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IMPACTS OF IRRIGATION DRAINWATER ON WETLANDS

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STRACT: Over the past four years, the U.S. Department of the Interior has en engaged in a program to identify, evaluate and respond to irrigation-duced contamination problems in the western states. To date, 20 areas in states have been selected for investigation. Reconnaissance-level dies focused on identification of irrigation-induced contamination blems have been completed at nine locations. Results of those studies veal significant adverse impacts on a number of wetland areas receiving rigation drainage water.
TERMS: Agriculture, drainage, hazardous waste, irrigation, pollution, er quality, wetlands, wildlife.

INTRODUCTION

The recent problem at the Kesterson National Wildlife Refuge in lifornia dramatically illustrated the severe adverse impacts that rigation drainwater can have on wetland habitat. At Kesterson, high rates waterfowl mortality, embryonic deformities, and reproductive failures re found beginning in 1983. Those impacts subsequently were linked to evated levels of the trace element selenium contained in the irrigation ainage water that flowed into Kesterson from the San Luis Unit of the reau of Reclamation's Central Valley Project (Presser and Ohlendorf 1987).

Unfortunately, adverse impacts of irrigation drainwater are not limited selenium, nor are they unique to California. As a result of the sterson situation, the Interior Department began checking existing formation in 1986 to see if similar problems existed at other irrigation jects, national wildlife refuges or other important wetland areas for ich the Department has responsibilities under the Endangered Species Act, igratory Bird Treaty Act and other legislation. It discovered evidence at irrigation drainage water might be adversely affecting fish and ildlife resources or human health at a number of other locations.

RECONNAISSANCE INVESTIGATIONS

To determine if such problems actually exist, reconnaissance studies re conducted at nine locations in seven states during the period 1986-988. The reconnaissance studies constitute the second phase of a five hased approach the Interior Department is using to address irrigation-nduced contamination problems. The five phased approach is described by eason (1986).

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Each study .involves sampling a number **of** environmental media (surface and ground water, sediment, and biological organisms) over a broad geographical area. Samples are analyzed for a large number of trace elements, organic pesticides and radiochemicals. Each study was designed to provide the maximum amount of information possible with **a** relatively modest investment.

Because of unique ecological systems and different geochemical conditions at each study area, each study design was somewhat different in terms **of** sampling schedules, numbers **of** samples at each site, biota sampled and analytes. At the same time, however, each study was designed to make the results comparable among areas to the extent possible. Each is guided by a common protocol (U.S. Department of the Interior **1986)** developed collectively by the agencies performing **the** field work: **U.S.** Geological Survey, **U.S.** Fish and Wildlife Service, and U.S. Bureau of Reclamation. Table **1** contains a list of inorganic constituents that are sample analytes in all studies.

Table 1. - Inorganic Analytes

Arsenic	Nickel
Barium	Selenium
Boron	Silver
Cadmium	Vanadium
Chromium	Zinc
Copper	Radium 226
Lead	Uranium
Mercury	Gross Alpha Radioactivity
Molybdenum	

STUDY RESULTS

A very brief summary of the most significant results from each of the nine reconnaissance investigations completed in 1988 is presented below. Readers are directed to the referenced reports to obtain a full understanding of the results of each investigation.

Lower Colorado River Valley Area, Arizona and California

The lower Colorado River study area (Radtke, et al. **1988)** is composed of the area along the mainstream Colorado River from Davis Dam, just north of the most northerly portion of the Arizona-California border, downstream to Imperial Dam just north of the Mexican border.

With the exception of one water sample yielding a cadmium concentration of 69 parts per billion (ppb), no inorganic trace elements were found in concentrations exceeding State of Arizona maximum allowable limits for protected uses of surface water. In addition, the only organic pesticide concentrations detected in the water column were the short-lived organophosphorus compounds diazinon, methylparathion, parathion, and chlorpyrifos.

Concentrations of barium, molybdenum, vanadium, zinc and TDS were significantly greater at stations under the direct influence of irrigation drainage than at other locations. Selenium concentrations, conversely, were lower at stations under the direct influence of agricultural discharges.

Selenium, arsenic, and uranium concentrations in bottom sediments at all stations exceeded geometric means of soils in the western United States. Selenium concentrations ranged from two to 30 times the geometric mean for western soils, although they tended to be at the low end of the range at stations under the direct influence of irrigation discharges. Organochlorine pesticides and other synthetic organic compounds were detected in bottom sediments in the study area. DDE was found in bottom sediments at all sampling sites and ranged from 0.1 to 7.5 parts per million (ppm).

Biological sampling results indicated that selenium is the inorganic constituent of greatest concern for the protection of fish and wildlife resources in the study area. Fish collected at all stations exceeded the waterfowl diet goal of 3.0 ppm selenium set by the U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service at the Kesterson National Wildlife Refuge in California (U.S. Bureau of Reclamation 1986). Trace element concentrations in fish and aquatic plant tissue were variable spatially, with no clear upstream to downstream trends detected. The most significant exception to this observation appeared to be selenium concentrations, which were lower at stations directly under the influence of agricultural drainage discharges.

Sampling results indicated that organic compounds do not appear to present environmental problems for fish in the lower Colorado River.

Salton Sea Area, California

The Salton Sea study area (Setmire, et al., 1989) includes the Imperial and Coachella Irrigation Districts, on the south and north ends, respectively, of the Salton Sea in southern California. The Salton Sea is a closed hydrologic basin receiving over one million acre-feet of irrigation drainage water annually. The Salton Sea National Wildlife Refuge supports the most diverse bird population of any national refuge and is a breeding ground for several endangered species.

Results of the reconnaissance study indicated that the primary constituent of concern in all environmental media is selenium. The range of selenium concentrations detected in water samples was 1-300 ppb, with a median concentration of 19 ppb. The maximum concentration of 300 ppb was

detected in a tile drain, as contrasted with selenium concentrations in bottom sediments, where the highest selenium concentration of 3.3 ppm was found in a composite bottom sediment sample from the Salton Sea.

Concentrations of boron in water also contrast with selenium, with the highest levels found in the Salton Sea and the lowest levels found in the Alamo River. The median concentration of boron was 1,750 ppb with a minimum of 680 ppb at the Alamo River outlet and a maximum of 11,000 ppb in the Salton Sea composite.

High organochlorine residues in bottom sediment samples indicate that DDT metabolites are very persistent in the Salton Sea area. The highest DDE concentration found was 64 ppb at the Alamo River outlet, immediately upstream of the Alamo River delta.

In biota, elevated concentrations of selenium were found in fish and birds. The mean concentrations for combined fish samples from all sample locations in the Salton Sea basin were: mosquitofish and mollies, 10 ppb; tilapia 13 ppm; and corvina, 3.9 ppm (dry weights). Selenium concentrations in bird levels approach those in ducks from the Kesterson National Wildlife Refuge. However, no embryonic deformities, reproductive failures or documented cases of selenium toxicosis in waterbirds were found.

Tulare Lake Area, California

The Tulare Lake study (Schroeder, et al. 1988) was conducted in the southern portion of the dry Tulare Lake Bed, which is located at the southern end of the Central Valley region in California. Specific sites included in the study were the Kern and Pixley National Wildlife Refuges (NWR) and the Westfarmers evaporation pond system, which is about five mi (8 km) west of the Kern Refuge.

The main constituents of concern in the Tulare Lake area were found to be boron, cadmium, chromium, copper, molybdenum, nickel and selenium. Pesticide residues in all samples from all areas were undetectable or far below values that would indicate adverse impacts.

In water, dissolved selenium, molybdenum, and boron concentrations were found to be 100 times higher in the Westfarmers evaporation ponds than at the Kern Refuge, whereas dissolved arsenic concentrations at Kern were ten times higher than at Westfarmers (although still less than EPA drinking water standards or wildlife protection criteria). Arsenic concentrations in fish from streams entering Kern NWR were found to be low, suggesting that excessive accumulation of the trace element by biological organisms on the Refuge is not occurring. No other constituents were detected in the refuges at concentrations indicating adverse impacts.

At the Westfarmers ponds, however, high boron, cadmium, copper, and selenium residues in aquatic insects may provide a route of exposure for aquatic birds. Concentrations of those constituents in shorebird livers and eggs, along with evidence of embryonic deformities and mortality, suggest that adverse biological impacts to shorebirds nesting at the ponds have occurred.

Stillwater Wildlife Management Area, Nevada

The Stillwater study area (Hoffman, et al., 1989) is located about 70 miles east of Reno in western Nevada. It includes a number of important wetland areas, such as Stillwater National Wildlife Refuge, Carson Lake wetlands, and the Fernley and Humboldt Wildlife Management Areas.

In areas affected by irrigation drainage, concentrations of the following constituents in water were found frequently to exceed recommended criteria for the protection of aquatic life or the propagation of wildlife: arsenic, boron, lithium, molybdenum, vanadium, dissolved solids, sodium, and un-ionized ammonia. In bottom sediments, arsenic, lithium, mercury and selenium were elevated. In biota, arsenic, boron, chromium, copper, mercury, selenium, vanadium and zinc were found in elevated concentrations. In some wetlands, selenium and mercury appear to be biomagnified, while arsenic is bioaccumulated. Some radioactive substances were substantially higher at the downstream sites compared to upstream background sites, but the significance of this to wildlife is unknown to present. Pesticide contamination in bottom sediments and biota was insignificant.

Adverse biological effects observed during the reconnaissance investigation ranged from gradual vegetative changes and species loss, to sudden fish die-offs, migratory bird disease epidemics and chronic migratory bird deaths.

Sun River Reclamation Project Area, Montana

The Sun River study area (Knapton, et al. 1988) was composed of three areas in Teton and Cascade Counties of west-central Montana: (1) the Greenfield-Fort Shaw Irrigation Districts, (2) Freezeout Lake Game Management Area (including Priest Butte Lake) and (3) Benton Lake National Wildlife Refuge. Each of these areas is directly affected by irrigation practices and return flows.

The study results did not indicate concentrations of any constituent within the Greenfield-Fort Shaw Irrigation Districts that would present a threat to human health, fish, or wildlife. Both the Freezeout Lake Game Management Area and the Benton Lake NWR, however, were found to contain elevated levels of several constituents in water, bottommaterial and biota.

The highest concentrations of constituents in water and bottom sediments were associated with saline seeps, which are common throughout the Northern Great Plains. For example, concentrations as high as 580 ppb selenium, 660 ppb cadmium, 7,000 ppb nickel, 2,500 ppb boron, and 19,000 ppb zinc were detected in saline seep water on Benton Lake NWR. However, flow volumes from such seeps were very small relative to total inflows to the lake.

In biological samples, boron concentrations in sago pondweed from Freezeout Lake and Benton Lake were at levels which may be a concern for consumer organisms limited to an aquatic vascular plant diet for an extended period of time. Several bird livers and eggs contained boron concentrations approaching levels found in diet studies to be indicative of boron related toxicity, while other bird livers and eggs were below such levels.

Selenium was found in the majority of biological samples. The highest levels in fish were found in Priest Butte Lake. Selenium concentrations in fish (48 ppm dry weight in yellow perch and 35 ppm dry weight in white sucker), invertebrates (32 ppm dry weight in odonates and 15 ppm dry weight in hemipterans), bird livers (28 ppm dry weight in avocets and 46 ppm dry weight in eared grebes), and bird eggs (4.9 ppm dry weight in avocet eggs and 18.0 ppm in eared grebe eggs) indicate that levels are present that could have toxic effects on fish and wildlife resources.

Milk Reclamation River Area, Montana

The Milk River study area (Lambing, et al. 1988) is centered around the Bowdoin NWR in northeastern Montana, about seven mi (11.2 km) east of the town of Matta.

In general, concentrations of trace elements, radiochemicals, and pesticides in the Refuge lakes were not found to be greatly elevated compared to upstream water supplies. Very few exceedances of water quality guide-lines were detected and none were prevalent at any particular site. High streamflows in the study area in 1986 probably caused some dilution of dissolved constituents compared to recent dry years, however.

In bottom sediments, trace element concentrations were generally similar to background concentrations found in soils.

Concentrations of trace elements and pesticides in biological organisms were generally less than values having known harmful effects on growth or reproduction. Maximum concentrations of several trace elements were considered elevated, but the occurrence was generally random among sites. Arsenic was found in all biological samples analyzed except for bird eggs, walleyes and hemipterans and was highest in plants and net plankton. The highest arsenic concentration measured was 21 ppm dry weight in net plankton. Boron was found in all biological specimens but one, and was generally found in higher concentrations in sago pondweed and filamentous algae than in other trophic levels sampled. The highest concentration of 810 ppm dry weight was detected in sago pondweed. Mercury was below detectable levels in plants and invertebrates, but was found at relatively low concentrations in bird eggs, bird livers and fish. The highest mercury concentration was 1.6 ppm dry weight in an avocet egg. Selenium was found in all classes of organisms sampled, with the highest concentrations (10-13 ppm dry weight) occurring in net plankton.

Lower Rio Grande - Laguna Atascosa National Wildlife Refuse Area, Texas

The Laguna Atascosa study (Wells, et al. 1988) was conducted in the lower Rio Grande Valley, which is located principally in the four southernmost counties in Texas: Starr, Hidalgo, Cameron, and Willacy. It includes the Laguna Atascosa NWR along the Gulf of Mexico in Cameron and Willacy Counties.

Results of sampling in the lower Rio Grande Valley and Laguna Atascosa NWR indicate that concentrations of dissolved trace elements in water generally are not elevated. The most significant element appears to be boron, which increases significantly from west to east. Concentrations of

boron ranged from 220 ppm to 5,300 ppb at all sampling locations except for Athel Pond, a lake in the Refuge that receives little freshwater inflow, where concentrations of dissolved boron as high as 11,000 ppb were detected.

Some fish tissue samples contained concentrations of arsenic, copper, mercury, selenium, and zinc that exceeded 85th percentile baseline values, but median concentrations of no inorganic constituent exceeded such baseline values.

Pesticide analytes in water samples included the triazine and chlorophenoxy herbicides and the organophosphorus, organochlorine, and carbamate insecticides. No chlorophenoxy herbicides or carbamate insecticides were detected. Three triazine compounds, three organophosphorus compounds, and one organochlorine compound were detected. In fish tissue, both toxaphene and DDT were detected in 12 samples at ranges of 0.98-5.1 ppm and 0.021-0.066 ppm wet weight, respectively. DDD was detected in 21 fish samples at ranges 0.015-0.16 ppm wet weight and DDE was detected in all fish samples analyzed, at ranges 0.36-9.9 ppm wet weight.

Middle Green River Basin Area, Utah

The Middle Green River Basin area consists of about 25,500 sq mi (66,100 km^2) along the main stream of the Green River and its tributaries south of Flaming Gorge Reservoir and north of the city of Green River, Utah. The study (Stephens, et al. 1988) focused on the Ouray National Wildlife Refuge and the Stewart Lake Waterfowl Management Area within the middle Green River Basin.

Generally, concentrations of all constituents except boron, selenium, zinc, and gross alpha radiation were less than the most appropriate guideline values.for water, sediment, and biological tissues contained in the Interior Department data interpretation guidelines discussed earlier. Of these, selenium appeared to be the principal constituent of concern. Concentrations of selenium entering Stewart Lake from subsurface drain pipes ranged from 14 to 140 ppb. Selenium concentrations in bottom material from the alluvial areas where the drains enter Stewart Lake ranged from 10 to 85 ppm. Liver tissue collected from coots at Stewart Lake contained from 4.9 to 26 ppm selenium dry weight. These concentrations indicate that adverse effects on wildlife reproduction and growth from selenium may be occurring.

At the Ouray NWR, concentrations of selenium in water ranged from 1 to 93 ppb, with the higher values occurring in the North Roadside Pond, which receives only irrigation drainage water. Liver tissue from coots on the North Roadside Pond contained a geometric mean concentration of 32 ppm selenium dry weight whereas liver tissue from coots collected in areas of the Refuge that receive water from the Green River contained less than 5 ppm selenium. Several embryonic deformities were also found in the North Roadside Pond.

Water samples from a marsh near Stewart Lake generally contained concentrations of boron and zinc that exceeded Utah standards for agriculture and wildlife protection, respectively. With few exceptions,

such was not the case for other water samples taken in the study area. Gross alpha radiation in drain water samples generally exceeded the Utah standard of 15 picocuries per liter.

Kendrick Reclamation Project Area, Wyoming

The Kendrick study area (Peterson, et al. 1988) was defined as the Kendrick Reclamation Project service area, just west of Casper, Wyoming. The study area is bounded on the east side by the North Platte River and Casper Creek and on the west side by the Casper Canal.

Analyses of water, bottom material and biological samples for trace elements, pesticides and radiochemicals indicated that the main constituent of concern is selenium, Concentrations of dissolved selenium in water ranged from less than 1 ppb to 300 ppb, with a median concentration of 7.5 ppb. The highest selenium concentrations were found in drains and ponds and small lakes with no outlets. Concentrations of dissolved selenium in the North Platte River, which supplies drinking water for several municipalities, ranged frcm less than 1 ppb to 4 ppb.

Bottom material samples contained selenium concentrations of 0.9 to 25 ppm, with the highest levels found in the same small lakes that contained the highest concentrations of dissolved selenium in water.

Selenium concentrations in fish and invertebrate samples taken at the same ponds were at levels that could cause adverse physiological effects. Most bird liver and egg samples from the ponds contained selenium concentrations that. could have toxic effects. For example, selenium ranged from 51 to i70 ppm (dry weight) .in avocet livers from Rasmus Lee Lake, from 13 to 16 ppm (dry weight) in blue-winged teal from Thirty-Three Mile Reservoir, and from 43 to 56 ppm (dry weight) in mallards from Illco Pond.

Other than selenium, the only constituent that may be of concern, based on the results of the reconnaissance study, is boron. Boron concentrations in rooted plants were found at levels that may be a minor concern for birds limited to a diet of aquatic vascular plants for any extended period of time.

EVALUATION

After completion of the studies, the results were evaluated by a Technical Review Team composed of representatives of the Geological Survey, Fish and Wildlife Service and Bureau of Reclamation.

A set of evaluation criteria, presented in Table 2, were developed to assist in making the evaluations as objective and consistent as possible. The evaluation criteria were used in a linear weighting formulation in which each study area was scored on each criterion, using a scale of 0-10. Each criterion, in turn, was multiplied by an assigned weight. The resulting weighted scores for each area were then summed to yield an overall weighted score. The overall scores for the study areas formed the basis for recommendations for further action at each location by the Technical Review Team to the Secretary of the Interior.

Table 2.-Reconnaissance Investigation Evaluation Criteria

Level of DOI Involvement
- Irrigation project constructed, funded, or managed by the Department
- National Wildlife Refuge or Waterfowl Management Area
- State of private waterfowl area
- Migratory waterfowl use of the area
- Endangered/threatened species use of the area

Study Area and Downstream Uses
- Public water supply/drinking water
  - o municipal
  - o rural
- Fish and wildlife
  - o wetland
  - o fishery
- Recreation (fishing/swimming/boating)
- Agriculture
  - o irrigation
  - o livestock

Human Health
- Exceedance of standards or criteria
  - o drinking water
- Health advisories
  - o drinking
  - o wildlife/fish consumption

Other Beneficial Uses
- Exceedance of standards or criteria
  - o irrigation
  - o livestock

Bottom Sediment
- Comparisons to geochemical baselines for soil

Fish and Wildlife Health
- Fish Observations
  - o fish
    - * die-offs
    - * behavioral effects
    - * growth effects
  - o wildlife
    - * die-offs
    - * behavioral effects
    - * growth effects
    - * deformities
- Experimental data comparisons
  - o exceedance of water quality criteria
    - * freshwater aquatic life
    - * marine aquatic life
  - o fish (body burden)
    - * levels above 85th percentile, NCBP
    - * levels indicating reproductive effects
    - * levels indicating lethal effects
  - o wildlife (body burden)
    - * levels indicating reproductive effects
    - * levels indicating growth effects
    - * levels indicating lethal effects
  - o aquatic invertebrates and plants
    - * exceedance of target levels to protect fish and wildlife

The Secretary announced subsequently (U.S. Department of the Interior 1988) that environmental conditions indicated by the reconnaissance investigations justified detailed studies at four locations. These are Stillwater, Nevada; Salton Sea, California: Green River, Utah; and Kendrick, Wyoming.

Additionally, long-term monitoring activities are planned at four additional locations: Lower Colorado River, Arizona and California: Sun and Milk Rivers, Montana; and Laguna Atascosa, Texas. Finally, follow-up work at the final area, Tulare Basin, California, is to be conducted by the joint Interior Department-State of California San Joaquin Valley Drainage Program.

GENERAL OBSERVATIONS

Several observations about the nature of irrigation-induced contamination problems can be made, based upon the evaluation process described above.

First, it appears that selenium is the constituent of concern most commonly found at elevated concentrations in wetland ecological systems receiving irrigation drainage water. Although selenium was not detected at elevated concentrations in all areas studied, nor was it found to be the constituent of greatest concern in all areas with elevated concentrations, it clearly was the constituent most frequently detected at elevated levels.

Second, concentrations of analytes were found to vary widely on a spatial basis in all environmental media sampled. This observation leads to the conclusion that irrigation-induced contamination problems are likely to be very site-specific. That is, problems can be quite severe on a localized basis while having a low level of relative significance on a regional basis.

Third, closed watersheds are an important physical characteristic of locations that may tend to exhibit symptoms of irrigation-induced contamination. The Salton Sea, Tulare Lake, Sun River, Stillwater, Green River and Kendrick areas all contain bodies of water having no surface outlets. In each case, the closed bodies of water contained some of the highest concentrations of constituents of concern within the study areas.

Fourth, other hydrologic and geochemical characteristics can also serve as indicators of potential problems with irrigation drainage. The presence of alkaline, highly seleniferous soils in highly arid environments (low precipitation with high evaporation rates) are examples. Such observations will improve the Bureau of Reclamation's ability to predict where irrigation-induced contamination problems will occur from planned or existing irrigation developments.

CONCLUSION

Completion of the first set of reconnaissance studies marks an important milestone for the Department's National Irrigation Water Quality Program. These results provide the first interdisciplinary evaluation of the magnitude and extent of irrigation-induced contamination problems across the West. At each location, further actions are underway to reduce stresses on receiving wetlands from existing problems or to monitor environmental conditions to ensure early detection of future problems.

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