, respectively, and these tests were terminated at 10 and 14 days, respectively. Alfalfa and squash did not reach the required percent germination rate, however sufficient germination was obtained to derive statically valid endpoints. Those tests were terminated on Day 15.

Endpoints measured in the soil toxicity tests with respect to comparison to the controls include: percent germination, mean shoot length (mm), mean root length (mm), mean total dry weight (mg), mean shoot weight (mg), and mean root weight (mg).

Several soil samples resulted in significantly less germination with respect to the controls as follows:

- 2 samples resulted in significantly less corn germination than controls (Soil-295-01 and Soil-270-01) (Table 2-8).
- 4 samples resulted in significantly less melon germination than controls (Soil-157-01, Soil-270-01, Soil-FR-01, and Soil-AV-01) (Table 2-9).
- all samples had the same or better alfalfa germination than controls (Table 2-10)
- 6 samples resulted in significantly less squash germination than controls (Soil-295-01, Soil-270-01, Soil-200-01, Soil-FR-01, Soil-AS-01, and Soil-AV-01) (Table 2-11)

Multiple soil samples produced plants with significantly shorter shoots and roots when compared to the controls as follows:

- 2 samples produced shorter corn shoots (Soil-295-01 and Soil-270-01)
- 7 samples produced shorter corn roots (Soil-157-01, Soil-295-01, Soil-270-01, Soil-TP-01, Soil-FR-01, Soil-AS-01, and Soil-AV-01)
- Only one sample (Soil-270-01) produced significantly shorter melon shoots
- 3 samples (Soil-157-01, Soil-270-01, and Soil-AV-01) produced significantly shorter melon roots
- 3 samples (Soil-295-01, Soil-270-01, and Soil-200-01) produced shorter squash shoots
- 8 samples produced shorter squash roots (Soil-157-01, Soil-295-01, Soil-270-01, Soil-200-01

Overall there were no significant effects on mean total dry weight, mean root weight or mean shoot weight with any of the soil samples except for Soil-270-01 (mean total dry weight, mean root weight and mean shoot weight) and Soil-200-01 (mean total dry weight) and squash (Table 2-11). The analysis of the results of the soil toxicity tests using corn, honeydew melon, alfalfa and squash are summarized in Table 2-8 through Table 2-11.

Soil-270-01 resulted in significant effects in 3 out of 4 plant species tested but did not have the highest concentration of any metal. Soil-200-01 resulted in no significant effects for 3 out of 4 plant species tested but had the highest metal concentration for 8 metals with five of those exceeding screening values. This suggests that observed effects on plants in the laboratory tests were not linked to measured soil metal concentrations.

Table 2-8. Summary of Zea mays L. (corn) survival and growth endpoints for soils. Shaded cells are significantly less than controls (p < 0.05).

Test ID	Site	% Germination	Mean Shoot Length (mm)	Mean Root Length (mm)	Mean Total Dry Weight (mg)	Mean Root Weight (mg)	Mean Shoot Weight (mg)
Tt04097	Control	92	231.1	249.4	142.4	39.4	95.6
Tt04098	Soil-157-01	96	283.1	159.2	260.7	83.9	176.8
Tt04099	Soil-295-01	44	163.9	83.2	150.5	32.5	118.1
Tt04100	Soil-270-01	44	146.3	108.0	153.6	24.5	129.1
Tt04101	Soil-200-01	88	255.4	214.3	198.6	51.6	146.9
Tt04102	Soil-TP-01	92	224.8	169.1	151.5	25.8	125.8
Tt04103	Soil-200-02	80	242.9	244.8	164.7	31.9	132.7
Tt04104	Soil-FR-01	76	239.7	134.4	155.2	17.7	136.8
Tt04105	Soil-AS-01	84	256.4	176.6	197.0	34.7	162.3
Tt04106	Soil-295-02	96	260.5	245.5	168.3	39.6	128.7
Tt04107	Soil-AV-01	92	198.0	96.1	217.7	42.8	174.9

Table 2-9. Summary of Cucumis melo (melon) survival and growth endpoints for Navajo Nation soils. Shaded cells are significantly less than controls (p < 0.05).

Test ID	Site	% Germination	Mean Shoot Length (mm)	Mean Root Length (mm)	Mean Total Dry Weight (mg)	Mean Root Weight (mg)	Mean Shoot Weight (mg)
Tt04086	Control	96	185.8	114.7	77.5	11.3	66.2
Tt04087	Soil-157-01	68	213.1	71.5	109.9	17.4	92.5
Tt04088	Soil-295-01	88	202.6	100.6	93.0	15.0	77.9
Tt04089	Soil-270-01	28	110.2	64.8	104.8	17.1	125.0
Tt04090	Soil-200-01	96	197.1	135.1	102.0	15.9	86.0
Tt04091	Soil-TP-01	100	197.7	104.9	94.5	14.7	79.9
Tt04092	Soil-200-02	88	209.3	117.3	87.8	12.5	75.2
Tt04093	Soil-FR-01	64	214.6	94.7	104.3	14.3	90.0
Tt04094	Soil-AS-01	84	213.8	98.7	104.6	23.6	80.9
Tt04095	Soil-295-02	92	210.7	130.7	118.8	23.6	95.2
Tt04096	Soil-AV-01	36	157.3	54	159.9	20.7	139.2

Table 2-10. Summary of Medicago sativa (alfalfa) survival and growth endpoints for soils. Shaded cells are significantly less than controls (p < 0.05).

Test ID	Site	% Germination	Mean Shoot Length (mm)	Mean Root Length (mm)	Mean Total Dry Weight (mg)	Mean Root Weight (mg)	Mean Shoot Weight (mg)
Tt04108	Control	64	52.4	38.6	7.3	2.6	4.7
Tt04109	Soil-157-01	60	80.1	37.7	8.5	4.1	4.4
Tt04110	Soil-295-01	52	53.3	40.2	5.5	1.3	4.2
Tt04111	Soil-270-01	40	49.2	44.0	3.5	0.9	2.5
Tt04112	Soil-200-01	64	69.7	44.1	7.3	1.8	5.5
Tt04113	Soil-TP-01	60	48.3	41.3	12.0	6.7	5.3
Tt04114	Soil-200-02	80	41.0	68.6	3.6	1.5	2.1
Tt04115	Soil-FR-01	76	72.3	41.2	9.5	3.3	6.3
Tt04116	Soil-AS-01	84	78.5	48.4	4.1	1.2	2.9
Tt04117	Soil-295-02	92	81.2	61.8	5.2	1.6	3.6
Tt04118	Soil-AV-01	64	56.9	47.2	8.4	4.2	4.2

Table 2-11. Summary of Cucurbita pepo (squash) survival and growth endpoints for soils. Shaded cells are significantly less than controls (p < 0.05).

Test ID	Site	% Germination	Mean Shoot Length (mm)	Mean Root Length (mm)	Mean Total Dry Weight (mg)	Mean Root Weight (mg)	Mean Shoot Weight (mg)
Tt04075	Control	60	130.1	91.4	31.6	13.2	18.4
Tt04076	Soil-157-01	68	131.2	60.1	37.1	11.4	25.6
Tt04077	Soil-295-01	12	51.4	31	23.5	8.0	15.5
Tt04078	Soil-270-01	0	0	0	0	0	0
Tt04079	Soil-200-01	12	47.2	27.2	9.5	4.1	7.9
Tt04080	Soil-TP-01	88	150.0	69.5	37.9	9.2	28.6
Tt04081	Soil-200-02	56	104.8	56.7	26.7	5.5	21.2
Tt04082	Soil-FR-01	32	69.5	28.1	18.5	10.6	7.9
Tt04083	Soil-AS-01	16	105.6	53.8	28	9.3	18.7
Tt04084	Soil-295-02	56	129.2	81.1	35.0[a]	11.9[a]	30.4[a]
Tt04085	Soil-AV-01	24	94	34.3	29.7	10.2	19.5

[a] Replicate E shoots were not dried completely upon weighing and skewed the weight measures. Replicate E shoots were removed from the analysis with respect to mean dry weight and mean shoot weight.

2.5 Other Considerations: Factors Affecting Metals Bioaccumulation in Crops

Bioavailability, and thus the uptake of various heavy metals from soil, is affected by factors including the concentration of metals in the soil, the type of metal, their form in the soil matrix and solubility; soil characteristics (e.g., sediment particle size composition, organic content, pH), the type of plant, phase of development, and various plant adaptations that affect the uptake, bioaccumulation, and translocation of heavy metals in plants (Tamakhina et al. 2018, Asati et al. 2016, Khan et al. 2015, Shah et al. 2010, Verbruggen et al. 2009, Benavides et al. 2005). As an example, regarding soil type, Van Lune and Zwart (1997, in Stasinos et al. 2014) found Cd uptake in carrots to be greater when grown in sandy vs sandy loam soils, even though the sandy-loam soils had higher Cd concentrations. Cd binds to organic matter and clays in soils, so sandy soils with little organic matter or clay can be associated with higher Cd uptake (Derrick 2006). Li et al. (2005) found that both metal concentration in the soil and genotype affected the uptake of Cd by rice, but that at lower soil concentrations of metal, soil properties that affected Cd mobility were also influential. A summary of literature assessing bioaccumulation is provided in Appendix A.

For Cd and some other metals, soil pH is a consistently important factor affecting availability and uptake of the metal (Tran and Popova 2013). Increasing pH increases Cd adsorption to the soil, making it less extractable (Christensen 1984 in Tran and Popova 2013). Grasses are less affected by soil pH effects on Cd bioavailability than other plants. Some weeds such as capeweed take up Cd to a greater extent than some plants in the cabbage family (e.g. broccoli, Chinese broccoli, brussels sprouts, cabbage, cauliflower and kohlrabi), which accumulate Cd to a greater extent than legumes, which accumulate more than grasses (Figure 2-1) (Derrick 2006).

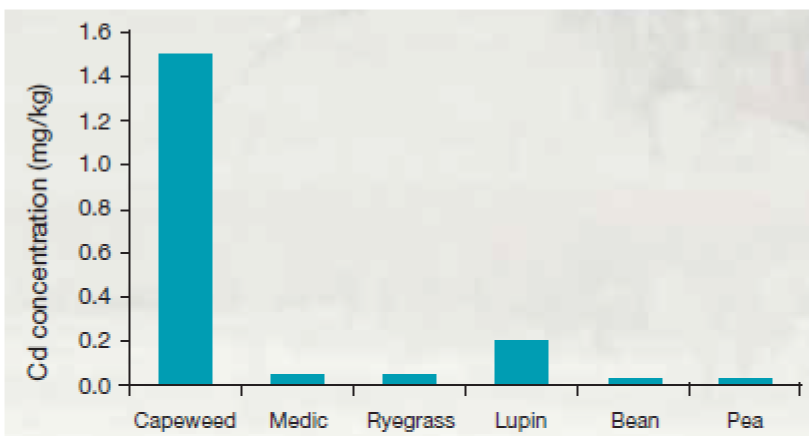

Figure 2-1: Cadmium concentrations in various plants (from Derrick 2006).

However, some field studies show more plant uptake at higher soil pH (e.g., Li et al. 2005 in Tran and Popova 2013). Cd is reported to be more bioavailable than As (Verbruggen et al. 2009). In field studies, rice plants took up more Cd as acidic soil was made more neutral (0.36 mg kg^{-1} of Cd in the rice grains at pH 4.95; 0.43 mg kg–1 Cd in grain at pH of 6.54) (Li et al. 2005).

The concentration of metals in soil is consistently listed as a factor influencing plant uptake and accumulation. Many experimental results suggest that higher soil concentration of metals results in higher concentrations in exposed plants; e.g., the uptake of Ni by lambsquarters (Mirshekali et al. 2012); the uptake of Cd and Pb by several *Inula* species (Tamakhina et al. 2018); the uptakes of Cd, Pb, or Zn by spinach (Alia et al. 2015). Other reports suggest non-linear responses to increasing metals exposures, for example, the uptake of Ni by sorghum (Mirshekali et al. 2012; see also John et al. 2009, Asati et al. 2016, Liu et al. 2013). Alia et al. (2015) found that root accumulation of Cd by spinach was greater in Cd-only treatments and was reduced in treatments in which Cd was combined with Pb, and more so when combined with Zn. In this same study, Alia et al. (2015) found Zn uptake by spinach roots was greater in Zn-only treatments, followed by Zn+Cd and then Zn+Pb. It should be noted that metals available for uptake by plants are those that are in soluble components in the soil or that can be solubilized by root exudates (Blaylock and Huang 2000, in Asati et al. 2016).

Field studies have reported moderate to strong relationships between degree of soil contamination with metals and level of uptake in various plants; however, for Cd and Pb, Tamakhina et al. (2018) found this relationship to be weak (r=0.35-043), and for Cu and Zn it was very weak (r<0.2).

Whether a metal is considered an essential element (playing a significant physiological role) or not also influences uptake and bioaccumulation, as this can influence the types of adaptations a plant has evolved (e.g., to assure sufficient quantities of essential metals are taken up and maintained, or to block uptake). Several metals (e.g., Pb, Cd, Hg, As) that are not considered essential for plant growth have toxic effects at low concentrations (Asati et al. 2016). For non-essential metals, the toxicity response (i.e. the dose-response curve) includes a no-effect and a toxicity zone; whereas for essential metals, there is also a deficiency zone (Sharma and Dietz 2006); i.e. plants can be sensitive to both deficiencies and excesses of essential metals (Asati et al. 2016). This difference is reflected in the growth responses of plants to the different types of metals.

Type of plant affects degree of metals uptake. For example, Cd is accumulated to higher levels by leafy vegetables and tubers than by fruits and cereals (Tran and Popova 2013). Such patterns are likely to be metal- and plant-specific. de Souza-Silva et al. (2014) found rice to be more sensitive to and more readily absorb several co-occurring heavy metals (Cd, Cu, Fe, Pb, and Zn) than soybeans. It also appears that certain practices, such as crop rotation and tillage, can influence uptake; for example, Mench et al. (1998, in Tran and Popova 2013) found crop rotation and tillage practices had more effect on Cd uptake than soil concentrations.

Temperature affects the uptake of Ni from soils in a non-linear (S-curve) fashion, with lower uptake at low temperatures (e.g., 2°C), and maximum absorption between 23 and 30°C (Bhalerao et al. 2015). Bhalerao et al. (2015) found that the addition of 2-4-dinitrophenol (20 µM) as well as anaerobic conditions inhibited Ni uptake by 91 and 86%, respectively.

There also is evidence that some plants chronically exposed to metals contamination develop tolerances to the metals (Ernst et al. 1990 and Schat et al. 1996 cited in Sharma and Dietz 2006), characterized as 'accelerated micro-evolution' (Sharma and Dietz 2006). Examples given of plants that have evolved this kind of tolerance to metals exposure include *Arabidopsis helleri* (rockcress) which is characterized as a Zn-hyperaccumulator; *Thlaspi* species (pennycress), which are Cd-/Zn- or Ni-hyperaccumulators; *Silene vulgaris* (bladder campion or maidenstears) that have Zn-, Cu-, and Cd-resistant ecotypes; and *Alyssum bertolonii*, which is a Ni-hyperaccumulator. Of importance is that such metal-tolerant eco- or genotypes exhibit altered dose-response curves, with wider no-effect zones, and possibly limited beneficial zones (Sharma and Dietz 2006). Plants able to accumulate Zn, Ni and Cd in excess of 1, 0.1, and 0.01% of dry weight are considered 'hyperaccumulators' of these metals (Sharma and Dietz 2006).

The bioaccumulation values used in this Report are those published by Oak Ridge National Laboratory (ORNL) (Baes et al. 1984). These values have been used by U.S. EPA in risk-based assessments and represent default element-specific bioaccumulation estimates that have wide applicability. The element-specific parameters include two types of soil-to-plant concentration factors (B_v and B_r) where the plant bioaccumulation factors are defined as

> B_v: bioaccumulation vegetative. These are applicable to vegetative (nonreproductive) parts of plants such as leaves and stems. These values are used for assessing crops and subsequent consumption of crops by livestock.
>
> B_r: bioaccumulation reproductive. These are applicable to the reproductive (fruit) parts of plants. These values are used to assess uptake of metals from soil by homegrown produce, and subsequent consumption of produce by humans.

Both values are presented in Table 2-2. The bioaccumulation value for vegetative plant parts was used in assessing exposure of cattle and sheep to crops irrigated with surface water as well as the uptake of metals from soils to crops, while the bioaccumulation value for reproductive plant parts (such as fruits and vegetables) was used to assess human exposure to homegrown produce.

3. Recommended Numeric Water Quality Metal Standards for Protection of Livestock

Some trace metals (e.g., Cu, Fe, Zn) are essential elements for physiological functions of livestock, while others (e.g., Cd) have no recognized physiological function. However, any element in excess can have detrimental effects on the condition, health, or survival of livestock, as well as on humans through consumption of livestock. The values in Table 3-1 comprise standards promulgated in 1972 for the protection of livestock based on dissolved metal concentration in water, as well as calculated risk-based concentrations that represent safe total concentrations of metals in water based on known toxicity and intake of water, feed, and soil irrigated with the same water source. When values were not available from NAS and NAE 1972, other published literature sources were identified as noted in the table.

Information on doses of metals that are safe for livestock is presented in diverse ways in published literature. Acceptable doses or tolerable values may be presented as a feeding rate (e.g., mg/kg of feed/day) or as total quantities that can be fed (e.g., mg of the metal per day, or per kg animal body weight), while others are presented as concentrations in feed (e.g., mg of metal per kg feed). Using an average body weight of the animal and average rate of daily food consumption, tolerable concentrations of metals per kg body weight can be calculated and used to derive risk-based concentrations for metals in water.

All of the Ayers & Westcot (1976, 1985) values in Table 3-1 and most of the Hicks (2002) values for livestock watering for metals in those tables are the same as those listed in NAS & NAE (1972). Although Pick (2011) cites the NAS & NAE (1972) source, Pick (2011) lists a lower value for As, and it lists values for barium (Ba), Fe, Mg, and manganese (Mn) that were not included in NAS & NAE (1972). Most of the Looper et al. (2002) livestock watering standards values for metals are different than those provided in NAS & NAE (1972).

The risk-based values in Table 3-1 address livestock consumption of water, ranch-produced feed and pastures irrigated with the water, and incidentally ingested soil by livestock, and are based on the potential toxicity of each metal to livestock. The calculation of risk-based values is described in Section 3.2.

Table 3-1. Summary of recommended AWQC for livestock

Metal	NAS & NAE 1972 (mg/L, dissolved)	Dissolved concentrations, various sources as noted (mg/L)	Calculated Risk-Based AWQC Value (mg/L, total) Cattle	Calculated Risk-Based AWQC Value (mg/L, total) Sheep
Aluminum	5		**190**	**170**
Antimony		No information found	**1.8**	**1.6**
Arsenic	0.2		**7.2**	**4.5**
Barium		10 (Pick 2011)	**75**	**65**
Beryllium		0.1 (Ayers and Westcot 1985 (Adapted from NAS & NAE 1972)	**2.8**	**2.5**
Cadmium	0.05		**2.3**	**1.5**
Chromium	1.0		**24**	**15**
Cobalt	1.0		**6**	**3.8**
Copper	0.5		**9.8**	**2.2**
Iron		0.3 (Pick 2011)	**120**	**75**
Lead	0.1		**23**	**15**
Manganese		125 mg/L (Pick 2011)	**490**	**300**
Mercury	0.01		**0.45**	**0.3**
Molybdenum		0.5 (Hicks 2002)	**1.2**	**0.75**
Nickel		0.25 (Looper et al 2002)	**24**	**15**
Selenium	0.05		**1.2**	**0.75**
Silver		No information found	**1100**	**1000**
Thallium		No information found	**9**	**8**
Vanadium	0.1		**12**	**7.5**
Zinc	25		**120**	**45**

Bolded values indicate those derived and recommended in this study.

3.1 Rationale for Recommended Metal Water Quality Standards for Protection of Livestock

As shown in Table 3-1, NAS & NAE 1972 presented water quality criteria based on toxicity for several metals. Further details regarding the NAS and NAE 1972 values are presented in Appendix B. In general, the NAS & NAE 1972 values are based on toxicity to the animal and in some cases (such as arsenic and mercury) also take into account permissible levels in meat products for human consumption. Additional information identified for each metal is also provided in the Appendix B discussion.

Risk-based values are based on the use of unfiltered water for livestock watering as well as irrigation of feed crops and pastures. These values take into account toxicity of each metal; exposure of livestock to each metal through water, feed, and incidental soil ingestion; and are adjusted for ambient concentrations of metals in soil as measured in the soil samples collected as part of this effort. The methods used for calculating risk-based concentrations involve exposure parameters for livestock (ingestion of feed, water, and soil; body weight) and are discussed in Section 3.2. Equations and exposure parameters for the risk-based calculations are presented in Table 3-2 while bioaccumulation values for metals are presented in Table 3-3. Toxicity values are presented in Table 3-4. Several sources were relied upon to determine toxicity reference values and toxicity-based screening levels for this evaluation. Water quality criteria specific to cattle and sheep are presented in Table 3-5 and Table 3-6, respectively. Each assessment includes an estimate of tissue concentration in livestock that was used in the assessment of human health exposure and risk in Section 4 of this Report.

Toxicity reference values and screening levels for agricultural receptors are presented in Table 3-2below. Toxicity reference values for livestock were calculated from maximum tolerable levels in feed (NRC 2005); a tolerable level is defined as the dietary level that, when fed for a defined period of time, will not impair animal health and performance. If a value was not available from NRC 2005, additional sources of toxicity information were used as noted in Table 3-2. All calculated values are based on total metals concentrations in water or soil. This is consistent with the agricultural pathways identified, which are best assessed using total metals concentrations as exposure to surface water is likely to occur without filtration or other treatment.

Table 3-2. Toxicity reference values and screening levels for agricultural receptors in calculating AWQC

Metal	CAS No.	Screening Levels							
		Water- Cattle and Sheep (mg/L)	Source	Soil – Plants (mg/kg)[1]	Source[2]	Tolerable level (Cattle) (mg/kg – day)	Source[2]	Tolerable level (Sheep) (mg/kg – day)	Source[2]
Aluminum	7429-90-5	NA	NA	50	2	38.14	4	55.57	4
Antimony	7440-36-0	NA	NA	5	2	0.35	6	0.35	6
Arsenic	7440-38-2	1	4	18	1	1.42	3,4	0.98	3,4
Barium	7440-39-3	NA	NA	500	2	15.00	4	15.00	6
Beryllium	7440-41-7	NA	NA	10	2	0.54	6	0.54	6
Cadmium	7440-43-9	NA	NA	32	1	0.47	4	0.33	4
Chromium	7440-47-3	NA	NA	1	2	4.72	4	3.28	4
Cobalt	7440-48-4	NA	NA	13	1	1.18	4	0.82	4
Copper	7440-50-8	NA	NA	70	1	1.89	4	0.49	5
Iron	7439-89-6	NA	NA	NA	NA	23.60	4	16.40	4
Lead	7439-92-1	NA	NA	120	1	4.72	4	3.28	4
Manganese	7439-96-5	NA	NA	220	1	94.41	4	65.59	4
Mercury	7439-97-6	NA	NA	0.30	2	0.09	4	0.07	4
Molybdenum	7439-98-7	NA	NA	2	2	0.24	4	0.16	4
Nickel	7440-02-0	NA	NA	38	1	4.72	4	3.28	4
Potassium	7440-09-7	NA	NA	NA	NA	944.12	4	655.88	4
Selenium	7782-49-2	NA	NA	0.52	1	0.24	4	0.16	4
Silver	7440-22-4	NA	NA	560	1	222.00	6	222.00	6
Thallium	7440-28-0	NA	NA	1	2	1.80	4	1.80	6
Vanadium	7440-62-2	NA	NA	2	2	2.36	4	1.64	4
Zinc	7440-66-6	NA	NA	160	1	23.60	4	9.84	4

1. Values from Table 2-3 of this report
2. Sources
    1) Eco SSLs, U.S. EPA
    2) Efroymson et al. 1997
    3) Ford and Beyer 2014
    4) Maximum tolerable levels in feed (NRC 2005), adjusted for body weight intake to estimate toxicity reference value. Food ingestion rate from Ford and Beyer 2014, and water ingestion rates for beef cattle and sheep are from NRCS 2003. Body weights are from Ford and Beyer 2014.
    5) Laboratory animal studies as references in U.S. EPA Integrated Risk Information System and ATSDR Toxicity Profiles.

3.2 Calculation of Protective Metal Thresholds for Livestock

Water supplies may be used for agricultural irrigation and livestock watering as shown in the CSM (Figure 1-1), yielding three potential exposure pathways for livestock:

1. Direct ingestion of water by livestock. Cattle and sheep were evaluated for direct ingestion of water used as a water supply to determine potential impacts to livestock health and to model intake by human receptors through consumption of cattle and sheep. AWQC for livestock for total metals in water were based on toxicity information and exposure information selected from Raisbeck et al. 2007, Raisbeck et al. 2011, and NRCS 2003 and Ford and Beyer 2014; and NRC 2005.

2. Ingestion of irrigated crops/pasture by livestock. Water use for irrigation of crops or pastures that allowed uptake to vegetation (subsequently fed to livestock) and deposition of metals in soils that could be ingested by livestock was evaluated;

3. Accumulation of metals in soils from irrigation water with subsequent incidental soil ingestion by livestock

As there is no standard guidance for performing a risk-based toxicity assessment for livestock, the conventional U.S. EPA risk assessment paradigm was used, including identifying toxicity information (i.e., hazard identification and dose-response assessment of each metal), exposure assessment, and risk characterization to calculate an acceptable water concentration based on the endpoint of interest. These components are integrated into an approach that is similar to that used for water quality guidelines for humans.

Table 3-3 summarizes both the equations and the parameters used to develop risk-based water concentrations for protection of livestock.

Table 3-3. Equations and Parameters Used to Develop Risk-Based Concentrations Protective of Livestock

Ingestion of water	Toxicity Value x BW_L / IR_w	Toxicity value = chemical specific BW_L = Body weight of livestock: cattle (272 kg); Sheep (68 kg) IR_w = Ingestion rate water, cattle (54.4 L/day); sheep (4 L/day
Ingestion of soil/crops/pasture	Soil ingestion: Soil concentration estimate x IR soil x BAF Where soil concentration estimated as: AWQC x Water use (L/m^2) x tillage depth (cm) x 1/ soil bulk density g/m^3 And intake from crops/pasture/soil is estimated as: Soil concentration estimate x BAF_{veg} x [IR_{feed} +IR_{soil}] / BW_L	BW_L = Body weight of livestock: cattle (272 kg); Sheep (68 kg) IR_{feed} = Ingestion rate feed, cattle (10.38 kg/day); sheep (3.78 kg/day) IR_{soil} = Ingestion rate of soil (approximately 10% of feed) BAF_{veg} – chemical specific

3.2.1 Method

Water quality standards for cattle and sheep were first calculated assuming intake of all water from a surface water body. The soil ingestion rates, feed ingestion rate, and body weights of cattle and sheep were selected from Ford and Beyer (2014) and water ingestion rates are from NRCS (2003). Toxicity reference values were derived from maximum tolerable levels in feed, as well as toxicity information for some metals that are not allowable in feed. The body weight, toxicity reference value, and water ingestion rate were used in the following equation:

Calculated AWQC (mg/L) = Toxicity Value (mg/kg-d) × Body weight (kg) / Ingestion Rate water (L/d)

The calculated AWQC for water ingestion only is presented in the last column of Table 3-5, along with the AWQC calculated for other exposure routes.

To calculate a total risk-based AWQC for cattle and sheep, soil concentrations were estimated using the same process as for crops and pasture land. The soil concentration was used to calculate the amount of uptake by plants (using bioaccumulation factors in Table 3-5), as well as being a direct exposure to livestock through soil ingestion. Ingestion of pasture/crop feed and soil were then estimated, and a hazard index calculated using the toxicity reference values. The AWQC corresponds to a hazard index of 1 through all exposure pathways.

In addition, the total estimated tissue concentration of each metal in cattle and sheep from water and irrigated pasture and crops was calculated. This calculation uses the total amount of metal ingested and a bioaccumulation factor (Baes et al. 1984) to estimate a potential total tissue concentration. This estimate is used in the evaluation of human exposures.

Water quality standards were developed for livestock by a forward calculation of potential hazards. The acceptable AWQC was that corresponding to an exposure with a ratio of 1.0 to the toxicity reference value

3.2.2 Exposure to Livestock Through Drinking Water

Inputs to the water quality calculation for cattle and sheep are presented in Table 3-3, Table 3-4 presents the bioaccumulation factors used to estimate a tissue concentration in beef. Soil and food ingestion rates were those used in Ford and Beyer 2014. Food ingestion rates for sheep and cattle were presented as dry weight values and were converted to wet weight using a weighted average dry-to-wet weight conversion value of 0.888 from Baes et al. 1984. Water ingestion rates were selected from NRCS 2003 and represent upper end of the range presented in that report to account for variation in water needs due to temperature fluctuations and activity over the course of a year in an arid climate. Uptake factors for bioaccumulation of COPCs are from ORNL 2019 and Baes et al. 1984.

Metals Bioaccumulation Beef

The bioaccumulation values used in Table 3-4 are those published by Oak Ridge National Laboratory (ORNL) (Baes et al. 1984). These values have been used by U.S. EPA in risk-based assessments and represent default element-specific bioaccumulation estimates that have wide applicability. The beef transfer factors represent the fraction of daily elemental intake in feed which is transferred to and remains in a kilogram of beef. The values were determined by Baes et al. (1984) from a review of literature or determined from elemental systematic assumptions. These factors were also used for sheep, in the absence of any bioaccumulation values specific to sheep.

Table 3-4. Ingestion-to-Beef Transfer Factor

Metal	Ingestion-to-Beef Transfer Factor (unitless)
Aluminum	0.0015
Antimony	0.001
Arsenic	0.002
Barium	0.00015
Beryllium	0.001
Cadmium	0.00055
Chromium	0.0055
Cobalt	0.02
Copper	0.01
Iron	0.02
Lead	0.0004
Manganese	0.0004
Mercury	0.25
Molybdenum	0.006
Nickel	0.006
Selenium	0.015
Silver	0.003
Thallium	0.04
Vanadium	0.0025
Zinc	0.1

3.2.3 Risk Based AWQC for Livestock

Table 3-5 presents the AWQC for cattle from water ingestion alone and for combined water, soil, and crop ingestion for cattle. As is associated with an AWQC of 7.2 mg/L for cattle. This is based on noncarcinogenic effects to the animal, as carcinogenic effects are not considered for livestock. However, it indicates that As is a metal that can have negative effects to cattle at a low concentration in water.

Table 3-6 presents the AWQC for sheep from water ingestion alone and for combined water, soil, and crop ingestion. This analysis assumed that sheep uptake factors were the same as those for cattle because no bioaccumulation factors specific to sheep were identified. However, lower ingestion rates for soil and water were assumed (NRCS 2003) as well as a lower body weight. Overall, the AWQC calculated for sheep are lower than those for cattle.

Both Table 3-5 and Table 3-6 present the tissue concentration of metals in edible meat from cattle and sheep, respectively, that have been exposed through consumption of water, irrigated crops, and soil. These values were used in estimated human exposure to meat products, described in Section 4 of this Report.

Table 3-5. AWQC for cattle from water ingestion alone and for combined water, soil, and crop ingestion for cattle

Chemical	Maximum Predicted Soil Concentrations from Irrigation										Tolerable Level (mg/kg-day)	Hazard Index for Soil, Feed and Water Ingestion	Water Screening Levels for cattle (water only) (mg/L)
	Water Quality Concentration (mg/L)	Soil Concentration 1 Year (mg/kg)	Plant BAF	Uptake to Alfalfa (BAF * Soil concentration) Wet weight Conc	Intake from food and soil (Cattle) mg/kg-day	Intake from Water (Cattle) (mg/kg-day)	Beef transfer coefficient	Tissue concentration from food and soil (Cattle) mg/kg	Tissue Concentration from Water Uptake (Cattle) (mg/kg)	Total Concentration in Cattle (mg/kg)			
Aluminum	190	1.01	0.001	1.01E-03	3.51E-03	3.80E+01	0.0015	5.26E-06	5.70E-02	5.70E-02	38.14	1	190.72
Antimony	1.8	0.01	0.05	4.79E-04	5.11E-05	3.60E-01	0.001	5.11E-08	3.60E-04	3.60E-04	0.35	1	1.75
Arsenic	7.2	0.04	0.01	3.83E-04	1.46E-04	1.44E+00	0.002	2.92E-07	2.88E-03	2.88E-03	1.42	1	7.08
Barium	75	0.40	0.0375	1.50E-02	1.94E-03	1.50E+01	0.00015	2.91E-07	2.25E-03	2.25E-03	15	1	75.00
Beryllium	2.8	0.01	0.0025	3.72E-05	5.26E-05	5.60E-01	0.001	5.26E-08	5.60E-04	5.60E-04	0.54	1	2.70
Cadmium	2.3	0.01	0.1375	1.68E-03	1.06E-04	4.60E-01	0.00055	5.84E-08	2.53E-04	2.53E-04	0.47	1	2.36
Chromium	24	0.13	0.0019	2.39E-04	4.47E-04	4.80E+00	0.0055	2.46E-06	2.64E-02	2.64E-02	4.72	1	23.60
Cobalt	6	0.03	0.005	1.60E-04	1.16E-04	1.20E+00	0.02	2.31E-06	2.40E-02	2.40E-02	1.18	1	5.90
Copper	9.8	0.05	0.1	5.21E-03	3.78E-04	1.96E+00	0.01	3.78E-06	1.96E-02	1.96E-02	1.89	1	9.44
Iron	120	0.64	0.001	6.38E-04	2.22E-03	2.40E+01	0.02	4.43E-05	4.80E-01	4.80E-01	23.6	1	118.01
Lead	23	0.12	0.0113	1.38E-03	4.73E-04	4.60E+00	0.0004	1.89E-07	1.84E-03	1.84E-03	4.72	1	23.60
Manganese	490	2.61	0.0625	1.63E-01	1.52E-02	9.80E+01	0.0004	6.07E-06	3.92E-02	3.92E-02	94.41	1	472.06
Mercury	0.45	0.00	0.225	5.39E-04	2.88E-05	9.00E-02	0.25	7.19E-06	2.25E-02	2.25E-02	0.09	1	0.47
Molybdenum	1.2	0.01	0.0625	3.99E-04	3.71E-05	2.40E-01	0.006	2.23E-07	1.44E-03	1.44E-03	0.24	1	1.18
Nickel	24	0.13	0.015	1.92E-03	5.11E-04	4.80E+00	0.006	3.07E-06	2.88E-02	2.88E-02	4.72	1	23.60
Selenium	1.2	0.01	0.0063	3.99E-05	2.34E-05	2.40E-01	0.015	3.52E-07	3.60E-03	3.60E-03	0.24	1	1.18
Silver	1100	5.85	0.1	5.85E-01	4.24E-02	2.20E+02	0.003	1.27E-04	6.60E-01	6.60E-01	222	1	1110.00
Thallium	9	0.05	0.001	4.79E-05	1.66E-04	1.80E+00	0.04	6.65E-06	7.20E-02	7.20E-02	1.8	1	9.00
Vanadium	12	0.06	0.0014	8.78E-05	2.23E-04	2.40E+00	0.0025	5.56E-07	6.00E-03	6.00E-03	2.36	1	11.80
Zinc	120	0.64	0.264	1.69E-01	8.62E-03	2.40E+01	0.1	8.62E-04	2.40E+00	2.40E+00	23.6	1	118.01

Table 3-5. AWQC for cattle from water ingestion alone and for combined water, soil, and crop ingestion for cattle

Assumptions:

a. Soil ingestion rate and food ingestion rate from Ford and Beyer 2014, and water ingestion rates for beef cattle are from NRCS 2003.
b. Tissue concentration from food and soil ingestion calculation: [(Ingestion rate food*concentration in plants + Concentration in soil * Ingestion Rate soil) *BAF]
c. Tissue concentration from water ingestion calculation: (Water ingestion * water concentration) *BAF
d. Beef: 272 kg body weight
e. Soil ingestion: 0.93 kg/day (9.5% of feed) (Ford and Beyer 2014)
f. Food Ingestion: 10.38 kg/day (Ford and Beyer 2014) (weighted dry to wet conversion factor of 0.888 for grains – Baes et al. 1984)
g. Water Ingestion: 54.4 L/day (20% of BW, NRC 2003)
h. Toxicity Values were estimated using maximum tolerable levels in feed (mg metal/kg feed), assuming that 1 L = 1 kg, and the listed food ingestion rate and body weight

Table 3-6. AWQC for sheep from water ingestion alone and for combined water, soil, and crop ingestion

Chemical	Maximum Predicted Soil Concentrations from Irrigation											Toxicity Value (mg/kg-day)	Hazard Index	Water Ingestion Only Screening Value (mg/L)
	Water Concentration (mg/L) [1]	Soil Concentration 1 Year (mg/kg)	Plant BAF	Uptake to Alfalfa (BAF * Soil concentration) Wet weight Conc	Transfer coefficient	Uptake by sheep [(IR wet wt plants + IR soil)]/BW	Water Uptake by Sheep (mg/kg-day)	Total Uptake in Sheep (mg/kg-day)	Tissue concentration from food and soil (uptake x BAF) (Sheep) mg/kg[2]	Tissue Concentration from Water Uptake (uptake x BAF) (Sheep) (mg/kg)	Total Concentration in Sheep			
Aluminum	170	0.90	0.001	9.04E-04	0.0015	0.0048	37.75	37.75	7.24E-06	5.66E-02	5.66E-02	38.14	1	1511.46
Antimony	1.6	0.01	0.05	4.26E-04	0.001	0.0001	0.36	0.36	6.86E-08	3.55E-04	3.55E-04	0.35	1	NA
Arsenic	4.5	0.02	0.01	2.39E-04	0.002	0.0001	1.00	1.00	2.79E-07	2.00E-03	2.00E-03	0.98	1	26.76
Barium	65	0.35	0.0375	1.30E-02	0.00015	0.0025	14.43	14.44	3.82E-07	2.17E-03	2.17E-03	15	1	408
Beryllium	2.5	0.01	0.0025	3.33E-05	0.001	0.0001	0.56	0.56	7.21E-08	5.55E-04	5.55E-04	0.54	1	14.69
Cadmium	1.5	0.01	0.1375	1.10E-03	0.00055	0.0001	0.33	0.33	5.67E-08	1.83E-04	1.83E-04	0.33	1	8.92
Chromium	15	0.08	0.001875	1.50E-04	0.0055	0.0004	3.33	3.33	2.36E-06	1.83E-02	1.83E-02	3.28	1	89.2
Cobalt	3.8	0.02	0.005	1.01E-04	0.02	0.0001	0.84	0.84	2.25E-06	1.69E-02	1.69E-02	0.82	1	22.3
Copper	2.2	0.01	0.1	1.17E-03	0.01	0.0001	0.49	0.49	1.27E-06	4.89E-03	4.89E-03	0.49	1	13.38
Iron	75	0.40	0.001	3.99E-04	0.02	0.0021	16.65	16.66	4.26E-05	3.33E-01	3.33E-01	16.4	1	446
Lead	15	0.08	0.01125	8.98E-04	0.0004	0.0005	3.33	3.33	1.88E-07	1.33E-03	1.33E-03	3.28	1	89.2
Manganese	300	1.60	0.0625	9.98E-02	0.0004	0.0140	66.62	66.63	5.59E-06	2.66E-02	2.67E-02	65.59	1	1784
Mercury	0.3	0.00	0.225	3.59E-04	0.25	0.0000	0.07	0.07	7.10E-06	1.67E-02	1.67E-02	0.07	1	1.78
Molybdenum	0.75	0.00	0.0625	2.49E-04	0.006	0.0000	0.17	0.17	2.10E-07	9.99E-04	9.99E-04	0.16	1	4.46
Nickel	15	0.08	0.015	1.20E-03	0.006	0.0005	3.33	3.33	2.93E-06	2.00E-02	2.00E-02	3.28	1	89.2
Selenium	0.75	0.00	0.00625	2.49E-05	0.015	0.0000	0.17	0.17	3.37E-07	2.50E-03	2.50E-03	0.16	1	4.46
Silver	1000	5.32	0.1	5.32E-01	0.003	0.0576	222.06	222.12	1.73E-04	6.66E-01	6.66E-01	222	1	6038.4
Thallium	8	0.04	0.001	4.26E-05	0.04	0.0002	1.78	1.78	9.08E-06	7.11E-02	7.11E-02	1.8	1	48.96
Vanadium	7.5	0.04	0.001375	5.49E-05	0.0025	0.0002	1.67	1.67	5.34E-07	4.16E-03	4.16E-03	1.64	1	44.6
Zinc	45	0.24	0.264	6.32E-02	0.1	0.0048	9.99	10.00	4.78E-04	9.99E-01	1.00E+00	9.84	1	267.6

1. All water quality values calculated in this column reflect ingestion of water, feed, and soil.
2. Beef transfer coefficient used for sheep

3.3 Assumptions and Limitations

The agricultural AWQC presented are based on toxicity to plants, and toxicity to livestock through ingestion of water and feed, pasture and soil irrigated with surface water. For all metals except iron, the AWQC developed here for livestock are higher than those from NAS & NAE 1972 for plants. However, the AWQC based solely on metals accumulation in soil (Table 5-2) are higher than the AWQC for livestock. AWQC for sheep are lower than those for cattle, which is expected given the larger intake of water by sheep relative to body weight. Most of the toxicity reference values for the metals are based on toxicity to cattle, which may not be an accurate assessment of their toxicity in sheep.

The toxicity reference values used in these calculations were based on tolerable levels in feed for cattle and sheep. The body weight and feed intake rates used to assess exposures are based on generally accepted values for sheep and cattle. However, these may not be representative exposure parameters for cattle or sheep in New Mexico due to different ranching practices, or temperature and climate conditions, as well as breed size and water/feed intake rates.

4. Human Exposure to Metals from Crops, Livestock, and Water

Human health risk assessment is the scientific process of evaluating the toxic properties of compounds and the conditions of human exposure to determine the likelihood that an exposed population will be adversely affected. The same process can be used to calculate risk-based water quality parameters and it can be adapted to other receptors (such as plants and livestock). Further, it is consistent with the process used to set AWQC for humans (U.S. EPA 2000). Following the risk assessment model presented by U.S. EPA (1989), the approach to establishing human health risk-based water quality parameters includes an exposure assessment, a toxicity assessment, and calculating risk-based values that include the exposures, toxicities and acceptable risks or hazard levels for all receptors. This assessment is meant to capture a range of exposures for the Navajo Nation, and includes documentation of all exposure assumptions and equations, toxicity values, exposure data, sources of uncertainty and data gaps, conclusions and recommendations. Using the established methodologies, exposure information, and potential toxicity of metals, the AWQCs are intended to protect human health. The recommended risk-based AWQC for humans calculated in this Report are presented in Table 4-1. Values for ingestion of water, ingestion of homegrown produce, and ingestion of homegrown meat products are listed as well as a combined AWQC that incorporates all three exposure pathways.

The methods for and the calculation of risk-based concentrations for water based on human exposures through water ingestion, and ingestion of crops and livestock irrigated with unfiltered surface water are described in Section 4.1. Section 4.1 includes the exposure evaluation describes the potential exposure routes and receptors. Exposure parameters, chemical specific inputs, and toxicity values are also discussed in Section 4.1. The mathematical expression of these data results in the risk-based concentrations presented in Tables Table 4-5, Table 4-6, and Table 4-7. Note that some information in this section relies on AWQC based on direct toxicity to crops and livestock that were presented in Sections 2 and 3.

Table 4-1. Summary of Risk-based AWQC for Humans.

	Direct Ingestion AWQC (mg/L)	Risk-based AWQC from Human Exposure Pathways		Combined AWQC (mg/L)
		Ingestion of Plants - AWQC (mg/L)	Ingestion of Homegrown Meat Products - Adjusted AWQC (mg/L) [3]	
Aluminum	**15**	**43000**	**864000**	15
Antimony	**0.006**	**0.37**	**579.3**	0.0059
Arsenic (non-cancer)	**0.005**	**1.4**	**217**	0.0045
Arsenic (cancer)[1]	**0.00002**	**0.000026**	**0.483**	0.0000113
Barium	**3**	**370**	**1930000**	2.98
Beryllium	**0.03**	**37**	**2900**	0.03
Cadmium	**0.008**	**0.185**	**2630**	0.0072
Chromium	**22.5**	**9200**	**395000**	22.4
Cobalt	**0.005**	**1.2**	**21.7**	0.0045
Copper	**0.6**	**4.4**	**5790**	0.53
Iron	**10.5**	**19500**	**50700**	10.5
Lead	**0.015**	**0.015**	**0.015**	0.005
Manganese	**2.1**	**77**	**507000**	2.04
Mercury	**0.005**	**0.042**	**1740**	0.0041
Molybdenum	**0.075**	**2.3**	**1210**	0.073
Nickel	**0.3**	**9.25**	**4830**	0.29
Selenium	**0.075**	**5.5**	**483**	0.074
Silver	**0.075**	**1.4**	**2410**	0.0712
Thallium[2]	**0.00015**	**0.690**	**0.362**	0.00015
Vanadium	**0.075**	**46**	**2900**	0.075
Zinc	**4.5**	**9.2**	**4340**	3.02

Bolded results indicate values derived and recommended in this study.
Shaded results indicate that screening level is based on carcinogenic risk.

1. AWQC for ingestion of homegrown meat products for arsenic (carcinogenic) was adjusted downward by a factor of 32000 to account for risk above 1E-6.
2. AWQC for ingestion of homegrown meat products for thallium was adjusted downward by a factor of 25.1 to account for hazard index above 1
3. All AWQC for livestock ingestion adjusted upwards except for arsenic and thallium

4.1 Rationale for AWQC

Three methodologies were used to calculate human exposure to metals through water: domestic ingestion of water; consumption of homegrown produce; and consumption of homegrown meat products. Each is described below.

Domestic Water Ingestion

The following equation from U.S. EPA 2000a was used to calculate a water quality criterion based on human ingestion of water:

AWQC (µg/L) = Toxicity value (mg/kg-d) × Body Weight (kg) × 1,000 (µg/mg) / IR (L/d)

For this analysis, a child receptor was selected for setting AWQC to provide the most conservative estimate. Children have a higher intake of water per body weight than adults, resulting in an AWQC that is protective of adults and children. As noted in Table 4-1, the body weight of a child is 15 kg and the ingestion rate used was 1 L/day, the 95th percentile of water ingestion rate for children (U.S. EPA 2011).

Consumption of Homegrown Fruits and Vegetables

To evaluate the consumption of metals through water used for irrigating a home garden, the concentration in water corresponding to a hazard index of 1.0 based on produce ingestion was calculated.

To estimate the amount of metals that could be applied to soils through irrigation, it was assumed that water would be applied to soil at a rate of 187 gallons per day to a 750 square foot garden (69.7 m2) (NMSU 2011). It was estimated that a garden would be irrigated 122 days, or every third day throughout the year. The tilling depth was assumed to by 6 inches (15 cm) to determine a volumetric content of metals in soil from irrigation water. The volumetric content was converted to a concentration by using a soil density of 1.6 g/cm3, the density of loam to sandy-loam soil (U.S. EPA 2017). Then, the bioaccumulation factor was used to estimate the amount of metal that would be aggregated to the reproductive parts of the plant (such as corn, squash, or melon).

The concentration in the produce was then used to estimate a daily intake of each metal by humans, and the toxicity value was used to determine the hazard. Metal intake from consumption of homegrown produce was calculated based on intake rates of 41.7 g/day of vegetables and 68.1 g/day of fruit by a child, with a body weight of 15 kg. The resulting calculated risk-based concentration represents a water concentration corresponding to a hazard index of 1.0 through the exposure pathway of ingestion of homegrown produce irrigated with unfiltered surface water.

Consumption of Homegrown Meat

After determining the exposure of cattle and sheep to metals through feed and water, a tissue concentration was estimated using bioaccumulation factors from Baes et al. 1984. The tissue concentration was used in determining the human-health based AWQC as a contributor to overall exposure.

The following equation was used to calculate the contribution of homegrown meat products to overall exposure:

$\text{Hazard} = IR_{meat} \times EF \times ED \times CF / BW \times AT$

Where:

IR_{meat} = Intake rate of homegrown meat products (54 g/day)

EF = Exposure Frequency (350 days/year)

ED = Exposure Duration (6 years)

CF = Conversion Factor (1E-6 kg/mg)

BW = Body Weight (15 kg)

AT = 2190 days (365 days per year for 6 years)

The beef ingestion hazard indices were calculated using a beef ingestion of 54 g/day (about 2 ounces) by a child, 350 days per year. The higher of beef or sheep tissue concentrations was used as the exposure concentration. The assessment focused on children as the most sensitive receptor. The resulting calculated risk-based concentration represents a water concentration corresponding to a hazard index of 1.0 through the exposure pathway of ingestion of homegrown meat product from livestock consuming with unfiltered surface water.

4.1.1 Exposure Evaluation: Exposure parameters and chemical-specific inputs

The estimation of uptake and exposure requires several different equations and input parameters. Table 4-2 presents all parameters used in the equations to calculate exposures and AWQC. Exposure parameters for humans for all pathways are based on the child receptor. The child receptor has a lower body weight and higher intake rate relative to adults, and therefore the calculated exposure and AWQC are more protective. The As evaluation is based on both carcinogenic and noncarcinogenic endpoints, consistent with its classification by U.S. EPA as causing both a carcinogen and noncarcinogen. The assessment of carcinogenic endpoints for the food ingestion pathways includes both children and adult receptors, consistent with U.S. EPA recommended methods.

Chemical-specific bioaccumulation values are used to calculate the human-health risk-based AWQC presented in Table 4-3 These parameters are bioaccumulation factors for metals from soil to vegetative parts of plants as well as to reproductive (fruit and vegetable) parts of plants. Uptake factors that estimate the accumulation of metals in animal tissue are also provided.

Table 4-2. Exposure Equations and Parameters used in Human Health-Based Water Quality Standards Assessment.

Receptor	Pathway	Equation	Parameters
Human	Ingestion of Water	AWQC = Toxicity Value x BW_c / IR_w	AWQC = Ambient Water Quality Criteria Toxicity value (mg/kg-day or 1/mg/kg-day, chemical specific) BW_c = Body weight, child (15 kg) IR_w = Ingestion Rate water (1 L/day)
	Consumption of Homegrown Produce	Soil concentration = AWQC x L used / (Acreage x Tillage Depth x Soil density) Then: Intake = Soil concentration x BAF_r x IR_{pc} x EF x ED x 1000 mg/g x 1E-6 kg/mg / AT x BW_c	AWQC = proposed value BAF_r = Bioaccumulation in plant reproductive parts IR_{pc} = Ingestion rate of child for fruits (68.1 g/day) and vegetables (41.7 g/day), 109.8 g/day EF = Exposure Frequency, 350 days/year ED = Exposure Duration, 6 years AT = 2190 days (365 days/year for 6 years) BW_c = Body Weight, child 15 kg
	Consumption of Homegrown Meat	Tissue metal concentration = Sum of tissue metal concentration from water ingestion and food ingestion Intake (mg/kg-day) = Tissue concentration x IR_{mc} x EF x ED x 1000 mg/g x 1E-6 kg/mg / AT x BW_c	Tissue Concentration = mg/kg (calculated) IR_{mc} = Ingestion rate of child for homegrown meat products, 54 g/day EF = Exposure Frequency, 350 days/year ED = Exposure Duration, 6 years AT = 2190 days (365 days/year for 6 years) BW_c = Body Weight, child 15 kg Adjusted intake for carcinogenic effects: IR = 32091500 mg-yr/kg-day based on child and adult exposures for a total of 40 years; AT = 25550 days (70 year lifespan). Body weight is excluded from equation.

Table 4-3. Bioaccumulation values

Metal	Vegetative Plant (BAF_{veg})	Fruit/Vegetable Plant (BAF_r)	Beef (sheep) transfer coefficient
Aluminum	0.001	0.00065	0.0015
Antimony	0.05	0.03	0.001
Arsenic	0.01	0.006	0.002
Barium	0.0375	0.015	0.00015
Beryllium	0.0025	0.0015	0.001
Cadmium	0.1375	0.15	0.00055
Chromium	0.001875	0.0045	0.0055
Cobalt	0.005	0.007	0.02
Copper	0.1	0.25	0.01
Iron	0.001	0.001	0.02
Lead	0.01125	0.009	0.0004
Manganese	0.0625	0.05	0.0004
Mercury	0.225	0.2	0.25
Molybdenum	0.0625	0.06	0.006
Nickel	0.015	0.06	0.006
Selenium	0.00625	0.025	0.015
Silver	0.1	0.1	0.003
Thallium	0.001	0.0004	0.04
Vanadium	0.001375	0.003	0.0025
Zinc	0.264	0.9	0.1

Bioaccumulation factors from Baes et al. 1984
Assumptions: Beef transfer coefficient used for sheep.

4.1.2 Toxicity Assessment

Table 4-4 presents the human toxicity values that were used for each evaluated metal in developing water quality standards. Table 4-4 presents the human toxicity values from U.S. EPA as well as information regarding target organ, sensitive life stages, and health effect or outcome. Most values can be found in U.S. EPA's Integrated Risk Information System (IRIS), although some values are provisional.

Water concentrations that correspond to an acceptable hazard level for human ingestion of homegrown plants and meat were based on the toxicity values in Table 4-4. Bioaccumulation factors for plants, cattle, and sheep were obtained from ORNL 2018 and Baes et al. 1984 and are presented in Table 4-3, and exposure parameters are presented in Table 4-2. Sections 2 and 3 present the toxicity information for plants and livestock, which are relied upon as a starting point for determining tissue concentrations that humans may ingest.

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
Aluminum	7429-90-5	1.00E+00	Provisional value; based on minimal neurotoxicity in the offspring of mice. Uncertainty factor = 100	**Nervous System.** Studies in animals have shown that the nervous system is a sensitive target of aluminum toxicity. https://www.atsdr.cdc.gov/phs/phs.asp?id=1076&tid=34	**Children.** Children with kidney problems who were given aluminum in their medical treatments developed bone diseases. It does not appear that children are more sensitive to aluminum than adults. Additionally, it is not known if aluminum can cause birth defects in people. Birth defects have not been seen in animals; however, aluminum in large amounts has been shown to be harmful to unborn and developing animals because it can cause delays in skeletal and neurological development. https://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=190&tid=34	**Nervous System Effects.** Oral exposure to aluminum is usually not harmful. Some studies have shown that people exposed to high levels of aluminum may develop Alzheimer's disease, but other studies have not found this to be true. https://www.atsdr.cdc.gov/phs/phs.asp?id=1076&tid=34
Antimony	7440-36-0	4.00E-04	IRIS 2018. Animal Study, Target organ - longevity, blood glucose, cholesterol. Schroeder et al. 1970. Uncertainty factor = 1000	**Hematological** - Limited information suggests that antimony can damage the **developing cardiovascular system** in rats.	Lack of sufficient information to know if **children** are more susceptible to antimony toxicity than **adults**; however, studies in workers and in rats have shown that antimony can decrease **infant growth.**	**Hematological/Developmental.** A high rate of **premature deliveries** among women workers in antimony smelting and processing was also observed. Aiello, G. (1955). Pathology of antimony. Folia Med. (Naples). 38: 100. (Ital.) One study indicated that women workers exposed in an antimony plant experienced a greater incidence of **spontaneous abortions** than did a control group of nonexposed working women. Belyaeva, AP. (1967). The effect of antimony on reproduction. Gig. Truda Prof. Zabol. 11: 32.

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
Arsenic (1)	7440-38-2	RfD = 3.00E-04 CSF = 1.5/mg/kg-day)	RfD: IRIS 1991. Animal study - hyperpigmentation, keratosis and possible vascular complications. Uncertainty factor – 3 CSF: IRIS 1995. Increased mortality from multiple internal organ cancers (liver, kidney, lung, and bladder) and an increased incidence of skin cancer were observed in populations consuming drinking water high in inorganic arsenic.	RfD: **Cardiovascular, dermal -** Hyperpigmentation, keratosis and possible vascular complications CSF: Classified as a class A carcinogen (known human carcinogen)	Infants and children following prenatal and early life exposure to arsenic in drinking water. https://www.atsdr.cdc.gov/toxprofiles/Arsenic_addendum.pdf Increase in skin lesions in individuals greater than 20 years. Blackfoot disease increases sharply in individuals greater than 40 years.	**Dermal Effects.** The data reported show an increased incidence of blackfoot disease that increases with age and dose. Blackfoot disease is a significant adverse effect. **Developmental and neurodevelopmental effects.** **https://www.atsdr.cdc.gov/toxprofiles/Arsenic_addendum.pdf**
Barium	7440-39-3	2.00E-01	IRIS 2005. Animal Study - Nephropathy, 2-year drinking water study in mice. NTP, 1994. Uncertainty factor - 300	**Kidney -** appears to be most sensitive target of toxicity resulting from repeated ingestion of soluble barium salts	There are no human data examining age-related differences in susceptibility to barium toxicity. Source: https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0010tr.pdf 1.50E+04	**220** **Urinary System Effects - Nephropathy** Data on the **reproductive and developmental** toxicity of barium compounds are limited. The data base consists of single-generation reproductive toxicity studies in rats and mice (Dietz et al. 1992) and a developmental toxicity study conducted by Tarasenko et al. (1977). Dietz, DD; Elwell, MR; Davis, WE, Jr.; et al. (1992) Subchronic toxicity of barium chloride dihydrate administered to rats and mice in the drinking water. Fund Appl Toxicol 19:527-537. Tarasenko, NY; Pronin, OA; Silyev, AA. (1977) Barium compounds as industrial poisons (an experimental study). J Hyg Epidemiol Microbiol Immunol 21:361-373.

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
Beryllium	7440-41-7	2.00E-03	IRIS 1998. Animal study - Small intestinal lesions, dog dietary study. Morgareidge et al. 1976. Uncertainty factor - 300	**Small intestine -** target organ found in dogs	Children would be expected to have a greater gastrointestinal absorption rate and be more susceptible to the effects than adults.	**Gastrointestinal Effects -** lesions of the small intestine found in dogs**.**
Cadmium	7440-43-9	5.00E-04 (water) 1.00E-3 (food)	IRIS 1989. Human study - Significant proteinuria, human studies involving chronic exposures. U.S. EPA, 1989. Uncertainty factor - 10	Regardless of the exposure route, cadmium is widely distributed in the body with the highest levels found in the **liver and kidneys**	It is likely that effects observed in adults exposed to cadmium will also be seen in children. Because cadmium is a cumulative toxin and has a very long half time in the body, exposure to children in even low amounts may have long-term consequences. Studies in animals suggest that children may be more susceptible than adults on cadmium-induced bone damage. https://www.atsdr.cdc.gov/toxguides/toxguide-5.pdf	**Urinary System and Musculoskeletal Effects.** The effects observed in humans include renal tubular damage, glomerular damage, decreases in bone mineralization increased risk of bone fractures. These effects typically occur after long term exposure to cadmium. **https://www.atsdr.cdc.gov/toxguides/toxguide-5.pdf**
Chromium	7440-47-3	1.50E+00	*Chromium assumed to be trivalent chromium; RfD is based on the no observed effects level, Uncertainty factor = 100	Absorbed chromium is distributed to nearly all tissues, with the highest concentrations found **in kidneys and liver**. Bone is also a major depot and may contribute to long-term retention. **https://www.atsdr.cdc.gov/toxguides/toxguide-7.pdf**	It is likely that effects observed in adults exposed to Cr (III) will also be seen in children.	**Metabolic Effects.** Trivalent chromium is an essential element. Deficiency causes adverse changes in the metabolism.
Cobalt	7440-48-4	3.00E-04	Provisional value; based on decreased uptake of iodine to thyroid in humans. Uncertainty factor = 3000	Can be found in most body tissues following oral exposure. Highest concentration found in the **liver.**	It is likely that effects observed in adults exposed to high levels of cobalt will also be seen in children. Studies in animals have suggested that children may absorb more cobalt from foods and liquids containing cobalt than adults. https://www.atsdr.cdc.gov/toxprofiles/tp33.pdf	Sensitive end points are **Hematological effects** (polycythemia) - increase levels of erythrocytes and hemoglobin in both humans and animals; and **cardiovascular effects -** cardiomyopathy Other effects involving the **hepatobiliary and urinary systems** have been noted in rats.

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
						https://www.atsdr.cdc.gov/toxprofiles/tp33.pdf
Copper	7440-50-8	NA	NA	Copper rapidly enters the **bloodstream** and is **distributed throughout** the body after ingesting either by food or drink. https://www.atsdr.cdc.gov/PHS/PHS.asp?id=204&tid=37	Exposure to high levels of copper will result in the same type of effects in children and adults. It is also not known if copper can cause birth defects or other developmental effects in humans. https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=205&tid=37	**Gastrointestinal Effects.** Ingesting high levels of copper can cause nausea, vomiting, and diarrhea**.** **Hepatobiliary and urinary systems** Very-high doses of copper can cause damage to the liver and kidneys, and can even cause death**.** https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=205&tid=37
Iron	7439-89-6	7.00E-01	PPTRV value; U.S. EPA 2018. Based on LOAEL for adverse GI effects. Uncertainty Factor = 1.5.			
Lead	7439-92-1	NA	NA	Lead bioaccumulates in the body, primarily in the skeleton **(bone).**	Lead has particularly significant effects in children, Children under 6 years old have a high risk of exposure because of their more frequent hand-to-mouth behavior (Centers for Disease Control and Prevention (CDC), 1991 http://www.cdc.gov/nceh/lead/publications/books/plpyc/contents.htm)	**Neurological (Nervous System), Renal (Urinary System or Kidneys)** Lead body burdens vary significantly with age, health status, nutritional state, maternal body burden during gestation and lactation, etc https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=22
Manganese	7439-96-5	1.40E-01	IRIS 1995. Human studies - CNS effects, human chronic ingestion data. NRC 1989; Freeland-Graves et al. 1987; WHO, 1973. Uncertainty factor - 1	**Brain**. Principal toxicity target of manganese https://www.atsdr.cdc.gov/toxprofiles/tp151.pdf	Children are potentially more sensitive to manganese toxicity than adults https://www.atsdr.cdc.gov/toxprofiles/tp151.pdf	**Neurological Effects.** Studies in children have suggested that extremely high levels of manganese exposure may produce undesirable effects on brain development, including changes in behavior and decreases in the ability to learn and remember. NOTE: A number of reports indicate that oral exposure to manganese,

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
						especially from contaminated water sources, can produce significant health effects. These effects have been most prominently observed in children. https://www.atsdr.cdc.gov/toxprofiles/tp151.pdf
Mercury	7439-97-6	NA	NA	**Kidneys.** Accumulates in the kidneys.	Children are particularly sensitive to exposures during the period from conception to maturity at 18 years of age in humans.	**Urinary; Gastrointestinal;** Cardiovascular effects. In addition to effects on the kidneys, inorganic mercury can damage the stomach and intestines, producing symptoms of nausea, diarrhea, or severe ulcers if swallowed in large amounts. Effects on the heart have also been observed in children after they accidentally swallowed mercuric chloride. Symptoms included rapid heart rate and increased blood pressure. There is little information on the effects in humans from long-term, low-level exposure to inorganic mercury. https://www.atsdr.cdc.gov/PHS/PHS.asp?id=112&tid=24
Molybdenum	7439-98-7	5.00E-03	IRIS 1992. Human study - Increased uric acid levels. Human 6-year to lifetime dietary exposure study. Koval'skiy et al. 1961. Uncertainty factor - 30	**Kidneys.** Available data from laboratory animal studies suggest that the kidney may be a target of molybdenum toxicity NOTE: Absorbed molybdenum distributes to various tissues. Human autopsy studies have found that the kidney and liver have the highest amounts of molybdenum	Children need small amounts of molybdenum to maintain good health. It is likely that the adverse health effects observed in adults exposed to higher than normal levels of molybdenum would also be observed in children; however, it is not known if children would	**Cardiovascular Effects.** There has been reposted a significant positive association between urinary molybdenum levels and high blood pressure among adults https://www.atsdr.cdc.gov/toxprofiles/tp212-c3.pdf **Urinary (Renal) Effects:** Several studies reported alterations

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
				https://www.atsdr.cdc.gov/toxprofiles/tp212-c3.pdf	be more susceptible to the toxicity of molybdenum than adults. https://www.atsdr.cdc.gov/toxprofiles/tp212-c1.pdf	in serum and urinary parameters that could be suggestive of altered renal function. **https://www.atsdr.cdc.gov/toxprofiles/tp212-c3.pdf**
Nickel	7440-02-0	2.00E-02	IRIS 1991. Animal study - decreased body and organ weights. Rat chronic oral study. Ambrose et al. 1976. Uncertainty factor - 300	Primary targets of toxicity appear to be the **immune system** and possibly the **reproductive system** and the developing organism following oral exposure. https://www.atsdr.cdc.gov/toxprofiles/tp15.pdf	It is likely that the health effects seen in children exposed to nickel will be similar to the effects seen in adults. It is unknown whether children differ from adults in their susceptibility to nickel. Human studies that examined whether nickel can harm the developing fetus are inconclusive. https://www.atsdr.cdc.gov/toxprofiles/tp15.pdf	**Developmental Effects.** Body weights in the high-dose male and female rats were significantly decreased compared with controls NOTE: In addition to the effects on organ weights described in the critical study, two other sensitive endpoints exist: neonatal mortality and dermatotoxicity. While no reproductive effects have been associated with nickel exposure to humans, several studies in laboratory animals have demonstrated fetotoxicity.
Selenium	7782-49-2	5.00E-03	IRIS 1991. Human epidemiological study. Clinical selenosis. Yang et al. 1989. Uncertainty factor - 3	Selenium distributes into many organs, but generally higher concentrations are found in the liver and kidneys. However, the liver appears to be the primary target organ for the oral toxicity of selenium in experimental animals following intermediate and chronic exposure. https://www.atsdr.cdc.gov/toxprofiles/tp92.pdf	Children will probably show the same sort of health effects from selenium exposure as adults, but some studies suggest that they may be less susceptible to health effects of selenium than adults. NOTE: Studies of selenium deficient populations suggest that children are more susceptible to the effects of selenium deficiency and have the highest need for selenium of any individuals in the population. https://www.atsdr.cdc.gov/toxprofiles/tp92.pdf	**Dermal Effects; Hematological Effects; Nervous System Effects.** Clinical signs observed included the characteristic "garlic odor" of excess selenium excretion in the breath and urine, thickened and brittle nails, hair and nail loss, lowered hemoglobin levels, mottled teeth, skin lesions and CNS abnormalities (peripheral anesthesia, acroparesthesia and pain in the extremities).

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
Silver	7440-22-4	5.00E-03	IRIS 1991. 2- to 9-year human i.v. study. Argyria. Gaul and Staud, 1935. Uncertainty factor - 3	Insufficient data exist to establish a target organ/tissue.	Lack of sufficient information to know if children are more susceptible to silver toxicity than adults	**Dermal Effects.** The dermal effect is argyria, a medically benign but permanent bluish-gray discoloration of the skin. **Cardiovascular and Hepatobiliary Effects.** Toxic effects of silver have also been reported for the cardiovascular and hepatic systems. Olcott, C.T. 1950. Experimental argyrosis. V. Hypertrophy of the left ventricule of the heart in rats ingesting silver salts. Arch. Pathol. 49: 138-149.
Thallium	7440-28-0	1.00E-05	PPTRV value; U.S. EPA 2018. Based on animal studies. NOAEL for adverse observations of coat and eyes in experimental animals. Uncertainty Factor = 3000	The highest thallium concentrations have typically been found in the **kidney** and the lowest concentrations in the **brain**. https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/1012tr.pdf Limited data on human and animal acute oral exposure to thallium suggests that the **nervous system** may be the target organ. https://www.atsdr.cdc.gov/toxprofiles/tp54.pdf	Children ages 1-11 years. Both male and female. Reed, D; Crawley, J; Faro, SN; et al. (1963) Thallotoxicosis. JAMA 183(7):516–522.	**Nervous System and Developmental Effects.** Neurological abnormalities; retardation; psychosis; death NOTE: Dose unknown Reed, D; Crawley, J; Faro, SN; et al. (1963) Thallotoxicosis. JAMA 183(7):516–522.
Vanadium	7440-62-2	5.00E-03	Based on Vanadium Pentoxide, adjusted for molecular weight (EPA 2017). RfD for Vanadium Pentoxide is dermal effects in experimental animals and has an uncertainty factor of 100.	**Target:** gastrointestinal tract, hematological system, and developing organism	The health effects seen in children from exposure to toxic levels of vanadium are expected to be similar to the effects seen in adults. It is not known if children are more sensitive to vanadium toxicity than adults. It is not known whether vanadium	**Gastrointestinal Effects.** The limited data available for assessing gastrointestinal effects suggest that exposure to vanadium may cause mild gastrointestinal irritation**.** **Hematological, Cardiovascular, Neurological, and Developmental Effects.** A number of effects have been

Table 4-4. Toxicity values for the human health risk-based AWQC

Chemical	CAS No.	Noncancer Chronic Toxicity Values		Toxicity Basis		
		Chronic RfD mg/kg-day	Basis of Chronic RfD	Target (organ/tissue)	Sensitive Life Stage	Health Effect/Outcome
					can cause birth defects in people. However, studies in animals exposed during pregnancy have shown that vanadium can cause decreases in growth and increases in the occurrence of birth defects. https://www.atsdr.cdc.gov/phs/phs.asp?id=274&tid=50	found in **rats and mice** ingesting several vanadium compounds. The effects include: Decreases in number of red blood cells Increased blood pressure Mild neurological effects Developmental effects in animals **https://www.atsdr.cdc.gov/phs/phs.asp?id=274&tid=50**
Zinc	7440-66-6	3.00E-01	IRIS 2005. Human studies - Decreases in erythrocyte Cu, Zn-superoxide dismutase (ESOD) activity in healthy male and female volunteers. Uncertainty factor - 3	Oral animal studies have identified several critical targets of zinc toxicity. These are: **Alterations in copper status** **Hematology**** **Kidneys** **Pancreas** **Gastrointestinal tract**	Data in humans are not available that examine whether children are more susceptible to the toxicity of zinc than adults. However, the RDA for children, expressed in terms of mg/kg-day, is greater than that for adults. Animal studies have, however, suggested that neonates and/or developing animals may be more susceptible to the toxic effects of excess zinc. https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0426tr.pdf	**Hematological Effects:** The most sensitive effects of oral exposure to excess zinc in humans involve the copper status of the body. Zinc exposure can result in a decreased absorption of copper, leading to low systemic copper levels and subsequent health effects https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0426tr.pdf

4.2 Human Health Risk Based Ambient Water Quality Standards

Human health-based AWQC, presented in Table 4-5 through Table 4-7, were calculated individually for each receptor and pathway. The methods used for the development of human health-risk based AWQC are described below. The pathway-specific AWQC are combined and presented in Table 4-8.

Domestic water use

The results of the AWQC calculations based on domestic water use (ingestion of water) are shown in Table 4-5. These values represent total metal concentration in water that would be acceptable for use by all humans of all ages for a domestic water supply. Note that the values for As are based on both noncarcinogenic and carcinogenic endpoints. The value for the carcinogenic endpoint is lower and will be protective of noncarcinogenic effects.

Note that no calculation was performed for Pb. Pb is evaluated differently than other metals, and the U.S. EPA Maximum Contaminant Level for Pb of 0.015 mg/L (15 µg/L) is set to be protective of children. The MCL for Pb was used as the AWQC in this Report.

Table 4-5. AWQC for Humans based on Domestic Water Use.

Metal	Exposure Parameters			Risk-based AWQC (mg/L)
	Toxicity Values [1]	Body Weight (kg)	Water Ingestion Rate (L/day)	
Aluminum	1.0E+00	15	1	15
Antimony	4.0E-04	15	1	0.006
Arsenic – carcinogenic	5E-5/µg/L	NA	NA	0.00002
Arsenic – noncarcinogenic	3.0E-04	15	1	0.005
Barium	2.0E-01	15	1	3
Beryllium	2.0E-03	15	1	0.03
Cadmium	5.0E-04	15	1	0.008
Chromium	1.5E+00	15	1	22.5
Cobalt	3.0E-04	15	1	0.005
Copper	4.0E-02	15	1	0.6
Iron	7.0E-01	15	1	10.5
Lead	NA	NA	NA	0.015
Manganese	1.4E-01	15	1	2.1
Mercury	3.0E-04	15	1	0.005
Molybdenum	5.0E-03	15	1	0.075
Nickel	2.0E-02	15	1	0.3
Selenium	5.0E-03	15	1	0.075
Silver	5.0E-03	15	1	0.075
Thallium	1.0E-05	15	1	0.00015
Vanadium	5.0E-03	15	1	0.075
Zinc	3.0E-01	15	1	4.5

Shaded results indicate that screening level is based on carcinogenic risk.

Consumption of Homegrown Fruits and Vegetables

As shown in Table 4-6, human consumption of homegrown produce results in AWQC that are higher than those of ingestion or water. These values are based on hazard to humans consuming homegrown produce, not on toxicity to plants. All are higher than AWQC based on domestic water ingestion and the toxicity-based AWQC for plants in Table 2-1 with the exception of the carcinogenic-based AWQC for As.

Table 4-6. AWQC based on human ingestion of homegrown produce.

Chemical	Maximum Predicted Soil Concentrations from Irrigation						Exposure Estimate	Toxicity Value	Hazard Quotient (risk)
	Water Concentration (mg/L)	Amount Applied to 1 cm2 of Soil in 1 Year (mg/cm²)	Amount contained in 1 cm2 x 15 cm depth of Soil in 1 Year (mg/cm3)	Soil Concentration, 1 Year (mg/kg)	Plant BAF	Concentration in Produce (mg/kg)			
Aluminum	43000	5.33E+03	3.55E+02	219213.5	6.50E-04	1.42E+02	1.00E+00	1.00E+00	1
Antimony	0.37	4.58E-02	3.06E-03	1.91	0.03	5.73E-02	4.02E-04	4.00E-04	1
Arsenic	1.4	1.73E-01	1.16E-02	7.23	6.00E-03	4.34E-02	3.04E-04	3.00E-04	1
Arsenic	0.000026	3.22E-06	2.15E-07	0.00013	6.00E-03	8.05E-07	6.66E-07	1.50E+00	1.00E-06
Barium	370	4.58E+01	3.06E+00	1909.83	0.015	2.86E+01	2.01E-01	2.00E-01	1
Boron	336	3.41E-01	2.27E-02	14.22	2	2.84E+01	2.00E-01	2.00E-01	1
Beryllium	37	4.58E+00	3.06E-01	190.98	1.50E-03	2.86E-01	2.01E-03	2.00E-03	1
Cadmium	0.185	2.29E-02	1.53E-03	0.95	0.15	1.43E-01	1.01E-03	1.00E-03	1
Chromium	9200	1.14E+03	7.60E+01	47487.76	4.50E-03	2.14E+02	1.50E+00	1.50E+00	1
Cobalt	1.2	1.49E-01	9.91E-03	6.19	7.00E-03	4.34E-02	3.04E-04	3.00E-04	1
Copper	4.4	5.45E-01	3.63E-02	22.71	0.25	5.68E+00	3.99E-02	4.00E-02	1
Iron	19500	2.42E+03	1.61E+02	100653.4	0.001	1.01E+02	7.07E-01	7.00E-01	1
Lead	0.015	1.86E-03	1.24E-04	0.08	9.00E-03	6.97E-04	4.89E-06	NA	NA
Manganese	77	9.54E+00	6.36E-01	397.45	0.05	1.99E+01	1.39E-01	1.40E-01	1
Mercury	0.042	5.20E-03	3.47E-04	0.22	0.2	4.34E-02	3.04E-04	3.00E-04	1
Molybdenum	2.3	2.85E-01	1.90E-02	11.87	0.06	7.12E-01	5.00E-03	5.00E-03	1
Nickel	9.25	1.15E+00	7.64E-02	47.75	0.06	2.86E+00	2.01E-02	2.00E-02	1
Selenium	5.5	6.81E-01	4.54E-02	28.39	0.025	7.10E-01	4.98E-03	5.00E-03	1
Silver	1.4	1.73E-01	1.16E-02	7.23	0.1	7.23E-01	5.07E-03	5.00E-03	1
Thallium	0.69	8.55E-02	5.70E-03	3.56	4.00E-04	1.42E-03	1.00E-05	1.00E-05	1
Vanadium	46	5.70E+00	3.80E-01	237.44	3.00E-03	7.12E-01	5.00E-03	5.00E-03	1
Zinc	9.2	1.14E+00	7.60E-02	47.49	0.9	4.27E+01	3.00E-01	3.00E-01	1

Shaded results indicate that screening level is based on carcinogenic risk.
ND = Not Detected
NA = Not Available
BAFs are for wet-weight plants (ORNL 2018)
Plant concentration (mg/kg) = Soil Concentration * BAF (wet weight)

Consumption of Homegrown Meat Products

To assess exposure through homegrown meat products based on consumption of beef or sheep by a resident, tissue concentrations corresponding to the livestock AWQC were developed. The tissue concentration is calculated as part of the water quality assessment for livestock and was used as the exposure concentration for human receptors (Table 3-5 and Table 3-6). In all cases, the higher tissue concentration was found in cattle and therefore, cattle tissue concentrations are used for evaluation. This calculation was based first on the toxicity-based water standards for livestock as described in Section 3. As a practical limitation, toxicity to livestock determines the upper bound concentration of metals that can be present in water used for livestock irrigation. The toxicity-based standards are then used to estimate the tissue concentration for livestock that may be consumed by humans. Next, the tissue concentration is used to estimate human-health hazard (or risk) from ingestion of meat products. Finally, the water concentration is adjusted based on the resulting hazard (or risk) so that it reflects a hazard of 1.0 (or risk of one in one million people [1E-6]) at the maximum. If the calculated hazard (or risks) is below a hazard of 1.0 (or risk of 1E-6), no adjustment is made.

Table 4-7 presents the results of these calculations. All hazards were below 1.0, except for Tl. In addition, the As risk associated with the estimated tissue concentration was 3.3E-2, higher than the acceptable risk of 1E-6 (U.S. EPA 2002). These AWQC values were adjusted downward in the combined AWQC to be equivalent to a hazard index of 1.0 and risk of 1E-6. For Tl, the AWQC of 9 µg/L was divided by 25.1, resulting in an adjusted AWQC for ingestion of meat products of 0.36 µg/L. For As, the AWQC of 7.2 µg/L was divided by 32000, resulting in an adjusted AWQC for ingestion of meat products of 0.00048 µg/L. All other metals were associated with a hazard index well below 1.0, and AWQC for this pathway were adjusted upward to calculate an AWQC equivalent to 1.0 but dividing the livestock-based AWQC by the calculated hazard index.

Table 4-7. AWQC for ingestion of homegrown meat products, including the adjustment to a hazard index of 1.0 and risk of 1E-6.

	Maximum Predicted Soil Concentrations from Irrigation				Human Dose from Ingestion of Meat	Toxicity Value	Hazard Quotient	Adjusted AWQC (mg/L)
	Water Concentration (mg/L) Cattle	Tissue concentration from food and soil (Cattle) mg/kg	Tissue Concentration from Water Uptake (Cattle) (mg/kg)	Total Concentration in Cattle (mg/kg)				
Aluminum	190	5.26E-06	5.70E-02	5.70E-02	1.97E-04	1.00E+00	1.97E-04	8.64E+05
Antimony	1.8	5.11E-08	3.60E-04	3.60E-04	1.24E-06	4.00E-04	3.11E-03	5.79E+02
Arsenic	7.2	2.92E-07	2.88E-03	2.88E-03	9.94E-06	3.00E-04	3.31E-02	2.17E+02
Arsenic	7.2	2.92E-07	2.88E-03	2.88E-03	9.94E-06	1.50E+00	1.49E-05	4.83E-01
Barium	75	2.91E-07	2.25E-03	2.25E-03	7.77E-06	2.00E-01	3.88E-05	1.93E+06
Beryllium	2.8	5.26E-08	5.60E-04	5.60E-04	1.93E-06	2.00E-03	9.67E-04	2.90E+03
Cadmium	2.3	5.84E-08	2.53E-04	2.53E-04	8.74E-07	1.00E-03	8.74E-04	2.63E+03
Chromium	24	2.46E-06	2.64E-02	2.64E-02	9.11E-05	1.50E+00	6.08E-05	3.95E+05
Cobalt	6	2.31E-06	2.40E-02	2.40E-02	8.29E-05	3.00E-04	2.76E-01	2.17E+01
Copper	9.8	3.78E-06	1.96E-02	1.96E-02	6.77E-05	4.00E-02	1.69E-03	5.79E+03
Iron	120	4.43E-05	4.80E-01	4.80E-01	1.66E-03	7.00E-01	2.37E-03	5.07E+04
Lead	23	1.89E-07	1.84E-03	1.84E-03	6.35E-06	NA	NA	15
Manganese	490	6.07E-06	3.92E-02	3.92E-02	1.35E-04	1.40E-01	9.67E-04	5.07E+05
Mercury	0.45	7.19E-06	2.25E-02	2.25E-02	7.77E-05	3.00E-04	2.59E-01	1.74E+00
Molybdenum	1.2	2.23E-07	1.44E-03	1.44E-03	4.97E-06	5.00E-03	9.94E-04	1.21E+03
Nickel	24	3.07E-06	2.88E-02	2.88E-02	9.94E-05	2.00E-02	4.97E-03	4.83E+03
Selenium	1.2	3.52E-07	3.60E-03	3.60E-03	1.24E-05	5.00E-03	2.49E-03	4.83E+02
Silver	1100	1.27E-04	6.60E-01	6.60E-01	2.28E-03	5.00E-03	4.56E-01	2.41E+03
Thallium	9	6.65E-06	7.20E-02	7.20E-02	2.49E-04	1.00E-05	2.49E+01	3.62E-01
Vanadium	12	5.56E-07	6.00E-03	6.00E-03	2.07E-05	5.00E-03	4.14E-03	2.90E+03
Zinc	120	8.62E-04	2.40E+00	2.40E+00	8.29E-03	3.00E-01	2.76E-02	4.34E+03

Grey shaded - arsenic (carcinogenic) calculation

4.3 Risk-Based Combined AWQC for Humans

As described in Section 4.2, individual AWQC were calculated for humans based on ingestion of water; ingestion of homegrown plants; and ingestion of homegrown meat products. To incorporate the contribution of each exposure pathway to overall exposure, each calculated risk-based AWQC for humans was combined to one value. The following the method, described below, was used to provide a total AWQC:

$$AWQC_{total} = 1/SUM$$

Where:

SUM = (1/(AWQC-Domestic water))+(1/(AWQC-from produce consumption))+(1/(AWQC-from consumption of livestock))

where

AWQC domestic water: risk-based WQC for human direct pathways (ingestion)

AWQC from produce consumption: risk-based WQC for human ingestion of homegrown produce

AWQC from consumption of livestock: risk-based WQC from ingestion of homegrown meat products

AWQC were based on a noncarcinogenic hazard of 1.0, or cancer risk of 1E-6 for As only. The total AWQC for humans is presented in Table 4-8. Each pathway was considered to contribute equally to total exposure, although the AWQC for ingestion of meat products were adjusted to account for their relative hazards as described above. Overall, the water ingestion pathway was the dominant exposure pathway. The combined AWQC are presented in Table 4-8.

Two results are presented for As. The AWQC value associated with carcinogenic effect of As are lower than those based on noncarcinogenic hazard. Carcinogenic endpoints are assessed only for humans, so it is only the AWQC for humans that two calculations were performed for As. As can be seen in the table, the pathway that drives the overall result is direct ingestion of water. Use of the combined AWQC, however, will be most protective of human health as it additionally accounts for the potential intake of metals from homegrown food products.

Table 4-8. Combined AWQC for human health.

	Direct Ingestion AWQC (mg/L)	Risk-based AWQC from Human Exposure Pathways		Combined AWQC (mg/L)
		Ingestion of Plants - AWQC (mg/L)	Ingestion of Homegrown Meat Products - Adjusted AWQC (mg/L) [3]	
Aluminum	**15**	**43000**	**864000**	15
Antimony	**0.006**	**0.37**	**579.3**	0.0059
Arsenic (non-cancer)	**0.005**	**1.4**	**217**	0.0045
Arsenic (cancer) [1]	**0.00002**	**0.000026**	**0.483**	0.0000113
Barium	**3**	**370**	**1930000**	2.98
Beryllium	**0.03**	**37**	**2900**	0.03
Cadmium	**0.008**	**0.185**	**2630**	0.0072
Chromium	**22.5**	**9200**	**395000**	22.4
Cobalt	**0.005**	**1.2**	**21.7**	0.0045
Copper	**0.6**	**4.4**	**5790**	0.53
Iron	**10.5**	**19500**	**50700**	10.5
Lead	**0.015**	**0.015**	**0.015**	0.005
Manganese	**2.1**	**77**	**507000**	2.04
Mercury	**0.005**	**0.042**	**1740**	0.0041
Molybdenum	**0.075**	**2.3**	**1210**	0.073
Nickel	**0.3**	**9.25**	**4830**	0.29
Selenium	**0.075**	**5.5**	**483**	0.074
Silver	**0.075**	**1.4**	**2410**	0.0712
Thallium [2]	**0.00015**	**0.690**	**0.362**	0.00015
Vanadium	**0.075**	**46**	**2900**	0.075
Zinc	**4.5**	**9.2**	**4340**	3.02

Bolded results indicate those derived and recommended in this study.
Shaded results indicate that screening level is based on carcinogenic risk.

1. AWQC for ingestion of homegrown meat products for arsenic (carcinogenic) was adjusted downward by a factor of 32000 to account for risk above 1E-6.
2. AWQC for ingestion of homegrown meat products for thallium was adjusted downward by a factor of 25.1 to account for hazard index above 1
3. All AWQC for livestock ingestion adjusted upwards except for arsenic and thallium

4.4 Assumptions and Uncertainties

The human health and agricultural AWQC were based on the domestic and agricultural water uses for the Navajo Nation, and upper-bound exposure parameters were chosen. This was a necessary assumption to address the uncertainty in the range of exposures. This assumption is associated with uncertainty that is intended to be protective of all ages.

There is uncertainty in the estimate of soil concentrations from the use of water for irrigation. Deeper tillage may act to decrease concentrations, as deposited metals would be dispersed through a larger soil column. Further, decreases in metals through runoff, plant uptake, addition of soil amendments, or other means were not factored into the estimates. In addition, the water usage may be over- or underestimated and could be better assessed if surface water withdrawal rates are known, as well as the acreage that is irrigated by surface water drawn from the river.

The bioaccumulation factors from Baes et al. 1984 are a general factor that is not specific to the types of crops that may be grown in New Mexico. Different types of crops will uptake metals at different rates, so it is possible that using one value as a surrogate is an overestimate of potential exposures through homegrown produce. Further, the availability of metals from soil is affected by pH. Soil pH was not addressed in the development of these AWQC.

The uptake factors used to estimate uptake of metals to crops are not specific to any crop, introducing an uncertainty. Similarly, uptake factors for beef for each metal were used to assess metals uptake by sheep in the absence of accumulation factors specific to sheep. This may over- or underestimate concentrations of metals in edible tissues of sheep. These uncertainties may over-or underestimate the amount of metals that humans would ingest through homegrown food products.

The toxicity reference values were based on tolerable levels in feed for cattle and sheep. The body weight and feed intake rates used to assess exposures are based on generally accepted values for sheep and cattle. However, these may not bound exposure parameters for cattle or sheep in New Mexico due to different ranching practices, or temperature and climate conditions, as well as breed size and water/feed intake rates.

Ingestion rates for human consumption of homegrown produce and meat are also associated with uncertainty. U.S. EPA intake rates based on homegrown meat and produce were used, and consumption may be less than this if other sources of food items are more commonly used. Conversely, if all food consumed is homegrown, then these intake rates may not fully capture Navajo exposures and they may lead to an underestimate of risk. Food preferences and sources could be surveyed in the community to determine which foodstuffs constitute the majority of the community’s diet. Specific dietary patterns of the affected communities could be used to better estimate exposures to homegrown food products. This information can be challenging to collect from individuals but can sometimes be collected from representative community leaders.

Long-term exposure to the most sensitive receptor (child) was used to develop AWQC for domestic water use. These values were the lowest of all human exposure pathways evaluated, and much lower than the AWQC associated with food products. The AWQC associated with As evaluated as a carcinogen through water ingestion and consumption of homegrown produce and meat products was the lowest AWQC calculated.

5. Summary and Conclusions

Most states and tribes include general agricultural uses, livestock watering, or irrigation as designated uses for water bodies. Most states and tribes that have numeric standards for agricultural designated uses cite or use U.S. U.S. EPA's 1972 Water Quality Criteria, however, calculations were not provided in U.S. EPA's 1972 criteria for livestock watering or crop irrigation and in most cases, clear rationale for state and tribal numeric standards are lacking. A risk-based approach was used to develop metal water quality criteria to protect human health, which included sources, transport mechanisms, points of exposure, exposure pathways, and intermediate receptors of importance to the Navajo Nation as well as other state and tribal agencies. The risk-based criteria are compared with criteria for crops and livestock recommended in U.S. EPA's 1972 guidance, aquatic life criteria, and drinking water criteria for metals of interest to provide context. Table 5-1 presents a comparison of the calculated risk-based water quality criteria and the 1972 U.S. EPA criteria for crops and livestock where criteria were identified in NAS & NAE 1972. Table 5-2 presents regulatorily established agricultural water quality standards for New Mexico, Utah, and Arizona. In general, calculated criteria are higher than the 1972 criteria or those standards used for example by New Mexico, Arizona, and Utah because the state water quality standards are based on dissolved rather than total recoverable concentrations in water. Note, there are several metals for which state standards are not available. These are shown as blank cells in the tables.

The risk-based criteria take into account toxicity only and not overall water salinity, hardness or metal solubility, which leads to higher calculated levels. For use of water for irrigation or as a livestock water supply, salinity and total suspended solids would limit the amount of a metal that could be present before the water is unusable. It is recommended that the calculated risk-based values be adjusted for the recommended limit of total dissolved salts in water for livestock of less than 5000 mg/L (CSU 1999). The values are likely to be lower than the calculated criteria presented in Tables Table 5-1 and Table 5-2 and will be more relevant for use.

Direct ingestion of water presents the most important pathway and drives the risk-based criteria calculated in this Report. Homegrown food products contribute some of the exposure and risk, depending on the bioaccumulation of the metal. In selecting the appropriate criteria, it may be appropriate to compare the risk-based values in this Report with drinking water standards for metals of concern. Using New Mexico's drinking water standards as an example, in general, the calculated risk-based values are lower. There are two main reasons for the difference:

(1) The calculated risk-based values are based on child exposure parameters, which incorporate a higher water ingestion rate and lower body weight than those of adults. Adult exposure parameters are typically used for setting regulatory levels, with the exception of Pb.
(2) The inclusion of homegrown produce and meat products in the calculation of human-health risk-based criteria. These pathways are not included in setting water quality standards for state and national programs.

Note also that the New Mexico state standards are based on dissolved concentrations of metals in water, rather than total metals. The use of a total metal concentration is a more conservative measure of exposure as it does not assume filtration of water prior to use; the adoption of dissolved metals criteria for total metals criteria assumes that all of the measured metal in water is potentially bioavailable.

The AWQC developed in this Report may serve as benchmarks or triggers for management of water resources in the Navajo Nation and beyond, notwithstanding several uncertainties. The human health and agricultural water quality criteria were based on domestic and agricultural water uses for the Navajo Nation, and upper-bound exposure parameters were chosen. This was a necessary assumption to address the uncertainty in the range of exposures and is associated with uncertainty that is intended to be protective of all ages. There is also uncertainty in the estimate of soil concentrations from the use of water for irrigation. Deeper tillage may act to decrease concentrations, as deposited metals would be dispersed through a larger soil column. Further, decreases in metals through runoff, plant uptake, addition of soil amendments, or other means were not factored into the estimates. In addition, the water usage may be over- or underestimated and could be better assessed if surface water withdrawal rates are known, as well as the acreage that is irrigated by surface water drawn from the river.

The toxicity reference values were based on tolerable levels in feed for cattle and sheep. The body weight and feed intake rates used to assess exposures are based on generally accepted values for sheep and cattle. However, these may not bound exposure parameters for cattle or sheep in New Mexico due to different ranching practices, or temperature and climate conditions, as well as breed size and water/feed intake rates.

Ingestion rates for human consumption of homegrown produce and meat are also associated with uncertainty. U.S. EPA intake rates based on homegrown meat and produce were used, and consumption may be less than this if other sources of food items are more commonly used. Conversely, if all food consumed is homegrown, then these intake rates may not fully capture Navajo exposures and they may lead to an underestimate of risk.

Table 5-1. Summary of risk-based water quality standards (mg/L) for crops, livestock, and human health.

Metal	Crops-calculated risk-based concentration	U.S. EPA 1972 Criteria crops	Cattle (calculated risk-based value)	Sheep (Calculated Risk based value)	U.S. EPA 1972 Criteria livestock	Human health – water ingestion	Human health – homegrown produce	Human health – homegrown meat
Aluminum	5	--	190	170	--	15	43000	864000
Antimony	0.5	--	1.8	1.6	--	0.006	0.37	579.3
Arsenic	0.1	0.10	7.2	4.5	0.2	0.00002/0.005	0.000026/1.41	4.83E-01/217
Barium	50	--	75	6.5	--	3	370	1930000
Beryllium	0.1	--	2.8	2.5	--	0.03	37	2900
Cadmium	0.01	0.01	2.3	1.5	50	0.008	0.185	2630
Chromium	0.1	--	24	15	--	22.5	9200	395000
Cobalt	1	--	6	3.8	--	0.005	1.2	21.7
Copper	0.2	0.2	9.8	2.2	0.5	0.6	4.4	5790
Iron	5	5	120	75	2.0	10.5	19500	50700
Lead	5	5	23	150	0.05	0.015	0.015	0.015
Manganese	0.2	--	490	300	--	2.1	77	507000
Mercury	0.03	--	0.45	0.3	--	0.005	0.042	1740
Molybdenum	0.01	--	1.2	0.75	--	0.075	2.3	1210
Nickel	0.2	0.2	24	15	--	0.3	9.25	4830
Selenium	0.02	--	1.2	0.75	--	0.075	5.5	483
Silver	56	--	1100	1000	--	0.075	1.4	2410
Thallium	0.1	--	9	8	--	0.00015	0.690	0.362
Vanadium	0.1	--	12	7.5	--	0.075	46	2900
Zinc	2	2.0	120	45	25.0	4.5	9.2	4340

Table 5-2. AWQC Comparisons.

Metal	Risk-based AWQC from Human, Crop, and Livestock Exposure Pathways					State Water Quality Standards - Agricultural					Water Quality Standards - Drinking Water
	Direct Ingestion - Human - AWQC (µg/L-total)	Combined Human Health-based AWQC (µg/L-total) [2]	AWQC - Toxicity to Plants (µg/L-total)	AWQC - Toxicity to Cattle (µg/L-total)	AWQC - Toxicity to Sheep (µg/L-total)	New Mexico - Irrigation (µg/L, dissolved)	New Mexico - Livestock (µg/L, dissolved)	Utah - Agricultural Standards (µg/L - dissolved)	Arizona - Irrigation (µg/L)	Arizona - Livestock (µg/L)	New Mexico Drinking Water Standards (dissolved, µg/L)
Aluminum	15,000	14,994.5	5,000	190,000	170,000	5,000					None
Antimony	6	5.9	500	1,800	1,600						6
Arsenic (nonc)	4.5	4.5	100	7,200	4,500	100	200	100	2,000 (total)	200 (total)	10
Arsenic (carc) [1]	0.02	0.01	100	7,200	4,5000						
Barium	3,000	2,975.9	50,000	75,000	65,000						2,000
Beryllium	30	30.0	100	2,800	2,500						4
Cadmium	7.5	7.2	10	2,300	1,500	10	50	10	50 (hardness dependent)	50 (hardness dependent)	5
Chromium	22,500	22,443.83	100	24,000	15,000	100	1,000	100	1,000 (hardness dependent)	1,000 (hardness dependent)	100
Cobalt	4.5	4.5	1,000	6,000	3,800	50					50
Copper	600	528.0	200	9,800	2,200	200	500	200	5,000 (total)	500 (total)	1,300
Iron	10,500	10,492.2	5,000	120,000	75,000						
Lead	15	5.0	5,000	23,000	15,000	5,000	100	100	10,000 (total)	100 (total)	15
Manganese	2,100	2,044.2	200	490,000	300,000				10,000		
Mercury	4.5	4.1	30	450	300		10			10 (total)	2
Molybdenum	75	72.6	10	1,200	750	1,000					None
Nickel	300	290.6	200	24,000	15,000						700
Selenium	75	74.0	20	1,200	750	130 [3]	50	50	20 (total)	50 (total)	50
Silver	75	71.2	56,000	1,100,000	1,000,000						

Table 5-2. AWQC Comparisons.

Metal	Risk-based AWQC from Human, Crop, and Livestock Exposure Pathways					State Water Quality Standards - Agricultural					Water Quality Standards - Drinking Water
	Direct Ingestion - Human - AWQC (µg/L-total)	Combined Human Health-based AWQC (µg/L-total) [2]	AWQC - Toxicity to Plants (µg/L-total)	AWQC - Toxicity to Cattle (µg/L-total)	AWQC - Toxicity to Sheep (µg/L-total)	New Mexico - Irrigation (µg/L, dissolved)	New Mexico - Livestock (µg/L, dissolved)	Utah - Agricultural Standards (µg/L - dissolved)	Arizona - Irrigation (µg/L)	Arizona - Livestock (µg/L)	New Mexico Drinking Water Standards (dissolved, µg/L)
Thallium [2]	0.15	0.15	100	9000	8,000						2
Vanadium	75	74.9	100	12000	7500	100	100				None
Zinc	4500	3019.8	2,000	120000	45000	25,000	25,000		10000 (total)	25000 (total)	10500

1. Carcinogenic effects – evaluated for humans only
2. Includes water ingestion, consumption of homegrown produce, and consumption of homegrown meat products
3. In presence of SO $_{+A20}$ <500 mg/L

Literature Cited

Agency for Toxic Substances and Disease Registry (ATSDR). (n.d). Toxicological Profiles. Retrieved from https://www.atsdr.cdc.gov/toxprofiledocs/index.html

Aiello, G. (1955). Pathology of antimony. *Folia Medica (Naples, Italy), 30*, 100.

Alia, N., et al. (2015). Toxicity and bioaccumulation of heavy metals in spinach (*Spinacia oleracea*) grown in a controlled environment. *International Journal of Environmental Research and Public Health, 12*, 7400-7416. doi:10.3390/ijerph120707400

Ambrose, A. M., Larson, D. S., Borzelleca, J. R., & Hennigar, Jr., G.R. (1976). Long-term toxicologic assessment of nickel in rats and dogs. *Journal of Food Science and Technology, 13*, 181-187.

American Society for Testing and Materials (ASTM). (2014). *Standard Guide for Conducting Terrestrial Plant Toxicity Tests, Annual Book of Standards*. (E1963-09). West Conshocken, PA.

Ammerman, C. B. (1969). SYMPOSIUM: Trace minerals; recent developments in cobalt and copper in ruminant nutrition: A review. *Journal of Dairy Science, 53*(8), 1097-1107.

Asati, A., Pichhode, M., & Nikhil, K. (2016). Effect of heavy metals on plants: An overview. *International Journal of Application or Innovation in Engineering & Management, 5*(3), 56-66.

Ayers, R. S., & Westcot, D. W. (1976). *Water Quality for Agriculture*. (FAO Irrigation and Drainage Paper, 29). Rome, Italy: Food and Agriculture Organization of the United Nations.

Ayers, R. S., & Westcot, D. W. (1985). *Water Quality for Agriculture*. (FAO Irrigation and Drainage Paper, 29 Rev. 1). Rome, Italy: Food and Agriculture Organization of the United Nations.

Baes, C. F., Sharp, R. D., Sjoreen, A. L., & Shor, R. W. (1984). *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*. (ORNL-5786). Oak Ridge National Laboratory.

Bakkali, K., Martos, N. R., Souhail, B., & Ballesteros, E. (2012). Determination of heavy metal content in vegetables and oils from Spain and Morocco by inductively coupled plasma mass spectrometry. *Analytical Letters, 45*, 907-919.

Balestrasse, K. B., Benavides, M. P., Gallego, S. M., & Tomaro, M. L. (2003). Effect on cadmium stress on nitrogen metabolism in nodules and roots of soybean plants. *Functional Plant Biology, 30*, 57-64.

Bampidis, V. A., Nistor, E., & Nitas, D. (2013). Arsenic, cadmium, lead and mercury as undesirable substances in animal feeds. *Animal Science and Biotechnologies, 46*(1), 17-22.

Belyaeva, A. P. (1967). The effect of antimony on reproduction. *Gigiena Truda I Professional'nye Zabolevaniia, 11*, 32.

Benavides, M. P., Gallego, S. M., & Tomaro, M. L. (2005). Cadmium toxicity in plants. *Brazilian Journal of*

Plant Physiology, 17(1), 21-34.

Bhalerao, S. A., Sharma, A. S., & Poojari, A. C. (2015). Toxicity of nickel in plants. *International Journal of Pure & Applied Bioscience, 3*(2), 345-355.

Bishnoi, N. R., Sheoran, I. S., & Singh, R. (1993). Influence of cadmium and nickel on photosynthesis and water relations in wheat leaves of different insertion level. *Photosynthetica, 28*, 473–479.

Blaylock, M. J., & Huang, J. W. (2000). Phytoextraction of metals. In I. Raskin & B. D. Ensle (Eds.), *Phytoremediation of Toxic Metals: Using Plants to Clean up the Environment* (pp. 53–70.). New York, NY: Wiley, New York.

Blood, D. C., Radostits, O. M., Arundel, J. H., & Gay, C. C. (1992). *Veterinary Medicine: A Textbook of the Diseases of Cattle, Sheep, Pigs, Goats and Horses* (Seventh ed.). London, UK: Bailli ere Tindall Ltd.

Bradley, C. H. (1993). Copper poisoning in a dairy herd fed a mineral supplement. *Canadian Veterinary Journal, 34*, 287-292.

Buchman, M. F. (2008). *NOAA Screening Quick Reference Tables*. (NOAA OR&R Report 08-1). Seattle, WA: National Oceanic and Atmospheric Administration, Office of Response and Restoration Division.

Bunzl, K., Trautmannsheimer, M., Sadaf, S., Schramel, P., & Reifenhauser, W. (2001). Availability of arsenic, copper, lead, thallium, and zinc to various vegetables grown in slag-contaminated soils. *Journal of Environmental Quality, 30*, 934–939.

Centers for Disease Control and Prevention (CDC). (1991). Cited in the following EPA IRIS link for lead. Retrieved from https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0277_summary.pdf#nameddest=rfd

Chapman Jr., H. L., & Kidder, R. W. (1964). Copper and cobalt for beef cattle. *Florida Agr. Exp. Sta., Bull., 674*.

Christensen, T. H. (1984). Cadmium soil sorption at low concentrations: I. Effect of time, cadmium load, pH, and calcium. *Water, Air & Soil Pollution, 21*, 105–114.

Colorado Department of Public Health and Environment. (2018). *Regulation No. 31 – The Basic Standards and Methodologies for Surface Water*. (5 CCR 1002-31). Denver, CO: Colorado Department of Public Health and Environmental, Water Quality Control Commission.

Connolly, E. L., & Guerinot, M. L. (2002). Iron stress in plants. *Genome Biology, 3*(8), 1-4.

Coup, M. R., & Campbell, A. G. (1964). The effect of excessive iron intake upon the health and production of dairy cows. *New Zealand Journal of Agricultural Research, 7*(4), 624-638. doi:10.1080/00288233.1964.10416390

Croteau, M.-N., Luoma, S. N., & Stewart, A. R. (2005). Trophic transfer of metals along freshwater food webs: evidence of cadmium biomagnification in nature. *Limnology and Oceanography, 50*, 1511-1519.

Dahal, B. M., Fuerhacker, M., Mentler, A., Karki, K. B., Shrestha, R. R., & Blum, W. E. H. (2008). Arsenic contamination of soils and agricultural plants through irrigation water in Nepal. *Environmental Pollution, 155*(157-163).

Das, P., Samantaray, S., & Rout, G. R. (1997). Studies on cadmium toxicity in plants: A review. *Environmental Pollution, 98*, 29-36.

De Filippis, L. F., & Ziegler, H. (1993). Effect of sublethal concentrations of zinc, cadmium and mercury on the photosynthetic carbon reduction cycle of Euglena. *Journal of Plant Physiology, 142*, 167–172.

de Souza Silva, M. L., Vitti, G. C., & Trevizam, A. R. (2014). Heavy metal toxicity in rice and soybean plants cultivated in contaminated soil. *Revista Ceres, Viçosa, 61*(2), 248-254.

Derrick, J. (2006). *Managing for Cadmium Minimization in Australian Livestock*. SAFEMEAT, Meat & Livestock Australia.

Dietz, D. D., Elwell, M. R., Davis, W. E., & Meirhenry, E. F. (1992). Subchronic toxicity of barium Chloride dihydrate administered to rats and mice in the drinking water. *Fundamental and Applied Toxicology, 19*(4), 527-537. doi:10.1016/0272-0590(92)90091-U

Ebbs, S., Talbott, J., & Sankaran, R. (2006). Cultivation of garden vegetables in Peoria Pool sediments from the Illinois River: A case study in trace element accumulation and dietary exposures. *Environment International, 32*, 766–774.

Economou-Eliopoulos, M., Megremi, I., & Vasilatos, C. (2011). Factors controlling the heterogeneous distribution of Cr(VI) in soil, plants and groundwater: evidence from the Assopos basin, Greece. *Chemie der Erde: Geochemistry, 71*(1), 39–52. doi:10.1016/j.chemer.2011.01.001

Efroymson, R. A., Will, M. E., Suter III, G. W., & Wooten, A. C. (1997). *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision*. (ES/ER/TM-85/R3). Washington, DC: U.S. Department of Energy, Office of Environmental Management.

Ernst, W. H. O., Verkleij, J. A. C., & Schat, H. (1990). Evolutionary biology of metal resistance in Silene vulgaris. *Evolutionary Trends in Plants, 4*, 45–51.

European Commission (EC). (2003). *Opinion of the Scientific Committee for Animal Nutrition on the Use of Zinc in Feedingstuffs*. European Commission Health and Consumer Protection Directorate General.

Federal Water Pollution Control Administration (FWPCA). (1968). *Water Quality Criteria: Report of the National Technical Advisory Committee to the Secretary of the Interior*. Washington, DC: U.S. Department of the Interior, Federal Water Pollution Control Administration.

Fipps, G. (2003). *Irrigation Water Quality Standards and Salinity Management Strategies*. (Agricultural Communications, Texas Cooperative Extension B-1667). College Station, TX: Texas A&M, Department of Agricultural Engineering.

Fodor, A., Szabo-Nagy, A., & Erdei, L. (1995). The effects of cadmium on the fluidity and H+-ATPase activity of plasma membrane from sunflower and wheat roots. *Journal of Plant Physiology, 14*, 787–792.

Ford, K. L., & Beyer, W. N. (2014). Soil criteria to protect terrestrial wildlife and open-range livestock from metal toxicity at mining sites. *Environmental Monitoring and Assessment, 186*, 1899–1905.

Foy, C. D., Chaney, R. L., & White, M. C. (1978). The physiology of metal toxicity in plants. *Annual Review of Plant Biology, 29*, 511-566.

Freeland-Graves, J. H., Bales, C. W., & Behmardi, F. (1987). Manganese requirements of humans. In E. Kies (Ed.), *Nutritional Bioavailability of Manganese* (pp. 90-104). Washington, DC: American Chemical Society.

Gaul, L. E., & Staud, A. H. (1935). Clinical spectroscopy. Seventy cases of generalized argyrosis following organic and colloidal silver medication. *The Journal of the American Medical Association, 104*, 1387-1390.

Ghani, A. (2010). Toxic effects of heavy metals on plant growth and metal accumulation in maize (Zea maysL.). *Iranian Journal of Toxicology, 3*(3), 325-334.

Ghosh, A. K., Bhatt, M. A., & Agrawal, H. P. (2012). Effect of long-term application of treated sewage water on heavy metal accumulation in vegetables grown in Northern India. *Environmental Monitoring and Assessment, 184*(2), 1025-1036. doi:10.1007/s10661-011-2018-6

Gough, L. P., Shacklette, H. T., & Case, A. A. (1979). *Element Concentrations Toxic to Plants, Animals, and Man: An Appraisal of the Toxicity Hazard to Plants, Animals, and Man from Natural and Manmade Element Concentrations of Environmental Concern*. (Geological Survey Bulletin 1466). Washington, DC: U.S. Government Printing Office.

Gray, J. S. (2002). Biomagnification in marine systems: the perspective of an ecologist. *Marine Pollution Bulletin, 45*(46-52).

Guenzel, L., Mitchell, R., Sullivan, K., & Cyterski, M. (2018). *Analysis of the biological data collected from the Animas and San Juan Rivers following the Gold King Mine release*. (EPA/830/R-18/003). Washington, DC: U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds.

Hejna, M., Gottardo, D., Baldi, A., Dell'Orto, V., Cheli, F., Zaninelli, M., & Rossi, L. (2018). Review: Nutritional ecology of heavy metals. *animal, 12*(10), 2156-2170. doi:10.1017/S175173111700355X

Hernandez, L. E., Carpena-Ruiz, R., & Garate, A. (1996). Alterations in the mineral nutrition of pea seedlings exposed to cadmium. *Journal of Plant Nutrition, 19*, 1581–1159.

Hicks, M. (2002). *Establishing Surface Water Quality Criteria for the Protection of Agricultural Water Supplies*. (Publication Number 00-10-073, Draft Discussion Paper). Washington State Department of Ecology, Water Quality Program.

John, R., Ahmad, P., Gadgil, K., & Sharma, S. (2009). Heavy metal toxicity: Effect on plant growth, biochemical parameters and metal accumulation by *Brassica juncea L*. *International Journal of Plant Production, 3*(3), 65-76.

Kabata-Pendias, A. (2001). *Trace Elements in Soils and Plants* (3rd ed.). Boca Raton, FL: CRC Press.

Khan, A., Khan, S., Khan, M. A., Qamar, Z., & Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review. *Environmental Science and Pollution Research, 22*(18), 13772-13799. doi:10.1007/s11356-015-4881-0

Kirkillis, C. G., Pasias, I. N., Miniadis-Meimaroglou, S., Thomaidis, N. S., & Zabetakis, I. (2012). Concentration levels of trace elements in carrots, onions and potatoes cultivated in Asopos region, Central Greece. *Analytical Letters, 45*(551-562).

Kumar, P., & Pathak, S. (2018). Short-term response of plants grown under heavy metal toxicity: Chapter 5. In *Heavy Metals* (pp. 69-89).

Li, Z., Li, L., & Chen, G. P. J. (2005). Bioavailability of Cd in a soil–rice system in China: soil type versus genotype effects. *Plant and Soil, 271*, 165–173.

Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J., . . . Brookes, P. C. (2013). Human health risk assessment of heavy metals in soil–vegetable system: A multi-medium analysis. *Science of the Total Environment, 463–464*, 530–540.

Looper, M. L., & Waldner, D. N. (2002). *Water for Dairy Cattle*. (Guide D-107). New Mexico State University and Oklahoma State University.

Mandal, P. (2017). An insight of environmental contamination of arsenic on animal health. *Emerging Contaminants, 3*, 17-22.

Marschner, H. (1986). *Mineral Nutrition of Higher Plants*. London, UK: Academic Press.

Mathys, W. (1975). Enzymes of heavy metal-resistant and non-resistant populations of Silene cucubalus and their interactions with some heavy metals in vitro and in vivo. *Physiologia Plantarum, 33*(2), 161-165.

McIntyre, J. K., & Beauchamp, D. A. (2007). Age and trophic position dominate bioaccumulation of mercury and organochlorines in the food web of Lake Washington. *Science of the Total Environment, 372*, 571-584.

Mench M., Vangronsveld, J., Lepp, N., & Edwards, R. (1998). Physicochemical aspects and efficiency of trace element in immobilisation by soil amendments. In J. Vangronsfield & S. Cunningham (Eds.), *In-situ Inactivation and Phytorestoration of Metal Contaminated Soils* (pp. 151–182). Georgetown, TX: Springer-Verlag, Landes Company.

Mirshekali, H., Hadi, H., Amirnia, R., & Khodaverdiloo, H. (2012). Effect of zinc toxicity on plant productivity, chlorophyll and Zn contents of sorghum (*Sorghum bicolor*) and common lambsquarter (*Chenopodium album*). *International Journal of Agriculture: Research and Review, 2*(3), 247-254.

Molas, J. (1997). Changes in morphological and anatomical structure of cabbage (*Brassica oleracea L.*) outer leaves and in ultrastructure of their chloroplasts caused by an in vitro excess of nickel. *Photosynthetica, 34*, 513–522.

National Academy of Sciences & National Academy of Engineering (NAS & NAE). (1972). *Water Quality Criteria 1972: A Report of the Committee on Water Quality Criteria*. Washington, DC: National Academy of Sciences & National Academy of Engineering.

National Research Council (NRC). (1989). *Recommended Dietary Allowances, 10 Edition Food and Drug Nutrition Board*. Washington, DC: National Academy Press.

National Research Council (NRC). (2001). *Nutrient Requirements of Dairy Cattle, 7th Revision*. Washington, DC: National Academy Press.

National Research Council (NRC). (2005). *Mineral Tolerances in Animals* (2nd Revised ed.). Washington, DC: National Academies Press.

National Resource Conservation Service (NRCS). (2003). *National Range and Pasture Handbook*. Washington, DC: U.S. Department of Agriculture Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043055.pdf

National Toxicology Program (NTP). (1994). *NTP Technical Report on the Toxicology and Carcinogenesis Studies of Barium Chloride Dyhadrate (CAS no. 10326-27-9) in F344/N Rats and B6C3F1 Mice (Drinking Water Studies)*. (NTP TR 432, NIH pub. no. 94 -3163. NTIS pub PB94-214178). Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service.

Navajo Nation Environmental Protection Agency (NNEPA). (2017). *San Juan Fish Contamination Study: November 2017*. Owings Mills, MD: Tetra Tech, Inc., Center for Ecological Sciences.

New Mexico State University (NMSU). (2011). *Low-Pressure Drip Irrigation for Small Plots and Urban Landscape*. (Research Report 773).

Oak Ridge National Laboratory (ORNL). (2018). Risk Assessment Information System (RAIS). RAIS Contaminated Media Risk Calculator. Retrieved from https://rais.ornl.gov/

Oak Ridge National Laboratory (ORNL). (2019). Risk Assessment Information System (RAIS). RAIS Contaminated Media Risk Calculator. Retrieved from https://rais.ornl.gov/

O'Brien, T. F. (1987). *Organochlorine and Heavy Metal Contaminant Investigation San Juan River basin, New Mexico, 1984*. Albuquerque, NM: U.S. Fish and Wildlife Services, Ecological Field Services Office.

Olkowski, A. A. (2009). *Livestock Water Quality A Field Guide for Cattle, Horses, Poultry, and Swine*: Minister of Agriculture and Agri-Food Canada.

Pendergrass, A., & Butcher, D. J. (2006). Uptake of lead and arsenic in food plants grown in contaminated soil from Barber Orchard, NC. *Microchemical Journal, 83*(1), 14-16. doi:10.1016/j.microc.2005.12.003

Perera, P. A. C. T., Kodithuwakku, S. R., Sundarabarathy, T. V., & Edirisinghe, U. (2015). Bioaccumulation of Cadmium in freshwater fish: an environmental perspective. *Insight Ecology, 4*, 1-12.

Pick, T. (2011). *Assessing Water Quality for Human Consumption, Agriculture, and Aquatic Life Uses*. (Environmental Technical Note No. MT-1 (Rev 2)). Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service.

Radostits, O. M., Gay, C. C., Blood, D. C., & Hinchcliff, K. W. (2002). Doenças causadas por substâncias químicas inorgâncias e produtos químicos utilizados nas fazendas. In *Clínica Veterinária: Um Tratado de Doenças Dos Bovinos, Ovinos, Suínos, Caprinos e Equinos* (pp. 1417-1471). Rio de Janeiro, Brazil: Guanabara Koogan.

Raisbeck, M. F., Riker, S. L., Tate, C. M., Jackson, R., Smith, M. A., Reddy, K. J., & Zygmont, J. R. (2007). *Water Quality for Wyoming Livestock and Wildlife: A Review of the Literature Pertaining to Health Effects of Inorganic Contaminants*. University of Wyoming Department of Veterinary Sciences and Department of Renewable Resources, Wyoming Department of Fish and Game, and Department of Environmental Quality.

Raisbeck, M. F., Wise, B., Zygmont, J. R., Smith, M. A., & Tate, C. M. (2011). *Water Quality for Wyoming Livestock and Wildlife*. (Final Report). University of Wyoming Department of Veterinary Sciences and Department of Renewable Resources, Wyoming Game and Fish Department, and Wyoming Department of Environmental Quality.

Reis, L. S., Pardo, P. E., Camargos, A. S., & Oba, E. (2010). Mineral element and heavy metal poisoning in animals. *Journal of Medicine and Medical Sciences, 1*(12), 560-579.

Rucinska-Sobkowiak, R. (2016). Water relations in plants subjected to heavy metal stresses. *Acta Physiologiae Plantarum, 38*, 257. doi:10.1007/s11738-016-2277-5

Sagardoy, R., Morales, F., Lopez-Millan, A.-F., Abadıa, A., & Abadıa, J. (2009). Effects of zinc toxicity on sugar beet (*Beta vulgaris L.*) plants grown in hydroponics. *Plant Biology, 11*, 339-350.

Samal, L., & Mishra, C. (2011). Significance of nickel in livestock health and production. *Journal of Agro and Veterinary and Medical Sciences, 5*(3), 349-361.

Sample, B. E., Opresko, D. M., & Sutter, G. W., II. (1996). *Toxicological Benchmarks for Wildlife: 1996 Revision*. (ES/ER/TM-86/R3). Oak Ridge, TN: U.S. Department of Energy, Risk Assessment Program, Health Sciences Research Division.

Schat, H., Vooijs, R., & Kuiper, E. (1996). Identical major gene loci for heavy metal tolerances that have independently evolved in different local populations and subspecies of *Silene vulgaris*. *Evolution, 50*, 1888–1895.

Schroeder, H. A., M., M., & P., N. A. (1970). Zirconium, niobium, antimony, vanadium and lead in rats: Life term studies. *Journal of Nutrition, 100*, 59-66.

Seregin, I. V., & Kozhevnikova, A. D. (2006). Physiological role of nickel and its toxic effects on higher plants. *Fiziol Rast, 53*, 285–308.

Shah, F. U. R., Ahmad, N., Masood, K. R., Peralta-Videa, J. R., & ud Din Ahmad, F. (2010). Chapter 4: Heavy metal toxicity in plants. In M. Ashraf, M. Ozturk, & M. S. A. Ahmad (Eds.), *Plant Adaptation and Phytoremediation*. Netherlands: Springer Science.

Sharma, S. S., & Dietz, K.-J. (2006). The significance of amino acids and amino acid-derived molecules in plant responses and adaptation to heavy metal stress. *Journal of Experimental Botany, 57*(4), 711–726.

Simpson, Z. R., & Lusk, J. D. (1999). *Environmental Contaminants in Aquatic Plants, Invertebrates, and FIshes of the San Juan River Mainstem, 1990-1996*. Albuquerque, NM: U.S. Fish and Wildlife Service, New Mexico Ecological Field Office.

Smith, S. R. (1994). Effect of soil pH on availability to crops of metals in sewage sludge-treated soils. II. Cadmium uptake by crops and implications for human dietary intake. *Environmental Pollution, 86*, 5-13.

Srek, P., M., Hejcman, M., & Kunzova, E. (2010). Multivariate analysis of relationship between potato (*Solanum tuberosum L*.) yield, amount of applied elements, their concentrations in tubers and uptake in a long-term fertilizer experiment. *Field Crops Research, 118*, 183–193.

Standish, J. F., Ammerman, C. B., Simpson, C. F., Neal, F. C., & Palmer, A. Z. (1969). Influence of graded levels of dietary ferrous sulfate on performance and tissue mineral composition of steers. *Journal of Animal Science, 29*(3), 496-503. doi:10.2527/jas1969.293496x

Stasinos, S., Nasopoulou, C., Tsikrika, C., & Zabetakis, I. (2014). The bioaccumulation and physiological effects of heavy metals in carrots, onions, and potatoes and dietary implications for Cr and Ni: A Review. *Journal of Food Science, 79*(5), R765.

Tamakhina, A. Y., Dzakhmisheva, I. S., Beslaneev, E. V., & Gadieva, A. A. (2018). Bioaccumulation of heavy metals by medicinal plants of the Inula genus. *Journal of Pharmaceutical Sciences and Research, 10*(5), 1263-1266.

Tarasenko, N. Y., Pronin, O. A., & Silayev, A. A. (1977). Barium compounds as industrial poisons (an experimental study). *J Hyg Epidemiol Microbiol Immunol, 21*(4), 361-373.

Terra, B. F., Araujo, F. G., Calza, C. F., Lopes, R. T., & Teixeira, T. P. (2008). Heavy metal in tissues of three fish species from different trophic levels in a tropical Brazilian river. *Water, Air, and Soil Pollution, 187*, 275-284.

Tokalioglu, S., Kartal, S., & Gultekin, A. (2006). Investigation of heavy-metal uptake by vegetables growing in contaminated soils using the modified BCR sequential extraction method. *International Journal of Environmental Analytical Chemistry, 86*, 417–430.

Tran, T. A., & Popova, L. P. (2013). Functions and toxicity of cadmium in plants: Recent advances and future prospects. *Turkish Journal of Botany, 37*, 1-13. doi:10.3906/bot-1112-16

U.S. Department of Agriculture (USDA). (2003). *National Range and Pasture Handbook*. (Revision 1). Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service, Grazing Lands Technology Institute. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043055.pdf

U.S. Department of Agriculture (USDA). (2011). Assessing Water Quality for Human Consumption, Agriculture, and Aquatic Life Uses. Natural Resources Conservation Service. Environment Technical Note No. MT-1 (Rev. 2) June 2011. Available at https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051302.pdf

U.S. Department of Agriculture (USDA). (2012). Census of Agriculture, National Agricultural Statistics Service. San Juan County New Mexico. County Profile. Retrieved from www.agcensus.usda.gov

U.S. Environmental Protection Agency (U.S. EPA). (1976). *Quality Criteria for Water*. (EPA 440-9-76-023). Washington, DC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (U.S. EPA). (1989). *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part A)*. (Interim Final. EPA/540-1-89/002). Washington, DC: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency (U.S. EPA). (1993). *Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria.* (M. Prothro Memorandum to EPA Regions and Water Management Division of Directors). Washington, DC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (U.S. EPA). (2000a). *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)*. (EPA-822-B-00-004). Washington, DC: U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology Retrieved from https://www.epa.gov/sites/production/files/2018-10/documents/methodology-wqc-protection-hh-2000.pdf

U.S. Environmental Protection Agency (U.S. EPA). (2000b). *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates, Second Edition*. (EPA/600/R-99/064). Duluth, MN and Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development, and Office of Science and Technology.

U.S. Environmental Protection Agency (U.S. EPA). (2002). *National Recommended Water Quality Criteria*. (EPA-822-R-02-047). Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Science and Technology

U.S. Environmental Protection Agency (U.S. EPA). (2003). *Ecological Soil Screening Level for Iron*. (Interim Final, OSWER Directive 9285.7-69). Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency (U.S. EPA). (2003-2007). *Ecological Soil Screening Levels for Aluminum, Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Nickel, Selenium, Silver, Vanadium, and Zinc*. (Various directives numbers). Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency (U.S. EPA). (2007). *Framework for Metals Risk Assessment*. (EPA/120/R-07/001). Washington, DC: U.S. Environmental Protection Agency, Office of the Science Advisor Risk Assessment Forum.

U.S. Environmental Protection Agency (U.S. EPA). (2011). *Exposure Factors Handbook: 2011 Edition*. (EPA/600/R-090/052F). Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment.

U.S. Environmental Protection Agency (U.S. EPA). (2017). *Documentation for EPA's Implementation of the Johnson and Ettinger Model to Evaluate Site-Specific Vapor Intrusion into Buildings Version 6.0*. (Revised September 2017). Washington, DC: U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation.

U.S. Environmental Protection Agency (U.S. EPA). (2018). U.S. EPA Regional Screening Levels, (RSLs). Retrieved from https://www.epa.gov/risk/regional-screening-levels-rsls

U.S. Environmental Protection Agency (U.S. EPA). (Various Years). Integrated Risk Information System (IRIS). Retrieved from https://www.epa.gov/iris

U.S. Geological Survey (USGS). (2019). Water usage, crop irrigation. San Juan county New Mexico. Retrieved from https://waterdata.usgs.gov/nm/nwis/water_use?format=html_table&rdb_compression=file&wu_area=County&wu_year=2015&wu_county=045&wu_category=IC&wu_county_nms=San%2BJuan%2BCounty&wu_category_nms=Irrigation%252C%2BCrop

Underwood, E. J. (1971). *Trace Elements in Human and Animal Nutrition* (3rd ed.). New York and London: Academic Press.

van Driel, W., van Luit, B., Smilde, K. W., & Schuurmans, W. (1995). Heavy-metal uptake by crops from polluted river sediments covered by non-polluted topsoil. I. Effects of topsoil depth on metal contents. *Plant and Soil, 175*(1), 93-104.

van Lune, P., & Zwart, K. B. (1997). Cadmium uptake by crops from the subsoil. *Plant and Soil, 189*(2), 231-237.

Verbruggen, N., Hermans, C., & Schat, H. (2009). Mechanisms to cope with arsenic or cadmium excess in plants. *Current Opinion in Plant Biology, 12*, 1-9.

Vijayarengan, P., & Mahalakshmi, G. (2013). Zinc toxicity in tomato plants. *World Applied Sciences Journal, 24*(5), 649-653.

Vincevica-Gaile, Z., Klavins, M., Rudovica, V., & Viksna, A. (2013). Research review trends of food analysis in Latvia: major and trace element content. *Environmental Geochemistry and Health, 35*, 693–703.

Weiss, W. P. (2008). Mineral tolerances of animals. In *Tri-State Dairy Nutrition Conference Proceedings, April 22 and 23, 2008* (pp. 59-64).

Weiss, W. P. (2010). *Tolerances of Animals*. Columbus, OH: The Ohio State University, Department of Animal Sciences, Ohio Agricultural Research and Development Center Retrieved from https://articles.extension.org/pages/26132/mineral-tolerances-of-animals

Wentink, G. H., Spierenburg, T. J., de Graaf, G. J., & van Exsel, A. C. A. (1985). A case of chronic zinc poisoning in calves fed with zinc-contaminated roughage. *Veterinary Quarterly, 7*(2), 153-157.

Wheeler, C. T., Hughes, L. T., Oldroyd, J., & Pulford, I. D. (2001). Effects of nickel on Frankia and its symbiosis with *Alnus glutinosa* (L.) Gaertn. *Plant and Soil, 231*, 81-90.

World Health Organization (WHO). (1973). *Trace Elements in Human Nutrition: Manganese. Report of a WHO Expert Committee*. (Technical Report Service, 532). Geneva, Switzerland: World Health Organization.

Yang, G., et al. (1989). Studies of safe maximal daily dietary Se-intake in a seleniferous area in China. Part II: Relation between Se-intake and the manifestation of clinical signs and certain biochemical alterations in blood and urine. *Journal of Trace Elements and Electrolytes in Health and Disease, 3*(3), 123-130.

Appendix A

This Appendix summarizes current regulatory practices regarding water quality standards for protection of crops and livestock, their scientific basis, and water quality standards that have been adopted by states and Tribes. A compilation of states that have agricultural water quality standards is provided in Table A-1 and detailed information from those states is provided in Table Table A-2, respectively. Tables A-3 and A-4 present tribal agricultural water quality standards. Detailed information from other reports on standards for protection of livestock and crops are presented in Tables A-5 and A-6, respectively.

A.1. State Agricultural Standards

As shown in Table A-1, consistent with Section 101(a) of the CWA (40 CFR 131.6(a)), most states include general livestock watering, or crop irrigation as designated uses (which some states refer to as agricultural uses). Four states (including the District of Columbia) did not specifically list an agricultural designated use. All states have numerical metals standards; however, most of these are aquatic life or human health ambient water quality standards. As detailed in Table A-2 and summarized in Table A-1, eleven states and two Water Quality Control Boards in California list numeric metals standards for agricultural uses in their water quality standards. Two states (Idaho and Washington) reference agricultural water quality standards for metals but do not provide specific values for these uses in their standards, as described further below

Table A-1. States with numeric agricultural water quality standards for metals

State	Numeric Agricultural Water Standards for Metals
Florida	Some numeric agricultural standards are the same as aquatic life or human health standards for metals. Copper and lead agricultural standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
Ohio	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
New Mexico	Most of the agricultural numeric standards correspond to those listed in U.S.EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of molybdenum, selenium, and zinc for irrigation.** Not all of the NAS & NAE 1972 criteria are listed in these standards. • Molybdenum for irrigation: 1,000 µg/L (*rationale for this concentration was not provided*) • Zinc for irrigation: 25,000 µg/L (*rationale for this concentration was not provided*; however, this concentration corresponds to the livestock standard from U.S. EPA's *Water Quality Criteria 1972* [NAS & NAE 1972]) • Dissolved selenium for irrigation: 0.13 mg/L (*rationale for this concentration was not provided*) • Dissolved selenium for irrigation, in presence of > 500 mg/L SO_4: 0.25 mg/L (*rationale for this concentration was not provided)*

Table A-1. States with numeric agricultural water quality standards for metals

State	Numeric Agricultural Water Standards for Metals
Missouri	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
Kansas	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of cadmium and nickel for livestock.** Not all of the NAS & NAE 1972 criteria are listed in these standards. • Cadmium for livestock: 20 µg/L *(rationale for this concentration was not provided*) • Nickel for livestock: 500 µg/L (*rationale for this concentration was not provided*; however, this concentration corresponds to the irrigation standard from the Federal Water Pollution Control Agency's (FWPCA's 1968) *Water Quality Criteria.*
North Dakota	The agricultural numeric standards correspond to aquatic life standards
Colorado	Most of the agricultural standards matched the NAS & NAE 1972 criteria correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of molybdenum** (Raisbeck et al. 2007 was cited for this standard of 300 µg/L [30-day]). Not all of the NAS & NAE 1972 criteria are listed in these standards.
Utah	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
Arizona	The agricultural numeric standards correspond to the 20-year irrigation standards listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the NAS & NAE 1972 criteria are listed in these standards.
Nevada	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
Alaska	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
California's San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan)	The livestock watering numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) for livestock, **with the exception of the livestock criterion for molybdenum**. Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. • Molybdenum for livestock: 0.5 mg/L (*rationale for this concentration was not provided)*
California's Water Quality Control Plan for the Central Coastal Basin (Region 3)	Most of the agricultural standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of the livestock criterion for molybdenum**. Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. • Molybdenum for livestock: 0.5 mg/L *(rationale for this concentration was not provided)*

Although Idaho does not specifically include numeric agricultural standards for metals in its water quality standards[1], it is indicated that water quality standards for agricultural water supplies will generally be satisfied by Idaho's numeric standards for toxic substances for waters designated for aquatic life, recreation, or domestic water supply use. It is further noted in Idaho's water quality standards that U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) will be used for determining standards when needed to protect a specific agricultural use.

Washington State also does not specifically list numeric agricultural standards for metals in its water quality standards[2], but references its *Proposed Agricultural Water Supply Criteria Decision Process for Ecology's Proposed Rule*. Washington's proposed agricultural water supply standards for metals are based on two key works—U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) and the Food and Agriculture Organization of the United Nations' (FAO's) *Water Quality for Agriculture* (Ayers and Westcot 1985).

[1] IDAPA 58, Title 01, Chapter 02, 58.01.02 – Water Quality Standards.

[2] Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC Amended May 9, 2011, Revised January 2012, Publication no. 06-10-091.

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
1	MA	314 CMR 4.00: Massachusetts Surface Water Quality Standards	Class B waters shall be suitable for irrigation and other agricultural uses; and and C waters should be suitable for the irrigation of crops used for consumption after cooking;	Additional Minimum Standards Applicable to all Surface Waters for Metals. All surface waters shall be free from pollutants in concentrations or combinations that are toxic to humans, aquatic life or wildlife. For pollutants not otherwise listed in 314 CMR 4.00, follow the National Recommended Water Quality Standards: 2002, U.S. EPA 822-R-02-047, November 2002 published by U.S. EPA pursuant to Section 304(a) of the Federal Water Pollution Control Act.	No	No
1	NH	Part Env-Wq 1703 Water Quality Standards Env-Wq 1703.01	Have narrative that would apply - Water Use Classifications. (a) State surface waters shall be divided into class A and class B, pursuant to RSA 485-A:8, I, II and III. Each class shall identify the most sensitive use which it is intended to protect (includes irrigation as a use).	RSA 485-A:8, I, II and III: Class A waters shall be considered as being potentially acceptable for water supply uses after adequate treatment. Class B waters shall be considered as being acceptable for fishing, swimming and other recreational purposes and, after adequate treatment, for use as water supplies.	No	No
1	ME	Chapter 584 Surface Water Quality Standards for Toxic Pollutants	No	Chapter 584. Appendix A. Statewide standards for toxic pollutants with national water quality standards for Priority Pollutants and non-Priority Pollutants. Patterned after the U.S. EPA's National Recommended Water Quality Criteria of November 2002 and December 2003.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
1	RI	State of Rhode Island Water Quality Standards	Indicates that Class A, B, B1, and C should be suitable for irrigation and other agricultural uses.	Per Table 1, none in such concentrations that would exceed the [EPA] Water Quality Standards and Guidelines as found in Appendix B. The ambient concentration of a pollutant in a water body shall not exceed the [EPA] Ambient Water Quality Standards and Guidelines, (Appendix B) for the protection of aquatic organisms from acute or chronic effects, unless the standards or guidelines are modified by the Director based on results of bioassay tests conducted in accordance with the terms and conditions provided in the RIDEM Site Specific Aquatic Life Water Quality Standards Development Policy.	No	No
1	CT	Connecticut Water Quality Standards	Class AA, A, and B- designated for water supply for agriculture and other uses.	Appendix D provides aquatic life standards and human health ambient water quality standards for these water classes for various metals.	No	No
1	VT	Vermont Water Quality Standards, Environmental Protection Rule Chapter 29(a)	Class B waters - designated use of Irrigation of crops and other agricultural uses - suitable, without treatment, for irrigation of crops used for human consumption without cooking and suitable for other agricultural uses.	In rivers, streams, brooks, creeks, and riverine impoundments, the human health based toxic pollutant standards listed in Appendix C shall be applied at the median annual flow for toxic substances that are classified as known, probable, or possible human carcinogens or at the 7Q10 flow for toxic substances that are classified as threshold toxicants (not known or probable carcinogens). In all other waters, the human health based toxic pollutant standards listed in Appendix C shall apply at all times.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
2	NY	§702.14 Procedures for deriving standards and guidance values for protection of aesthetic quality	(b) Protection of the best usage of fishing shall include standards and guidance values to prevent tainting of aquatic food, including but not limited to taste, odor, and discoloration. Such values are referred to as Aesthetic (Food Source) values and derived based on an evaluation of reported levels of the substance that affect the aesthetic quality of the fish flesh, aquatic life, wildlife, **or livestock** that are consumed by humans and that acquire such flavor, odor, or color because of habitation in, passage through, or ingestion of waters. This use is E(FS) for Aesthetic (Food Source).	Table 1 (cf. section 703.5) Water Quality Standards Surface Waters and Groundwater includes metals standards but no metal standards are specifically listed for E(FS)	No	No
2	NJ	N. J. A. C. 7:9B, Surface Water Quality Standards	7:9B-1.12 Designated uses: Pineland (PL) uses include cranberry bog water supply and other agricultural uses; FW2 uses include agricultural water supply	A table is provided under 7. Surface Water Quality Standards for Toxic Substances: Several metals standards for FW2 for aquatic life and human health ambient water quality standards	No	No
3	WV	Requirements Governing Water Quality Standards Rule - Title 47CRS2	Category D - Agriculture and wildlife uses (D1 - irrigation; D2 - livestock watering; and D3 - wildlife).	Appendix E, Table 1 includes standards for "all other uses" in addition to those for human health and aquatic life protection -only metal listed is As at 100 µg/L	No	No
3	DC	Water Quality Standards (21 DCMR Ch. 11)	No ag designated uses	Only for other uses	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
3	DE	Delaware Department of Natural Resources and Environmental control Surface Water Quality Standards	Agricultural Water Supply designated use.	Section 4.6.3.2.1: Waters of the State shall not exhibit acute toxicity to fish, aquatic life, and wildlife, except in special cases applying to regulatory mixing zones as provided in Section 6.4.6.3.2. Tables 1 and 2 provide aquatic life and human health standards	No	No
3	PA	Chapter 93. Water Quality Standards	LWS - Livestock water supply designated use, IRS - irrigation	Section 16.1 Water quality standards are the numeric concentrations, levels or surface water conditions that need to be maintained or attained to protect existing and designated uses. They are designed to protect the water uses listed in Chapter 93 (relating to water quality standards). The most sensitive of these protected uses are generally water supply, recreation and fish consumption, and aquatic life related. Therefore, standards designed to protect these uses will normally protect the other uses listed in Chapter 93.	No	No
3	MD	COMAR 26.08.02.04	Class I.B includes agricultural water supply - applies to all surface water use classes in MD.	Code of Maryland Regulations (COMAR) Section 26.08.02.03-2.A. Numerical toxic substance standards shall be applied: (1) In intermittent streams, at the end of the discharge pipe; and (2) In all other water bodies, at the edge of the mixing zones determined in accordance with Regulation .05C—E of this chapter.	No	No
3	VA	9 VAC 25-260 Virginia Water Quality Standards.	A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the **production of edible and marketable natural resources**, e.g., fish and shellfish.	9VAC25-260-140. Standards for surface water - table of aquatic life and human health ambient water quality standards; includes standards for nickel and zinc that are applicable to all other surface waters (based on fish consumption) - 4,600 µg/L for nickel and 26,000 for zinc	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
4	TN	Rule 1200-4-3-.03	(5) Irrigation and (6) Livestock Water and Wildlife: (c) Hardness or Mineral Compounds, (f) Toxic Substances, (g) Other Pollutants. 1200-4-3-.05 Interpretation of Standards. (4) Water quality standards for fish and aquatic life and livestock watering and wildlife set forth shall generally be applied on the basis of the following stream flows: unregulated streams - stream flows equal to or exceeding the 7-day minimum, 10-year recurrence interval; regulated streams - all flows in excess of the minimum critical flow occurring once in ten years as determined by the division.	1200-4-3-.03 Standards for Water Uses. (1) Domestic Water Supply. (j) Toxic Substances - The waters shall not contain toxic substances, whether alone or in combination with other substances, which will produce toxic conditions that materially affect the health and safety of man or animals or impair the safety of conventionally treated water supplies. Table provided for overall limits, including several metals.	No	No
4	AL	Alabama Department of Environmental Management, Water Division - Water Quality Program, Chapter 335-6-10, Water Quality Standards	335-6-10-.09 Specific Water Quality Standards. (6) Limited Warmwater Fishery (b) Best usage of waters (May through November): **agricultural irrigation, livestock watering**, industrial cooling and process water supplies, and any other usage, except fishing, bathing, recreational activities, including water-contact sports, or as a source of water supply for drinking or food-processing purposes. (c) Conditions related to best usage (May through November): 1. The waters will be suitable for agricultural irrigation, livestock watering, and industrial cooling waters.	**335-6-10-.06 Minimum Conditions Applicable to All State Waters.** (c) State waters shall be free from substances attributable to sewage, industrial wastes or other wastes in concentrations or combinations which are toxic or harmful to human, animal or aquatic life to the extent commensurate with the designated usage of such waters. Lists human health and aquatic life standards in Table 1.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
4	FL	Florida Chapter 62-302: Surface Water Quality Standards	62-302.400 Classification of Surface Waters, Usage, Reclassification, Classified Waters. Class IV - Agricultural Water Supply designated use.	62-302.530 Table: Surface Water Quality Standards - contains both numeric and narrative surface water quality standards to be applied except within zones of mixing.	Yes for Class IV: **As ≤ 50 µg/L (same as aq life standards);** Be ≤ 100 µg/L in waters with a hardness in mg/L of $CaCO_3$ of less than 250 and shall not exceed 500 µg/L in harder waters; **Cr (III) ≤ $e^{(0.819[lnH]+0.6848)}$µg/L (same as human health standards)**; **Cr (VI) ≤ 11 µg/L (same as human health standards);** Cu ≤ 500 µg/L; **Fe ≤ 1.0 mg/L (same as human health standards)**; Pb ≤ 50 µg/L; **Hg ≤ 0.2 µg/L**; **Ni ≤ 100 µg/L; Zn ≤ 1000 µg/L**	No, some are the same as aquatic life or human health standards. Copper and lead are the same as the NAS & NAE (1972) values. Not all of the NAS & NAE 1972 criteria are listed in these standards.
4	GA	391-3-6-.03 Water Use Classifications and Water Quality Standards.	(2) Water Quality Enhancement: (a) The purposes and intent of the State in establishing Water Quality Standards are to provide enhancement of water quality and prevention of pollution; to protect the public health or welfare in accordance with the public interest for drinking water supplies, conservation of fish, wildlife and other beneficial aquatic life, **and agricultural**, industrial, recreational, and other reasonable and necessary uses and to maintain and improve the biological integrity of the waters of the State.	(5) General Standards for All Waters - contains narrative standards and numeric standards for human health and aquatic life. All waters shall be free from toxic, corrosive, acidic and caustic substances discharged from municipalities, industries or other sources, such as nonpoint sources, in amounts, concentrations or combinations which are harmful to humans, animals or aquatic life. Metals standards are listed for these uses.	No	No
4	KY	401 KAR 10.031. Surface water standards	Section 4. Aquatic Life. (1) Warm water aquatic habitat. The following parameters and associated standards shall apply for the protection of productive warm water aquatic	Table 1 provides warm water habitat metals standards for Ag, As, Cd, Cr3, Cr6, Cu, Fe, Pb, Hg, Ni, Se, Zn, but appears is based on toxicity to aquatic life	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
			communities, fowl, animal wildlife, arboreous growth, **agricultural,** and industrial uses.			
4	SC	R.61-68, Water Classifications & Standards	**A. Purpose and Scope:** It is also a goal [of the Department] to provide, where appropriate and desirable, for drinking water after conventional treatment, shellfish harvesting, and industrial **and agricultural uses. 8. Trout Waters.** The State recognizes three types of trout waters: Natural; Put, Grow, and Take; and Put and Take. Also suitable for primary and secondary contact recreation and as a source for drinking water supply after conventional treatment in accordance with the requirements of the Department. These waters are suitable also for industrial and **agricultural uses**. **10. Freshwaters (FW)** for primary and secondary contact recreation and as a source for drinking water supply after conventional treatment in accordance with the requirements of the Department. They are suitable also for industrial and **agricultural uses. Water Pollution Control Permits: R61-9** includes information on **spray irrigation** of sewage sludge.	Appendix: Water Quality Numeric Standards for the Protection of Aquatic Life and Human Health: includes metals standards but not specifically for agricultural uses.	No	No
4	MS	State of Mississippi Water Quality Standards for Intrastate, Interstate, and Coastal Waters (WPC-2)	No - not listed as a designated use	Table 2. Numeric Standards for All Waters (µg/l) - provides human health and aquatic life standards for metals and other chemicals	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
4	NC	Subchapter 2B - Surface Water and Wetland Standards, Section .0100 - Procedures for Assignment of Water Quality Standards	15A NCAC 02B .0211 Fresh Surface Water Quality Standards for Class C Waters. General. (1) Best Usage of Waters: aquatic life propagation and maintenance of biological integrity (including fishing and fish), wildlife, secondary recreation, **agriculture** and any other usage except for primary recreation or as a source of water supply for drinking, culinary or food processing purposes; (2) Conditions Related to Best Usage: the waters shall be suitable for aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, **and agriculture.**	Toxic substances: numerical water quality standards (maximum permissible levels) for the **protection of human health applicable to all fresh surface waters** are in Rule .0208 of this Section. Numerical water quality standards (maximum permissible levels) **to protect aquatic life applicable to all fresh surface waters** are also provided.	No	No
5	IN	Indiana Article 2. Water Quality Standards	327 IAC 2-1-3 Surface water use designations; multiple uses. Sec 3a(4) All waters that are used for **agricultural purposes** must, as a minimum, meet the standards established in section 6(a) of this rule. Sec. 6. (a) is Minimum Surface Water Quality Standards	Table 6-1 Surface Water Quality Standards for Specific Substances are referenced in Sec. 6. (a). It includes human health and aquatic life standards for metals	No	No
5	OH	State of Ohio Water Quality Standards Chapter 3745-1 of the Administrative Code	Agricultural Water supply designated use - waters are suitable for irrigation and livestock watering without treatment Table 7-12. Statewide water quality standards for the protection of agricultural uses.	Separate ones, depending on uses	Yes for - As - 100 µg/L, Be - 100 µg/L, Cd - 50 µg/L, Total Cr - 100 µg/L, Cu - 500 µg/L, Fe - 5,000 µg/L, Pb - 100 µg/L, Hg - 10 µg/L, Ni - 200 µg/L, Se - 50 µg/L; and Zn - 25,000 µg/L- applied as an OMZA (outside mixing zone average)	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
5	MI	PART 4. Water Quality Standards	Agriculture designated use - water for agricultural purposes, including livestock watering, irrigation, and crop spraying. R 323.1100 Designated uses. Rule 100. (1) At a minimum, all surface waters of the state are designated and protected for all of the following uses: (a) Agriculture.	(2) Levels of toxic substances in the surface waters of the state shall not exceed the aquatic life values specified in tables 1 and 2 [including metals], or, in the absence of such values, value derived according to the following processes, unless site-specific modifications have been developed pursuant to subdivision (r) of this subrule.	No	No
5	WI	Chapter NR 102, Water Quality Standards for Wisconsin Surface Waters	NR 102.01(2) Water quality standards shall protect the public interest, which includes the protection of public health and welfare and the present and prospective uses of all waters of the state for public and private water supplies, propagation of fish and other aquatic life and wild and domestic animals, domestic and recreational purposes, **and agricultural**, commercial, industrial, and other legitimate uses. In all cases where the potential uses are in conflict, water quality standards shall protect the general public interest.	Various aquatic life and human health standards, including those for metals, are provided as links in NR 105	No	No
5	IL	Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter I: Pollution Control Board, Part 302, Water Quality Standards, Subpart A: General Water Quality Provisions	Section 302.202 Purpose: The General Use standards will protect the State's water for aquatic life (except as provided in Section 302.213), wildlife, **agricultural use**, secondary contact use and most industrial uses and ensure the aesthetic quality of the State's aquatic environment. Primary contact uses are protected for all General Use waters whose physical configuration permits such use.	Section 302.208 Numeric Standards for Chemical Constituents includes human health and aquatic life standards for metals and other constituents	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
5	MN	Chapter 7050, Minnesota Pollution Control Agency, Waters of the State, Water Quality Standards for Protection of Waters of the State	IR means agriculture irrigation use, Class 4A waters; LS means agriculture livestock and wildlife use, Class 4B waters. 7050.0224 Specific Water Quality Standards for Class 4 Waters of the State; Agriculture and Wildlife. The quality of Class 4A waters of the state shall be such as to permit their use for irrigation without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area, including truck garden crops. The quality of Class 4B waters of the state shall be such as to permit their use by livestock and wildlife without inhibition or injurious effects.	7050.0220 Specific Water Quality Standards by Associated Use Classes. Numeric water quality standards are tabulated in this table for all uses applicable to four common categories of surface waters, so that all applicable standards for each category are listed together in subparts 3a to 6a.	No	No - but cite Handbook 60 published by the Salinity Laboratory of the USDA
6	LA	Title 33, Part IX, Subpart 1, March 2015 Environmental Regulatory Code 1	Agriculture designated use - the use of water for crop spraying, irrigation, livestock watering, poultry operations, and other farm purposes not related to human consumption. B. Water Use 1. It is the policy of the state of Louisiana that all state waters should be protected for recreational uses and for the preservation and propagation of desirable species of aquatic biota and indigenous species of wildlife. Use and value of water for public water supplies, **agriculture**, industry, and other purposes, as well as navigation, shall also be considered in setting standards.	Table 1A Numerical Standards for Metals and Inorganics for human health and aquatic life	No	No
6	AR	Arkansas Pollution Control and Ecology Commission Regulation No. 2, As Amended	Agricultural Water Supply - I - this beneficial use designates waters which will be protected for crop irrigation and/or consumption by livestock	Reg. 2.508 Toxic Substances - Toxic substances shall not be present in receiving waters, after mixing, in such quantities as to be toxic to human, animal, plant or aquatic life or to interfere with the normal propagation, growth and survival of the indigenous aquatic biota. Aquatic life standards for several metals are provided.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
6	NM	Standards for Interstate and Intrastate Surface Waters, Title 20 Chapter 6 Part 4	Irrigation and Irrigation Storage; Livestock watering designated uses	Yes, and specific ones for Irr - irrigation; LW - livestock watering uses	Irrigation (dissolved metals in µg/L): Al: 5000; As: 100; Cd: 10; Cr: 100; Co: 50; Cu: 200; Pb: 5000; **Mo: 1000**; V: 100; **Zn: 25000**; **Dissolved Se: 0.13 mg/L; Dissolved Se in presence of >500 mg/L SO_4 = 0.25 mg/L**; Livestock watering (dissolved metals in µg/L) = As: 200; Cd: 50; Cr: 1000; Co: 1000; Cu: 500; Pb: 100, Hg: 10; Se: 50; V: 100; Zn: 25000	No, but most match the NAS & NAE 1972 criteria except for Mo, Zn for irrigation, and Se for irrigation; not all of the NAS & NAE 1972 criteria are listed in these standards
6	OK	2013 Oklahoma Water Quality Standards	785:45-5-13. Agriculture 4) Ag - Agriculture beneficial use. Agriculture - surface waters of the State shall be maintained so that toxicity does not inhibit continued ingestion by livestock or crop. Two sub-categories - Irrigation and Livestock. (2) **Irrigation Agriculture** means a subcategory of the Agriculture beneficial use requiring water quality conditions that are dictated by individual crop tolerances. (3) **Livestock Agriculture** is a subcategory of the Agriculture beneficial use requiring much less stringent protection than crop irrigation.	Table 2. Numerical Standards to Protect Beneficial Uses and All Subcategories Thereof contains fish and wildlife propagation, drinking water, and fish consumption human health standards	No, but Cl, SO4, and TDS	No
6	TX	2014 Texas Surface Water Quality Standards, §§307.1-307.10	(4) Water in the state must be maintained to preclude adverse toxic effects on aquatic life, terrestrial life, **livestock**, or domestic animals, resulting from contact, consumption of aquatic organisms, consumption of water, or any combination of the three.	Table 1 provides aquatic life standards for contaminants, including metals; Table 2 provides human health standards for contaminants, including metals	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
7	MO	Department of Natural Resources, Division 20—Clean Water Commission, Chapter 7—Water Quality	4. Irrigation (IRR)—Application of water to cropland or directly to cultivated plants that may be used for human or livestock consumption. Occasional supplemental irrigation, rather than continuous irrigation, is assumed. 5. Livestock and wildlife protection (LWP)—Maintenance of conditions in waters to support health in livestock and wildlife. All waters described in subsection (2)(A) shall also be assigned Livestock and wildlife protection and Irrigation designated uses, as defined in this rule.	Yes, a table provides metals standards for AQL = Protection of Aquatic Life, HHF = Human Health Protection-Fish Consumption, DWS = Drinking Water Supply, IRR = Irrigation, LWW = Livestock Wildlife Watering, and GRW = Groundwater	LWW (µg/L) - Co: 1000, Cu: 500; IRR (µg/L) - As: 100, Be: 100, Cr3: 100.	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards
7	IA	Chapter 61, Water Quality Standards, 567	567—61.3(455B) Surface water quality stanards. The general use segments are to be protected for livestock and wildlife watering, aquatic life, noncontact recreation, crop irrigation, and industrial, agricultural, domestic and other incidental water withdrawal uses.	Table 1. Standards for Chemical Constituents - Aquatic life, drinking water, and human health standards are provided.	No	No
7	NE	Title 117 - Nebraska Surface Water Quality Standards	004.02 Agricultural, 004.02A General Standards. Wastes or toxic substances introduced directly or indirectly by human activity in concentrations that would degrade the use (i.e., would produce undesirable physiological effects in crops or livestock) shall not be allowed. Agricultural Class A - conductivity < 2000 umhos/cm; nitrate/nitrate < 100 mg/L; and Se < 0.02 mg/L; Class B - no water quality standards assigned to protect this use.	Metals standards provide for human health and aquatic life.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
7	KS	Kansas Department of Health and Environment Amended Regulation, Article 16. - Surface Water Quality Standards	Agriculture Use - Livestock and Irrigation	Table 1a. Aquatic Life, Agriculture, And Public Health Designated Uses Numeric Standards.	WQC for Livestock (µg/L) - As: 200, **Cd: 20**, Cr: 1000, Cu: 500, Pb: 100, Hg: 10, **Ni: 500**, Se: 50, Zn: 25000; WQC for Irrigation (µg/L): As: 100, Cd: 10, Cr: 100, Cu: 200, Pb: 5000, Ni: 200, Se: 20, Zn: 2000.	No, but most match the NAS & NAE 1972 criteria except for Cd and Ni for livestock; not all of the NAS & NAE 1972 criteria are listed in these standards
8	SD	Chapter 74:51:01, Surface Water Quality Standards	74:51:01:42. Beneficial uses of waters established. (10) Irrigation Waters - designated use.	Surface water standards for human health and aquatic life for contaminants including metals are provided in a table	No, only conductivity and sodium	No
8	MT	Chapter 30 Water Quality, Subchapter 6, Surface Water Quality Standards and Procedures	17.30.622 A-1 Classification Standards, (2) Water quality must be maintained suitable for bathing, swimming, and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply	Circular DEQ-7, Montana Numeric Water Quality Standards for aquatic life and human health	No	No
8	ND	Chapter 33-16-02.1. Standards for Quality for Waters of the State	33-16-02.1-09. Surface water classifications, mixing zones, and numeric standards. a. Class I and 1A streams. The quality of the waters in this class shall be suitable for the propagation or protection, or both, of resident fish species and other aquatic biota and for swimming, boating, and other water recreation. The quality of the waters shall be **suitable for irrigation**, stock watering, and wildlife without injurious effects. Agricultural uses - waters suitable for irrigation, stock watering, and other agricultural uses, but not suitable for use as a source of domestic supply for the farm unless satisfactory treatment is provided.	Aquatic life and human health water quality standards are presented in Table 2	Class I and IA streams - same as aquatic life	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
8	WY	Water Quality Rules and Regulations, Chapter 1, Wyoming Surface Water Quality Standards	Section 3. Water Uses. (a) Agriculture. For purposes of water pollution control, agricultural uses include irrigation or stock watering. All waters meet the agricultural water supply use.	Aquatic life and human health water quality standards are presented in a table	No	From WY Agricultural Use Protection Policy: Though the goal is simple, achieving it is not. For the most part, managing water quality for continued agricultural support requires managing the concentration and chemical makeup of dissolved solids. Because of local differences in crop types, soil types and natural water quality and availability, it isn't possible to establish simple numeric standards for pollutants such as TDS and SAR that will allow an efficient use of surface water for irrigation purposes. The determination of what is acceptable water quality for irrigation must necessarily involve an evaluation of local agricultural practices and background water quality conditions. For livestock watering uses, it is somewhat less complicated because there are fewer variables to consider.

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
8	CO	Colorado Department of Public Health and Environment, Water Quality Control Commission, Regulation No. 31, The Basic Standards and Methodologies for Surface Water (5 CCR 1002-31)	31.13 State Use Classifications, (b) Agriculture: These surface waters are suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock.	Tables I and II provide aquatic life standards, human health standards, agricultural standards, and domestic water quality standards for metals	As (µg/L): 100(A) (30-day); Be (µg/L): 100(A,B) (30-day); Cd (µg/L): 10(B) (30-day); Cr3 and Cr6 (µg/L): 100(B) (30-day); Cu (µg/L): 200(B); Pb (µg/L): 100(B) (30-day); **Mn (µg/L): 100(B) (30-day)**; **Mo (µg/L): 300(O) (30-day)(16);** Ni (µg/L): 200(B) (30-day); Se (µg/L): 20(B,D) (30-day); Zn (µg/L): 2000(B) (30-day)	Most standards matched the NAS & NAE 1972 criteria except for manganese and molybdenum; not all of the NAS & NAE 1972 criteria are listed in these standards.Cites Raisbeck et al. 2007 for Mo for 300 µg/L Indicates how Mo standards was established for Agricultural use (page 197). The molybdenum criterion of 300 µg/l for agriculture is intended to protect livestock from the effects of molybdenosis. The agriculture table value assumes that the safe copper:molybdenum ratio is 4:1. Total copper and molybdenum intakes are calculated from the following equations:Cu intake mg/day = [([Cu] forage, mg/kg) x (forage intake, kg/day)] + [([Cu] water, mg/l) x (water intake, L/day)] + (Cu supplementation, mg/day)Mo intake mg/day = [([Mo] forage, mg/kg) x (forage intake, kg/day)] + [([Mo] water, mg/l) x (water intake, L/day)] + (Mo supplementation, mg/day)The assumed values for these equations are as follows:[Cu] forage = 7 mg/kg, [Mo] forage = 0.5 mg/kg, forage intake = 6.8 kg/day, [Cu] water = 0.008 mg/L, [Mo] water = 0.375 mg/L, water intake = 54.6 L/day, Cu supplementation = 48 mg/day, Mo supplementation = 0 mg/day.Food and water intake is based on a 273 kg (600 lb) feeder steer consuming 6.8 kg/day of dry matter and 20% of its body weight in water per day. Site-specific water intake rates should be based on estimates of actual water consumption rates based on maximum air temperatures rather than need since cattle typically consume more water than strictly necessary. In general, assumptions about copper, molybdenum, and sulfur exposure for the purpose of deriving site-specific molybdenum standards should reflect current or potential exposure levels that are reasonable for the area, including dietary supplements. When calculating site-specific standards, copper supplementation should be as low as possible and not higher than 400 mg/day.

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
8	UT	R317 - Environmental Quality, Water Quality	Class 4 - protected for agricultural uses including crop irrigation and stock watering.	R317-2-14 Numeric Standards - Table 2.14.1 Numeric Table for Domestic, Recreation, and Agricultural Uses, includes values for metals	Numeric Ag Standards in mg/L - As: 0.1, Cd: 0.01, Cr: 0.10, Cu: 0.2; Pb: 0.1; Se: 0.05	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards
9	AZ	Title 18: Environmental Quality, Chapter 11: Department of Environmental Quality, Article 1: Water Quality Standards	AgI - agriculture irrigation means the use of a surface water for crop irrigation; AgL - agricultural livestock watering means the use of a surface water as a water supply for consumption by livestock. R18-11-104. Designated Uses A. The Director shall adopt or remove a designated use or subcategory of a designated use by rule. B. Designated uses of a surface water may include full-body contact, partial-body contact, domestic water source, fish consumption, aquatic and wildlife (cold water), aquatic and wildlife (warm water), aquatic and wildlife (ephemeral), aquatic and wildlife (effluent-dependent water), **agricultural irrigation, and agricultural livestock watering.**	APPENDIX A. Numeric Water Quality Standards, Table 1. Water Quality Standards By Designated Use provides standard for various designated uses for metals and other chemicals	Metals in µg/L: As - AgI: 2,000 T, AgL: 200 T; Cd - AgI and AgL: 50; total Cr - AgI and AgL: 1000; Cu - AgI: 5000 T, AgL: 500 T'; Pb - AgI: 10000 T, AgL: 100 T; Mn - AgI: 10000; Hg - AgL: 10 T; Se - AgI: 20 T, AgL: 50 T; Zn - AgI: 10,000 T, AgL: 25,000 T	No, but the ones listed match the NAS & NAE 1972 criteria; irrigation standards listed match the NAS & NAE 1972 20-year irrigation criteria. Not all of the NAS & NAE 1972 criteria are listed in these standards.
9	HI	Amendment and Compilation of Chapter 11-54, Hawaii Administrative Rules	§11-54-3 Classification of water uses, (b) Inland waters. (2} Class 2 - protective of ag water supplies	Numeric standards for aquatic life and human health are provided in a table; values are provided for several metals	No	No
9	CA (9 Water Quality Control Boards)	1 - Water Quality Control Plan for the North Coast Region	All surface and ground waters of the State are considered to be suitable, or potentially suitable, for municipal or domestic water supply and should be so designated by the Regional Boards. Waters designated for use as agricultural supply (AGR) shall not contain concentrations of chemical constituents	Tables of Inorganic, Organic, and Fluoride Concentrations Not to Be Exceeded in Domestic or Municipal Supply, as well as tables of Objectives for Protection of Marine Aquatic Life are provided	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
			in amounts which adversely affect such beneficial use.			
9	CA (9 Water Quality Control Boards)	2 - San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan)	2.1.1 AGRICULTURAL SUPPLY (AGR) - applicable to entire state. Uses of water for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing. The standards discussed under municipal and domestic water supply (MUN) also effectively protect farmstead uses. To establish water quality standards for livestock water supply, the Water Board must consider the relationship of water to the total diet, including water freely drunk, moisture content of feed, and interactions between irrigation water quality and feed quality. The University of **California Cooperative Extension has developed threshold and limiting concentrations for livestock and irrigation water.** Continued irrigation often leads to one or more of four types of hazards related to water quality and the nature of soils and crops. These hazards are (1) soluble salt accumulations, (2) chemical changes in the soil, (3) toxicity to crops, and (4) potential disease transmission to humans through reclaimed water use. Irrigation water classification systems, arable soil classification systems, and public health standards related to reuse of wastewater have been developed with consideration given to these hazards.	3.3.22 Constituents of Concern for Municipal and Agricultural Water Supplies: At a minimum, surface waters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of constituents in excess of the maximum (MCLs) or secondary maximum contaminant levels (SMCLs) specified in the following provisions of Title 22, which are incorporated by reference into this plan: Table 64431-A (Inorganic Chemicals) of Section 64431, Water Quality Control Plan for the San Francisco Bay Basin and Table 64433.2-A (Fluoride) of Section 64433.2, Table 64444-A (Organic Chemicals) of Section 64444, and Table 64449-A (SMCLs-Consumer Acceptance Limits) and 64449-B (SMCLs-Ranges) of Section 64449. This incorporation-by-reference is prospective, including future changes to the incorporated provisions as the changes take effect. Table 3-5 contains water quality objectives for municipal supply, including the MCLs contained in various sections of Title 22 as of the adoption of this plan.At a minimum, surface waters designated for use as agricultural supply (AGR) shall not contain concentrations of constituents in excess of the levels specified in Table 3-6.	Yes, see Table 3-6 on PDF pg 98 (in units of mg/L for livestock watering): Al: 5.0; As: 0.2; Cd: 0.05; Cr: 1.0; Co: 1.0; Cu: 0.5; Pb: 0.1; Mo: 0.5; Se: 0.05; V: 0.1; Zn: 25.	a. For an extensive discussion of water quality for agricultural purposes, see "A Compilation of Water Quality Goals," Central Valley Regional Water Quality Control Board, May 1993.The ones listed match the NAS & NAE 1972 livestock standards (except for Mo, which matches the NAS & NAE 1972 irrigation standard). Not all of the NAS & NAE 1972 criteria are listed in these standards.

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
9	CA (9 Water Quality Control Boards)	3 - Water Quality Control Plan for the Central Coastal Basin	Chemical Constituents - Waters shall not contain concentrations of chemical constituents in amounts which adversely affect the agricultural beneficial use. Interpretation of adverse effect shall be as derived from the University of California Agricultural Extension Service guidelines provided in Table 3-1. In addition, waters used for irrigation and livestock watering shall not exceed concentrations for those chemicals listed in Table 3-2. Salt concentrations for irrigation waters shall be controlled through implementation of the anti-degradation polic (Appendix A-2) to the effect that mineral constituents of currently or potentially usable waters shall not be increased. It is emphasized that no controllable water quality factor shall degrade the quality of any groundwater resource or adversely affect long-term soil productivity. Where wastewater effluents are returned to land for irrigation uses, regulatory controls shall be consistent with Title 22 of the California Code of Regulations and with relevant controls for local irrigation sources.	Yes, but specific ones for agriculture.	Table 3-2. Water Quality Objectives for Agricultural Water Uses in mg/L- see PDF page 47: Al: 5.0 - Irrig; 5.0 - Livestock; As: 0.1 - Irrig; 0.2 - Livestock; Be: 0.1 - Irrig Cd: 0.01 - Irrig; 0.05 - Livestock Cr: 0.10 - Irrig; 1.0 - Livestock Co: 0.05 - Irrig; 1.0 - Livestock Cu: 0.2 - Irrig; 0.5 - Livestock Fe: 5.0 - Irrig; Pb: 5.0 - Irrig; 0.1 - Livestock Li: 2.5 - Irrig; Mn: 0.2 - Irrig; Hg: 0.01 - Livestock; Mo: 0.01 - Irrig; 0.5 - Livestock; Ni: 0.2 - Irrig; Se: 0.02 - Irrig; 0.05 - Livestock; V: 0.1 - Irrig; 0.10 - Livestock; Zn: 2.0 - Irrig; 25 - Livestock	Values listed match those in NAS & NAE 1972; molybdenum value for livestock is likely the aquatic life criterion from NAS & NAE 1972 because no livestock standards was provided in the 1972 source. Footnote: a. Values based primarily on "Water Quality Standards 1972" National Academy of Sciences-National Academy of Engineers, Environmental Study Board, ad hoc Committee on Water Quality Standards furnished as recommended guidelines by University of California Agriculture Extension Service, January 7, 1974; maximum values are to be considered as 90 percentile values not to be exceeded.
9	CA (9 Water Quality Control Boards)	4 - Los Angeles Region Basin Plan	Agricultural Supply (AGR) - Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing.	Surface waters shall not contain concentrations of chemical constituents in amounts that adversely affect any designated beneficial use. A table of standards (including for metals) is provided for domestic or municipal supply.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
9	CA (9 Water Quality Control Boards)	5a- Water Quality Control Plan for the Sacramento River and San Joaquin River Basins	Agricultural Supply (AGR) - Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation (including leaching of salts), stock watering, or support of vegetation for range grazing.	Waterbody-specific standards	No	No
9	CA (9 Water Quality Control Boards)	5b- Water Quality Control Plan for the Tulare Lake Basin	Agricultural Supply (AGR) - Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation (including leaching of salts), stock watering, or support of vegetation for range grazing.	References California's standards for domestic or municipal supply	No	No
9	CA (9 Water Quality Control Boards)	6 - Water Quality Control Plan for the Lahontan Region North and South Basins	AGR Agricultural Supply. Beneficial uses of waters used for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, and support of vegetation for range grazing.	Waterbody-specific standards	No	No
9	CA (9 Water Quality Control Boards)	7 - Water Quality Control Plan, Colorado River Basin - Region 7	AGR Agriculture Supply Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing.	Surface waters shall not contain concentrations of chemical constituents in amounts that adversely affect any designated beneficial use. A table of standards (including for metals) is provided for domestic or municipal supply.	No	No
9	CA (9 Water Quality Control Boards)	8 - Water Quality Control Plan - Santa Ana River Basin (8)	AGR Agriculture Supply Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing.	A table of metals standards is provided for domestic or municipal supply.	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
9	CA (9 Water Quality Control Boards)	9 - Water Quality Control Plan for the San Diego Basin	Agricultural Supply (AGR) - Includes uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing.	Table 3-4 provides metals standards for domestic or municipal supply. Table C-1 provides metals standards for specific waterbody types and for drinking water.	No	No
9	NV	Chapter 445A - Water Controls	NAC 445A.122 Standards applicable to beneficial uses. (NRS 445A.425, 445A.520): 1. The following standards are intended to protect both existing and designated beneficial uses and must not be used to prohibit the use of the water as authorized under title 48 of NRS: (a) Watering of livestock. The water must be suitable for the watering of livestock without treatment. (b) Irrigation. The water must be suitable for irrigation without treatment.	NAC 445A.1236 Standards for toxic materials applicable to designated waters. (NRS 445A.425, 445A.520) 1. Except for waters which have site-specific standards for toxic materials or as otherwise provided in this section, the standards for toxic materials prescribed in subsection 2 are applicable to the waters specified in NAC 445A.123 to 445A.2234, inclusive.	As: 100 µg/L (Irrigation), 200 µg/L (Watering of Livestock); Be (Irrigation): 100 µg/L; Cd: 10 µg/L (irrigation), 50 µg/L (Watering of Livestock); Cr (total): 100 µg/L (Irrigation), 1000 (Watering of Livestock); Cr: 200 µg/L (Irrigation), 500 µg/L (Watering of Livestock); Fe: 5,000 (Irrigation); Pb: 5,000 µg/L (Irrigation), 100 µg/L (Watering of Livestock); Mn: 200 µg/L (Irrigation); Hg: 10 µg/L (Watering of Livestock); Ni: 200 µg/L (Irrigation); Se: 20 µg/L (Irrigation), 50 µg/L (Watering of Livestock); Zn: 2000 µg/L (Irrigation); 25,000 µg/L (Watering of Livestock)	Values listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards. They cite Gold book, Red Book, and Blue book (mainly Blue Book); c. U.S. Environmental Protection Agency, Pub. No. EPA 440/9-76-023, Quality Standards for Water (Red Book) (1976); d. National Academy of Sciences, Water Quality Standards (Blue Book) (1972).

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
10	AK	18 AAC 70, Water Quality Standards	18 AAC 70.020. Protected water use classes and subclasses; water quality standards; water quality standards table. (a) Classes and subclasses of use of the state's water protected by standards set out under (b) of this section are: (1) fresh water, (A) water supply, (i) drinking, culinary, and food processing; **(ii) agriculture, including irrigation and stock watering;** (iii) aquaculture; and (iv) industrial.	The concentration of substances in water may not exceed the numeric standards for drinking and stockwater and irrigation water shown in the Alaska Water Quality Standards Manual (see note 5). 18 AAC 70.236. Waterbodies subject to site-specific standards. (a) Under 18 AAC 70.235, the department has established site-specific standards that modify certain general standards set out in 18 AAC 70.020(b) for the waterbodies listed in (b) of this section. The site-specific standards apply only to the affected designated use class indicated in (b) of this section. All other standards set out in 18 AAC 70.020(b) continue to apply to the waterbodies listed in (b) of this section. Some metals are listed here.	Al: 5000 µg/L (irrigation); As: 50 µg/L (stock watering), 100 µg/L (irrigation); Be: 100 µg/L (irrigation); Cd: 10 µg/L (stock watering), 10 µg/L (irrigation); Cr: 100 µg/L (total recoverable - irrigation); Cr+6: 50 µg/L (stock watering); Cu: 200 µg/L (irrigation); Fe: 5000 µg/L (irrigation); Pb: 50 µg/L (stock water), 5000 µg/L (irrigation water); Mn: 200 µg/L (irrigation); Mo: 10 µg/L (irrigation); Ni: 200 µg/L (irrigation); Se: 10 µg/L (stock watering), 20 µg/L (irrigation); V: 100 µg/L (irrigation); and Zn: 2000 µg/L (irrigation)	Values listed match the NAS & NAE 1972 and FWPCA 1968 standards; not all of the NAS & NAE 1972 and FWPCA standards are listed in these standards. References U.S. EPA Blue Book, U.S. EPA Green Book
10	ID	IDAPA 58, Title 01, Chapter 02, 58.01.02 - Water Quality Standards	08. Beneficial Use. Any of the various uses which may be made of the water of Idaho, including, but not limited to, domestic water supplies, industrial water supplies, agricultural water supplies, navigation, recreation in and on the water, wildlife habitat, and aesthetics.	A table for 210.Numeric Criteria for Toxic Substances for Waters Designated for Aquatic Life, Recreation, or Domestic Water Supply Use is provided and includes metals.	No	02. Agricultural. Water quality criteria for agricultural water supplies will generally be satisfied by the water quality criteria set forth in Section 200. Should specificity be desirable or necessary to protect a specific use, "Water Quality Criteria 1972" (Blue Book), Section V, Agricultural Uses of Water, U.S. EPA, March 1973 will be used for determining criteria.
10	OR	Division 41 Water Quality Standards: Beneficial Uses, Policies, and Criteria for Oregon	Not listed as a designated use; standards are undergoing a triennial review	Tables for aquatic life and human health standards include metals	No	No

Table A-2. Compilation of State Agricultural Water Quality Standards

EPA Region	State	Source	Does State Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
10	WA	Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC	(3) Water supply uses. The water supply uses are domestic, agricultural, industrial, and stock watering. 173-201A-600 Use designations — Fresh waters. (1) All surface waters of the state not named in Table 602 are to be protected for the designated uses of: Salmonid spawning, rearing, and migration; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; harvesting; commerce and navigation; boating; and aesthetic values.	Aquatic life standards (including for metals) are provided in a table	No, but they have proposed some	Refer to Proposed Agricultural Water Supply Criteria Decision Process for Ecology's Proposed Rule. This document lists criteria for metals and other parameters and cites two key works (NAS and NAE, 1972; and Ayes and Westcot, 1985)

A.2. Agricultural Water Standards Used by Tribes

As shown in Table A-3, consistent with Section 101(a) of the CWA (40 CFR 131.6(a)), most tribes found eligible to administer a water quality standards program include general agricultural uses, livestock watering, or irrigation as designated uses. The term "agricultural uses" is not strictly defined and has been interpreted to mean water use for crop irrigation, livestock watering, farm/ranch needs, or landscape irrigation but does not include domestic use. As detailed in Table A-4 and summarized in Table A-3, nineteen tribes include numeric metals standards for agricultural uses in their water quality standards. One tribe (the Bishop Paiute Tribe) references agricultural water quality standards for metals but does not provide specific values for these uses in their standards, as described further below.

Table A-3. Tribes with numeric agricultural standards for metals

Tribe	Numeric Agricultural Standards for Metals
Seminole Tribe of Florida	Most numeric agricultural standards are the same as aquatic life standards for metals, **with the exception of mercury**. • Mercury: 0.02 µg/L *(rationale for this concentration was not provided)*
Pueblo of Acoma	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of mercury for livestock and selenium for irrigation and livestock**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Mercury for livestock: 0.012 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 0.13 mg/L, 0.25 mg/L (when SO_4 > 500 mg/L) *(rationale for this concentration was not provided)* • Selenium for livestock: 0.002 mg/L *(rationale for this concentration was not provided)*
Pueblo of Isleta	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria* 1972 (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
Pueblo of Laguna	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.
Pueblo of Nambé	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of mercury for livestock and selenium for irrigation and livestock**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Mercury for livestock: 0.012 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 0.13 mg/L, 0.25 mg/L (when SO_4 > 500 mg/L) *(rationale for this concentration was not provided)* • Selenium for livestock: Se (total): 0.002 mg/L *(rationale for this concentration was not provided)*
Ohkay Owingeh	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards.

Table A-3. Tribes with numeric agricultural standards for metals

Tribe	Numeric Agricultural Standards for Metals
Picuris Pueblo	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of mercury for livestock and selenium for irrigation and livestock**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Mercury for livestock: 0.012 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 0.13 mg/L, 0.25 mg/L (when SO_4 > 500 mg/L) *(rationale for this concentration was not provided)* • Selenium for livestock: Se (total): 0.002 mg/L *(rationale for this concentration was not provided)*
Pueblo of Pojoaque	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of mercury for livestock and selenium for irrigation and livestock.** Not all of the NAS & NAE 1972 criteria are listed in these standards. • Mercury for livestock: 0.012 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 0.13 mg/L, 0.25 mg/L (when SO_4 > 500 mg/L) *(rationale for this concentration was not provided)* • Selenium for livestock: Se (total): 0.002 mg/L *(rationale for this concentration was not provided)*
Pueblo of Sandia	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of molybdenum for irrigation**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Molybdenum for irrigation: 1.0 mg/L *(rationale for this concentration was not provided)*
Pueblo of Santa Clara	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of mercury, molybdenum, and selenium**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Molybdenum for irrigation: 1.0 mg/L (*rationale for this concentration was not provided)* • Dissolved selenium for irrigation: 0.13 mg/L *(rationale for this concentration was not provided)* • Mercury (total) for livestock: 0.012 µg/L *(rationale for this concentration was not provided)* • Selenium for livestock: 0.002 mg/L *(rationale for this concentration was not provided)*
Pueblo of Santa Ana	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of molybdenum for irrigation**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Molybdenum for irrigation: 1.0 mg/L *(rationale for this concentration was not provided)*
Pueblo of Taos	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of molybdenum and selenium for irrigation**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Molybdenum for irrigation: 1,000 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 130 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 250 µg/L (when SO_4 > 500 mg/L) *(rationale for this concentration was not provided)*

Table A-3. Tribes with numeric agricultural standards for metals

Tribe	Numeric Agricultural Standards for Metals
Pueblo of Tesuque	Most of the agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), **with the exception of mercury for livestock and selenium for irrigation and livestock**. Not all of the NAS & NAE 1972 criteria are listed in these standards. • Mercury (total) for livestock: 0.012 µg/L *(rationale for this concentration was not provided)* • Selenium for irrigation: 0.13 mg/L (in the presence of <500 mg/L of SO_4) *(rationale for this concentration was not provided)* • Selenium for livestock: 0.002 mg/L *(rationale for this concentration was not provided)*
Ute Mountain Ute Tribe	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. The Food and Agriculture Organization of the United Nations' (FAO's) *Water Quality for Agriculture* (Ayers and Westcot 1985) is cited.
Hopi Tribe	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. Note that the irrigation standards listed correspond to the 20-year values listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972).
Hualapai Tribe	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972). Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. Note that the irrigation standards listed correspond to the 20-year values listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972).
Navajo Nation	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) **with the exception of molybdenum.** Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. • Molybdenum for irrigation: 1.0 mg/L *(rationale for this concentration was not provided)* Note that the irrigation standards listed correspond to the 20-year values listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972).
Pyramid Lake Paiute Tribe	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) **with the exception of cobalt for livestock**. Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. • Cobalt for livestock: 5,000 µg/L *(rationale for this concentration was not provided)*
White Mountain Apache Tribe of the Fort Apache Indian Reservation	The agricultural numeric standards correspond to those listed in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) **with the exception of selenium for irrigation and livestock.** Not all of the U.S. EPA's (NAS & NAE 1972) agricultural criteria are listed in these standards. • Selenium for irrigation: 0.13 mg/L *(rationale for this concentration was not provided)* • Selenium for livestock: 0.002 mg/L *(rationale for this concentration was not provided)*

Although the Bishop Paiute Tribe does not specifically list numeric agricultural standards for metals in its water quality standards[3], it is indicated that the tribe will refer to water quality goals and recommendations from sources such as FAO's *Water Quality for Agriculture* (Ayers and Westcot 1985).

[3] Bishop Paiute Tribe Water Quality Control Plan.

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
2	Saint Regis Mohawk Tribe	Yes	Water Quality Standards for the Saint Regis Mohawk Tribe	Primary contact and ceremonial use, agricultural and water supply use are other designated uses of Tribal Surface Waters. Agricultural Water Supply Use: the use of water for irrigation. Agriculture or Farm Water Supply listed as a designated use.	Yes, but for other uses (human health, aquatic life)	No	No
4	Miccosukee Tribe of Indians of Florida	Yes	Water Quality Standards for Surface Waters of the Miccosukee Tribe of Indians of Florida	CLASS III-B WATERS: Those Tribal water bodies which are used for agricultural or livestock water supply or other beneficial uses. Designated use - Traditional Agriculture, i.e., growing corn without the addition of fertilizers or other chemicals	Yes, but they are human health ambient water quality standards that are applicable to Class III-B waters	No	No
4	Seminole Tribe of Florida	Yes	Seminole Tribe of Florida, Part 1, General Provisions for Water Quality	Class 3. Agricultural purposes.	TABLE 12 Standards for all Reservation Surface Waters on the Big Cypress and Brighton Reservations for metals standards and other standards	Yes - As: ≤ 10 µg/L; Cd: exp(0.7409[InH]-; Cr+3: exp(0.819[lnH]+0.6848), Cr6: 11 µg/L; Cu: exp(0.8545[lnH]-1.702); Pb: Pbexp(1.273[lnH]-; Hg: 0.02 µg/L; Ni: exp(0.846[lnH]+0.0584); Ag: exp(1.72[lnH]-6.59); Zn: exp(0.8473[lnH]+0.884)	No - values are mainly the same as those for protecting aquatic life uses, except for Hg (which is greater than the aquatic life criterion)
5	Bad River Band of the Lake Superior Tribe of Chippewa Indians	Yes	Bad River Band of the Lake Superior Tribe of Chippewa Indians Water Quality Standards	Commercial (C2). Supports the use of water in propagation of fish fry for the Tribal Hatchery and/or irrigation of community agricultural projects.	Tables provide aquatic life standards, human health standards, and standards for the protection of wildlife for most metals.	No, but based on designated use table, all waterbodies are covered by aquatic life standards	No
5	Fond du Lac Band of Lake Superior Chippewa	Yes	Fond du Lac Band of Lake Superior Chippewa Water Quality Standards of the Fond du Lac Reservation	Section 302 Standards of Designated Use, e. Cultural, f. Agricultural: The water quality is adequate for uses in irrigation and livestock watering.	Table provides standards for aquatic life, human health, and wildlife, including for metals.	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
5	Grand Portage Band of Chippewa	Yes	Grand Portage Band of Chippewa, Water Quality Standards	Wild Rice Areas: A stream, river, lake, or impoundment, or portion thereof, presently has or historically had the potential to sustain the growth of wild rice (also known as *Zizania palustris* or *manoornin*).V. DESIGNATED USES. E. CULTURAL: 1. Wild Rice Areas - a stream, river, lake, wetland or impoundment, or portion thereof, presently, historically or with the potential to be vegetated with wild rice. F. FORESTRY WATER SUPPLY - all waters of the Reservation shall be of sufficient quality for use in forestry applications.	Waters must be free from substances entering the water as a result of human activity in concentrations that are toxic or harmful to human, animal, plant or aquatic life. Tables provide aquatic life standards, human health standards, and standards for the protection of wildlife for most metals.	No	No
5	Sokaogon Chippewa Community	Not numeric ones	Sokaogon Chippewa Community Water Quality Standards	B. [151.11] Designated Uses, Tribal Designated Uses include: 5) Agricultural/Forestry: Use of All Tribal Waters in forestry and/or agricultural practices.	1) For all pollutants in the Great Lakes Guidance (40 CFR Part 132), the applicable criterion will be the more protective value of either: a) SCC Ambient Water Quality Values, as defined in Section V of this document and reported in the SCC Clean Water Act 106 Grants Final Report, using statistically sound and scientifically defensible methods that are being developed by the SCC Environmental Department, or **[Note, that no specific WQC are provided in Section V of the document]** b) U.S. EPA Great Lakes Guidance Numeric Standards (40 CFR. 132.6, Tables 1 - 4). Tables provide aquatic life standards, human health standards, and standards for the protection of wildlife for most metals.	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
6	Pueblo of Acoma	Yes	Pueblo of Acoma Water Quality Standards	B. Specific Water Quality Uses and Standards.6. Agricultural Irrigation (AgI) and Agricultural Livestock Watering (AgL). Agricultural irrigation means the use of surface waters or groundwaters for irrigation of crops. Agricultural livestock watering means the use of surface waters or groundwaters as a supply for water consumption by livestock. Standards specific to the uses are outlined in Appendix A, Table A-3.	Table A-3 provides standards applicable to Agricultural Irrigation, Agricultural Livestock Watering, and other uses (e.g., aquatic life, fish consumption, domestic water source, partial body contact), including for metals. Agricultural irrigation: The use of a water for the irrigation of crops. Agricultural livestock watering: The use of a water as a supply of water for consumption by livestock.	Available for dissolved metals: Al (5.0 mg/L - for both AgI and AgL), As (0.10 AgI and 0.20 mg/L for AgL), Cd: (0.01 for AgI and 0.05 for AgL); Cr (0.10 for AgI and 1.0 for AgL - both for total and hex); Co (0.05 for AgI and 1.0 for AgL); Cu (0.20 for AgI and 0.5 for AgL); Pb (5.0 for AgI and 0.1 for AgL); **Hg (0.012 µg/L for AgL)**; **Se (0.13 mg/L, 0.25 mg/L (when SO4 > 500 mg/L) for AgI and 0.002 mg/L for AgL);** V (0.1 mg/L for both AgI and AgL); Zn (2.0 mg/L for AgI and 26.0 mg/L for AgL). Most concentrations were similar to those listed for aquatic life, although some were only listed for agricultural use (e.g., Co, V).	No, but the ones listed match the NAS & NAE 1972 criteria, except for Hg and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Isleta	Yes	Pueblo of Isleta, Surface Water Quality Standards	Agricultural water supply use means the use of water for irrigation and livestock watering. Agricultural Water Supply Use. Agricultural water supply use means the use of water for irrigation and livestock watering.	SECTION IV. Water Body Uses and Standards Specific to the Uses, F.	Available for dissolved metals: Al (5.0 mg/L - for both livestock and irrigation), As (0.20 mg/L for livestock), Cd: (0.05 for livestock); Cr (1.0 for livestock); Co (0.05 for irrigation and 1.0 for livestock); Cu (0.5 for livestock); Hg - total (0.01 for livestock); Mo (0.01 for irrigation), Se - total recoverable (0.05 for livestock); V (0.1 for both livestock and irrigation)	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards.

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
6	Pueblo of Laguna	Yes	Pueblo of Laguna Water Quality Standards	(27) Irrigation means the intentional application of water to agricultural crops and other plants by means of ditches, pipes, sprinkler systems, water-spreading berms, or other means, whether traditional, historical, or contemporary. (28) Livestock and Wildlife Watering means water consumed by livestock, nondomestic animals (including migratory birds), or both for water supply, habitation, growth, or propagation.	Subchapter IV. Designated Uses and Associated Numeric Water Quality Standards, Section 11-2-41. List of Designated Uses and Associated Standards	Irrigation: Al (dissolved): 5.0 mg/L; Co (dissolved): 0.05 mg/L; Li (dissolved): 2.5 mg/L, Mo (dissolved): 0.1 mg/L. Livestock and Wildlife Watering (dissolved): Al: 5.0 mg/L; As: 0.2 mg/L; Cd: 0.05 mg/L, Cr: 1.0 mg/L; Co: 1.0 mg/L; Cu: 0.5 mg/L; Hg (total): 0.01 mg/L; Se: 0.05 mg/L; and V: 0.1 mg/L.	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Nambé	Yes	Pueblo of Nambé Water Quality Code	Agricultural Water Supply Use - The use of water for irrigation. Designated uses include irrigation, livestock watering and wildlife habitat. B.4. Livestock Watering and Wildlife Habitat Use: Waters designated for livestock watering and wildlife habitat use shall not exceed the numeric criteria listed in Table 4.B.5. Irrigation Use: Waters designated for irrigation use (Figure 3) shall not exceed the numeric criteria shown in Table 5. Livestock watering & wildlife habitat - A stream reach, lake, or impoundment where water temperature and other characteristics are suitable for consumption by livestock or wildlife or plants for wildlife that are not considered as pathogens or vectors for pathogens.	B. Water Body Uses and Specific Standards	Livestock water and wildlife habitat (dissolved): Al: 5.0 mg/L; As: 0.2 mg/L, Cd: 0.05 mg/L; Cr: 1.0 mg/L; Co: 1.0 mg/L; Pb: 0.1 mg/L; **Hg (total): 0.012 µg/L**; **Se (total): 0.002 mg/L**; V: 0.1 mg/L; Zn: 25.0 mg/L. Irrigation use (dissolved): Al: 5.0 mg/L; As: 0.10 mg/L; Cd: 0.01 mg/L; Cr: 0.10 mg/L; Co: 0.05 mg/L; Cu: 0.20 mg/L; Pb: 5.0 mg/L; Mo: 0.01 mg/L; **Se (in the presence of < 500 mg/L SO4): 0.13 mg/L**; V: 0.1 mg/L; Zn: 2.0 mg/L; **Se (in the presence of > 500 mg/L SO4): 0.25 mg/L**	No, but the ones listed match the NAS & NAE 1972 criteria, except for Hg and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Ohkay Owingeh	Yes	Ohkay Owingeh Surface Water Quality Standards	SECTION IV. Water Body Uses and Standards Specific to the Uses, G. Agricultural Water Supply Use: Agricultural water supply use means the use of water for irrigation and livestock watering.	SECTION IV. Water Body Uses and Standards Specific to the Uses	Livestock (dissolved): Al: 5.0 mg/L; Co: 1.0 mg/L; V: 0.1 mg/L; Irrigation (dissolved): Al: 5.0 mg/L; Co: 0.05 mg/L; Li: 2.5 mg/L; Mo: 0.01 mg/L; V: 0.1 mg/L	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pawnee Nation	No	Pawnee Nation - Partial Approval of Pawnee Nation of Oklahoma Application for Program Authorization under §303(c) and §401 of the Clean Water Act	No	No	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
6	Picuris Pueblo	Yes	Water Quality Code for the Picuris Pueblo Adopted May	Agricultural Water Supply Use - The use of water for irrigation.	2. Specific Water Quality Standards	D. Livestock Watering & Wildlife Habitat Use (dissolved): Al: 5.0 mg/L; As: 200 µg/L; Cd: 0.05 mg/L; Cr: 1.0 mg/L; Co: 1.0 mg/L; Cu: 0.5 mg/L; Pb: 0.1 mg/L; **Hg (total): 0.012 µg/L**; **Se (total): 0.002 mg/L;** V: 0.1 mg/L; Zn: 25.0 mg/L. E. Irrigation Use (dissolved): Al: 5.0 mg/L; As: 0.10 mg/L; Cd: 0.01 mg/L; Cr: 0.10 mg/L; Co: 0.05 mg/L; Cu: 0.20 mg/L; Pb: 5.0 mg/L; Mo: 0.01 mg/L; **Se (in presence of < 500 mg/L SO4): 0.13 mg/L;** V: 0.1 mg/L; Zn: 2.0 mg/L; **Se (in presence of > 500 mg/L of SO4): 0.25 mg/L.**	No, but the ones listed match the NAS & NAE 1972 criteria, except for Hg and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Pojoaque	Yes	Pueblo of Pojoaque Water Quality Standards	A. Segments Designated for Irrigation, 8. Segments Designated for Livestock and Wildlife Habitat	Section IV. Water Body Uses and Standards Specific to Use	A. Segments Designated for Irrigation (Dissolved): Al: 5.0 mg/L; As: 0.10 mg/L; Cd: 0.01 mg/L; Cr: 0.10 mg/L; Co: 0.05 mg/L; Cu: 0.20 mg/L; Pb: 5.0 mg/L; **Se (in presence of > 500 mg/L sulfate): 0.25 mg/L; Se (in presence of < 500 mg/L sulfate): 0.10 mg/L**; Zn: 2.0 mg/L. B. Segments Designated for Livestock and Wildlife Habitat (Dissolved): Al: 5.0 mg/L; As: 0.2 mg/L; Cd: 0.05 mg/L; Cr: 1.0 mg/L; Co: 1.0 mg/L; Cu: 0.50 mg/L; Pb: 0.10 mg/L; **Hg (total): 0.012 µg/L; Se (total): 0.002 mg/L**, V: 0.10 mg/L; Zn: 25 mg/L	No, but the ones listed match the NAS & NAE 1972 criteria, except for Hg and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Sandia	Yes	Pueblo of Sandia Water Quality Standards	G. Agricultural Water Supply Use Agricultural water supply use means the use of water for irrigation and livestock watering.	Section IV. Water Body Uses and Standards Specific to the Uses	Livestock (dissolved): Co: 1.0 mg/L; V: 0.1 mg/L. Irrigation (dissolved): Co: 0.05 mg/L, Li: 2.5 mg/L; **Mo: 1.0 mg/L**; V: 0.1 mg/L	No, but the ones listed match the NAS & NAE 1972 criteria, except for Mo; not all of the NAS & NAE 1972 criteria are listed in these standards.

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
6	Pueblo of Santa Clara	Yes	Water Quality Code of the Pueblo of Santa Clara	Irrigation and Livestock and Wildlife are designated uses	Section IV. Standards Applicable to Existing, Attainable or Designated Uses	D. Irrigation (dissolved): Al: 5.0 mg/L; As: 0.10 mg/L; Cd: 0.01 mg/L; Cr: 0.10 mg/L; Co: 0.05 mg/L; Cu: 0.20 mg/L ; Pb: 5.0 mg/L; **Mo: 1.0 mg/L; Se: 0.13 mg/L;** V: 0.1 mg/L; Zn: 2.0 mg/L. F. Livestock and Wildlife (dissolved): 5.0 mg/L; As: 0.2 mg/L; Cd: 0.05 mg/L; Cr: 1.0 mg/L; Co: 1.0 mg/L; Cu: 0.5 mg/L; Pb: 0.1 mg/L; **Hg (total): 0.012 µg/L; Se (total): 0.002 mg/L;** V: 0.1 mg/L; 25.0 mg/L	No, but the ones listed match the NAS & NAE 1972 criteria, except for Hg, Mo, and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Santa Ana	Yes	Pueblo of Santa Ana Water Quality Standards	Agricultural water supply use means the use of water for irrigation and livestock watering.	Section IV. Water Body Uses and Standards Specific to the Uses	F. Agricultural water supply use: Livestock (dissolved): Co: 1.0 mg/L, V: 0.1 mg/L; Irrigation: Co: 0.05 mg/L, Li: 2.5 mg/L; **Mo: 1.0 mg/L**; V: 0.1 mg/L	No, but the ones listed match the NAS & NAE 1972 criteria, except for Mo; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Taos	Yes	Pueblo of Taos, Water Quality Standards	Irrigation and Wildlife and Livestock Watering are designated uses	Appendices: Numeric Standards for Designated Uses	E. Agriculture & Wildlife Watering Irrigation Criterion (dissolved, µg/L): Al: 5000; As: 100, Cd: 10, Cr: 100, Co: 50, Cu: 200, Pb: 5000, **Mo: 1000**, **Se: 130**, **Se (with sulfate > 500 mg/L): 250**, V: 100, Zn: 2000. Wildlife & Livestock Watering Criterion (dissolved, µg/L): Al: 5000, As: 200, Cd: 50, Cr: 1000, Co: 1000, Cu: 500, Pb: 100, Hg (total): 10, Se: 50, V: 100, Zn: 25000.	No, but the ones listed match the NAS & NAE 1972 criteria, except for Mo and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.
6	Pueblo of Tesuque	Yes	Pueblo of Tesuque Water Quality Standards	Section IV. Water Body Uses and Standards Specific to Use	Section IV. Water Body Uses and Specific Standards, B. Water Body Uses and Specific Standards	E. Livestock Watering & Wildlife Habitat Use (dissolved, mg/L): Al: 5.0, As: 0.2, Cd: 0.05, Cr: 1.0, Co: 1.0, Cu: 0.5, Pb: 0.1, **Hg (total): 0.012 µg/L**, **Se: (total): 0.002,** V: 0.1, Zn: 25.0 F. Irrigation Use (dissolved, mg/L): Al: 5.0, As: 0.10, Cd: 0.01, Cr: 0.10, Co: 0.05, Cu: 0.20, Pb:	No, but the ones listed match the NAS & NAE 1972 criteria, except for Hg and Se; not all of the NAS & NAE 1972 criteria are listed in these standards.

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
						5.0, Mo: 0.01, **Se (in the presence of <500 mg/L of SO4): 0.13**, V: 0.1, Zn: 2.0	
8	Fort Peck Assiniboine and Sioux Tribes	Yes	Water Quality Standards for the Fort Peck Assiniboine and Sioux Tribes	Agriculture: These surface waters are suitable or intended to become suitable for crops usually grown on the reservation and which are not hazardous as drinking water for livestock.	Aquatic life standards and human health ambient water quality standards for pollutants, including metals - see Table B-1	No	No
8	Blackfeet Tribe	No					
8	Northern Cheyenne Tribe of the Northern Cheyenne Indian Reservation	Yes	Northern Cheyenne Tribe of the Northern Cheyenne Indian Reservation Surface Water Quality Standards	13. Agriculture: These surface waters are suitable or intended to become suitable for crops usually grown on the reservation and are not hazardous as drinking water for livestock	Aquatic life standards and human health ambient water quality standards for pollutants, including metals - see Appendix A	No	No
8	Confederated Salish and Kootenai Tribes of the Flathead Reservation	Yes	Confederated Salish and Kootenai Tribes of the Flathead Reservation, Surface Water Quality Standards and Antidegradation Policy	Waters classified as A-1, B-1, B-2, B-3, C-1, C-2, and C-3 include **agricultural** and industrial water supply purposes. Also, no increases are allowed above naturally occurring concentrations of sediment, contaminated sediment, settleable solids, oils, or floating solids that create or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, fish, or wildlife.	Aquatic life standards and human health ambient water quality standards for pollutants, including metals - see priority pollutant and non-priority pollutant tables	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
8	Ute Mountain Ute Tribe	Yes	Ute Mountain Ute Tribe, Water Quality Standards for Surface Waters of the Ute Mountain Ute Indian Reservation & Supplemental Information	AG designated use code: agriculture, irrigation and/or livestock watering. This use is listed for all waterbodies except for one (which currently has no designated uses) in Table 12.1 Designated Uses for Tribal Waters, Colorado and New Mexico. It is listed as a use for all waterbodies in Table 12.2. Designated Uses for Tribal Waters, Utah.	Table 12.6 Standards for Metallic Inorganics and Selenium (µg/L), includes standards primarily for aquatic life and human health, but some agriculture-specific standards are provided in addition to standards for other uses	As (total recoverable): 100 µg/L (30-Day); Cd (total recoverable): 10 µg/L (30-Day); Cr3 (total recoverable): 100 µg/L (30-Day); Cr6 (total recoverable): 100 µg/L (30-Day); Cu (total recoverable): 200 µg/L (30-Day); Hg (total recoverable): 10 µg/L (30-day); Ni (total recoverable): 200 µg/L (30-Day); Pb (total recoverable): 100 µg/L (30-Day); Se (total recoverable): 20 µg/L (30-Day); and Zn (total recoverable): 2,000 µg/L (30-Day)	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards. In note JJ, they cite: Water Quality for Agriculture, 1976, Food and Agriculture Organization of the United Nations.
9	Big Pine Indian Reservation Big Pine Paiute Tribe of the Owens Valley	Yes	Water Quality Standards Big Pine Indian Reservation Big Pine Paiute Tribe of the Owens Valley	AGR: Agricultural Supply. Beneficial uses of waters used for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, and support of vegetation for range grazing. Waters designated as AGR shall not contain concentrations of chemical constituents in amounts that adversely affect the water for beneficial uses.	Table 4. Maximum Contaminant Levels Inorganic Chemicals for waters designated as MUN (Municipal and Domestic Supply). Beneficial uses of waters used for community, military, or individual water supply systems including, but not limited to, drinking water supply.	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
9	Bishop Paiute Tribe	Yes	Bishop Paiute Tribe Water Quality Control Plan	AGR Agricultural Supply Designated uses of waters used for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, and support of vegetation for range grazing.	The concentration of toxic pollutants for all surface waters shall not exceed the more stringent of the aquatic life criteria for freshwater or the human health concentration criteria for consumption of water and organisms or for consumption of organisms only in the priority toxic pollutant table of the U.S. EPA National Recommended Water Quality Standards, 2002, or the most recent version. Waters designated as MUN shall not contain concentrations of chemical constituents in excess of the maximum contaminant level (MCL) specified in the California Department of Health Services (DHS) MCLs. Waters designated as AGR shall not contain concentrations of chemical constituents in amounts that adversely affect designated uses (i.e., agricultural purposes). Waters shall not contain concentrations of chemical constituents in amounts that adversely affect designated uses.	It references various sources but does not list specific Ag WQS for metals	References to Agriculture or AGR designations: In determining compliance with standards including references to the AGR designated Use, the Tribe will refer to water quality goals and recommendations from sources such as Natural Resources Conservation Service Irrigation - Handbooks and Manuals - National Engineering Handbook Part 652 - Irrigation Guide (210-vi-NEH, September 1997) and Water Quality for Agriculture, R.S. Ayers and D.W. Wescott, 1989.
9	Big Pine Indian Reservation, Big Pine Paiute Tribe of the Owens Valley	Yes	Water Quality Standards, Big Pine Indian Reservation, Big Pine Paiute Tribe of the Owens Valley	AGR Agricnltural Supply. Beneficial uses of waters used for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, and support of vegetation for range grazing.	Waters designated as MUN shall not contain concentrations of chemical constituents in excess of the maximum contaminant level (MCL) or secondary maximum contaminant level (SMCL) based upon drinking water standards specified in the following provisions: **Table 4 (Inorganic Chemicals)**,....Waters designated as AGR shall not contain concentrations of chemical constituents in amounts that adversely affect the water for beneficial uses.	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
9	Gila River Indian Community	No	Decision Document for the U.S. Environmental Protection Agency's Approval of the Gila River Indian Community's Application				
9	Havasupai Tribe	No	EPA website (https://www.epa.gov/wqs-tech/epa-actions-tribal-water-quality-standards-and-contacts)				
9	Hoopa Valley Tribe	Yes	Hoopa Valley Tribe, Water Quality Control Plan, Hoopa Valley Indian Reservation	Use Designation: (B) Agricultural Supply (AGR) includes crop, orchard and pasture irrigation, stock watering, support of vegetation for range grazing and all uses in support of farming and ranching operations.	Toxic substances shall not be introduced into waters within the boundaries of the Hoopa Valley Indian Reservation. Numeric criteria concentrations, which have the potential to either singularly or cumulatively adversely, affect beneficial water uses, cause acute or chronic toxicity to the most sensitive biota, or adversely affect public health. Additional standards for toxins that cause adverse effects from bioaccumulation are listed in Appendix F (this appendix consists of aquatic life and human health criteria for metals and other contaminants)	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
9	Hopi Tribe	Yes	Hopi Water Quality Standards Prepared by The Hopi Tribe Water Resources Program	G. Agricultural Irrigation (AgI) and Agricultural Livestock Watering (AgL). Agricultural irrigation means the use of surface waters for irrigation of crops. Agricultural livestock watering means the use of surface waters as a supply for water consumption by livestock.	Standards specific to the uses are presented in Appendix A.	AgI: - Al: 5.0 mg/L, dissolved; Co: 0.05 mg/L, dissolved; Li: 2.5 mg/L, dissolved; Mo: 0.01 mg/L, dissolved; V: 0.1 mg/L, dissolved; As: 2000 µg/L, total recoverable; Cd: 50 µg/L; Cr: 1000 µg/L, total recoverable; Cu: 5000 µg/L, total recoverable; Pb: 10,000 µg/L, total recoverable; Mn: 10,000 µg/L; Se: 20 µg/L, total recoverable; V: 100 µg/L; Zn: 10,000 µg/L. AgL: Al: 5.0 mg/L, dissolved; Co: 1.0 mg/L, dissolved; V: 0.1 mg/L; As: 200 µg/L, total recoverable; Cd: 50 µg/L; Cr: 1000 µg/L, total; Cu: 500 µg/L, total recoverable; Pb: 100 µg/L, total recoverable; Hg: 10 µg/L, total recoverable; Se: 50 µg/L, total recoverable; V: 100 µg/L; Zn: 25,000 µg/L, total recoverable	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards. Note that irrigation standards listed match the NAS & NAE 1972 20-year ones.
9	Hualapai Tribe	Yes	Hualapai Environmental Review Code, Subtitle I. Water Resources and Wetlands, Part I. Water Resources Ordinance	A. The purposes of this Ordinance are as follows: 5. To protect the health and welfare of the Hualapai people by ensuring that water is safe for recreation, drinking, domestic, and agricultural purposes. B. "Agricultural irrigation" or "AgI" means the use of a surface water for the irrigation of crops. C. "Agricultural use/livestock watering" or "AgL" means the use of a surface water as a supply of water for irrigation and livestock watering A. Designated uses of Tribal waters may include one or more of the following: 9.	Appendix A: Table 1. Human Health and Agricultural Designated Use Numeric Water Quality Standards	Cd: 50 µg/L (total recoverable) for both AgI and AgL; Cr (total): 1,000 µg/L for both AgI and AgL; Cu: 5,000 µg/L (total recoverable) for AgI and 500 µg/L (total recoverable) for AgL; Pb: 10,000 µg/L (total recoverable) for AgI and 100 µg/L for AgL; Mn: 10,000 µg/L for AgI; Hg: 10 µg/L (total recoverable) for AgL; Se: 20 µg/L (total recoverable) for AgI and 50 µg/L (total recoverable) for AgL; and Zn: 10,000 µg/L (total recoverable) for AgI and 25,000 µg/L (total recoverable) for AgL.	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards. Note that irrigation standards listed match the NAS & NAE 1972 20-year ones.

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
				Agricultural irrigation, 10. Agricultural use/Livestock watering			
9	Lac du Flambeau Tribe	Yes	Lac du Flambeau Water Quality Standards	104.A: (4) Wild Rice. Supporting wild rice habitat for sustainable growth and consumption. (5) Water Supply. Supports the use of water for industrial, agricultural, or aquaculture purposes.	Aquatic life standards criteria and human health standards for metals and other contaminants are provided in Tables 2 and 3	No	No
9	Navajo Nation	Yes	Navajo Nation Surface Water Quality Standards 2007	103 Purpose: The purpose of these surface water quality standards is to protect, maintain, and improve the quality of Navajo Nation surface waters for public and private drinking water supplies; to promote the habitation, growth, and propagation of native and other desirable aquatic plant and animal life; to protect existing, and future, domestic, cultural, agricultural, recreational and industrial uses; and to protect any other existing and future beneficial uses of Navajo Nation surface waters. "Agricultural Water Supply (AgWS)" means the use of the water for the irrigation of crops that could be used for human consumption. "Livestock Watering (LW)" means water used by livestock for consumption (ingestion).	Table 206.1. Numeric Surface Water Quality Standards (including metals) for aquatic life, human health, agricultural water supply livestock watering, and other uses	Agricultural Water Supply (total): As: 2000 µg/L; Cd: 50 µg/L; Cr: 1000 µg/L; Co: 50 µg/L; Cu: 200 µg/L (dissolved); Pb: 10000 µg/L; **Mo: 1000 µg/L (dissolved);** Se: 20 µg/L; V: 100 µg/L (dissolved); Zn: 10000 µg/L Livestock Watering (total): As: 200 µg/L; Cd: 50 µg/L; Cr: 1000 µg/L; Co: 1000 µg/L; Cu: 500 µg/L (dissolved); Pb: 100 µg/L; Se: 50 µg/L; V: 100 µg/L (dissolved); Zn: 25000 µg/L	No, but the ones listed match the NAS & NAE 1972 criteria, except for Mo; not all of the NAS & NAE 1972 criteria are listed in these standards. Note that some irrigation standards listed match the NAS & NAE 1972 20-year ones.
9	Pyramid Lake Paiute Tribe	Yes	Pyramid Lake Paiute Tribe Water Quality Control Plan	IRRG - Irrigation. Beneficial uses of water for the purpose of irrigation including, but not limited to, farming, horticulture, range and range vegetation (TR/PS/SWB). LSWT - Livestock Watering. For the purpose of watering range and farm livestock (TR/PS/SWB). Waters designated as IRRG or LSWT shall not contain concentrations of chemical	Table II. 4 Numeric Standards of Water Quality - Additional Standards Which Apply to Either Pyramid Lake or the Truckee River†	Al: 5000 µg/L for both IRRG and LSWT; Co: 50 µg/L for IRRG and **5000 µg/L for LSWT**; Fe: 5000 µg/L for IRRG; Mn: 200 µg/L for IRRG; Mo: 10 µg/L for IRRG; V: 100 µg/L for IRRG.	No, but the ones listed match the NAS & NAE 1972 criteria; not all of the NAS & NAE 1972 criteria are listed in these standards. Note that the livestock standards for Co listed in NAS & NAE 1972 is 1 mg/L (or 1,000 µg/L). References National

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
				constituents in amounts that adversely affect their beneficial uses for agricultural purposes.			Academy of Sciences – 1972.
9	Twenty-nine Palms Band of Mission Indians	Yes	Twenty-nine Palms Band of Mission Indians Tribal Water Quality Standards	agricultural (AGR) and wildlife and livestock habitat (WILD) designated uses Uses of water include pasture and crop irrigation, stock watering, horticulture, and support of vegetation for range grazing, as well as other miscellaneous uses in support of farming and ranching. Uses of water include those that support terrestrial ecosystems including, but not limited to, the preservation and enhancement of terrestrial habitats, vegetation, wildlife, livestock, and the water and food sources.	Tribal waters shall not contain concentrations of chemical constituents in excess of the limits specified in the U.S. EPA 2002 National Recommended Water Quality Criteria (See Priority Toxic Pollutants Table in Appendix A) with the exception of Arsenic, which shall not exceed the National Drinking Water Standard of 10 µg/L.	No	No
9	White Mountain Apache Tribe of the Fort Apache Indian Reservation	Yes	Water Quality Protection Ordinance, White Mountain Apache Tribe of the Fort Apache Indian Reservation	Designated uses include irrigation and livestock and wildlife	Section 3.6 - Designated Uses and Specific Standards lists specific standards for tribal designated uses	Irrigation (dissolved): Al: 5.0 mg/L; Cd: 0.01 mg/L; Cr: 0.10 mg/L; Co: 0.05 mg/L; Cu: 0.20 mg/L; Pb: 5.0 mg/L; Mo: 0.01 mg/L; **Se: 0.13** mg/L; V: 0.1 mg/L; Zn: 2.0 Livestock and Wildlife (dissolved): Al: 5.0 mg/L; Cd: 0.05 mg/L; Cr: 1.0 mg/L; Co: 1.0 mg/L; Cu: 0.5 mg/L; Pb: 0.1 mg/L; **Se (total):**	No, but the ones listed match the NAS & NAE 1972 criteria, except for Se; not all of the NAS & NAE 1972 criteria are listed in these standards.

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
						0.002 mg/L; V: 0.1 mg/L; Zn: 25.0 mg/L	
10	Colville Confederated Tribes Indian Reservation	Yes	40 CFR § 131.35	(1) Class I (Extraordinary)—(i) Designated uses. The designated uses include, but are not limited to, the following: (A) Water supply (domestic, industrial, **agricultural**) (2) Class II (Excellent) —(i) Designated uses. The designated uses include but are not limited to, the following: (A) Water supply (domestic, industrial, **agricultural**). (3) Class III (Good) —(i) Designated uses. - The designated uses include but are not limited to, the following: (A) Water supply (industrial, **agricultural**).	Toxic, radioactive, nonconventional, or deleterious material concentrations shall be less than those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect designated water uses	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
10	Confederated Tribes of the Chehalis Reservation	Yes	Confederated Tribes of the Chehalis Reservation Surface Water Quality Standards	Class AA (extraordinary), (a) General Characteristic. Water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses. Class A (excellent), (a) General Characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses. Class B (good), (a) General Characteristic. Water quality of this class shall meet or exceed the requirements for most uses. (b) Characteristic uses. Characteristic uses shall include but not be limited to the following: (i) Water supply (domestic, industrial, agricultural)	Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the Department. Aquatic life and human health standards for metals and other contaminants are provided in Section 5. Toxic Substances	No	No
10	Confederated Tribes of the Umatilla Indian Reservation	Yes	Confederated Tribes of the Umatilla Indian Reservation, Water Quality Standards, Beneficial Uses, and Treatment Criteria	Designated Use 2 - Agricultural or Farm Water Supply	Table 3 provides water quality standards for toxic pollutants for metals and other contaminants for aquatic life and human health.	No	No
10	Confederated Tribes of the Warm Springs Indian Reservation of Oregon	Yes	Confederated Tribes of the Warm Springs Indian Reservation of Oregon Water Quality Standards, Beneficial Uses and Treatment Standards	Designated Use 4 - Irrigation; Designated Use 5 - Livestock watering	Table 3 Water Quality Standards Summary provides water quality standards for metals and other contaminants for aquatic life, human health, and drinking water	No	No
10	Kalispel Indian Reservation	Yes	Water Quality Standards Applicable to Waters within the Kalispel Indian Reservation	Agricultural Water Supply listed as a Designated Use	Table 2. Toxic Substances provides water quality standards for metals and other contaminants for aquatic life and human health	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
10	Lummi Indian Reservation	Yes	Water Quality Standards for Surface Waters of the Lummi Indian Reservation	17 LAR 07.030 General Water Use and Standards Classes, (a) Class AA (extraordinary), (1) General characteristic. Water quality of this class shall uniformly exceed the requirements for all or substantially all uses. (b) Class A (excellent), (1) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses. (c) Class B (good), (1) General characteristic. Water quality of this class shall meet or exceed the requirements for most uses. (d) Lake class (1) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses. (2) Characteristic uses. Characteristic uses shall include, but not be limited to, the following: (A) Water supply (domestic, commercial, municipal, industrial**, agricultural**).	Table 4. Toxic Substance Standards for Surface Waters of the Lummi Indian Reservation Aquatic Life Standards Human provides water quality standards for metals and other contaminants for aquatic life and human health	No	No
10	Makah Tribe Water	Yes	Makah Tribe Water Quality Standards for Surface Waters	The following uses are designated for protection of the fresh surface waters of the Makah Indian Reservation: (1) Characteristic uses. Characteristic uses shall include, but not be limited to the following: (a) Ceremonial and religious; (b) Cultural; (c) Water supply (domestic, industrial, **agricultural**).	Table A-1. National Recommended Water Quality Standards for Priority Pollutants provides water quality standards for metals and other contaminants for aquatic life and human health	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
10	Port Gamble S'Klallam Tribe	Yes	Port Gamble Skallam Tribe Water Quality Standards for Surface Waters	(1) The designated uses for which the fresh surface waters of the Port Gamble S'Klallam Reservation are to be protected include, but are not limited to, the following: (a) Domestic Water Supply. Surface waters which are suitable or intended to become suitable for drinking water supplies. **(b) Agricultural Water Supply. Surface waters which are suitable or intended to become suitable for the irrigation of crops or as drinking water for livestock.**	Water Quality Standards for Toxic Pollutants table provides water quality standards for metals and other contaminants for aquatic life and human health	Not for metals	No
10	Puyallup Tribe	Yes	Water Quality Standards for Surface Waters of the Puyallup Tribe	Section 4. General Water Use and Standards Classes. The following standards shall apply to the various classes of surface waters of the Puyallup Tribe: (1) Class AA (extraordinary). (a) General characteristic. Water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses. (2) Class A (excellent). (a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses. (3) Class B (good). (a) General characteristic. Water quality of this class shall meet or exceed the requirements for most uses. (5) Lake class. (a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses. (b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following: (i) Water supply (domestic, industrial, **agricultural**).	A water quality standards table for aquatic life and a water quality table for human health are provided; they contain standards for metals and other contaminants.	No	No

Table A-4. Compilation of Tribes Agricultural Water Quality Standards

EPA Region	Tribe	Has WQS?	Source	Does Tribe Have Standards for Protection of Agriculture?	Overarching General WQS Relevant to Metals?	Specific Agricultural WQS for Metals?	Methodology on How Agricultural WQS Developed?
10	Spokane Tribe of Indians	Yes	Spokane Tribe of Indians Surface Water Quality Standards	(1) Class AA (Extraordinary), (a) General characteristics. Water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all designated uses. (2) Class A (Excellent), (a) General characteristics. Water quality of this class shall meet or exceed the requirements for all or substantially all designated uses. (3) Lake Class, (a) General characteristics. Water quality of this class shall meet or exceed the requirements for all or substantially all designated uses, particularly cultural, fish and shellfish, and domestic water supply uses. (b) Designated uses. Designated uses shall include, but not be limited to, the following: (iii) Water supply (domestic, industrial, **agricultural**)	A water quality standards table for aquatic life and a water quality table for human health are provided; they contain standards for metals and other contaminants.	No	No
10	Coeur d'Alene Tribe	Yes	Water Quality Standards for Approved Surface Waters of the Coeur D'Alene Tribe and Technical Support Document for Action on the Water Quality Standards for Approved Surface Waters of the Coeur d'Alene Tribe	(2) Agricultural Water Supply. Surface waters which are suitable or intended to become suitable for the irrigation of crops or as drinking water for livestock.	A water quality standards table for aquatic life and human health is provided; they contain standards for metals and other contaminants.	No	No

Note: Tribes with water quality standards identified on U.S. EPA's website (https://www.epa.gov/wqs-tech/epa-actions-tribal-water-quality-standards-and-contacts)

Table A-5. Livestock Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards.

Metal	Sources Cited in State and Tribal Water Quality Standards								
	NAS & NAE 1972	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972)**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Looper et al. 2002 Oklahoma Upper Limits for Cattle**	**Hicks 2002 - Washington State Dept of Ecology (cites Univ of California 1974)**	**Raisbeck, et al. 2007**
Aluminum	5 mg/L	---	---	5 mg/L	5.0 mg/L	5 mg/L	0.50 ppm	5,000 µg/L	---
Arsenic	0.2 mg/L	0.05 mg/L	---	0.2 mg/L	0.2 mg/L	0.01 mg/L	0.05 ppm	200 µg/L	1 mg/L short (days-weeks exposure); 1 mg/L chronic (months) exposure
Barium	---	---	---	---	---	10 mg/L	10.0 ppm	---	---
Beryllium	---	---	---	No data	0.1 mg/L (criteria for aquatic life used)	No data	---	---	---
Cadmium	50 µg/L	0.01 mg/L	---	0.05 mg/L	0.05 mg/L	0.05 mg/L	0.005 ppm	50 µg/L	---
Chromium	1.0 mg/L	0.05 mg/L as hexavalent chromium	---	1.0 mg/L	1.0 mg/L	1 mg/L	0.10 ppm	1000 µg/L	---
Cobalt	1.0 mg/L	---	---	1.0 mg/L	1.0 mg/L	1 mg/L	1.0 ppm	1000 µg/L	---
Copper	0.5 mg/L	---	---	0.5 mg/L	0.5 mg/L	0.5 mg/L (dependent on Mo and sulfate)	1.0 ppm	500 µg/L	---
Iron	N/A, but a few ppm of iron can cause clogging of lines to stock watering equipment or an undesirable staining and deposit on the equipment itself	---	---	No data	Not needed	over 0.3 mg/L may affect taste	2.0 ppm	---	---
Lead	0.1 mg/L	0.05 mg/L	---	0.1 mg/L	0.1 mg/L (criteria for aquatic life used)	0.1 mg/L	0.015 ppm	100 µg/L	---

Table A-5. Livestock Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards.

Metal	Sources Cited in State and Tribal Water Quality Standards								
	NAS & NAE 1972	FWPCA 1968	EPA 1976	Ayers and Westcot 1976	Ayers and Westcot 1985 (Adapted from NAS & NAE 1972)	Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)	Looper et al. 2002 Oklahoma Upper Limits for Cattle	Hicks 2002 - Washington State Dept of Ecology (cites Univ of California 1974)	Raisbeck, et al. 2007
Lithium	---	---	---	---	---	---	---	---	---
Magnesium	---	---	---	---	< 250 mg/L for poultry and swine; 250 mg/L for horses, cows (lactating), ewes with lambs; 400 mg/L for beef cattle; 5000 mg/L for adult sheep on dry feed	> 125 mg/L	---	---	---
Manganese	A few mg/L	---	---	No data	0.05 mg/L (human drinking water value)	>0.05 mg/L may affect taste	0.05 ppm	---	---
Mercury	10 µg/L; this limit provides an adequate margin of safety to humans who will subsequently not be exposed to as much as 0.5 ppm of mercury through the consumption of animal tissue.	---	0.05 µg/L	0.01 mg/L	0.01 mg/L	0.01 mg/L	0.01 ppm	10 µg/L	---

Table A-5. Livestock Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards.

Metal	Sources Cited in State and Tribal Water Quality Standards								
	NAS & NAE 1972	FWPCA 1968	EPA 1976	Ayers and Westcot 1976	Ayers and Westcot 1985 (Adapted from NAS & NAE 1972)	Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)	Looper et al. 2002 Oklahoma Upper Limits for Cattle	Hicks 2002 - Washington State Dept of Ecology (cites Univ of California 1974)	Raisbeck, et al. 2007
Molybdenum	---	---	---	No data	---	No data	---	500 µg/L	0.3 mg/L short (days-weeks exposure); 0.3 mg/L chronic (months) exposure
Nickel	---	---	---	---	---	---	0.25 ppm	---	---
Selenium	0.05 mg/L	0.01 mg/L	---	0.05 mg/L	0.05 mg/L	0.05 mg/L	0.05 ppm	50 µg/L	0.1 short (days-weeks exposure); 0.1 mg/L chronic (months) exposure
Vanadium	0.1 mg/L	---	---	0.10 mg/L	0.10 mg/L	0.10 mg/L	0.10 ppm	100 µg/L	---
Zinc	25 mg/L	---	---	24 mg/L	24.0 mg/L	25 mg/L	5.0 ppm	25,000 µg/L	---

Missing reference: University of California. 1974. Guidelines for Interpretation of Water Quality for Agriculture. University of California, Committee of Consultants. Farm and Home Advisors Office. Ventura, California.

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

	Sources Cited in State and Tribal Water Quality Standards									
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
Aluminum	5.0 mg/L - continuous use on all soils; 20 mg/L - use on fine textured neutral to alkaline soils over a period of 20 years.	1.0 mg/L for water used continuously on all soils and 20.0 mg/L for short-term use on fine textured soils only	---	5.0 mg/L for waters continuously used on soils; 20 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	5 mg/L for water used continuously on all soils; 20 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	5.0 mg/L	5.0 mg/L long-term; 20 mg/L short-term	5.0 mg/L	---	5000 µg/L
Arsenic	0.10 mg/L for continuous use on all soils; 2 mg/L for use up to 20 years on fine textured neutral to alkaline soils	1.0 mg/L for water used continuously on all soils and 10.0 mg/L for short-term use on fine textured soils only	0.10 mg/L for continuous use on all soils	0.1 mg/L for waters continuously used on soils; 2.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.1 mg/L for water used continuously on all soils; 2.0 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.10 mg/L	0.10 mg/L long-term; 2.0 mg/L short-term	0.10 mg/L	100 µg/L (cites U.S. EPA 1976)	100 µg/L
Barium	---	---	---	---	---	---	---	---	---	---
Beryllium	0.10 mg/L for continuous use on all soils; 0.50 mg/L for use on neutral to alkaline fine textured soils for a 20-year period.	0.5 mg/L for water used continuously on all soils and 1.0 mg/L for short-term use on fine textured soils only	0.10 mg/L for continuous use on all soils; 0.50 mg/L for use on neutral to alkaline fine textured soils for a 20-year period.	0.1 mg/L for waters continuously used on soils; 0.5 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.1 mg/L for water used continuously on all soils; 0.5 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.10 mg/L	0.10 mg/L long-term; 0.5 mg/L short-term	0.10 mg/L	100 µg/L (cites U.S. EPA 1972,1976)	100 µg/L

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

	Sources Cited in State and Tribal Water Quality Standards									
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
Cadmium	0.010 mg/L for continuous use on all soils; 0.050 mg/L on neutral and alkaline fine textured soils for a 20-year period	0.005 mg/L for water used continuously on all soils and 0.05 mg/L for short-term use on fine textured soils only	---	0.01 mg/L for waters continuously used on soils; 0.05 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.01 mg/L for water used continuously on all soils; 0.05 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.01 mg/L	0.01 mg/L long-term; 0.05 mg/L short-term	0.01 mg/L	10 µg/L (cites U.S. EPA 1972)	10 µg/L
Chromium	0.1 mg/L is recommended for continuous use on all soils; 1.0 mg/L on neutral and alkaline fine textured soils for a 20-year period	5.0 mg/L for water used continuously on all soils and 20.0 mg/L for short-term use on fine textured soils only	---	0.1 mg/L for waters continuously used on soils; 1.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.1 mg/L for water used continuously on all soils; 1 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.10 mg/L	0.1 mg/L long-term; 1.0 mg/L short-term	0.10 mg/L	100 µg/L (cites U.S. EPA 1972) for Cr VI	100 µg/L
Cobalt	0.050 mg/L for continuous use on all soils; 5.0 mg/L for neutral and alkaline fine-textured soils for a 20-year period.	0.2 mg/L for water used continuously on all soils and 10.0 mg/L for short-term use on fine textured soils only	---	0.05 mg/L for waters continuously used on soils; 5.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.05 mg/L for water used continuously on all soils; 5 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.05 mg/L	0.05 mg/L long-term; 5.0 mg/L short-term	0.05 mg/L	---	50 µg/L
Copper	0.20 mg/L copper is recommended for continuous use on all soils; 5.0 mg/L is recommended for neutral and	0.2 mg/L for water used continuously on all soils and 5.0 mg/L for short-term use on fine textured soils only	---	0.2 mg/L for waters continuously used on soils; 5.0 mg/L for use up to 20 years on fine	0.2 mg/L for water used continuously on all soils; 5 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.20 mg/L	0.2 mg/L long-term; 5.0 mg/L short-term	0.20 mg/L	200 µg/L (cites U.S. EPA 1972)	200 µg/L

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

Sources Cited in State and Tribal Water Quality Standards										
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
	alkaline fine textured soils for use over a 20-year period			textured soils of pH 6.0 to 8.5						
Iron	5.0 mg/L - continuous use on all soils; 20 mg/L - neutral to alkaline soils for a 20-year period. The use of waters with large concentrations of suspended freshly precipitated iron oxides and hydroxides is not recommended, because these materials also increase the fixation of phosphorous and molybdenum	---	---	5.0 mg/L for waters continuously used on soils; 20.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	5 mg/L for water used continuously on all soils; 20 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	5.0 mg/L	5.0 mg/L long-term; 20.0 mg/L short-term	5.0 mg/L	---	5000 µg/L
Lead	5.0 mg/L for continuous use on all soils; 10 mg/L for a 20-year period on neutral and	5.0 mg/L for water used continuously on all soils and 20.0 mg/L for short-term use on fine	---	5.0 mg/L for waters continuously used on soils; 10.0 mg/L for use up to 20 years on fine	5 mg/L for water used continuously on all soils; 10 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	5.0 mg/L	5.0 mg/L long-term; 10.0 mg/L short-term	5.0 mg/L	100 µg/L (cites U.S. EPA 1972)	5000 µg/L

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

Sources Cited in State and Tribal Water Quality Standards										
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
	alkaline fine textured soils.	textured soils only		textured soils of pH 6.0 to 8.5						
Lithium	2.5 mg/L for continuous use on all soils, except for citrus where the recommended maximum concentration is 0.075 mg/L for all soils. For short-term use on fine textured soils the same maximum concentrations are recommended because of lack of inactivation in soils.	5.0 mg/L for water used continuously on all soils and 5.0 mg/L for short-term use on fine textured soils only	---	2.5 mg/L for waters continuously used on soils; 2.5 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	2.5 mg/L for water used continuously on all soils; 2.5 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	2.5 mg/L	2.5 mg/L long-term; 2.5 mg/L short-term	---	---	2500 µg/L
Magnesium	---	---	---	---	---	---	---	---	---	---

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

Sources Cited in State and Tribal Water Quality Standards										
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
Manganese	0.20 mg/L for continued use on all soils ; 10 mg/L for use up to 20 years on neutral and alkaline fine textured soils. Concentrations for continued use can be increased with alkaline or calcareous soils, and also with crops that have higher tolerance levels.	2.0 mg/L for water used continuously on all soils and 20.0 mg/L for short-term use on fine textured soils only	---	0.2 mg/L for waters continuously used on soils; 10.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.2 mg/L for water used continuously on all soils; 10 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.20 mg/L	0.2 mg/L long-term; 10.0 mg/L short-term	0.20 mg/L	200 µg/L (cites U.S. EPA 1972)	200 µg/L
Mercury	---	---	---	---	---	---	---	---	---	---
Molybdenum	0.010 mg/L – continued use on soils based on animal toxicities from forage. 0.050 mg/L - short term use on soils that react with this element	0.005 mg/L for water used continuously on all soils and 0.05 mg/L for short-term use on fine textured soils only	---	0.01 mg/L for waters continuously used on soils; 0.05 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5 - for acid fine textured soils with relatively high iron oxide	0.01 mg/L for water used continuously on all soils; 0.05 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.01 mg/L	0.01 mg/L long-term; 0.05 mg/L short-term	0.01 mg/L	300 µg/L (cites Raisbeck et al. 2007 - intended to protect livestock from effects of molybdenosis)	10 µg/L

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

	Sources Cited in State and Tribal Water Quality Standards									
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
Nickel	0.20 mg/L for continued uses on all soils; 2.0 mg/L for neutral fine textured soils for a period up to 20 years.	0.5 mg/L for water used continuously on all soils and 2.0 mg/L for short-term use on fine textured soils only	Concentrations of nickel at or below 100 µg/L should not be harmful to irrigated plants or marine and freshwater aquatic organisms	0.2 mg/L for waters continuously used on soils; 2.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.2 mg/L for water used continuously on all soils; 2 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.20 mg/L	0.2 mg/L long-term; 2.0 mg/L short-term	0.20 mg/L	---	200 µg/L
Selenium	With the low levels of selenium required to produce toxic levels in forages, the recommended maximum concentration in irrigation waters is 0.02 mg/L for continuous use on all soils. The same recommended maximum concentration should be used on neutral and alkaline fine textured soils until greater infomraiton is	0.05 mg/L for water used continuously on all soils and 0.05 mg/L for short-term use on fine textured soils only	---	0.02 mg/L for waters continuously used on soils; 0.02 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.02 mg/L for water used continuously on all soils; 0.02 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.02 mg/L	0.02 mg/L long-term; 0.02 mg/L short-term	0.02 mg/L	20 µg/L (cites U.S. EPA 1972 and Parmetrix 1976)	20 µg/L

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

Metal	NAS & NAE 1972	FWPCA 1968	EPA 1976	Ayers and Westcot 1976	Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)	Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)	Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)	California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)	Colorado Department of Public Health and Environment Reg. No. 31 (2018)	Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)
	obtained on soil reactions.									
Vanadium	0.10 mg/L - continued use on all soils. 1.0 mg/L - 20-year period on neutral and alkaline fine textured soils.	10.0 mg/L for water used continuously on all soils and 10.0 mg/L for short-term use on fine textured soils only	---	0.1 mg/L for waters continuously used on soils; 1.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	0.1 mg/L for water used continuously on all soils; 1 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	0.10 mg/L	0.1 mg/L long-term; 1.0 mg/L short-term	0.10 mg/L	---	100 µg/L
Zinc	2.0 mg/L for continuous use on all soils, assuming adequate use of liming materials to keep pH >6 10 mg/L for a 20-year period on	5.0 mg/L for water used continuously on all soils and 10.0 mg/L for short-term use on fine textured soils only	---	2.0 mg/L for waters continuously used on soils; 10.0 mg/L for use up to 20 years on fine textured soils of pH 6.0 to 8.5	2.0 mg/L for water used continuously on all soils; 10 mg/L for up to 20 years on fine-textured soils of pH 6. to 8.5	2.0 mg/L	2.0 mg/L long-term; 10.0 mg/L short-term	2.0 mg/L	2000 µg/L (cites U.S. EPA 1972)	2000 µg/L

Table A-6. Crop Irrigation Numeric Standards from U.S. EPA and Other Sources Cited in State and Tribal Water Quality Standards

Sources Cited in State and Tribal Water Quality Standards										
Metal	**NAS & NAE 1972**	**FWPCA 1968**	**EPA 1976**	**Ayers and Westcot 1976**	**Pick 2011 - USDA Tech Note (Cites NAS & NAE 1972)**	**Ayers and Westcot 1985 (Adapted from NAS & NAE 1972 and Pratt 1972)**	**Fipps 2003 Texas A&M (cites Rowe and Abel-Magid 1995)**	**California EPA 2000 (cites Ayers and Westcot 1985 as the primary source)**	**Colorado Department of Public Health and Environment Reg. No. 31 (2018)**	**Hicks 2002 - Washington State Dept of Ecology (cites NAS & NAE 1972)**
	netural and alkaline soils; on fine textured calcareous soils and on organic soils, the concentrations can exceed this limit by a factor of two or three with low probability of toxicities in a 20-year period									

Missing references:

Pratt, P.F. 1972. Quality criteria for trace elements in irrigation waters. Calif. Agric. Expt. Sta. 46p

Source: Rowe, D.R. and L.M. Abdel-Magid. 1995. Handbook of Wastewater Reclamation and Reuse. CRC Press Inc. 550 pp (it looks like they used U.S. EPA's standards, so I'm not sure it's necessary to find)

Appendix B: Metal Toxicity to Plants: Description of Information from NAE and NAS 1972 and other Published Literature

This Appendix provides background supporting information for the NAS and NAE 1972 criteria for toxicity to plants, as well as summarizing additional published reports

B.1. Aluminum (Al)

Al has been recognized as one of the main causes of nonproductivity in acid soils. Toxicity and reduced growth in plants has been observed at Al concentrations of 1 mg/L and 0.1 mg/L Al in nutrient solutions. Most irrigated soils are naturally alkaline, and many are buffered with calcium carbonate, and therefore have great capacities to precipitate soluble Al and to prevent its toxicity to plants. It has been recommended that acidic soils (pH<5.5) be treated with limestone to reduce the toxicity of Al (NAS & NAE 1972). It was estimated in NAS & NAE (1972) that at irrigation rates of 3-acre feet of water/year, 11.5 tons per acre calcium carbonate would be needed for the 5 mg/L Al concentration for 100 years, and 9 tons/acre calcium carbonate equivalent would be needed for the 20 mg/L Al concentration for 20 years.

U.S. EPA Recommended Criterion: 5.0 mg/L Al for continuous use on all soils; 20 mg/L for use on fine textured neutral to alkaline soils over a period of 20 years.

B.2. Arsenic (As)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), levels of 0.5 mg/L arsenic in nutrient solutions reduced crop growth. Assuming that the added As is mixed with the surface six inches of soil and that it is in the arsenate form, it was indicated in NAS & NAE (1972) that the amounts that would produce toxicity for sensitive plants varied from 10 lb/acre for sandy soils to 300 lb/acre for clay soils. NAS & NAE (1972) indicated that the possible leaching of As in sandy soils and reversing to less soluble and less toxic forms of As over time would allow for higher amounts to cause toxicity (i.e., 200 lb/acre in sandy soils and 600 lb/acre in clay soils) over many years. The standards were based on the assumption that 3-acre feet of water are used per acre per year (1 mg/L equals 2.71 lb/acre foot of water), and that the added As becomes mixed in a 6-inch layer of soil. NAS & NAE (1972) indicated that removal of small amounts in harvested crops provides an additional safety factor.

U.S. EPA Recommended Criterion: 0.10 mg/L As for continuous use on all soils; 2 mg/L for use up to 20 years on fine textured neutral to alkaline soils.

As is not considered an essential plant nutrient (Verbruggen et al. 2009). It is taken up through the same plant transport mechanism as phosphate (P), and the toxicity of the arsenate form may be due in part to P replacement in cellular metabolism. The reduced arsenite form can, like Cd, act as a sulphur-seeking ion. Rice in particular is noted as taking up significant amounts of As from soil. However, As is considered less bioavailable than Cd, and large fractions of the As taken up (50%-85%) can be eliminated by root efflux (Verbruggen et al. 2009). Some plants (ferns in the family Pteridaceae) have evolved high tolerance to As through exclusion mechanisms; and a few are 'hyperaccumulators' (to concentrations >0.1%) (Verbruggen et al. 2009). As causes oxidative stress and is also mutagenic.

While the above studies provide useful information regarding arsenic effects on plants, a potential threshold or standard was not provided in these references. Currently the best information available for setting a water quality standard for arsenic for protection of crops is based on the NAS &NAE (1972) published document

B.3. Beryllium (Be)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), concentrations of Be ranging from 0.5 mg/L to 5 mg/L in nutrient solutions caused toxicity or reduced growth in various crops. Given a recommended Be concentration in irrigation water of 0.1 mg/L (see Table A-4), approximately 80 pounds of Be would be added in 100 years (NAS & NAE 1972) 0.1 mg/L (or in 20 years at a concentration of 0.5 mg/L) at an average irrigation rate of 3-acre feet of water per acre per year.

U.S. EPA Recommended Criterion: 0.10 mg/L Be for continuous use on all soils; 0.50 mg/L Be for use on neutral to alkaline fine textured soils for a 20-year period (as recommended by U.S. EPA and in multiple state and tribal standards, Table A-4).

B.4. Cadmium

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), decreases in crop yields were observed at concentrations ranging from 0.10 mg/L to 1.0 mg/L Cd in nutrient solutions.

U.S. EPA Recommended Criterion: 0.010 mg/L for continuous use on all soils; 0.050 mg/L on neutral and alkaline fine textured soils for a 20-year period.

Cd is not an essential plant nutrient (Verbruggen et al. 2009). It is taken up from soil via Ca, Fe, Mn and Zn transport processes. Excess Cd can result in chlorosis, inhibition of growth, browning of roots, and mortality (Asati et al. 2016, Das et al. 1997). Other effects of excess Cd on plants can include impaired uptake, transport, and use of Ca, Mg, P and K (Das et al. 1997); reduced nitrate activity including reduced nitrate absorption and nitrate transport from roots to shoots due to reduced nitrate reductase; and decreased nitrogen fixation and ammonia simulation (Hernandez et al. 1996, Mathys 1975, Balestrasse et al. 2003), and impaired water balance (Costa and Morel 1994). In addition to these and other impacts on cellular processes (e.g., Fodor et al. 1995, De Filippis and Ziegler 1993), Cd can impact seed germination, plant nutrient content, and growth (various references in Asati et al. 2016). The uptake of Cd may be active transport across cell membranes but is more widely considered to be mainly passive (Tran and Popova 2013).

In a lab-based experiment comparing homogenized soils treated with farmyard manure, John et al. (2009) found Cd to be more toxic to mustard (*Brassica juncea*) plants than Pb, causing greater declines in root length, shoot length, chlorophyll-a and-b content, and carotenoid and protein content at lower concentrations (Table 2-2). More Cd was also taken up by mustard than Pb, with greater accumulation in the roots than the shoots (John et al. 2009). However, maximum accumulation of both Cd and Pb was not observed at the highest experimental soil concentrations. For Cd exposures of 0, 150, 300, 450, 600, 750, and 900 µM, the maximum Cd accumulation in mustard root occurred at the 750 µM exposure (116.32 mg/g dw) (John et al. 2009). For Cd (and Pb), accumulation in roots (and shoots) declined at higher metal concentrations. The greater accumulation in roots than shoots suggests that roots of the mustard plant function as a barrier to Cd and Pb translocation (from roots to shoots). In contrast, the accumulation of

Cd and Pb in *Inula* species apparently reflects the lack of physiological barriers, allowing accumulation in aerial parts of the plant (Tamakhina et al. 2018).

In another lab study, Ghani (2010) found that Cd alone, or Cd plus several other metals (Co, Hg, Mn, Pb and Cr, in contrast to individual doses of these other metals) had the greatest effects on maize seedlings in terms of stunted shoot, root, and seed growth (see also Table B-1). They classified the relative phytotoxicity of the metals they studied as Cd > Co > Hg > Mn > Pb > Cr. In a lab (potted plant) study examining Cd, Pb, and Zn individual and combined toxicity on spinach, Alia et al. (2015) reported that Cd was more toxic (i.e. toxic at lower soil concentrations) than Pb or Zn (Table B-1**Error! Reference source not found.**). In addition, the combination of Cd + Pb and Cd + Zn were more toxic that Cd alone, though not as toxic as the sum of the individual metal toxicities.

While the above studies presented information regarding cadmium effects on various crops, none of these references provided clear toxicological thresholds that could be used to derive defensible water quality standards for protection of crops.

B.5. Chromium (Cr)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Cr

concentrations ranging between 0.5 mg/L in water cultures and 10 mg/kg in soil cultures reduced crop growth, with Fe deficiencies observed in several different crops. Because little is known about the accumulation of Cr in soils in relation to its toxicity, a concentration of less than 1.0 mg/L in irrigation waters is desirable. At a concentration of 1.0 mg/L, using 3-acre feet water/acre/yr, more than 80 lb of Cr would be added per acre in 100 years. Using a concentration of 1.0 mg/L for a period of 20 years and applying water at the same rate, approximately 160 pounds of Cr would be added to the soil.

U.S. EPA Recommended Criterion 0.1 mg/L is recommended for continuous use on all soils;1.0 mg/L on neutral and alkaline fine textured soils for a 20-year period is recommended (as recommended by U.S. EPA and in multiple state and tribal standards, Tables Table A-2 and Table A-4).

B.6. Cobalt (Co)

Co concentrations of 0.1 mg/L were found to be toxic to tomato plants and 5 mg/L were highly toxic to oats (NAS & NAE 1972). In neutral to alkaline pH soils, its reaction with soil increases with time; therefore, 5.0 mg/L might be tolerated in fine textured and neutral soils when added in small amounts annually.

U.S. EPA Recommended Criterion: 0.050 mg/L for continuous use on all soils; 5.0 mg/L for neutral and alkaline fine-textured soils for a 20-year period (as recommended by U.S. EPA and in multiple state and tribal standards, Tables Table A-2 and Table A-4).

B.7. Copper (Cu)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Cu concentrations ranging from 0.1 to 1.0 mg/L in nutrient solutions are toxic to many crops. Toxicity of crops in soils that had accumulated 800 lb/acre was observed. Cu toxicity in soils can be reduced by using lime (if the soil is acid), applying phosphate fertilizer, and applying Fe salts. A concentration of 0.20 mg/L in water used at a rate of 3-acre feet of water per year would add 160 pounds of Cu in 100 years, and a concentration of 5.0 mg/L in water used at a rate of 3-acre feet per year would add 800 pounds of Cu in 20 years.

U.S. EPA Recommended Criterion: 0.20 mg/L Cu is recommended for continuous use on all soils; on neutral and alkaline fine textured soils for use over a 20-year period, a maximum concentration of 5.0 mg/L is recommended.

Cu is a micronutrient for plants (Asati et al. 2016), playing a role in CO_2 assimilation and ATP synthesis (Pichhode and Nikhil 2015 in Asati et al. 2016). It is also an essential component of various proteins that are components of the photosynthetic system and the respiratory electron transport chain. Mining, smelting of Cu ores, and possibly other industries are sources of increased Cu in the environment, including in soils where it contributes to cytotoxicity in plants. Toxicity is evidenced by plant growth retardation and leaf chlorosis, plant mortality, reduced biomass and seed production, and root malformation and reduction (Asati et al. 2016). However, definitive threshold concentrations or ranges of threshold concentrations were not provided in these references.

B.8. *Iron (Fe)*

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Fe is unlikely to cause toxicity to plants because it is insoluble in aerated soils at pH levels at which plants grow well. Reduction in quality of cigar wrapper tobacco was observed at concentrations of 5 mg/L Fe in irrigation water, due to the precipitation of Fe oxides on leaves.

U.S. EPA Recommended Criterion: 5.0 mg/L is recommended for continuous use on all soils; 20 mg/L is recommended on neutral to alkaline soils for a 20-year period. In addition, the use of waters with large concentrations of suspended freshly precipitated Fe oxides and hydroxides is not recommended, because these materials also increase the fixation of phosphorous and Mo.

Iron is an essential element but can still be toxic to plants at higher concentrations (Connolly and Guerinot 2002). Fe is naturally abundant (>4% of both igneous and sedimentary rocks), with concentrations in soils of 0.2% to 55% (20,000 to 550,000 mg/kg) (U.S. EPA 2003). The trivalent (ferric) form is most abundant naturally, while the divalent (ferrous) form is more soluble and bioavailable; acidic and reducing conditions (which can include lowland and waterlogged soils) promote the soluble ferrous form and therefore the bioavailability of Fe (U.S. EPA 2003). As an essential element functioning in the formation of chlorophyll and in some enzymes of the respiratory system, plants regulate Fe uptake, with mechanisms to absorb and store Fe, including the production of a sequestering protein called ferrtin (Connolly and Guerinot 2002). In addition to natural soil conditions that provide limited bioavailable Fe, Fe deficiencies can be induced by excess Mn and Cu (U.S. EPA 2003). Thus, some of the apparent toxic effects of these metals, particularly chlorosis, are actually thought to be due to the induced Fe deficiency that occurs. There are potential interactions with soil nitrate, where increasing nitrate can lead to reduced Fe uptake; as well as with phosphate and Mo, which can also reduce Fe uptake. Zn deficiency, in contrast, can increase Fe uptake (U.S. EPA 2003).

Excess Fe has been associated with a variety of plant diseases, such as 'bronzing' of rice in flooded agriculture, and 'freckle leaf' in Hawaiian sugarcane (Foy et al. 1978). Foy et al. (1978) characterized soil concentrations of Fe >400ppm as toxic, and >500 ppm as highly toxic to rice (see also Table B-1). Excess concentrations of Cu, Ni, Zn, and P can induce Fe deficiency in plants, leading to chlorosis; while excess Fe can also make Zn deficiency worse (Foy et al. 1978).

The more recent information summarized above helps explain some of the dynamics involving effects if excess Fe on crops, relevant thresholds or ranges were not available with which to derive recommended water quality standards.

B.9. *Lead (Pb)*

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), lead nitrate concentrations of 25 mg/L caused toxicity to oat and tomato plants, and 10 mg/L lead nitrate caused reduced root growth in bean plants. Soluble Pb concentrations in soil range from approximately 0.05 to 5.0 mg/kg; therefore, little toxicity to crops would be expected at these concentrations.

U.S. EPA Recommended Criterion: 5.0 mg/L for continuous use on all soils; 10 mg/L for a 20-year period on neutral and alkaline fine textured soils.

Pb can impair photosynthesis by reducing chlorophyll content and can also reduce the uptake of Mg and Fe, which can further impair photosynthetic and enzymatic processes (Alia et al. 2015). At doses of 500 mg/kg added to potted soils, Pb significantly decreased growth of both shoots and roots of spinach (Alia et al. 2015; see Table B-1). Pb combined with Cd was more toxic than the toxicity of the individual metals; however, Pb combined with Zn was less toxic to spinach than Pb or Zn individually (Alia et al. 2015).

Maximum accumulation of Pb was not observed at the highest experimental soil concentrations in a lab-based experiment comparing homogenized soils treated with farmyard manure (John et al. 2009). For Pb exposures of 0, 150, 300, 600, 900, 1200, and 1500 µM, the maximum Pb accumulation in mustard (*Brassica juncea*) root occurred at the 1200 µM exposure (85.97 mg/g dw). For Pb (and Cd), accumulation in roots (and shoots) declined at higher metal concentrations. Bioaccumulation of lead and other metals is discussed in Section 2.4 ("Other relevant information").

B.10. Manganese (Mn)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), concentrations of a few tenths to a few milligrams per liter of Mn in nutrient solutions are toxic to a number of crops. Application of ground limestone can usually eliminate the toxicity of Mn in acidic soils, when the pH is increased to the 5.5 to 6.0 range.

U.S. EPA Recommended Criterion: 0.2 mg/L for continued use on all soils; 10 mg/L for use up to 20 years on neutral and alkaline fine textured soils. Concentrations for continued use can be increased with alkaline or calcareous soils, and also with crops that have higher tolerance levels.

B.11. Mercury (Hg)

No recommended standards or information is presented for Hg and crops in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972) or in other sources reviewed in this evaluation.

B.12. Molybdenum (Mo)

Mo does not cause toxicity in plants at concentrations usually found in soils and waters (NAS & NAE 1972). Mo concentrations of 0.10 mg/L or greater in soil solutions were shown to cause associated animal toxicity from consuming clover grown on these soils. In addition, molybdosis of cattle was associated with soils that contained 0.01 to 0.10 mg/L of Mo in saturation extracts of soils.

U.S. EPA Recommended Criteria: 0.010 mg/L for continued use of water on soils, based on animal toxicities from forage; 0.050 mg/L for short-term use on soils that react with Mo (as recommended by U.S. EPA and in multiple state and tribal standards, Tables Table A-2 and Table A-4)

B.13. Nickel (Ni)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Ni concentrations ranging from 0.5 to 1.0 mg/L in sand and solution cultures are toxic to a number of plants. Ni was found to be toxic to corn at 10 mg/L and no toxicity was observed in tobacco plants at 30 mg/L.

U.S. EPA Recommended Criterion: 0.2 mg/L for continued uses on all soils; 2.0 mg/L for neutral fine textured soils for a period up to 20 years.

While an essential element, Ni is usually found in low concentrations in plants, 0.05-10 mg/kg dry weight (Bhalerao et al. 2015). On average, soil concentrations of Ni are 2-750 mg/kg; farm soil concentrations of Ni are usually 3-1,000 mg/kg but can range up to 24,000 mg/kg in soils near metal refineries, and up to 53,000 mg/kg in dried sludge (Bhalerao et al. 2015). Excess Ni can reduce the uptake of Mg, Fe, and Zn, where reductions in Mg and Fe are a cause of chlorosis (Bhalerao et al. 2015). For example, increasing soil Ni concentration from 50 to 200 mg/kg can decrease Cu, Mg, and Ca in wheat.

B.14. Selenium (Se)

Se at 0.025 mg/L in nutrient solutions decreased yields of alfalfa (NAS & NAE 1972). Applications of Se to soil at a rate of a few kilograms per hectare produced plant concentrations of Se that causes toxicity to animals. Applications of approximately 0.2 kg/hectae of Se resulted in 1.0 to 10.5 mg/kg forage and vegetable crop tissues (NAS & NAE 1972).

U.S. EPA Recommended Criterion: 0.02 mg/L for continuous use on all soils, based on low levels of Se that cause toxic levels in forages (at a rate of 3 acre feet of water/acre/year this concentration represents 3.2 pounds per acre in 20 years). The relative mobility of this element in soils in comparison to other trace elemetns and slow removal in harvested crops produce a sufficient safety margin.

B.15. Vanadium (V)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), 10 mg/L V was toxic to barley. Flax, soybeans, and peas showed toxicity to V at a concentration range of 0.5 to 2.5 mg/L, and 560 pounds/acre of V added as ammonium matavanadate to rice paddy soils produced toxicity to rice.

U.S. EPA Recommended Criterion: 0.10 mg/L for continued use on all soils; 1.0 mg/L for a 20-year period on neutral and alkaline fine textured soils (as recommended by U.S. EPA and multiple state and tribal standards, Tables Table A-2 and Table A-4).

B.16. Zinc (Zn)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Zn in concentrations of 16 to 32 mg/L caused Fe deficiencies in sugar beets. Zn concentrations of 0.4 mg/L to 1.6 mg/L have killed soybeans. Liming acid soil has been shown to reduces Zn toxicity to plants. NAS & NAE (1972) indicated that toxicity of added Zn is highest in clay and peat soils, and lowest in sands.

U.S. EPA Recommended Criterion: 2.0 mg/L, assuming adequate use of liming materials to keep pH values high (≥ 6). For a 20-year period on neutral and alkaline soils the recommended maximum is 10 mg/L. On fine textured calcareous soils and on organic soils, the concentrations can exceed this limit by a factor of two or three with low probability of toxicities in a 20-year period.

Zn is also essential to plants, with a function in the production of chlorophyll (Asati et al. 2016). Zn deficiencies can be manifested in leaf discoloration (chlorosis) and stunted growth. Excess Zn (and Cd) can result in toxicity, with effects including a decrease in growth of roots and shoots; reduced development, germination, and metabolism; reduced production of chlorophyll, carotenoids, sugars, and amino acids; induced senescence and oxidative damage; and alteration of enzyme efficiencies.

Effects such as chlorosis can also result from a Zn -induced Fe deficiency, since hydrated form of Zn and Fe are similar in size (Marschner 1986). Zn can cause Mn and Cu (Cu) deficiencies in plants, possibly due to reduced transfer of nutrients from roots to shoots (Asati et al. 2016). Zn can also result in phosphorus deficiencies that are seen as purple or red leaf discoloration. In a lab study of rice and soybean plant responses to naturally collected contaminated soils with a combination of heavy metals, de Souza-Silva et al. (2014) found that Zn interfered with Fe metabolism, as a mechanism for observed chlorosis and associated plant toxic responses.

In a study evaluating the uptake and accumulation of 19 elements, including the metals As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn, in vegetables (including beans, broccoli, carrots, onions, and tomatoes) grown in reclaimed sediments from the 'Peoria Pool' of the Illinois River, Ebbs et al. (2006) found that only Zn (Zn) and Mo were accumulated in any of the vegetables to levels greater than those grown in reference soils. Zn was found up to 3X higher, and Mo up to 10X higher in beans.

In a lab study of growth effects on spinach, Alia et al. (2015) found Zn significantly reduced both shoot and root growth at relatively high concentrations (700 mg/kg; see Table B-1). Mixture of Zn with Pb reduced its toxicity.

Additional information regarding the toxicity of metals in soil to crops was identified and is presented below. This information has not used in calculating the water concentrations presented in this Report but does show that some studies have found that increasing levels of metals in soil may decrease plant health, growth, and crop yield.

Table B-1. Additional Information Identified regarding Metal Toxicity to Plants

Plant	Concentration (mg/kg unless otherwise indicated)	Effect	Reference
Cadmium			
Mustard (*Brassica juncea*)	300 µM	17% decline in root length; 4% decline in stem height	John et al. 2009
	900 µM	54% decline in root length; 51% decline in stem height; 80% decline in Chlorophyll-b; 80% decline in carotenoid content; 87% decline in protein content	
Maize seedling (*Zea maize*)	377.34 mg/kg	63.4% reduction in shoot growth (dry wt); 70.5% reduction in root growth (dry wt)	Ghani 2010
Spinach (*Spinacia oleracea*)	1.5 mg/kg	Reduced growth compared to control: Shoot length 18%; shoot wt (fresh) 25.3%; root length 19.7%; root wt (fresh) 35.1%	Alia et al. 2015
Sorghum	70 ppm and 150 ppm (cadmium nitrate)	Stress response indicated by increased MDA (malondialdehyde) and hydrogen peroxide content	Kumar and Pathak 2018
Iron			
Rice seedlings	490 ppm (at soil pH 3.6)	Seedling mortality	Foy et al. 1978
Lead			
Mustard (*Brassica juncea*)	900 µM	22% decline in root length; 23% decline in stem height; 35% decline in Chlorophyll-a; 24% decline in Chlorophyll-b	John et al. 2009
	1500 µM	50% decline in root length; 43% decline in stem height; 77% decline in protein content	
Maize seedling (*Zea maize*)	377.34 mg/kg	26.3% reduction in shoot growth (dry wt); 29.1% reduction in root growth (dry wt)	Ghani 2010
Spinach (*Spinacia oleracea*)	500 mg/kg	Reduced growth compared to control:	Alia et al. 2015

Table B-1. Additional Information Identified regarding Metal Toxicity to Plants

Plant	Concentration (mg/kg unless otherwise indicated)	Effect	Reference
		Shoot length 13%; shoot wt (fresh) 24.7%; root length 15.8%; root wt (fresh) 28.1%	
Nickel			
Wheat (*Triticum aestivum*)	Sand with 10 mM Ni in nutrient solution	Decreased leaf water potential, stomatal conductance, transpiration rate, total moisture content	Bishnoi et al. 1993 in Bhalerao et al. 2015
Wheat (*Triticum aestivum*)	1 mM $NiSO_4$ in nutrient solution	Decreased mesophyll thickness, size of vascular bundles, vessel diameter in main and lateral vascular bundles, width of epidermal cells in leaves.	Seregin and Kozhevnikova 2006 in Bhalerao et al. 2015
PIdegeon pea (*Cajanus cajan*)	sand with 1 mM $NiCl_2$ in nutrient solution	40% decrease in leaf area	Bhalerao et al. 2015
Cabbage/broccoli (*Brassica oleracea*)	Agar with 5–20 g/m^3 $NiSO_4.7H_2O$	Decreased leaf area	Bhalerao et al. 2015
Cabbage/broccoli (*Brassica oleracea*)	10–20 g/m^3 $NiSO_4$-$7H_2O$ in agar	Decreased volumes of intercellular spaces and palisade and sponge mesophyll, decrease in chloroplast size and numbers and the disorganization of chloroplast ultrastructure	Molas 1997 in Bhalerao et al. 2015
Alder (*Alnus glutinosa*)	0.025 mM	Decreased number of leaves (24%) and chlorophyll contents (47%)	Wheeler et al. 2001 in Bhalerao et al. 2015.
Maize	Increased concentration of Ni from 20 (control) to 100 µM (exposure)	Chlorophyll-a decreased 70%, chlorophyll-b decreased 50%	Wheeler et al. 2001 in Bhalerao et al. 2015.
Maize	250 and 500 µM Ni	No effects on chlorophyll content of maize leaves	Wheeler et al. 2001 in Bhalerao et al. 2015.
Zinc			
Tomato (*Lycopersicon esculentum*)	50 and 100 mg/kg treatments	Increased growth and yield parameters (root and shoot length, total leaf area and dry weight of root and shoot)	Vijayarengan and Mahalakshmi 2013

Table B-1. Additional Information Identified regarding Metal Toxicity to Plants

Plant	Concentration (mg/kg unless otherwise indicated)	Effect	Reference
	150, 200, and 250 mg/kg treatments	Decreased growth and yield parameters (root and shoot length, total leaf area and dry weight of root and shoot)	
able 3-1 (continued).Lambsquarters (*Chenopodium album*)	100.7, 300.7, 500.7, 900.7, 1300.7 and 2100.7 mg/kg	With increasing Zn concentration in soil, plant height, content of a, b, and total chlorophyll and biomass were decreased significantly ($p \leq 0.05$); tolerant at low and medium concentrations (<900 mg/kg),	Mirshekali et al. 2012
Sorghum (*Sorghum bicolor*)	100.7, 300.7, 500.7, 900.7, 1300.7 and 2100.7 mg/kg	With increasing Zn concentration in soil, plant height, content of a, b, and total chlorophyll and biomass were decreased significantly ($p \leq 0.05$); sorghum tolerated high concentrations of Zn.	Mirshekali et al. 2012
Spinach (*Spinacia oleracea*)	700 mg/kg	Reduced growth compared to control: Shoot length 3%; shoot wt (fresh) 23%; root length 12.7%; root wt (fresh) 14.4%	Alia et al. 2015

B.17. Factors Affecting Metals Bioaccumulations in Plants

Bioavailability, and thus the uptake of various heavy metals from soil, is affected by factors including the concentration of metals in the soil, the type of metal, their form in the soil matrix and solubility; soil characteristics (e.g., sediment particle size composition, organic content, pH), the type of plant, phase of development, and various plant adaptations that affect the uptake, bioaccumulation, and translocation of heavy metals in plants (Tamakhina et al. 2018, Asati et al. 2016, Khan et al. 2015, Shah et al. 2010, Verbruggen et al. 2009, Benavides et al. 2005). As an example, regarding soil type, Van Lune and Zwart (1997, in Stasinos et al. 2014) found Cd uptake in carrots to be greater when grown in sandy vs sandy loam soils, even though the sandy-loam soils had higher Cd concentrations. Cd binds to organic matter and clays in soils, so sandy soils with little organic matter or clay can be associated with higher Cd uptake (Derrick 2006). Li et al. (2005) found that both metal concentration in the soil and genotype affected the uptake of Cd by rice, but that at lower soil concentrations of metal, soil properties that affected Cd mobility were also influential. A summary of literature assessing bioaccumulation is provided in Table B-2 and discussed below.

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
Arsenic				
Bean (stem)	0.5 (0.1)	0.2 (<0.1)		Ebbs et al. 2006
Vegetables[1]	0.0326	--	15.5107	Liu et al. 2013
Carrot	1.2 (in red-sludge soil), 0.36 (in black-sludge soil)	0.11		Bunzl et al. 2001 in Stasinos et al. 2014
Carrot	Below DL	Below DL in control soil and carrots	178 µg/g	Pendergrass and Butcher 2006 in Stasinos et al. 2014
Onion	0.55 in leaves; 0.45 in bulbs		6.1 to 16.7 (irrigated with water <0.005 to 1.014 mg/L)	Dahal et al. 2008 in Stasinos et al. 2014
Onion	14.7 to 22.5 µg/kg			Bakkali et al. 2012 in Stasinos et al. 2014
Potato	Correlation between As content of soil and the water. Highest As in the roots than shoots > leaves > edible parts		6.1 to 16.7 (irrigated with water <0.005 to 1.014 mg/L)	Dahal et al. 2008 in Stasinos et al. 2014
Potato	0.03 to 0.07			Srek et al. 2010
Cadmium				
Pepper (fruit)	0.8 (0.1)	0.5 (0.1)		Ebbs et al. 2006
Carrot	--	0.12		Stasinos et al. 2014
Carrot	0.011	0.004		Kirkillis et al. 2012 in Stasinos et al. 2014
Vegetables[1]	0.0472	--	0.7206	Liu et al. 2013
Carrot	[uptake in carrots increased linearly with increasing soil concentrations]		0.87 to 7.0 mg/kg (in sandy soil); 0.21 to 2.8 mg/kg (in sandy loam soil)	Van Lune and Zwart 1997 in Stasinos et al. 2014
Carrots	0.15		0.06 mg/l in treated sewage added to soil	Ghosh et al. 2012 in Stasinos et al. 2014
Carrots	2.55 in leaves, 1.48 in tubers	0.1 in leaves, 0.08 in tubers	Grown in polluted river sediments	Van Driel et al. (1995) in Stasinos et al. 2014

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
Onion	0.12			Vincevica-Gaile et al. 2013 in Stasinos et al. 2014
Onion	23.6 to 32.3 μg/kg			Bakkali et al. 2012 in Stasinos et al. 2014
Onion	No significant difference in concentration in onion from Thiva basin and control sample			Kirkillis et al. 2012 in Stasinos et al. 2014
Potato	0.02 to 0.07			Srek et al. 2010
Potato	Cd levels in potato peels >> than peeled tubers; declined with increasing soil pH			Smith 1994 in Stasinos et al. 2014
Elecampane (*Inula helenium*, aka horse-heal, elfdock)	2.06±0.19 32 (BAR 1.78) (above ground biomass) 0.28±0.04 32 (BAR 2.04) (below ground biomass)	1.53±0.44 32 (BAR 3.48) (above ground biomass) 0.45±0.08 32 (BAR 1.02) (below ground biomass)		Tamakhina et al. 2018
yellowhead or meadow fleabane (*Inula britannica)*	0.47±0.06 32 (BAR 2.04) (above ground biomass) 0.35±0.09 32 (BAR 1.52) (below ground biomass)	0.97±0.09 32 (BAR 4.85) (above ground biomass) 0.88±0.07 32 (BAR 4.40) (below ground biomass)		Tamakhina et al. 2018
A yellow daisy (*Inula germanica)*	0.76±0.10 32 (BAR 3.3) (above ground biomass) 0.31±0.09 32 (BAR 1.35) (below ground biomass)	0.28±0.05 32 (BAR 1.33) (above ground biomass) 0.22±0.06 32 (BAR 1.05) (below ground biomass)		Tamakhina et al. 2018
Rice (leaves)	4.86		25	de Souza-Silva et al. 2014
	0.87		23	
	0.59		20	
	0.25		23	
	0.36		26	
	0.22		28	
	0.28		27	
	1.50		25	

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
Soybean (leaves)	0.22		23	de Souza-Silva et al. 2014
	0.24		20	
	0.42		23	
	0.36		26	
	0.03		28	
	0.32		27	
Copper				
Carrot root (peeled)	**8.5 (0.6)**	**6.1 (0.6)**	--	Ebbs et al. 2006
Carrot	7.2 (in red-sludge soil), 8.1 (in black-sludge soil)	5.1	--	Bunzl et al. 2001 in Stasinos et al. 2014
Carrots	11.5 in leaves, 9.54 in tubers	8.01 in leaves, 7.18 in tubers	Grown in polluted river sediments	Van Driel et al. (1995) in Stasinos et al. 2014
Carrots	2.7 - 7.6 (average 5.9)		Grown in contaminated soil; ratio of concentration in soil to carrots ranged from 0.17-43%	Economou-Eliopoulos et al. 2012 in Stasinos et al. 2014
Onion	No significant difference in concentration in onion from Thiva basin and control sample			Kirkillis et al. 2012 in Stasinos et al. 2014
Potato	3.5 to 5.7			Srek et al. 2010
Elecampane (*Inula helenium*, aka horse-heal, elfdock)	29.9±2.54 32 (BAR 2.41) (above ground biomass) 8.86±3.91 32 (BAR 0.71) (below ground biomass)	15.40±3.32 (BAR 4.4) (above ground biomass) 4.21±1.63 32 (BAR 1.2) (below ground biomass)		Tamakhina et al. 2018
yellowhead or meadow fleabane (*Inula britannica*)	4.60±1.28 32 (BAR 0.11) (above ground biomass) 5.68±2.17 32 (BAR 0.14) (below ground biomass)	6.03±2.44 32 (BAR 1.40) (above ground biomass) 3.21±1.15 32 (BAR 0.75) (below ground biomass)		Tamakhina et al. 2018

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
A yellow daisy (*Inula germanica*)	16.20±3.58 32 (BAR 0.40) (above ground biomass) 5.68±2.71 32 (BAR 0.14) (below ground biomass)	7.12±2.11 32 (BAR 1.45) (above ground biomass) 4.81±1.12 32 (BAR 0.98) (below ground biomass)		Tamakhina et al. 2018
Rice (leaves)	316.6		272	de Souza-Silva et al. 2014
	26.7		141	
	22.2		115	
	18.2		121	
	20.6		144	
	20.9		166	
	24.2		153	
Soybean (leaves)	12.1		272	de Souza-Silva et al. 2014
	9.5		141	
	8.9		115	
	7.5		121	
	7.1		144	
	8.5		166	
	8.2		153	
Iron				
Onion	23 µg/g,			Tokalioglu et al. 2006 in Stasinos et al. 2014
Rice (leaves)	840.9		537	de Souza-Silva et al. 2014
	63.7		936	
	82.5		861	
	104.6		510	
	93.2		99	
	92.6		100	
	273.7		97	
Soybean (leaves)	33.8		537	de Souza-Silva et al. 2014
	56.7		936	
	47.3		861	
	45.1		510	
	28.8		99	
	43.6		100	
	38.7		97	
Lead				
Carrot	--	0.05	--	Stasinos et al. 2014

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
Vegetables[1]	0.426	--	68.6444	Liu et al. 2013
Carrot	9.1 (in red-sludge soil), 4.1 (in black-sludge soil)	0.27	--	Bunzl et al. 2001 in Stasinos et al. 2014
Carrot	20 µg/g	Below DL in control soil and carrots	585 µg/g	Pendergrass and Butcher 2006 in Stasinos et al. 2014
Onion	0.12			Vincevica-Gaile et al. 2013 in Stasinos et al. 2014
Onion	No significant difference in concentration in onion from Thiva basin and control sample			Kirkillis et al. 2012 in Stasinos et al. 2014
Elecampane (*Inula helenium*, aka horse-heal, elfdock)	12.51±2.37 32 (BAR 0.43) (above ground biomass) 5.03±1.14 32 (BAR 0.17) (below ground biomass)	5.46±1.17 32 (BAR 1.14) (above ground biomass) 2.14±0.64 32 (BAR 0.45) (below ground biomass)		Tamakhina et al. 2018
yellowhead or meadow fleabane (*Inula britannica)*	0.58±0.07 32 (BAR 0.03) (above ground biomass) 0.71±0.11 32 (BAR 0.04) (below ground biomass)	5.54±1.72 32 (BAR 1.32) (above ground biomass) 5.10±1.68 32 (BAR 1.21) (below ground biomass)		Tamakhina et al. 2018
A yellow daisy (*Inula germanica)*	0.93±0.12 32 (BAR 0.05) (above ground biomass) 1.43±0.53 32 (BAR 0.07) (below ground biomass)	3.46±1.18 32 (BAR 1.13) (above ground biomass) 2.82±1.02 32 (BAR 1.05) (below ground biomass)		Tamakhina et al. 2018
Rice (leaves)	322.5		333	de Souza-Silva et al. 2014
	20.1		208	
	17.4		174	
	13.8		198	
	15.6		226	

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
	15.6		244	
	19.5		229	
Soybean (leaves)	9.4		333	de Souza-Silva et al. 2014
	6.5		208	
	5.4		174	
	3.9		198	
	3.1		226	
	3.5		244	
	4.1		229	
Nickel				
Bean (seed)	8.9 (1.9)	5.1 (0.2)		Ebbs et al. 2006
Carrot	--	0.28		Stasinos et al. 2014
Carrot	--	0.031-0.042		Bakkali et al. 2012 in Stasinos et al. 2014
Carrot	0.474	0.093		Kirkillis et al. 2012 in Stasinos et al. 2014
Carrots	0.3		0.25 mg/l in treated sewage added to soil	Ghosh et al. 2012 in Stasinos et al. 2014
Carrots	3.0 – 4.0 (average 3.5)		Grown in contaminated soil; ratio of concentration in soil to carrots ranged from 0.17-43%	Economou-Eliopoulos et al. 2012 in Stasinos et al. 2014
Onion	0.25			Vincevica-Gaile et al. 2013 in Stasinos et al. 2014
Onion	Concentration in onion from Thiva basin significantly elevated compared to the concentration of Ni in control sample			Kirkillis et al. 2012 in Stasinos et al. 2014

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	**Metal Concentration mg/kg (dry wt)**		**Corresponding Soil Concentration (mg/kg)**	**Reference**
	Grown in Contaminated Soils	**Grown in Reference Soils**		
Potato	800 µg/kg, up to 9 times higher than the one in control samples	78 µg/kg		Kirkillis et al. 2012 in Stasinos et al. 2014
Zinc				
Pepper (shoot)*	69	42		Ebbs et al. 2006
Pepper (fruit)*	22	16		Ebbs et al. 2006
Bean (stem)*	35	17		Ebbs et al. 2006
Bean (leaf)*	33	23		Ebbs et al. 2006
Bean (seed)*	34	28		Ebbs et al. 2006
Brocolli*	22	10		Ebbs et al. 2006
Carrot (root)	29	20		Ebbs et al. 2006
Lambsquarters (*Chenopodium album*)	86.23		100 (BCF 0.9)	Mirshekali et al. 2012
	462.06		300 (BCF 1.5)	
	666.62		500 (BCF 2.3)	
	1001.36		900 (BCF 1.1)	
	1067.82		1300 (BCF 0.8)	
	1213.18		2100 (BCF 0.6)	
Sorghum (*Sorghum bicolor*)	272.95		100 (BCF 2.7)	Mirshekali et al. 2012
	2208.34		300 (BCF 7.3)	
	2538.09		500 (BCF 5.1)	
	2022.85		900 (BCF 2.2)	
	1629.3		1300 (BCF 1.3)	
	1714.9		2100 (BCF 0.8)	
Carrot	63 (in red-sludge soil), 45 (in black-sludge soil)	16	--	Bunzl et al. 2001 in Stasinos et al. 2014
Carrots	88.4 in leaves, 40.2 in tubers	23.8 in leaves, 17.0 in tubers	Grown in polluted river sediments	Van Driel et al. (1995) in Stasinos et al. 2014
Carrots	18 – 19 (average 19)		Grown in contaminated soil; ratio of concentration in soil to carrots ranged from 0.17-43%	Economou-Eliopoulos et al. 2012 in Stasinos et al. 2014

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
Onion	11 µg/g,			Tokalioglu et al. 2006 in Stasinos et al. 2014
Potato	13.6 to 24.5			Srek et al. 2010
Elecampane (*Inula helenium*, aka horse-heal, elfdock)	23.48±5.61 32 (BAR 0.70) (above ground biomass) 18.75±3.18 32 (BAR 0.56) (below ground biomass)	20.62±5.87 32 (BAR 0.93) (above ground biomass) 16.83±4.24 32 (BAR 0.76) (below ground biomass)		Tamakhina et al. 2018
yellowhead or meadow fleabane (*Inula britannica)*	18.07±2.14 32 (BAR 0.18) (above ground biomass) 20.63±3.18 32 (BAR 0.21) (below ground biomass)	22.63±4.39 32 (BAR 3.97) (above ground biomass) 4.02±1.21 32 (BAR 0.70) (below ground biomass)		Tamakhina et al. 2018
A yellow daisy (*Inula germanica)*	14.32±2.37 32 (BAR 0.14) (above ground biomass) 18.45±3.15 32 (BAR 0.18) (below ground biomass)	25.37±4.25 32 (BAR 1.17) (above ground biomass) 6.15±1.13 32 (BAR 0.28) (below ground biomass)		Tamakhina et al. 2018
Rice (leaves)	2,562.1		544	de Souza-Silva et al. 2014
	543.1		189	
	386.5		113	
	145.3		106	
	119.4		106	
	108.4		108	
	94.2		102	
Soybean (leaves)	599.6		544	de Souza-Silva et al. 2014
	152.4		189	
	157.9		113	
	68.2		106	
	55.2		106	
	59.9		108	
	81.8		102	
Sugar beet	50, 100 and 300 µm in nutrient solution	Control 1.2 µm in nutrient solutio	decreased root and shoot fresh and dry mass, and increased	Sagardoy et al. 2009

Table B-2. Bioaccumulation levels of heavy metals in plants. (When applicable, significant differences are in bold; standard deviations are in parentheses following the means).

Plant	Metal Concentration mg/kg (dry wt)		Corresponding Soil Concentration (mg/kg)	Reference
	Grown in Contaminated Soils	Grown in Reference Soils		
			root ⁄ shoot ratios. compared to control conditions (1.2 lm Zn). Inward-rolled leaf edges and a damaged, brownish root system with short lateral roots; decreased N, Mg, K and Mn in all plant parts; increased P and Ca in shoots; Leaves in 50 and 100 µm Zn symptoms of Fe deficiency; in 300 µm Zn decreased photosystem II efficiency.	

*estimated from a bar graph

1. including rape, celery, cabbages, carrots, asparagus lettuces, cowpeas, tomatoes and cayenne pepper

Appendix C: Toxicity of Metals to Livestock

C.1. Arsenic (As)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), the acute toxicity of inorganic As for farm animals is 0.05–1.0 g/animal for poultry; 0.5–1.0 g/animal for swine; 10.0–15.0 g/animal for sheep, goats, and horses; and 15–30 g/animal for cattle. During the time these standards were developed, the permissible levels of As in muscle meats was 0.5 ppm; 1.0 ppm in edible meat by-products; and 0.5 ppm in eggs. It was indicated in NAS & NAE (1972) that natural waters seldom contain more than 0.2 mg/L. *U.S. EPA Recommended Criterion*: 0.2 mg/L

A factor to consider with respect to levels of As (or other metals) in water is that both water and feed (including grazing, which can also include exposure through incidental consumption of soils) represent exposure pathways through consumption. Thus, slightly higher concentrations in water can be tolerated if levels in feed are low (see, for example, CCME guidelines, Olkowski 2009). Remembering also that determination of safe to toxic levels in water is affected by type of animal and form of the As, the range of no-effects levels in drinking water (across all animals and As forms) from this evidence is 0.025 to 0.5 mg/l (Table C-1). The lowest or sublethal effects level of As ranges from 2.9 to 5.0 mg/l, and the only lethal level summarized here is two orders of magnitude higher, at 500 mg/l. The higher end of the no-effects level, or 0.5 mg/l, might be considered a conservative screening level, and something between this and the low end of the sublethal doses, or 2.9 mg/l, as a threshold level of concern

Table C-1. Arsenic toxicity in water to livestock.

	Sheep	Cattle	Other
No effects (safe levels)		0.025 mg/l (cattle; or 0.500 mg/l if level in feed is low) (CCME guideline)	0.292 mg arsenite/l (NOAEL-based benchmark; white-tailed deer)
Sublethal	5 mg As/L (cattle and sheep; provides minimum toxic dose of 1 mg As/kg BW to grazing animals in warm weather)	5 mg As/L (cattle and sheep; will provide the minimum toxic dose of 1 mg As/kg BW to grazing animals in warm weather)	2.921 mg arsenite/l (LOAEL-based benchmark; white-tailed deer)
Lethal			500 mg sodium arsenite/l (pig; lethal)

Additional Research Findings on As: The toxic oral dose of sodium arsenite is 6.5 mg/kg of body weight for horses, 7.5 mg/kg of body weight for cattle, 11 mg/kg of body weight for sheep, and 2 mg/kg of body weight for pigs (Blood et al. 1992, and NRC 2001 in Mandal 2017; and Blood et al. 1992 in Bampidis et al. 2013). Levels of 0.019 mg/kg/day and 0.191 mg/kg/day of As (as arsenite) in feed were the no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL), respectively, in white-tailed deer (Sample et al. 1996). Levels of 0.292 mg/L and 2.921 mg/L of As (as arsenite) in water were the NOAEL and LOAEL, respectively, in white-tailed deer (Sample et al. 1996). A maximum safe level of 2 mg/kg (complete diet) in livestock has been recommended by the European Union (Henja et al. 2018).

C.2. Cadmium (Cd)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), a recommended limit of <100 µg/L should be used for drinking waters, based on toxicity observed in rats and dogs, and accumulation and retention of Cd in the liver and kidney. Reduced longevity in rats and mice was observed at a level of 5 mg/L in drinking water. It was indicated in NAS & NAE (1972) that cows are efficient at keeping Cd out of their milk and that that meat seemed well protected against Cd accumulation.

U.S. EPA Recommended Criterion: 50 µg/L should allow for an adequate margin of safety for livestock.

The range of no-effects levels for Cd in drinking water (across all animals and forms of Cd) is 0.08 to 4.1 mg/l (Table C-2), a relatively wide range. The range of lowest or sublethal effects levels of Cd is also wide, from 1.0 to 41.3 mg/l. The higher variability in the levels presented make recommending a threshold a bit problematic, especially given the overlap between the no-effects and sublethal levels. The lowest sublethal level reported (1 mg Cd/l) is well within the no-effects range reported. Thus, the interval between the highest no-effects level (4.1 mg/l) and the lowest effects level (41.3 mg Cd/l) would be a reasonable screening or threshold level to screen and identify water concentrations of concern.

Table C-2. Cadmium compound toxicity in water.

	Sheep	Cattle	Other
No effects (safe levels)		0.08 mg/l (CCME guideline)	4.132 mg cadmium chloride/l (NOAEL-based benchmark; white-tailed deer)
Sublethal	as low as 1 mg/kg (= 1 mg/l) in drinking water (animals; renal function impairment, hypertension, disturbance of trace mineral metabolism (copper, zinc and manganese), and acute degenerative damage in the intestinal villi)	as low as 1 mg/kg in drinking water (animals; renal function impairment, hypertension, disturbance of trace mineral metabolism (copper, zinc and manganese), and acute degenerative damage in the intestinal villi)	as low as 1 mg/kg in drinking water (animals; renal function impairment, hypertension, disturbance of trace mineral metabolism (copper, zinc and manganese), and acute degenerative damage in the intestinal villi) 41.323 mg cadmium chloride/l (LOAEL-based benchmark; white-tailed deer)
Lethal			

Additional Research Findings on Cd: Cd in feed levels ranging from 5 to 30 mg/kg interferes with Cu and Zn absorption, resulting in symptoms usually associated with deficiencies in these elements in most animals (Bampidis et al. 2013). Cd feed levels > 30 mg/kg for ruminants causes anorexia, reduced growth, decreased milk production, and abortion (Bampidis et al. 2013). Cd feed levels of 18 mg/kg for calves, 60 mg/kg for sheep, and 50 mg/kg for pigs causes chronic Cd intoxication (Bampidis et al. 2013). Levels of 0.271 mg/kg/day and 2.706 mg/kg/day of Cd (as cadmium chloride) in feed were the no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL), respectively, in white-tailed deer (Sample et al. 1996). Levels of 4.132 mg/L and 41.323 mg/L of Cd (as cadmium chloride) in water were the NOAEL and LOAEL, respectively, in white-tailed deer (Sample et al. 1996).

C.3. Copper (Cu)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Cu is an essential trace element. Diet requirements are 4 ppm in for chicks and turkey poults; 4 ppm in beef cattle on rations low in Mo and sulfur, with double or triple this requirement when these elements are high; 5 ppm in pregnant and lactating ewes and their lambs; and 6 ppm for swine. In sheep, 25 ppm Cu in the diet was considered toxic, with approximately 9 mg/animal/day considered to be a safe tolerance level. Other livestock tolerate higher concentrations of Cu in their diet. As described in NAS & NAE (1972), Cu does not appear to accumulate to high levels in muscle tissues.

U.S. EPA Recommended Criterion**:** 0.5 mg/L

The range of no-effects levels reported for Cu in drinking water is broad, from 0.05 to 5.0 mg/l for cattle, to 65.2 mg/l for other animals (white-tailed deer) (Table C-3). The lowest effects level reported for white-tail deer is only slightly higher than this upper no-effects level, at 85.8 mg/l. As with all the metals, the cooper concentration of concern in water will be affected by the other amounts of Cu consumed in feed or exposure to Cu in soils, as well as by the species of animal under consideration, and may account for the variability in reported values. A threshold range could be considered between the highest no-effects level reported (~65 mg/l Cu) and the lowest effects level (85.8 mg/kg) to screen for Cu concentrations of concern, though the upper safe level reported for cattle, 5 mg/l of Cu in water, would be a more conservative safety threshold.

Table C-3. Copper compounds toxicity in water.

	Sheep	Cattle	Other
No effects (safe levels)		0.05 - 5.0 mg/l (CCME guideline)	65.2 mg copper sulfate/l (NOAEL-based benchmark; white-tailed deer)
Sublethal			85.8 mg copper sulfate/l (LOAEL-based benchmark; white-tailed deer)
Lethal			

Additional Research Findings on Cu*:* Concentrations in feed over a 2-year period of 37.5 mg/kg and 22.6 mg/kg Cu for lactating and dry cows, respectively, caused sublethal effects (e.g., acute anorexia, weakness, mental dullness, poor pupillary light reflexes, jaundice, chocolate-colored blood) and lethal effects in 14% of the herd (Bradley 1993). Maximum safe levels in feed of 20 mg/kg in Jersey cows, 15 mg/kg in milking cows, 35 mg/kg in bovines other than milking cows, 170 mg/kg in 12-week old pigs, and 25 mg/kg in pigs > 12 weeks old have been recommended by the European Union (Henja et al. 2018).

C.4. Iron (Fe)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Fe salt concentrations of 9,000 mg/kg diet caused a phosphorus deficiency in chicks. Levels of Fe ranging from 4,000 to 5,000 mg/kg in the diet caused phosphorus deficiency in weanling pigs. No recommended criteria were provided; however, a few parts per million of Fe can cause clogging of lines to stock watering equipment or an undesirable staining and deposit on the equipment itself.

Additional Research Findings on Fe: Looper et al. (2002) suggested that 2 ppm of Fe in water should be used as an upper limit for cattle in Oklahoma. Levels of 30,000 mg/day of Fe in feed were shown to cause reduction in body weight and to impact milk yield in cows (Coup and Campbell 1964). Levels of 500 ppm Fe in feed caused secondary Cu deficiency and possible secondary deficiency of Se and vitamin E in cattle (Weiss 2008, 2010). Maximum safe levels in feed of 250 mg/day in weanling pigs, 750 mg/day in non-weanling pigs, and 750 mg/day for cattle have been recommended by the European Union (Henja et al. 2018).

C.5. Lead (Pb)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), a daily intake of 6-7 mg Pb /kg of body weight was thought to cause toxicity to cattle. Horses are more sensitive to Pb toxicosis than sheep and cattle. There has been evidence of Pb accumulating in tissues and being transferred to milk at levels that could be toxic to humans (see Sections 3 and 5). Mice and rats were shown to be more susceptible to infections when exposed to sublethal Pb concentrations (e.g., 5 mg/L in drinking water). As described in NAS & NAE (1972), U.S. lake and river waters usually contain < 0.5 mg/L Pb.

U.S. EPA Recommended Criterion**:** 0.1mg/L

Based on results for cattle and other animals (white-tailed deer), water concentrations of Pb from 0.1 mg/l to as high as 34.3 mg/l should be safe, while 342.7 mg/l is reported as the lowest level of Pbthat will result in sublethal effects (Table C-4). A screening level for Pb in water between these values (34-340 mg/l) could be used.

Table C-4. Lead compound toxicity in water.

	Sheep	Cattle	Other
No effects (safe levels)		0.1 mg/l (CCME guideline)	34.27 mg lead acetate/l (NOAEL-based benchmark; white-tailed deer)
Sublethal			342.72 mg lead acetate/l (LOAEL-based benchmark; white-tailed deer)
Lethal			

Additional Research Findings on Pb: Pb levels in feed ranging from 400 to 600 mg/kg and 600 to 800 mg/kg cause acute toxicity in young cattle and adult cattle, respectively (Radostits et al. 2002 in Reis et al. 2010). Pb levels in feed ranging from 6 to 7 mg/kg of body weight cause chronic toxicity in cattle (Radostits et al. 2002 in Reis et al. 2010). Pb levels in feed of 100 mg/kg of body weight, 33 to 66 mg/kg of body weight, 4.5 mg/kg of body weight, and 400 mg/kg of body weight cause chronic toxicity in horses, pigs, sheep, and goats, respectively (Radostits et al. 2002 in Reis et al. 2010). Levels of 2.24 mg/kg/day and 22.44 mg/kg/day of l Pb (as lead acetate) in feed were the no NOAEL and LOAEL, respectively, in white-tailed deer (Sample et al. 1996). Levels of 32.47 mg/L and 342.72 mg/L of Pb (as lead acetate) in water were the

NOAEL and LOAEL, respectively, in white-tailed deer (Sample et al. 1996). A maximum safe level in feed of 5 mg/kg for livestock has been recommended by the European Union (Henja et al. 2018).

C.6. Nickel (Ni)

As shown in Table A-2, livestock watering standards for Ni based on protection of animal health or subsequent consumption of animal products by humans was not provided in NAS & NAE (1972).

Based on results for cattle and other animals (white-tailed deer), water concentrations of Ni from 1.0 mg/l to 171.36 mg/l should be safe, while 342.72 mg/l is reported as the lowest level of Ni that will result in sublethal effects (Table C-5). A screening level for Ni in drinking water for livestock and wildlife between these values (171-340 mg Ni/l) could be used as a screening range.

Table C-5. Nickel compound toxicity in water.

	Sheep	Cattle	Other
No effects (safe levels)		1.0 mg/l (CCME guideline)	171.36 mg/l (NOAEL-based benchmark; nickel sulfate hexahydrate; white-tailed deer)
Sublethal			342.72 mg/l (LOAEL-based benchmark; nickel sulfate hexahydrate; white-tailed deer)
Lethal			

Additional Research Findings on Ni: Looper et al. (2002) suggested that 0.25 ppm of Ni in water should be used as an upper limit for cattle in Oklahoma. A level of 1.2 ppm Ni (as nickel sulfate) in feed was found to cause tremors, paresis, and mortality in mallard ducklings (Samal and Mishra 2011). Levels of 11.22 mg/kg/day and 22.44 mg/kg/day of Ni (as nickel sulfate hexahydrate) in feed were the no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL), respectively, in white-tailed deer (Sample et al. 1996). Levels of 171.36 mg/L and 342.72 mg/L of Ni (as nickel sulfate hexahydrate) in water were the NOAEL and LOAEL, respectively, in white-tailed deer (Sample et al. 1996).

C.7. Zinc (Zn)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), Zn is a dietary requirement of all poultry and livestock, with 70 mg/kg of diet recommended for poults up to 8 weeks, and 70 mg/kg of diet for chicks up to 8 weeks. Zn deficiencies were reported in cattle grazing on forage with Zn concentrations between 18 and 83 ppm. Sheep require 30 ppm in diet for maximum growth. Chickens showed reduced water consumption, egg production, and body weight when exposed to 2,320 mg/L of Zn in water. Levels of >500 mg/kg in diet cause toxicity in ruminants. Swine have tolerated 1,000 ppm dietary Zn. Bioaccumulation of Zn in animal tissues was not high and tissue levels fell off rapidly after Zn dosing was stopped. As described in NAS & NAE (1972), most U.S. surface waters contain < 0.05 mg/L, but it has been detected at concentrations as high as 50 mg/L near areas where it is mined.

U.S. EPA Recommended Criterion: 25 mg/L

A single safe level of Zn in drinking water is reported for cattle as 50 mg/l (Table C-6). With no additional information, a threshold cannot be defined from this value.

Table C-6. Zinc compounds toxicity in water.

	Sheep	Cattle	Other
No effects (safe levels)		50 mg/l (CCME guideline)	
Sublethal			
Lethal			

Additional Research Findings on Zn*:* A level of 500 mg/kg in feed is considered to be safe for steer/heifers, while a level of 900 mg/kg in feed causes sublethal impacts in steers/heifers, including reduced weight gain and lower feeding efficiency (EC 2003). Levels of 3,000 to 7,300 mg/kg Zn in dry weight feed have caused mortality in calves (Wentink et al. 1985). Maximum safe levels in feed of 150 mg/kg in pigs and 100 mg/kg in cattle have been recommended by the European Union (Henja et al. 2018).

C.8. Other Metals

C.8.1. Aluminum (Al)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), there is no evidence that Al is essential for animal growth and very little Al has been detected in animal tissues. A level of 4,000 mg/kg Al in the diet was shown to cause phosphorus deficiency in chicks. Al in livestock waters was not expected to cause problems, except under unusual conditions with acid waters.

U.S. EPA Recommended Criterion: 5 mg/L

C.8.2. Beryllium (Be)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), laboratory rats survived 2 years on a diet which supplied about 18 mg/kg Be daily. If these data are transposed to cattle, it would be estimated that a cow could drink 250 gallons of water containing 6,000 mg/L Be, without harm. No livestock watering standards were recommended for Be by U.S. EPA (NAS & NAE 1972), and there are still insufficient data available to develop a recommended livestock watering criterion.

C.8.3. Chromium (Cr)

Even in its most soluble forms, Cr is not readily absorbed by animals nor does it appear to concentrate in mammalian tissues or increase in concentration in mammalian tissues with age (NAS & NAE 1972). The maximum nontoxic level in rats, based on growth effects, was 500 mg/L in drinking water. Some beneficial effects were observed in rats and mice fed a low Cr diet and given drinking water containing 5 mg/L Cr III over a lifetime. Levels of 100 ppm Cr VI in chick diets had no effect on the performance of the birds over a 21-day period. As described in NAS & NAE (1972), the maximum and average concentrations of chromium detected were 0.1 mg/L and 0.001 mg/L, respectively, in lake and river water.

U.S. EPA Recommended Criterion 1.0 mg/L should allow for an adequate margin of safety for livestock (as recommended by U.S. EPA and in multiple state and tribal standards, Tables Table A-2 and Table A-4).

C.8.4. Cobalt (Co)

Co is part of the vitamin B12 molecule and is therefore an essential element (NAS & NAE 1972). When administered to nonruminants in amounts much higher those present in food and feeds, Co induced polycythemia. Approximately 1.1 mg/kg of body weight administered daily to calves prior to rumen development caused depression of appetite and loss of weight. As described in NAS & NAE (1972), most U.S. surface waters contained less than 0.001 mg/L of Co.

U.S. EPA Recommended Criterion: 1.0 mg/L offers a satisfactory margin of safety (as recommended by U.S. EPA and in multiple state and tribal standards, Tables Table A-2 and Table A-4).

C.8.5. Manganese (Mn)

As described in U.S. EPA's *Water Quality Criteria 1972* (NAS & NAE 1972), it is generally found at low levels in natural waters as manganous salts that are precipitated in the presence of air as manganic oxide. Although it can be toxic at high levels in feed, it is unlikely that it would be found at toxic levels in natural waters. No standards were recommended; however, a few milligrams per liter in water can cause objectionable deposits on watering equipment.

C.8.6. Mercury (Mn)

The ratios between blood and brain levels of methylmercury ranged from 10 in rats to 0.2 in monkeys and dogs (NAS & NAE 1972). Further, blood levels of Hg appeared to increase approximately in proportion to increases in dietary intake. From this, NAS & NAE (1972) assumed a 0.2 greater blood-to-tissue ratio for Hg in livestock. To maintain 0.5 ppm Hg or less in all tissues, it was calculated that a maximum daily intake of 2.3 µg of Hg per kilogram body weight was necessary. Based upon daily water consumption by meat animals at approximately 8% of body weight, NAS & NAE (1972) estimated that water containing 30 µg/L of Hg as methylmercury would result in 0.25 ppm Hg in the whole animal body. NAS & NAE (1972) applied a steady-state accumulation factor in humans of 15.2 times weekly intake to meat animals in this calculation.

U.S. EPA Recommended Criterion: 10 µg/L; this limit provides an adequate margin of safety to humans who will subsequently not be exposed to as much as 0.5 ppm of Hg through the consumption of animal tissue.

C.8.7. Molybdenum (Mo)

Mo is an essential element (NAS & NAE 1972). Cattle grazed on pastures where the herbage contained 20 to 100 ppm of Mo on a dry basis developed a toxicosis known as teart. Cu added to the diet have been used to control this. Sheep are less sensitive to Mo exposure than cattle, and horses and swine are much less sensitive to Mo exposure than cattle. NAS & NAE (1972) also noted that natural surface waters usually contained less than 1 mg/L Mo. No standards were set for Mo for livestock watering.

C.8.8. Selenium (Se)

Se has an essential role in animal nutrition, with levels of 0.1- 0.2 ppm recommended in the diets of poultry (NAS & NAE 1972). Selenite (but not selenate) at concentrations of 2 mg/L in drinking water has caused deaths in rats. At the time that U.S. EPA compiled the 1972 Water Quality Criteria (NAS & NAE 1972), it was found that livestock in the United States had been receiving 0.5 ppm or greater concentrations of Se in their diets continuously, without indication of toxicity or accumulation of Se in their tissues that would make the meat or livestock products unfit for human consumption.

U.S. EPA Recommended Criterion: 0.05 mg/L (as recommended by U.S. EPA and in multiple state and tribal standards, Tables Table A-2 and Table A-4**Error! Reference source not found.**).

C.8.9. Vanadium (V)

V was found to be an essential element for the growing rat, with physiologically required levels being at or below 0.1 ppm of the diet (NAS & NAE 1972). At 10 ppm in the diet as ammonium metavanadate, it caused toxicity in chicks. As described in NAS & NAE (1972), V concentrations are usually less than 0.05 mg/L in U.S. surface waters.

U.S EPA Recommended Criterion: 0.1 mg/L (as recommended by U.S. EPA and multiple state and tribal standards, Tables Table A-2 and Table A-4**Error! Reference source not found.**).

C.9. Other Information: Toxicity Thresholds in Feed for Protection of Livestock

C.9.1. Arsenic (As): In Feed (or direct consumption)

The forms of As to which livestock are exposed matters with respect to estimating appropriate threshold levels - trivalent As compounds (arsenites) are found to be more toxic than pentavalent forms (arsenates) (Raisbeck et al. 2011; Gough et al. 1979). Some forms of arsenic--arsenilic acid, 4-nitrophenylarsonic acid, 3-nitro-4-hydroxyphenylarsenic acid, and arsenobenzene--are used as growth stimulants for pigs and poultry (Underwood 1971 sited in Gough et al. 1979). In addition, some types of livestock appear to be more sensitive to As than others.

Sheep: Non-adverse levels of total As in feed have been estimated at 2 mg/kg of complete feed (Table C-7) for livestock (including sheep, cattle, and pigs) by the European Union (Henja et al. 2018, Mandal 2017). This would have to be multiplied by average feeding rates for sheep (or other livestock species) to estimate a total (daily) dose that should not be exceeded. A 72 kg sheep (average range 45-100 kg) eating 2.5% of their live weight in dry weight (DW) of feed would consume about 1.8 kg DW of feed per day. Assuming an average DM of feed of 75%, this would be a consumption of about 2.4 kg of complete feed. This would, on average, expose them to 4.6 mg/day of As.

There is substantial overlap in the ranges of apparently sublethal and lethal doses of As as arsenite for sheep (Table C-7), with a sublethal range for arsenite of from 5-12 mg /kg BW (equivalent to single doses of about 360 – 864 mg/animal for a 72 kg sheep); and a lethal range of 1-25 mg /kg BW (equivalent to single doses of about 50 – 2,500 mg/animal). For arsenic trioxide, the sublethal (but toxic) exposure is 33-55 mg /kg BW (equivalent to about 1,500-5,500 mg/animal) (Table C-7). Thus, toxic effects are found at doses much higher than the reported safe concentrations in feed, which represent safe ‘daily doses’. A threshold for sheep lies between the safe dosage of 2 mg As/kg feed (or about 4.6 mg As/day) and toxic doses of as low as 50 mg As (as a single dose).

Table C-7. Arsenic toxicity to sheep.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	2 mg total As/kg (max safe dose in complete feed)[2]		[see footnote 1]
	58 mg As/kg feed for 3 wks (no effect)[3]		[see footnote 2]
Sublethal		11 mg Arsenite /kg BW (toxic oral dose) [=~792 mg/animal for a 72 kg sheep)	
		5-12 mg Arsenite/kg BW (single dose, acutely toxic) [=~ 360 – 864 mg/animal for a 72 kg sheep]	
		33-55 mg Arsenic trioxide/kg BW (toxic oral dose; =~ 1.5 – 5.5 g/animal)	
Lethal		2-4 g total As (2,000-4,000 mg) (2%-93% mortality) (or about 28-56 mg/kg BW)	1 g Arsenate/day (100% mortality in 6 to 94 days)
		1-25 mg Arsenite /kg **B**W (lethal oral dose, most animals) [=~72 – 1,800 mg/animal]	

[1] – reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range). Assumed range of BW's for sheep to be 45-100 kg (use 72 kg for calculations).

[2] – if sheep eat 2-3% of their BW in DM/day (use 2.5% for calculations) and weigh 45-100 kg (use 72 kg for calculations), then this would be a dose of about 2.4-5.4 mg As/day (or about 0.002-0.005 g/day).

[3] – assuming this is reported as wet mass, and assuming 75% DM, and then assuming sheep eat 2-3% of their BW in feed per day, this would be equivalent to a dose of about 69.6-154.6 mg As/day (→ 0.07 – 0.15 g/d) (for 3 wks).

Cows/Cattle: As discussed above, safe levels of total As in feed have been estimated at 2 mg/kg of complete feed (**Error! Reference source not found.**). Assuming an average weight for cattle of 753 kg, and an average feeding rate of 2.5% of BW/day, this would lead to an As exposure of about 50 mg/day. In contrast to this 'safe' limit, an 'upper' threshold after which toxic symptoms can occur was reported for cattle of 250 ppm (mg/kg feed) (Table C-8), which is 5 times higher than the reported safe level of As. A different study observed sublethal symptoms in cattle at a daily dose of 50 µg/kg BW/day, which for an average-weight cow would be about 37.7 mg/animal/day, suggesting that a 'safe' threshold for daily ingestion of As would be below this (i.e. between 2 and 37.7 mg/animal/day). Single-dose toxic levels of As ranged from 7.5 mg Arsenite/ kg BW (about 5,650 mg/animal) as the lowest reported dose resulting in sublethal effects, to 25 mg Arsenite/kg BW for a lethal dose, which is equivalent to about 18,800 mg as a single dose for an average-weight cow. As observed for sheep, there was a lot of overlap in the range of sublethal and lethal dosages (Table C-8). Thus, a threshold for cattle probably lies between the chronic threshold dosage of 250 mg As/kg feed and toxic dose of as low as 5,650 mg As (as a single dose).

Table C-8. Toxicity of Arsenic compounds to Cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	2 mg total As/kg (max safe dose in complete feed) 250 ppm (=mg/kg) As (chronic limit)	50 mg inorganic As/kg BW (max tolerable dose) [=~37,650 mg/animal) 100 mg organic As/kg BW (max tolerable dose) [=~75,300 mg/animal]	
Sublethal		>200-300 mg inorganic As/kg (signs of toxicity) [=~150,600-225,900 mg/animal] 7.5 mg Arsenite/ kg BW (toxic oral dose) [=~5,648 mg/animal] 33-55 mg Arsenic trioxide/kg BW [=~24,850-41,415 mg/animal]	50 µg/kg BW/day [=~37.65 mg/animal/day] (organic arsenic, acute tox effects, e.g., abdominal cramping, hyperesthesia in extremities, abdominal patellar reflexes and abdominal electrocardiogram)
Lethal		2-4 g total As (2%-93% mortality) (or about 2.7-5.3 mg/kg BW) 1-4 g Arsenite/ animal (lethal) (or about 1.3-5.3 mg/kg BW) 1-25 mg Arsenite /kg BW (lethal oral dose, most animals) [=~753-18,825 mg/animal]	

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).
2. if cows eat 2-3% of their BW in DM/day (use 2.5% for calculations), and weight 45-100 kg (use 72 kg for calculations), then this would be a dose of about 2.4-5.4 mg As/day (or about 0.002-0.005 g/day).

Other Animals: There is information on As toxicity for a range of other domestic and wild animals, including pigs, horses, chickens, goats, white-tailed deer, and pheasant (Table C-9). The 2 mg As/kg of complete feed is applied to most animals. The NOAEL-based (no effects, or safe, level) food benchmark for white-tailed deer is quite a bit lower than this at 0.621 mg/kg food/day (Table C-9). The lowest effects level was 10-times this value at 6.21 mg/kg food/day. These were derived from the NOAEL and LOAEL for white-tailed deer of 0.019 mg/kg BW/day and at 0.191 mg/kg BW/day, respectively. A lethal single dose for white-tails was reported as 34 mg /kg BW (for arsenite). Nevertheless, a safe threshold concentration for white-tailed deer is likely close to the NOAEL, or between the NOAEL and the LOAEL.

Though only one value for goats is available, it is a safe single does, and at 30 mg/kg BW, is higher than the safe does for some other domestic animals (e.g., a sublethal toxic dose for pigs is 7.5-11 mg/kg BW for arsenic trioxide, but only 2mg/kg BW for sodium arsenite, Table C-9). Horses are similar to cattle and sheep in their relative sensitivity (33-55 mg arsenic trioxide/kg BW), while chicken embryos are the most sensitive (sublethal effects observed at 0.03-0.3 µg arsenite /embryo). Since not definitive 'safe' (or no-effects) levels are given for these animals, the safe threshold can only be suggested as lying below these reported levels. A 10x factor is sometimes used to extrapolate between no-effects and lowest-effects levels (Sample et al. 1996), which could be applied for estimating safe levels in this case.

Table C-9. Arsenic compounds toxicity, other animals.

	Concentration in feed	**Single dose[1]**	**Daily dose**
No effects (safe levels)	2 mg total As/kg (max safe dose in complete feed)	30 mg/kg BW (m ax tolerable dose, inorganic As, goats)	0.019 mg/kg BW/day (NOAEL, white-tail deer) [~0.86 mg As/animal/day]
	0.621 mg/kg food/day (NOAEL-based food benchmark, white-tail deer)		
Sublethal	6.21 mg/kg food/day (LOAEL-based food benchmark, white-tail deer)	(single dose, malformation, chicken)	0.191 mg/kg BW/day (LOAEL, white-tail deer) [~8.6 mg As/animal/day]
	1 g/kg of diet (clinical signs of toxicity, arsanilic acid, pigs)	6.5 mg Arsenite /kg BW (toxic oral dose, horses)	
		7.5-11 mg Arsenic trioxide/kg BW (toxic oral dose, pigs) [=~ 0.75-1.98 g/animal]	
		33-55 mg arsenic trioxide/kg BW (toxic dose; cattle, sheep, horses)	
		2 mg sodium arsenite/kg BW (toxic oral dose, pigs) [=~ 0.2-0.36 g/animal)	
Lethal	500 mg/kg food (32-day LD_{50}, mallard)	34 mg Arsenite/kg BW (lethal dose, whitetail deer)	2-4 mg Arsenite/kg BW/day (14 wk, lethal, horse)
		1-25 mg Arsenite/kg BW (lethal oral dose, most animals)	
	Concentration in feed	Single dose1	Daily dose
		323 mg Arsenite/kg BW (LD50 single dose, mallard)	

Table C-9. Arsenic compounds toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
		47.6 mg Arsenite/ kg BW (LD50 single dose, quail)	
		386 mg Arsenite/kg BW (LD50 single dose, ring-neck pheasant)	
		100-200 mg Arsenite/kg BW (single dose, lethal, pig) [=~10-36 g/animal]	
		0.1-2.0 µg Arsenite /embryo (single dose, 34% mortality, chicken)	

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

In Soil: The Wildlife Soil Criteria (WSC) and Risk Management Criteria (RMC) summarized in Table C-10 represent a range of threshold screening values. The WSC includes a soil exposure factor and a soil-plant uptake factor (Ford and Beyer 2014), so these values seem relevant to potential exposure routes of livestock through grazing. Ford and Beyer (2014) indicate that at soil concentrations below the WSC, increased tissue concentrations of metals, as well as biochemical signs of increased exposure may be observed; while at metal concentrations above the WSC, signs of impaired health might be observed. Similarly, RMC's are intended to provide action levels to assist managers in making resource/land management decisions (Ford and Beyer 2014). While the screening levels in Table C-10**Error! Reference source not found.** are presented by animal type, the levels are close enough (352 – 431 mg As/kg soil) that the upper values in this range (419 – 431 mg As/kg soil) can be considered a reasonable threshold range.

Table C-10. Arsenic compounds toxicity in soil.

	Sheep	Cattle	Other
Safe threshold	353 mg/kg (WSC[1])	355 mg/kg (WSC[1])	431 mg/kg (WSC[1], horse)
	352 mg/kg (RMC[2])	419 mg/kg (RMC[2])	

1. WSC = Wildlife Soil Criteria
2. RMC = Risk Management Criteria

C.9.2. Cadmium (Cd): In Feed (or direct consumption)

Sheep: A relatively wide (10x) range of 'safe' (no-effects) levels of Cd in feed was found, from 0.5 to 5 mg/kg feed (Table C-11). Most sublethal toxic levels were found to range between 5 and 60 mg/kg, though one study reported sublethal effects at 1 mg/kg feed. This suggests a safe threshold of Cd in feed-stuffs for sheep would be between 0.5 and 1 mg/kg.

Table C-11. Cadmium compounds toxicity to sheep.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	0.5 mg Cd/kg feed (max feed content, all animals)		
	1 mg Cd/kg in complete feed (max safe level, ruminants (cattle, sheep, goats))		
	≤5 mg/kg in feed (farm ruminants; unlikely to see effects)		
Sublethal	5 to 30 mg Cd/kg of diet (interferes copper zinc absorption, most animals)		30-60 ppm Cd/day (for 91 days, reduced growth and food intake)
	60 mg Cd/kg diet for 137 days (chronic intoxication)		60 mg Cd/kg diet/day for 137 days (chronic Cd intoxication)
	>40 mg Cd/ kg DM (toxicity)		
	> 40 mg of Cd/Kg of DM (parakeratosis, reduction on appetite, body weight gain and testicle development)		
	>30 mg Cd/kg in diet (ruminants; anorexia, reduced growth, decreased milk production and abortion)		
	5 to 60 mg Cd/Kg DM (increased copper in liver and kidney)		
	1 mg Cd/kg in complete feed (max safe level, ruminants (cattle, sheep, goats))		
	(as low as) 1 mg Cd/kg in the diet (range of non-lethal impairments, most animals)		
	5 - 30 mg Cd/kg diet (various sublethal effects; most animals)		
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Cows/Cattle: The safe range of Cd in feed for cattle is also relatively wide, from 0.5 mg Cd/kg feed to 10 ppm (mg/kg feed) as a maximum tolerable level (Table C-12). Several of the sublethal and lethal dosages in feed were substantially higher than this range of safe levels (from 160 up to 2,560 mg Cd/kg feed). Because some of these values were for calves and some for adult cattle, it is difficult to use average weights and feeding rates to convert these to, for instance daily doses, for comparison to other study results. Though several of the sublethal doses are relatively high (e.g., 3 g/animal/day or more; 22 g/animal as a single dose], at least one study indicated doses of Cd as low as 1 mg/kg feed could lead to sublethal toxic symptoms (Table C-12), suggesting that a safe threshold may lie between this value (1 mg/kg feed) and reported maximum safe value of 10 mg/kg feed, or the lower sublethal value of 160 mg/kg feed.

Table C-12. Cadmium compounds toxicity to cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	10 ppm (MTL)		
	0.5 mg Cd/kg feed (max feed content, all animals)		
	1 mg Cd/kg in complete feed (max safe level, ruminants (cattle, sheep, goats))		
Sublethal	(as low as) 1 mg Cd/kg in the diet (range of non-lethal impairments, most animals) [~18.8 mg/animal/day]	18 mg Cd/kg BW (calves; chronic Cd intoxication)	15 mg Cd/kg bodyweight daily (feed intake and body weights decreased during the six-week feeding period) [~56.5 g/animal/day]
	160 mg Cd/kg ration (calves; depressed growth rate) [~3.0 g/animal/day]	≥ 30 mg of Cd/Kg BW (toxic dose – health disorders) (~22.6 g/animal)	
Lethal	2,560 mg Cd/kg ration (100% mortality within 8 wks)		
	640 mg Cd/kg ration (25% mortality within 6 wks)		

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Other Animals: The upper no-effects level for Cd in feed reported for white-tailed deer is ~8.8 mg/kg feed (Table C-13), near the high end of the safe range reported for cattle. The LOAEL for white-tailed deer is 10x this value, or 87.9 mg/kg feed. The only 'safe' value for Cd in feed reported for goats is near the low end of the range (1 mg/kg feed). Overall, the no-effects range for Cd in feed for other animals is comparable to that report for cattle and sheep. And again, similarly to the pattern discussed for cattle and sheep, the levels of Cd resulting in sublethal and lethal effects in other animals is, with one exception, quite a bit higher than the reported safe levels (50 mg/kg feed or higher).

Table C-13. Cadmium compounds toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	8.787 mg cadmium chloride/kg feed (white-tail deer; NOAEL-based benchmark (food)) 0.5 mg Cd/kg feed (max feed content, all animals) 1 mg Cd/kg in complete feed (max safe level, ruminants (cattle, sheep, goats))		0.271 mg cadmium chloride/kg BW/day (NOAEL (estimated); white-tail deer; 2.706 mg/kg/day)
Sublethal	87.871 mg cadmium chloride/kg feed (white-tailed deer, LOAEL-based benchmark (food)) 50 mg Cd/kg diet for 42 days (pigs; chronic cadmium toxicity) [using 140kg as an average pig weight and consumption rate of 2.5% of BW/day, this would be ~175 mg/animal/day] (as low as) 1 mg Cd/kg in the diet (range of non-lethal impairments, most animals)		2.706 mg cadmium chloride/kg BW/day (LOAEL (estimated); white-tail deer)
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

In Soil: The levels of WSC's and RMC's given in Table C-14for Cd are similar (12 – 23 mg Cd/kg soil). The upper values in this range, 20 – 23 mg Cd/kg soil can be considered a reasonable threshold range.

Table C-14. Cadmium compounds toxicity in soil.

	Sheep	Cattle	Other
Safe threshold	23 mg/kg (WSC[1]) 12 mg/kg (RMC[2])	20 mg/kg (WSC[1]) 15 mg/kg (RMC[2])	21 mg/kg (WSC[1], horse)

1. WSC = Wildlife Soil Criteria
2. RMC = Risk Management Criteria

C.9.3. Copper (Cu): In Feed (or direct consumption)

The metabolic processing of Cu can be affected by, among other things, the presence of Zn, making it difficult to determine exact dietary Cu requirements (Ammerman 1969). Sheep and young cattle are more susceptible to Cu toxicity than mature cattle. The pattern of Cu toxicity can start with a period of accumulation, especially in the liver or blood, and progress to 'haemolytic crisis', which can include jaundice, methemoglobin, hemoglobinuria, and ultimately death (Ammerman 1969). Compounds such as sulfate and Mo can reduce body accumulation of Cu; such interactions can affect apparent toxic reactions to particular Cu exposures. Cu and Fe also interact, such that high levels of dietary Fe may depress Cu accumulation, or conversely that Cu deficiency may result in excess Fe accumulation in the liver (Chapmann and Kidder 1964 and Standish et al. 1969 in Ammerman 1969).

Sheep: A 'safe' (no-effects) level of Cu for sheep is reported at about 40 mg/kg total diet (Table C-15). Chronic (sublethal) effects were reported at single doses of 20-110 mg Cu/kg BW, which for an average-weight sheep (assuming 72 kg) would be about 1.4-7.9 g/animal; and at a daily dose of 3.5 mg/kg BW, which would be about 252 mg Cu/animal/day (Table C-15). This suggests a screening threshold for Cu in feed-stuffs for sheep might lie between 40 and 250 mg/kg.

Table C-15. Copper compound toxicity to sheep.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	35 mg/kg (max permitted level; 88 per cent dry matter (DM)) =~ 40 mg/kg of total diet DM (livestock)		
Sublethal		20 to 110 mg Cu/Kg of BW (acute poisoning) [~1.4-7.9 g/animal]	3.5 mg of copper/kg of BW (chronic poisoning) [~252 mg Cu/animal/day]
Lethal	1.5 mg fed/sheep/ day for 30 days (lethal)	80 - 160 mg per head (lethal)	

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Cows/Cattle: 'Safe' (no-effects) levels of Cu for cattle range between 15 and 40 mg/kg feed (Table C-16). For the average weight cow (753kg) eating 2.5% of their body weight per day, this would amount to about 282-753 mg Cu/animal/day. At concentrations at least twice this high, 80-115 mg/kg feed (~1.5-2.2 g/animal/day] consumed over 2-3 months, chronic (sublethal) effects were reported. A daily dose of 3-5 mg Cu/kg BW/day was also reported to result in sublethal to lethal effects. For an average-weight cow, this would be about 2.3-3.8 g/animal/day. This range is similar to the sublethal feed concentrations reported. Single dosages of Cu that are toxic to cattle are much higher than this (Table C-16). A screening threshold for Cu in feed-stuffs for adult cattle might lie between the upper no-effects levels of 40 mg/kg in feed and lower sublethal concentration of 80 mg/kg feed.

Table C-16. Copper compound toxicity to cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	40 ppm Cu sulfate, Cu chloride (MTL) [~753 mg/animal/day] 35 mg/kg (max safe level; non-milking cows) 35 mg/kg (88 per cent dry matter (DM)) =~ 40 mg/kg of total diet DM (livestock) 20 ppm (max safe level) 15 mg/kg feed (max safe level; milking cows) [~282 mg/animal/day]		
Sublethal	80 mg of Cu/Kg feed/day for 60 days (poisoning, adult cattle) 115 mg of Cu/Kg feed/day, for 91 days (poisoning of calves)	20 - 110 mg of copper/kg BW (acute poisoning, calves) 200 to 400 g copper sulfate or 200 mg copper/Kg BW (acute poisoning, adult cattle) [~150.6 g/animal] 220 - 880 mg copper/kg BW (lethal)	3 - 5 mg Cu/Kg BW/day (chronic poisoning, lethal) [~2.3-3.8 g Cu/animal/day] 1 to 2 g copper/day (chronic poisoning of calves)
Lethal	37.5 mg/kg (lactating cows; chronic long-term (>2-year) feeding; 14% mortality) 22.6 mg/kg (dry cows; chronic long-term (>2-year) feeding; 14% mortality)	mineral mix containing 328 mg of Cu/Kg (high mortality)	

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Other Animals: 'Safe' (no-effects) levels of Cu for other animals represents a wide range, from 25 to 170 mg/kg feed (Table C-17). Sublethal effects are reported for white-tail deer and other animals at concentrations not much higher than the upper 'safe' level (~182 mg/kg feed). Thus, a screening threshold between the upper 'no-effects' level of 170 mg/kg feed and the lower sublethal level of 182 mg/kg feed might be recommended.

Table C-17. Copper compound toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	138.6 mg copper sulfate/kg (NOAEL-based benchmark (food); white-tail deer) [assuming a 45 kg deer that eats the same 2.5% BW as other livestock (a random assumption), this would amount to ~156 mg/animal/day] 170 mg/kg (max safe level; piglets) 25 mg/kg (max safe level; other pigs) [		4.3 mg copper sulfate/kg BW/day (NOAEL (estimated); white-tail deer) [assuming a white-tail deer weighs ~45 kg, this would amount to ~194 mg/animal/day]
Sublethal	182.4 mg copper sulfate/kg (LOAEL-based benchmark (food); white-tail deer) [~205.2 mg/animal for a 45 kg deer eating 2.5% BW/day]		5.6 mg copper sulfate/kg BW/day (LOAEL (estimated); white-tail deer) [~252 mg/animal for a 45 kg deer]
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

In Soil: The levels of WSCs and RMCs given in Table C-18 for Cu are quite variable among types of animals (Table C-18). The values for sheep, 86-102 mg Cu/kg soil, are two to four times lower than the values reported for cattle of 281-413 mg/kg. The WSC for horses is almost an order of magnitude higher than that for cattle, 2,013 mg Cu/kg. demonstrates species differences in sensitivity to a particular metal and may also be complicated by the influence of consumption of Cu through other (food/grazing) sources.

Table C-18. Copper compounds toxicity in soil.

	Sheep	Cattle	Other
Safe threshold	102 mg/kg (WSC[1]) 86 mg/kg (RMC[2])	281 mg/kg (WSC[1]) 413 mg/kg (RMC[2])	2,013 mg/kg (WSC[1], horse)

1. WSC = Wildlife Soil Criteria
2. RMC = Risk Management Criteria

C.9.4. Iron (Fe): In Feed (or direct consumption)

Sheep: No study results relevant to the potential toxicity to sheep of Fe in feed was found.

Cows/Cattle: The evidence summarized on safe (no-effects) concentrations in feed or daily doses of Fe to cattle shows a relatively wide spread in estimated safe dosages, from 500 mg/kg, which for an average-weight animal would be an exposure to about 9.4 g/animal/day; down to 750 mg/animal/day (=0.75 g/animal/day) (**Error! Reference source not found.**Table C-19). There is then another jump to a range of sublethal Fe exposures of about 22.6-60 g/animal/day. A threshold to screen for Fe concentrations in feed of concern should probably fall between the higher no-effects level of 9.4 g/animal/day (or 500 mg/kg feed) and the lower sublethal concentration of 22.6 g/animal/day (or given average BW and feeding rate, about 1,200 mg/kg feed).

Table C-19. Iron compound toxicity to cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	500 ppm Fe sulfate, Fe chloride (MTL) [~9.4 g/animal/day]		750 mg/day (max safe level)
Sublethal		30 g ferric hydroxide/day (non-lethal - affected milk yield, digestion of herbage, other)	30 mg ferric hydroxide/kg live weight/day (for 7 months; non-lethal effects, e.g., depressed liver and blood copper, caeruloplasmin, and amine oxidase levels) [~22.6 g/animal/day]
		30-60 g ferric hydroxide/day (non-lethal - loss of bodyweight, lowered production of butterfat)	
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Other Animals: Little information on Fe toxicity to other animals was available, except for safe levels for weanling and non-weanling pigs (Table C-20). The value for non-weanling pigs is similar to the maximum safe level reported above for cattle and is on the low end of the recommended threshold range for cattle.

Table C-20. Iron compound toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)			250 mg/day (max safe level; weanling pigs) 750 mg/day (max safe level; non-weanling pigs)
Sublethal			
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

C.9.5. Lead (Pb): In Feed (or direct consumption)

Sheep: No effects levels of Pb in feed for sheep fall between 5 and 100 mg/kg feed (Table C-21). No information is available on sublethal concentrations for sheep. However, at the least, the higher end of this no-effects level, or 100 mg/kg feed, may represent a reasonable threshold for screening Pb concentrations in food-stuffs for sheep.

Table C-21. Lead compound toxicity to sheep.

	Concentration in feed	Single dose[1]	Daily dose
No effects	5 mg/kg feed (all animals) 100 mg Pb/kg DM of diet (MTL)		
Sublethal			
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Cows/Cattle: The no-effects concentrations of Pb in feed for cattle is the same as that presented above for sheep, between 5 and 100 mg/kg feed (Table C-22). The sublethal concentrations are two to three times higher than this (200-300 mg/kg feed). This is equivalent to about 5.03 – 7.53 g/animal/day (based on assumptions regarding average weight of cattle and average feeding rates). Single-dose sublethal levels are also quite variable, ranging from levels comparable to the daily exposures from feed (more or less 4-5 g/animal), to substantially higher doses, equivalent to about 300-600 g Pb/animal (Table C-22).

Table C-22. Lead compound toxicity to cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	100 ppm (MTL) 5 mg/kg feed (all animals) 100 mg Pb/kg DM of diet (MTL) [~2.5 g Pb/animal/day]		
Sublethal	200 to 300 mg of Pb/Kg of DM diet (chronic poisoning) [~5.03 – 7.53 g/animal/day]	400 to 600 mg of Pb/Kg BW (acute poisoning, young cattle) [301.2 g/animal to 451.8 g/animal] 600 to 800 mg of Pb/Kg BW (acute poisoning, adult cattle) [451.8 g/animal to 602.4 g/animal] 6 to 7 mg of Pb/ Kg BW (chronic poisoning) [4.5 to 5.3 g/animal]	4.5 mg of Pb/Kg of BW (chronic poisoning) [~3.4 g/animal/day]
Lethal		200 mg Pb/kg BW single dose (lethal) 200 - 400 mg of Pb/Kg of BW (single dose, calf mortality) 10 to 100 g of lead acetate (single dose, adult cattle mortality)	

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Other Animals: Safe consumption levels of Pb for other animals was variable, from 5-73 mg Pb/kg feed (about 5.6-82 mg/animal/day for a 45 kg deer), or 2.24 mg/kg BW/day (about 101 mg/animal/day). A sublethal Pb level in feed for other animals (deer in this case) is 727.78 mg/kg feed (or about 820 mg/animal/day). Sublethal single dosage levels were higher than this (Table C-23).

Table C-23. Lead compound toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
No effects	72.88 mg Lead acetate /kg feed (NOAEL-based benchmark (food); white-tailed deer) [~82 mg/animal/day] 5 mg/kg feed (max safe content, all animals) [~5.6 mg/animal]		2.24 mg Lead acetate/kg BW/day (NOAEL (estimated); white-tailed deer) [~101 mg/animal for an average 45 kg deer]
Sublethal	728.78 mg Lead acetate /kg feed (LOAEL-based benchmark (food); white-tailed deer) [~820 mg PB/animal/day]	100 mg of Pb/Kg of BW (horse, chronic poisoning) [~69 g/animal for an average-weight 690 kg horse] 33 to 66 mg of Pb/Kg of BW (pig, chronic poisoning) [4.62-9.24 g/animal] 400 mg of Pb/Kg (goat, chronic poisoning)	22.44 mg Lead acetate/kg BW/d (LOAEL (estimated); white-tailed deer) [~1.01 g/animal]
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

In Soil: The WSC's and RMC's given for Pb levels in soil in Table C-24are quite variable among types of animals and between the two metrics (Table C-24). For sheep, the RMC is only 203 mg Pb/kg soil, while the WSC is 1,146 mg/kg (Table C-24). For cattle these values are similar – 244 and 1,127 mg Pb/kg, respectively. However, for horses the WSC is only 142 mg Pb/kg.

Table C-24. Lead compound toxicity in soil.

	Sheep	Cattle	Other
Safe threshold	1,146 mg/kg (WSC[1]) 203 mg/kg (RMC[2])	1,127 mg/kg (WSC[1]) 244 mg/kg (RMC[2])	142 mg/kg (WSC[1], horse)

1. WSC = Wildlife Soil Criteria
2. RMC = Risk Management Criteria

C.9.6. Nickel (Ni): In Feed (or direct consumption)

Sheep: No study results relevant to the potential toxicity to sheep of Ni in feed was found.

Cows/Cattle: A no-effects Ni concentration in feed of 100 ppm (=100 mg Ni/kg feed) was reported (Table C-25).

Table C-25. Nickel compound toxicity to cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	100 ppm Ni (MTL)		
Sublethal			
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Other Animals: The no-effects level of Ni in feed for other animals (white-tailed deer in this case) is 364 mg Ni/kg feed (about 410 mg/animal/day), or 11.22 mg Ni/kg BW/day (about 505 mg/animal/day) (Table C-26). The sublethal (lowest effects) levels for white-tailed deer were twice these levels, and the sublethal dietary concentration for chicks was similar to the LOAEL-derived dietary concentration for white-tails (Table C-26).

Table C-26. Nickel compound toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	364.39 mg nickel sulfate hexahydrate/kg feed (NOAEL-based benchmark (food); white-tailed deer) [~410 mg Ni/animal/day]		11.22 mg nickel sulfate hexahydrate/kg BW/day (NOAEL; white-tailed deer) [~505 mg Ni/animal/day]
Sublethal	700 ppm in diet (chicks; non-lethal)		22.44 mg nickel sulfate hexahydrate/kg BW/day (LOAEL (estimated); white-tailed deer) [~1,010 mg/animal/day]
	728.78 mg nickel sulfate hexahydrate /kg feed (LOAEL-based benchmark (food); white-tailed deer) [~820 mg/animal/day]		1.2 ppm fed daily, days 1-90 (mallard ducklings; lethal and sublethal)
Lethal	1.1 g nickel sulfate/kg BW (chickens; mortality, anemia)		

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

In Soil: No information on the potential toxicity of Ni in soils to livestock or wildlife was found.

C.9.7. Zinc (Zn): In Feed (or direct consumption)

Sheep: A no-effects level for Zn to sheep is 500 mg/kg feed (or less) (Table C-27). A range of sublethal effects are reported at Zn concentrations in feed from 1,000 to 1,700 mg Zn/kg feed. Thus, with respect to sheep, screening for Zn at 500 mg/kg (ppm) or up to 1,000 ppm would seem reasonable

Table C-27. Zinc compound toxicity to sheep.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	<500 ppm in diet (no effects)		
Sublethal	1,000-1,500 ppm in diet (reduced feeding and weight gain) 1,000 mg Zn/Kg of diet (reduced feed efficiency and weight gain) 1,500 mg Zn/Kg diet (reduced food intake) 1,700 mg Zn/Kg of diet (perversion of appetite)		
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Cows/Cattle: No-effects concentrations of Zn in feed for cattle range from 100-500 mg/kg feed (Table C-28). A range of sublethal effects on cattle from Zn in feed occurred at 500-2,000 mg Zn/kg feed, a relatively wide range. These values are similar to those reported for sheep (above).

Table C-28. Zinc compounds toxicity to cattle.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	500 ppm in feed (MTL) 500 mg/kg (ppm) feed (Safe) 100 mg Zn/kg (cattle; safe level)		
Sublethal	900 mg/kg (ppm) feed (non-lethal impacts) 1,700 ppm in diet (more sever non-lethal effects) 500 mg Zn/kg DM (non-lethal) 700 mg Zn/Kg diet (reduced feed intake and body weight, nitrogen digestibility and hematocrit) 900 to 1 000 mg Zn/Kg diet (decreased growth, nitrogen digestibility and hematocrit) 2,000 mg Zn/kg of diet (decreased milk production)		30-40 mg/kg (severe chronic poisoning, 1 month; calves)
Lethal	3,000 to 7,300 mg/kg in roughage (feed) DW (mortality)	150 g zinc oxide (lethal)	75 g zinc oxide during 3 to 4 days (probably lethal)

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

Other Animals: The range of no-effects (safe) concentrations of Zn to other animals is relatively wide, 150-1,000 mg Zn/kg feed (Table C-29), reflecting essential differences between weanling and adult pigs. Sublethal effects were reported to occur at Zn concentrations from 1,000-4,000 mg Zn/kg feed.

Table C-29. Zinc compound toxicity, other animals.

	Concentration in feed	Single dose[1]	Daily dose
No effects (safe levels)	1,000 ppm in diet (no effect, weanling pigs) 150 mg Zn/kg (safe level; pigs)		
Sublethal	1,000 ppm in diet (depresses growth, weanling pigs) 4,000-8,000 ppm in diet (high mortality, weanling pigs) 4,000 mg Zn/kg diet (pigs; reduced growth)		
Lethal			

1. reported as total dose, or as dose per body weight (BW) of the animal, for which average animal weight used to estimate a total dose (or a range).

In Soil: Estimates of safe levels for sheep of Zn in soils range from 545-992 mg/kg (Table C-30). For cattle these levels are 1,082-1,600 mg Zn/kg soil; and for other animals (horses in this case) it is 1,000-1,674 mg/kg. Sublethal toxic levels for horses are higher, at 3,600-8,500 mg/kg (Table C-30). These results suggest a threshold range between 1,000-3,600 mg Zn/kg soil to screen for Zn levels of concern.

Table C-30. Zinc compounds toxicity in soil.

	Sheep	Cattle	Other
Safe threshold	992 mg/kg (WSC[1]) 545 mg/kg (RMC[2])	1,600 mg/kg (WSC[1]) 1,082 mg/kg (RMC[2])	1,674 mg/kg (WSC[1], horse) 1,300 - 20,000 ppm (exposure in pastures, horses) 1,000 ppm (horses; back-calculated from NAOEL)
Sublethal			3,600 - 5,400 ppm a day (toxic concentrations; horses) 8,500 ppm (horses; back-calculated from LAOEL)

1. WSC = Wildlife Soil Criteria
2. RMC = Risk Management Criteria

C.10. Toxicity Summary

Table C-31 is summary of identified thresholds of concern for 7 metals in feed, water, and soils, across a range of livestock and wildlife obtained from literature.

Table C-31. Summary of identified thresholds of concern for 7 metals in feed, water and soils, across a range of livestock and wildlife.

Metal	Feed-stuffs	Water	Soil
Arsenic	2-250 mg As/kg feed (or higher*)	0.5-2.9 mg As/l	419 431 mg As/kg soil
Cadmium	1-160 mg Cd/kg feed	4.1-41.3 mg Cd/l	20–23 mg Cd/kg soil
Copper	170-182 mg Cu/kg feed	65-85 mg Cu/l	281-413 mg Cu/kg soil (or as high as 2,000 mg Cu/kg soil)
Iron	500-1,200 mg Fe/kg feed	--	--
Lead	100-200 mg Pb/kg feed (up to 730 mg Pb/kg feed)	34-340 mg Pb/l	1,127-1,146 mg Pb/kg soil (upper safe levels, not necessarily a threshold of concern)
Nickel	>100mg Ni/kg feed; 360-720 mg Ni/kg feed	171-340 mg Ni/l	--
Zinc	500 - 1,000 mg Zn/kg feed	50 mg/L(a safe level, not a threshold of concern)	1,000-3,600 mg Zn/kg soil

* many of the sublethal effects of As were presented as single doses, and there was a wide range across different animal types and forms of arsenic

Appendix D: Summary of Assessment Performed for San Juan River in Utah

Utah DEQ San Juan River Screening Risk Assessment

On behalf of Utah Department of Environmental Quality (DEQ), Tetra Tech conducted a screening level human health, ecological, and agricultural risk assessment (SLRA) for San Juan River and Lake Powell with respect to potential impacts from the Gold King Mine (GKM) release in August 2015. Approximately three million gallons of acid mine water containing mine waste sediments and heavy metals was released into Cement Creek, a tributary of the Animas River. The release flowed downstream as an orange-colored plume that became diluted as the Animas River joined the San Juan River by water releases from the Navajo Lake Dam.

The SLRA serves as a screening, which is designed to conservatively estimate the potential risks associated with exposure to water and sediment of the San Juan River due to the release of contaminants from the GKM incident. The SLRA was completed in accordance with the U.S. EPA guidance for human health and ecological risk assessment under the Comprehensive Environmental Response, Compensation and Liability Act (specifically, the U.S. EPA's Risk Assessment Guidance for Superfund 1989).

The SLRA applied conservative assumptions to evaluate the potential risks to wildlife, humans, and crops under a range of relevant scenarios. Given the conservative assumptions used in the SLRA a finding of little or no potential for risk would provide assurance that wildlife, human health, and crops are unlikely to be adversely affected by constituents present in the sediments, surface water, or as accumulated in soil.

Human Health Risk Assessment

The evaluation of total metal concentration in surface water showed that eight metals are potential hazards when compared to U.S. EPA Regional Screening Levels (As, Ba, Be, Cd Co, Pb, Tl, and V), six exceeded chronic Environmental Media Evaluation Guidelines (EMEGs) for children (Sb, As, Ba, Be, Cd, and Ni) with four also exceeding chronic adult EMEGs (As, Ba, Be, and Cd), one exceeded acute EMEGs for children (Cu), and eight exceeded Utah's drinking water maximum contaminant levels or action levels (Sb, As, Ba, Be, Cd, Cr, Pb, and Tl). These exceedances were based on total metal concentrations in surface water and therefore may not be representative of at-the tap measurements from filtered or treated water. In addition, it is possible, if not likely, that domestic water supplies are from groundwater rather than directly from the river. Nonetheless, these exceedances indicate that domestic use of SJR water could result in adverse health effects to children and adults.

Dissolved concentrations of Fe and Mn in water were found to be above Utah Department of Environmental Quality agricultural screening levels, indicating that use of SJR water for irrigation has the potential to decrease the health or yield of some types of crops. In addition, the dissolved concentration of Pb measured in the SJR slightly exceeded Utah's domestic water quality standard which could result in adverse human health impacts such as elevated blood Pb levels in children. However, this exceedance was found to be in only one sample and may not be indicative of long-term exposure concentrations.

Agricultural Risk Assessment

Al that may accumulate in irrigated soil was estimated to exceed benchmark levels for plant health, although U.S. EPA Ecological Soil Screening Levels note that toxicity from Al is possible only if soil pH is less than 5.5. This evaluation was based on assumed water usage, a moderate depth of tillage, and the assumption that all metals were retained in the soil. This did not account for background concentrations, and therefore could be an underestimate of potential risk, but the intent of the screening-level risk assessment was to focus on incremental risks.

Tl in beef was associated with a hazard quotient above 1.0. This hazard applies to human ingestion of beef, rather than effects to cattle. This estimate is based on (1) direct ingestion of SJR water by cattle; (2) incidental ingestion by cattle of soil irrigated with SJR water; and (3) ingestion of plants and pasture grass irrigated by SJR water, using the total metal concentrations measured in water. This may result in an overestimate of tissue concentration, as the inputs may overestimate exposure of cattle due both to concentration and bioaccumulation potential. However, the estimates do not include the contribution of background concentrations.

Ecological Risk Assessment

A screening level ecological risk assessment (SLERA) was performed for constituents of potential concern (COPCs) in sediment and surface water in the San Juan River before and after the Gold King Mine (GKM) spill. The results of the screening Step 1 analysis identified multiple inorganic constituents as COPCs in both sediment and surface water and the conservative Step 2 food-chain modeling indicated a potential for risk to certain types of receptors that are likely present in the study area. The identification of inorganics as COPCs and the identification of receptors of concern potentially at risk supports the recommendation to conduct additional steps of the ecological risk assessment (ERA) process to provide more realistic estimates of exposure and risk, consistent with U.S. EPA guidance.

Pre-GKM Spill

Based on the sediment and surface water maximum concentrations available for the SJR before the GKM spill entered Utah, sediment concentrations of Ba and surface water concentrations of Fe and Mn were greater than the ESVs. Certain inorganics including sediment concentrations of strontium (Sr) and surface water concentrations of Sb, Be, Cd, calcium, chloride, Co, Mo, nitrate, nitrite, Na, Sr, Tl and V were not measured in the SJR prior to the spill, thus pre-spill risks due to these COPCs could not be quantified. Using the full list of COPCs identified in the post-spill GKM, pre-spill concentrations of these COPCs were evaluated in Step 2. The Step 2 upper trophic level risk assessment indicated that all COPCs, except Ag, are recommended for further evaluation.

GKM Spill

Post GKM spill analysis of maximum measured surface water and sediment concentrations in the entire Utah portion of the SJR and Lake Powell, resulted in fourteen constituents identified as posing potential risk and needing further evaluation. In sediment, Ba and Sr, were the only two COPCs with detected maximum concentration greater than ESVs; while in surface water, fourteen COPCs (Al, Ba, Be, Co, Cu, Fe, Pb, Mn, Hg, nitrate-nitrite, Ag, Sr, V, and Zn) were identified as having maximum detected concentration greater than ESVs. All COPCs identified in Step 1 were retained in Step 2 due to at least one receptor (lower or upper trophic level) indicating potential risk. Therefore, all fourteen COPCs evaluated in Step 2 indicate risk and should be further evaluated.

Risk Summary

Based on the evaluation of risks associated with direct human and wildlife exposure to San Juan River (SJR) water and sediment, agricultural exposure pathways, and potential accumulation of metals in soil, there are no immediate risks to human health, wildlife, or agricultural receptors. However, there were some exceedances of risk- based screening levels as discussed above.

Appendix E: Sediment Toxicity and Aquatic Receptors

E.1. Sediment Toxicity Study

Sediment

Sediment samples were collected by Navajo personnel and consisted of various sediments found in the San Juan River, tributaries, and canals in the region. Table E-1summarizes the sediment samples used in this study.

Table E-1. Summary of sediments collected by Navajo Nation personnel and used in sediment toxicity evaluations.

Area	Unit Name	Sample Label
San Juan River	San Juan River at Nenahnezad	10SANJUANR38
	San Juan River at Area 7 (downstream from Shiprock)	10SANJUANR26
	San Juan River at Four Corners	02SANJUANR06
	San Juan River at Montezuma Creek	02SANJUANR07
Tributaries	Chaco River near mouth	06CHACORIV04
	Mancos River at mouth	07MANCOSRI01
Irrigation Canals	Fruitland Canal at first bridge	10FRUCANAL40
	Fruitland Canal several miles from head gate	10FRUCANAL45
	Hogback Canal between head gate and first waste way	10HOGBACKC43
	Hogback Canal several miles from head gate	10HOGBACKC44

Methods: Sediment

Sediment Toxicity

Sediment toxicity tests were conducted using the freshwater amphipod, Hyalella azteca, following methods in U.S. EPA (2000b). The 42-day test consisted of a 28-day exposure to sediment and a 14-day post-sediment exposure in laboratory water. Test organisms were placed in twelve (12) replicate beakers of sediment with laboratory culture water as overlying water. Overlying water was renewed twice daily as per the test method and each beaker was fed 1.0 mL of a mixture of yeast, trout chow, and cerophyll grass (YTC) daily. After 28-days of exposure to the sediment, test organisms from four replicates were counted, dried for 24 hours at 100°C and weighed. Test organisms from the additional eight replicates were removed from the sediment and placed in beakers with only overlying laboratory water. These test organisms were evaluated after 7 days (35 days total test length) for survival and reproduction and after 14 days (42 days total test length) for survival, reproduction, and growth.

Endpoints measured in the sediment toxicity tests with respect to comparison to the controls included: 28-day survival (%), 35-day survival (%), and 42-day survival (%); 28-day growth and biomass (mg), 42-day growth and biomass (mg); and 42-day reproduction per female (young/female).

Sediment Chemistry

Fully-homogenized sediment sub-samples were sent to ALS Environmental in Kelso, WA for the analysis of total solids (EPA 160.3), pH (EPA 9045C), particle size (ASTM D422M), metals (EPA 6020A), and Hg (EPA 7471B).

Results

Sediment Chemistry

Overall, the sediment samples consisted of 54.6 – 75.5% solids, acid volatile sulfides (AVS) concentrations between non-detect (0.007 µmole/g) to 0.9 µmole/g, and total organic carbon (TOC) percentage between 0.2 to 1.25%. Sediment 10SANJUANR38 had the highest concentration of AVS and TOC (Table E-2).

The analysis of total metals in the sediments indicated that there were no exceedances of sediment screening values for toxicity (Buchman, 2008) for all sediment samples except Mn in sediment 10SANJUANR38 (Table E-3). The results of chemical analysis of the sediments are summarized in Table E-2.

Sediment Toxicity

Overall, only one sediment, 10SANJUAN38, resulted in a significant difference from control with respect to Hyalella survival. There were no significant differences from the controls with respect to growth (28-day and 42-day); biomass (28-day and 42-day) or reproduction (42-day average young/female). The analysis of the results of the sediment toxicity tests with Hyalella are summarized in Table E-3.

Table E-2. Summary of general chemistry and metals analysis on Navajo Nation sediments. Bolded values indicate the maximum measured value across all sediments. Shaded cells indicate measured value above the Sediment Screening Level (Buchman, 2008). Shaded cells indicate measured value above the Soil Screening Level of plants (Efoymson et al. 1997).

Parameter	Units	Sediments										
		Sediment Screening Level	02SANJUANR07	02SANUANR06	10SANJUANR38	10HOGBACKC43	10SANJUANR26	06CHACORIV04	10HOGBACKC44	07MANCOSRI01	10FRUCANAL45	10FRUCANAL40
Total Solids	**%**	NA	68.1	70.2	57.2	**75.5**	56.8	54.6	69.8	59.1	63	71.5
Acid Volatile Sulfide (AVS)	**µmole/g**	NA	0.308	0.37	**0.9**	0.007 U	0.57	0.007 U	0.57	0.037	0.39	0.26
Total Organic Carbon (TOC)	**%**	NA	0.82	0.73	**1.25**	0.25	0.85	0.62	0.2	0.97	0.63	0.41
Aluminum	**mg/Kg**	NA	11300	9140	12000	6050	13300	**15700**	5930	11300	9690	7320
Antimony	**mg/Kg**	3	**0.109**	0.092	0.085	0.067	0.097	0.08 J	0.052	0.07 J	0.076	0.07
Arsenic	**mg/Kg**	5.9	**5.88**	4.32	4.87	2.4	5.56	6.26	2.38	4.5	4.08	2.77
Barium	**mg/Kg**	NA	220	208	294	240	242	224	209	134	257	**358**
Beryllium	**mg/Kg**	NA	0.9	0.668	1.08	0.484	1.04	1.17	0.472	**1.47**	0.831	0.601
Cadmium	**mg/Kg**	0.583	**0.316**	0.192	0.191	0.079	0.239	0.235	0.082	0.34	0.172	0.12
Chromium	**mg/Kg**	26	12.7	9.56	10.2	6.87	11.1	**13.5**	5.31	6.13	8.03	6.29
Cobalt	**mg/Kg**	50	7.49	5.9	**8.18**	4.39	7.82	7.94	3.77	6.46	6.7	4.92
Copper	**mg/Kg**	28	17.9	13.1	18.1	7.88	18.1	**19**	7.73	13.9	15.8	10.3
Iron	**mg/Kg**	NA	16300	12700	15500	8890	16200	**17900**	8640	13100	13700	10300
Lead	**mg/Kg**	31	12.9	9.68	13.8	6.52	13.5	14.7	7.04	**16**	13.4	9.59
Manganese	**mg/Kg**	460	394	354	**571**	222	450	330	219	199	385	241
Mercury	**mg/Kg**	0.174	0.026 J	0.016 J	0.023 J	0.007 J	0.026 J	0.03 J	0.005 J	0.045 J	0.019 J	0.01 J
Molybdenum	**mg/Kg**	NA	**1.41**	0.864	0.482	0.309	0.885	0.719	0.293	0.688	0.478	0.272
Nickel	**mg/Kg**	16	**15.4**	11.4	10.6	5.91	12.3	13.6	5.42	10	8.73	6.4
Selenium	**mg/Kg**	NA	0.62 J	0.36 J	0.29 J	0.14 J	0.5 J	0.47 J	0.14 J	0.67 J	0.24 J	0.18 J
Silver	**mg/Kg**	0.5	0.082	0.054	0.08	0.024	0.081	**0.09**	0.024	0.087	0.07	0.047

Table E-2. Summary of general chemistry and metals analysis on Navajo Nation sediments. Bolded values indicate the maximum measured value across all sediments. Shaded cells indicate measured value above the Sediment Screening Level (Buchman, 2008). Shaded cells indicate measured value above the Soil Screening Level of plants (Efoymson et al. 1997).

Parameter	Units	Sediments										
		Sediment Screening Level	02SANJUANR07	02SANUANR06	10SANJUANR38	10HOGBACKC43	10SANJUANR26	06CHACORIV04	10HOGBACKC44	07MANCOSRI01	10FRUCANAL45	10FRUCANAL40
Thallium	**mg/Kg**	NA	**0.285**	0.195	0.212	0.108	0.258	0.27	0.097	0.268	0.173	0.126
Vanadium	**mg/Kg**	NA	26.4	20.7	23.2	13.9	25.7	**28.8**	12.8	14	19.4	14.8
Zinc	**mg/Kg**	98	54.9	42.3	59.3	29.2	58	58.7	31.7	48.1	**62.5**	43.4

Table E-3. Summary of Hyalella azteca survival, growth and reproduction endpoints for San Juan River sediments. Shaded cells are significantly less than controls ($p < 0.05$).

Test ID	Location	28 Day Mean % Survival (N = 12)	28 Day Mean % Survival (N = 8)	35 Day Mean % Survival (N = 8)	42 Day Mean % Survival (N = 8)	28 Day Mean Weight of Survivors (mg)	28 Day Mean Individual Weight based on 10 Organisms per Chamber (mg)	42 Day Mean Weight of Survivors (mg)	42 Day Mean Individual Weight based on 10 Organisms per Chamber (mg)	42 Day Average Young/Female
Tt04050	Controls	84.2	87.5	82.5	81.3	0.30	0.24	0.49	0.40	2.8
Tt04040	02SANJUANR07	90	90	90	88.8	0.70	0.63	0.74	0.66	6.6
Tt04041	02SANJUANR06	86.7	86.3	83.8	82.5	0.55	0.49	0.58	0.48	2.0
Tt04042	10SANJUANR38	56.7	50	47.5	45.0	0.33	0.23	0.71	0.32	5.9
Tt04043	10HOGBACKC43	93.3	88.8	87.5	87.5	0.29	0.30	0.58	0.51	4.1
Tt04044	10SANJUANR26	96.7	98.8	91.3	91.3	0.62	0.57	0.70	0.64	8.6
Tt04045	06CHACORIV04	82.5	96.3	96.3	96.3	0.84	0.46	0.50	0.48	2.3
Tt04046	10HOGBACKC44	89.2	87.5	87.5	90	0.44	0.41	0.67	0.61	4.7
Tt04047	07MANCOSRI01	76.7	73.8	73.8	73.8	0.33	0.27	0.52	0.39	1.7
Tt04048	10FRUCANAL45	89.2	86.3	83.8	83.8	0.83	0.79	0.71	0.60	4.4
Tt04049	10FRUCANAL40	88.3	95.0	90	90	0.65	0.49	0.63	0.57	3.4

E.2. Navajo Fish Tissue Study

In 2015, the plume from the Gold King Mine (GKM) waste water release flowed through Navajo Nation lands, subjecting downstream waters to high metal concentrations. Concerns remained regarding possible resuspension and remobilization of metals in sediments, and latent exposures to aquatic life or humans. The Navajo Nation Environmental Protection Agency (NNEPA) recognized the importance of recreation in the San Juan River basin, including fishing, and the potential exposure of humans to contaminants through fish consumption. It is because of that recreational importance and the possibility of latent human exposure to metal contamination that NNEPA authorized the 2017 San Juan River Fish Tissue Contaminant Study. The goal of the study was to provide a screening level assessment of metals in fish fillet tissue to help identify the prevailing human health risk associated with fish consumption subsequent to the GKM spill. The study was not designed to determine causes or locate sources of fish tissue contamination. Channel Catfish (*Ictalurus punctatus*) were selected as an indicator species based on their ecology, their sportfish status and human consumption potential, and their relative abundance in the river.

A total of 10 composite fish samples (five fish in each composite -- 50 total fish) were collected in April 2017. Sampling occurred in two distinct river segments – an upstream reach in New Mexico and a downstream reach in Utah. The fillet composites were analyzed for a suite of 25 metals (see Table E-4 through Table E-8). Results showed that:

- Nine of the 25 target metals were detected in at least one fillet fish tissue composite.
- Six metals (Cu, Mg, Hg, potassium (K), sodium (Na), and Zn) were detected in all composites.
- Average concentrations of Cu in fish fillets were similar to those from previous San Juan River fish tissue surveys (from between 1993 and 2000).
- Average levels of Mg and Zn were lower in 2017 than in previous studies.
- Total Hg was the only frequently detected metal that was higher in the 2017 composites than in samples from previous studies.
- Hg concentrations in Channel Catfish fillet tissue collected during 2017 were below U.S. EPA's 0.3 mg/Kg tissue-based water quality criterion.

United States Environmental Protection Agency (U.S. EPA) risk-based fish consumption limits are published and available for four of the target metals -- As, Cd, Hg, and Se. The human health screening value applied for Hg was the U.S. EPA fish tissue-based water quality criterion for methylmercury and is the same threshold used by the states of New Mexico and Utah in their fish consumption advisory programs. All fillet results from the 2017 San Juan River collections were below the Hg criterion. As, Cd, and Se concentrations in fillets were all below the method reporting limits; however, the analytical methods did not enable detection down to levels that allowed consideration of all consumption categories. Because of that, it is not possible to make fish consumption recommendations based on those chemicals at this time without new (more sensitive) analytical methods and further data collection.

The 2017 fillet tissue results indicate that human health risk from recreational consumption of San Juan River fish (with respect to metal concentrations) is low. It is important to note that published U.S. EPA consumption advice and human health benchmarks were applied, which may not reflect the consumption patterns of selected local populations or a subsistence fishing community; however, they are appropriate (based on San Juan River Fish Tissue Study goals) for a screening level assessment of fish tissue contaminants. The results presented here provide current [2017] information on metals in San Juan River fish tissue as well as baseline data for any future studies of temporal trends.

E.3. Other Relevant Fish Tissue Information from the Literature

Metal accumulation in fish is a global public health concern, because the consumption of contaminated fish accounts for the primary exposure of humans to toxic metals. For this literature review, Tetra Tech identified body burdens of several metals, including Cu, Cd, As, Zn, Fe, and Ni in various fish species, some of which are relevant to the San Juan River and Lake Powell. Reliable data were obtained for the following species: Channel Catfish (*Ictalurus punctatus*), Carp (*Cyprinus carpio*), Bluehead Sucker (*Catostomus discobolus*), Brown Trout (*Salmo trutta*), Flannelmouth Sucker (*Catostomus latipinnis*), Speckled Dace (*Rhinichthys osculus*), and Rainbow Trout (*Oncorhynchus mykiss*).

As shown in Table E-4, metal tissue concentrations in fish varies with the species and probably depends on many species-specific factors such as sex, age, size, reproductive cycle, swimming pattern, feeding behavior, and geographical location (McIntyre & Beauchamp 2007). Data for Fe and, to some extent, Ni tissue levels, are generally unavailable for many of the fish species reviewed. This is probably due in part to greater research interest in metals that are known to be toxic at fairly low concentrations and have been observed in fish tissues in other studies. Zn had some of the highest tissue concentrations in several fish species (Table E-4) which may reflect higher concentrations of this metal in the river than other metals evaluated. However, none of the tissue concentrations reported are likely to be toxic to wildlife or humans.

Bioaccumulation is the net result of the interaction of uptake, storage, and elimination of a chemical (Perera et al. 2015). However, differences in metal accumulation between species may be related to living and feeding habits. Overall, species in relatively lower trophic levels are exposed to comparatively lower contamination, although plants can accumulate metals in high levels (Terra et al. 2008). On the other hand, fish species of higher trophic levels (carnivores/piscivores) are prone to accumulate metals to higher levels. This trend is somewhat borne out by the data for some metals in Table E-5 however there are many exceptions. For example, Gray (2002) concluded that metal biomagnification in aquatic food chains is an exception rather than the rule among metals and metalloids. Unambiguous evaluations of metal biomagnification in nature are rare because metal concentrations in whole-body prey are often compared with those in a predator's specific tissues without knowledge of the bioaccumulation processes (Croteau et al. 2005).

Tables Table E-6 and Table E-7 present information of fish tissue concentrations at upstream and downstream locations of the San Juan River for comparison to other published reports.

Table E-4. Summary of literature fish tissue concentrations observed for several metals of concern in fish species that are relevant to the San Juan River and Lake Powell. dw = dry weight, ww = wet weight.

Species	Metal	Body burden	Notes
Channel catfish	copper	2.40 mg kg^{-1} dw	Simpson and Lusk, 1999
	cadmium	ND (Not Detected)	NNEPA 2017
	arsenic	0.21 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	73.4 mg kg^{-1} dw	Simpson and Lusk, 1999
	iron	4.3–7.4 mg kg^{-1} ww	NNEPA 2017
	nickel	0.052 -0.28 mg kg^{-1} ww	NNEPA 2017
Carp	copper	4.34 mg kg^{-1} dw	Simpson and Lusk, 1999

Table E-4. Summary of literature fish tissue concentrations observed for several metals of concern in fish species that are relevant to the San Juan River and Lake Powell. dw = dry weight, ww = wet weight.

Species	Metal	Body burden	Notes
	cadmium	0.01 mg kg^{-1} dw	O'Brien, 1987
	arsenic	0.21 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	183.7 mg kg^{-1} dw	Simpson and Lusk, 1999
	nickel	0.1 mg kg^{-1} dw	O'Brien, 1987
Bluehead sucker	copper	2.75 mg kg^{-1} dw	Simpson and Lusk, 1999
	cadmium[1]	0.02 – 3.47 mg kg^{-1} dw	Guenzel et al. 2018
	arsenic	0.48 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	50.9 mg kg^{-1} dw	Simpson and Lusk, 1999
Brown trout	copper	4.74 mg kg^{-1} dw	Simpson and Lusk, 1999
	cadmium	0.1 mg kg^{-1} dw	Guenzel et al. 2018
	arsenic	0.24 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	84.2 mg kg^{-1} dw	Simpson and Lusk, 1999
Flannelmouth sucker	copper	2.59 mg kg^{-1} dry weight	Simpson and Lusk, 1999
	cadmium[1]	0.02 – 47.41 mg kg^{-1}	Guenzel et al. 2018
	arsenic	0.21 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	50.3 mg kg^{-1} dw	Simpson and Lusk, 1999
Speckled dace	copper	3.65 mg kg^{-1} dw	Simpson and Lusk, 1999
	cadmium[2]	0.01 -0.02 mg kg^{-1} dw	Guenzel et al. 2018
	arsenic	0.35 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	164.1 mg kg^{-1} dw	Simpson and Lusk, 1999
Rainbow trout	copper	6.29 mg kg^{-1} dw	Simpson and Lusk, 1999
	arsenic	0.31 mg kg^{-1} dw	Simpson and Lusk, 1999
	zinc	81.4 mg kg^{-1} dw	Simpson and Lusk, 1999

1. Values represent March 2017 (first value) and August 2016 (second value) taken from liver
2. Values represent March 2017 (first value) and August 2016 (second value) taken from muscle

Table E-5. Trophic levels and main dietary items for select fish species relevant to the San Juan River and Lake Powell.

Species	Trophic level	Classification	Diet
Channel catfish	3.4 – 4.16	Carnivore	Animals (fish and invertebrates)
Carp	3.05	Omnivore	Detritus, plant, zoobenthos
Bluehead sucker	2.8 [1]	Omnivore	Detritus, benthic invertebrates
Brown trout	3.80	Carnivore	Nekton (fish) and zoobenthos
Flannelmouth sucker	2.8 [1]	Omniovre	Detritus, benthic invertebrates
Speckled dace	2.93	Omnivore	plants/detritus+animals
Rainbow trout	3.53 – 4.08	Carnivore	Zoobenthos, nekton

1. Based on trophic level of closest relatives (*Catostomus* sp.)

Table E-6. San Juan River Upstream (New Mexico) Reach fillet tissue concentrations (mg/Kg, wet weight)

Sample ID			Upstream Composite 1			Upstream Composite 2			Upstream Composite 3			Upstream Composite 4		
CAS	**Analyte**	**Units**	**VALUE**	**RL**	**MDL**	**VALUE**	**RL**	**MDL**	**VALUE**	**RL**	**MDL**	**VALUE**	**RL**	**MDL**
7429-90-5	Aluminum	mg/Kg	ND	2.9	1.8	ND	3.2	1.9	ND	3.2	2	ND	3.1	1.9
7440-36-0	Antimony	mg/Kg	ND	0.19	0.032	ND	0.21	0.034	ND	0.22	0.035	ND	0.21	0.034
7440-38-2	Arsenic	mg/Kg	ND	0.097	0.02	ND	0.11	0.021	ND	0.11	0.022	ND	0.1	0.021
7440-39-3	Barium	mg/Kg	ND	0.97	0.046	ND	1.1	0.05	ND	1.1	0.051	ND	1	0.049
7440-41-7	Beryllium	mg/Kg	ND	0.097	0.024	ND	0.11	0.026	ND	0.11	0.026	ND	0.1	0.025
7440-43-9	Cadmium	mg/Kg	ND	0.097	0.01	ND	0.11	0.011	ND	0.11	0.011	ND	0.1	0.011
7440-70-2	Calcium	mg/Kg	ND	49	7.8	ND	53	8.5	ND	54	8.6	ND	52	8.3
7440-47-3	Chromium	mg/Kg	ND	0.19	0.079	ND	0.21	0.086	ND	0.22	0.088	ND	0.21	0.084
7440-48-4	Cobalt	mg/Kg	ND	0.049	0.008	ND	0.053	0.0086	ND	0.054	0.0088	ND	0.052	0.0085
7440-50-8	Copper	mg/Kg	0.25	0.19	0.12	0.32	0.21	0.13	0.44	0.22	0.13	0.36	0.21	0.13
7439-89-6	Iron	mg/Kg	ND	4.9	3.6	5.3	5.3	3.9	ND	5.4	4	ND	5.2	3.8
7439-92-1	Lead	mg/Kg	ND	0.097	0.047	ND	0.11	0.051	ND	0.11	0.052	ND	0.1	0.05
7439-95-4	Magnesium	mg/Kg	220	49	3.2	230	53	3.5	230	54	3.6	230	52	3.4
7439-96-5	Manganese	mg/Kg	ND	0.49	0.17	ND	0.53	0.18	ND	0.54	0.19	ND	0.52	0.18
7439-98-7	Molybdenum	mg/Kg	ND	0.49	0.076	ND	0.53	0.083	ND	0.54	0.084	ND	0.52	0.081
7440-02-0	Nickel	mg/Kg	ND	0.097	0.029	ND	0.11	0.031	0.12	0.11	0.032	0.052	0.1	0.03
9/7/7440	Potassium	mg/Kg	3600	49	5.2	3600	53	5.6	3800	54	5.8	3800	52	5.5
7782-49-2	Selenium	mg/Kg	ND	0.49	0.12	ND	0.53	0.13	ND	0.54	0.13	ND	0.52	0.13
7440-22-4	Silver	mg/Kg	ND	0.097	0.013	ND	0.11	0.014	ND	0.11	0.014	ND	0.1	0.014
7440-23-5	Sodium	mg/Kg	620	49	20	580	53	22	660	54	23	640	52	22
7440-24-6	Strontium	mg/Kg	ND	0.49	0.033	ND	0.53	0.036	ND	0.54	0.037	ND	0.52	0.035
7440-28-0	Thallium	mg/Kg	ND	0.097	0.0038	ND	0.11	0.0041	ND	0.11	0.0042	ND	0.1	0.004
7440-62-2	Vanadium	mg/Kg	ND	0.097	0.055	ND	0.11	0.059	ND	0.11	0.061	ND	0.1	0.058
7440-66-6	Zinc	mg/Kg	4.3	0.49	0.28	4.5	0.53	0.3	4.3	0.54	0.31	4.6	0.52	0.3
7439-97-6	Mercury	mg/Kg	0.16	0.034	0.0076	0.15	3	1.8	0.15	0.031	0.0069	0.14	0.034	0.0075

Note: RL = Reporting Limit; MDL = Method Detection Limit; ND = Not Detected

Table E-7. San Juan River Upstream (New Mexico) Reach fillet tissue concentrations (mg/Kg, wet weight) (continued)

Sample ID			Upstream Composite 5			Upstream Composite 6		
CAS	**Analyte**	**Units**	**VALUE**	**RL**	**MDL**	**VALUE**	**RL**	**MDL**
7429-90-5	Aluminum	mg/Kg	ND	2.9	1.8	ND	3.1	1.9
7440-36-0	Antimony	mg/Kg	ND	0.2	0.032	ND	0.21	0.034
7440-38-2	Arsenic	mg/Kg	ND	0.098	0.02	ND	0.1	0.021
7440-39-3	Barium	mg/Kg	ND	0.98	0.046	ND	1	0.049
7440-41-7	Beryllium	mg/Kg	ND	0.098	0.024	ND	0.1	0.025
7440-43-9	Cadmium	mg/Kg	ND	0.098	0.01	ND	0.1	0.011
7440-70-2	Calcium	mg/Kg	ND	49	7.9	ND	52	8.4
7440-47-3	Chromium	mg/Kg	ND	0.2	0.08	ND	0.21	0.085
7440-48-4	Cobalt	mg/Kg	ND	0.049	0.008	ND	0.052	0.0085
7440-50-8	Copper	mg/Kg	0.41	0.2	0.12	0.31	0.21	0.13
7439-89-6	Iron	mg/Kg	ND	4.9	3.6	5.6	5.2	3.8
7439-92-1	Lead	mg/Kg	ND	0.098	0.047	ND	0.1	0.05
7439-95-4	Magnesium	mg/Kg	230	49	3.3	230	52	3.5
7439-96-5	Manganese	mg/Kg	ND	0.49	0.17	0.58	0.52	0.18
7439-98-7	Molybdenum	mg/Kg	ND	0.49	0.077	ND	0.52	0.082
7440-02-0	Nickel	mg/Kg	0.088	0.098	0.029	0.28	0.1	0.031
9/7/7440	Potassium	mg/Kg	3600	49	5.2	3700	52	5.6
7782-49-2	Selenium	mg/Kg	ND	0.49	0.12	ND	0.52	0.13
7440-22-4	Silver	mg/Kg	ND	0.098	0.013	ND	0.1	0.014
7440-23-5	Sodium	mg/Kg	610	49	21	700	52	22
7440-24-6	Strontium	mg/Kg	ND	0.49	0.034	ND	0.52	0.036
7440-28-0	Thallium	mg/Kg	ND	0.098	0.0038	ND	0.1	0.0041
7440-62-2	Vanadium	mg/Kg	ND	0.098	0.055	ND	0.1	0.059
7440-66-6	Zinc	mg/Kg	5.1	0.49	0.28	4.7	0.52	0.3
7439-97-6	Mercury	mg/Kg	0.17	0.034	0.0075	0.14	0.037	0.0082

Note: RL = Reporting Limit; MDL = Method Detection Limit; ND = Not Detected

Table E-8. San Juan River Downstream (Utah) Reach fillet tissue

Sample ID			Downstream Composite 1			Downstream Composite 2			Downstream Composite 3			Downstream Composite 4		
CAS	Analyte	Units	VALUE	RL	MDL	VALUE	RL	MDL	VALUE	RL	MDL	VALUE	RL	MDL
7429-90-5	Aluminum	mg/Kg	ND	3	1.8	ND	3	1.8	ND	3	1.8	ND	3.2	1.9
7440-36-0	Antimony	mg/Kg	ND	0.2	0.032	ND	0.2	0.033	ND	0.2	0.032	ND	0.21	0.035
7440-38-2	Arsenic	mg/Kg	ND	0.099	0.02	ND	0.1	0.02	ND	0.099	0.02	ND	0.11	0.022
7440-39-3	Barium	mg/Kg	ND	0.99	0.047	ND	1	0.047	ND	0.99	0.047	ND	1.1	0.05
7440-41-7	Beryllium	mg/Kg	ND	0.099	0.024	ND	0.1	0.024	ND	0.099	0.024	ND	0.11	0.026
7440-43-9	Cadmium	mg/Kg	ND	0.099	0.01	ND	0.1	0.011	ND	0.099	0.01	ND	0.11	0.011
7440-70-2	Calcium	mg/Kg	ND	50	7.9	ND	50	8	ND	50	7.9	ND	53	8.5
7440-47-3	Chromium	mg/Kg	ND	0.2	0.081	ND	0.2	0.082	ND	0.2	0.081	ND	0.21	0.087
7440-48-4	Cobalt	mg/Kg	ND	0.05	0.0081	ND	0.05	0.0082	ND	0.05	0.0081	ND	0.053	0.0087
7440-50-8	Copper	mg/Kg	0.39	0.2	0.12	0.31	0.2	0.12	0.37	0.2	0.12	0.38	0.21	0.13
7439-89-6	Iron	mg/Kg	7.4	5	3.6	6.2	5	3.7	4.3	5	3.6	ND	5.3	3.9
7439-92-1	Lead	mg/Kg	ND	0.099	0.048	ND	0.1	0.048	ND	0.099	0.048	ND	0.11	0.051
7439-95-4	Magnesium	mg/Kg	310	50	3.3	220	50	3.3	220	50	3.3	250	53	3.5
7439-96-5	Manganese	mg/Kg	ND	0.5	0.17	ND	0.5	0.17	ND	0.5	0.17	ND	0.53	0.19
7439-98-7	Molybdenum	mg/Kg	ND	0.5	0.078	ND	0.5	0.078	ND	0.5	0.078	ND	0.53	0.083
7440-02-0	Nickel	mg/Kg	ND	0.099	0.029	ND	0.1	0.029	ND	0.099	0.029	ND	0.11	0.031
7440-09-7	Potassium	mg/Kg	5000	50	5.3	3600	50	5.4	3800	50	5.3	3800	53	5.7
7782-49-2	Selenium	mg/Kg	ND	0.5	0.12	ND	0.5	0.12	ND	0.5	0.12	ND	0.53	0.13
7440-22-4	Silver	mg/Kg	ND	0.099	0.013	ND	0.1	0.013	ND	0.099	0.013	ND	0.11	0.014
7440-23-5	Sodium	mg/Kg	890	50	21	560	50	21	590	50	21	590	53	22
7440-24-6	Strontium	mg/Kg	ND	0.5	0.034	ND	0.5	0.034	ND	0.5	0.034	ND	0.53	0.037
7440-28-0	Thallium	mg/Kg	ND	0.099	0.0039	ND	0.1	0.0039	ND	0.099	0.0039	ND	0.11	0.0041
7440-62-2	Vanadium	mg/Kg	ND	0.099	0.056	ND	0.1	0.057	ND	0.099	0.056	ND	0.11	0.06
7440-66-6	Zinc	mg/Kg	5.7	0.5	0.29	4.5	0.5	0.29	4.2	0.5	0.29	4	0.53	0.31
7439-97-6	Mercury	mg/Kg	0.19	0.033	0.0074	0.13	0.035	0.0078	0.095	0.034	0.0075	0.16	0.036	0.0081

.