Why is selenium a problem?

Selenium is an essential trace nutrient for all animals including humans, serving in beneficial metabolic functions. However, based on the known margins of safety between required and toxic dietary exposure, selenium can be more poisonous than either arsenic or mercury (Sorensen 1991). Selenium deficiency (too little) as well as toxicity (too much) can cause adverse effects to both fish and wildlife. Interestingly, both deficiency and toxicity cause similar effects including lowered reproductive success, anemia, weight loss, and immune dysfunction. Among vertebrates, reproductive failure is one of the most likely outcomes. Egg-laying vertebrates, such as birds and fish, have substantially lower toxicity thresholds than mammals (NIWQP 1998). The toxicity threshold for selenium is remarkably similar for fish and aquatic birds (Lemly 1995, 1996b), the two groups most likely to be adversely affected by contamination from agricultural or industrial sources. Selenium concentrations in normal wildlife tissue averages about 2 parts-per-million (ppm) or less. Selenium concentrations of 10 to 20 ppm in wildlife tissues or 3 to 5 ppm in diets, commonly found in the Grand Valley and lower Gunnison basin, are above the threshold of toxicity for sensitive and moderately sensitive species. When selenium tissue concentrations reach levels of 50 to 100 ppm, catastrophic impacts are highly likely (NIWQP 1998).

Selenium accumulates in and disperses from animal tissues fairly rapidly. Tissue selenium concentrations can change within days, weeks or months (Wilber 1980; Bennett etal. 1986; USFWS 1990a; Heinz et al. 1990; Heinz and Fitzgerald 1993a; Heinz 1993). Furthermore, the overt symptoms of near fatal selenium poisoning in adult birds and mammals can be quickly reversed if the source of selenium exposure is eliminated (Ruta and Haider 1989; Heinz and Fitzgerald 1993b). By contrast, embryonic deformities caused by selenium poisoning are not reversible (Lemly 1993b). In the wild, embryonic deformities caused by selenium toxicity are rarely seen because the affected species do not act normal or respond to natural environmental conditions and are eaten by predators.


Razorback sucker larvae: left – deformed; right - normal.

Waterborne selenium alone is not very toxic to fish and wildlife. When water is the only exposure route, toxic thresholds for selenium are generally greater than 1,000 parts-per-billion (ppb) for adult fish.

However, much lower concentrations of selenium in water can be bioaccumulated to toxic levels in fish and wildlife through dietary exposure via the food chain. Field cases of selenium poisoning in fish and birds have been documented for water averaging as little as 1 to 10 ppb due to its effects on food chain organisms (Seiler and Skorupa 1995). Food chain organisms may include zooplankton, invertebrates and small fish. It is commonly accepted that selenium concentrations of less than 2 ppb in water are considered safe for all species.

The Environmental Protection Agency has established 4.6 ppb as the chronic national standard. States are required to adopt standards that are at least as stringent as this standard, but some states have adopted more stringent standards. The State of Colorado has adopted 4.6 ppb as the state standard for all water bodies and identified stream segments which are out-of-compliance with the standard including the following segments in western Colorado:

- Uncompahgre River from Hwy 90 to Confluence Park,
- Gunnison River from the Uncompahgre River to Colorado River confluence,
- Colorado River from the Gunnison River confluence to state line,
- numerous tributaries to the Gunnison, Uncompahgre, and Colorado Rivers, and
- Sweitzer Lake and Walter Walker Wildlife Area ponds.

Selenium concentrations in food organisms that are consumed by fish or birds above 3 ppm are considered potentially toxic (Lemly 1996a). At Sweitzer Lake, south of Delta, selenium concentrations in invertebrates were greater than 20 ppm. This caused the progressive mortality of stocked game fish and continues to limit reproduction of all fish species that occupy the lake. Studies that were performed by the USGS Biological Research Division, utilizing fish, invertebrates, and water from the Colorado River and adjoining backwaters, showed that invertebrates with 4.6 ppm whole body selenium concentrations fed to endangered larval razorback suckers adversely affected their survival (Hamilton 2002).

Selenium concentrations in whole body fish above 4 ppm and above 8 ppm in muscle tissue are considered cause for concern. Muscle plugs taken from endangered Colorado pikeminnow in the Colorado River within the Grand Valley of Western Colorado had selenium concentrations that ranged from 3 ppm to 30 ppm. Sixteen Colorado pikeminnow muscle plug samples collected at Walter Walker State Wildlife Area in Grand Junction contained a mean selenium concentration of 17 ppm, more than twice the muscle tissue toxicity threshold of 8 ppm (Osmundson 2000).

Selenium concentrations in the Uncompahgre River downstream from Montrose, the Gunnison River downstream from the confluence of Uncompahgre River, and Colorado River downstream from the confluence of the Gunnison River usually exceed toxicity guidelines for water, invertebrates, fish and aquatic birds. Based on these exceedences in the upper Colorado River basin, and biological effects measured in reproduction studies, conducted by USGS Biological Research Division (Hamilton 2002), many people believe selenium contamination is adversely affecting razorback suckers in these areas.

Observing the effects in the wild is very difficult because young birds and fish that are born with deformities rarely survive because they are very susceptible to predators. However, several deformed birds and many unhatched eggs have been found locally. They have been found to have high selenium concentrations with deformities typical of toxic selenium levels. Within the areas of western Colorado described above, the weight of evidence points to selenium as causing reproductive effects to both fish and birds.

Additional information on selenium impacts can be obtained from the U.S. Fish and Wildlife Service (see contact list at the end of this document).

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What are the sources of selenium in the Lower Gunnison River Basin and Grand Valley?

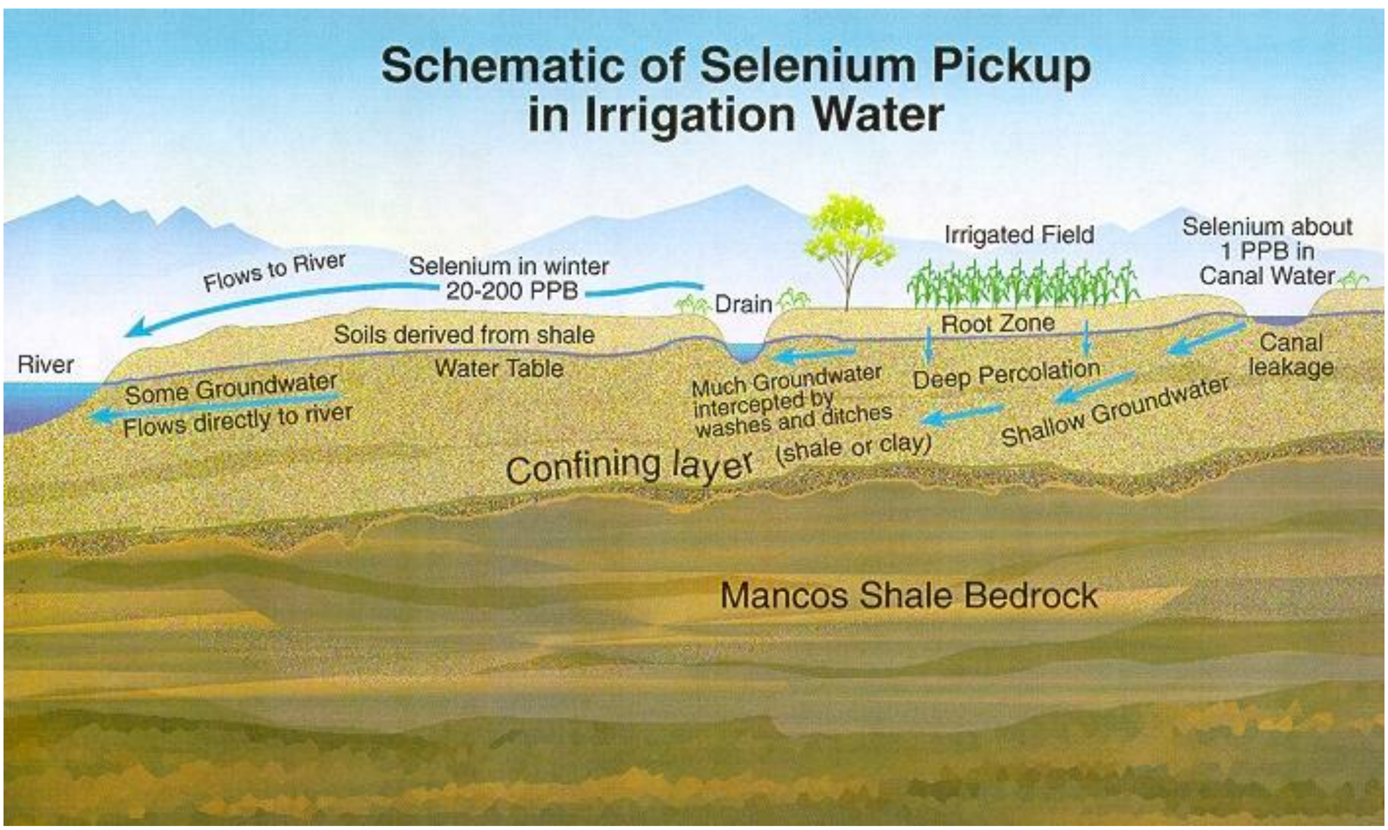
The lower Gunnison and Grand Valleys exist in an area of Western Colorado that is rich in Mancos Shale. The Mancos Shale was formed in a marine environment as a product of deposition approximately 80 million years ago during the Cretaceous period. The sediments that make up the Mancos are typically high in selenium. As a result, many rivers and streams in the region contain relatively high concentrations of selenium. Some of the highest selenium values ever recorded in surface waters in the western United States have been measured in the lower Gunnison River basin. Selenium is mobilized in the ecosystem as a direct result of irrigation in one form or another; including agricultural, residential, and commercial applications. Selenium is also mobilized by rainfall and snowmelt, however; infrequent precipitation events have been shown to mobilize substantially less selenium compared to sustained irrigation applications.

Soil Sources: Some of the highest naturally-occurring selenium concentrations in soils in the western United States occur within this area. However, a high degree of variability exists within the Mancos shale soils. Studies have shown that extended periods of past irrigation of some of local soils have significantly reduced the soluble and total selenium levels in the upper 6 feet of the soil profile. They have also shown a strong correlation when comparing irrigated to non-irrigated soils. Non-irrigated top soils were shown to have 34 times more *soluble* selenium than irrigated soils. Non-irrigated soils had 2.3 times more *total* selenium than irrigated soils.

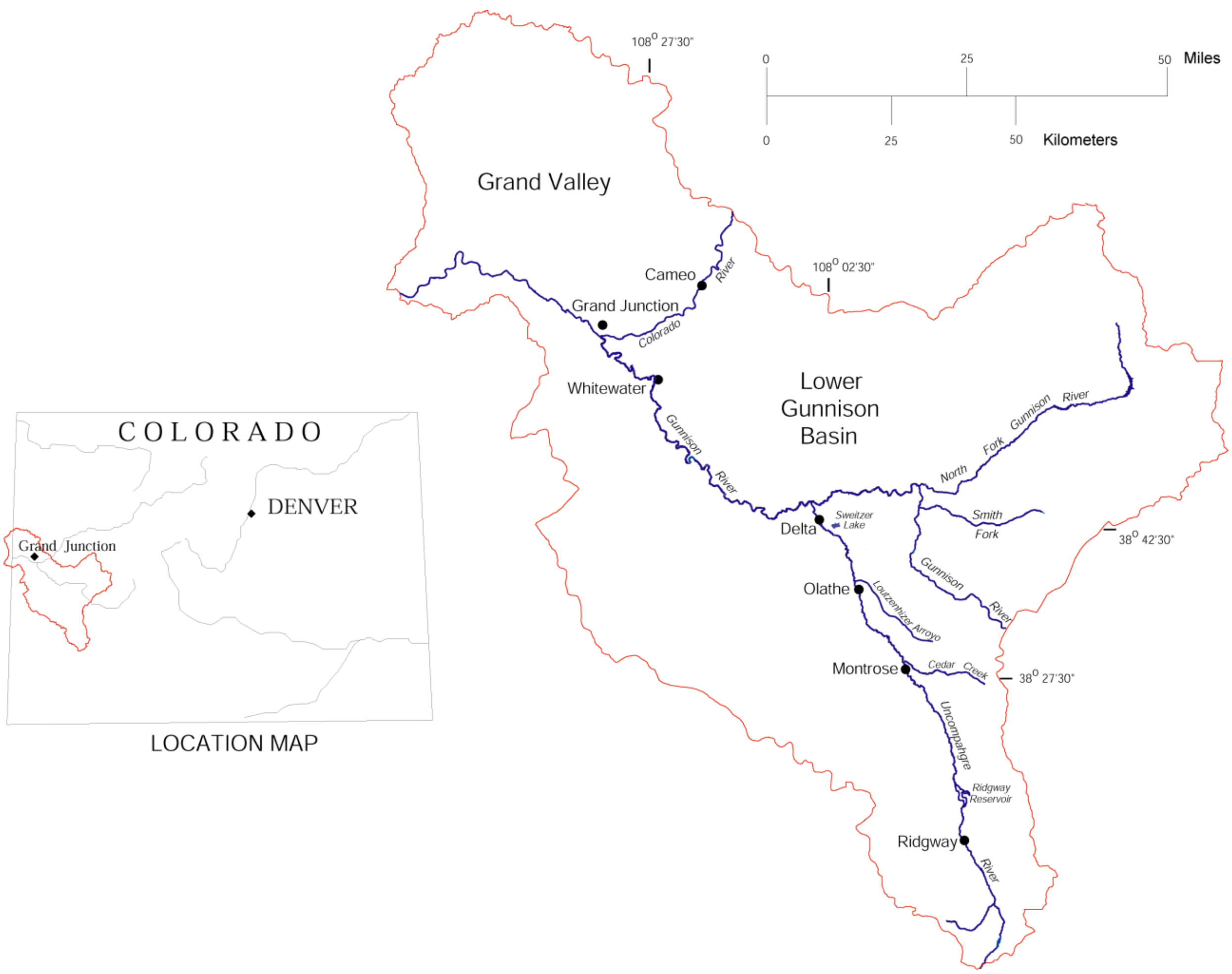
Another important consideration is the high degree of weatherability of the Mancos shale bedrock. This is especially true of the soft shale bedrock that often occurs between the soil overburden and hard-shale bedrock below. One study has shown that repeated saturation with water can cause this soft shale to break down into soil material. Over a 50-year period, soils with bedrock contact, that have been repeatedly irrigated, have increased in soil depths from 20 to greater than 60 inches. In theory, as this shale continues to break down into soil material, new surfaces and seams within the shale bedrock are being exposed to water where additional salts and heavy metals are subsequently entering into solution and being transported.

Soil studies have also supported the contention that deep percolation and seepage are the driving forces in the solution and transportation of selenium. Water, when it comes in contact with Mancos Shale derived soils and Mancos Shale bedrock, causes naturally occurring elements within the soil, such as selenium, to enter into solution. Whenever water is moved below the root zone of plants, the potential for deep percolation exists. In these valleys before men started irrigation, very few soils were subject to deep percolation due to the desert-like conditions. In areas of Mancos shale soils that occur within areas of higher precipitation (generally greater than 18 inches per year), salts and heavy metals have been significantly leached out through natural deep percolation. Irrigation within the drier areas of Mancos shale soils has accelerated the leaching process, subjecting soils that have not previously undergone deep percolation to this process. Information on the soils in your area may be obtained from local soil surveys.

The largest selenium loads originate from the irrigated portions of the Grand Valley and lower Gunnison River Basin. Primary sources of excess deep percolation and seepage are from agricultural and residential irrigation, unlined ponds and the unlined (and un-piped) irrigation-water delivery systems. The illustration below shows how these sources mobilize selenium from areas overlying the Mancos shale.



Water quality: Data collected at four USGS streamflow gaging stations (see table, next page) from 1991-2003 were used to evaluate dissolved-selenium concentrations and loading sources in the area shown below.



The eighty-fifth percentile of dissolved-selenium concentrations and median loads were calculated for each gage. Loading was reported in pounds per day and calculated as the product of instantaneous streamflow times selenium concentration, multiplied by a conversion factor. The data indicate that approximately 50% of the selenium load measured at the Stateline gage was from loading sources in the Gunnison River basin. Approximately 60% of the load measured at the Gunnison River near Whitewater gage came from loading sources in the Uncompahgre River Basin, primarily from irrigated areas on the east side of the Uncompahgre Valley. This figure includes loads measured for the

Uncompahgre River at Delta, plus various tributaries such as the Sunflower Drain and other diffuse sources.

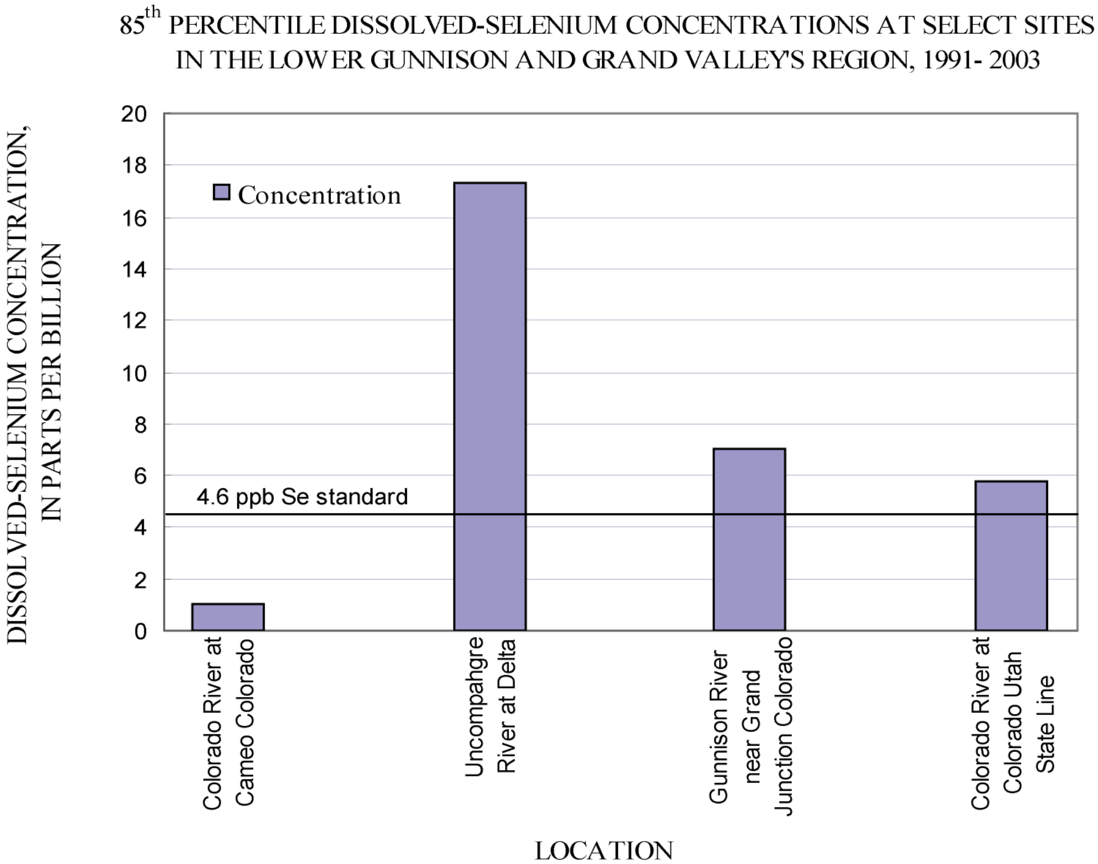
In the Grand Valley, approximately 8% of the selenium load at the Stateline gage came from areas upstream of Cameo, and the rest of the loading measured at the Stateline gage (42%) was from sources within the Grand Valley.

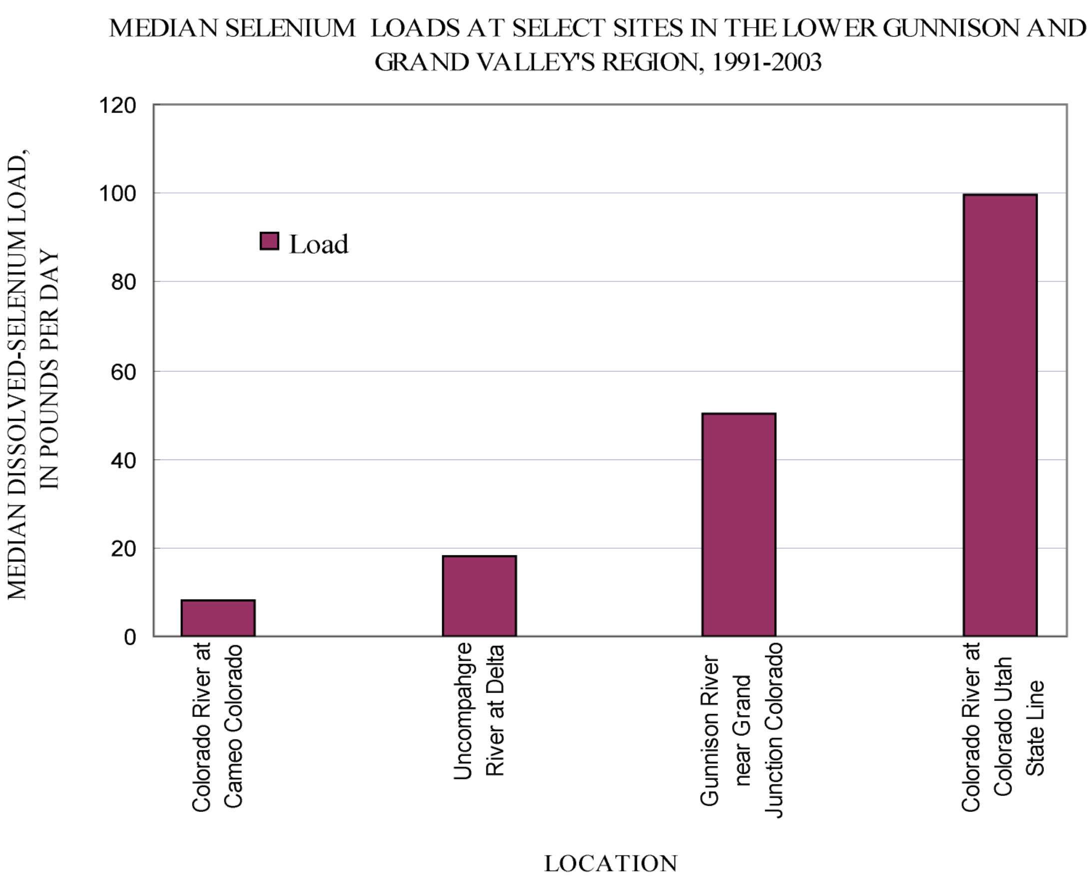
Station Name	85th Percentile for 1991-2003	Median Load for 1991-2003	Percent of Median Load At Stateline gage
	ppm (μg/L)	lbs/day	
Colorado River at Cameo	1.0	7.9	8
Uncompahgre River at Delta	17.3	18.2	18
Gunnison River at Whitewater	7.0	50.4	50
Colorado River at CO/UT Stateline	5.8	99.7	100

The highest dissolved-selenium concentration among these gages was 26.0 ppb, observed at the Uncompahgre River gage on March 21, 1991. The highest values observed at the other gage sites were recorded in the winters of 2002 and 2003, with the Colorado River at Cameo having a dissolved-selenium concentration of 2.2 ppb on March 11, 2002, the Gunnison River having a dissolved-selenium concentration of 16.4 ppb on March 2, 2003, and the Colorado River at the Colorado/Utah Stateline having a concentration of 11.1 ppb on September 17, 2002. Dissolved-selenium values below the minimum-reporting limit of 1 ppb were never observed at the Uncompahgre River and Gunnison River gages during the 1991-2003 period. The following figures show 85^{th} percentile concentrations and median daily loads for dissolved selenium at each of the gages.

Additional data summarizing concentrations and loads in these areas are contained in several USGS reports, including the following recent ones:

- Characterization of Selenium in the Lower Gunnison River Basin, CO 1988-2000 (Water Resources Investigation Report 02-4151)
- Physical, Chemical, and Biological Data for the Uncompahgre Project Area and the Grand Valley, West-Central Colorado, 1993-98 (Open File Report 99-453)


85th PERCENTILE DISSOLVED-SELENIUM CONCENTRATIONS AT SELECT SITES IN THE LOWER GUNNISON AND GRAND VALLEY'S REGION, 1991- 2003
DISSOLVED-SELENIUM CONCENTRATION, IN PARTS PER BILLION
20
18
16
14
12
10
8
6
4
2
0
Concentration
4.6 ppb Se standard
Colorado River at Cameo Colorado
Uncompahgre River at Delta
Gunnison River near Grand Junction Colorado
Colorado River at Colorado Utah State Line
LOCATION


MEDIAN SELENIUM LOADS AT SELECT SITES IN THE LOWER GUNNISON AND GRAND VALLEY'S REGION, 1991-2003
MEDIAN DISSOLVED-SELENIUM LOAD, IN POUNDS PER DAY
120
100
80
60
40
20
0
Load
Colorado River at Cameo Colorado
Uncompahgre River at Delta
Gunnison River near Grand Junction Colorado
Colorado River at Colorado Utah State Line
LOCATION

What are some solutions to the selenium issue?

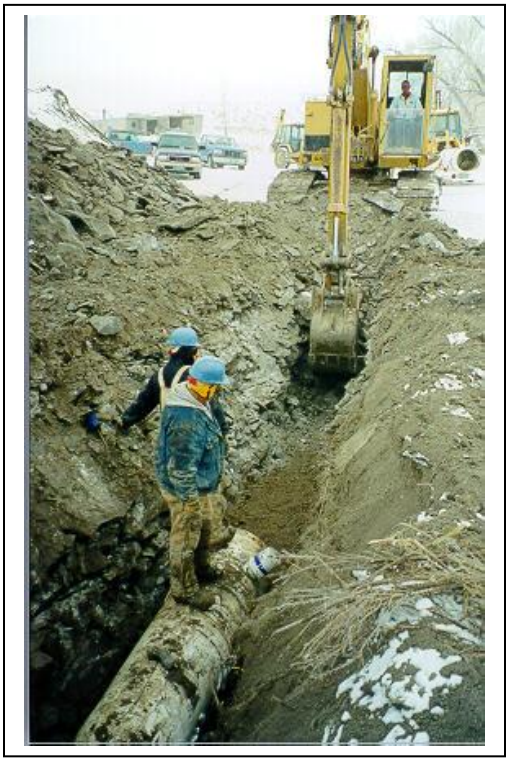
To help solve the selenium problem, care should be exercised when using water on Mancos shale soils where naturally occurring annual precipitation is less than 18 inches. Irrigation and water use practices should be done in ways to minimize deep percolation and seepage. Additional care should be taken in previously non-irrigated Mancos shale soils. Studies of these impacts of deep percolation from irrigation on previously non-irrigated Mancos shale soils have shown potentially large selenium impacts from relatively small acreages subject to new irrigation. Deep percolation can occur in watering of crops, pasture, lawns, and gardens and from septic tank leach fields. Seepage is a concern from unlined irrigation delivery systems and unlined ponds. The key to management on Mancos shale soils is to utilize proper water management and minimize deep percolation and seepage.

There are two primary areas of concern where solutions (selenium reductions) are needed in western Colorado and are currently being pursued:

- the **mainstem lower Gunnison River** (below the Uncompahgre River confluence) and the **Colorado River** (below the Gunnison River confluence)
- **tributaries** to these rivers, such as the Loutzenhizer Arroyo in the Uncompahgre Valley and Persigo Wash in the Grand Valley.
  This partitioning is necessary because each situation has somewhat differing remediation needs, and thus, a different list of potential solutions.

1. To meet water-quality standards and protect endangered fish in the ***mainstem Gunnison and Colorado Rivers***, efforts are underway to reduce selenium loading from the large contributing areas on the Mancos Shale higher up in the basin, particularly in the Uncompahgre Valley. Reducing pollution sources higher in the basin is believed to be the most cost-effective approach since it reduces concentrations in each of the downstream river segments of concern. The following is a list of various efforts that are currently reducing selenium loading or have the potential to reduce selenium from these areas:

   a. The 1998-99 Montrose Arroyo Demonstration Project (USGS report entitled "Effects of Piping Irrigation Laterals on Selenium and Salt Loads", Water-Resources Investigations Report 01-4204) established that piping irrigation laterals in the Uncompahgre Valley could be a very effective solution. Additionally, this type of improvement is very desirable from a water users' perspective. Thus far, 8 miles of laterals have been piped, and



additional 20 miles is scheduled to be piped in the next 3 to 4 years. This effort may eventually pipe all the irrigation laterals on the east side of the Valley.

b. The ongoing water conservation efforts being implemented under the Natural Resources Conservation Service's EQIP are likely having similar selenium reduction effects for on-farm irrigation (however, to date, reductions have not been documented).
c. Stakeholders have also implemented several demonstration projects in other agricultural settings to examine their selenium reduction possibilities. Additionally, some water-conserving projects are being implemented by individual landowners for economic reasons that may be beneficial to selenium reduction goals. These stakeholder and individual landowner projects include the following:
   i. Phyto-remediation (growing crops that extract selenium from the soil)
   ii. Polyacrylamide (a.k.a. PAM; used to seal leaky irrigation canals)
   iii. Hydrogel (a form of PAM used to hold moisture in the crop root zone & potentially reduce irrigation requirements)
   iv. Pond lining (to reduce seepage from leaky ponds)
   v. Sprinkler irrigation (reduces deep percolation)
   vi. Drip Tape (reduces deep percolation)
d. Non-agricultural water applications are being addressed in the lower Gunnison basin and Grand Valley through the development of a list of Best Management Practices (BMPs) which local governments are being asked to support and promote. These BMPs cover:
   i. Residential water use
   ii. Golf courses
   iii. Small acreage irrigation
   iv. Pond construction
   v. Septic systems

2. Studies of potential solutions were undertaken for the Grand Valley ***tributaries*** to the Colorado River. Most "tribs" in western Colorado are ephemeral, meaning that in a natural situation, they are dry except after precipitation events. In the irrigated areas, water applications during the growing season have made these tribs perennial, because irrigation induced ground-water drains year around. In the case of the tribs, identifying reasonable solutions is much different than the mainstem, primarily because the tribs lack sources of sufficient dilution at critical times of the year. In the mainstem rivers, concentrations can be reduced by reducing selenium loading to a particular reach, since most of the flow originates higher in the basin and normally has low selenium concentrations.

Most of the flow in the tribs during the irrigation season is the result of surface and sub-surface irrigation return flow and, occasionally, operational spills from the canal system. Selenium concentrations exceed standards but are still much lower than in the non-irrigation season (winter) when tributary flow is primarily sub-surface inflow and typically much higher in selenium. At these times there is no dilution available, except for the infrequent precipitation events. A key to addressing the non-irrigation season problem is finding dilution water needed to reduce concentrations.

Thus far, identifying ways to reduce selenium concentrations in the Grand Valley tribs has been difficult, and cost–effective solutions have yet to be found. It is believed that many of the findings from the Grand Valley studies will be readily transferable and adaptable for the Gunnison basin tributary segments that require attention.

For additional information, please contact:

Fish and wildlife impacts: Rick Krueger, US Fish & Wildlife Service, 970-245-3290, ext. 17
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