

TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE STATE OF COLORADO NATURAL RESOURCES CONSERVATION SERVICE

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To: All Colorado Area, Field and SCD Offices

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Conservation Planning For Water Quality Concerns: Toxic Element Selenium

PURPOSE AND SCOPE

This Technical Note is adapted from Water Quality Series No. W1 "Conservation Planning for Water Quality Concerns, Toxic Element – Selenium," prepared by John D. Hedlund, Water Quality Specialist, USDA-SCS, West National Technical Center, Portland, Oregon, 1993.

BACKGROUND ON SELENIUM

Selenium (Se) is a non-metal type-p semiconducting element with chemistry similar to that of sulfur, and may replace sulfur to form analogous compounds. Selenium occurs naturally in the environment, and is mobilized through a variety of natural processes, as well as urban and other development, mining activities, agricultural activities, and other land uses. This Technical Note is focused on potential natural and agricultural selenium loading sources and possible management activities, but due to the number of sources and prevalence of Se in some areas, it is not inclusive of all land uses or activities with a potential to increase Se loading rates.

Selenium can be thought of as an "essential poison." The difference is a very fine line, but like a lot of things in life on this planet, a little is very beneficial and vital, but too much is a killer. Eating too much Se contaminated fish and fowl or drinking water contaminated with Se could be hazardous to your health. How water is managed for irrigation may impact the concentration of Se. Seepage and deep percolation of irrigation water has the potential to increase Se concentrations in certain areas. When irrigation drain water is allowed to evaporate and bioconcentrate Se in wetland areas, it is acutely toxic to fish and waterfowl. This Technical Note discusses the distribution of Se in the West; its toxicity to humans, livestock, fish and wildlife; and possible solutions to manage Se.

SELENIUM DISTRIBUTION IN THE WEST

Selenium is found in many geologic formations throughout the world, and is most abundant in sedimentary rocks such as shale, sandstone, limestones, and phosphorite rock, as well as soils derived from these materials (**Figure 1**). Selenium compounds are highly mobile and biologically available in arid regions with alkaline soils typical of

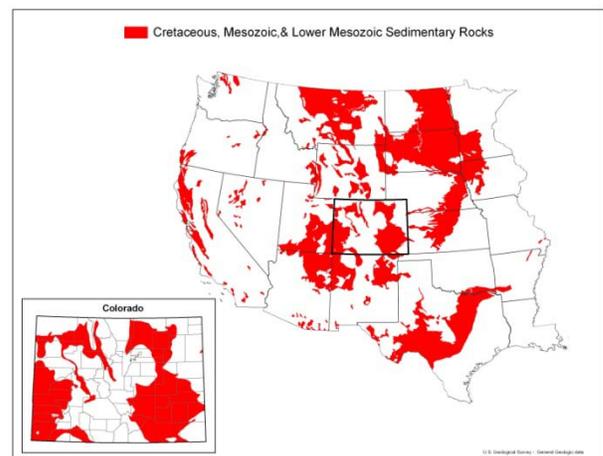


Figure 1: Distribution of geologic sedimentary formations with potential for selenium loading.

the Western United States, particularly in areas with less than 20 inches of annual precipitation (**Figure 2**).

A number of plants, such as loco weed (*Astragalus and Oxytropis spp.*), have the ability to concentrate Se extracted from the soil into bioavailable organoselenium compounds which, when eaten, are toxic to livestock. Other plants, such as prince's plume (*Stanleya pinnata*), can produce volatile organoselenium compounds. Selenium has the potential to be mobilized or released from the soil by a crop-fallow management system or irrigation activities. Saline seeps that develop in rotational systems including fallow may have high concentrations of Se. Seepage from irrigation canals, impoundments, and other water bodies or deep percolation and runoff from inefficient irrigation systems may contribute to surface and groundwater contamination. Elevated concentrations of Se can be toxic to fish, wildlife, livestock, and humans.

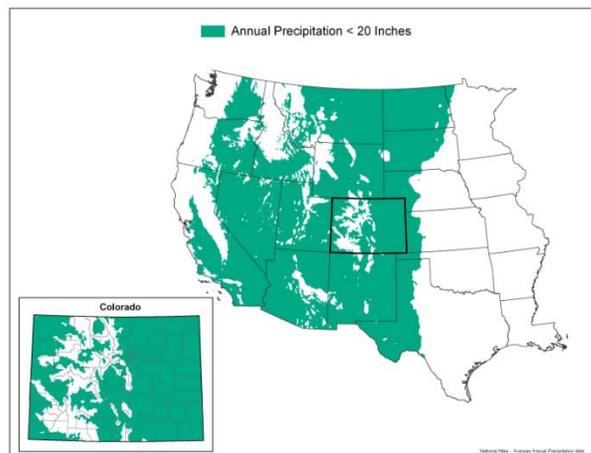


Figure 2: Regions of the Western United States where annual average precipitation is less than 20 inches.

From USGS ground water quality records at 100,400 sites, 1,420 wells have been identified in the Western U.S. where the Se concentration exceeds 10 ug/L. Available ground water quality records indicate Se concentrations, but may not be all inclusive. Remember, a well is a sampling point in the water table, integrating water quality over a vertical range. A measurement in a lake, drain, sump, or stream integrates water from possibly hundreds of thousands of acres over depths of several tens of feet.

SELENIUM PROBLEMS AND SOLUTIONS

Water quality criteria from EPA 440/5-86-001: Total recoverable inorganic selenite criterion to protect freshwater aquatic life is 35 ug/L as a 24-hour average, and the concentration should not exceed 260 ug/L at any time. For inorganic selenate the acute toxicity to freshwater aquatic life occurs at concentrations as low as 760 ug/L. The current U.S. EPA human health standard, set in 1992, for ambient water quality for Se is recommended to be less than 50 ug/L. Check your state for its recommended health standard.

The concentration of Se in rivers, streams, lakes, and wetland areas has a potential to increase due to irrigation drainage return flow in certain areas of the West. Streams above irrigated areas in the Colorado River may have Se concentrations of less than 1 microgram per liter (ug/L or 1 part per billion (ppb)), while downstream from irrigated areas the concentration may be greater than 30 ug Se/L. Drainage return flow from the Westlands Irrigation Project in California averaged 300 ug Se/L, and ranged from 160 to 1400 ug Se/L. Selenium was further concentrated in artificially created wetland areas by evaporation and bio-accumulation. Levels were high enough in plants and animals to cause mortality and impair reproduction of aquatic birds and fish.

The discovery of the dual role of Se as both an essential and potentially poisonous element in animal and human nutrition has created interest. In the West, Se should always be considered in conservation planning when determining the effects of alternative Resource Management Systems (RMS).

Some of the activities are:

1. Avoid bio-accumulation of Se in shallow ponds and wetland areas to toxic levels for fish and wildlife.
2. Control livestock grazing of plants which accumulate Se to poisonous levels.

3. Identify safe and effective methods of increasing Se concentrations in plants in deficient parts of the nation.
4. Reclamation and control of Se contamination of soils, surface water, and ground water from uranium, coal, bentonite, and phosphate mining operations.
5. Minimizing deep percolation and seepage from irrigation, and manage drain flow containing high concentrations of Se.

HUMAN TOXICITY

Human toxicity from high levels of Se in diets derived from food grown on seleniferous soils is relatively rare. Toxic symptoms from drinking contaminated water are also relatively rare.

1. Adults in the U.S. consume approximately 160 ug Se/day. Daily recommended allowance is 50 to 200 ug Se/day (National Academy of Science, 1983). The 1992 Drinking Water Standards and Health Advisories place the Reference Dose (RfD) (daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime) at 5 ug/kg/day for a 70-kg adult.
2. The 1977 Safe Drinking water Act of U.S. EPA established an allowable standard for drinking water of 10 ug Se/L; the April, 1992 Drinking Water Regulations and Health Advisories published by U.S. EPA place the Maximum Contaminant Level Goal (MCLG) and MCL at 50 ug/L.
3. In China no toxic symptoms were detected in individuals consuming up to 750 ug Se/day. However, individuals consuming 5000 ug Se/day or more had symptoms of hair and nail loss and skin lesions.
4. A family in Durango, Colorado, including a dog, suffered hair loss, nausea, and fatigue by drinking water from a domestic well contaminated by Se. The Se concentration was 9,000 ug/L and the well was located in a shale and siltstone formation.
5. Drinking water from ponds, seeps, or creeks may become contaminated. A heading in the Sunday Oregonian, December 11, 1988, read, "Doctor learns of Se too late to save victim." Girard Perkins of Burns, Oregon died with every organ in his body, from his brain to his kidney, containing high Se counts, probably from drinking spring water polluted with Se.
6. If the diet does not supply sufficient Se, diseases such as Keshan (juvenile cardiomyopathy) and Kaschin-Beck (chondrodystrophy in children) may occur.

PROTECTING THE HUMAN ENVIRONMENT

Drinking water should be tested to see if it meets the allowable health standard set by state water quality standards of 50 ug/L established by U.S. EPA. Most municipal systems have periodic tests and deliveries don't exceed these limits for any significant time periods. Remember, ground water supplies 100 million Americans with drinking water.

Rural domestic wells need testing also, particularly if any of the symptoms of Se poisoning occur such as hair and nail loss, nausea, skin lesions, and fatigue. Alternative solutions are drinking bottled water or treatment to remove Se.

Eating fish from water bodies with high concentrations of Se is permissible if the daily recommended allowance by EPA of 210 ug/day is not exceeded. Several ponds in the Colorado River Basin have Se warnings such as: "Due to the high level of Se in the fish of the lake, it is advisable not to eat any fish caught." State health advisories may recommend consumption of no more than 10 ounces of fish per week for adult males.

DOMESTIC LIVESTOCK TOXICITY

Symptoms of acute Se poisoning in livestock include anorexia, labored breathing, abnormal movement and posture, prostration, and diarrhea, which is followed by death in a few hours. Chronic Se poisoning of livestock produces anorexia, liver cirrhosis, lameness, hoof malformations, loss of hair, anemia, and emaciation (NAS-NRC, 1976). Reduced reproductive performance is the most significant effect in livestock eating forages of 5 to 10 mg Se/kg dry weight (Olson, 1978).

1. Deficiency in Se is likely when the concentration in food is less than 0.05 mg Se/kg. Selenium deficiency causes white muscle disease in calves and lambs. Death losses occur. Selenium deficiency in livestock is more common around the world than toxicity.
2. Sufficiency in Se in livestock food is in the range of 0.1 to 1.0 mg Se/kg.
3. The chronic toxicity threshold for lab animals is from diets providing 4 to 5 mg Se/kg body weight of Se daily. The Food and Nutrition Board of the National Academy of Sciences (1980) has established 5 mg Se/kg as the critical level between toxic and non-toxic feeds.
4. Open-range grazing of primary Se-accumulator plants may produce acute poisoning to livestock such as horses, cattle, and sheep. This usually only happens during drought when plants that concentrate Se are grazed. Normally these plants are not palatable to livestock and have an offensive odor due to Se. The Great Plains from Texas to Canada have documentation of conditions leading to poisoning from consumption of Se-accumulator plants. Selenium concentrations in vegetation that cause acute poisoning range between 400 and 800 mg/kg (Girling, 1984).

PROTECTING DOMESTIC LIVESTOCK

Selenium deficiency in livestock diets can be overcome by adding feed supplements containing Se. Selenium fertilizer can be added to increase Se in crops grown on deficient soils. Some fertilizer materials may contribute Se for use by plants. Fertilizer made from rock phosphate may contain as much as 200 mg Se/kg. Liming acid soils was found to increase the uptake of Se by plants (Cary, 1967). Conflicting results are reported on Se solubility and changes in plant uptake due to adding lime, gypsum, sulfate, and phosphate. The contradictory effects can usually be explained by evaluating site-specific information. Only two countries, New Zealand and Finland, have begun adding Se legally to fertilizers used for production of both forage and human food.

Selenium poisoning of livestock can best be controlled by proper grazing management. This requires the exclusion of livestock grazing on range where Se is concentrated in plants on seleniferous soils. Usually only during drought or when livestock are starving will they eat the normally non-palatable, acutely toxic Se-accumulator plants, such as loco weed; however, it has been found that some livestock have a greater propensity to ingest toxic plants than others. Chronic toxicity can be reduced by knowing the Se-accumulator plants and restricting grazing of them. Pest management to control or eliminate those plants which are Se-accumulators on rangeland is another possible treatment. Range seeding and alternative land uses should also be considered for these areas.

Testing water supplies for Se is another preventative measure to reduce the hazard of toxic poisoning of livestock. Alternative water sources for livestock may have to be found. If you are going to assist a farmer or rancher to build a pond, consider the Se hazard. Consider the factors of Se distribution: Is it located in an area of less than 20 inches annual precipitation, in an area with Cretaceous shale formations, is seleniferous vegetation present, or do ground water or surface water records indicate a Se hazard? If a Se hazard is identified, alternative sources of livestock water should be found.

FISH AND WILDLIFE TOXICITY

Toxicity varies for different forms of Se, animal species, duration of exposure, method of uptake, and other factors. In wetland areas, bio-accumulation and bio-magnification increase concentrations of Se in the food chain. Selenium is taken up by aquatic biota including phytoplankton, zooplankton, and insects which contribute to the diet of higher forms of wildlife. Dietary plant Se is readily absorbed by animals. Most of the Se (70-80%) is quickly excreted in the urine, breath, perspiration, and bile. The remaining Se becomes bound or incorporated into blood and tissue and is only slowly eliminated (Olson, 1978).

1. Selenium transfer in the food chain has caused Se toxicity in aquatic birds, not only as hatching deformity and death, but also as mortality of adult fowls. Hatchability of chicken eggs is reduced when dietary concentrations are 6 to 9 mg Se/kg.
2. Waterborne Se is acutely toxic to certain aquatic invertebrates at concentrations of 70 to 760 ug Se/L (U.S. EPA, 1980)
3. Waterborne Se is acutely toxic to certain fish. Ponds contaminated with Se from coal fly ash have caused reduced fish populations. Lemly (1985) found that Se contamination of 10 ug Se/L eliminated 16 of 20 fish species. Only carp, black bullheads, and mosquito fish were present throughout the study. Mosquito fish were the only fish found in Kesterson ponds, CA, during 1983-1985 because of Se contamination from irrigation return flow.
4. Several years of testing at the Monticello Ecological Research station (MERS) have shown that adverse effects on bluegills may occur at Se concentrations as low as 2.5 ug Se/L in the water. Selenium is bio-accumulated and toxicity comes about through the food chain (Communications May 24, 1991, with Roger O. Hermanutz, Research Aquatic Biologist, MERS).

PROTECTING FISH AND WILDLIFE

Selenium poisoning of fish and wildlife due to human activities affecting the biological availability of Se has been reported when wetlands or water bodies receive Se through subsurface agricultural irrigation drainage water or fly ash from coal-fired power plants. The most pronounced effect in wildlife species has been found in birds that fed regularly at Kesterson National Wildlife Refuge near Gustine, California. The solution at Kesterson has been to cut off the irrigation drainage flow and cover up the artificially created wetlands (evaporation ponds). In the San Joaquin Valley of California there are approximately 6,850 acres of evaporation ponds for disposal of irrigation drain water, most with elevated concentrations of Se. Source control measures to reduce irrigation use include improved irrigation water management, crop management, alternative land use, selective land retirement, and alternative drainage disposal (reuse and agroforestry, for example).

TOTAL RESOURCE MANAGEMENT

A complete conservation management system which may assist with controlling Se contamination as well as other problems of the soil and water, and protect the plant, animal, and air resources is called a Resource Management System (RMS). **Table 1** displays options designed to help protect soil, water, plants, and animals from Se pollution.

A conservation management system may include practices such as irrigation water management, changing to a cropping sequence which reduces saline seep conditions, proper disposal of irrigation drain water, planned grazing systems and proper grazing use, pest management of Se-accumulator plants, and domestic well testing. Reducing contamination to meet established quality criteria will be the goal.

The RMS will consider other soil and water problems and the plant community condition for livestock forage and food production goals, the health of the animal kingdom for fish and wildlife, and the quality

of the water for domestic, livestock, and wildlife use. The RMS should be planned with the farmer or rancher to help protect their domestic water supply, reduce or prevent potential livestock poisoning, and reduce or prevent the potential poisoning of fish and wildlife. Some practices outside the farmer arena to reduce Se contamination would be management of mining operations and control of fly ash from coal-fired power plants.

SUMMARY

Consider the Se hazard to man, livestock, fish, and wildlife when you assist a farmer or rancher build a reservoir, plan a grazing system, improve an irrigation and drainage system, construct a wetland, construct a pond, or evaluate a domestic well.

Consider the factors of Se distribution: Is the farm or ranch in an area of Cretaceous, Mesozoic, or Jurassic shale formation? Is this an area with less than 20 inches of annual precipitation? Is seleniferous vegetation, such as loco weed, present? Do ground water and surface water quality records indicate Se?

Consider the conservation practices or auxiliary actions that can be taken to help prevent chronic or acute poisoning of humans, livestock, or fish and wildlife by selenium. Also, be prepared to make recommendations to overcome selenium deficiencies.

Table 1: Conservation practices and auxiliary actions to control selenium contamination or deficiencies.

Conservation Practices and Auxiliary Actions	Soil Condition	Water Quality	Plants and Nutrient Management	Animal Health	Air Quality
Rural and Domestic Water Supply					
Well Testing		X		X	
Water Treatment		X			
Use of Reverse Osmosis		X			
Geologic Investigation	X	X			
Livestock Se Deficiency					
Feed Se Supplements			X	X	
Apply Se Fertilizer	X		X	X	
Livestock Se Poisoning					
Proper Grazing Use			X	X	X
Livestock Exclusion			X	X	X
Pest Mangement			X	X	
Range Seeding	X		X	X	X
Altenative Land Use			X	X	X
Testing Water Supplies		X		X	
Fish and Wildlife Se Poisoning					
Eliminate Flow From Irrigation Drains		X		X	
Fill In Ponds	X			X	
Irrigation Water Management		X	X	X	
Drainage Water Management		X	X	X	
Crop Management		X	X	X	
Conservation Cropping Sequence	X		X		
Altenative Land Use		X	X	X	

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