U.S. Department of the Interior Investigations of Irrigation-Induced Contamination of Water, Sediment, and Biota

Water-Quality Constraints on Irrigated Agriculture

Since irrigated agriculture began, drainwater disposal and other water-quality issues have put constraints on the management of irrigation projects. Salt buildup in the root zone requires the application of more water than plants need so that salts do not accumulate in the soil and reduce crop productivity. The excess water may generate large volumes of saline drainwater which requires the construction of drains and facilities for disposing of the water. Until the early 1980's, the primary water-quality concerns for the drainwater were salinity, nutrients, and pesticides. Since then, trace elements in drainwater, such as selenium, were recognized as being important constraints as well.

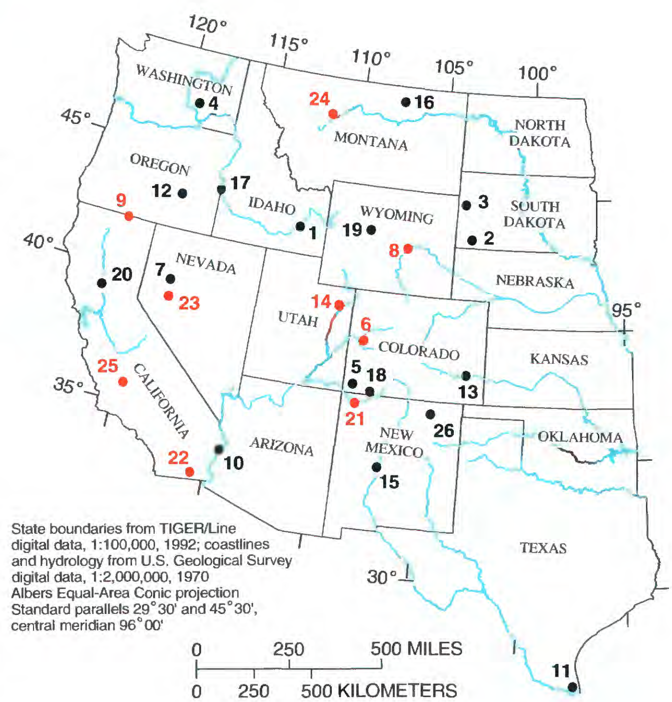
In 1982–83, incidents of mortality, deformity, and reproductive failure in waterfowl were discovered at Kesterson Reservoir, a national wildlife refuge in western San Joaquin Valley, Calif. The cause of these adverse biological effects was selenium carried by irrigation drainwater into wildlife habitat (Ohlendorf and others, 1986). The U.S. Congress and the public questioned whether the effects at Kesterson Reservoir were an aberration, or were symptomatic of a larger problem that might occur elsewhere in the Nation.

National Irrigation Water Quality Program

In 1985, the U.S. Department of the Interior (DOI) implemented the National Irrigation Water Quality Program (NIWQP) to address public and Congressional concerns about the quality of irrigation drainage and its potentially harmful effects on humans, fish, and wildlife. The objective of NIWQP was to identify the type and extent of irrigation-induced water-quality problems in areas of DOI responsibility under environmental laws, or in areas that affected DOI-managed lands, including national wildlife refuges.

The DOI has constructed, financed, or manages more than 600 irrigation/drainage projects and facilities and national wildlife refuges in the 17 conterminous Western States. NIWQP personnel made a comprehensive site survey and selected 26 of these areas for reconnaissance investigations (fig. 1). From 1986 to 1993, the areas were studied by interagency study teams of scientists and engineers from the U.S. Geological Survey, U.S. Fish and Wildlife Service, Bureau of Reclamation, and Bureau of Indian Affairs.

Results from the investigations indicated that irrigation drainage had caused significant harmful effects to fish and wildlife in 9 of the 26 areas. Subsequent detailed investigations by NIWQP personnel were made to identify the causes, extent, magnitude, and effects of contamination in eight of these areas. The ninth area was studied in detail by a separate Federal/State cooperative research program.



STUDY AREA NAMES

1 American Falls Reservoir, Idaho
2 Angostura Reclamation Unit, South Dakota
3 Belle Fourche Reclamation Unit, South Dakota
4 Columbia River Basin, Washington
5 Dolores-Ute Mountain Area, Colorado
6 Gunnison River Basin/Grand Valley Project, Colorado
7 Humboldt River Area, Nevada
8 Kendrick Reclamation Project Area, Wyoming
9 Klamath Basin Refuge Complex, California and Oregon
10 Lower Colorado River Valley, California and Arizona
11 Lower Rio Grande and Laguna Atascosa National Wildlife Refuge, Texas
12 Malheur National Wildlife Refuge, Oregon
13 Middle Arkansas River Basin, Colorado and Kansas
14 Middle Green River Basin, Utah
15 Middle Rio Grande and Bosque del Apache National Wildlife Refuge, New Mexico
16 Milk River Basin, Montana
17 Owyhee-Vale Reclamation Project, Oregon and Idaho
18 Pine River Area, Colorado
19 Riverton Reclamation Project, Wyoming
20 Sacramento Refuge Complex, California
21 San Juan River Area, New Mexico
22 Salton Sea Area, California
23 Stillwater Wildlife Management Area, Nevada
24 Sun River Area, Montana
25 Tulare Lake Bed Area, California
26 Vermejo Project, New Mexico

Figure 1. Areas investigated for irrigation-induced contamination. Red symbols and numbers signify areas where detailed investigations were done.

In 1992, NIWQP personnel initiated a data-synthesis project to evaluate all the data collected for the reconnaissance and detailed investigations. The overall objective of the data-synthesis project was to identify dominant geologic, climatic, hydrologic, and biologic factors that result in contamination of water and biota in irrigated areas of the Western United States.

What Contaminants are Associated with Irrigation?

Contaminants most commonly associated with irrigation drainage were identified by determining which trace elements and pesticides most frequently had concentrations exceeding criteria (Seiler and others, in press). The U.S. Environmental Protection Agency (USEPA) and State agencies promulgate criteria for contaminant concentrations in water to protect freshwater aquatic life. The USEPA has not promulgated criteria for boron, molybdenum, or uranium. The criteria used to evaluate boron and molybdenum concentrations were from the California State Water Resources Control Board and the criterion used to evaluate uranium concentrations was the proposed Canadian Water-Quality Objective.

Selenium, boron, and molybdenum are the trace elements most commonly associated with irrigation in the Western United States (fig. 2). One reason that so many samples exceeded the criterion for selenium is that many of the NIWQP study areas were selected for investigation because of known or suspected selenium contamination. Heavy metals such as cadmium and lead rarely exceeded criteria.

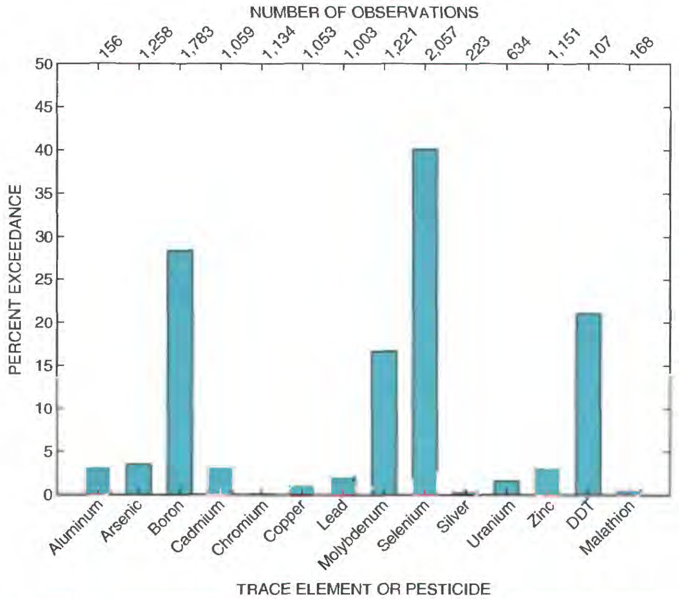


Figure 2. Percentage of trace-element and pesticide in surface water samples with concentrations that exceeded selected water-quality criteria.

DDT and malathion were the only pesticides found in surface water at concentrations exceeding criteria. For total DDT, 21 percent of the samples exceeded the criterion, however, almost all surface-water samples in which DDT exceeded the criterion were from a single study area, the Owyhee-Vale Reclamation Project Areas in Oregon and Idaho (area 17; fig. 1). Erosion of agricultural soils is the probable source of DDT now found in surface water. DDT and its degradation products, DDE and DDD, commonly were found in bottom sediment. DDE was found in 81 percent of the bottom-sediment samples and in all study areas where bottom sediment was examined for pesticides. Malathion contamination is not a common problem; only 1 of 168 samples exceeded the criterion.

What is the Source of Trace-Element Contaminants?

In most of the study areas, trace elements occur naturally in the agricultural soils. Infiltrating irrigation water dissolves salts and trace elements from the soils. Drainage from irrigated land transports the dissolved contaminants to wetland areas or streams where fish and wildlife may be exposed to them.

Some of the most productive agricultural land in the Western United States is derived from rocks that were deposited in oceans millions of years ago. These rocks contain salts and trace elements from those oceans. Of particular concern are marine deposits formed during the Cretaceous Period, which ended some 65 million years ago. During this period, a large inland sea covered much of what is now the Western United States. Rock deposited in that environment and soils formed on them by weathering commonly contain elevated concentrations of salts and trace elements such as selenium. Irrigated areas in the Western United States where these rocks or soils are present often have selenium problems (Seiler and others, in press).

In some areas, contamination has resulted because trace elements are brought into the areas from upstream. For example, the Salton Sea—Imperial Valley area in southern California

Marine rocks, like those exposed at the base of Mount Garfield, Colo., are the source of trace elements in many irrigated areas of the Western United States. Photograph by James G. Crock, U.S. Geological Survey.

(area 22; fig. 1) has elevated concentrations of selenium, even without a local geologic source for it (Seiler and others, in press). Selenium is transported into the area in irrigation water from the Colorado River. The Colorado River and some of its major tributaries dissolve trace elements from marine rocks hundreds of miles upstream from the Salton Sea; in addition, the river accumulates selenium from upstream irrigation projects.

Where is Irrigation Likely to Cause Pesticide and Trace-Element Contamination?

The occurrence of pesticide contamination depends principally on the pesticides being used and on past and present application practices within the agricultural area. DDT remains a potential problem in some localities because large amounts of this stable pesticide were used in the past. Contamination is less likely to occur when smaller amounts of less persistent pesticides are used.

In contrast, the occurrence of trace-element contamination is determined largely by the physical characteristics of the agricultural area. Irrigation is most likely to cause trace-element contamination in areas with local geologic sources of trace elements. For example, selenium is likely to be a problem in areas where soils are derived from Upper Cretaceous marine sedimentary rocks (Seiler and others, in press).

Climate is one of the most important factors in determining where irrigation drainage will cause trace-element contamination. For example, selenium contamination from irrigation has been observed only in arid or semi-arid areas (Seiler and others, in press). Typically, soils that develop in dry climates are poorly leached. Evaporation can cause salts and trace elements leached from these soils during irrigation to accumulate in streams and lakes downstream. Because of climate differences, trace-element contamination from irrigation is much more likely to occur in the Western United States rather than the Eastern United States.

Contamination by salts and trace elements commonly is found in areas with terminal lakes or ponds (Seiler and others, in press). In these water bodies, salts and trace elements can reach elevated concentrations because the only outlet for water is by evaporation. Water is lost to the atmosphere and potentially toxic salts remain behind. In areas where abundant freshwater is available, flushing of accumulated salts during spring runoff can prevent toxic concentrations from developing in wetland areas.

Are Some Trace Elements Usually Found Together?

Does the presence of elevated selenium concentrations, for example, also mean that concentrations of other trace elements will be elevated? Associations of salts and other contaminants in surface water were examined by Seiler and others (in press) using a statistical technique called principal-components analysis. Selenium was found to be associated with sulfate and uranium. Selenium is chemically similar to sulfur, and minerals that contain sulfur commonly contain selenium. Selenium and uranium commonly occur in sediment enriched in organic matter and both are dissolved by the percolation of alkaline, oxygenated irrigation water through the soil (Seiler and others, in press).

Boron and molybdenum are associated with chloride, which suggests that evaporation controls their concentrations (Seiler and others, in press). The highest boron and chloride concentrations measured during the NIWQP investigations were in terminal lakes in California and Nevada.

Arsenic concentrations were highest in areas where volcanic rocks are exposed (Seiler and others, in press). The element is not commonly associated with trace elements originating in marine sedimentary deposits. In fact, arsenic concentrations typically are low in areas where selenium concentrations are high.

How Much Harm are These Trace Elements Actually Causing?

When irrigation-induced contamination is severe, effects on wildlife populations can be overtly evident. The confirmed presence of deformed embryos at Kesterson Reservoir and at four of the NIWQP study areas (areas 6, 8, 14, and 25; fig. 1) provide dramatic evidence of selenium effects. Deformities of bird embryos are a clear, unambiguous indication that wildlife is being harmed by a contaminant. Tens to hundreds of embryos must be examined to determine if deformities are occurring in an area; however, in some of the study areas, few or no embryos were examined. If the geologic and climatic conditions described above are present in these areas, deformities may be occurring even though none were observed.

Usually, adverse biological effects from trace elements are subtle, and dead or deformed wildlife are seldom observed. Sublethal selenium poisoning of adult birds causes emaciation and lethargy. The unhealthy birds are more susceptible to predation and diseases and are less able to make long migrations, establish nests, and raise chicks. Selenium caused the collapse of the warm-water fishery at Kesterson Reservoir, with mosquito fish being the only surviving fish species. Changes in the number and types of species found in an area are a common indicator of stress and are not specific to irrigation-induced contamination. Other stresses include disease and increased numbers of predators.

Northern Pintail from Tulare Lake Bed area (25) showing selenium caused deformities.

Reduced hatchability of bird eggs is an example of harm to wildlife that can be statistically related to the chemical content of the eggs. NIWQP analyzed more than 2,000 bird eggs for contaminant concentrations. Selenium reduces the hatchability of bird eggs at concentrations much less than those required to cause deformities. In nine areas (areas 3, 6, 8, 13, 14, 19, 23, 24, and 25; fig. 1) 25 percent or more of the eggs contained selenium concentrations high enough that hatchability probably was reduced.

Can Trace Element Concentrations in Water be Related to Specific Biological Effects?

Contaminant concentrations in water can sometimes be associated with specific effects in populations of birds or fish. Of 804 surface-water sites where selenium was analyzed, 78 could be matched with nesting sites where bird eggs were collected. Of the 78 sites, 44 had water samples collected during April–July. Samples collected during April–July more likely represent the water that breeding birds are exposed to than would samples collected during August–March.

At the 44 sites where water samples were collected, 937 eggs from 31 species of birds were collected. Analytical results for these eggs were grouped into 158 sets; a set being a group of egg samples that represents a distinct breeding population of birds. Selenium concentrations exceeding 6 micrograms per gram (μg/g) is considered embryotoxic because it is associated with significantly reduced hatching success for black-necked stilts (Skorupa, 1998). An average selenium concentration in the range of 1–3 μg/g is considered normal.

The relation between the selenium concentration in water at nesting sites and the average selenium concentration in sets of eggs from NIWQP study areas is shown in figure 3. The graph shows that as the selenium concentration in water near a nesting site increases, the average selenium concentration in sets of bird eggs also increases. Sixty-five sets of bird eggs were collected from sites where the selenium concentration in the water equaled or exceeded 5 micrograms per liter (μg/L), the USEPA chronic criterion for selenium, and 55 of those sets of bird eggs contained embryotoxic concentrations of selenium. Nineteen of the 93 sets of bird eggs collected from sites where the selenium concentration in the water was less than 5 μg/L contained embryotoxic concentrations of selenium. Only 4 of 54 sets of bird eggs had embryotoxic concentrations of selenium when selenium in the water was less than 1 μg/L.

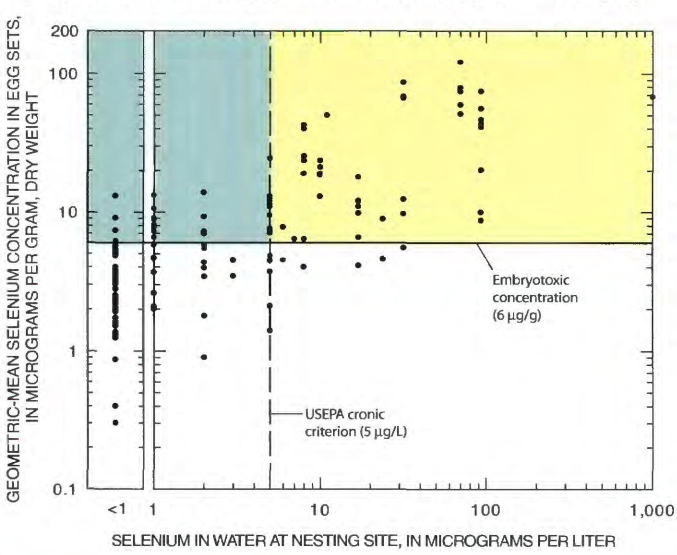


Figure 3. Relation between selenium concentrations in sets of bird eggs and in water at nesting sites. U.S. Environmental Protection Agency.

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Fact sheets and information on other technical reports related to the National Irrigation Water Quality Program (NIWQP) can be obtained from:

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Additional information on NIWQP can be found by accessing the "home page" on the World Wide Web or by searching the phrase "NIWQP" on an Internet search engine. Other related pages also can be found on the NIWQP home page.

For more information on the U.S. Geological Survey studies described in this Fact Sheet, or on other aspects of water resources in Nevada:

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A product of the National Irrigation Water Quality Program