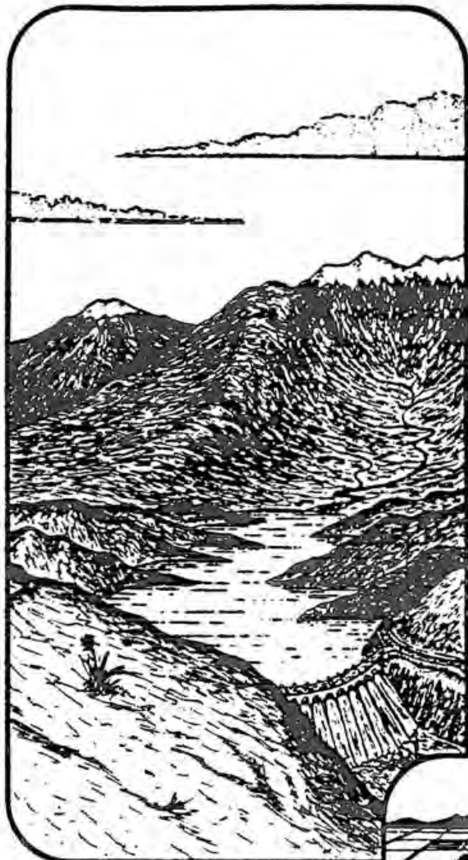
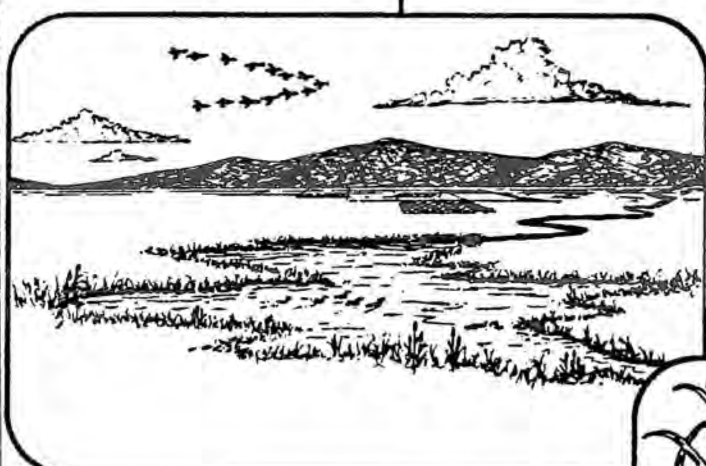


Detailed study of selenium and selected constituents in water, bottom sediment, soil, and biota associated with irrigation drainage in the San Juan River area, New Mexico, 1991-95



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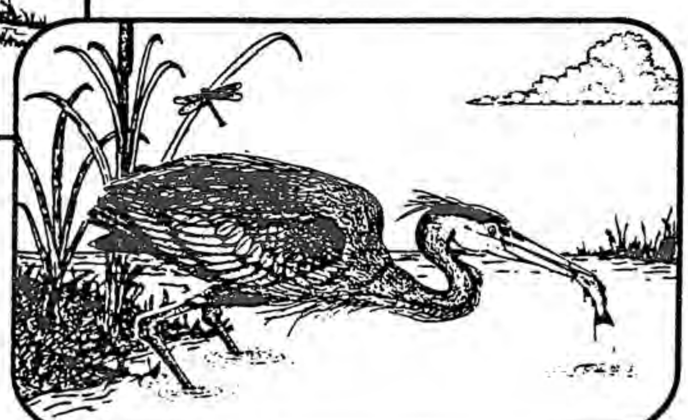

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DETAILED STUDY OF SELENIUM AND SELECTED CONSTITUENTS IN WATER, BOTTOM SEDIMENT, SOIL, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE SAN JUAN RIVER AREA, NEW MEXICO, 1991-95

By Carole L. Thomas, U.S. Geological Survey;
R. Mark Wilson, Joel D. Lusk, and R. Sky Bristol, U.S. Fish and Wildlife Service;
and Arlyn R. Shineman, Bureau of Reclamation

U.S. GEOLOGICAL SURVEY

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U.S. GEOLOGICAL SURVEY
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF RECLAMATION
BUREAU OF INDIAN AFFAIRS

Albuquerque, New Mexico
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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

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For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
4501 Indian School Road NE, Suite 200
Albuquerque, NM 87110-3929

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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot	1,233	cubic meter
cubic foot per second	0.028317	cubic meter per second
inch	2.540	centimeter
foot	0.3048	meter
mile	1.609	kilometer

Wet-weight and dry-weight concentrations in biological tissue can be converted by the following equations

Wet-weight concentration = (dry-weight concentration) x (1-percent moisture/100).

Dry-weight concentration = (wet-weight concentration) / (1-percent moisture/100).

Temperature in degrees Celsius (^{o}C) can be converted to degrees Fahrenheit (^{o}F) by the equation:

$$^{o}F = 9/5\ (^{o}C) + 32.$$

Chemical concentration in water is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L), which are equivalent to parts per million and parts per billion, respectively, when the concentration of dissolved solids is less than about 7,000 milligrams per liter (Hem, 1992, p. 55).

Chemical concentration in sediment is reported in micrograms per gram (µg/g) or percent. Micrograms per gram is equal to parts per million. Percent is equal to parts per hundred.

Chemical concentration in biological tissue is reported in micrograms per gram (µg/g) or micrograms per kilogram (µg/kg), which are equivalent to parts per million and parts per billion, respectively.

DETAILED STUDY OF SELENIUM AND SELECTED CONSTITUENTS IN WATER, BOTTOM SEDIMENT, SOIL, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE SAN JUAN RIVER AREA, NEW MEXICO, 1991-95

By Carole L. Thomas, U.S. Geological Survey; R. Mark Wilson, Joel D. Lusk, R. Sky Bristol, U.S. Fish and Wildlife Service; and Arlyn R. Shineman, Bureau of Reclamation

Abstract

In response to increasing concern about the quality of irrigation drainage and its potential effects on fish, wildlife, and human health, the U.S. Department of the Interior began the National Irrigation Water Quality Program (NIWQP) to investigate these concerns at irrigation projects sponsored by the Department. The San Juan River area in northwestern New Mexico was one of the areas designated for study.

Study teams composed of scientists from the U.S. Geological Survey, the U.S. Fish and Wildlife Service, the Bureau of Reclamation, and the Bureau of Indian Affairs collected water, bottom-sediment, soil, and biological samples at 61 sites in the San Juan River area during 1993-94. Supplemental data collection conducted during 1991-95 by the Bureau of Indian Affairs and its contractor extended the time period and sampling sites available for analysis. Analytical chemistry performed on samples indicated that most potentially toxic elements other than selenium generally were not high enough to be of concern to fish, wildlife, and human health.

Element concentrations in some water, bottom-sediment, soil, and biological samples exceeded applicable standards and criteria suggested by researchers in current literature. Selenium concentrations in water samples from 28 sites in the study area exceeded the 2-microgram-per-liter (μg/L) wildlife-habitat standard. Vanadium concentrations in water exceeded the 100-μg/L standard for livestock-drinking water at one site. In biota, selenium and aluminum concentrations regularly equaled or exceeded avian dietary threshold concentrations. In bottom sediment and soil, element concentrations above the upper limit of the baseline range for western soils were: selenium, 24 exceedances; lead, 2 exceedances; molybdenum, 2 exceedances; strontium, 4 exceedances; and zinc, 4 exceedances.

Concentrations of total selenium in bottom-sediment and soil samples were significantly greater for Cretaceous than for non-Cretaceous soil types in the study area and were generally similar for habitats within and outside irrigation-affected areas. Mean and median total-selenium concentrations in samples from areas with Cretaceous soil types were 4.6 and 2.2 micrograms per gram (μg/g), respectively. Mean and median total-selenium concentrations in samples from areas with non-Cretaceous soil types were 0.6 and 0.15 μg/g, respectively.

Samples from the study area had low concentrations of organic constituents. Organochlorine pesticides and polychlorinated biphenyls were detected in a few biological samples at low concentrations. Polycyclic aromatic hydrocarbon (PAH) compounds were not detected in whole-water samples collected using conventional water-sampling techniques. In tests involving the use of semipermeable-membrane devices to supplement conventional water assays for PAH's, low concentrations of PAH's were found at several locations in the Hammond Irrigation Supply Canal, but were not detected in the Hammond ponds at the downstream reach of the Hammond irrigation service area. PAH compounds do not appear to reach the San Juan River through the Hammond Canal.

Data indicate that water samples from irrigation-drainage-affected habitats had increased mean selenium concentrations compared with samples from irrigation-delivery habitat. The mean selenium concentration in water was

greatest at seeps and tributaries draining irrigated land (17 μg/L); less in irrigation drains and in ponds on irrigated land (6 μg/L); and least in backwater, the San Juan River, and irrigation-supply water (0.5 - 0.6 μg/L).

Statistical tests imply that irrigation significantly increases selenium concentrations in water samples when a Department of the Interior irrigation project is developed on selenium-rich sediments. Water samples from sites with Cretaceous soils had significantly greater selenium concentrations than water samples from sites with non-Cretaceous soils. Water samples from Department of the Interior project irrigation-drainage sites developed on Cretaceous soils contained a mean selenium concentration about 10 times greater than those in samples from Department of the Interior project sites developed on non-Cretaceous soils.

Selenium was much less concentrated in water than in bottom sediment, soil, or biota in the study area. The range in concentrations of dissolved selenium in water was less than 1 μg/L to 37 μg/L (less than 1 to 37 parts per billion). The range in concentrations of total selenium in bottom sediment and soil was less than 0.1 to 23 μg/g (less than 100 to 23,000 parts per billion). The range in concentration of selenium in biota was less than 0.1 to 24.0 μg/g (less than 100 to 24,000 parts per billion).

Data indicated that bioaccumulation and leaching from soil were the important processes at the study area that lead to elevated levels of selenium. Other processes examined included: (1) evapoconcentration of selenium; (2) atmospheric deposition of aerosols containing selenium; and (3) contamination of surface water by point-source or non-point-source discharges.

Selenium concentrations in biological samples were evaluated by a number of variables including: (1) media sampled (emergent and submergent plants, nektonic and benthic invertebrates, omnivore/herbivore and carnivore fish, and terrestrial and aquatic amphibians); (2) habitat (San Juan River main-stem reaches, backwaters, tributary reaches, irrigation delivery or drainage canals, and ponds); (3) irrigation project area and reference sites; and (4) soil type (non-Cretaceous or Cretaceous soils). Graphical techniques and nonparametric statistical tests were applied to determine the influence of selected physiographic variables on selenium concentrations in biological samples collected in the San Juan River area. Species of sucker and of smaller fish contained significantly higher selenium concentrations in the upstream portion of the river where a productive community of plants and animals is found that is associated with warming, nutrient-rich waters discharged from an upstream reservoir.

Selenium concentrations in algae, odonates, and mosquitofish collected from both irrigation-drain and pond habitats underlain by Cretaceous soils were significantly greater than in those collected from similar habitats underlain by non-Cretaceous soils. Investigators conclude that the major factor affecting the variability of selenium accumulation in biota at aquatic habitats was the presence of underlying Cretaceous soils. Median selenium concentrations were less than 2 μg/g for plant samples, less than 7 μg/g for invertebrate samples, and less than 6 μg/g for whole-fish samples collected from aquatic habitats underlain by non-Cretaceous soils. Similar samples collected from aquatic habitats underlain by Cretaceous soils contained median selenium concentrations two to five times greater. Leaching of selenium from Cretaceous soils in the San Juan River area increases the accumulation of selenium concentrations in the biota and thereby increases the exposure and potential health risks associated with selenium to migratory birds, fish, and other wildlife that use these aquatic habitats extensively. Aquatic habitats presenting the greatest average exposure to excess selenium concentrations in the diets of resident wildlife are from consumption of plants, invertebrates, and fish at irrigation-drain habitats underlain by Cretaceous soils.

Of the irrigation projects evaluated in the San Juan River area, the highest median selenium concentrations in algae, cattail leaves, odonate nymphs, mosquitofish, and leopard frog samples from the study area were collected from the east hogback irrigation drain.

INTRODUCTION

In 1983, the U.S. Fish and Wildlife Service documented incidences of mortality, deformities, and reproductive failures in migratory birds that were using irrigation impoundments in Kesterson National Wildlife Refuge in the western San Joaquin Valley in California. Concentrations of selenium greater than water-quality criteria for the protection of aquatic life (U.S. Environmental Protection Agency, 1987) were detected in subsurface drainage from irrigated land in the western San Joaquin Valley. Subsequently, studies of other areas receiving irrigation drainage in the Western States also have detected potentially toxic elements and pesticide residues in irrigation drainage.

In response to concern about the quality of irrigation drainage and its potentially harmful effects on fish and wildlife resources and on human health, the U.S. Department of the Interior (DOI) in 1985 began the National Irrigation Water Quality Program (NIWQP) to determine whether irrigation-related problems existed at other irrigation projects managed or constructed by the DOI, national wildlife refuges, or wetland areas for which the DOI has responsibilities under the Migratory Bird Treaty Act, the Endangered Species Act, or other legislation. The National Research Council's Committee on Irrigation-Induced Water-Quality Problems provided assistance in structuring and evaluating the program. NIWQP evolved into five phases: (1) site identification, (2) reconnaissance investigations, (3) detailed studies, (4) remediation planning, and (5) remediation. Activities in the first three phases are conducted by study teams composed of scientists from the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (USFWS), the Bureau of Reclamation (BOR), and the Bureau of Indian Affairs (BIA). Activities for phases 4 and 5 are conducted by the Interior Department agency that constructed, funded, or managed a given irrigation project.

The San Juan River area in northwestern New Mexico (fig. 1) was one of the areas designated for study because of the presence there of five DOI-sponsored irrigation projects and seleniferous soils. In October 1989 the USGS, USFWS, BOR, and BIA began a reconnaissance investigation of the area. The investigation focused on determining whether irrigation drainage (1) had caused adverse effects to fish, wildlife, or human health, (2) had the potential to adversely affect fish, wildlife, or human health, or (3) might reduce the suitability of water for beneficial uses.

The San Juan River area reconnaissance investigation (Blanchard and others, 1993) reported concentrations of selenium in biota that exceeded criteria suggested by researchers. Plant, invertebrate, amphibian, and fish samples from streams, ponds, and irrigation-drainage canals contained concentrations of selenium as great as 32.3 μg/g, dry weight, which exceeded the 4- to 8-μg/g, dry weight, dietary threshold criterion for waterfowl-food items (Heinz and others, 1989) and the 5-μg/g, dry weight, dietary threshold criterion for fish-food items (Lemly and Smith, 1987). The median concentration of selenium was 31.2 μg/g in six samples of liver and kidney tissue in birds collected from the Gallegos Canyon ponds, which exceeded the 30-μg/g, dry weight, concentration above which deformities can be expected to occur (Skorupa and others, 1990). Some whole-body and edible-portion samples of brown trout and common carp from the reach of the San Juan River below Navajo Dam were above the selenium criterion for waterfowl-food items and fish-food items. Furthermore, external lesions were observed on flannelmouth suckers and channel catfish, and the incidence of external lesions on fish exceeded 28 percent (Blanchard and others, 1993). As a result of the findings of the reconnaissance investigation, the NIWQP manager directed that a detailed study be conducted in the San Juan River area in northwestern New Mexico during 1993-95.

Purpose and Scope

The NIWQP needs basic technical information concerning the processes contributing to the elevated selenium in the San Juan River area to make decisions regarding the need for and type of appropriate remedial action. The objectives of the detailed study were to (1) quantify the concentration of selenium and other selected chemical constituents in water, sediment, and biota associated with irrigation drainage and the upper reach of the San Juan River from Navajo Dam (fig. 1) to 10 miles downstream, (2) evaluate levels of selenium and other constituents in water, bottom sediment, soil, and biota, and (3) provide an understanding of the processes leading to elevated levels of selenium and other contaminants in the San Juan River study area.

The report also evaluates the suitability of water for beneficial uses and avian risks related to feeding. A complete listing of the data used in this report is published in a separate report (Thomas and others, 1997).

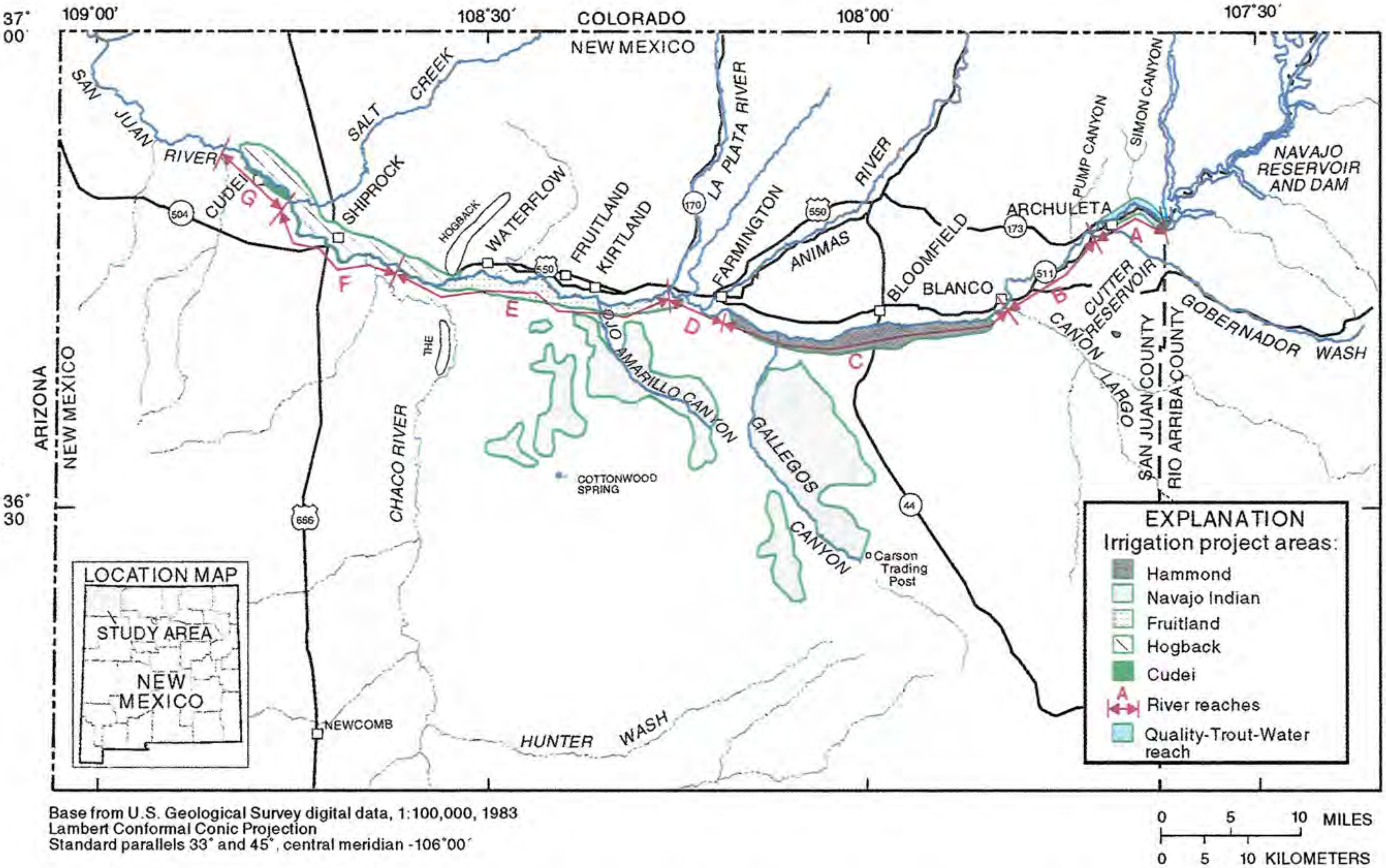


Figure 1.--Location of the San Juan River study area, New Mexico, irrigation projects sponsored by the U.S. Department of the Interior (DOI), and river reaches of the San Juan River

Two different sources funded data-collection and analysis activities for this report. NIWQP funding was used to collect samples during 1993-94 at sites listed in table 1. BIA funding associated with the Navajo Indian Irrigation Project (NIIP) was used to collect samples at sites listed in table 2 during 1991-95 The data collected during 1991-95 by the BIA and its contractor (Keller-Bliesner Engineering) are referred to as supplemental data in this report.

Data collection funded by the NIWQP included air, water, bottom-sediment, and biological samples from 61 sites in northwestern New Mexico during 1993-94. Data collection was designed to evaluate irrigation effects, sample a variety of habitats and reference sites, and sample the major components of the environment and the food web. Samples were collected from (1) sites located within DOI irrigation project service areas, or areas that receive drainage from irrigation projects; (2) reference sites for comparison with irrigation project sites; and (3) sites located within the upper reach of the San Juan River from Navajo Dam to 10 miles downstream. The types of habitat sampled included the main stem of the San Juan River, backwater areas adjacent to the San Juan River, tributaries to the San Juan River, ponds, seeps, irrigation-delivery canals, irrigation-drainage canals, a stock tank, and shallow ground water Samples were analyzed for concentrations of major ions, selected trace elements, organochlorine pesticides, polychlorinated biphenyls, polycyclic-aromatic-hydrocarbon (PAH) compounds, and stable isotopes of hydrogen and oxygen.

Acknowledgments

The authors acknowledge with appreciation the many individuals who assisted in this study. Leif Ahlm and Bob Larson from the New Mexico Department of Game and Fish were of particular assistance in the collection of trout samples from the San Juan River Quality-Trout-Water reach. Appreciation is extended to the many land owners in the study area who graciously allowed access to their property, particularly to Will Ed and Sylvia Paul, and to Raymond Drolet, who allowed the installation of streamflow-measurement stations on their property. Thanks are extended to Justin Gathings of the Hammond Conservancy District, who obtained access to irrigated land within the Hammond Irrigation Project. We also appreciate the assistance of Ron Bliesner and Mike Peterson of Keller-Bliesner Engineering who provided supplemental water and biological data used in this report.

DESCRIPTION OF THE STUDY AREA

The San Juan River study area is located in San Juan County, northwestern New Mexico (fig. 1). The area includes an approximately 80-mile reach of the San Juan River Valley from Navajo Dam to the western border of the Hogback Irrigation Project and an upland area south of the San Juan River Valley. The San Juan River is subdivided into reach segments designated A, B, C, D, E, F, and G (fig. 1) for analytical purposes. Five DOI-sponsored irrigation projects are located within the study area: Hammond, NIIP, Fruitland, Hogback, and Cudei (fig. 1). Irrigation projects are located adjacent to the San Juan River and south of the river

Three of the irrigation projects were sponsored and constructed by the BIA: the Fruitland, Hogback, and Cudei. The NIIP was sponsored by the BIA but is being constructed by the BOR. The Hammond Irrigation Project was sponsored and constructed by the BOR. All projects obtain water from the San Juan River or Navajo Reservoir. Following use, water that is not consumed by plants or evaporated returns by overland flow, seepage, or subsurface tile drains to the San Juan River or to the ground-water system in the San Juan River Valley.

The Hammond, Fruitland, Hogback, and Cudei Projects each consist of a diversion dam, a main canal, and a series of field laterals; the Hammond and Hogback Projects also have pumping plants and main laterals. Water is applied to croplands in the Fruitland, Hogback, and Cudei Irrigation Projects primarily by flood irrigation. Water is applied to Hammond Project croplands by flood irrigation and by hand-move and wheel-move sprinkler systems. Diversions of water from the San Juan River to the Hammond, Fruitland, Hogback, and Cudei Projects typically begin about April 15 and end about October 15. Alfalfa, winter wheat, other grains, corn, and potatoes are the principal crops grown on these projects.

Irrigation water for the NIIP is diverted from Navajo Reservoir on the San Juan River and is stored in and regulated by Cutter Reservoir (fig. 1), about 8 miles from Navajo Lake (Blanchard and others, 1993, p. 13). Water is delivered from Cutter Reservoir to the project area about 20 miles away by the Main Canal,

Table 1.--Sampling sites for the National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94

[Sites located on the San Juan River were given a river reach designation of A, B, C, D, E, F, or G (fig. 1). API, above private irrigation; HP, Hammond Project; REF, reference site for Department of Interior (DOI) irrigation projects; NIIP, Navajo Indian Irrigation Project; FP, Fruitland Project; HBP, Hogback Project; CP, Cudei Project; ft, foot; mi, mile; --, no data]

Site number (fig. 3)	Site name	Irrigation project area or river reach	U.S. Geological Survey station number[1]	Site latitude	Site longitude	Habitat
1	San Juan River 300 ft below dam near Archuleta	A	364817107365810	36°48′17″ N	107°36′58″ W	San Juan River
2	Pond on north bench San Juan River 0.6 mi below dam near Archuleta	API	364835107370410	36°48′35″ N	107°37′04″ W	Pond
3	Backwater south of San Juan River 0.9 mi below dam near Archuleta	API	364820107373410	36°48′20″ N	107°37′34″ W	Backwater
4	San Juan River at Texas Hole 1.4 mi below dam near Archuleta	A	--	36°49′03″ N	107°37′46″ W	San Juan River
5	Backwater south of San Juan River 3.1 mi below dam near Archuleta	API	364919107385710	36°49′19″ N	107°38′57″ W	Backwater
6	San Juan River at Simon Canyon 3.5 mi below dam near Archuleta	A	--	36°48′45″ N	107°39′53″ W	San Juan River
7	Dug hole at Simon Canyon at San Juan River near Archuleta	API	364923107393501	36°49′23″ N	107°39′35″ W	San Juan River tributary
8	Dug hole at Gobernador Wash at Highway 511 near Archuleta	API	364747107423001	36°47′47″ N	107°42′30″ W	San Juan River tributary
9	Dug hole at Pump Canyon at Highway 173 near Archuleta	API	364704107440701	36°47′04″ N	107°44′07″ W	San Juan River tributary
10	San Juan River at Pump Canyon 9.5 mi below dam near Archuleta	B	--	36°46′50″ N	107°42′58″ W	San Juan River

Table 1.--Sampling sites for the National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94--Continued

Site number (fig. 3)	Site name	Irrigation project area or river reach	U.S. Geological Survey station number[1]	Site latitude	Site longitude	Habitat
11	San Juan River at Shriner's property 10.6 mi below dam near Archuleta	B	--	36°46'17" N	107°44'08" W	San Juan River
12	East Hammond Project pond near Blanco	HP	364203107502410	36°42'03" N	107°50'24" W	Pond
13	Hammond Canal at Hammond Conservancy District near Blanco	HP	364125107515110	36°41'25" N	107°51'51" W	Irrigation delivery
14	Hammond Canal above Bloomfield Refinery near Bloomfield	HP	364155107574210	36°41'55" N	107°57'42" W	Irrigation delivery
15	Hammond Canal below Bloomfield Refinery near Bloomfield	HP	364148107584310	36°41'48" N	107°58'43" W	Irrigation delivery
16	Hammond Canal 0.3 mi west of Highway 44 near Bloomfield	HP	364128107594410	36°41'28" N	107°59'44" W	Irrigation delivery
17	East drain at west Hammond pond near Bloomfield	HP	364121108015710	36°41'21" N	108°01'57" W	Irrigation drainage
18	West drain at west Hammond pond near Bloomfield	HP	364122108015810	36°41'22" N	108°01'58" W	Irrigation drainage
19	Irrigation drain at manhole 800 ft above west Hammond pond near Bloomfield	HP	364108108020310	36°41'08" N	108°02'03" W	Irrigation drainage
20	Irrigation drain at manhole 500 ft above west Hammond pond near Bloomfield	HP	364112108015810	36°41'12" N	108°01'58" W	Irrigation drainage

Table 1.--Sampling sites for the National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94--Continued

Site number (fig. 3)	Site name	Irrigation project area or river reach	U.S. Geological Survey station number[1]	Site latitude	Site longitude	Habitat
21	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	HP	364115108015810	36°41′15″ N	108°01′58″ W	Irrigation drainage
22	West Hammond pond near Bloomfield	HP	364121108020010	36°41′21″ N	108°02′00″ W	Pond
23	Gallegos Canyon near Carson Trading Post	REF	09357245	36°27′23″ N	108°00′15″ W	San Juan River tributary
24	Dug hole at Gallegos Canyon near Carson Trading Post	REF	362723108001501	36°27′23″ N	108°00′15″ W	San Juan River tributary
25	NIIP irrigation-supply canal 0.2 mi south of Highway N3003 near Bloomfield	NIIP	363625108052510	36°36′25″ N	108°05′25″ W	Irrigation delivery
26	Center pivot sprinkler near Gallegos Canyon drainage middle pond near Farmington	NIIP	363840108065510	36°38′40″ N	108°06′55″ W	Irrigation delivery
27	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	NIIP	363841108070010	36°38′41″ N	108°07′00″ W	Seep
28	South seep to Gallegos Canyon drainage middle pond near Farmington	NIIP	363841108070110	36°38′41″ N	108°07′01″ W	Seep
29	Gallegos Canyon drainage middle pond near Farmington	NIIP	363841108070210	36°38′41″ N	108°07′02″ W	Pond

Table 1.--Sampling sites for the National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94--Continued

Site number (fig. 3)	Site name	Irrigation project area or river reach	U.S. Geological Survey station number[1]	Site latitude	Site longitude	Habitat
30	Gallegos Canyon near Farmington	NIIP[2]	09357255	36°41′27″ N	108°06′32″ W	San Juan River tributary
31	East seep to Ojo Amarillo Canyon drainage southwest pond near Farmington	NIIP	363947108190310	36°39′47″ N	108°19′03″ W	Seep
32	Ojo Amarillo Canyon drainage north pond near Farmington	NIIP	363947108190311	36°39′47″ N	108°19′03″ W	Pond
33	Northeast seep to Ojo Amarillo Canyon drainage north pond near Farmington	NIIP	363941108190410	36°39′41″ N	108°19′04″ W	Seep
34	Ojo Amarillo Canyon drainage southwest pond near Farmington	NIIP	363943108190610	36°39′43″ N	108°19′06″ W	Pond
35	Ojo Amarillo Canyon near Fruitland	NIIP[2]	09367536	36°42′38″ N	108°20′35″ W	San Juan River tributary
36	Fruitland irrigation drain 300 ft above wetland, near Fruitland	FP	364332108223410	36°43′32″ N	108°22′34″ W	Irrigation drainage
37	Fruitland irrigation drain at wetland near Fruitland	FP	364333108223410	36°43′33″ N	108°22′34″ W	Irrigation drainage
38	Secondary channel of San Juan River near Kirtland	E	364345108222210	36°43′45″ N	108°22′22″ W	Backwater
39	Pond at Cottonwood Spring near Newcomb	REF	363209108242410	36°32′09″ N	108°24′24″ W	Pond

Table 1.--Sampling sites for the National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94--Continued

Site number (fig. 3)	Site name	Irrigation project area or river reach	U.S. Geological Survey station number[1]	Site latitude	Site longitude	Habitat
40	Stock tank at Cottonwood Spring near Newcomb	REF	363209108242411	36°32′09″ N	108°24′24″ W	Stock tank
41	Seep at Cottonwood Spring near Newcomb	REF	363209108242510	36°32′09″ N	108°24′25″ W	Seep
42	San Juan River backwater at Hogback Diversion Dam near Waterflow	E	364442108315910	36°44′42″ N	108°31′59″ W	Backwater
43	Pond draining Fruitland Irrigation Project at Hogback near Waterflow	FP	364439108320610	36°44′39″ N	108°32′06″ W	Pond
44	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	HBP	364532108350210	36°45′32″ N	108°35′02″ W	Irrigation drainage
45	Hogback irrigation-supply canal near Waterflow	HBP	364545108350610	36°45′45″ N	108°35′06″ W	Irrigation delivery
46	Leaking well near Waterflow	HBP	364527108352001	36°45′27″ N	108°35′20″ W	Well
47	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	HBP	364527108352010	36°45′27″ N	108°35′20″ W	Irrigation drainage
48	East hogback irrigation drain 0.2 mi above San Juan River near Waterflow	HBP	364524108353210	36°45′24″ N	108°35′32″ W	Irrigation drainage
49	East hogback irrigation drain 300 ft above San Juan River near Waterflow	HBP	364524108354110	36°45′24″ N	108°35′41″ W	Irrigation drainage
50	Salt Creek at highway bridge near Shiprock	HBP	364932108433210	36°49′32″ N	108°43′32″ W	San Juan River tributary

Table 1.--Sampling sites for the National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94--Concluded

Site number (fig. 3)	Site name	Irrigation project area or river reach	U.S. Geological Survey station number[1]	Site latitude	Site longitude	Habitat
51	Cudei irrigation canal at turnout from San Juan River near Cudei	CP	365021108444710	36°50′21″ N	108°44′47″ W	Irrigation delivery
52	Cudei irrigation drain near Cudei	CP	365210108475310	36°52′10″ N	108°47′53″ W	Irrigation drainage
HB1-1	Hogback Irrigation Project site 1	HBP	--	36°45′28″ N	108°35′02″ W	Irrigation drainage
HB2-1,2	Hogback Irrigation Project reference site	HBP	--	36°45′32″ N	108°35′06″ W	--
HB3-1,2	Hogback Irrigation Project site 3	HBP	--	36°45′33″ N	108°35′00″ W	Irrigation drainage
HB4-1,2	Hogback Irrigation Project site 4	HBP	--	36°45′40″ N	108°34′58″ W	Irrigation drainage
HU1-1,2	Hammond Irrigation Project site 1	HP	--	36°41′12″ N	108°01′50″ W	Irrigation drainage
HU2-1,2,3,4	Hammond Irrigation Project site 2	HP	--	36°40′56″ N	108°01′55″ W	Irrigation drainage
HU3-1,2	Hammond Irrigation Project reference site	HP	--	36°41′17″ N	108°01′46″ W	--
HU4-1,2	Hammond Irrigation Project site 4	HP	--	36°41′14″ N	108°01′34″ W	Irrigation drainage
HU5-1,2,3	Hammond Irrigation Project site 5	HP	--	36°41′15″ N	108°01′29″ W	Irrigation drainage

[1]U.S. Geological Survey station number is a unique identifier used in the U.S. Geological Survey's Water-Data Storage and Retrieval System (WATSTORE) electronic data base and is composed of 15 or 8 digits. A 15-digit station number represents the approximate latitude and longitude location of the site (first 13 digits), plus the sequence number (last two digits). An eight-digit station number is the downstream order number assigned to a U.S. Geological Survey streamflow-gaging station.
[2]Site is affected by irrigation drainage from NIIP

Table 2.--Sampling sites for supplemental water and biological data collected in association with the Navajo Indian Irrigation Project, New Mexico, 1991-95

[Sites located on the San Juan River were given a river reach designation of A, B, C, D, E, F, or G (fig. 1). API, above private irrigation, NA, not applicable; NIIP, Navajo Indian Irrigation Project; RM, river mile]

Site number (fig. 4)	Site name	Irrigation project area or river reach	Site latitude	Site longitude	Habitat
01S	San Juan River at Navajo Dam	A	36°48′28″ N	107°36′31″ W	San Juan River
02S	San Juan River at hydro plant below Navajo Dam	A	36°48′21″ N	107°36′46″ W	San Juan River
03S	San Juan River about 1 mile below Navajo Dam	A	36°48′56″ N	107°37′30″ W	San Juan River
04S	San Juan River above Gobernador Canyon	A	36°48′34″ N	107°41′32″ W	San Juan River
05S	San Juan River at Archuleta Bridge	A	36°48′17″ N	107°41′57″ W	San Juan River
06S	Gobernador Canyon	API	36°47′43″ N	107°42′23″ W	San Juan River tributary
07S	San Juan River below Gobernador	A	36°47′38″ N	107°42′49″ W	San Juan River
08S	San Juan River below Gobernador	A	36°47′20″ N	107°42′55″ W	San Juan River
09S	San Juan River above Cañon Largo	B	36°43′18″ N	107°48′45″ W	San Juan River
10S	San Juan River at Blanco Bridge	B	36°43′27″ N	107°48′48″ W	San Juan River
11S	San Juan River above Cañon Largo	B	36°44′05″ N	107°49′04″ W	San Juan River
12S	San Juan River above Cañon Largo	B	36°44′52″ N	107°49′08″ W	San Juan River
13S	San Juan River below Cañon Largo	C	36°42′19″ N	107°50′23″ W	San Juan River
14S	San Juan River below Cañon Largo	C	36°42′18″ N	107°50′55″ W	San Juan River
15S	Kutz Canyon 2-mile pond	NA	36°34′54″ N	107°55′52″ W	Pond
16S	Kutz Canyon 1-mile pond	NA	36°35′30″ N	107°56′36″ W	Pond
17S	San Juan River above Bloomfield	C	36°42′36″ N	107°56′47″ W	San Juan River
18S	San Juan River below Bloomfield Refinery	C	36°42′05″ N	107°59′06″ W	San Juan River

Table 2.--Sampling sites for supplemental water and biological data collected in association with the Navajo Indian Irrigation Project, New Mexico, 1991-95--Continued

Site number (fig. 4)	Site name	Irrigation project area or river reach	Site latitude	Site longitude	Habitat
19S	San Juan River at Bloomfield Bridge	C	36°41′59″ N	107°59′11″ W	San Juan River
20S	San Juan River above Kutz Wash	C	36°41′49″ N	107°59′47″ W	San Juan River
21S	Animas River at Aztec Bridge	NA	36°49′34″ N	108°00′08″ W	San Juan River tributary
22S	Block 5 - pond	NIIP	36°32′30″ N	108°00′39″ W	Pond
23S	San Juan River above Kutz Wash	C	36°42′08″ N	108°00′52″ W	San Juan River
24S	San Juan River below Kutz Wash	C	36°41′19″ N	108°03′44″ W	San Juan River
25S	San Juan River below Kutz Wash	C	36°41′24″ N	108°04′57″ W	San Juan River
26S	San Juan River at Hammond Bridge	C	36°41′23″ N	108°05′42″ W	San Juan River
27S	Pond near Gallegos Siphon	NIIP	36°32′11″ N	108°06′18″ W	Pond
28S	San Juan River above Gallegos Wash	C	36°41′43″ N	108°06′29″ W	San Juan River
29S	Gallegos Canyon	NIIP	36°41′27″ N	108°06′32″ W	San Juan River tributary
30S	1-18 pond	NIIP	36°38′41″ N	108°07′02″ W	Pond
31S	San Juan River just below Gallegos Wash	C	36°42′04″ N	108°07′16″ W	San Juan River
32S	1-25 pond	NIIP	36°37′56″ N	108°07′43″ W	Pond
33S	1-25 small pond	NIIP	36°35′56″ N	108°07′47″ W	Pond
34S	1-35 pond	NIIP	36°35′47″ N	108°08′02″ W	Pond
35S	San Juan River 1 mile below Gallegos Wash	C	36°41′58″ N	108°08′14″ W	San Juan River
36S	San Juan River 3 miles below Gallegos Wash	D	36°42′32″ N	108°10′03″ W	San Juan River
37S	La Plata River at La Plata Bridge	NA	36°55′44″ N	108°11′00″ W	San Juan River tributary
38S	Animas River at Flora Vista Bridge	NA	36°43′38″ N	108°11′25″ W	San Juan River tributary

Table 2.--Sampling sites for supplemental water and biological data collected in association with the Navajo Indian Irrigation Project, New Mexico, 1991-95--Continued

Site number (fig. 4)	Site name	Irrigation project area or river reach	Site latitude	Site longitude	Habitat
39S	San Juan River 4 miles below Gallegos Wash	D	36°42′20″ N	108°11′35″ W	San Juan River
40S	Animas River at Farmington-Miller Bridge	NA	36°43′13″ N	108°12′07″ W	San Juan River tributary
41S	San Juan River at Animas	D	36°42′49″ N	108°13′18″ W	San Juan River
42S	San Juan River below Animas Confluence	D	36°43′03″ N	108°13′19″ W	San Juan River
43S	San Juan River at Highway 371 Bridge	D	36°43′17″ N	108°13′25″ W	San Juan River
44S	La Plata River at mouth	NA	36°44′23″ N	108°14′52″ W	San Juan River tributary
45S	San Juan River above Ojo Amarillo	E	36°44′08″ N	108°15′08″ W	San Juan River
46S	Ojo Amarillo small pond	NIIP	36°39′44″ N	108°19′00″ W	Pond
47S	Ojo Amarillo Pond	NIIP	36°39′43″ N	108°19′06″ W	Pond
48S	San Juan River above Ojo Amarillo	E	36°43′31″ N	108°20′29″ W	San Juan River
49S	Ojo Amarillo Canyon	NIIP	36°42′48″ N	108°20′35″ W	San Juan River tributary
50S	San Juan River below Ojo Amarillo	E	36°43′38″ N	108°21′48″ W	San Juan River
51S	San Juan River below Ojo Amarillo	E	36°43′38″ N	108°22′49″ W	San Juan River
52S	2-74 pond	NA	36°42′30″ N	108°23′43″ W	Pond
53S	San Juan River RM 168-167	E	36°44′06″ N	108°23′52″ W	San Juan River
54S	San Juan River at Fruitland Bridge (Kirtland)	E	36°44′21″ N	108°24′10″ W	San Juan River
55S	San Juan River RM 166.5-166	E	36°45′06″ N	108°24′56″ W	San Juan River
56S	San Juan River RM 166-165	E	36°44′48″ N	108°25′23″ W	San Juan River
57S	San Juan River RM 165-164	E	36°44′28″ N	108°26′16″ W	San Juan River
58S	San Juan River above Hogback Diversion	E	36°44′43″ N	108°32′11″ W	San Juan River

Table 2.--Sampling sites for supplemental water and biological data collected in association with the Navajo Indian Irrigation Project, New Mexico, 1991-95--Concluded

Site number (fig. 4)	Site name	Irrigation project area or river reach	Site latitude	Site longitude	Habitat
59S	Chaco Wash	NA	36°43′15″ N	108°34′39″ W	San Juan River tributary
60S	San Juan River above Chaco Wash	F	36°46′15″ N	108°37′18″ W	San Juan River
61S	San Juan River below Chaco Wash	F	36°46′01″ N	108°39′53″ W	San Juan River
62S	San Juan River below Chaco Wash	F	36°46′39″ N	108°40′57″ W	San Juan River
63S	San Juan River at Shiprock Bridge	F	36°46′51″ N	108°41′30″ W	San Juan River
64S	San Juan River at Shiprock	F	36°47′20″ N	108°41′44″ W	San Juan River
65S	San Juan River below Shiprock	F	36°47′25″ N	108°42′09″ W	San Juan River
66S	San Juan River at Cudei	G	36°50′14″ N	108°44′43″ W	San Juan River
67S	San Juan River below Cudei	G	36°52′03″ N	108°46′46″ W	San Juan River
68S	San Juan River at Mixer above Red Wash	NA	36°53′20″ N	108°53′06″ W	San Juan River
69S	San Juan River at Mixer	NA	36°53′21″ N	108°54′12″ W	San Juan River
70S	San Juan River at Mixer below Red Wash	NA	36°54′20″ N	108°55′04″ W	San Juan River
71S	Mancos River near Four Corners	NA	36°59′15″ N	108°57′46″ W	San Juan River
72S	San Juan River at Four Corners	NA	37°00′08″ N	109°01′54″ W	San Juan River

which includes several tunnels and siphons. Presently, the NIIP is still under construction but when completed, the project will include about 110 miles of open canals, and the water delivery system will transport as much as 1,800 cubic feet per second (ft^3/s) (Blanchard and others, 1993, p. 13).

Diversions to the NIIP begin about March 15 and terminate about October 31 of each year. Water is applied to cropland exclusively by sprinkler irrigation systems (Robert Krakow, Bureau of Indian Affairs, oral commun., 1994). About 90 percent of the cropland is irrigated by center-pivot systems; the remaining 10 percent is irrigated by wheel-move or hand-move sprinkler systems. The drain system on the NIIP includes about 200 miles of channels to collect storm runoff, overland irrigation-return flow, and ground-water seepage from irrigated land (Blanchard and others, 1993, p. 13).

Between 10 and 15 ponds for stock watering have been created on the NIIP by damming small drainages (Blanchard and others, 1993, p. 17). These ponds are filled by seepage, irrigation runoff, storm runoff, or diversion of irrigation-application water. Other ponds have been formed by diversion of irrigation-application water to small enclosed drainages. Since the completion of the reconnaissance study (1991), the middle pond in the Gallegos Canyon drainage and the two Ojo Amarillo Ponds in the Ojo Amarillo Canyon drainage have been diluted with irrigation-application water to decrease selenium concentrations. Since the completion of this study the dam at the middle pond in the Gallegos Canyon drainage has been breached to prevent ponding (Robert Krakow, oral commun., 1997).

Ponds and wetlands provide aquatic and riparian wildlife habitat on and adjacent to each of the irrigation projects. The ponds and wetlands provide suitable feeding, stopover, and, in some cases, nesting habitat for migratory waterfowl and shorebirds and many other kinds of aquatic and semiaquatic wildlife.

Also included in the study area is the Quality-Trout-Water reach (fig. 1) downstream from Navajo Dam. This first 4.0-mile reach of the San Juan River downstream from Navajo Dam is a tailwaters reach that the New Mexico Department of Game and Fish manages as a trophy trout fishery. This river segment is important for recreational fishing and is internationally famous for the numerous and large size of trout caught there. In 1996, the first 7-mile reach of the San Juan River downstream from Navajo Dam received approximately 390,000 angler hours of pressure (Mark Wethington, New Mexico Department of Game and Fish, oral commun., 1997); approximately 290,000 of these angler hours (74 percent) were spent in the Quality-Trout-Water reach. This represented approximately a 140,000-angler-hour increase over that measured in 1993. This recent increase in angling pressure on the San Juan River probably is attributable in part to the rising popularity of flyfishing. Also, the San Juan River generally can be fished year-round, whereas many other premier trout fisheries in the Western United States (for example, those in Yellowstone Park) are either statutorily closed in the winter, are inaccessible due to snow or ice, or have average winter temperatures too cold to permit an enjoyable angling experience on a consistent basis.

Climate

The climate of the San Juan River area is semiarid to arid and is characterized by small annual precipitation, large potential evaporation, and large daily and annual fluctuations in temperature. Average annual precipitation in the San Juan River area ranged from 7.5 inches at Shiprock to 9.6 inches at Bloomfield for the 30-year period 1961 through 1990 (U.S. Department of Commerce, 1993, p. 2-3). Nearly half the annual precipitation falls during July through October, usually during thunderstorms. Average annual potential evaporation is 77 inches at Farmington and 79 inches at Navajo Dam (Blanchard and others, 1993, p. 8). For 1961 through 1990 average temperatures at Fruitland were 28.6 degrees Fahrenheit in January and 75 degrees Fahrenheit in July (U.S. Department of Commerce, 1993, p. 10, 28). The growing season is about 160 days (Blanchard and others, 1993, p. 8).

Geology and Soils

The geology (fig. 2) and soils of the San Juan River area were discussed by Blanchard and others (1993, p. 9-11). That discussion describes the study area as lying within the Colorado Plateau physiographic province and characterized by mesas, buttes, cuesta ridges, and rock terraces separated by broad, open valleys and occasional canyons and hogbacks. A prominent geographic feature in the San Juan River Valley is The Hogback about 8 miles east of Shiprock (fig. 1), an approximately north-trending monocline that dips steeply to the east.

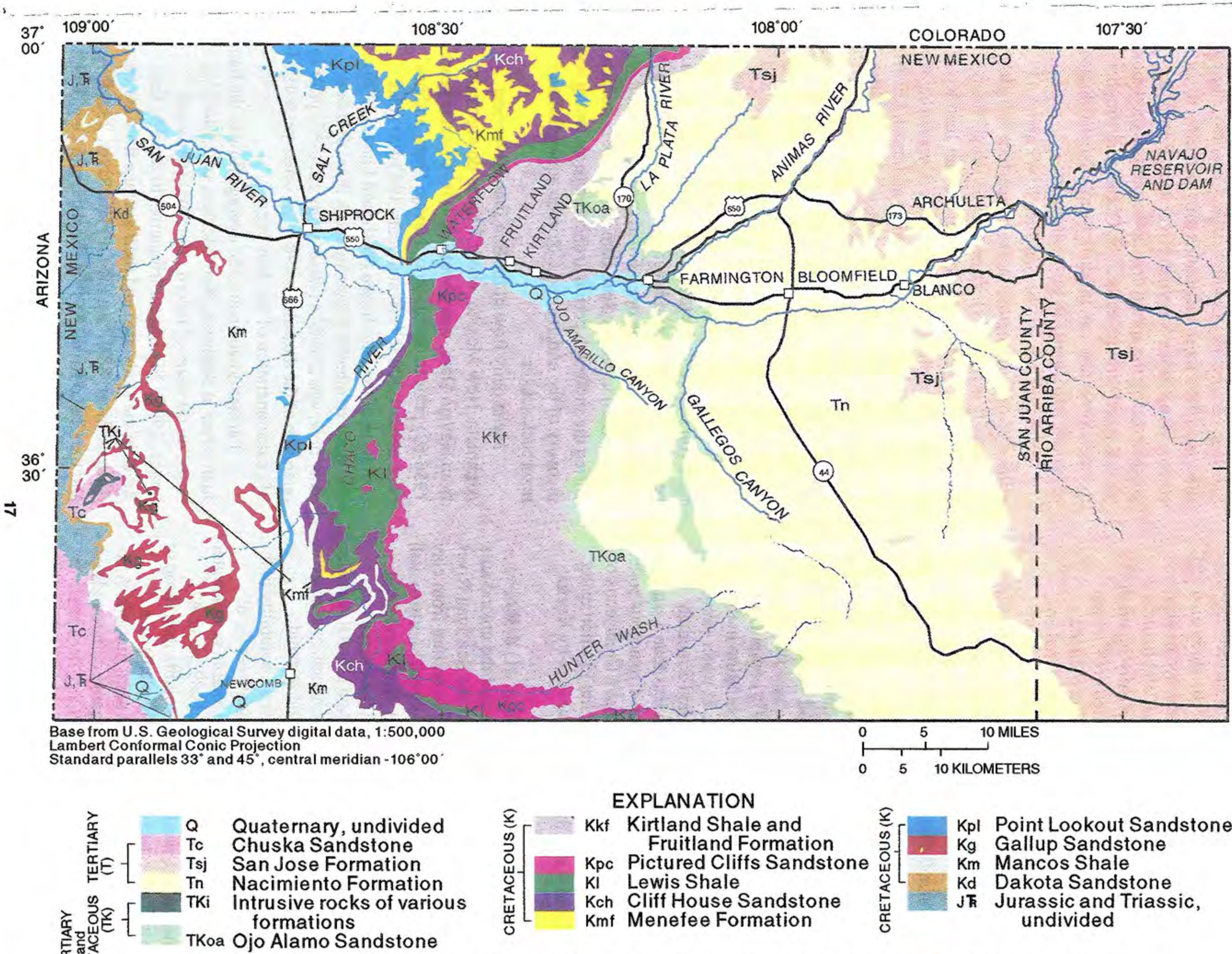


Figure 2.--Geology of the San Juan River study area, New Mexico (modified from Dane and Bachman, 1965).

Surficial geology of the San Juan River area is a combination of unconsolidated and consolidated sediments generally ranging from Cretaceous to Quaternary age (fig. 2). Triassic and Jurassic sediments are found at the western border of the study area (fig. 2). Unconsolidated sediments composed of clay, silt, sand, and gravel, and terrace gravel and boulder deposits of Quaternary age are typically found in the San Juan River Valley. Consolidated-rock strata typically consist of sequences of interbedded sandstone, mudstone, shale, and occasional coal deposits (Blanchard and others, 1993, p. 9).

Shale commonly is thought to have higher selenium concentrations than igneous rocks, metamorphic rocks, or other types of sedimentary rocks (Lakin and Davidson, 1967; Burau, 1989). Shale units in the strata of the San Juan River study area generally occur in geologic formations of Cretaceous age. Cretaceous soils derived from geologic formations of Cretaceous age have the potential to contribute dissolved trace elements, including selenium, to the surface-water environment (Blanchard and others, 1993, p. 9). Nolan and Clark (1997) computed a median dissolved-selenium concentration in the Western United States of 14 µg/L in water samples from areas with Cretaceous soils and a median dissolved-selenium concentration less than 1 µg/L in water samples from areas with non-Cretaceous soils. Investigators determined sites to have Cretaceous or non-Cretaceous soils based upon site location using figures 3 and 4 and the general soil map by Keetch (1980).

Blanchard and others (1993, p. 11) described soils in the San Juan River Valley and the upland area where the NIIP is located. Soils in the San Juan River Valley typically are alkaline, vary in texture from clay to sand, are poorly stratified, range from poorly to well drained, and range in permeability from moderately rapid to moderately slow. Soils in the upland area typically are derived from eolian and alluvial material, are deep and well to excessively drained, and range in permeability from moderately rapid to rapid.

For neutral and alkaline soils the solubility of the selenate ion (SeO_4^{2-}), a geochemical species of selenium, causes it to be widely available in soil-water-plant system interactions (Burau, 1989, p. 42-47). Selenate salts generally are more soluble than those of sulfate and are readily absorbed by plants as a substitute for sulfate, an essential plant nutrient. Also readily absorbed by plants are organic compounds of selenium in soil derived from partially decayed seleniferous vegetation.

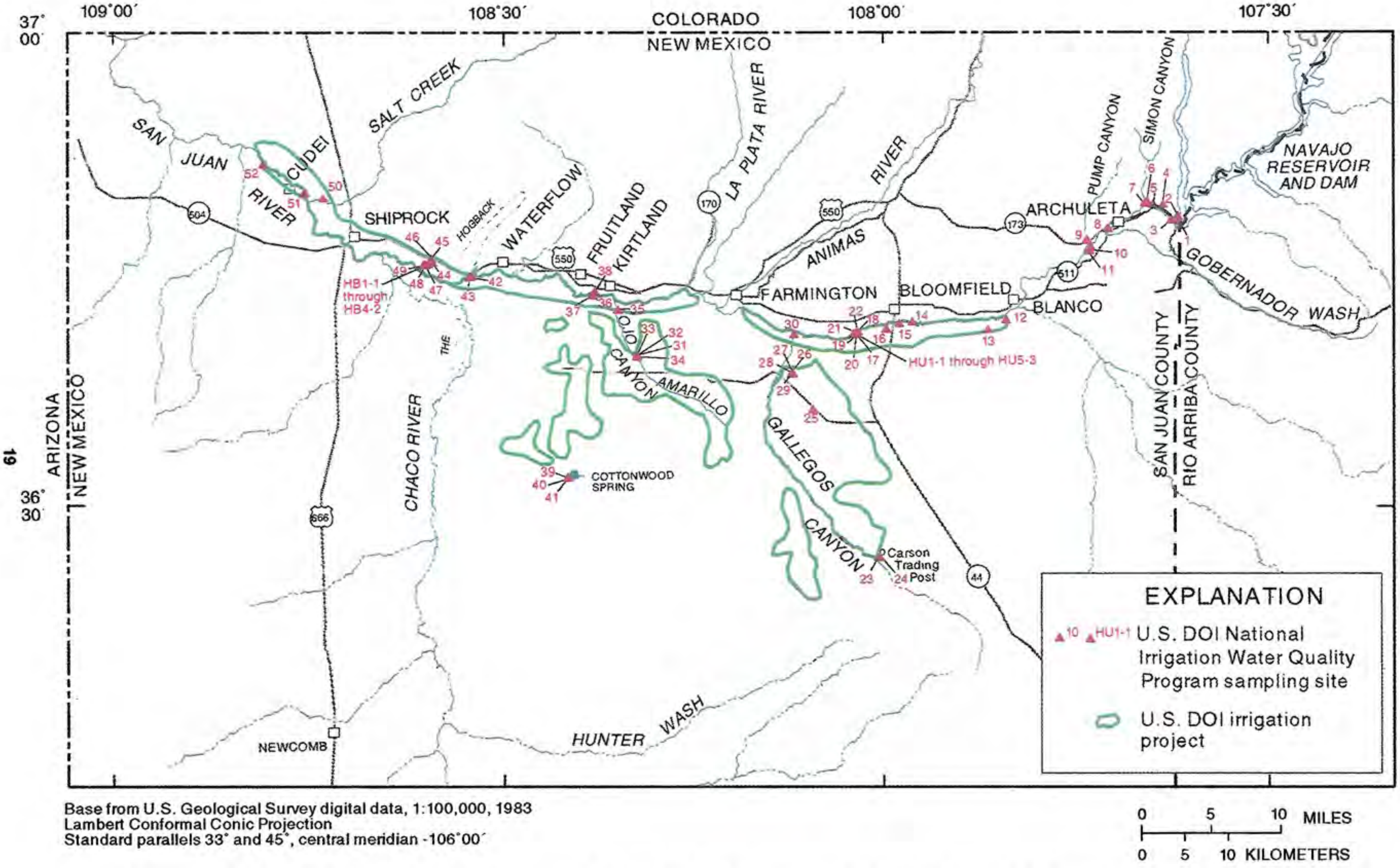
Hydrologic Setting

The headwaters of the San Juan River are in the San Juan Mountains in southwestern Colorado. Spring snowmelt from these mountains provides most of the surface water in the San Juan River area. Runoff is greatest during the spring and early summer snowmelt period, April through early July. Occasional summer thunderstorms also can produce locally large volumes of runoff, particularly at lower altitudes.

Navajo Dam, on the San Juan River about 33 miles east of Farmington, marks the eastern boundary of the study area (fig. 1). Prior to 1963 when Navajo Dam became operational, flows in the San Juan River generally were characterized by peak flows during the April through July snowmelt period and much lower flows during the remainder of the year, except during storms. Between 1963 and 1992, Navajo Dam was operated in a manner that maximized water storage and delivery for irrigation purposes, as well as providing flood control, recreation, and water for domestic and industrial uses. This generally resulted in a year-round stabilization of flows in the San Juan River, and the reservoir served to average out the sharp differences between peak flows and low flows. Since 1992, the BOR has changed the operational management of Navajo Dam to recreate pre-dam peak-flow conditions during the snowmelt period to encourage spawning and recovery of the endangered Colorado squawfish and razorback sucker.

Mean daily flow in the San Juan River near Archuleta, New Mexico, about 7 miles downstream from Navajo Dam, was about 1,300 ft^3/s (water years 1956-62) prior to operation of Navajo Dam, and has been about 1,200 ft^3/s (water years 1963-95) since operation of the dam began (Ortiz and Lange, 1996). The most frequently occurring daily flow, or mode daily flow, was 250 ft^3/s (water years 1956-62) prior to operation of the dam and is 498 ft^3/s (water years 1963-95) since operation of the dam began.

Farther downstream, the average flow in the San Juan River at Shiprock, New Mexico, is 2,144 ft^3/s, based on 60 years of record (1935-95) (Ortiz and Lange, 1996). Significant tributaries to the San Juan River in the study area and their average flow are the Animas River, 884 ft^3/s; the La Plata River, 29.4 ft^3/s; and the Chaco River, 48 ft^3/s (Borland and Ong, 1995; Ortiz and Lange, 1996).



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic Projection
Standard parallels 33° and 45°, central meridian -106°00′

Figure 3.--Location of sampling sites for the U.S. Department of the Interior (DOI) National Irrigation Water Quality Program (NIWQP), San Juan River area, New Mexico, 1993-94

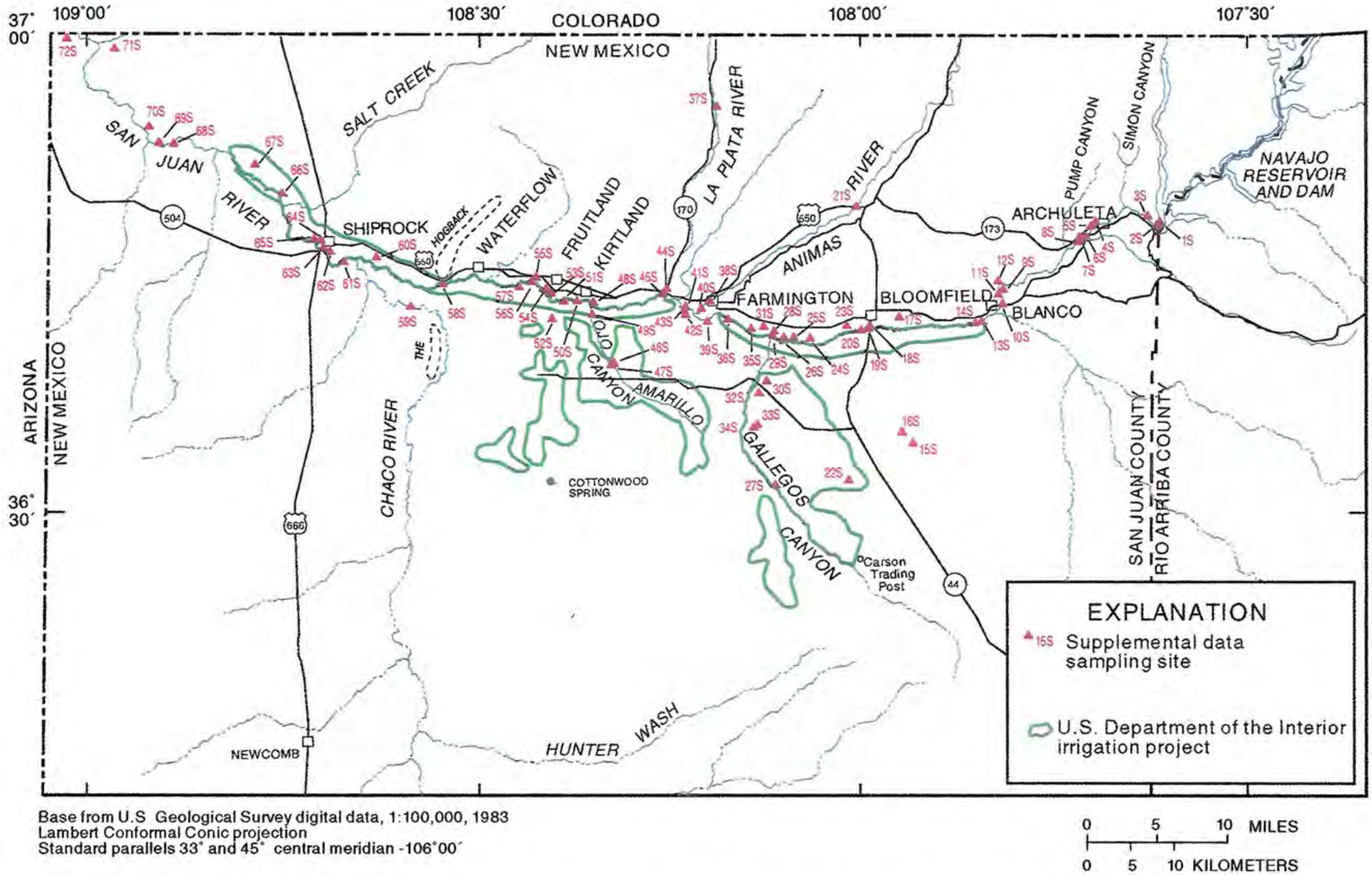


Figure 4 --Location of sampling sites where supplemental water and biological data were collected in association with the Navajo Indian Irrigation Project (NIIP), San Juan River area, New Mexico, 1991-95

About 520,000 acre-feet of water was used in San Juan County in 1985; most of this was surface water from the San Juan River and Navajo Reservoir and used along the San Juan River corridor (Wilson, 1986). Irrigation accounted for 78 percent of this water use; virtually all irrigation water is obtained from surface-water sources.

Ecotypical Setting

The upper reaches of the San Juan River and its tributaries are considered important big game wintering habitat. The piñon-juniper habitat of the northern La Plata River Valley and the areas adjacent to the Carson National Forest support significant wintering populations of mule deer and elk (Bureau of Land Management, 1991).

Several species of migratory waterfowl, especially Canada geese and mallards, nest along the San Juan River and its associated backwaters and tributaries. Thousands of waterfowl use the river for resting during annual migrations as do many species of wading birds and shorebirds.

Federally Listed Threatened and Endangered Species

Federally listed threatened and endangered species are present (at least periodically) within the study area. They are the Mancos milkvetch, Mesa Verde cactus, bald eagle, peregrine falcon, southwestern willow flycatcher, Colorado squawfish, and razorback sucker.

Mancos Milkvetch

The Mancos milkvetch is a diminutive, tufted perennial plant known only in northwestern New Mexico and extreme southwestern Colorado. It is most commonly found in scattered populations between the town of Towaoc, in southwestern Colorado, and the Chaco River in New Mexico. It grows on the Cretaceous Point Lookout and Cliff House Sandstones of the Mesaverde Group, at approximately 5,000-5,400 feet in altitude. Twelve of the 13 extant populations are primarily on lands of the Navajo Nation and Ute Mountain Ute Tribe.

Mesa Verde Cactus

The Mesa Verde cactus typically has a single stem but may form clusters of as many as 15 stems, 1 to 1.66 inches tall and of equal diameter. The cactus produces cream to yellow flowers 0.25 inch in diameter The Mesa Verde cactus is known from only four isolated populations in northwestern New Mexico and one isolated population in southwestern Colorado. Three of the New Mexico populations grow on the Navajo Nation.

Bald Eagle

During 1992-93 when the study plan for the San Juan NIWQP was developed, the bald eagle was a federally listed endangered species. In 1995, however, the eagle was upgraded to threatened status (U.S. Fish and Wildlife Service, 1995).

Wintering bald eagles enter New Mexico in October and November and leave in March or early April. While in the State, most tend to congregate around reservoirs and other sizeable bodies of water, including larger rivers. The number of bald eagles wintering along the San Juan River and around Navajo Reservoir has increased, mirroring a recent statewide trend.

Peregrine Falcon

No peregrine falcon aeries currently are known within the study-area portion of the San Juan River Valley. However, the species may use the area during migration and prey upon avian species feeding in ponds on project lands that receive irrigation-return flows.

Southwestern Willow Flycatcher

The southwestern willow flycatcher is a small neotropical passerine approximately 15 centimeters (5.75 inches) in length. The flycatcher is an insectivorous bird, foraging within and above dense riparian vegetation, capturing its prey while in flight or from foliage (Wheelock, 1912; Bent, 1963). The current rangewide estimate of the total number of flycatcher territories is between 400 and 500 (Unitt, 1987). The State of New Mexico lists the flycatcher as endangered (New Mexico Department of Game and Fish, 1988).

The San Juan River in New Mexico has been surveyed only sporadically for willow flycatchers. The

Bureau of Land Management, New Mexico Department of Game and Fish, and private consultants have conducted very limited surveys. Vegetation in portions of the river appears to be suitable, particularly immediately downstream from Navajo Dam where dense coyote willow/tamarix vegetation borders the river.

Colorado Squawfish

The reach of the San Juan River from Farmington, New Mexico, to Lake Powell in Utah was designated as critical habitat for the endangered Colorado squawfish on April 21, 1994 (U.S. Fish and Wildlife Service, 1994). Habitat alteration, fragmentation, and degradation arising from dam construction, and competition and predation from introduced nonnative fishes have been cited as the major factors responsible for the decline of the species (U.S. Fish and Wildlife Service, 1991). As a top level predator, the Colorado squawfish may experience bioaccumulation of contaminants from its prey.

Endemic to the Colorado River Basin, the squawfish historically has been found in the San Juan and Animas Rivers (Koster, 1957, 1960; Platania, 1990). The species is adapted to rivers that have seasonally variable flow, high silt loads, and turbulence. The Colorado squawfish does utilize wetlands and backwater areas that receive irrigation drainage as nursery habitat.

The USFWS is actively trying to recover the San Juan River population of Colorado squawfish by means of intensive research on aquatic habitat and by stocking and monitoring the progress of reintroduced juvenile squawfish. As of 1997, no Colorado squawfish had been released upstream from the Hogback Diversion Dam.

Razorback Sucker

Endemic to the Colorado River system, the razorback sucker was listed as an endangered species by the USFWS on October 23, 1991. On April 21, 1994, the section of the San Juan River between the Hogback Diversion Dam and the upper reach of Lake Powell was designated as critical habitat for the razorback sucker (U.S. Fish and Wildlife Service, 1994).

Causes for the decline of the razorback sucker have been identified as fragmentation of its habitat by construction of dams, manipulation of flows with attendant alterations of temperature and water quality, and the introduction of nonnative fishes. Once abundant throughout the main stem of the Colorado River and its major tributaries, the species now occupies only an estimated 25 percent of its historic range and its population is extremely low.

Because significant recruitment to any population of the species in the entire Colorado River system has not been documented (Platania, 1990), the USFWS in 1994 began stocking razorback suckers in the San Juan River in an attempt to assist in recovering this species. The USFWS monitors the locations and movements of these tagged fish throughout the year. This fish species uses wetlands and backwaters receiving irrigation drainage as nursery habitat. Approximately 5 percent of the males indicated spawning capability (production of milt) in 1996, and the USFWS predicts that attempts to spawn may occur in 1997 (Dale Ryden, U.S. Fish and Wildlife Service, Colorado River Fisheries Project, oral commun., November 1996).

COLLECTION AND ANALYSIS OF DATA

Sample collection and analysis for the NIWQP, San Juan River area, New Mexico, were cooperative efforts among four DOI agencies and several Federal and contract laboratories. Samples were collected by the USGS, USFWS, BOR, and BIA. Laboratories analyzing samples included the USGS National Water Quality Laboratory (NWQL) in Arvada, Colorado; USGS Isotope Laboratory in Reston, Virginia; USGS Branch of Geochemistry in Lakewood, Colorado; BOR Interregional Soil and Water Laboratory and Environmental Research Chemistry Laboratory in Denver; Environmental Trace Substance Laboratory in Columbia, Missouri; Geochemical and Environmental Research Group in College Station, Texas; and Mississippi State Chemical Laboratory at Mississippi State University in Mississippi. Semipermeable-membrane devices (SPMD's) were analyzed by Dr. Harry F Prest of the Long Marine Laboratory at the University of California in Santa Cruz.

National Irrigation Water Quality Program Sampling Sites

Sampling sites consisted of (1) 43 sites located within DOI irrigation project areas or areas receiving drainage from these projects (sites 12-22; 25-38; 42-52; HB1-1, HB3-1,2; HB4-1,2, HU1-1,2; HU2-1,2,3,4, HU4-1,2; and HU5-1,2,3); (2) 7 reference sites for the DOI irrigation projects (sites 23, 24, 39-41, HB2-1,2; and HU3-1,2); and (3) 11 sites located within the reach of the San Juan River from Navajo Dam to 10 miles downstream from the dam (sites 1-11). Figure 3 shows the locations of the sampling sites. Table 1 lists the site number, site name, irrigation project area or river reach, USGS station number, latitude and longitude, and habitat.

Forty-three sites within DOI irrigation projects were sampled. Sites located within DOI irrigation projects included those sampled during the reconnaissance that had elevated concentrations in biota of selenium (sites 22, 29, 34, 44, and 47) or lead (sites 12 and 37) plus additional sites.

Seven reference sites were sampled. These sites included an ephemeral streamflow site and a dug hole in Gallegos Canyon upstream from any irrigation projects (sites 23 and 24), and a pond, galvanized-steel stock-watering tank, and seep within the study area but outside the influence of agricultural irrigation projects (sites 39-41, respectively). The reference sites served as a point of comparison for assessment of effects from irrigation projects.

Eleven sites were sampled in the 10-mile reach of the San Juan River downstream from Navajo Dam (sites 1-11), which includes the Quality-Trout-Water reach. The reach exhibits characteristics common to tailwaters downstream from many reservoirs. Water temperatures are colder and subject to less seasonal fluctuation, turbidity is lower, and benthic-invertebrate density is higher compared to riverine habitats farther downstream from the reservoir (Holden and others, 1980). Several small, privately funded, direct-ditch irrigation projects also are operating adjacent to this reach of the San Juan River. Thus, although this reach is free from any influences related to return flows emanating from a DOI irrigation service area, the physical, chemical, and biological components of the river within this reach are different from other study sites, and these differences need to be taken into consideration when comparing data from sites within this reach with data from downstream sites.

The habitats sampled included the main stem of the San Juan River, backwater areas adjacent to the San Juan River, tributaries to the San Juan River, ponds, seeps, irrigation-delivery canals, irrigation-drainage canals, a stock tank, and ground water. The types of media sampled included water, bottom sediment beneath water bodies, soil from upland drainage areas, aquatic plants, aquatic invertebrates, amphibians, and fish. Semipermeable membrane devices (SPMD's) were used as a surrogate medium to sample both air and water in some instances. A wide variety of habitats and media were sampled to help determine the environmental pathway for accumulation of constituent concentrations.

Supplemental Sampling Sites

The BIA and its contractor (Keller-Bliesner Engineering) collected numerous water and biological samples from 1991 through 1995 in association with the NIIP Many of these samples were collected at sites that were within the San Juan River study area. Figure 4 is a map showing locations of sites where supplemental data were collected that were within the San Juan River area. Table 2 lists the site number, site name, irrigation project area or river reach, latitude and longitude, and habitat.

Sampling Procedures, Frequency, and Analyses

The frequency of sample collection and types of analyses conducted varied for water, bottom-sediment, soil, and biological samples. Selenium and trace-metal analyses were conducted on water, bottom sediment, soil, and biota. In addition, various samples were analyzed for major ions, organic compounds, stable isotopes, and physical properties. Thomas and others (1997) discussed sampling procedures, specific schedules for frequency of sample collection, and the types of analyses conducted.

Investigators tested hypotheses for statistical significance using two different kinds of statistical software. Hypotheses related to selenium concentrations in water and bottom sediment were tested using the nonparametric Kruskal-Wallis ANOVA (Analysis of Variance) software (SAS Institute, Inc., 1990, p. 1195-1210). Hypotheses related to selenium concentrations in biota were tested using the nonparametric Kruskal-Wallis ANOVA software known as Statistica 5.0 (StatSoft, Inc., 1994a, p. 1445-1469). The level of statistical significance was 5 percent, which means that a true hypothesis will be declared false 1 time in 20.

OCCURRENCE AND DISTRIBUTION OF SELENIUM IN WATER, BOTTOM SEDIMENT AND SOIL, AND BIOTA

Burau (1989, p. 42-47) stated that selenium occurs within all major compartments of the environment: land, water, biosphere, and the atmosphere. Selenium also is found in soils and geologic formations. In the presence of oxygen, selenium is soluble in water, and therefore is transferred from place to place dissolved in water It enters biological food webs through plant uptake and can be bioaccumulated by animals feeding on selenium-rich food items. It is released into the air by microorganisms and plants that form volatile selenium compounds. Volcanic activity releases selenium to the atmosphere. The burning of fossil fuels, especially coal, can also deliver large amounts of selenium to the atmosphere.

Water

Summary statistics and hypothesis tests were used to evaluate selenium concentration in water samples. Summary statistics describe the occurrence and distribution of selenium concentrations in water samples. Hypothesis tests help to evaluate the effect of irrigation, habitat, DOI project, and soil type on selenium concentrations.

Summary statistics of total-selenium and dissolved-selenium concentrations (table 3) in NIWQP and supplemental water samples, by site, show that total- and dissolved-selenium concentrations generally were similar and that sites with the greatest mean total- or dissolved-selenium concentrations were in three areas. In the Ojo Amarillo Canyon drainage of the NIIP, water samples from sites 31, 33, 35, and 49S contained mean dissolved-selenium concentrations ranging from 9 to 23 μg/L. In the Gallegos Canyon drainage of the NIIP, water samples from sites 27-30, 29S, 30S, and 32S contained mean dissolved-selenium concentrations ranging from 9 to 21 μg/L. At Hogback Project sites 44 and 47-49, all on the same drain and within 0.7 mile of each other, mean dissolved-selenium concentrations in water samples ranged from 9 to 15 μg/L.

Water samples from NIWQP and supplemental sites were grouped to evaluate DOI irrigation and habitat effects on selenium concentration. First, the water samples were identified by site and grouped into one of two categories: samples from sites located within or receiving drainage from DOI irrigation projects, or samples from sites located outside areas affected by DOI irrigation projects. Secondly, the water samples were subgrouped by habitat (table 4). Summary statistics by these groupings show that water samples from irrigation-affected sites generally had greater mean, median, and maximum dissolved-selenium concentrations than samples from unaffected sites (table 4). The mean dissolved-selenium concentration was 17 μg/L for water samples from irrigation-affected tributaries, whereas the concentration was 4 μg/L for water samples from San Juan River tributaries outside the area affected by irrigation (table 4). In water samples from seeps within irrigated land the mean dissolved-selenium concentration was 17 μg/L, but in samples from a seep outside the area affected by irrigation the concentration was 2 μg/L (table 4). Water samples from ponds within the DOI irrigation projects had a mean dissolved-selenium concentration of 6 μg/L, whereas samples from ponds outside the DOI irrigation projects had a mean dissolved-selenium concentration of 2 μg/L (table 4).

Habitats with the smallest mean concentrations of dissolved selenium in water had the same or similar concentrations for areas both affected and unaffected by DOI irrigation projects. Habitats having the smallest mean concentrations were the San Juan River (0.5 μg/L), backwater (0.5 μg/L), irrigation supply (0.6 μg/L), a well (0.5 μg/L), dug holes (2 μg/L), and the stock tank site (2 μg/L) (table 4). The San Juan River and backwater sites had the same mean selenium concentration for both areas affected and areas unaffected by DOI irrigation projects (table 4). The dissolved-selenium concentration in water samples from San Juan River sites affected by DOI irrigation projects was not significantly different from that in water samples from San Juan River sites unaffected by DOI irrigation.

Table 3.--Summary statistics for selenium concentration in water samples at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico

[µg/L, micrograms per liter; ft, foot; --, not applicable; <, less than; mi, mile; *, statistics calculated from one sample]

Site number (figs. 3 and 4)	Site name	Number of samples		Mean[1]		Minimum		Maximum	
		Selenium, total	Selenium, dissolved	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)
1	San Juan River 300 ft below dam near Archuleta	--	2	--	0.5	--	<1	--	<1
2	Pond on north bench San Juan River 0.6 mi below dam near Archuleta	--	2	--	0.5	--	<1	--	<1
3	Backwater south of San Juan River 0.9 mi below dam near Archuleta	--	3	--	0.5	--	<1	--	<1
5	Backwater south of San Juan River 3.1 mi below dam near Archuleta	--	2	--	0.5	--	<1	--	<1
7	Dug hole at Simon Canyon at San Juan River near Archuleta	--	2	--	0.5	--	<1	--	<1
8	Dug hole at Gobernador Wash at Highway 511 near Archuleta	--	2	--	0.5	--	<1	--	<1
9	Dug hole at Pump Canyon at Highway 173 near Archuleta	--	2	--	0.5	--	<1	--	<1
12	East Hammond Project pond near Blanco	--	3	--	0.5	--	<1	--	<1
13	Hammond Canal at Hammond Conservancy District near Blanco	--	1	--	0.5*	--	<1*	--	<1*
14	Hammond Canal above Bloomfield Refinery near Bloomfield	--	2	--	0.5	--	<1	--	<1
15	Hammond Canal below Bloomfield Refinery near Bloomfield	--	2	--	0.5	--	<1	--	<1
16	Hammond Canal 0.3 mi west of Highway 44 near Bloomfield	--	4	--	0.5	--	<1	--	<1

Table 3.--Summary statistics for selenium concentration in water samples at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico--Continued

Site number (figs. 3 and 4)	Site name	Number of samples		Mean[1]		Minimum		Maximum	
		Selenium, total	Selenium, dissolved	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)
17	East drain at west Hammond pond near Bloomfield	--	5	--	2	--	1	--	4
18	West drain at west Hammond pond near Bloomfield	--	3	--	3	--	3	--	4
19	Irrigation drain at manhole 800 ft above west Hammond pond near Bloomfield	--	2	--	1	--	1	--	1
20	Irrigation drain at manhole 500 ft above west Hammond pond near Bloomfield	--	4	--	3	--	3	--	3
21	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	--	5	--	4	--	2	--	5
22	West Hammond pond near Bloomfield	--	5	--	3	--	<1	--	6
23	Gallegos Canyon near Carson Trading Post	1	17	15*	6	15*	<1	15*	12
24	Dug hole at Gallegos Canyon near Carson Trading Post	--	2	--	6	--	3	--	10
25	NIIP irrigation-supply canal 0.2 mi south of Highway N3003 near Bloomfield	--	2	--	0.5	--	<1	--	<1
26	Center pivot sprinkler near Gallegos Canyon drainage middle pond near Farmington	--	1	--	0.5*	--	<1*	--	<1*
27	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	--	3	--	21	--	18	--	24
28	South seep to Gallegos Canyon drainage middle pond near Farmington	--	3	--	19	--	17	--	24
29	Gallegos Canyon drainage middle pond near Farmington	--	3	--	20	--	13	--	26

Table 3.--Summary statistics for selenium concentration in water samples at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico--Continued

Site number (figs. 3 and 4)	Site name	Number of samples		Mean[1]		Minimum		Maximum	
		Selenium, total	Selenium, dissolved	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)
30	Gallegos Canyon near Farmington	--	53	--	11	--	2	--	30
31	East seep to Ojo Amarillo Canyon drainage southwest pond near Farmington	--	2	--	14	--	7	--	22
32	Ojo Amarillo Canyon drainage north pond near Farmington	--	1	--	1*	--	1*	--	1*
33	Northeast seep to Ojo Amarillo Canyon drainage north pond near Farmington	--	2	--	9	--	9	--	9
34	Ojo Amarillo Canyon drainage southwest pond near Farmington	--	3	--	6	--	2	--	9
35	Ojo Amarillo Canyon near Fruitland	--	52	--	23	--	7	--	37
36	Fruitland irrigation drain 300 ft above wetland, near Fruitland	--	1	--	0.5*	--	<1*	--	<1*
37	Fruitland irrigation drain at wetland near Fruitland	--	3	--	0.5	--	<1	--	<1
38	Secondary channel of San Juan River near Kirtland	--	2	--	0.5	--	<1	--	<1
39	Pond at Cottonwood Spring near Newcomb	--	4	--	2	--	2	--	3
40	Stock tank at Cottonwood Spring near Newcomb	--	2	--	2	--	2	--	2
41	Seep at Cottonwood Spring near Newcomb	--	4	--	2	--	2	--	3
42	San Juan River backwater at Hogback Diversion Dam near Waterflow	--	2	--	0.5	--	<1	--	<1

Table 3.--Summary statistics for selenium concentration in water samples at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico--Continued

Site number (figs. 3 and 4)	Site name	Number of samples		Mean[1]		Minimum		Maximum	
		Selenium, total	Selenium, dissolved	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)
43	Pond draining Fruitland Irrigation Project at Hogback near Waterflow	--	2	--	0.5	--	<1	--	<1
44	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	--	4	--	12	--	10	--	14
45	Hogback irrigation-supply canal near Waterflow	--	2	--	0.5	--	<1	--	<1
46	Leaking well near Waterflow	--	1	--	0.5*	--	<1*	--	<1*
47	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	--	7	--	11	--	8	--	16
48	East hogback irrigation drain 0.2 mi above San Juan River near Waterflow	--	1	--	15*	--	15*	--	15*
49	East hogback irrigation drain 300 ft above San Juan River near Waterflow	--	3	--	9	--	7	--	11
50	Salt Creek at highway bridge near Shiprock	--	1	--	37*	--	37*	--	37*
51	Cudei irrigation canal at turnout from San Juan River near Cudei	--	4	--	0.8	--	<1	--	1
52	Cudei irrigation drain near Cudei	--	2	--	0.5	--	<1	--	<1
01S	San Juan River at Navajo Dam	12	12	0.7	0.5	<1	<1	<5	1
02S	San Juan River at hydro plant below Navajo Dam	12	12	0.5	0.5	<1	<1	<1	<1
05S	San Juan River at Archuleta Bridge	12	12	0.5	0.5	<1	<1	<1	<1

Table 3.--Summary statistics for selenium concentration in water samples at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico--Continued

Site number (figs. 3 and 4)	Site name	Number of samples		Mean[1]		Minimum		Maximum	
		Selenium, total	Selenium, dissolved	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)
06S	Gobernador Canyon	12	12	0.5	0.5	<1	<1	<1	<1
10S	San Juan River at Blanco Bridge	12	12	0.5	0.5	<1	<1	<1	1
19S	San Juan River at Bloomfield Bridge	24	24	0.5	0.5	<1	<1	<1	1
21S	Animas River at Aztec Bridge	24	24	0.5	0.6	<1	<1	<1	1
26S	San Juan River at Hammond Bridge	12	12	0.5	0.5	<1	<1	<1	<1
29S	Gallegos Canyon	11	11	8	9	1	2	22	20
30S	1-18 pond	11	11	11	11	2	2	20	19
32S	1-25 pond	11	11	11	9	<1	<1	25	22
34S	1-35 pond	22	22	3	3	<1	<1	13	12
37S	La Plata River at La Plata Bridge	12	12	2	1	<1	<1	4	4
38S	Animas River at Flora Vista Bridge	12	12	0.5	0.5	<1	<1	<1	1
40S	Animas River at Farmington-Miller Bridge	12	12	0.5	0.5	<1	<1	1	<1
43S	San Juan River at Highway 371 Bridge	12	12	0.7	0.5	<1	<1	<5	<1
44S	La Plata River at mouth	12	12	1	1	<1	<1	3	3
47S	Ojo Amarillo Pond	11	11	4	4	<1	<1	13	12
49S	Ojo Amarillo Canyon	10	10	20	21	9	9	33	32
54S	San Juan River at Fruitland Bridge (Kirtland)	12	12	0.6	0.6	<1	<1	1	<2

Table 3.--Summary statistics for selenium concentration in water samples at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico--Concluded

Site number (figs. 3 and 4)	Site name	Number of samples		Mean[1]		Minimum		Maximum	
		Selenium, total	Selenium, dissolved	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)	Selenium, total (µg/L)	Selenium, dissolved (µg/L)
58S	San Juan River above Hogback Diversion	12	12	0.5	0.5	<1	<1	1	1
59S	Chaco Wash	12	12	2	2	<1	<1	<10	4
63S	San Juan River at Shiprock Bridge	24	24	0.7	0.6	<1	<1	3	1
71S	Mancos River near Four Corners	10	10	7	6	1	<1	12	11

[1]Mean selenium concentrations were computed by replacing "less than" values with the midpoint between 0 and the less than value. For example, <1 was replaced by 0.5 to compute mean values.

Table 4.--Summary statistics for dissolved-selenium concentration in water samples, within and outside Department of the Interior (DOI) irrigation project drainage, by habitat at National Irrigation Water Quality Program (NIWQP) sampling sites and supplemental sampling sites, San Juan River area, New Mexico

[Concentrations are in micrograms per liter; <, less than; *, statistics calculated from one sample]

Habitat	Number of samples	Mean[1]	Median	Minimum - maximum
Sites located within or receiving drainage from DOI irrigation projects				
San Juan River (sites 9S-14S, 17S-20S, 23S-26S, 28S, 31S, 35S, 36S, 39S, 41S-43S, 45S, 48S, 50S, 51S, 53S-58S, 60S-67S)	108	0.5	<1	<1 - 1
San Juan River tributary (Gallegos Canyon, Ojo Amarillo Canyon, Salt Creek; sites 30, 35, 50, 29S, 49S)	127	17	17	2 - 37
Backwater (sites 38, 42)	4	0.5	<1	<1 - <1
Pond (sites 12, 22, 29, 32, 34, 43, 22S, 27S, 30S, 32S-34S, 46S, 47S)	72	6	3	<1 - 26
Irrigation supply (sites 13-16, 25, 26, 45, 51)	18	0.6	<1	<1 1
Irrigation drainage (sites 17-21, 36, 37, 44, 47-49, 52)	40	6	3	<1 - 16
Seep (sites 27, 28, 31, 33)	10	17	17.5	7 24
Well (site 46)	1	0.5*	<1*	<1* - <1*
Sites located outside area affected by DOI irrigation projects				
San Juan River (sites 1, 4, 6, 1S-5S, 7S, 8S)	38	0.5	<1	<1 - 1
San Juan River tributary (Gallegos Canyon, Gobernador Canyon; sites 23, 6S)	29	4	1	<1 - 12
Backwater (sites 3, 5)	5	0.5	<1	<1 - <1
Pond (sites 2, 39)	6	2	2	<1 - 3
Seep (site 41)	4	2	2.5	2 - 3
Dug hole (sites 7-9, 24)	8	2	<1	<1 - 10
Stock tank (site 40)	2	2	2	2 - 2

[1]Mean selenium concentrations were computed by replacing "less than" values with the midpoint between 0 and the less than value. For example, <1 was replaced by 0.5 to compute mean values.

Summary statistics (table 5) show differences for data grouped by river reach, irrigation project, or soil type. Dissolved-selenium concentrations were greater for water samples from within the irrigation projects than for samples from the river reaches. Water samples from the NIIP and Hogback Irrigation Projects had greater mean dissolved-selenium concentrations (14 and 11 μg/L) than samples from the Hammond (2.5 μg/L), Fruitland (0.5 μg/L), or Cudei (0.5 μg/L) Irrigation Projects. Water samples from sites located on Cretaceous soils contained greater mean dissolved-selenium concentrations (12 μg/L) than those from sites located on non-Cretaceous soils (4.1 μg/L).

Hypothesis tests performed on data grouped by sites affected or unaffected by irrigation projects showed significantly greater selenium concentrations in samples from tributaries affected by irrigation than in samples from unaffected tributaries (tables 4 and 6). Sample size prohibited hypothesis testing for some subgroups. Subgroups with less than 15 observations were not considered to fairly represent the population and were not used in hypothesis testing.

Hypothesis tests performed on data grouped by river reaches A-G (fig. 1 and tables 1-2) showed only one significant difference (table 6). River reaches B, D, and G were not included in the hypothesis testing because the number of water samples was less than 15 (table 5). The hypothesis was that water samples from these reaches have equal dissolved-selenium concentrations. Concentrations in water samples from river reach A were significantly less than those in water samples from river reach E (table 6) based on the Kruskal-Wallis test. Mean statistics indicate only a small difference between reach A (0.5 μg/L) and reach E (0.6 μg/L) (table 5).

Results of the hypothesis tests performed on data grouped by irrigation project (fig. 1 and tables 1-2) were based on the hypothesis that dissolved-selenium concentrations in water samples from the irrigation projects and those in water samples from reference sites were equal. Results showed that irrigation-drainage water at both the NIIP and Hogback Projects had significantly greater selenium concentrations than water from reference sites (table 6). Dissolved-selenium concentrations in water samples from seeps, ponds, and drains of the NIIP and Hogback Projects were significantly greater, at the 5-percent level, than those in water samples from a reference seep, reference ponds, and reference tributaries (tables 5 and 6), suggesting that irrigation significantly increases dissolved-selenium concentrations in seeps, ponds, and drains of the NIIP and Hogback Projects. Sites at the Hogback Project were not very well distributed throughout the project, but were concentrated on the same drain within 0.7 mile of each other. The increased concentrations at the NIIP and Hogback Projects probably are due to seleniferous soil conditions at these project sites, discussed in more detail later in this report. Dissolved-selenium concentrations in water samples from the Hammond Project pond and drains were not significantly different from those in water samples from a reference seep, reference ponds, and reference tributaries (tables 5 and 6). Although the number of samples was less than 15 and precluded hypothesis testing of data for the Fruitland and Cudei drains, dissolved-selenium concentrations in water samples from the Fruitland and Cudei drains were less than 1 μg/L (table 5) in all samples collected, which probably indicates no irrigation effects at the Fruitland and Cudei Projects.

Hypothesis tests performed on data grouped by Cretaceous and non-Cretaceous soils showed that water samples from sites located on Cretaceous soils contained significantly greater dissolved-selenium concentrations than samples from sites located on non-Cretaceous soils (table 6). The mean and median dissolved-selenium concentrations in water samples from Cretaceous soils were 12 and 9 μg/L, respectively, whereas in samples from non-Cretaceous soils they were 4.1 and less than 1 μg/L, respectively. The median values are similar to those computed by Nolan and Clark (1997) for water samples from areas with Cretaceous soils (14 μg/L) and non-Cretaceous soils (1 μg/L) in the Western United States.

The preceding results imply that irrigation significantly increases selenium concentration in water samples from DOI irrigation project sites developed on selenium-rich sediments. In the San Juan River study area water samples from sites with Cretaceous soils had significantly greater selenium concentration than samples from sites with non-Cretaceous soils. The Hogback Project is developed on Mancos Shale (figs. 1 and 2), a Cretaceous formation, and the NIIP is developed partly on Cretaceous formations and partly on non-Cretaceous formations (figs. 1 and 2). In contrast, the Cudei, Fruitland, and Hammond Projects are developed wholly on non-Cretaceous formations (alluvium or the Nacimiento Formation) (figs. 1 and 2). The mean selenium concentrations in water samples from irrigation-drainage sites on the Hogback and NIIP

Table 5.--Summary statistics for dissolved-selenium concentration in water samples by river reach, irrigation project, or soil at National Irrigation Water Quality Program (NIWQP) and supplemental sampling sites, San Juan River area, New Mexico

[Concentrations are in micrograms per liter; <, less than; --, not applicable]

Site	Number of samples	Mean[1]	Median	Minimum maximum
River reach (tables 1, 2, figs 3, 4)				
A (sites 1, 4, 6, 1S-5S, 7S, 8S)	38	0.5	<1	<1 - 1
B (sites 10, 11, 9S-12S)	12	0.5	<1	<1 - 1
C (sites 13S, 14S, 17S-20S, 23S-26S, 28S, 31S, 35S)	36	0.5	<1	<1 - 1
D (sites 36S, 39S, 41S-43S)	12	0.5	<1	<1 - <1
E (sites 45S, 48S, 50S, 51S, 53S-58S)	24	0.6	<1	<1 - 1
F (sites 60S-65S)	24	0.6	<1	<1 - 1
G (sites 66S-67S)	0	--	--	--
Irrigation project (tables 1, 2; figs. 3, 4)				
Hammond				
Ponds, drains (sites 12, 17-22)	27	2.5	3	<1 - 6
Navajo Indian Irrigation Project				
Seeps, ponds, tributaries (sites 27-35, 22S, 27S, 29S, 30S, 32S-34S, 46S, 47S, 49S)	198	14	12	<1 - 37
Fruitland				
Drains (sites 36 and 37)	4	0.5	<1	<1 - <1
Hogback				
Drains (sites 44, 47-49)	15	11	10	7 16
Cudei				
Drain (site 52)	2	0.5	<1	<1 <1
Reference				
Seeps, ponds, tributaries (sites 2, 23, 39, 41, 6S)	39	3	2	<1 - 12
Soil				
Non-Cretaceous	420	4 1	<1	<1 - 32
Cretaceous	131	12	9	<1 37

[1]Mean selenium concentrations were computed by replacing "less than" values with the midpoint between 0 and the less than value. For example, <1 was replaced by 0.5 to compute mean values.

Table 6.--Results of hypothesis tests related to selenium concentration in water samples

[River reaches B, D, and G and the Fruitland and Cudei Projects were not tested because the number of samples was less than 15. >, greater than; <, less than; NIIP, Navajo Indian Irrigation Project]

Hypothesis	Result
Dissolved-selenium concentrations in water samples from areas affected by irrigation are equal to dissolved-selenium concentrations in water samples from areas unaffected by irrigation.	•San Juan River within irrigation areas = San Juan River outside irrigation areas •San Juan River tributaries within irrigation areas > San Juan tributaries outside irrigation areas
Dissolved-selenium concentrations in water samples from river reaches A, C, E, and F are equal.	•A = C; •A < E; •A = F; •C = E; •C = F; •E = F
Dissolved-selenium concentrations in water samples from seeps, ponds, and drains of the Hammond, NIIP, Fruitland, Hogback, and Cudei Projects are equal to dissolved-selenium concentrations in reference samples.	•Hammond = reference •NIIP > reference •Hogback > reference
Dissolved-selenium concentrations in water samples from non-Cretaceous soils are equal to dissolved-selenium concentrations in water samples from Cretaceous soils	•Non-Cretaceous soils < Cretaceous soils

were about 10 times greater than those in samples from sites on the Hammond, Fruitland, and Cudei Projects (table 5). The mean selenium concentrations at the Hogback and NIIP were 11 and 14 μg/L, and at the Hammond, Fruitland and Cudei Projects were 2.5, 0.5, and 0.5 μg/L, respectively (table 5).

Hypothesis tests imply that DOI irrigation drainage does not significantly increase the selenium concentration in the San Juan River Elevated selenium concentrations in water samples are restricted to sites having a small quantity of flow and because of dilution do not appear to have much effect on concentrations in the San Juan River.

Bottom Sediment and Soil

As was done for water samples, bottom-sediment and soil samples were grouped to evaluate irrigation and habitat effects (table 7) on selenium concentrations in the study area. Bottom-sediment samples also were grouped to evaluate differences in selenium concentrations among river reach A, project areas, reference sites, and Cretaceous and non-Cretaceous soil types (table 8).

Bottom-sediment samples from the stock tank at the Cottonwood Spring reference site had the greatest mean selenium concentration (8.2 μg/g) (table 7). Bottom-sediment samples were observed to be composed of detritus from algae growing in the stock tank and demonstrate the ability of algal plants to bioaccumulate selenium. Bottom-sediment samples from irrigation-drainage ditches had a mean total-selenium concentration of 5.2 μg/g (table 7). When sites affected by irrigation drainage were grouped by irrigation project, bottom-sediment samples from the Hogback Project drains (table 8) had the greatest mean total-selenium concentration (9.5 μg/g). Bottom-sediment samples representing irrigation drainage from the other project areas had mean total-selenium concentrations ranging from 0.4 to 1 3 μg/g (table 8).

Table 7.--Summary statistics of total-selenium concentration in bottom-sediment and soil samples, within and outside Department of the Interior (DOI) irrigation project drainage, by habitat at National Irrigation Water Quality Program (NIWQP) sampling sites, San Juan River area, New Mexico

[Concentrations are in micrograms per gram; <, less than; *, statistics calculated from one sample]

Habitat	Number of samples	Mean[1]	Median	Minimum	Maximum
Sites located within or receiving drainage from DOI irrigation projects					
San Juan River tributary (Gallegos Canyon, Ojo Amarillo Canyon bottom sediment)	4	0.2	0.1	<0.1	0.7
Backwater (bottom sediment)	4	0.8	0.8	<0.1	0.1
Pond (bottom sediment)	10	1.1	1.2	0.1	2.6
Irrigation supply (bottom sediment)	8	0.3	0.3	<0.1	0.4
Irrigation drainage (bottom sediment)	17	5.2	1.8	0.2	23
Seep (bottom sediment)	2	3.4	3.4	2.5	4.4
Hogback Project (soil)	7	1.9	1.5	0.4	3.6
Hammond Project (soil)	13	0.08	<0.1	<0.1	0.2
Sites located outside area affected by DOI irrigation projects					
San Juan River (bottom sediment)	2	0.1	0.1	0.1	0.1
San Juan River tributary (Gallegos Canyon, bottom sediment)	1	0.05*	<0.1*	<0.1*	<0.1*
Dug hole (bottom sediment)	3	0.05	<0.1	<0.1	<0.1
Seep (bottom sediment)	1	3.2*	3.2*	3.2*	3.2*
Stock tank (bottom sediment)	2	8.2	8.2	8.1	8.4
Backwater (bottom sediment)	5	0.7	0.6	<0.1	1.2
Pond (bottom sediment)	5	1.2	0.7	0.4	2.7

[1]Mean concentrations were computed by replacing "less than" values with the midpoint between 0 and the less than value. For example, <0.1 μg/g was replaced by 0.05 μg/g to compute mean values.

Table 8.--Summary statistics for total-selenium concentration in bottom-sediment samples by river reach, irrigation project, or soil at National Irrigation Water Quality Program (NIWQP) sampling sites, San Juan River area, New Mexico

[Concentrations are in micrograms per gram; <, less than]

Site	Number of samples	Mean[1]	Median	Minimum - maximum
	River reach (tables 1, 2, figs. 3, 4)			
A (sites 1, 4, 6)	2	0.1	0.1	0.1 - 0.1
	Irrigation project (tables 1, 2; figs. 3, 4)			
Hammond Ponds, drains (sites 12, 17-22)	9	0.8	0.4	0.1 - 2.6
Navajo Indian Irrigation Project Seeps, ponds, tributaries (sites 27-35)	9	1.3	0.7	<0.1 - 4.4
Fruitland Drains (sites 36, 37)	2	0.4	0.4	0.4 - 0.4
Hogback Drains (sites 44, 47-49)	9	9.5	8.1	1.8 - 23
Cudei Drain (site 52)	2	0.5	0.5	0.3 - 0.7
Reference Seeps, ponds, tributaries (sites 2, 23, 39, 41)	7	1.3	0.7	<0.1 - 3.2
	Soil			
Non-Cretaceous	54	0.6	0.15	<0.1 - 4.4
Cretaceous	27	4.6	2.2	<0.1 - 23

[1]Mean selenium concentrations were computed by replacing "less than" values with the midpoint between 0 and the less than value. For example, <0.1 was replaced by 0.05 to compute mean values.

Bottom-sediment samples from seeps, tributaries, ponds, and backwaters had similar total-selenium concentrations regardless of their locations within or outside areas influenced by irrigated agriculture (table 7). The mean total-selenium concentration in bottom-sediment samples was 3.4 µg/g for seeps and 0.2 µg/g for tributaries within or receiving drainage from the DOI irrigation projects, and was 3.2 µg/g for a seep and 0.5 µg/g for a tributary not affected by DOI irrigation projects (table 7). The mean total-selenium concentration in bottom-sediment samples from ponds within DOI irrigation projects was 1.1 µg/g and in samples from a pond outside DOI irrigation projects was 1.2 µg/g (table 7). Mean total-selenium concentrations in bottom-sediment samples were 0.8 and 0.7 µg/g, respectively, for backwater sites affected and unaffected by irrigation drainage and 0.3 µg/g for irrigation-supply sites.

Hogback Project soils had greater selenium concentrations than Hammond Project soils (table 7). Near-surface samples from the three irrigated sites at the Hogback Project contained selenium concentrations of 2.9, 2.6, and 1.5 µg/g, and the top sample from the nonirrigated site was 3.6 µg/g (Thomas and others, 1997, p. 119). Selenium concentrations at the Hammond Project ranged from less than 0.1 to 0.2 µg/g (Thomas and others, 1997, p. 118-119). Hogback Project soils are developed on the Cretaceous Mancos Shale, and Hammond Project soils are developed on the Tertiary Nacimiento Formation.

Hypothesis tests were performed on data grouped by Cretaceous and non-Cretaceous soils. Bottom-sediment and soil samples from areas underlain by Cretaceous sediment had significantly greater total-selenium concentrations than those with non-Cretaceous soils. The mean and median total-selenium concentrations in samples from areas with Cretaceous soils were 4.6 and 2.2 µg/g, respectively. The mean and median total-selenium concentrations in samples from areas with non-Cretaceous soils were 0.6 and 0.15 µg/g, respectively.

Biota

Selenium concentrations in biological samples were evaluated by a number of variables. These included (1) media sampled (emergent and submergent plants, nektonic and benthic invertebrates, omnivore/herbivore and carnivore fish, terrestrial and aquatic amphibians); (2) habitat (San Juan River main-stem reaches and backwaters, tributary main-stem reaches, irrigation-delivery or -drainage canals, and ponds); (3) irrigation project or reference area (table 1); and (4) underlying soil type (non-Cretaceous or Cretaceous).

No species was available at all sites, sites were sampled unequally, and replicate aquatic habitats were not found on each irrigation project or underlain by each soil type. In particular, there were too few biological samples from irrigation delivery canal habitats to make valid comparisons. The conditions introduced by species availability and the study design complicated the evaluation of selenium variability in biota. Therefore, investigators used an approach similar to that of Seiler (1995), Seiler and Skorupa (1995), and Nolan and Clark (1997) to determine the influence of selected physiographic variables on selenium concentrations in biological samples collected in the San Juan River study area. The approach involved the use of graphical techniques as well as nonparametric statistical tests applied to selenium data. These authors examined the influence of similar variables (habitat, irrigation history, and soil) on surface-water selenium concentrations and selenium accumulation in wildlife tissue. They determined that the source of the soil had the greatest effect on selenium variability in surface water.

For statistical analyses in this study, the few concentrations in biological samples (about 3 percent of 329 analyses) that contained selenium concentrations below the analytical reporting limit were replaced with values one-half the analytical reporting limit. Statistical hypotheses related to selenium concentrations in biota by physiographic variables were tested using the nonparametric Kruskal-Wallis ANOVA test (StatSoft, Inc., 1994a, p. 1445-1469). The geometric-mean selenium concentration provided a measurement of the central tendency that is resistant to the effects of outliers and was calculated using data converted to their natural logarithms.

Selenium concentrations in aquatic vegetation ranged from less than 0.1 to 20.0 µg/g, dry weight (table 9). Selenium concentrations in submergent species were significantly greater than those in emergent species from the same site. The greatest geometric-mean concentrations were found in plants collected from site 39, a reference pond, and site 49, the east hogback irrigation drain (table 9). Only plant samples from irrigation-drain and pond habitats were sampled sufficiently to make a valid comparison between underlying soil types. Selenium concentrations were greater in all plants collected from

Table 9.--Geometric mean and range of selenium concentrations in aquatic vegetation samples by type, habitat, and site, San Juan River area, New Mexico, 1993-94

[N, number of samples analyzed; Gmean, geometric mean; min, minimum concentration detected; max, maximum concentration detected; µg/g, dry wt, micrograms per gram, dry weight; <, less than; --, no data. Not all plant samples were classified as submergent or emergent (for example, duckweed). *, statistics calculated from one sample]

	All plants			Submergent plants[1]		Emergent plants[2]	
Habitat and site number (fig. 3; table 1)	N	Gmean (µg/g, dry wt)	Min - max (µg/g, dry wt)	N	Gmean (µg/g, dry wt)	N	Gmean (µg/g, dry wt)
Study total	70	0.90	<0.1 - 20.0	44	1.34	22	0.67
San Juan River	11	1 12	<0.2 - 3.2	8	1.56	2	0.20
Site 4	3	1.84	0.6 - 2.6	2	1.62	--	--
Site 6	3	0.75	<0.2 - 3.2	2	2.04	1	0.10*
Site 10	2	1.26	0.9 - 1.7	2	1.26	--	--
Site 11	3	0.94	0.4 - 2.7	2	1.43	1	0.40*
San Juan River backwater	12	0.85	<0.2 - 2.4	9	1.05	3	0.46
Site 3	4	0.93	0.4 - 1.4	3	1.23	1	0.40*
Site 5	5	0.92	<0.2 - 2.4	3	1.40	2	0.49
Site 38	2	0.50	0.5 - 0.5	2	0.50	--	--
Site 42	1	1.20*	--	1	1.20*	--	--
Irrigation delivery	3	0.64	0.6 - 0.7	2	0.62	--	--
Site 51	3	0.64	0.6 - 0.7	2	0.62	--	--
Irrigation drainage	14	0.90	<0.2 20.0	8	1.21	5	0.30
Site 37	6	0.40	<0.2 - 1.0	4	0.61	2	0.17
Site 49	5	5.23	0.9 20.0	2	10.73	2	1.30
Site 52	3	0.25	<0.1 1.0	2	0.55	1	<0.20*
Tributary rivers	7	1.33	0.4 4.0	5	1.79	2	0.63
Site 30	4	0.68	0.4 1.0	2	0.72	2	0.63
Site 35	3	3.27	2.5 - 4.0	3	3.27	--	--
Ponds	24	0.79	<0.2 - 20.0	12	1.58	10	0.39
Site 2	5	1.12	0.6 - 2.6	3	1.09	2	1 16
Site 12	2	<0.2	<0.2 - <0.2	--	--	2	<0.2
Site 22	5	0.83	0.2 - 1.8	3	1 12	2	2.75
Site 29	2	1.93	1 7 - 2.2	1	2.20*	1	1 70
Site 34	1	2.20*	--	1	2.20*	--	--
Site 39	3	8.28	4.3 - 20.0	3	8.28	--	
Site 43	4	0.19	<0.2 2.6	1	<0.2*	3	0.30

[1] Includes algae, coontail, and other submergent plants.
[2] Includes cattails and bullrushes.

irrigation-drain and pond habitats underlain by Cretaceous soils than in plants from similar sites underlain by non-Cretaceous soils (fig. 5).

Selenium concentrations in aquatic invertebrates ranged from less than 0.4 to 24.0 µg/g (table 10). Selenium concentrations in nektonic invertebrates were not significantly different from concentrations in benthic invertebrates, although geometric-mean selenium concentrations in nektonic invertebrates generally were greater than those in benthic invertebrates, especially from pond habitats (table 10). The three greatest geometric-mean selenium concentrations in invertebrates were from site 35, the Ojo Amarillo Canyon; site 29, a pond on the NIIP; and site 49, the east hogback irrigation drain (table 10). Selenium concentrations in invertebrates collected from irrigation drains and ponds underlain by Cretaceous soils were significantly greater than those in invertebrates collected from similar habitats underlain by non-Cretaceous soils (fig. 5).

Selenium concentrations in whole fish ranged from 0.3 to 24.0 µg/g (table 11). Selenium concentrations in carnivorous species were not significantly different from those in omnivorous or herbivorous species. The highest geometric-mean selenium concentration in fish was from site 49, the east hogback irrigation drain. Because a large variety of fish species were collected within the whole-fish group, finding a common species for statistical testing was difficult. Only mosquitofish were collected from irrigation drains, but they were insufficient in numbers to be statistically tested by soil type. Selenium concentrations in two mosquitofish samples from the east hogback drain (mean = 23 µg/g) appeared different from the one mosquitofish sample from the Fruitland Project drain (1.4 µg/g). The east hogback drain is underlain by Cretaceous soils and the Fruitland Project drain is underlain by non-Cretaceous soils.

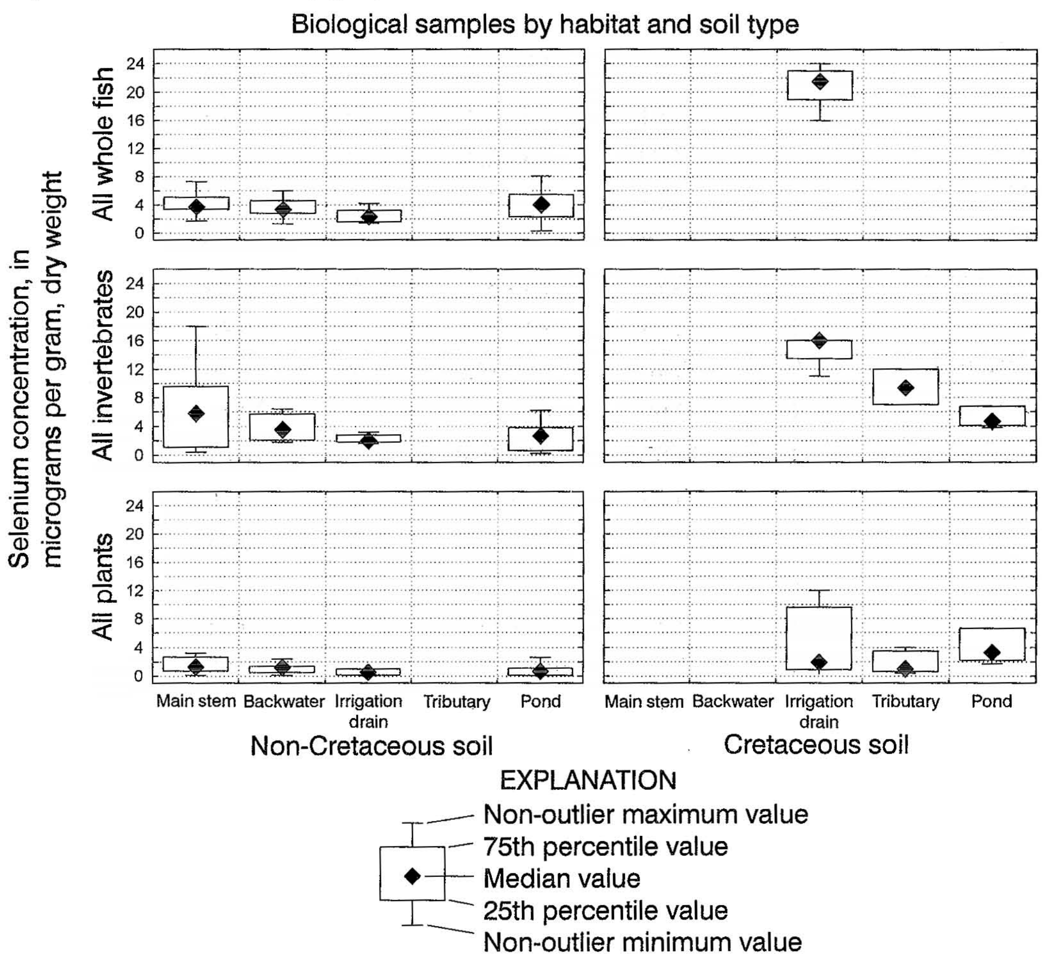


Figure 5.--Effects of habitat and soil on selenium concentrations in all plants, invertebrates, and whole fish collected in the San Juan River area, New Mexico, 1993-94. An explanation of non-outlier maximum and minimum values is given in StatSoft, Inc., 1994b, p. GRA-2390.

Table 10.--Geometric mean and range of selenium concentrations in aquatic invertebrate samples by type, habitat, and site, San Juan River area, New Mexico, 1993-94

[N, number of samples analyzed; Gmean, geometric mean; min, minimum concentration detected, max, maximum concentration detected, µg/g, dry wt, micrograms per gram, dry weight; --, no data; <, less than, *, statistics calculated from one sample]

Habitat and site number (fig. 3; table 1)	All aquatic invertebrates			Nektonic invertebrates[1]		Benthic invertebrates[2]	
	N	Gmean (µg/g, dry wt)	Min - max (µg/g, dry wt)	N	Gmean (µg/g, dry wt)	N	Gmean (µg/g, dry wt)
Study total	62	3.03	<0.4 - 24.0	42	3.64	20	1.94
San Juan River	12	3.51	0.4 - 18.0	4	2.76	8	3.95
Site 4	5	4.11	0.6 - 18.0	1	7.40*	4	3.55
Site 6	3	2.50	0.5 - 6.9	1	4.20*	2	1 93
Site 10	2	6.86	4.7 - 10.0	1	4.70*	1	10.0
Site 11	2	2.00	0.4 - 10.0	1	0.40*	1	10.0
San Juan River backwater	10	3.37	1.8 6.4	8	3.42	2	1.80
Site 3	4	3.51	1.8 6.4	2	3.84	2	1.80
Site 5	3	2.30	1.8 - 3.2	3	2.30	--	--
Site 38	2	4.28	3.9 - 4.7	2	4.28	--	--
Site 42	1	5.70*	--	1	5.70*	--	--
Irrigation delivery	3	3.94	3.4 - 5.3	3	3.94	--	--
Site 51	3	3.94	3.4 - 5.3	3	3.94	--	--
Irrigation drainage	9	5.10	1.6 - 16.0	7	5.39	2	4.20
Site 37	4	2.00	1.6 - 2.8	3	2.16	1	1.60
Site 49	4	14.57	11 - 16.0	3	16.0	1	11.0
Site 52	1	3.20*	--	1	3.20*	--	--
Tributary rivers	3	9.24	7.0 - 12.0	3	9.24	--	--
Site 30	--	--	--	--	--	--	--
Site 35	3	9.24	7.0 - 12.0	3	9.24	--	--
Ponds	25	1.89	<0.4 - 24.0	17	2.85	8	0.80
Site 2	6	1.21	<0.4 - 4.0	4	1.68	2	0.63
Site 12	5	0.55	0.3 - 1.0	3	0.67	2	0.41
Site 22	5	2.84	0.7 - 6.2	3	0.17	2	1.00
Site 29	1	24.00*	--	1	24.0*	--	--
Site 34	2	5.28	4.1 - 6.81	2	5.28	--	--
Site 39	2	4.23	3.8 - 4.7	2	4.23	--	--
Site 43	4	2.24	0.9 - 3.8	2	3.20	2	1.57

[1]Includes odonates, diving beetles, whirligigs, backswimmers, midges, and other nektonic invertebrates.
[2]Includes snails, crayfish, annelids, oligiocheates, and other benthic invertebrates.

Table 11.--Geometric mean and range of selenium concentrations in whole-fish samples by type, habitat, and site, San Juan River area, New Mexico, 1993-94

[N, number of samples analyzed; Gmean, geometric mean; min, minimum concentration detected, max, maximum concentration detected; µg/g, dry wt, micrograms per gram, dry weight; --, no data; *, statistics calculated from one sample]

	All fish combined			Omnivore-herbivore[1]		Carnivore-predator[2]	
Habitat and site number (fig. 3; table 1)	N	Gmean (µg/g, dry wt)	Min - max (µg/g, dry wt)	N	Gmean (µg/g, dry wt)	N	Gmean (µg/g, dry wt)
Study total	134	3.84	0.3 - 24.0	31	3.09	139	3.67
San Juan River	73	4.03	1.7 - 9.6	1	3.40*	104	3.55
Site 4	23	3.26	1.7 - 6.9	--	--	33	2.82
Site 6	11	3.91	2.4 - 7.8	1	3.40*	14	3.54
Site 10	19	4.52	3.1 - 8.7	--	--	28	3.83
Site 11	20	4.71	2.5 - 9.6	--	--	29	4.31
San Juan River backwater	33	3.49	1.3 - 7 9	16	3.02	22	3.76
Site 3	8	2.72	1.3 - 4.6	7	2.63	1	3.40*
Site 5	16	3.80	2.4 - 5.2	4	3.45	18	3.56
Site 38	5	3.15	1.8 - 5.5	4	3.34	--	--
Site 42	4	4.69	3.1 - 7 9	1	3.10*	3	5.39
Irrigation delivery	4	4.24	2.3 - 6.0	2	3.59	2	5.59
Site 51	4	4.24	2.3 - 6.0	2	3.59	2	5.59
Irrigation drainage	14	5.00	1.4 - 24.0	10	4.52	4	6.42
Site 37	7	2.07	1.4 - 3.5	6	2.21	1	1.40*
Site 49	5	20.76	16.0 - 24.0	3	19.39	2	23.0
Site 52	2	3.11	2.3 - 4.2	1	4.20*	1	2.30*
Tributary rivers	--	--	--	--	--	--	--
Site 30	--	--	--	--	--	--	--
Site 35	--	--	--	--	--	--	--
Ponds	9	2.27	0.3 - 8.1	2	0.46	7	3.59
Site 2	--	--	--	--	--	--	--
Site 12	3	0.50	0.3 - 0.7	2	0.46	1	0.60*
Site 22	2	6.49	5.2 - 8.1	--	--	2	6.46
Site 29	--	--	--	--	--	--	--
Site 34	--	--	--	--	--	--	--
Site 39	--	--	--	--	--	--	--
Site 43	4	4.18	3.4 - 5.5	--	--	4	4.18

[1]Includes flannelmouth sucker, carp, long-nosed dace, fathead minnows, and other omnivorous or herbivorous fish.

[2]Includes rainbow trout, brown trout, and mosquitofish.

The sediments of each river reach are a mixture of Cretaceous and non-Cretaceous soils. They are likely well leached of selenium and are identified (fig. 2, Keetch, 1980) as overlying non-Cretaceous soils. Several fish (trout, suckers, carp, and minnows) were evaluated by river reach designation (table 1) to determine whether any particular reach contained fish with elevated selenium concentrations compared with the same fish in other reaches. Trout (rainbow trout and brown trout) and common carp were collected only from selected river reaches. Trout are found only in the upper reaches of the Navajo Reservoir tailwaters, which support their habitat requirements such as cold water temperatures. Selenium concentrations in trout were not significantly different among reaches A, B, and C (fig. 6). Selenium concentrations in carp also were not significantly different by river reach (fig. 6). Suckers (bluehead and flannelmouth suckers combined) and "minnows" (all small fish combined: flathead minnows, speckled dace, red shiners, banded killifish, western mosquitofish, and composite samples of mixed species of small fish) were available at each river reach, and selenium concentrations in suckers and minnows were significantly different by river reach. Minnows from reach C contained the highest median selenium concentrations compared with minnows from

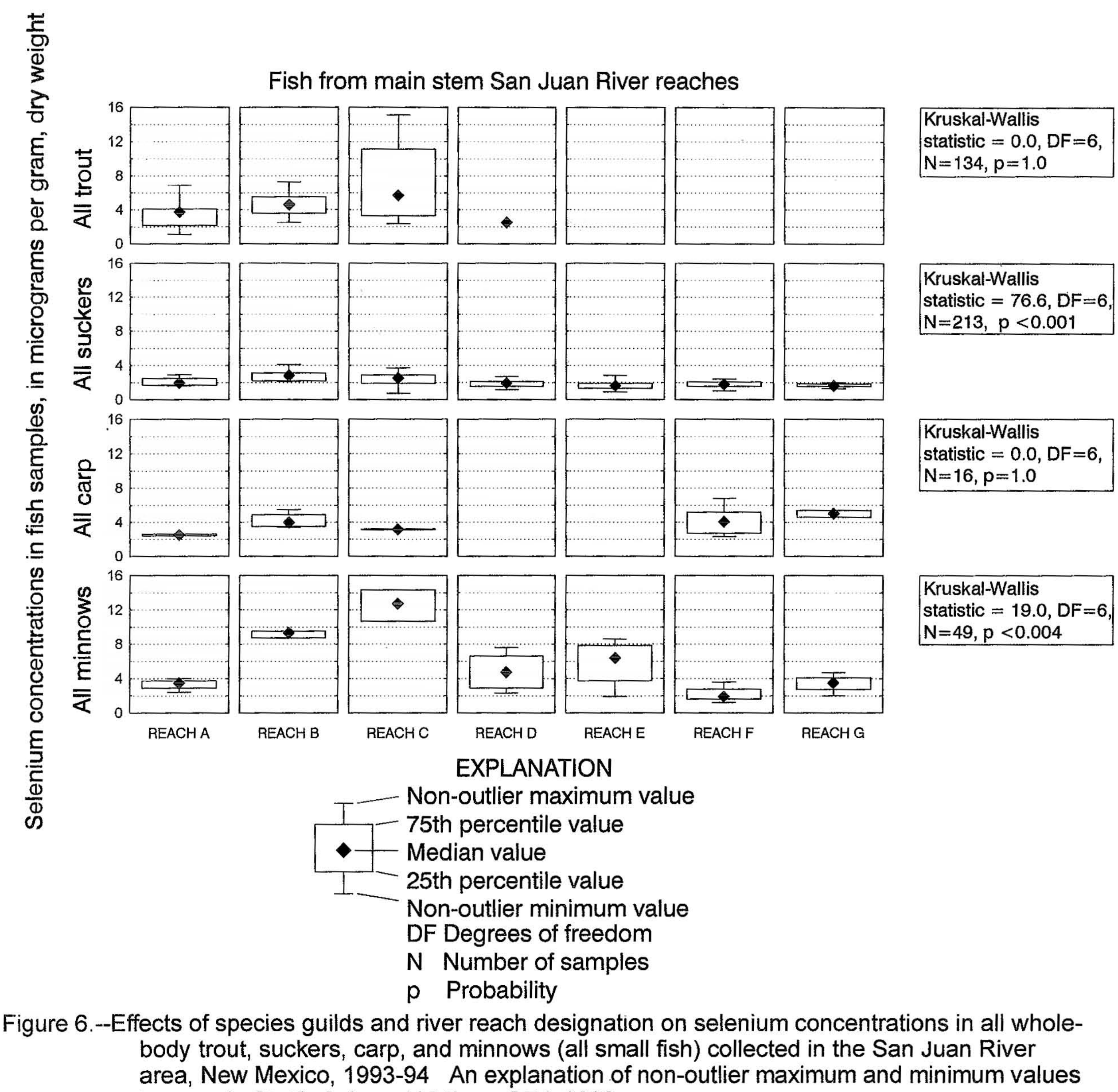


Figure 6.--Effects of species guilds and river reach designation on selenium concentrations in all whole-body trout, suckers, carp, and minnows (all small fish) collected in the San Juan River area, New Mexico, 1993-94 An explanation of non-outlier maximum and minimum values is given in StatSoft, Inc., 1994b, p GRA-2390

downstream river reaches (fig. 6). Suckers from reaches B and C contained higher median selenium concentrations than suckers from downstream reaches (fig. 6). Two possible factors might explain the increased selenium concentrations in suckers and minnows from upstream reaches. In the area of reaches B and C, nutrient-rich water is discharged from Navajo Reservoir and begins to warm, supporting a unique and rich diversity of plants and invertebrates compared with the downstream reaches (San Juan River Recovery Implementation Program, 1994, Jacobi and others, 1997). Also, organic matter (one potential measure of productivity) and selenium contents were higher in the sediments from these upstream reaches than in sediments from the downstream main-stem reaches.

Selenium concentrations in amphibians ranged from 0.6 to 20.3 µg/g, dry weight (table 12). Selenium concentrations in terrestrial species were not significantly greater than in aquatic species. The greatest geometric-mean selenium concentrations were in a leopard frog sample from site 49, the east hogback irrigation drain, and in toad samples from site 35, the Ojo Amarillo Canyon (table 12). Amphibians were sampled too infrequently to meaningfully compare habitats, irrigation projects, and soil types.

To evaluate further the influence of habitat, irrigation project, and soil type on the variability of selenium concentrations in biota, only those species that were common to most habitats, irrigation projects, and soil types were selected (algae, odonates (both damselfly and dragonfly nymphs combined), and mosquitofish) (figs. 7-9). Although the median concentrations varied, overall selenium concentrations in algae, odonates, and mosquitofish were not significantly different when compared by habitats. Compared to soil types, habitats had minor, subtle influences on the accumulation of selenium in biota in the San Juan River area. Selenium concentrations in algae, but not odonates or mosquitofish, were significantly different by irrigation project. Selenium concentrations were highest in algae from the Hogback Project and the reference sites (fig. 7). The variable having the most significant differences on selenium concentrations in biota was underlying soil type (figs. 7-9).

Although selenium concentrations in algae from the Hogback Project and the reference sites were significantly greater than in algae from the other irrigation project areas, investigators attribute this difference to the Cretaceous soils at the Hogback Project and reference sites. Moreover, the highest median and geometric-mean selenium concentrations in algae, cattail leaves, odonate nymphs, mosquitofish, and leopard frog samples from the study area were collected from the east hogback irrigation drain on the Hogback Project. Selenium concentrations in water and biota from irrigation drains underlain by selenium-rich soils are often elevated compared with those in samples from reference sites (Butler and others, 1993). In this study, however, all reference sites were underlain by Cretaceous soils, and this could account for the elevated selenium concentrations compared with those in biota from non-Cretaceous soils. It may be possible to identify other reference sites underlain by non-Cretaceous soils whose biota contain much lower selenium concentrations than those found in this study.

Selenium concentrations in biota (as identified by medians in the box plots of figures 7-9 and by geometric-mean concentrations in tables 9-12) from the Hogback Project, NIIP, and the reference sites, at a variety of habitats underlain by Cretaceous soils, generally are greater than selenium concentrations in biota from other irrigation projects at similar habitats underlain by non-Cretaceous soils (figs. 7-9). Median selenium concentrations were less than 2 µg/g for plants, less than 7 µg/g for invertebrates, and less than 6 µg/g for whole fish from aquatic habitats underlain by non-Cretaceous soils. Plant, invertebrate, and whole-fish samples contained median selenium concentrations two to five times greater in biota from aquatic habitats underlain by Cretaceous soils than those underlain by non-Cretaceous soils in the San Juan River area. Investigators conclude that Cretaceous soil is the major factor affecting the variability of selenium accumulation in biota at the aquatic habitats sampled in the San Juan River area.

Processes Leading to Elevated Levels of Selenium in the Study Area

A variety of natural and anthropogenic processes can lead to elevated levels of selenium in the air, land, water, and biota of the San Juan River study area. Processes examined to understand the elevated selenium levels included (1) bioaccumulation, (2) leaching from soil, (3) evapoconcentration, (4) atmospheric deposition, and (5) contamination of surface water by point-source or non-point-source discharges.

Table 12.--Geometric mean and range of selenium concentrations in amphibian samples by type, habitat, and site, San Juan River area, New Mexico, 1993-94

[N, number of samples analyzed; Gmean, geometric mean; min, minimum concentration detected; max, maximum concentration detected, µg/g, dry wt, micrograms per gram, dry weight; -- , no data; <, less than; *, statistics calculated from one sample]

Habitat and site number (fig. 3; table 1)	All amphibians combined			Terrestrial[1]		Aquatic[2]	
	N	Gmean (µg/g, dry wt)	Min - max (µg/g, dry wt)	N	Gmean (µg/g, dry wt)	N	Gmean (µg/g, dry wt)
Study total	13	4.67	0.6 - 20.3	9	5.22	8	4.12
San Juan River	1	2.90*	--	--	--	1	2.90*
Site 4	--	--	--	--	--	--	--
Site 6	1	2.90*	--	--	--	1	2.90*
Site 10	--	--	--	--	--	--	--
Site 11	--	--	--	--	--	--	--
San Juan River backwater	3	4.32	3.6 - 6.2	1	3.60*	2	4.72
Site 3	2	4.72	3.6 - 6.2	--	--	2	4.72
Site 5	--	--	--	--	--	--	--
Site 38	--	--	--	--	--	--	--
Site 42	1	3.60*	--	1	3.60*	--	--
Irrigation delivery	2	4.10	4.0 - 4.2	2	4.10	--	--
Site 51	2	4.10	4.0 - 4.2	2	4.10	--	--
Irrigation drainage	3	6.66	2.2 - 20.3	1	6.60*	2	6.68
Site 37	1	2.20*	--	--	--	1	2.20*
Site 49	2	11.57	6.6 - 20.3	1	6.60*	1	20.30*
Site 52	--	--	--	--	--	--	--
Tributary rivers	4	7.76	3.5 - 18.0	4	7.76	--	--
Site 30	1	3.60*	--	1	3.60*	--	--
Site 35	3	10.03	3.5 - 18.0	3	10.03	--	--
Ponds	4	2.75	0.6 - 8.2	1	2.00*	3	3.06
Site 2	--	--	--	--	--	--	--
Site 12	--	--	--	--	--	--	--
Site 22	--	--	--	--	--	--	--
Site 29	--	--	--	--	--	--	--
Site 34	1	8.20*	--	--	--	1	8.20*
Site 39	1	5.70*	--	--	--	1	5.70*
Site 43	2	1 10	0.6 - 2.0	1	2.0*	1	0.61*

[1]Includes the western spadefoot toad.

[2]Includes leopard frogs, bullfrog tadpoles, and tiger salamanders.

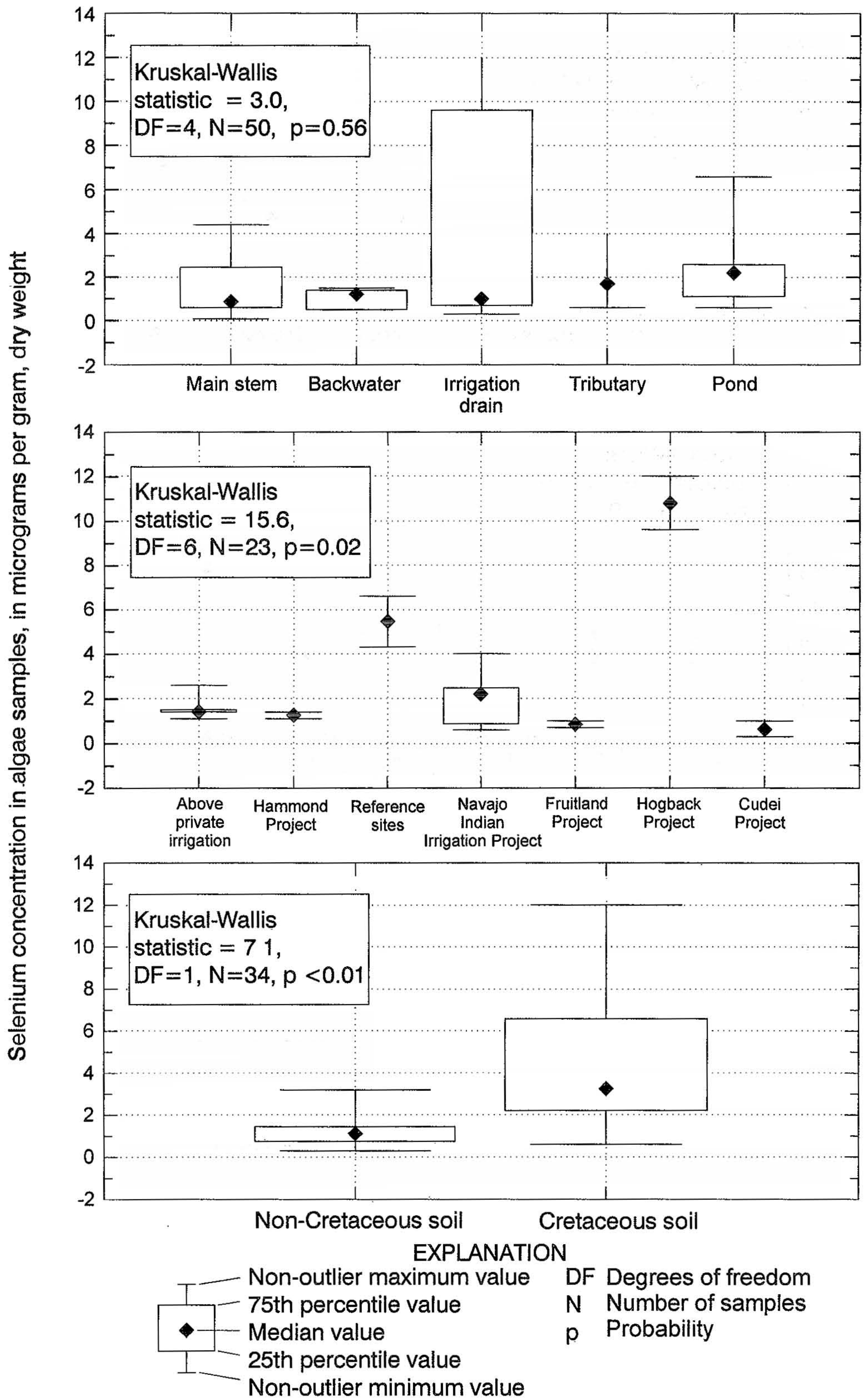


Figure 7.--Effects of habitat, irrigation project, and soil on selenium concentrations in algae samples collected in the San Juan River area, New Mexico, 1993-94. An explanation of non-outlier maximum and minimum values is given in StatSoft, Inc., 1994b, p. GRA-2390.

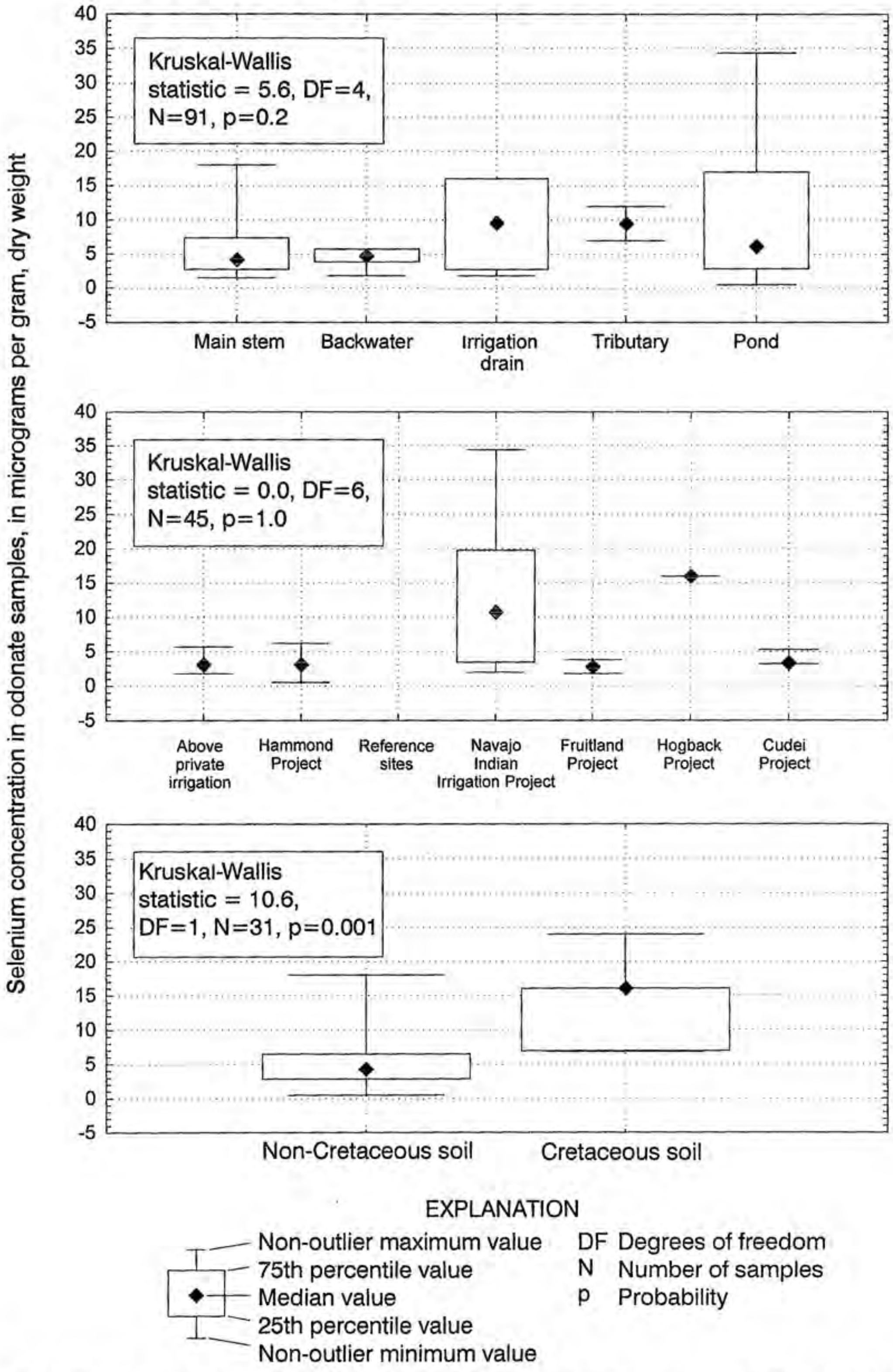


Figure 8.--Effects of habitat, irrigation project, and soil on selenium concentrations in odonates (both damselfly and dragonfly nymphs combined) collected in the San Juan River area, New Mexico, 1993-94. An explanation of non-outlier maximum and minimum values is given in StatSoft, Inc., 1994b, p. GRA-2390.

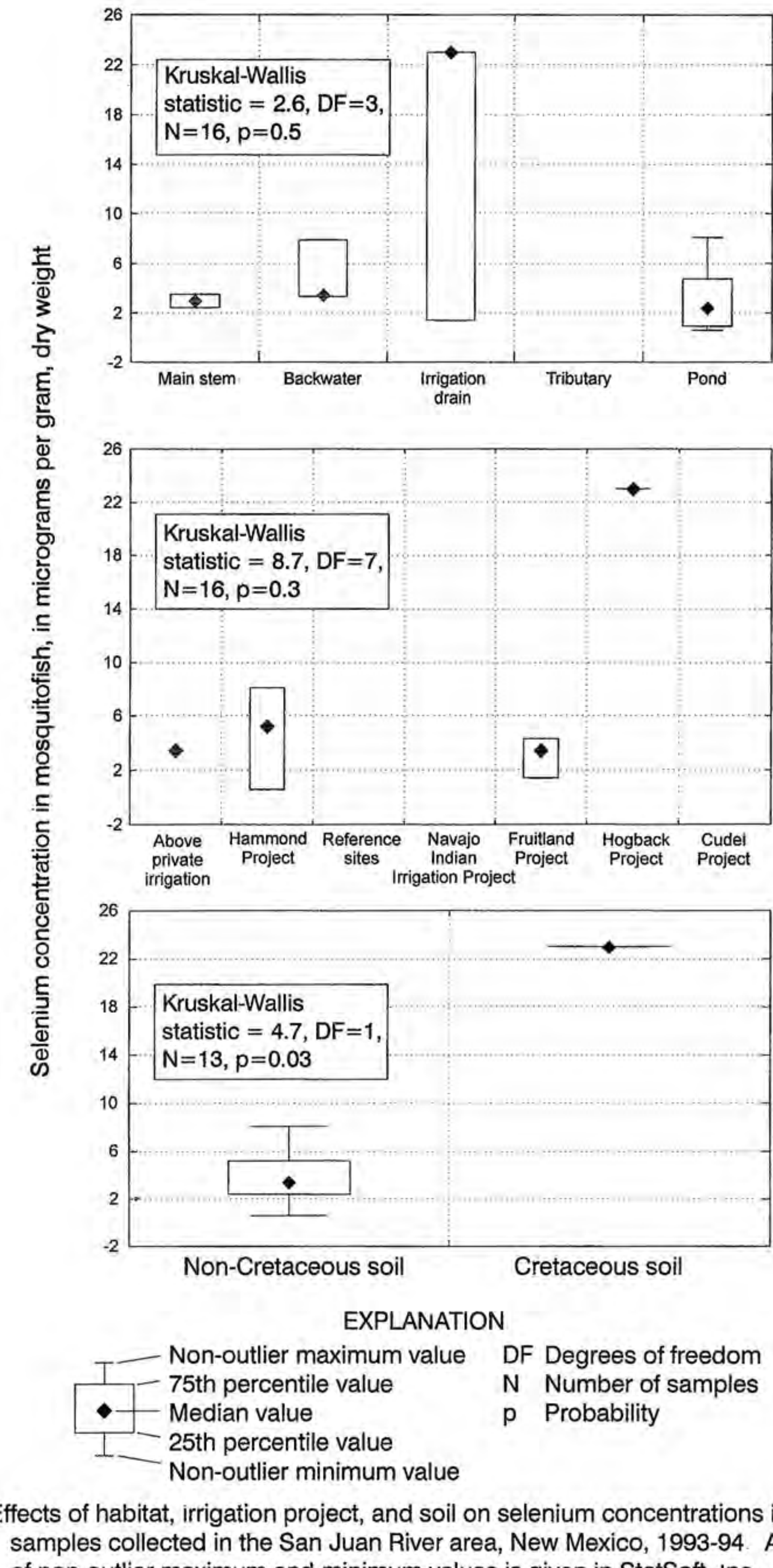


Figure 9 --Effects of habitat, irrigation project, and soil on selenium concentrations in mosquitofish samples collected in the San Juan River area, New Mexico, 1993-94. An explanation of non-outlier maximum and minimum values is given in StatSoft, Inc., 1994b, p. GRA-2390.

Bioaccumulation

Several researchers have suggested that selenium found in natural and anthropogenic sources contributes to bioaccumulation of selenium in plants and animals (Gutenmann and others, 1976, p. 966-967; Cherry and Guthrie, 1977, p. 1227-1236; Micallef and Tyler, 1989, p. 344; Tanji and Valoppi, 1989, p. 229-274; and Schuler and others, 1990, p. 845-853). Although selenium occurs naturally in soil, anthropogenic selenium is introduced into the root zone of crops to enhance agricultural productivity in selenium-deficient soils (Tanji and Valoppi, 1989, p. 229-274). Selenium can be introduced by way of irrigation water, fertilizers, soil and water amendments, animal manures, sewage effluents and sludges, and pesticides. The portion of these additives not consumed by crops may be lost through surface runoff, percolation beyond the root zone, and volatization, and also may be stored or immobilized in the root zone in the soil matrix and microbial biomass and in soil organic matter (Tanji and Valoppi, 1989, p. 233).

Gutenmann and others (1976, p. 966-967) discussed bioaccumulation of selenium in plants and animals. Selenium in concentrations exceeding 200 parts per million (ppm), dry weight, has been found in white sweet clover voluntarily growing on beds of fly ash in central New York State. Guinea pigs fed this clover concentrated selenium in their tissues. However, the contents in the stomachs of honey bees foraging on the seleniferous clover contained neglible selenium. Mature vegetables grown in 10 percent (by weight) fly-ash-amended soil absorbed as much as 1 ppm selenium. Cabbage grown on fly-ash (containing from 1.2 to 16.5 ppm selenium)-amended soil absorbed selenium (as much as 3 7 ppm) in direct proportion (correlation coefficient, r = 0.89) to the selenium concentration in the respective fly ash. Aquatic weeds, algae, dragonfly nymphs, polliwogs, and tissues of bullheads and muskrats from a fly-ash-contaminated pond contained concentrations of selenium markedly elevated over those of controls.

Schuler and others (1990, p. 845-853) reported bioaccumulation of selenium at Kesterson Reservoir in the San Joaquin Valley of California. Kesterson Reservoir, a closed basin, received subsurface agricultural drainage containing high levels of salts and selenium from farmland. High concentrations of selenium were found in benthic sediments, terrestrial and aquatic plants, and aquatic insects. Mean selenium concentrations in aquatic plants and insects ranged from 1.5 to 170 μg/g, dry weight, and were about 11 to 290 times those found at a nearby reference site. Concentrations in some waterfowl food plants and insects at Kesterson were as much as 64 times the levels reported to be a health hazard to birds. Selenium concentrations were more seasonally variable in aquatic plants than in aquatic insects. Deposition of selenium in plant parts was not uniform; rhizomes contained higher concentrations than seeds, and leaves were intermediate. Most biota bioaccumulated maximum selenium concentrations that were 1,000 to nearly 5,000 times the concentration in water.

Cherry and Guthrie (1977, p. 1227-1236) studied concentrations of selenium and other trace elements in the water, benthic sediment, plants, invertebrates, and vertebrates of an ash basin and its drainage system at a coal-burning power plant of the Savannah River Project, Aiken, South Carolina. They reported that selenium was more concentrated in sediment and biota than in water. Sediment was composed primarily of heavy ash. In the 2 years of the study vertebrates were the greatest accumulators of selenium and in 1 of the years exceeded the sediment concentration for this element. Different biota in a food web biomagnify the various trace elements at different rates. The high benthic sediment concentration of all elements provided a continual source to the water and to the biota within the system (Cherry and Guthrie, 1977, p. 1233).

In the San Juan River area study, selenium was much less concentrated in water samples than in bottom sediment, soil, or biota samples. The concentration of dissolved selenium in water samples ranged from less than 1 to 37 μg/L (less than 1 to 37 parts per billion (ppb)). The concentration of total selenium in bottom-sediment and soil samples was less than 0.1 to 23 μg/g (less than 100 to 23,000 ppb), and biota samples ranged from less than 0.1 to 24.0 μg/g (less than 100 to 24,000 ppb).

Data indicated that bioaccumulation is the process that leads to elevated levels of selenium in biota. The geometric-mean, dry-weight, selenium concentration was greatest in amphibians (4.67 μg/g) and fish (3.84 μg/g), less in aquatic invertebrates (3.03 μg/g), and least in aquatic vegetation (0.90 μg/g) and showed increasing concentration at the higher trophic levels. In addition, the range in selenium concentration in biota was about 1,000 times that in water and about the same as that in bottom sediment and soil.

The ability of algal plants to bioaccumulate selenium was demonstrated at site 40, the stock tank at Cottonwood Spring. Visual inspection of the tank revealed a large amount of algal growth and a detrital silt on the bottom. The water, algae, and detrital silt were analyzed for selenium content. Two water samples collected from the tank contained a dissolved-selenium concentration of 2 μg/L (table 13) for each sample. Analysis of the algae determined a selenium concentration of 6.6 μg/g, dry weight (Thomas and others, 1997), one of the greatest plant selenium concentrations in the study area. Bottom-sediment samples from the tank contained a mean selenium concentration of 8.2 μg/g (table 7), one of the greatest mean concentrations in the study area. The selenium concentration in algae was 3,300 times that in water, and in bottom sediment was 4,100 times that in water and 1.25 times that in algae.

Leaching from Soil

High levels of selenium in irrigation-drainage water that are accompanied by only slight enrichment in deuterium (^{2}H) and oxygen-18 (^{18}O) isotopes relative to the irrigation-supply water confirm that leaching from soils, rather than evaporative concentration, is the mechanism that produces elevated selenium levels in irrigation-drainage water in the study area.

Selenium concentration in irrigation-drainage and seep samples is high relative to irrigation-supply water. Samples from Hogback Irrigation Project drainage (sites 44, 47, 48, and 49) contained selenium concentrations ranging from 7 to 16 μg/L (table 13); samples from irrigation-supply water (site 45) contained selenium concentrations less than 1 μg/L (table 13). Similarly, the NIIP samples from irrigation seepage sites at Gallegos Canyon (sites 27 and 28) and Ojo Amarillo Canyon (sites 31 and 33) contained selenium concentrations ranging from 7 to 24 μg/L (table 13); samples from irrigation-supply water (sites 25 and 26) contained selenium concentrations less than 1 μg/L (table 13). At the Hogback Irrigation Project and NIIP, the previously mentioned drainage and seep sites are representative of water draining by gravity from irrigated uplands. Water drains from a perched water table that has been created over many years of irrigation.

Isotopic ratios of environmental water samples can be compared to make inferences concerning the origin of the water. Waters from different origins generally have distinct isotopic ratios (Hoefs, 1987, p. 118-119). For example, in the San Juan River study area, irrigation-supply water has an isotopic composition distinct from surface water at site 23. There are two stable isotopes of hydrogen, ^{1}H and ^{2}H, and three stable isotopes of oxygen, ^{16}O, ^{17}O, and ^{18}O. The most important isotope ratios, $^{2}H/^{1}H$ and $^{18}O/^{16}O$, for the samples collected in this study were analyzed and plotted in figure 10.

Samples collected from Hogback Irrigation Project drainage (sites 44, 47, 48, and 49) have isotopic ratios (table 13; fig. 10) very similar to those of Hogback irrigation-supply water (site 45). This implies that the irrigation-supply water is not altered by mixing with other water or by evaporation as it flows to the drainage ditches.

Irrigation-supply water at the NIIP increases in selenium concentration after moving through the soils. A comparison of samples from the NIIP irrigation-supply canal (site 25) and a sample from the irrigation sprinkler near Gallegos Canyon middle pond (site 26) shows a small shift in isotopic ratios to the right of the meteoric water line (a mathematically defined line along which continental precipitation samples tend to plot (Hoefs, 1987, p. 188)) at a lesser slope than the meteoric water line (fig. 10), indicative of evaporation (Ferronsky and Polyakov, 1982, p. 60-74, 111). However, the selenium concentration is less than 1 μg/L in both the irrigation canal and the sprinkler (table 13), and this indicates that evaporation did not cause an increase in selenium concentration. A comparison of samples from the irrigation seepage sites at Gallegos Canyon (sites 27 and 28) and Ojo Amarillo Canyon (sites 31 and 33) with the sample from the irrigation sprinkler (site 26) again shows a small shift in isotopic ratios to the right of the meteoric water line at a lesser slope than the meteoric water line (fig. 10), indicative of evaporation. However, the selenium concentration increases from less than 1 μg/L to a maximum of 24 μg/L only when water moves from the sprinkler through the soils.

At both the Hogback Project and NIIP the selenium concentrations increase between the application of irrigation water to the ground and the seepage of the irrigated water from the ground. Increased selenium concentrations in water samples after contact with the soil imply that leaching is the process causing increases in dissolved-selenium concentrations. At the NIIP the increase in selenium concentration from the point of application at the center-pivot sprinkler to the middle pond Gallegos Canyon seepage could not be due to mixing with regional ground water because this site is at an altitude of about 5,600 feet and is located on a bluff that places it above the altitude of the regional water table.

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico

[µg/L, micrograms per liter; ft, foot; mi, mile; <, less than; --, no data; NIIP, Navajo Indian Irrigation Project]

Site number (fig. 3)	Date	Site name	$^{2}H/^{1}H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (µg/L)
1	08-23-93	San Juan River 300 ft below dam near Archuleta	-94.5	-13.14	<1
1	07-18-94	San Juan River 300 ft below dam near Archuleta	-99.8	-13.36	<1
2	08-25-93	Pond on north bench San Juan River 0.6 mi below dam near Archuleta	-93.8	-12.69	<1
2	07-28-94	Pond on north bench San Juan River 0.6 mi below dam near Archuleta	-96.5	-12.90	<1
3	08-24-93	Backwater south of San Juan River 0.9 mi below dam near Archuleta	-93.8	-12.81	<1
3	08-24-93	Backwater south of San Juan River 0.9 mi below dam near Archuleta	-93.3	-12.83	<1
3	07-19-94	Backwater south of San Juan River 0.9 mi below dam near Archuleta	-99.2	-13.32	<1
5	07-19-94	Backwater south of San Juan River 3.1 mi below dam near Archuleta	-99.0	-13.34	<1
7	08-24-93	Dug hole at Simon Canyon at San Juan River near Archuleta	-28.8	-6.00	<1
7	08-02-94	Dug hole at Simon Canyon at San Juan River near Archuleta	-53.1	-8.48	--
8	08-23-93	Dug hole at Gobernador Wash at Highway 511 near Archuleta	-58.2	-8.17	<1
8	07-18-94	Dug hole at Gobernador Wash at Highway 511 near Archuleta	-77.7	-9.62	<1
9	08-24-93	Dug hole at Pump Canyon at Highway 173 near Archuleta	-55.7	-7.90	<1
9	07-18-94	Dug hole at Pump Canyon at Highway 173 near Archuleta	-64.8	-9.31	<1
12	08-19-93	East Hammond Project pond near Blanco	-75.7	-9.64	<1
12	03-09-94	East Hammond Project pond near Blanco	-88.2	-11.77	<1
13	09-27-94	Hammond Canal at Hammond Conservancy District near Blanco	-98.4	-13.36	<1

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico--Continued

Site number (fig. 3)	Date	Site name	$^{2}H/^{1}H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (μg/L)
14	09-28-93	Hammond Canal above Bloomfield Refinery near Bloomfield	-95.3	-13.02	<1
14	09-28-94	Hammond Canal above Bloomfield Refinery near Bloomfield	-98.1	-13.29	<1
15	09-28-93	Hammond Canal below Bloomfield Refinery near Bloomfield	-96.0	-13.06	<1
15	09-28-94	Hammond Canal below Bloomfield Refinery near Bloomfield	-98.6	-13.27	<1
16	09-30-93	Hammond Canal 0.3 mi west of Highway 44 near Bloomfield	-94.6	-13.04	<1
16	09-30-93	Hammond Canal 0.3 mi west of Highway 44 near Bloomfield	-96.1	-13.10	<1
16	09-28-94	Hammond Canal 0.3 mi west of Highway 44 near Bloomfield	-99.9	-13.28	<1
16	09-28-94	Hammond Canal 0.3 mi west of Highway 44 near Bloomfield	-98.8	-13.26	<1
17	03-17-93	East drain at west Hammond pond near Bloomfield	-88.1	-11.65	1
17	08-19-93	East drain at west Hammond pond near Bloomfield	-89.2	-11.84	1
17	03-09-94	East drain at west Hammond pond near Bloomfield	-88.7	-11.89	2
17	07-20-94	East drain at west Hammond pond near Bloomfield	-89.4	-11.92	2
17	09-27-94	East drain at west Hammond pond near Bloomfield	-89.2	-11.84	4
18	03-17-93	West drain at west Hammond pond near Bloomfield	-91.0	-12.38	4
18	08-19-93	West drain at west Hammond pond near Bloomfield	-91.8	-12.22	--
18	03-09-94	West drain at west Hammond pond near Bloomfield	-90.5	-12.10	3
18	07-20-94	West drain at west Hammond pond near Bloomfield	-90.8	-12.26	3
19	03-17-93	Irrigation drain at manhole 800 ft above west Hammond pond near Bloomfield	-89.0	-12.05	1

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico--Continued

Site number (fig. 3)	Date	Site name	$^{2}H/^{1}H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (µg/L)
19	03-17-93	Irrigation drain at manhole 800 ft above west Hammond pond near Bloomfield	-88.6	-12.09	1
20	03-17-93	Irrigation drain at manhole 500 ft above west Hammond pond near Bloomfield	-89.9	-12.31	3
20	08-19-93	Irrigation drain at manhole 500 ft above west Hammond pond near Bloomfield	-91.3	-12.29	3
20	03-09-94	Irrigation drain at manhole 500 ft above west Hammond pond near Bloomfield	-91.3	-12.17	3
20	07-20-94	Irrigation drain at manhole 500 ft above west Hammond pond near Bloomfield	-90.7	-12.29	3
21	03-17-93	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	-90.1	-12.42	5
21	08-19-93	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	-90.3	-12.27	3
21	03-09-94	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	-89.9	-12.14	5
21	07-20-94	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	-90.8	-12.24	2
21	09-27-94	Irrigation drain at manhole 200 ft above west Hammond pond near Bloomfield	-89.5	-12.04	3
22	03-17-93	West Hammond pond near Bloomfield	-89.4	-12.00	6
22	08-19-93	West Hammond pond near Bloomfield	-89.3	-11.83	2
22	03-09-94	West Hammond pond near Bloomfield	-88.1	-11.58	<1
22	07-20-94	West Hammond pond near Bloomfield	-89.9	-12.03	3
23	08-20-93	Gallegos Canyon near Carson Trading Post	-46.6	-6.17	11
23	09-03-94	Gallegos Canyon near Carson Trading Post	-41.9	-7.31	1
24	08-20-93	Dug hole at Gallegos Canyon near Carson Trading Post	-72.0	-8.99	3
24	07-25-94	Dug hole at Gallegos Canyon near Carson Trading Post	-49.8	-6.68	10

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico--Continued

Site number (fig. 3)	Date	Site name	$^{2}H/^{1}H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (µg/L)
25	08-20-93	NIIP irrigation-supply canal 0.2 mi south of Highway N3003 near Bloomfield	-96.2	-13.29	<1
25	07-19-94	NIIP irrigation-supply canal 0.2 mi south of Highway N3003 near Bloomfield	-98.6	-13.34	<1
26	07-22-94	Center pivot sprinkler near Gallegos Canyon drainage middle pond near Farmington	-91.4	-12.13	<1
27	03-18-93	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	-83.7	-10.62	24
27	03-08-94	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	-84.1	-10.55	20
27	07-22-94	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	-83.3	-10.55	18
28	03-18-93	South seep to Gallegos Canyon drainage middle pond near Farmington	-85.3	-10.81	24
28	03-08-94	South seep to Gallegos Canyon drainage middle pond near Farmington	-84.3	-10.58	17
28	07-22-94	South seep to Gallegos Canyon drainage middle pond near Farmington	-85.7	-10.58	17
29	03-18-93	Gallegos Canyon drainage middle pond near Farmington	-83.8	-10.44	26
29	03-08-94	Gallegos Canyon drainage middle pond near Farmington	-84.0	-10.39	21
29	07-22-94	Gallegos Canyon drainage middle pond near Farmington	-81.6	-9.78	13
30	08-17-93	Gallegos Canyon near Farmington	-79.8	-9.67	4
30	08-17-93	Gallegos Canyon near Farmington	-79.3	-9.55	5
30	03-08-94	Gallegos Canyon near Farmington	-83.8	-10.07	19
30	07-20-94	Gallegos Canyon near Farmington	-76.3	-8.72	4
31	03-18-93	East seep to Ojo Amarillo Canyon drainage southwest pond near Farmington	-82.4	-10.18	22
31	03-08-94	East seep to Ojo Amarillo Canyon drainage southwest pond near Farmington	-82.7	-10.26	7

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico--Continued

Site number (fig. 3)	Date	Site name	$^2H/^1H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (µg/L)
32	07-22-94	Ojo Amarillo Canyon drainage north pond near Farmington	-93.7	-12.64	1
33	03-18-93	Northeast seep to Ojo Amarillo Canyon drainage north pond near Farmington	-77.9	-9.81	9
33	03-08-94	Northeast seep to Ojo Amarillo Canyon drainage north pond near Farmington	-78.1	-9.75	9
34	03-18-93	Ojo Amarillo Canyon drainage southwest pond near Farmington	-77.0	-9.41	6
34	03-08-94	Ojo Amarillo Canyon drainage southwest pond near Farmington	-77.8	-9.73	9
34	07-22-94	Ojo Amarillo Canyon drainage southwest pond near Farmington	-40.3	-0.25	2
35	08-10-93	Ojo Amarillo Canyon near Fruitland	-89.7	-11.66	10
35	03-08-94	Ojo Amarillo Canyon near Fruitland	-81.3	-10.06	27
35	07-21-94	Ojo Amarillo Canyon near Fruitland	-84.9	-10.68	21
36	03-08-94	Fruitland irrigation drain 300 ft above wetland, near Fruitland	-93.7	-12.61	<1
37	08-18-93	Fruitland irrigation drain at wetland near Fruitland	-94.6	-12.51	<1
37	03-08-94	Fruitland irrigation drain at wetland near Fruitland	-93.9	-12.56	<1
37	07-21-94	Fruitland irrigation drain at wetland near Fruitland	-97.3	-12.87	<1
38	08-12-93	Secondary channel of San Juan River near Kirtland	-101.0	-13.68	<1
38	07-27-94	Secondary channel of San Juan River near Kirtland	-97.9	-13.22	<1
39	03-18-93	Pond at Cottonwood Spring near Newcomb	-51.9	-4.90	3
39	08-17-93	Pond at Cottonwood Spring near Newcomb	13.9	10.18	--
39	03-07-94	Pond at Cottonwood Spring near Newcomb	-42.7	-3.01	2

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico--Continued

Site number (fig. 3)	Date	Site name	$^{2}H/^{1}H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (µg/L)
39	07-21-94	Pond at Cottonwood Spring near Newcomb	22.4	11.92	2
39	07-21-94	Pond at Cottonwood Spring near Newcomb	21.7	12.00	2
40	09-29-93	Stock tank at Cottonwood Spring near Newcomb	-53.2	-5.92	2
40	07-21-94	Stock tank at Cottonwood Spring near Newcomb	-43.8	-2.88	2
41	03-18-93	Seep at Cottonwood Spring near Newcomb	-64.4	-8.76	3
41	08-17-93	Seep at Cottonwood Spring near Newcomb	-66.8	-8.82	2
41	03-07-94	Seep at Cottonwood Spring near Newcomb	-64.3	-8.70	3
41	07-21-94	Seep at Cottonwood Spring near Newcomb	-66.0	-8.64	2
42	08-12-93	San Juan River backwater at Hogback Diversion Dam near Waterflow	-96.5	-12.90	<1
42	07-26-94	San Juan River backwater at Hogback Diversion Dam near Waterflow	-93.8	-12.34	<1
43	08-12-93	Pond draining Fruitland Irrigation Project at Hogback near Waterflow	-94.0	-12.65	<1
43	07-26-94	Pond draining Fruitland Irrigation Project at Hogback near Waterflow	-92.2	-12.08	<1
44	03-19-93	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	-95.3	-12.96	12
44	08-13-93	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	-95.9	-13.15	14
44	07-27-94	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	-99.6	-13.27	10
44	07-27-94	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	-97.6	-13.36	10
45	08-13-93	Hogback irrigation-supply canal near Waterflow	-98.0	-13.41	<1
45	07-27-94	Hogback irrigation-supply canal near Waterflow	-95.7	-12.91	<1

Table 13.--Hydrogen and oxygen stable isotopic ratios and dissolved-selenium concentrations in water samples, San Juan River area, New Mexico--Concluded

Site number (fig. 3)	Date	Site name	$^{2}H/^{1}H$ stable isotope ratio per mil	$^{18}O/^{16}O$ stable isotope ratio per mil	Selenium, dissolved (µg/L)
46	07-27-94	Leaking well near Waterflow	-94.6	-12.56	<1
47	03-19-93	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-95.7	-12.89	16
47	08-13-93	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-95.6	-12.99	9
47	08-13-93	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-96.6	-13.07	9
47	09-29-93	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-96.3	-13.12	8
47	03-10-94	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-96.1	-12.83	14
47	03-10-94	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-96.7	-12.85	13
47	07-27-94	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	-98.1	-13.08	9
48	03-19-93	East hogback irrigation drain 0.2 mi above San Juan River near Waterflow	-94.0	-12.75	15
49	08-13-93	East hogback irrigation drain 300 ft above San Juan River near Waterflow	-96.3	-13.08	8
49	03-10-94	East hogback irrigation drain 300 ft above San Juan River near Waterflow	-95.0	-12.56	11
49	07-27-94	East hogback irrigation drain 300 ft above San Juan River near Waterflow	-96.5	-13.01	7
50	03-19-93	Salt Creek at highway bridge near Shiprock	-95.6	-13.00	37
51	03-15-93	Cudei irrigation canal at turnout from San Juan River near Cudei	-96.1	-13.04	1
51	08-11-93	Cudei irrigation canal at turnout from San Juan River near Cudei	-98.3	-13.24	<1
51	03-09-94	Cudei irrigation canal at turnout from San Juan River near Cudei	-101.0	-13.42	1
51	07-26-94	Cudei irrigation canal at turnout from San Juan River near Cudei	-96.9	-12.99	<1
52	08-11-93	Cudei irrigation drain near Cudei	-93.7	-12.60	<1
52	07-26-94	Cudei irrigation drain near Cudei	-94.2	-12.66	<1

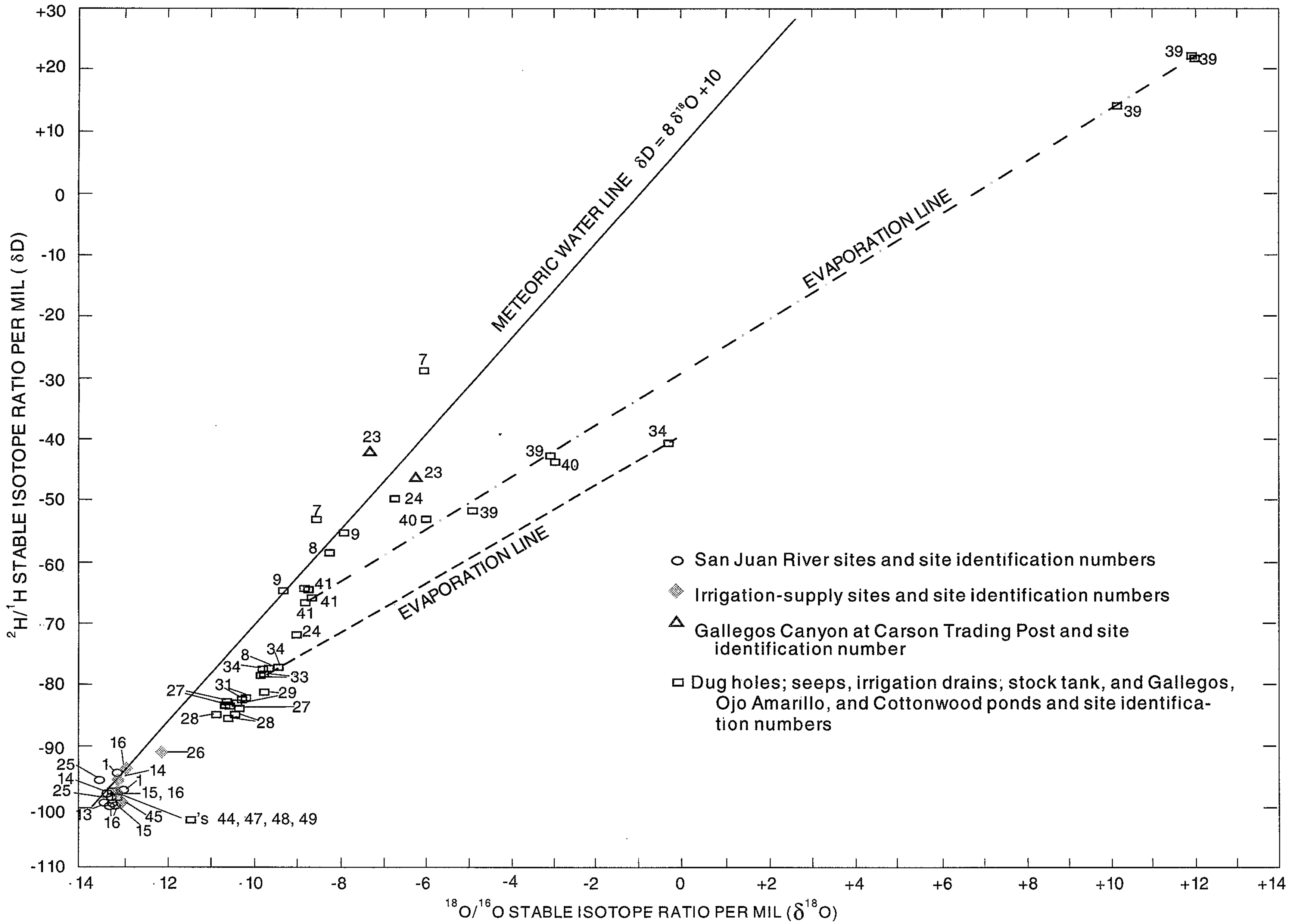


Figure 10.--Stable isotopic ratios of hydrogen and oxygen for selected data-collection sites in the San Juan River area, New Mexico.

Evapoconcentration

Evapoconcentration of selenium is not taking place in the ponds that were sampled for this study. In fact, at the Cottonwood Springs site (site 40) a biologically remediated removal of aqueous selenium appears likely.

Evaporation at the Ojo Amarillo Canyon drainage southwest pond (site 34) became a dominant process when the level of the pond dropped below the outlet control and operated for a time with no flow through the outlet. During phase changes of water between liquid and gas, the heavier water molecules tend to concentrate in the liquid phase and the lighter molecules pass into the gas phase. The evaporation process is confirmed by isotopic ratios that shift to the right of the meteoric water line at a lesser slope than the meteoric water line (fig. 10). The $^{2}H/^{1}H$ stable isotope ratio per mil (δD) and $^{18}O/^{16}O$ stable isotope ratio per mil ($\delta^{18}O$) changed from $\delta D = -77.8$, $\delta^{18}O = -9.73$ to $\delta D = -40.3$, $\delta^{18}O = -0.25$ (fig. 10; table 13) between samples collected March 8, 1994, and July 22, 1994. Selenium concentration decreased from 9 to 2 μg/L (table 13) for the two samples; an increase would be expected because of evapoconcentration. This decrease may be due to biological removal of selenium by plants.

A pond, a nearby stock tank, and a natural seep (sites 39-41) at Cottonwood Spring near Newcomb, New Mexico (fig. 3), were sampled and analyzed for the $^{2}H/^{1}H$ stable isotopic ratio and the $^{18}O/^{16}O$ stable isotopic ratio. Water from the natural seep is allowed to collect in an open stock tank. Water from the tank is periodically spilled to the pond for watering cattle. This is a closed pond with no outlet. Isotopic ratios of hydrogen and oxygen show that water in the tank is more evaporated than the source water at the seep and that water in the pond can become highly evaporated (fig. 10). Isotopic ratios of hydrogen and oxygen reached $\delta D = +22.4$, $\delta^{18}O = +12.00$ at the pond, the most enriched in heavy isotopes of all sites sampled in the study area. Despite the high degree of evapoconcentration at the pond, which is verified by a maximum dissolved-solids concentration of 5,900 milligrams per liter (mg/L) (Thomas and others, 1997), the dissolved-selenium concentration in four samples ranged from 2 to 3 μg/L (table 13). This is the same as the range in dissolved selenium in four samples from the seep (table 13). An increase in selenium concentration consistent with evapoconcentration did not occur. The lack of an increase in selenium concentration may be due to biological removal of selenium by plants.

All other ponds sampled in the study area were usually operated in a flow-through manner with inflow from seepage and outflow at an outlet structure on the pond. The flow-through type of operation minimizes evapoconcentration of pond water.

Atmospheric Deposition

Deposition of atmospheric aerosols has been cited as a mechanism that brings selenium to land and water surfaces (Rahn and Lowenthal, 1986, p. 62-65; Burau, 1989, p. 42-47; Micallef and Tyler, 1989, p. 344; and Velinsky and Cutter, 1991, p. 179-191). Atmospheric aerosols are tiny particles suspended in the atmosphere that are washed out by rain or fall to the earth, called wet and dry atmospheric deposition, respectively. Carried by wind, atmospheric aerosols may travel hundreds or thousands of miles from their origin before deposition and, under very dry conditions, particles can be airborne for weeks or months (Rahn and Lowenthal, 1986, p. 62-65).

Deposition of selenium-rich atmospheric aerosols is possible in the study area because of the presence of two large coal-burning power plants. Coal is rich in selenium and when burned, it creates a fine ash residue (fly ash) that is trapped by electrostatic precipitators at the power plant. However, selenium is concentrated in extremely fine fly ash that escapes the electrostatic precipitator and goes into the atmosphere (Gutenmann and others, 1976, p. 966-967). Gutenmann and others (1976, p. 967) reported that the total selenium content of fly ash sampled in 21 States contained an average selenium concentration of 8,000 ppb.

Although the selenium content of wet and dry atmospheric deposition and the deposition rate were not measured directly during this study, selenium deposition can be estimated. The range of deposition rates for selenium cited by Peirson and others (1974, p. 675) and Velinsky and Cutter (1991, p. 186) is 0.15 to 0.23 milligram per square meter per year. By assuming that the cited selenium depositional rate is a reasonable estimate for the study area, and that a water body is 1 meter deep, the selenium concentration would increase by 0.15 to 0.23 μg/L over a year in a closed water body. It would take about 5 years for a closed body of water to increase its selenium concentration by 1 ppb from atmospheric deposition alone. However, most of the ponds in the study area are operated in a flow-through manner and assumed to have a relatively short residence time because they are small. Therefore, direct atmospheric deposition should have little influence on selenium concentration in water bodies in the study area. Washoff from the watershed or catchment area could result in a much higher delivery rate.

Contamination of Surface Water by Point-Source or Non-Point-Source Discharge

Investigators identified a leaking well (site 46) discharging to the irrigation-drainage canal at the Hogback Project as the only potential point source for selenium in the study area. Selenium input from this leaking well proved to be unlikely, however, because the selenium concentration in the well water was less than 1 μg/L. The well is now properly capped.

Runoff from land surfaces, particularly from drainage basins containing selenium-rich deposits such as the Mancos Shale, may increase the selenium content of water in the study area. Hogback Project selenium concentrations in top-interval soil samples ranged from 1.5 to 3.6 μg/g (Thomas and others, 1997) and were greater than the baseline maximums of 0.77 μg/g for the San Juan Basin and 1.4 μg/g for the Western States (table 14). The sample containing the greatest selenium concentration from the saturated soil paste extract, 1.26 μg/g (Thomas and others, 1997, p. 119), represents the nonirrigated soils of the Hogback Project area. The immediate area from which this sample was obtained is not contributing dissolved selenium to the San Juan River from irrigation-return flows, but may be contributing dissolved selenium from runoff.

Table 14.--Baseline concentration ranges for selected trace elements in soils and concentration ranges for National Irrigation Water Quality Program (NIWQP) samples, 1993-94

[All values are in micrograms per gram; <, less than]

Element	Western soils, baseline range[1]	San Juan Basin soils, baseline range[2]	Study area, bottom-sediment range	Study area, soils range
Arsenic	1.2 - 22	2.3 - 13	2.2 - 7.1	3.4 - 8.0
Chromium	8.5 - 200	7 9 - 41	2 - 58	3 - 59
Copper	4.9 - 90	2.3 - 33	2 - 31	3 - 27
Lead	5.2 - 55	6.5 - 22	4 - 58	10 - 24
Mercury	0.0085 - 0.25	0.01 - 0.07	<0.02 - 0.03	<0.02 - <0.02
Molybdenum	0.18 - 4.0	0.4 3.5	<2 - 26	<2 - 2
Nickel	3.4 - 66	3.1 24	2 - 24	4 - 26
Selenium	0.039 - 1.4	0.03 0.77	<0.1 - 23	<0.1 - 3.6
Strontium	43 - 930	85 410	130 - 2,600	130 - 360
Vanadium	18 - 270	18 - 110	8 - 110	10 - 140
Zinc	17 - 180	15 100	9 - 380	11 - 88

[1]Central 95 percent of observed concentrations (Shacklette and Boerngen, 1984).
[2]Central 95 percent of observed concentrations (Severson and Gough, 1981, Ebens and Shacklette, 1982).

OCCURRENCE AND DISTRIBUTION OF OTHER CHEMICAL CONSTITUENTS

Although determining the occurrence and distribution of selenium in water, sediment, soil, and biota was a primary objective of this study, determining the occurrence and distribution of selected inorganic and organic chemical constituents was also an objective of the NIWQP. Dissolved arsenic, boron, chromium, copper, lead, mercury, molybdenum, vanadium, zinc, cadmium, and major dissolved ions were analyzed to determine their concentrations in water samples. Total arsenic, chromium, copper, lead, mercury, molybdenum, nickel, strontium, uranium, vanadian, and zinc were analyzed in bottom-sediment and soil samples. Biological samples were analyzed for 19 trace elements to determine the concentrations of these constituents in tissue. In addition, concentrations of organochlorine pesticides and polychlorinated biphenyls (PCB's) in biota and PAH's in water, bottom sediment, and biota were determined.

Inorganic Constituents in Water

The ranges for major dissolved cations and anions in water at sampling sites were: dissolved calcium, 2.7 to 610 mg/L, dissolved magnesium, 0.20 to 150 mg/L, dissolved sodium, 11 to 2,300 mg/L, dissolved potassium, less than 0.10 to 18 mg/L, alkalinity, 77 to 2,520 mg/L; dissolved sulfate, 37 to 5,400 mg/L, and dissolved chloride, less than 0.10 to 1,700 mg/L (Thomas and others, 1997). Dissolved-solids concentration ranged from 145 to 8,600 mg/L (Thomas and others, 1997). The minimum dissolved-calcium and -magnesium concentrations were in samples from site 23, Gallegos Canyon near Carson Trading Post; maximum dissolved-calcium and -magnesium concentrations were in samples from site 2, pond on north bench of the San Juan River, and site 44, east hogback irrigation drain 0.7 mile above the San Juan River near Waterflow. Samples from site 25, NIIP irrigation-supply canal 0.2 mile south of Highway N3003 near Bloomfield, contained the minimum concentrations of dissolved sodium, alkalinity, and sulfate. Samples from site 12, the east Hammond Project pond near Blanco, contained the maximum concentrations of dissolved sulfate and dissolved solids. Samples from site 46, leaking well near Waterflow, contained the maximum concentrations of dissolved sodium, alkalinity, and chloride. Samples from site 39, pond at Cottonwood Spring near Newcomb, contained the maximum concentration of dissolved potassium. In general, water samples from the irrigation-supply sites and San Juan River sites contained smaller concentrations of major dissolved cations and anions than those from ponds, tributaries, or irrigation-drainage sites.

The ranges for trace-element concentrations in water samples collected in the study area were: dissolved arsenic, less than 1 to 17 μg/L, dissolved boron, 10 to 1,600 μg/L, dissolved chromium, less than 1 to 20 μg/L; dissolved copper, less than 1 to 200 μg/L, dissolved lead, less than 1 to 47 μg/L; dissolved molybdenum, less than 1 to 15 μg/L; dissolved vanadium, less than 1 to 390 μg/L, and dissolved zinc, less than 3 to 200 μg/L (Thomas and others, 1997). Dissolved cadmium was analyzed but not detected in water samples (Thomas and others, 1997). Dissolved mercury was analyzed but not detected in any of the NIWQP samples; however, it was detected in a few of the supplemental samples.

Quality-assurance/quality-control results for supplemental samples cast doubt on the validity of mercury concentrations in supplemental samples that are above the laboratory reporting limit (Thomas and others, 1997). The quality-assurance/quality-control samples show that mercury was present in one, but not both of the duplicate samples obtained by the split method in four instances and that mercury was present above the reporting limit in the dissolved state but below the reporting limit in the total state in three instances (Thomas and others, 1997). The total mercury present in a sample should be at least as great or greater than the dissolved mercury present in a sample. Therefore, only the NIWQP sample data were used to evaluate mercury concentrations in the San Juan River area.

The minimum trace-element concentrations reported above occurred in samples from numerous sites, generally those sites that are irrigation-supply or San Juan River sites. The maximum dissolved-arsenic, -boron, and -molybdenum concentrations were in samples from site 39, pond at Cottonwood Spring near Newcomb. Samples from site 23, Gallegos Canyon near Carson Trading Post, contained the maximum concentrations of dissolved chromium, copper, lead, and vanadium. A sample from site 30S, 1-18 pond, contained the maximum concentration of dissolved mercury. A sample from site 19, irrigation drain at manhole 80 feet above west Hammond pond near

Bloomfield, contained the maximum concentration of dissolved molybdenum. In general, water samples from the irrigation-supply sites and San Juan River sites contained smaller concentrations of trace elements than those from ponds, tributaries, or irrigation-drainage sites.

Inorganic Constituents in Bottom Sediment and Soil

Geochemical baseline values for selected trace elements in western soils have been compiled by several researchers. Shacklette and Boerngen (1984) presented a baseline range for concentrations of arsenic, chromium, copper, lead, mercury, molybdenum, nickel, selenium, strontium, uranium, vanadium, and zinc in soils of the United States west of the 97th parallel (table 14). Concentrations of the previous 12 elements in 47 soil samples collected in the San Juan Basin are presented by Severson and Gough (1981) and summarized by Ebens and Shacklette (1982) (table 14). The central 95 percent of the observed concentrations is called the western soils, baseline range in table 14. These values are considered the geochemical baseline values for the study area.

Lead, molybdenum, selenium, strontium, and zinc in bottom sediment or soil at some of the NIWQP sites exceeded the upper limit of the western soils, baseline range (tables 14 and 15). At some shallow soil-sampling sites at the Hogback Project chromium, lead, nickel, and vanadium (Thomas and others, 1997, p. 91-99) were found at concentrations greater than the maximum value listed for the San Juan Basin soils, baseline range (table 14). Selenium exceedances (24) outnumbered lead (2), molybdenum (2), strontium (4), and zinc (4) exceedances in bottom sediment and soil (table 15).

Hogback Project soils contain greater concentrations of the selected constituents than Hammond Project soils do. This difference is due primarily to the Cretaceous Mancos Shale underlying the Hogback soils.

The BOR has considerable saturated-extract data for these constituents from a number of studies completed in the past 10 years. The range in values for water-soluble concentrations obtained from soil samples from the Hogback and Hammond Projects are comparable with data from other BOR studies.

Inorganic Constituents in Biota

Analyses of plant, invertebrate, amphibian, and fish samples showed that plants, particularly algae, generally had the greatest concentrations of 19 selected trace elements (Thomas and others, 1997, p. 101-125). The maximum concentrations, in dry weight, were in algae for the following constituents: aluminum (84,500 μg/g), barium (2,450 μg/g), beryllium (0.94 μg/g), lead (49 μg/g), magnesium (13,400 μg/g), manganese (16,100 μg/g), vanadium (41 μg/g), and zinc (272 μg/g). The maximum concentrations were in cattail, coontail, or duckweed for the following constituents: arsenic (24 μg/g), boron (588 μg/g), iron (31,900 μg/g), molybdenum (3.6 μg/g), and strontium (2,440 μg/g). The maximum concentrations were in invertebrates for the following constituents: cadmium (3.94 μg/g), chromium (121 μg/g), and copper (98 μg/g). The maximum concentration of nickel (53.2 μg/g) was in amphibians. The maximum concentration of mercury (0.42 μg/g) was in fish, and the maximum concentration of selenium (24 μg/g) was in both a fish sample and an invertebrate sample.

Organic Constituents in Water and Bottom Sediment

PAH compounds were not detected in whole-water samples collected in the study area above the minimum laboratory reporting limit. PAH compounds also were not present in bottom sediment at or above the minimum laboratory reporting limit with one exception. Bis (2-ethylhexyl) phthalate concentration was 1,500 micrograms per kilogram (μg/kg) in bottom sediment from site 16, Hammond Canal 0.3 mile west of Highway 44 near Bloomfield (Thomas and others, 1997).

Organochlorine Pesticides and Polychlorinated Biphenyls in Biota

Biological samples were analyzed for organochlorine pesticides and PCB concentration. Selected fish samples were analyzed only for organochlorine pesticides. Organochlorine pesticide residues generally were below the detection limit (Thomas and others, 1997, p. 126-130). Dichloro-diphenyl dichloroethylene (DDE) was the organochlorine pesticide most often present at concentrations above the detection limit. The greatest

Table 15.--Sampling sites where bottom-sediment or soil samples contained constituent concentrations greater than the upper limit of the western soils, baseline range listed in table 14

[μg/g, micrograms per gram; mi, mile; ft, foot]

Site number (fig. 3)	Habitat	Site name	Constituent	Number of samples	Samples with concentrations greater than the upper limit of western soils, baseline range (percent)	Range of concentrations that were greater than the upper limit of western soils, baseline range (μg/g)
2	Pond	Pond on north bench San Juan River 0.6 mi below dam near Archuleta	Molybdenum	2	100	13 - 26
			Selenium	2	100	1.6 - 2.7
			Strontium	2	100	1,200 - 2,600
22	Pond	West Hammond pond near Bloomfield	Selenium	3	67	1.6 - 2.6
27	Seep	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	Selenium	1	100	2.5
28	Seep	South seep to Gallegos Canyon drainage middle pond near Farmington	Selenium	1	100	4.4
29	Pond	Gallegos Canyon drainage middle pond near Farmington	Selenium	1	100	1.8
34	Pond	Ojo Amarillo Canyon drainage southwest pond near Farmington	Selenium	1	100	1.5
38	Backwater	Secondary channel of San Juan River near Kirtland	Lead	2	50	56
			Zinc	2	50	220

Table 15.--Sampling sites where bottom-sediment or soil samples contained constituent concentrations greater than the upper limit of the western soils, baseline range listed in table 14--Concluded

Site number (fig. 3)	Habitat	Site name	Constituent	Number of samples	Samples with concentrations greater than the upper limit of western soils, baseline range (percent)	Range of concentrations that were greater than the upper limit of western soils, baseline range (μg/g)
40	Tank	Stock tank at Cottonwood Spring near Newcomb	Lead	2	50	58
			Selenium	2	100	8.1 - 8.4
			Strontium	2	100	960 - 1,000
			Zinc	2	100	300 - 350
41	Seep	Seep at Cottonwood Spring near Newcomb	Selenium	1	100	3.2
			Zinc	1	100	380
44	Irrigation drainage	East hogback irrigation drain 0.7 mi above San Juan River near Waterflow	Selenium	3	100	8.1 - 23
47	Irrigation drainage	East hogback irrigation drain 0.4 mi above San Juan River near Waterflow	Selenium	4	100	4.4 - 13
49	Irrigation drainage	East hogback irrigation drain 300 ft above San Juan River near Waterflow	Selenium	2	100	1.8 - 9.8
HB1-1, HB2-1, HB3-1, HB4-1	Irrigation drainage	Hogback Irrigation Project sites, depth from 0 to 5 feet	Selenium	4	100	1.5 - 3.6

concentration of DDE was 0.021 µg/g, wet weight, in a rainbow trout sample from San Juan River at Pump Canyon (site 10). Only the 1993 biological samples were analyzed for all PCB congeners as well as for total concentrations of PCB's. One mosquitofish sample collected from the backwater south of the San Juan River 0.9 mi below the dam (site 3) contained a PCB concentration above the laboratory minimum reporting limit; other samples from this site contained no detectable contamination.

Polycyclic Aromatic Hydrocarbons in Biota

Investigators in this study tested for the presence of PAH contaminants in the aquatic environment because of the large number of dermal lesions observed on fish during the reconnaissance study (Blanchard and others, 1993) that were similar in appearance and location to lesions linked with PAH contamination in other studies. More recently, Wilson and others (1995) indicated that PAH contamination in streams throughout much of the San Juan River Basin is relatively minor (except for a reach of the Animas River near Farmington), and new evidence is less supportive of a hypothesis that the high numbers of dermal lesions may be photoactively induced by PAH contamination.

Also, preliminary histological examinations of fresh samples of fish containing lesions submitted in 1996 to the USGS, Biological Resources Division (BRD) National Fisheries Center (Leetown, West Virginia), indicate that tissue damage observed at the cellular level is different from the histological anomalies (described in the limited literature) that have been associated with PAH photoactivation. New evidence suggests that the primary causative agents may be heretofore unidentified crystalline inclusions that BRD pathologists isolated from within the dermal lesions in 1996 (Vicki Blazer, U.S. Geological Survey, oral commun., 1996).

PAH's are composed of hydrogen and carbon atoms arranged as two or more fused benzene rings. Thousands of PAH compounds exist, each differing in the number and position of aromatic rings and in the position of substituents on the basic ring structure. Eisler (1987a) provided a synthesis of technical literature on ecological and toxicological aspects of PAH's in the environment, with special reference to natural resources:

> "PAH's are ubiquitous in nature--as evidenced by their detection in sediments, soils, air, surface waters, and plant and animal tissues--primarily as a result of natural processes such as forest fires, microbial synthesis, and volcanic activities. Anthropogenic activities associated with significant production of PAH's--leading in some cases to localized areas of high contamination--include high-temperature (greater than 700 degrees Celsius) pyrolysis of organic materials typical of some processes used in the iron and steel industry, heating and power generation, and petroleum refining. Aquatic environments may receive PAH's from accidental releases of petroleum and its products, from sewage effluents, and from other sources."

The U.S. Environmental Protection Agency (EPA) has listed many of the PAH's among 65 priority pollutants (Chapman, 1982). Several of these also are listed among the 25 hazardous substances thought to pose the most significant potential threat to human health at priority Superfund sites (U.S. Department of Health and Human Services and U.S. Environmental Protection Agency, 1987). Higher molecular weight PAH's include some of the most carcinogenic chemicals known. Many PAH's and several breakdown products of this class of compounds have been documented as oncogenic, teratogenic, and mutagenic to a variety of wildlife, including fish, amphibians, birds, and mammals (Eisler, 1987a).

As the molecular weight of these compounds increases, solubility in lipids increases and resistance to oxidation and reduction decreases. Therefore, PAH's will vary in their behavior in the environment and in their biological effects. Due to their higher solubility, lower molecular weight PAH's such as naphthalene and phenanthrene are highly mobile in the aquatic environment (H.F Prest, oral commun., 1996) and present significant acute toxicity to many organisms (Eisler, 1987a). Higher molecular weight PAH's such as benzo[a]pyrene are less acutely toxic to aquatic organisms, but present greater oncogenic risks (J. Huckins, U.S. Geological Survey, oral commun., 1995). Eisler (1987b) noted that, in general, toxicity increases as molecular weight increases (although high-molecular-weight PAH's have low acute toxicity, perhaps due to their low solubility in water) and with increasing alkyl substitution on the aromatic ring.

A relatively recent discovery is that aquatic organisms exposed to certain PAH compounds that are simultaneously or subsequently exposed to sunlight (or other sources of ultraviolet radiation) have greater adverse effects than they would if merely exposed to PAH's alone (Mount, 1995). This increased sensitivity, commonly referred to as photo-activated toxicity, appears to be the result of photochemically induced chain reactions that cause free radical cycling and oxidative stress, resulting in cellular lysis and substantial tissue disruption (David Mount, U.S. Environmental Protection Agency, oral commun., 1996).

Eisler (1987a) and Baumann (1992) summarized the findings of numerous researchers who have associated PAH's with skin lesions (and with neoplasms, carcinomas, and adverse histopathological and mutagenic effects) in fish and other aquatic biota. During the San Juan NIWQP reconnaissance investigation, Blanchard and others (1993, p. 54) reported external lesions on fish collected within the study area:

> "Twenty-eight percent of flannelmouth sucker and 35 percent of channel catfish sampled had external lesions. The largest incident rate of lesions in both species was in reach F (Shiprock to Cudei)--50 percent for flannelmouth sucker and 37 percent for channel catfish."

Blanchard and others (1993) suggested that the incident rate of fish lesions in reach F was not related to selenium concentrations in water and sediment.

In 1991-92, other researchers working in the San Juan Basin noted what seemed to be an unusually high occurrence of abnormal growths on fish from the San Juan River (C. Shanks, U.S. Fish and Wildlife Service, written commun., 1993). Multiple reports of abnormalities in fish collected from the river prompted personnel from the U.S. Fish and Wildlife Service's Pinetop Fish Health Center near Pinetop, Arizona, to initiate a preliminary histopathological survey of San Juan River piscifauna. Tissue samples obtained from diseased and healthy fish were collected from the San Juan River between the Hogback diversion and Mexican Hat, Utah, in October 1992 and from secondary channels of the river between Shiprock and Bluff, Utah, in May 1993. A total of 31 apparently diseased fish and 11 healthy fish were collected in October, and 15 diseased fish and 3 healthy fish were collected in May (C. Shanks, U.S. Fish and Wildlife Service, written commun., 1993). Fish were examined in the field, and tissue samples were transferred to the Pinetop Fish Health Center for pathogen identification (Shanks, 1993).

Concurrently with some of the other 1991-92 observations and investigations suggesting associations between PAH's and lesions in San Juan River fish, Waddell and Wiens (1993) measured concentrations of PAH metabolites in bile samples collected from fish in Zahn Bay on the San Juan arm of Lake Powell. The concentrations of PAH metabolites in some of the fish examined in their study suggested gross exposure to PAH's (Bruce Waddell, U.S. Fish and Wildlife Service, oral commun., 1993).

Several fundamental reasons led to the hypothesis that PAH's might be associated with San Juan River fish disease. First, widespread potential sources of PAH contamination are in the region (for example, oil and gas exploration, production, and refining activities). Petty and others (1992) indicated that there are in excess of 20,000 oil and gas wells and several petroleum processing facilities, including oil refineries, gas processing plants, and conveyance pipelines, in San Juan County, New Mexico. Also, two large coal-fired electrical generation plants (the San Juan and Four Corners Power Plants) are located a few miles west of Farmington, New Mexico. These energy-related facilities can contribute to releases of fossil fuel-related contamination, including PAH's, into the surrounding environment (Petty and others, 1992). Secondly, by 1992, a significant body of research (Couch and Harshbarger, 1985; Baumann, 1992) had linked exposure to PAH's with elevated frequencies of fish lesions (hyperplasia and neoplasia). Finally, as previously noted above, independent studies and observations in the early 1990's throughout the San Juan River Basin questioned whether PAH's were potentially linked (possibly as an inducer) to lesions in fish. Because of concerns about whether PAH's might be adversely affecting endangered species in the San Juan River Basin, investigators used SPMD's (Huckins and others, 1993), supplemented by sediment and water assays, to determine whether water supplied to or draining from DOI irrigation projects along the San Juan River in northwest New Mexico was transporting

PAH compounds. Scientists at the USGS BRD's Midwest Science Center, in Columbia, Missouri, developed SPMD's containing a thin film of pure lipid (Triolein) for in situ passive concentration and separation of trace quantities of aqueous organic contaminants. The passive partitioning process controlling SPMD uptake simulates the tendency of aquatic life to bioconcentrate trace organic constituents. The devices enable investigators to rapidly and cost-effectively measure the presence of and estimate fish exposure to organic contaminants. The SPMD is based on concepts similar to those commonly used in passive air monitors; SPMD's also were used for atmospheric PAH assays (Petty and others, 1993) during the 1994 part of this investigation.

1993 Semipermeable-Membrane-Device Findings

In 1993, five locations (sites 14, 15, 16, 40, and 47) were selected to initially screen irrigation supply and drainage for organic contaminants (PAH's, triazine herbicide, organochlorine pesticide residues, and so on). Of primary interest was the Hammond Canal (sites 14-16), the main irrigation-supply canal used for the Hammond Irrigation Project. The Hammond Canal traverses the perimeter of a refinery southeast of the City of Bloomfield. At the time this investigation commenced, the refinery was operating under an EPA Resource Conservation Recovery Act (RCRA) enforcement action and was conducting remediation activities to remove petroleum-related contamination from ground water beneath the refinery. During the nonirrigation season, the ground-water gradient is toward the dry canal. The refinery had been pushing up berms within the canal at points above and below contact with the contaminated ground-water plume to capture any potentially contaminated water that surfaced within the unlined canal. The refinery then removed any impounded water and the berms from the canal prior to the onset of irrigation use. This study attempted to ascertain if residual PAH's in Hammond Canal sediments or in ground-water seepage entering the canal were being mobilized by the delivery of supply water during the irrigation season. Site 40, the stock tank filled by Cottonwood Spring, was used as the control site for this project. Site 47 was on the east hogback irrigation drain immediately downstream from a small inflow of produced water leaking from an abandoned oil production well.

The total concentration of PAH's accumulated in the SPMD's during the 30-day test period of 1993 is shown in figure 11. A detailed presentation of the findings is presented in Prest and Jacobson (1994). The SPMD technology is a more sensitive technique for measuring PAH's than the customary water- and sediment-collection techniques. In SPMD technology, the SPMD is submerged in water, in this case for 30 days, allowing accumulation of PAH compounds by absorption, and is proportional to both the amount of water contacted and the duration of the contact. In the customary water- and sediment-collection techniques, a sample of water or sediment is collected at a particular point in time, representing an instantaneous concentration rather than an accumulated concentration.

For this study customary water and sediment samples were collected and analyzed for PAH concentration, in addition to SPMD samples. The customary water and sediment samples gave different results than the SPMD samples. Concentrations of PAH's measured for customary sampling methods in water and sediment at sites 14, 15, 16, and 47 (Thomas and others, 1997) were below detection limits with one exception. At site 16, Bis (2-ethylhexyl) phthalate concentration was 1,500 μg/kg in sediment.

The 1993 SPMD data indicate that PAH's transported in Hammond Canal irrigation-supply water probably were at concentrations too low to be detected by customary water and sediment tests or occurred in intermittent pulses that did not coincide with sediment and water sampling events. The PAH concentration at site 40 (reference site) appears representative of a true background concentration (compared with the other four sites). On the basis of PAH concentrations in the SPMD's at site 47 (fig. 11), the malodorous (probably from hydrogen sulfide) water leaking from the abandoned petroleum production well apparently was relatively low in PAH compounds or the PAH component in leakage was heavily diluted by the volume of water in the east hogback irrigation drain.

1994 Semipermeable-Membrane-Device Findings

NIWQP investigators expanded the use of SPMD's in 1994 to include three new aquatic sampling sites and three atmospheric sites. Sites 40 and 47 were not resampled in 1994. Whereas the 1993 SPMD study had been conducted principally to screen probable locations where organic contaminants were likely to be found in irrigation water, the 1994 study focused on Hammond Canal irrigation-related activities because this location appeared to present the greatest PAH

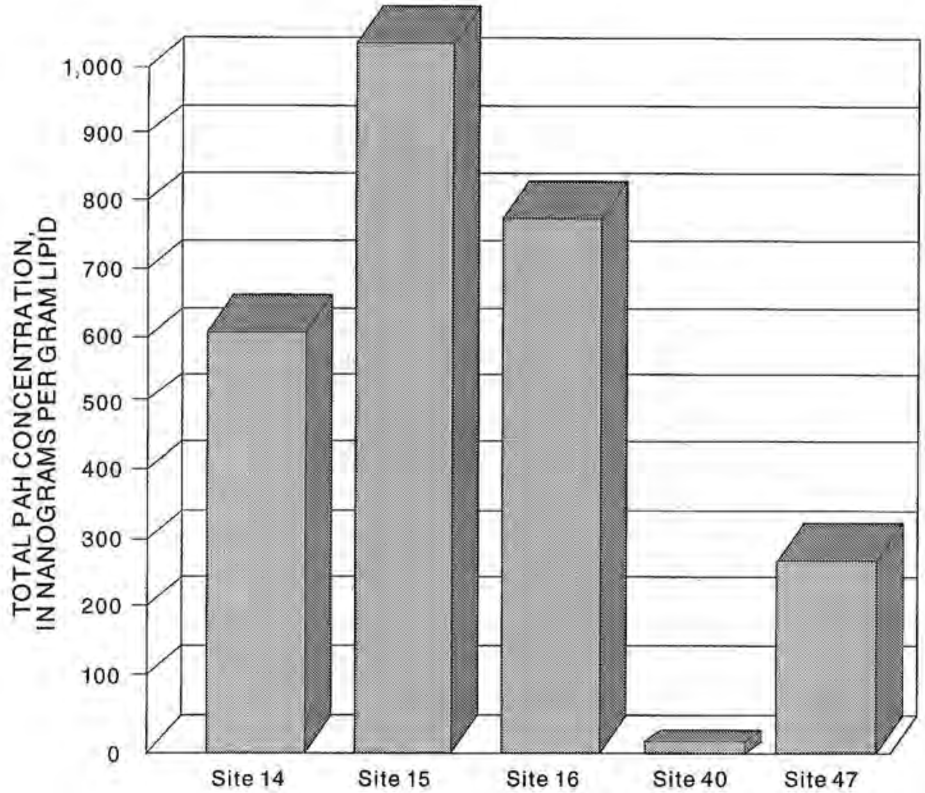


Figure 11.--Sum of polycyclic aromatic hydrocarbon (PAH) concentrations in water-sampling semipermeable-membrane devices at study sites, San Juan River area, New Mexico, 1993 Sum does not include naphthalene, 1 methyl and 2-methyl naphthalene, biphenyl, or phenanthrene D-10.

exposure risks to fish and wildlife. Site 13 was added because it was approximately 6 miles upstream from site 14 and hopefully beyond the range of whatever influence the refinery might have had on site 14 due to atmospheric deposition of PAH's. Site 21 was added to measure PAH's in the lower reaches of the Hammond irrigation drain, and site 17 was added to measure residual PAH's at the Hammond irrigation drain's confluence with the Hammond pond (a pond/wetland complex at the terminus of the Hammond drain where irrigation-return flows seep back into the San Juan River). Site 17 was especially important because the Hammond pond/wetland complex was rich in aquatic fish and wildlife and was the point where any residual aquatic PAH's potentially could enter the San Juan River

Because PAH's were the only organic contaminants measured by the 1993 SPMD samplers, the 1994 aquatic SPMD samplers were used to test only for PAH's in the Hammond Canal and pond. Analysis of figure 12 indicates that the refinery or some other influence in close proximity is affecting concentrations of PAH's associated with Hammond Canal flows. PAH's appeared to persist in the reach of the Hammond Canal between sites 14 and 16, but apparently had dissipated, probably due to biodegradation, photo-oxidation, or adsorption to sediments, by the time flows reached site 21 If the refinery is the source of the PAH's measured in the reach of the Hammond Canal approximately 0.5 mile upstream and downstream from the facility, then atmospheric deposition probably plays a significant role because any plume of hydrocarbon-contaminated ground water from the refinery would not be expected to extend 0.5 mile upstream (to site 14) against the hydrological gradient created by the canal. However, the most important finding in the 1994 aquatic SPMD data is that PAH levels associated with Hammond Project irrigation-return flows have dissipated to very low, probably background concentrations by the time irrigation-return flows arrive at the Hammond pond, then flow into the San Juan River through an outlet in the pond.

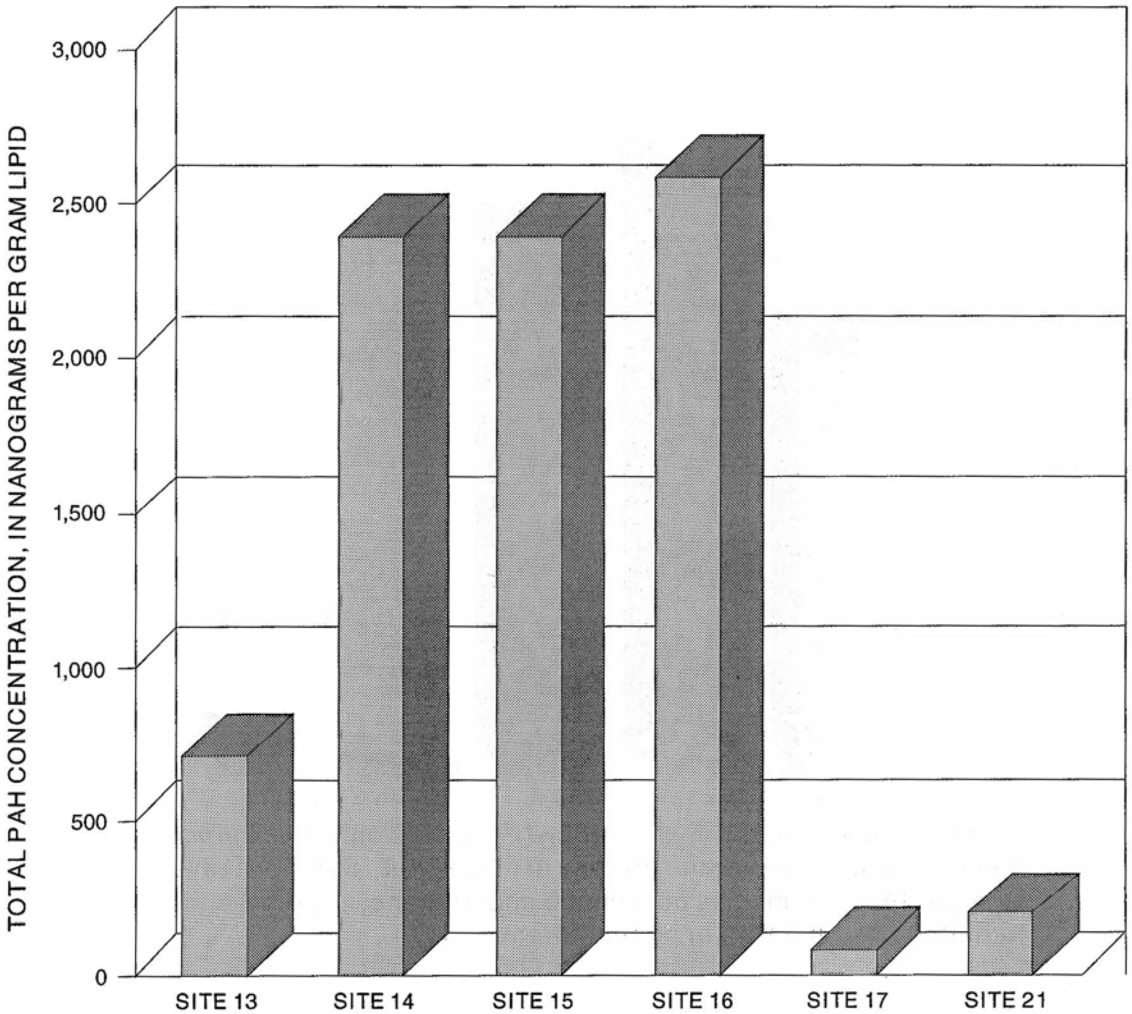


Figure 12.--Sum of polycyclic aromatic hydrocarbon (PAH) concentrations in water-sampling semipermeable-membrane devices at study sites, San Juan River area, New Mexico, 1994. Sum does not include naphthalene or 1-methyl or 2-methyl naphthalene

The 1993 and 1994 aquatic SPMD data are not directly comparable. Due to differences in the preparation of the SPMD's, analytical methodologies, and constituents tested for in 1993 and 1994, the data should be used principally for inferring trends and making relative comparisons between sites.

The three atmospheric SPMD sampling stations were located at sites 13, 14, and 15. Site 13 was selected primarily as a reference site for comparing any differences between sites 14 and 15 because the area around the Hammond Conservancy District Headquarters was believed to be secure and thus the SPMD's were unlikely to be tampered with. Site 14 was located approximately 0.5 mile east and downwind (according to the prevailing wind) of site 15. The atmospheric SPMD samplers were positioned in close proximity to aquatic SPMD samplers at sites 13 and 14. However, investigators believed the area around site 15 (the site nearest to the refinery) was too exposed for an atmospheric sampler and thus would have been subject to a high likelihood of tampering. Therefore, the atmospheric SPMD sampler associated with site 15 was located on the south side of the San Juan River, directly across from the Bloomfield City Park, at the foot of the high bank beneath the refinery facility. The atmospheric SPMD data are presented in Thomas and others (1997) and in figure 13 of this report.

The atmospheric SPMD bar graph data shown in figure 13, coupled with the numerical data in Thomas

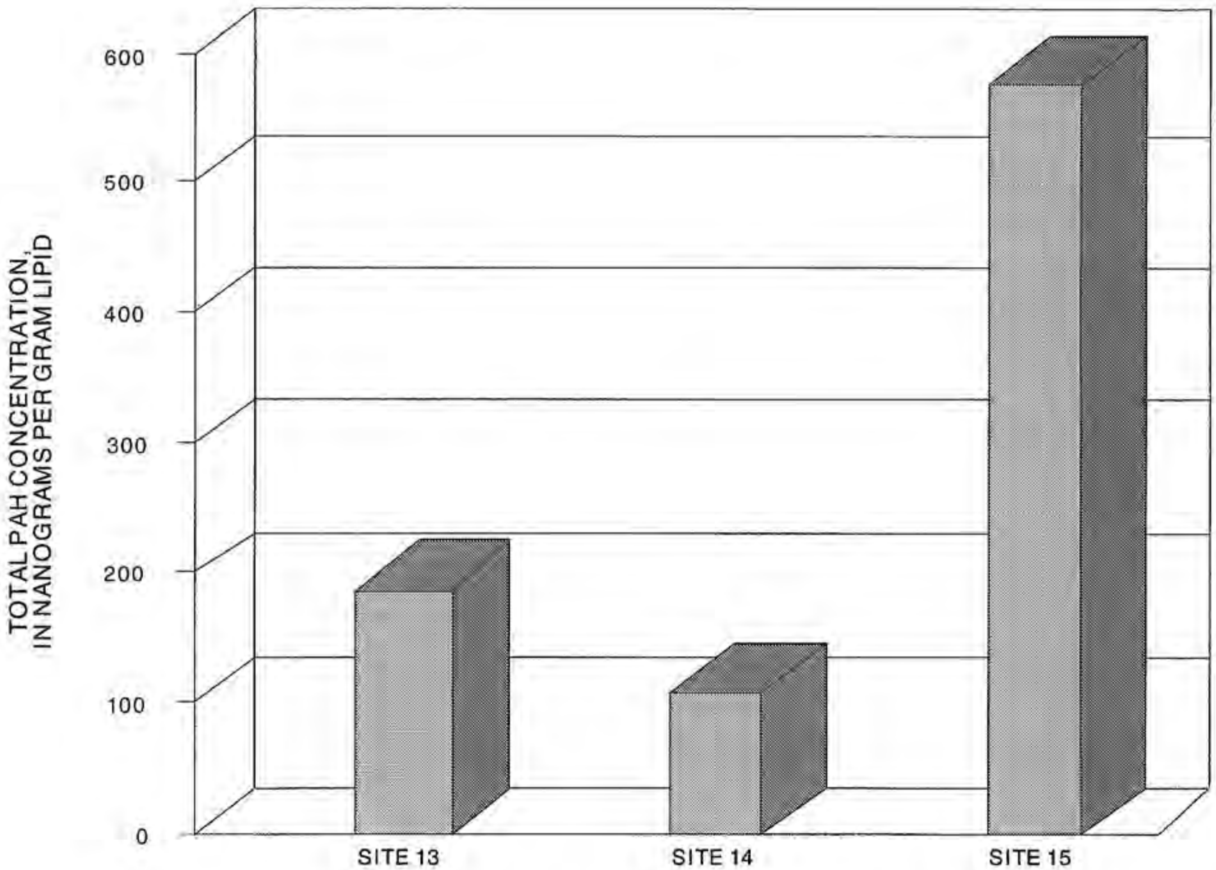


Figure 13 --Sum of polycyclic aromatic hydrocarbon (PAH) concentrations in air-sampling semipermeable-membrane devices at study sites, San Juan River area, New Mexico, 1994. Sum does not include naphthalene or 1-methyl or 2-methyl naphthalene.

and others (1997), indicate a PAH profile around the refinery that is greatly diminished at sites 13 and 14. Also, investigators were surprised to discover a greater total concentration of PAH's at site 13 (reference site) than at site 14, due to site 14's relatively close proximity to site 15. However, the differences between sites 13 and 14 are probably within the normal range of variability for the current atmospheric SPMD technology and likely do not represent substantially different levels of atmospheric PAH.

CONCERNS

Selenium and other trace elements are essential for many life forms, but can cause illnesses, deformities in offspring, and toxicity when present at high levels in animal and human diets. Various standards have been set and criteria suggested to protect animals and humans from ill effects related to elevated chemical-constituent concentrations in water and food items. Standards are enforceable limits set by agencies with legal responsibility. Criteria are non-enforceable limits suggested by agencies or individuals.

Plants that grow in soils rich in selenium may concentrate selenium and cause death to animals consuming them. Selenium poisoning in grazing animals was reported as early as 1857 in an area of western South Dakota (Gough and others, 1979, p. 41-42). Chronic selenium poisoning is caused by animals consuming plants containing 10-30 ppm selenium, dry weight, according to Weswig (1973, p. 183-203). Gough and others (1979, p. 42) cited studies reporting selenium poisoning in diets containing 5 ppm or more of selenium.

Selenium poisoning in humans through the consumption of food and water is reported to be rare and tends to be restricted to some highly seleniferous areas whose populations depend largely on local agricultural produce (Gough and others, 1979, p. 43). Gough and others (1979, p. 44) cited reports listing selenium concentrations higher than 3 ppm in the whole diet as toxic to humans. The maximum contaminant level for selenium in human drinking water is 50 ppb (table 16) according to the EPA (U.S. Environmental Protection Agency, 1994).

Water Quality and Beneficial Uses of Water

Water-quality standards are set by the State or EPA to protect water for beneficial uses (table 16). The suitability of water in the study area for wildlife-habitat, fishery, livestock, and irrigation use and for human consumption was determined by comparing analytical results to the water-quality standards listed in table 16. Wildlife-habitat standards were the most often exceeded.

Wildlife-Habitat Use

Wildlife-habitat standards for total mercury and total selenium (table 16) were compared to water samples collected at NIWQP sites for mercury and NIWQP and supplemental sites for selenium (figs. 3 and 4, tables 1 and 2). Samples were from river, tributary, backwater, pond, or seep sites where wildlife might be found. These sites included those with a habitat listed as San Juan River, San Juan River tributary, backwater, pond, or seep. Irrigation-drainage sites also were considered as sites where wildlife might be found except for the Hammond Project drains that are underground.

Mercury was not present in the samples collected at concentrations greater than the wildlife-habitat standard. Dissolved mercury was not detected above the laboratory reporting limit in any of the NIWQP samples. Mercury concentrations detected in supplemental samples were disqualified because of quality-assurance/quality-control data.

Dissolved-selenium values were compared to total-selenium standards when whole-water samples were not collected. The assumption was that total selenium would be equal to or greater than dissolved selenium; therefore, any dissolved-selenium concentrations exceeding the standard implied that total selenium also exceeded the standard.

Comparisons show that selenium concentrations in water exceeded the 2-µg/L standard for wildlife habitat at 28 sites (table 17). Samples from 10 of 17 tributary sites, 8 of 18 pond sites, 5 of 5 seep sites, 4 of 7 surface irrigation-drainage sites, and 1 of 57 river sites exceeded the standard. Multiple samples were collected temporally during 1993-94 at each site. Selenium concentrations in water from the 10 tributary sites exceeded the standard in 8.3 to 100 percent of the samples collected from each site and had an overall range of 3 to 37 µg/L. Five of the 10 tributary sites at which the standard also was exceeded are outside the area of hydrologic influence by DOI irrigation projects. Selenium concentrations at these sites ranged from 3 to 12 µg/L; exceedances per site ranged from 8.3 to 90 percent of the samples collected at each site.

Selenium concentrations in samples from eight pond sites ranged from 3 to 26 µg/L, exceedances per site ranged from 25 to 100 percent of the samples collected. Seven of the eight pond sites are located within the area of irrigated agriculture. Selenium concentrations in samples from five seeps exceeded the standard in 50 to 100 percent of the samples collected, and the selenium concentrations that exceeded the standard ranged from 3 to 24 µg/L. Four of the seeps are located downgradient from irrigated fields. The fifth seep, site 41 at Cottonwood Spring near Newcomb, is a reference seep located outside the area of irrigated agriculture, and selenium concentrations in samples that exceeded the standard were 3 µg/L.

Most of the samples that exceeded the 2-µg/L standard for wildlife habitat were collected from sites within the area of hydrologic influence by DOI irrigation projects. Interestingly, however, selenium concentrations in water from reference sites outside the area of hydrologic influence by DOI irrigation projects also exceeded the standard for wildlife habitat, suggesting that background concentrations of selenium are naturally greater than the standard. Just how much the irrigation process might elevate selenium concentrations in water is not known.

Fishery Use

Cadmium, chromium, copper, lead, selenium, and zinc standards for fishery waters (table 16) were compared to analyses of water collected at NIWQP and supplemental sites (figs. 3 and 4; tables 1 and 2) upstream from the Blanco Bridge and within the

Table 16.-- Water-quality standards for beneficial uses of water (modified from Butler and others, 1993)

[Standards are enforceable limits set by agencies with legal responsibility. Chronic standards are for protection of wildlife from adverse effects, such as lethality, growth impairment, disease, and reproductive problems caused by long-term exposure. Acute standards are for protection of wildlife from lethal or other toxic effects within 96 hours. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level, µg/L, micrograms per liter; mg/L, milligrams per liter; --, no value]

Constituent	Fishery water Chronic standards[1]	Fishery water Acute standards[1]	Wildlife-habitat water standards[1]	Public drinking-water standards MCL[1]	Public drinking-water standards MCL[2]	Public drinking-water standards SMCL[2]	Livestock drinking-water standards[1]	Irrigation water standards[1]
Dissolved arsenic (µg/L)	--	--	--	50	50	--	200	100
Dissolved boron (µg/L)	--	--	--	--	--	--	5,000	750
Dissolved cadmium (µg/L)	[3]1.1/3.4	[3]3.9/19	--	10	5	--	50	10
Dissolved chromium (µg/L)	[3]210/640	[3]1,700/5,400	--	50	100	--	1,000	100
Dissolved copper (µg/L)	[3]12/39	[3]18/65	--	--	1,300	--	500	200
Dissolved lead (µg/L)	[3]3.1/19	[3]82/480	--	50	15	--	100	5,000
Total mercury (µg/L)	0.012	2.4	[5]0.012	2	--	--	10	--
Dissolved mercury (µg/L)	--	--	--	--	2	--	--	--
Dissolved molybdenum (µg/L)	--	--	--	--	--	--	--	1,000
Total selenium (µg/L)	2	20	[5]2	--	--	--	--	--
Dissolved selenium (µg/L)	--	--	--	50	50	--	50	[4]130/250
Dissolved vanadium (µg/L)	--	--	--	--	--	--	100	100
Dissolved zinc (µg/L)	[3]110/340	[3]120/380	--	--	--	5,000	25,000	2,000
Dissolved chloride (mg/L)	--	--	--	--	--	250	--	--
Dissolved solids (mg/L)	--	--	--	--	--	500	--	--
Dissolved sulfate (mg/L)	--	--	--	--	--	250	--	--

[1]New Mexico Water Quality Control Commission, 1995.
[2]U.S. Environmental Protection Agency, 1994.
[3]Standards are based on water hardness. Values were computed using a water hardness of 100 mg/L/400 mg/L.
[4]Standard is based on sulfate content. Values are for water with sulfate content less than 500 mg/L/sulfate content greater than 500 mg/L.
[5]Standard is applicable for sites without specific information indicating background levels higher than listed value.

Table 17.--San Juan River, San Juan River tributary, backwater, pond, or seep sites that contained constituent concentrations greater than the standards for wildlife habitat listed in table 16

[µg/L, micrograms per liter]

Site number (figs. 3 and 4)	Habitat	Site name	Constituent	Number of samples	Number of samples with concentrations greater than standard	Range of concentrations that were greater than standard (µg/L)
22	Pond	West Hammond pond near Bloomfield	Selenium	5	2	3-6
23	San Juan River tributary	Gallegos Canyon near Carson Trading Post	Selenium	17	11	3-12
27	Seep	Southeast seep to Gallegos Canyon drainage middle pond near Farmington	Selenium	3	3	18-24
28	Seep	South seep to Gallegos Canyon drainage middle pond near Farmington	Selenium	3	3	17-24
29	Pond	Gallegos Canyon drainage middle pond near Farmington	Selenium	3	3	13-26
30	San Juan River tributary	Gallegos Canyon near Farmington	Selenium	53	50	3-30
31	Seep	East seep to Ojo Amarillo Canyon drainage southwest pond near Farmington	Selenium	2	2	7-22
33	Seep	Northeast seep to Ojo Amarillo Canyon drainage north pond near Farmington	Selenium	2	2	9
34	Pond	Ojo Amarillo Canyon drainage southwest pond near Farmington	Selenium	3	2	6-9
35	San Juan River tributary	Ojo Amarillo Canyon near Fruitland	Selenium	52	52	7-37

Table 17.--San Juan River, San Juan River tributary, backwater, pond, or seep sites that contained constituent concentrations greater than the standards for wildlife habitat listed in table 16--Continued

Site number (figs. 3 and 4)	Habitat	Site name	Constituent	Number of samples	Number of samples with concentrations greater than standard	Range of concentrations that were greater than standard (µg/L)
39	Pond	Pond at Cottonwood Spring near Newcomb	Selenium	4	1	3
41	Seep	Seep at Cottonwood Spring near Newcomb	Selenium	4	2	3
44	Irrigation drainage	East hogback irrigation drain 0.7 mile above San Juan River near Waterflow	Selenium	4	4	10-14
47	Irrigation drainage	East hogback irrigation drain 0.4 mile above San Juan River near Waterflow	Selenium	7	7	8-16
48	Irrigation drainage	East hogback irrigation drain 0.2 mile above San Juan River near Waterflow	Selenium	1	1	15
49	Irrigation drainage	East hogback irrigation drain 300 feet above San Juan River near Waterflow	Selenium	3	3	7-11
50	San Juan River tributary	Salt Creek at highway bridge near Shiprock	Selenium	1	1	37
29S	San Juan River tributary	Gallegos Canyon	Selenium	11	8	3-22
30S	Pond	1-18 pond	Selenium	11	10	4-20
32S	Pond	1-25 pond	Selenium	11	6	6-25
34S	Pond	1-35 pond	Selenium	22	8	4-13

Table 17.--San Juan River, San Juan River tributary, backwater, pond, or seep sites that contained constituent concentrations greater than the standards for wildlife habitat listed in table 16--Concluded

Site number (figs. 3 and 4)	Habitat	Site name	Constituent	Number of samples	Number of samples with concentrations greater than standard	Range of concentrations that were greater than standard (µg/L)
37S	San Juan River tributary	La Plata River at La Plata Bridge	Selenium	12	3	3-4
44S	San Juan River tributary	La Plata River at mouth	Selenium	12	1	3
47S	Pond	Ojo Amarillo Pond	Selenium	11	4	4-13
49S	San Juan River tributary	Ojo Amarillo Canyon	Selenium	10	10	9-33
59S	San Juan River tributary	Chaco Wash	Selenium	12	1	4
63S	San Juan River	San Juan River at Shiprock Bridge	Selenium	24	1	3
71S	San Juan River tributary	Mancos River near Four Corners	Selenium	10	9	3-12

Quality-Trout-Water reach (sites 1, 3, 4, 5, 6, 10, 11, 1S, 2S, 3S, 4S, 5S, 7S, 8S, 9S, and 10S). Mercury standards for fishery waters (table 16) were compared to analyses of water collected at NIWQP sites 1, 3, 4, 5, 6, 10, and 11. Water samples did not exceed the fishery standards

Livestock Use

Vanadium was the only constituent exceeding the standards for livestock drinking water listed in table 16. Standards for livestock drinking water were compared to analyses of water collected at NIWQP and supplemental sites (figs. 3 and 4; tables 1 and 2) where livestock might water. These sites included those with a river, tributary, backwater, pond, or stock tank habitat. A vanadium concentration of 390 µg/L (Thomas and others, 1997) exceeded the 100-µg/L standard for livestock drinking water in one of two samples collected at Gallegos Canyon near Carson Trading Post (site 23).

Irrigation Use

Standards for irrigation water listed in table 16 were compared to water samples collected at NIWQP and supplemental sites (figs. 3 and 4; tables 1 and 2) listed as irrigation-delivery sites. Water samples did not exceed irrigation-water standards.

Human Consumption

Water samples collected at the Animas River at Aztec Bridge (site 21S) (fig. 4, table 2) did not exceed standards for public drinking-water supplies (table 16). The Animas River supplies drinking water for the City of Farmington.

Avian Risks Related to Feeding

Because the DOI is a trustee for migratory birds, a comparison procedure was used to determine which, if any, contaminants found at a site were present in concentrations that may be harmful to migratory birds. The concentrations in sampled invertebrates, whole fish, and amphibians (identified as likely bird-food items) were compared to dietary threshold concentrations (table 18); if the concentration equaled or exceeded threshold concentrations, further assessment was considered warranted. Aluminum and selenium in invertebrate, fish, and amphibian samples regularly exceeded dietary threshold concentrations (table 19).

Although concentrations above dietary threshold concentrations do not indicate the level or type of risk involved, concentrations below the threshold should not result in significant adverse effects to avian species. When concentrations in environmental samples regularly exceed dietary threshold concentrations, there is sufficient concern regarding potential adverse effects to avian species to warrant further investigation. These avian dietary threshold concentrations are meant to be used only for screening purposes. They are not regulatory criteria and are not applicable to other species of wildlife such as fish, amphibians, or mammals.

At about a third of the collection sites 50 percent or more of samples collected equaled or exceeded the dietary aluminum threshold concentration (200.0 µg/g, wet weight). Aluminum concentrations in biota most likely indicate the presence of mineral matter (for example, in the gut or on the tissue surface) rather than the actual incorporation of aluminum into the tissue. This study was not designed to distinguish the difference. Therefore, the evaluation of health risks likely is conservative. Nonetheless, areas where investigators found elevated aluminum in biota approximately correspond to the 31-mile reach of the San Juan River (bounded by the confluences of the Animas and Chaco Rivers) that has been identified as having water-quality impairment due to excessive dissolved aluminum (New Mexico Water Quality Control Commission, 1994, table 18, p. B-22).

The dietary threshold concentration for selenium was equaled or exceeded in invertebrate, whole-fish, or amphibian samples at 18 sites (sites 2, 3, 4, 5, 6, 10, 11, 22, 29, 34, 35, 38, 39, 42, 43, 49, 51, and 52). At several sites (sites 10, 29, 34, and 49) biological samples (invertebrates, whole fish, and amphibians) regularly equaled or exceeded the dietary threshold concentration (table 19). The highest selenium concentrations in biological samples were collected from the east hogback irrigation drain near Waterflow (site 49), and predation by wildlife likely presents some health risks.

Several other constituents (barium, cadmium, chromium, iron, mercury, and zinc) in biological samples occasionally equaled or exceeded dietary threshold concentrations. The highest concentration of cadmium was detected at site 51 near Cudei. Mercury concentrations that equaled or exceeded avian dietary thresholds were found in biological samples collected from sites in the Quality-Trout-Water reach of the San Juan River.

Table 18.--Dietary threshold concentrations suggested for avian species

[Dietary threshold concentrations are not legally enforceable limits; rather, they are based on laboratory feeding studies or suggested by agencies or individuals. References indicate the source of the threshold concentration. When threshold concentrations were reported in dry weight, the concentration was converted to wet weight using either the reported moisture content or 75 percent moisture. Threshold concentrations in avian dietary items (such as in invertebrates, fish, and amphibians) are conservative and are attempts to ensure protection of avian species from adverse effects, such as lethality, bioaccumulation, growth impairment, disease, and reproductive problems, caused by long-term ingestion. However, individual species' responses are variable and the reader is advised to consult the original reference prior to using any values in this table]

Constituent	Dietary threshold concentration (microgram per gram, wet weight)	Reference
Aluminum	200.0	National Research Council, 1980
Arsenic	30.0	Eisler, 1994
Barium	20.0	National Research Council, 1980
Boron	30.0	Eisler, 1990
Cadmium	0.1	Eisler, 1985
Chromium	5.1	Eisler, 1986
Copper	300.0	National Research Council, 1980
Iron	1,000.0	National Research Council, 1980
Lead	50.0	National Research Council, 1980
Magnesium	3,000.0	National Research Council, 1980
Manganese	2,000.0	National Research Council, 1980
Mercury	0.1	Eisler, 1987a
Molybdenum	100.0	National Research Council, 1980
Nickel	100.0	National Research Council, 1980
Selenium	0.8	Lemly and Smith, 1987[1]
Strontium	3,000.0	National Research Council, 1980
Vanadium	10.0	National Research Council, 1980
Zinc	44.5	Eisler, 1993[2]
Dichlorodiphenyltrichloroethane (DDT)	1.0	International Joint Commission, 1993
Polychlorinated biphenyl (PCB)	0.1	International Joint Commission, 1993

[1]Reported concentration was 3 μg/g, dry weight.

[2]Reported concentration was 178 μg/g, dry weight.

Table 19.--Sampling sites where biological samples (invertebrates, amphibians, and whole fish) contained constituent concentrations equal to or greater than the dietary threshold concentrations suggested for avian species listed in table 18

[µg/g, micrograms per gram]

Site number (fig. 3)	Site name	Constituent	Number of samples with concentrations equal to or greater than lower limit of detection/ number of samples analyzed	Percentage of samples with concentrations equal to or greater than dietary threshold concentrations	Range of wet-weight concentrations that were equal to or greater than dietary threshold concentrations (µg/g)
12	Pond on north bench San Juan River 0.6 mile below dam near Archuleta	Cadmium	6/6	16.7	0.1
		Selenium	5/6	16.7	1 1
3	Backwater south of San Juan River 0.9 mile below dam near Archuleta	Aluminum	14/14	42.9	205 - 542
		Cadmium	13/14	21.4	0.1 - 0.2
		Mercury	14/14	7.1	0.1
		Selenium	14/14	64.3	0 9 - 2.3
		Zinc	14/14	42.9	49.2 - 77.4
4	San Juan River at Texas Hole 1.4 mile below dam near Archuleta	Aluminum	27/28	7.4	339 - 636
		Selenium	28/28	75.0	0.9 - 2.7
5	Backwater south of San Juan River 3 1 miles below dam near Archuleta	Aluminum	19/19	5.3	226
		Selenium	19/19	57.9	0.9 - 1.4
6	San Juan River at Simon Canyon 3 5 miles below dam near Archuleta	Aluminum	15/15	20.0	228 - 578
		Barium	9/9	11.1	21.9
		Cadmium	14/15	6.7	0.2
		Mercury	15/15	6.7	0.1
		Selenium	15/15	60.0	0.8 - 1.8
10	San Juan River at Pump Canyon 9 5 miles below dam near Archuleta	Aluminum	21/21	9.5	710 - 720
		Cadmium	21/21	4.8	0.2
		Selenium	21/21	100.0	0.8 - 2.2
11	San Juan River at Shriner's property 10.6 miles below dam near Archuleta	Aluminum	22/22	9.1	642 - 923
		Selenium	22/22	81.8	0.9 - 2.6
12	East Hammond Project pond near Blanco	Aluminum	7/7	14.3	274

Table 19.--Sampling sites where biological samples (invertebrates, amphibians, and whole fish) contained constituent concentrations equal to or greater than the dietary threshold concentrations suggested for avian species listed in table 18--Continued

Site number (fig. 3)	Site name	Constituent	Number of samples with concentrations equal to or greater than lower limit of detection/ number of samples analyzed	Percentage of samples with concentrations equal to or greater than dietary threshold concentrations	Range of wet-weight concentrations that were equal to or greater than dietary threshold concentrations (µg/g)
22	West Hammond pond near Bloomfield	Aluminum	7/7	28.6	206 - 234
		Selenium	7/7	71.4	1 1 - 2.0
29	Gallegos Canyon drainage middle pond near Farmington	Selenium	1/1	100.0	4.25
34	Ojo Amarillo Canyon drainage southwest pond near Farmington	Selenium	3/3	100.0	1.0 - 1.4
35	Ojo Amarillo Canyon near Fruitland	Aluminum	6/6	66.7	231 - 2,182
		Barium	6/6	16.7	128.8
		Cadmium	5/6	16.7	0.3
		Iron	6/6	16.7	1,553
		Selenium	6/6	83.3	1.4 - 3.4
		Zinc	6/6	16.7	70 4
37	Fruitland irrigation drain at wetland near Fruitland	Aluminum	12/12	66.7	240 - 1,850
		Iron	12/12	8.3	1,211
		Zinc	12/12	8.3	70.5
38	Secondary channel of San Juan River near Kirtland	Aluminum	7/7	85 7	292 - 991
		Cadmium	7/7	28.6	0.1 - 0.2
		Selenium	7/7	28.6	1.2 - 1 7
39	Pond at Cottonwood Spring near Newcomb	Selenium	3/3	66.7	1 1 - 1.4
		Zinc	3/3	33.3	40 - 62
42	San Juan River backwater at Hogback Diversion Dam near Waterflow	Aluminum	6/6	50.0	283 - 712
		Cadmium	6/6	33.3	0.1 - 0 1
		Selenium	6/6	66.7	0.8 - 2.4
		Zinc	6/6	16.7	47 8
43	Pond draining Fruitland Irrigation Project at Hogback near Waterflow	Aluminum	10/10	30.0	226 393
		Cadmium	10/10	10.0	0.1
		Iron	10/10	30.0	1,230 - 2,349
		Selenium	10/10	40.0	0.8 - 1.2

Table 19.--Sampling sites where biological samples (invertebrates, amphibians, and whole fish) contained constituent concentrations equal to or greater than the dietary threshold concentrations suggested for avian species listed in table 18--Concluded

Site number (fig. 3)	Site name	Constituent	Number of samples with concentrations equal to or greater than lower limit of detection/ number of samples analyzed	Percentage of samples with concentrations equal to or greater than dietary threshold concentrations	Range of wet-weight concentrations that were equal to or greater than dietary threshold concentrations (μg/g)
49	East Hogback irrigation drain 300 feet above the San Juan River near Waterflow	Aluminum	11/11	54.5	214 613
		Chromium	11/11	9.1	21.3
		Selenium	11/11	100.0	1.2 6.2
51	Cudei irrigation canal at turnout from San Juan River near Cudei	Aluminum	10/10	50.0	215 - 1,132
		Cadmium	10/10	40.0	0.1 - 1.4
		Chromium	10/10	10.0	6.7
		Selenium	10/10	40.0	0.9 - 1 8
		Zinc	10/10	20.0	61.8 - 66.8
52	Cudei irrigation drain near Cudei	Aluminum	3/3	66.7	246 - 372
		Cadmium	3/3	33.3	0.2
		Selenium	3/3	33.3	1.0

Biological samples were similarly evaluated for organochlorine pesticide residues and PCB's. No organochlorine pesticide residues or PCB's were detected that exceeded dietary threshold concentrations (table 18). However, this assessment was based on total PCB's. Total PCB's represent a class of 209 chemicals that have varying physical properties and degree of toxicity. This assessment did not take into account individual PCB toxicity.

SUMMARY AND CONCLUSIONS

The USGS, USFWS, BOR, and BIA collected water, bottom-sediment, soil, and biological samples at 61 sites in the San Juan River area during 1993-94 as part of a NIWQP investigation to determine the quality of irrigation drainage and its potential effects on fish, wildlife, and human health. Most potentially toxic elements other than selenium generally were not sufficiently elevated to be of concern to fish, wildlife, and human health, although concentrations in some water, bottom-sediment, soil, and biological samples exceeded applicable standards and criteria.

Selenium was much less concentrated in water samples than in bottom-sediment, soil, or biota samples collected in the San Juan River study area. The dissolved-selenium concentration in water ranged from less than 1 to 37 µg/L (less than 1 to 37 ppb). Total-selenium concentration in bottom sediment and soil ranged from less than 0.1 to 23 µg/g (less than 100 to 23,000 ppb). The range of selenium concentration in biota was less than 0.1 to 24.0 µg/g (less than 100 to 24,000 ppb). Selenium-concentration ranges in biota, by trophic level, were: aquatic vegetation, less than 0 1 to 20 µg/g; aquatic invertebrates, less than 0.4 to 24.0 µg/g; whole fish, 0 3 to 24.0 µg/g; and amphibians, 0.6 to 20 3 µg/g.

Mean selenium concentrations in water samples were greatest from seeps and tributaries draining irrigated lands (17 µg/L); less concentrated at irrigation-drainage sites and ponds on irrigated land (6 µg/L); and least concentrated at irrigation-supply sites, backwater, and San Juan River sites (0.5 to 0.6 µg/L). Mean dissolved-selenium concentrations, by site, in NIWQP and supplemental water samples were greatest in three areas: the Ojo Amarillo Canyon drainage of the NIIP (9 to 23 µg/L at sites 31, 33, 35, and 49S); the Gallegos Canyon drainage of the NIIP (9 to 21 µg/L at sites 27-30, 29S, 30S, and 32S); and the Hogback Project drainage sites (9 to 15 µg/L at sites 44 and 47-49). At a reference seep outside the area affected by irrigation, site 41, the mean dissolved-selenium concentration was 2 µg/L and at tributary sites unaffected by irrigation, sites 23 and 6S, the mean dissolved-selenium concentrations were 4 µg/L.

Water samples from sites with Cretaceous soils had significantly greater selenium concentrations than water samples from sites with non-Cretaceous soils. The Hogback Project is developed on the Cretaceous Mancos Shale, and the NIIP is developed partly on Cretaceous formations and partly on non-Cretaceous formations. In contrast, the Cudei, Fruitland, and Hammond Projects are developed wholly on non-Cretaceous formations (alluvium or the Nacimiento Formation). Mean selenium concentrations in water samples from irrigation-drainage sites on the Hogback and NIIP were about 10 times greater than those from the Hammond, Fruitland, and Cudei Projects. Mean selenium concentrations at the Hogback and NIIP were 11 and 14 µg/L, and at the Hammond, Fruitland, and Cudei Projects were 2.5, 0.5, and 0.5 µg/L, respectively. Samples from the Hogback and NIIP Projects showed increased selenium concentrations compared with reference sites. The application of irrigation water to selenium-rich Cretaceous soils increases the possibility of leaching and selenium mobilization from soils.

Concentrations of total selenium in bottom-sediment and soil samples were significantly greater for Cretaceous than for non-Cretaceous soil types in the study area. Mean and median total-selenium concentrations in samples from areas with Cretaceous soils were 4.6 and 2.2 µg/g. Mean and median total-selenium concentrations in samples from areas with non-Cretaceous soils were 0.6 and 0 15 µg/g, respectively. Selenium concentrations in samples collected from similar habitat within and outside irrigation-affected areas were not significantly different.

Graphical techniques and statistical tests show that species of sucker and smaller fish contained significantly greater selenium concentrations in the upstream part of the San Juan River. Increased selenium concentrations in fish in this part of the river may be linked with the productive community of plants and animals found associated with warming, nutrient-rich waters discharged from the upstream reservoir.

Selenium concentrations in algae, odonate nymphs, and mosquitofish collected from both irrigation-drain and pond habitats underlain by

Cretaceous soils were significantly greater than in these same species collected from similar habitats underlain by non-Cretaceous soils. Median selenium concentrations were less than 2 µg/g for plants, less than 7 µg/g for invertebrates, and less than 6 µg/g for whole fish from aquatic habitats underlain by non-Cretaceous soils. Plant, invertebrate, and whole-fish samples contained median selenium concentrations two to five times greater in biota from aquatic habitats underlain by Cretaceous soils than from those underlain by non-Cretaceous soils in the San Juan River area. Investigators conclude that the geologic variable of Cretaceous soils is the major factor affecting the variability of selenium accumulation in biota at the aquatic habitats sampled in the San Juan River area. Cretaceous soils increase the accumulation of selenium concentrations in biota and thereby increase the exposure and potential health risks associated with selenium to migratory birds, fish, and other wildlife that use these aquatic habitats exclusively. The greatest average exposure to excess selenium concentrations in the diets of resident wildlife is from consumption of plants, invertebrates, and fish at irrigation-drain habitats underlain by Cretaceous soils in the San Juan River area.

Of the irrigation projects evaluated in the San Juan River area, selenium concentrations were generally greatest in water, biota, soil, and sediment samples collected from the Hogback Project and NIIP Median selenium concentrations were greatest in algae, cattail leaves, odonate nymphs, mosquitofish, and leopard frog samples collected from the east hogback irrigation drain, and consumption by wildlife likely presents some health risks. Selenium concentrations generally were smallest in water, biota, soil, and sediment samples from the San Juan River main stem and the Hammond, Fruitland, and Cudei Projects.

Algae samples from reference sites contained greater median selenium concentration than those from the San Juan River main stem and the Hammond, Fruitland, and Cudei Projects, indicating that relatively large concentrations of selenium may occur naturally in the study area. Selenium-rich Cretaceous soils appear to be the source.

Data indicated that leaching from soil and bioaccumulation were the processes leading to elevated levels of selenium in water and biota in the San Juan River study area rather than atmospheric deposition of selenium-containing aerosols, evapoconcentration of selenium, or contamination of surface water through point-source or non-point-source discharges. Plots of the stable isotopic ratios of hydrogen and oxygen in water indicated that leaching from soil leads to elevated levels of selenium in water in the study area. Also, selenium concentrations in irrigation-supply water and irrigation-drainage water indicated that selenium is being leached from soil. Bioaccumulation was indicated as a process leading to elevated levels of selenium in biota. Geometric-mean selenium concentrations were greatest in amphibians (4.67 µg/g) and fish (3.84 µg/g), less in aquatic invertebrates (3.03 µg/g), and least in aquatic vegetation (0.90 µg/g), showing increasing concentration at the higher trophic levels. In addition, the concentration range of selenium in biota is about 1,000 times that of dissolved selenium in water and about the same as that in bottom sediment and soil.

Lead, molybdenum, selenium, strontium, and zinc in bottom sediment and selenium in soil at some of the NIWQP sites exceeded the upper limit of the western soils, baseline range. Selenium exceedances (24) outnumbered those for lead (2), molybdenum (2), strontium (4), and zinc (4). Hogback Project soils had greater concentrations of selenium than Hammond Project soils.

Samples from the study area contained low concentrations of organic constituents. Organochlorine pesticides and PCB's were detected in a few biological samples at low concentrations. PAH compounds were not detected in whole-water samples collected using conventional water-sampling techniques. One PAH compound was detected above the minimum laboratory reporting limit in one bottom-sediment sample. In tests involving the use of SPMD's to supplement conventional water assays for PAH's, low concentrations of PAH's in water were found at several locations in and around the Hammond irrigation-supply canal. PAH's were found within the reach of the canal immediately upstream and downstream from a refinery near Bloomfield. However, PAH's were not detected at the Hammond ponds located at the extreme downstream reach of the Hammond irrigation service area; thus, PAH's in the Hammond Canal water supply do not appear to reach the San Juan River by this route. Also, no PAH's were detected by an SPMD at site 46 (leaking petroleum production well). Atmospherically deployed SPMD's detected greater concentrations of PAH's around the refinery near Bloomfield than at the other two locations.

Water-quality standards for wildlife habitat, fishery waters, livestock-drinking water, irrigation water, and human drinking water were compared to water collected at NIWQP and supplemental study sites. Selenium concentrations in water samples from 28 sites exceeded the 2-µg/L wildlife-habitat standard set by the State of New Mexico. Vanadium exceeded the 100-µg/L standard for livestock-drinking water at one site. Irrigation-water standards were not exceeded at the irrigation-delivery sites. Human drinking-water standards were not exceeded at the one study site on the Animas River that supplies drinking water for the City of Farmington.

Selenium and aluminum concentrations contained in biota sampled in this study equaled or exceeded avian dietary threshold concentrations at many sites. Barium, cadmium, chromium, iron, mercury, and zinc in biological samples equaled or exceeded dietary thresholds for avian species at some sites in 1993 and 1994.

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