

Methods to Identify Areas Susceptible to Irrigation-Induced Selenium Contamination in the Western United States



U.S. Department of the Interior—U.S. Geological Survey

Unforeseen Consequences of Irrigation Drainage

Before 1980, regulation of irrigation return flow from agricultural projects focused mainly on management of salts, nutrients, and pesticide residues. In the early 1980's, selenium mobilized by irrigation water was discovered to be the cause of congenital deformities and mortality of birds at Kesterson Reservoir, a National Wildlife Refuge in central California. This unforeseen result of using irrigation drain water to sustain a wetland prompted the U.S. Department of the Interior (DOI) to create the National Irrigation Water Quality Program (NIWQP) to determine whether events at Kesterson could happen elsewhere in the United States.

Satellite imagery indicates that more than 66,000 mi² of land in the 17 conterminous Western States is irrigated for agriculture. Because complete investigation of every irrigated area in the Western United States is impractical, managers need to be able to predict where selenium contamination is likely.

Investigations in U.S. Department of the Interior Irrigation Project Areas

The DOI has constructed or manages more than 600 irrigation or irrigation-drainage projects and National Wildlife Refuges in 17 Western States. NIWQP grouped these projects and refuges into 192 areas. Scientists from the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and Bureau of Reclamation investigated 26 of the 192 NIWQP areas (fig. 1) to determine if irrigation drainage had caused or had the potential to cause harmful effects on human health or on fish and wildlife. Detailed investigations were made in 9 of the 26 areas after reconnaissance investigations confirmed that irrigation drainage had caused significant harmful effects. Summaries of these investigations and identification of the principal factors involved in irrigation-related selenium contamination of water and biota are contained in reports by Engberg and Sylvester (1993), Presser and others (1994), and Seiler (1995).

The 26 NIWQP areas were classified as selenium contaminated or uncontaminated on the basis of selenium concentrations measured in surface water (Seiler, 1995). An area was considered contaminated if at least 25 percent of the surface-water samples from it contained levels of selenium that equal or exceed the U.S. Environmental Protection Agency chronic criterion for the protection of freshwater aquatic life (5µg/L). By using this criterion, 12 of the 26 NIWQP areas were classified as contaminated (fig. 1).

Factors Affecting Severity of Selenium Contamination

During the 1930's, irrigation was considered a remedial measure for seleniferous soils because the drain water removed soluble selenium from the soils. Whether selenium is mobilized by irrigation and reaches levels toxic to fish and wildlife depends on the geology, climate, and hydrology of an area.

Geology

Knowledge of bedrock lithology is very important because the bedrock commonly is the parent material for the irrigated soils. The sources of selenium in soils and the distribution of seleniferous rocks in the United States were studied intensively during the 1930's and 1940's after selenium in pasturage was shown to cause a fatal disease in cattle and horses in South Dakota. One of the conclusions of that research was that any area

where the soil is derived from material of Cretaceous age is likely to contain harmful quantities of selenium (Lakin and Byers, 1941). In 12 of the 26 NIWQP areas, Upper Cretaceous marine sedimentary rocks form the bedrock, and 9 of these 12 areas have selenium-contaminated water. In the 17 Western States, areas of Upper Cretaceous marine sedimentary rocks total about 311,000 mi² (fig. 2).

Upper Cretaceous and Tertiary marine sedimentary deposits in nearby mountains are the principal sources of selenium for contaminated areas in the San Joaquin Valley of California (Presser, 1994). Erosion and local drainage carry selenium from seleniferous rocks in the mountains to irrigated land in the valley. Upper Cretaceous and Tertiary marine sedimentary rocks form the bedrock beneath 396,000 mi² in the Western United States (fig. 2).

The occurrence of elevated selenium concentrations in other sedimentary rocks in the Western United States is localized. Trelease and Beath (1949) noted that Tertiary sedimentary deposits differ greatly in selenium content. Continental deposits of Tertiary age may be seleniferous if they were derived from Upper Cretaceous marine sedimentary rocks.

Climate

Selenium contamination caused by irrigation has been observed only in arid or semiarid environments. To compare the aridity of different parts of the United States, the precipitation and evaporation rates were combined into a single number called the evaporation index (EI). The EI is calculated from the expression

$$EI = FWSE \div PRECIP$$

where FWSE is annual free-water-surface evaporation and PRECIP is the annual precipitation. In the Eastern United States, the EI is less than 2.0, but in the Western United States, EI values greater than 2.5 characterize about 1,020,000 mi², or more than half the land area (fig. 3).

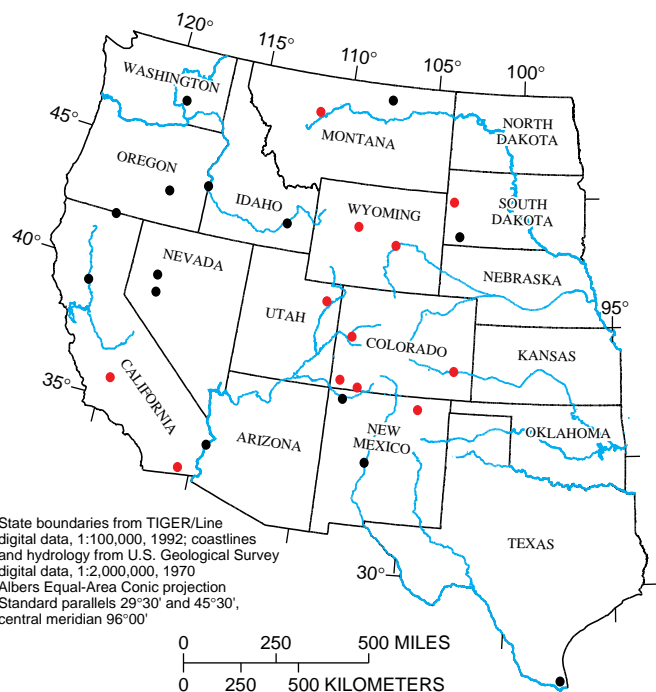


Figure 1. Location of National Irrigation Water Quality Program areas investigated for potential irrigation-induced selenium contamination. Red signifies areas that were classified as selenium contaminated because 25 percent of the surface-water samples contained levels of selenium that equal or exceed 5µg/L.

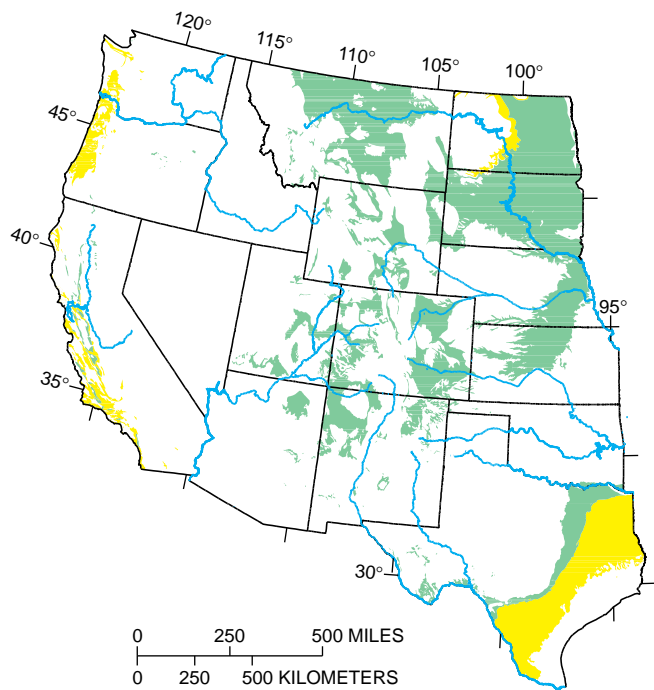


Figure 2. Areas of Upper Cretaceous (green) or Tertiary (yellow) marine sedimentary deposits. Geology from King and Beikman (1974).

Analysis of data from the 26 areas investigated by the NIWQP showed that an EI value of about 2.5 separated contaminated from uncontaminated areas (Seiler, 1995). Contamination was not observed in any NIWQP study area where the EI value was less than about 2.5, even where a local source of selenium has been identified. Given local sources, areas were found to be contaminated if EI values equaled or exceeded about 3.5, and most areas were contaminated at EI values of about 3.0. Where seleniferous rocks are upland from irrigated lands or where selenium is imported in water used for irrigation, EI values of about 4.5 or 8.0, depending on geology (fig. 4), separate contaminated from uncontaminated areas.

Hydrology

Because drain water frequently is reused for irrigation downstream, it can be a source of selenium to other areas. An example of an area contaminated by imported selenium is the Imperial Valley in California, which receives selenium from drain water discharged to the Colorado River from irrigated areas in Utah, Colorado, and New Mexico. Because Imperial Valley has no local geologic source of selenium, it is contaminated because irrigation water supplies the selenium (Seiler, 1995).

Whether lakes or ponds in an area are terminal (that is, have no outlet) during nonflood years is also important. In terminal water bodies, selenium accumulates but is not flushed out during normal spring runoff.

Methods to Identify Areas Susceptible to Irrigation-Induced Selenium Contamination

Two methods were devised to allow managers to identify lands susceptible to selenium problems caused by irrigation. The first uses a decision tree (fig. 4) that poses questions about regional geology, climate, and hydrology to predict whether a specific irrigation project area is likely to have selenium problems (Seiler, 1995). The second uses a map (fig. 5) that combines geologic and climatic data to identify geographic regions where selenium problems are likely.

Because typically only limited site-specific information is available during an initial screening, many factors and processes that influence the actual amount or extent of contamination in a given area are not considered when using these methods. For example, the amount of land that overlies Upper Cretaceous or Tertiary rocks and the actual selenium content of the rocks are not considered.

Individual Areas

The decision tree (fig. 4) ranks an irrigation area according to whether a selenium problem is unlikely, possible, likely, or very probable. On the basis of this classification, a resources manager or planner can assess the need to collect additional information to quantify potential selenium contamination from irrigation drainage.

To use the decision tree, several yes/no questions are answered sequentially. Whether a particular area is characterized by Upper Cretaceous or Tertiary marine sedimentary deposits may be determined from the geologic map of the United States (King and Beikman, 1974) or from a larger-scale map such as a State geologic map. Approximate values for EI can be obtained from figure 3. If more exact values are needed, the FWSE rate from evaporation maps of the United States (Farnsworth and others, 1982) can be divided by the annual precipitation. Answers to hydrogeologic questions can be obtained by examining topographic and geologic maps of the drainage basin supplying water to the area of interest.

Broad Geographic Areas

Areas susceptible to selenium problems caused by irrigation were identified by creating a map (fig. 5) showing areas where Upper Cretaceous or Tertiary marine sedimentary rocks form the bedrock (fig. 2) and where EI values exceed 2.5 (fig. 3). About 160,000 mi² of land in the Western United States thereby was identified as susceptible. The greater the EI, the more likely is the occurrence of selenium problems. The areas that are most susceptible to selenium problems have EI values greater than 3.5 (fig. 5)—about 52,600 mi².

Land adjacent to areas mapped as susceptible should be treated provisionally as susceptible because rocks upland from irrigated areas can yield selenium to downgradient areas. In California, the areas mapped as susceptible in figure 5 are all in the mountains, whereas the actual susceptible areas are in the valleys below.

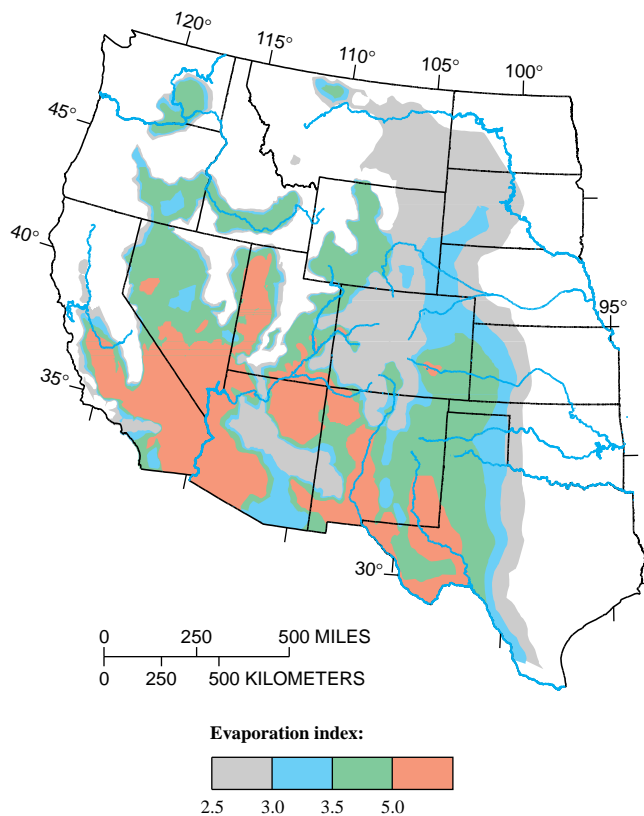


Figure 3. Areas where evaporation index is greater than 2.5. Climatic data from Farnsworth and others (1982) and G.H. Taylor (Oregon State Climatologist, written commun., 1994).

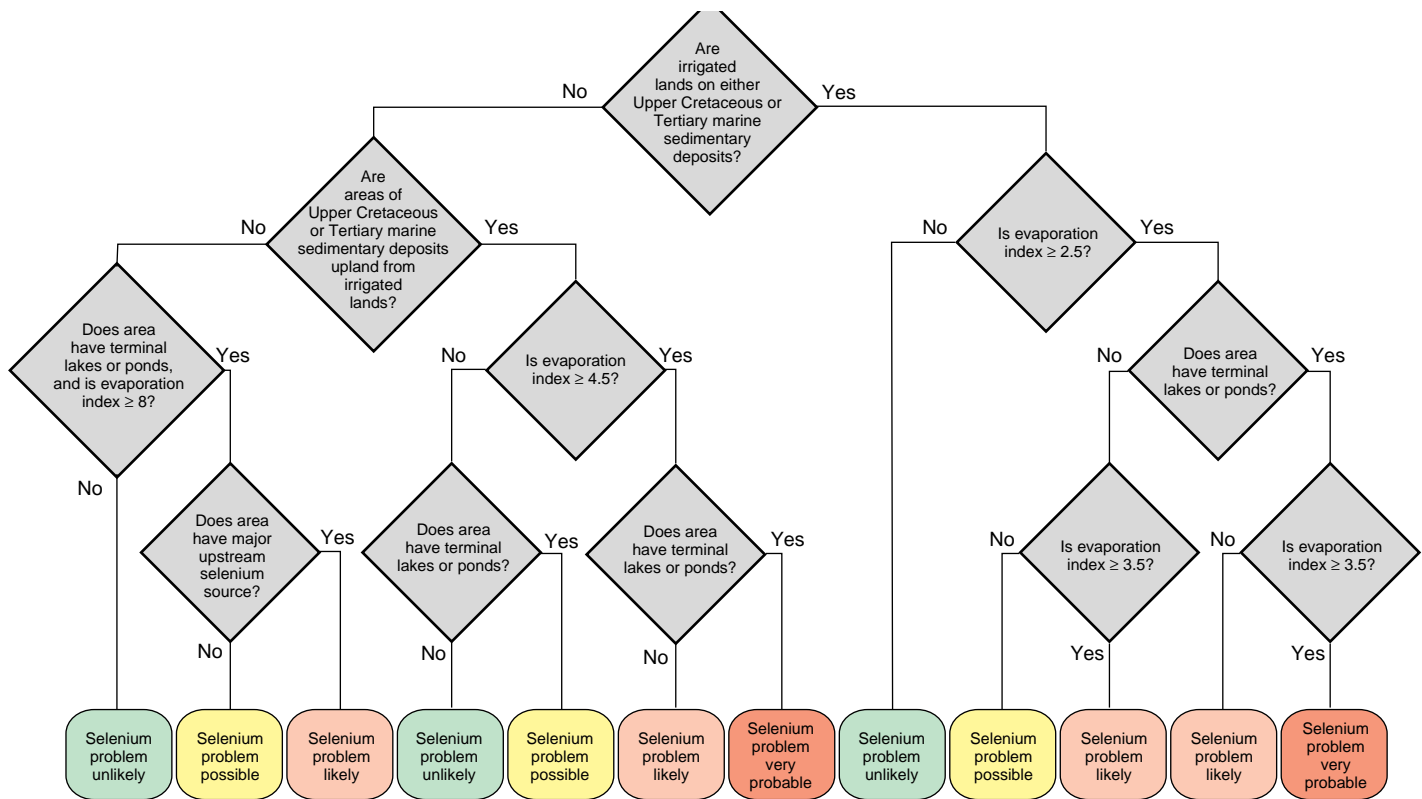


Figure 4. Decision tree for predicting likelihood of selenium problems. \geq , greater than or equal to. Modified from Seiler (1995) and used with permission of American Society of Agronomy.

The susceptibility map (fig. 5) cannot identify every susceptible area because important hydrologic factors, such as whether an area downstream from irrigated land has terminal ponds and whether selenium is imported into an area, are not readily mappable. However, most of the areas where the NIWQP found irrigation-induced selenium contamination of surface water and all the areas where deformed birds were found can be identified by the map.

A great advantage of maps as a means of identifying susceptible areas is that maps of land-use data can be superimposed. Then managers quickly can identify areas of interest where selenium problems may occur. Maps showing the susceptible areas and the locations of National Wildlife Refuges and Bureau of Reclamation project areas are being prepared jointly by the USGS and the USFWS for the DOI. However, managers of all Federal, State, local, and private entities that provide irrigation water or that receive irrigation drain water need to know whether and where selenium problems are likely. Figure 6 shows the irrigated areas in the Western United States and, by inference, which of those areas are susceptible to irrigation-induced selenium contamination. About 4,100 mi² of irrigated land is within areas mapped as susceptible.

Limitations of the Methods

Identifying circumstances when the methods presented here will not work is important. Both the decision tree and the map were constructed as if only those soils derived from Upper Cretaceous or Tertiary marine sedimentary deposits are seleniferous. Thus, the methods fail to identify areas where soils are derived from local seleniferous deposits that are not of Late Cretaceous or Tertiary age.

Although no specific instances have been identified, another circumstance under which the methods might fail is where soils in irrigated areas are much more seleniferous than in the areas investigated by the NIWQP. In these areas, toxic concentrations could be reached even though EI values are less than 2.5. In extremely seleniferous areas, irrigation water could mobilize so much selenium that toxic concentrations could occur without much evaporative enrichment.

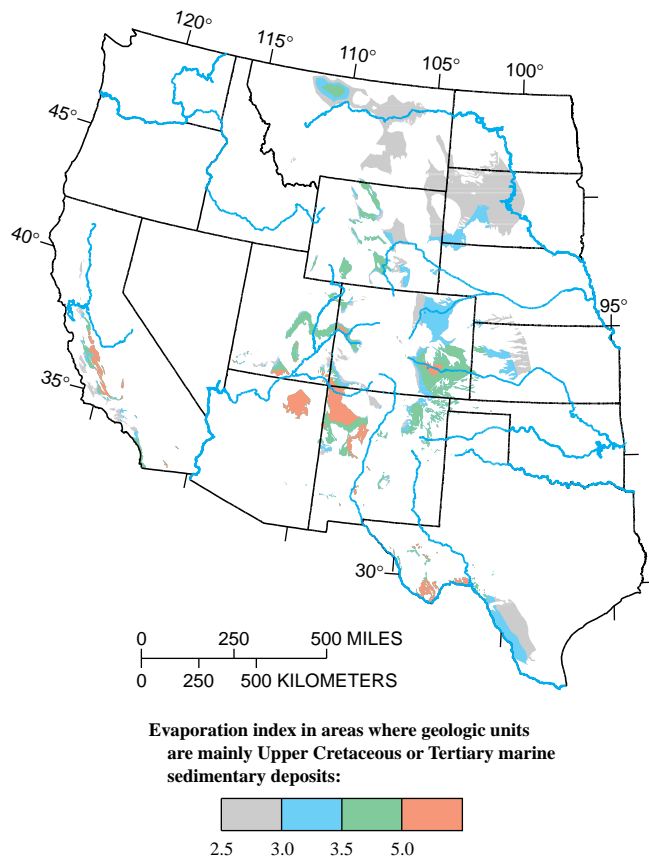


Figure 5. Areas predicted to be susceptible to irrigation-induced selenium contamination on the basis of geologic (fig. 2) and climatic (fig. 3) data.

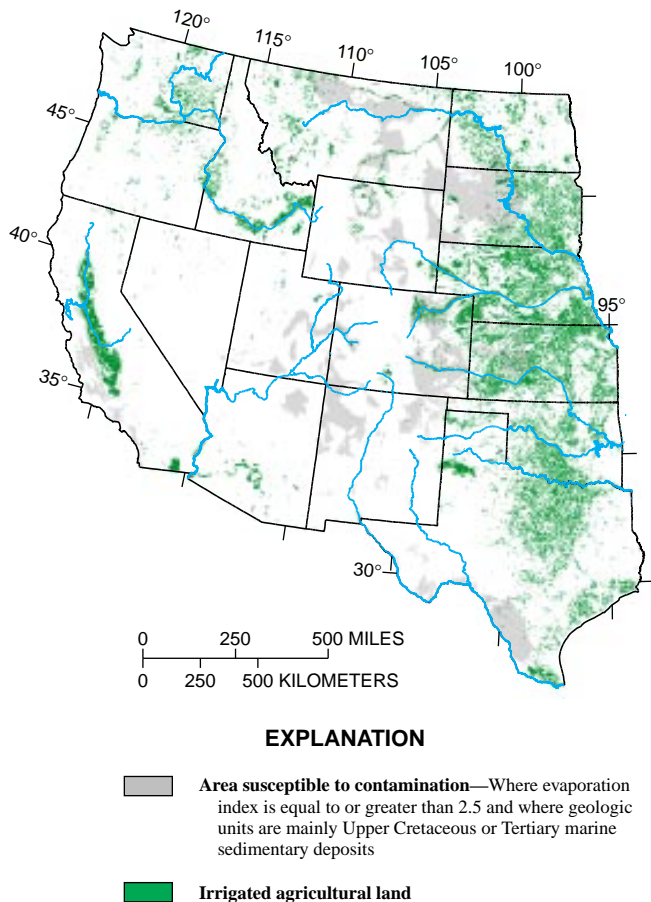


Figure 6. Spatial relation between irrigated areas and areas susceptible to irrigation-induced selenium contamination. Irrigated-areas data derived from Advanced Very High Resolution Radiometer data (resolution, 1.0 km² or 0.39 mi²) from the Earth Resources Observation System Data Center (1990).

Which Method to Use?

The advantages and disadvantages of each method are presented here to help decide which method is the most appropriate. The principal advantages of using the decision tree (fig. 4) are that it considers more of the factors that determine whether irrigation causes selenium contamination and that it actually ranks the likelihood that an area has (or may have) selenium problems. By slightly modifying the questions, the decision tree could be used for areas where seleniferous rocks of other than Late Cretaceous or Tertiary age are known to be the parent material for the soils. A disadvantage of using the decision tree is that it requires more information and is more time-consuming than using the maps.

The principal advantage of using the maps (figs. 5 and 6) is that the risk of selenium problems in broad geographic regions can quickly be evaluated without the need to gather new information. Land-use overlays can be created to aid Federal, State, and local water managers to evaluate whether areas for which they are responsible are susceptible to selenium contamination. A disadvantage of the maps is that they do not take into account some important hydrologic factors in evaluating the risk of irrigation-induced selenium problems. Also, the small scale at which they are produced herein may reduce their usefulness, but the principles identified here can be used to create larger-scale State maps.

Sources of Additional Information

The publications cited in this fact sheet contain additional information on selenium in irrigation drain water and on the methods used to predict where selenium problems may occur:

- Earth Resources Observation System Data Center, 1990, *Prototype 1990 conterminous U.S. land-cover characteristics data set [CD-ROM]*: U.S. Geological Survey, Earth Resources Observation System Data Center.
- Engberg, R.A., and Sylvester, M.A., 1993, *Concentrations, distribution, and sources of selenium from irrigated lands in Western United States*: *Journal of Irrigation and Drainage Engineering*, v. 119, no. 3, p. 522–536.
- Farnsworth, R.K., Thompson, E.S., and Peck, E.L., 1982, *Free water surface exchange, 1956–70*, map 3 of *Evaporation atlas for the contiguous 48 United States*: National Oceanic and Atmospheric Administration Technical Report NWS 33, scale 1:5,000,000.
- King, P.B., and Beikman, H.M., comps., 1974, *Geologic map of the United States (exclusive of Alaska and Hawaii)*: U.S. Geological Survey, three sheets, scale 1:2,500,000.
- Lakin, H.W., and Byers, H.G., 1941, *Selenium occurrence in certain soils in the United States, with a discussion of related topics—Sixth Report*: U.S. Department of Agriculture Technical Bulletin 783, 27 p.
- Presser, T.S., 1994, "The Kesterson effect": *Environmental Management*, v. 18, no. 3, p. 437–454.
- Presser, T.S., Sylvester, M.A., and Low, W.H., 1994, *Bioaccumulation of selenium from natural geologic sources in the Western United States and its potential consequences*: *Environmental Management*, v. 18, no. 3, p. 423–426.
- Seiler, R.L., 1995, *Prediction of areas where irrigation drainage may induce selenium contamination of water*: *Journal of Environmental Quality*, v. 24, no. 5, p. 973–979.
- Trelease, S.F., and Beath, O.A., 1949, *Selenium—Its geological occurrence and its biological effects in relation to botany, chemistry, agriculture, nutrition, and medicine*: Burlington, Vt., Champlain Printers, 292 p.
- Information on geochemical and statistical tools to identify irrigated areas where surface water might contain elevated concentrations of selenium are available in U.S. Geological Survey Fact Sheet FS-077-96. Fact sheets and information on other technical reports and hydrologic data related to the National Irrigation Water Quality Program can be obtained from
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