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U.S. FISH & WILDLIFE SERVICE
REGION 6

CONTAMINANTS PROGRAM

MONITORING OF SELENIUM CONCENTRATIONS IN BIOTA FROM THE KENDRICK RECLAMATION PROJECT, NATRONA COUNTY, WYOMING 1992 - 1996

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ABSTRACT

Selenium is bioaccumulating in fish and aquatic birds inhabiting the Kendrick Reclamation Project (Kendrick) in Natrona County, Wyoming as a result of mobilization associated with irrigation return flows. Field studies conducted in the 1980's by the U.S. Geological Survey (Survey) and the U.S. Fish and Wildlife Service (Service) as part of the Department of Interior's National Irrigation Water Quality Program (NIWQP) revealed elevated selenium concentrations in water, sediment and biota at Kendrick and immediately downstream in the North Platte River. Selenium concentrations found in biota exceeded levels known to cause mortality and embryonic deformities in birds and impaired reproduction in fish. Additionally, reduced hatchability was documented in nesting aquatic birds.

Monitoring of selenium concentrations in water, sediment and biota was conducted by the Service and the Survey from 1992 to 1996 to assist the U.S. Bureau of Reclamation (Reclamation) in developing a remediation plan as well as to determine trends and assist in measuring remediation effectiveness. Selenium concentrations continue to exceed levels known to cause adverse effects to fish and aquatic birds. American avocet eggs collected from 1992 to 1996 contained selenium exceeding the 15 ug/g level known to cause impaired egg hatchability. In 1993, eight out of 62 (13 percent) addled avocet eggs contained deformities. Selenium concentrations in all pondweed and aquatic invertebrates exceeded the 3 ug/g dietary threshold for aquatic birds at all sites except 33-Mile Reservoir. At 33-Mile Reservoir all aquatic invertebrates exceeded the 3 ug/g dietary threshold for aquatic birds and pondweed exceeded this level in only two years of the five-year study. Whole-body selenium concentrations in rainbow trout collected from the North Platte River immediately downstream of Kendrick consistently exceeded the 4 ug/g level associated with reproductive impairment. Remediation planning for the selenium problem at Kendrick is ongoing.

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INTRODUCTION

Irrigation of seleniferous soils is known to mobilize selenium making it available for accumulation in the aquatic food chain (Presser 1994). Selenium mobilization associated with irrigation return flows from the Kendrick Reclamation Project (Kendrick), Natrona County, Wyoming is causing bioaccumulation in fish and aquatic birds (See et al. 1992, Naftz et al. 1993). Field studies conducted in 1986, 1988 and 1989 by the U.S. Geological Survey (Survey) and the U.S. Fish and Wildlife Service (Service) as part of the National Irrigation Water Quality Program (NIWQP) revealed elevated selenium concentrations in water, sediment and biota at Kendrick and immediately downstream in the North Platte River (Peterson et al. 1988, See et al. 1992). Selenium concentrations in pondweed *(Potamogeton vaginatus)*, aquatic invertebrates, aquatic bird eggs and livers, and fish exceeded threshold levels known to cause mortality and embryonic deformities. Additionally, reduced hatchability was also documented in nesting aquatic birds.

As part of the NIWQP, the U.S. Bureau of Reclamation (Reclamation) initiated a remedial planning study in 1992 to find a solution to the selenium contamination problem at Kendrick. Monitoring of selenium concentrations in water, sediment and biota was conducted by the Service and the Survey from 1992 to 1996 to assist Reclamation in developing a remediation plan as well as determine trends and assist in measuring remediation effectiveness.

STUDY AREA DESCRIPTION

The Kendrick project area is located immediately west of Casper in central Wyoming and encompasses 188 square miles (mi^2). Approximately 38 mi^2 or 20 percent of the project area is irrigated. The Kendrick area is semi-arid and receives an average of 12 inches of precipitation each year. Soils at Kendrick are derived from seleniferous Cretaceous shales (See et al. 1992). Irrigation at Kendrick began in 1946. Alfalfa and improved pasture are the principal crops grown at Kendrick. Over 9,000 acres of wetlands occur at Kendrick and provide habitat for aquatic birds, fish and other wildlife. Wetlands at the study area consist of large closed basins, small reservoirs and stock ponds, and riparian areas. Monitoring of biological media was conducted at four major wetlands at Kendrick: Rasmus Lee Lake (120 acres); Goose Lake (100 Acres); Illco Pond (2 acres); and 33-Mile Reservoir (10 acres).

METHODS

Pondweed, aquatic invertebrates, and bird eggs were collected from the four major wetlands at Kendrick (Figure 1). Fish were collected from Illco Pond, 33-Mile Reservoir, major tributaries draining Kendrick and from the North Platte River. Pondweed, aquatic invertebrates, and fish were also collected from several smaller wetlands and tributaries at Kendrick (Figure 2).

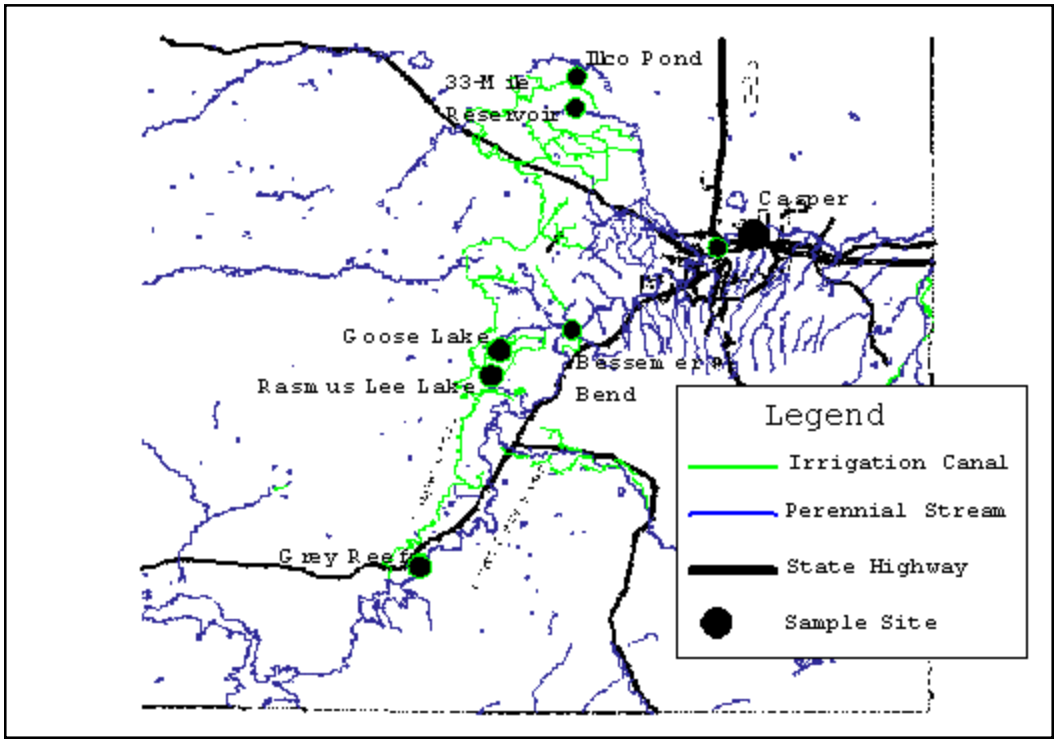

Figure 1. Sampling locations at the four major wetlands and the North Platte River for the Kendrick Reclamation Project selenium monitoring study.

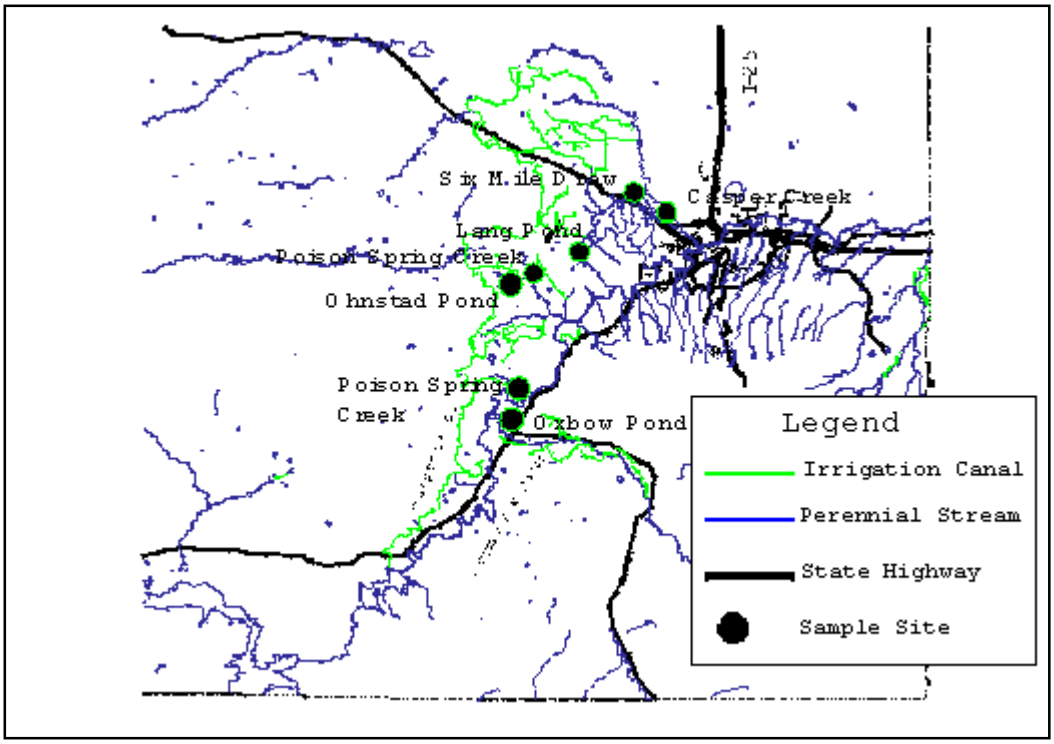

Figure 2. Location of sampling sites on North Platte River tributaries within the Kendrick Reclamation Project, Natrona County, Wyoming.

All biota samples were immediately frozen after collection. Pondweed was collected by hand and placed in whirl-pak bags. Aquatic invertebrates were collected with dip nets and light traps as described by Espinosa and Clark (1972), and placed in chemically-clean glass vials. Biota were collected between March and August from 1992 through 1996. Aquatic invertebrates collected included midge fly larvae (Chironomidae), damselfly larvae (Odonata), amphipods (Amphipoda), water beetles (Coleoptera) and waterboatmen (Corixidae). Addled American avocet eggs *(Recurvirostra americana)* were collected from the nesting colony at Rasmus Lee Lake between June and July from 1992 through 1996. Addled eared grebe eggs *(Podiceps nigricolis)* were collected from Goose Lake in 1994 and 1995. Grebes did not nest at Kendrick in 1992, 1993 and 1996. Addled Canada goose *(Branta canadensis)* eggs were collected from Rasmus Lee Lake in 1993. Aquatic bird eggs were dissected, the embryos were examined for deformities and placed in chemically-clean glass jars.

Rainbow trout *(Oncorhynchus mykiss)* were collected from several reaches of the North Platte River using an electro-fishing boat in 1992, 1994, 1995 and 1996. The reaches consisted of a reference site upstream of Kendrick and sites downstream of tributaries draining the irrigation project. Common carp *(Cyprinus carpio)* were collected from Illco Pond and 33-Mile Reservoir with gill nets. Fish do not inhabit Rasmus Lee and Goose lakes. In 1994 and 1995, creek chubs *(Semotilus atromaculatus)* were collected with minnow traps from tributaries draining Kendrick. Large fish such as trout and carp were wrapped in aluminum foil and immediately frozen. Smaller fish were placed in whirl-pak bags and frozen.

Samples were submitted to the Research Triangle Institute (RTI) Laboratory, Research Triangle Park, North Carolina for selenium analyses. Selenium was analyzed using graphite furnace absorption spectroscopy. Quality assurance/quality control (QA/QC) was checked by the Services' Patuxent Analytical Control Facility (PACF). QA/QC was confirmed through procedural blanks, duplicate analysis, test recoveries of spiked materials and reference material analyses with oversight by PACF. Selenium concentrations in muscle tissue from rainbow trout collected in 1988 and reported in See et al. (1992) were converted to whole-body concentrations as described in Lemly and Smith (1987) to allow comparison with whole-body concentration data obtained in 1992 and 1994. Selenium data from pondweed, aquatic invertebrates and aquatic bird eggs collected from 1992 through 1996 were compared to data collected in 1988 and 1989 and reported in See et al. (1992). All selenium concentrations in biota are reported in ug/g (ppm) dry weight. Medians were computed for the selenium data to avoid influence by extreme values or outliers. Statistical comparisons between years for each site were made using the Kruskal-Wallis test.

RESULTS and DISCUSSION

Rasmus Lee Lake

Selenium in all pondweed and aquatic invertebrate samples exceeded the 3 ug/g dietary threshold for aquatic birds reported by Lemly and Smith (1987) and Lemly (1993) (Table 1).

Table 1. Selenium concentrations in ug/g in pondweed and aquatic invertebrates from Rasmus Lee Lake in the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

Pondweed

Year	n	Minimum	Maximum	Median	Mean
1992	3	67.7	71.4	69.0	69.3
1993	5	28.4	42	30.5	33.5
1994	5	15.6	42.9	33.2	30.08
1995	5	32.2	48.0	37.0	39.5
1996	5	46.8	63.0	71.4	76.2

Aquatic Invertebrates

Year	n	Minimum	Maximum	Median	Mean
1992	3	125	146	131	134
1993	3	43.7	112	88.1	81.2
1994	5	29.2	113	110	92.8
1995	5	117	127	121	121.6
1996	5	137.4	167	161.4	157

Mean dietary selenium levels in pondweed and aquatic invertebrates from this closed basin ranged from 10 to 25 times and 27 to 52 times the dietary threshold, respectively, during the monitoring period. A change in aquatic invertebrate species composition was observed at Rasmus Lee Lake during the monitoring period. Species collected during the detailed investigation by See et al. (1992) included damselfly (Odonata) and midge fly (Chironomidae) larvae, waterboatmen (*Arctocorixa interrupta*), and amphipods (Amphipoda). During the monitoring period, species composition changed to primarily water beetles (Coleoptera). This change may be due to increases in water conductivity. Ninety-seven percent of the American avocet eggs collected from 1992 to 1996 contained selenium exceeding the 15 ug/g level reported by J. Skorupa (Personal communications, December 14, 1995) to cause impaired egg hatchability (Table 2).

Table 2. Selenium concentrations in ug/g in American avocet eggs from Rasmus Lee Lake in the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

Year	n	Minimum	Maximum	Median	Mean
1992	5	23.1	110.8	85.9	69.5
1993	10	40.7	99	71	69.9
1994	32	21.2	124	82.8	85.9
1995	18	8.3	55	35.8	33.2
1996	5	22.7	120.2	27.1	56.5

The lowest mean selenium concentrations in avocet eggs occurred in 1995 and 1996. In 1993, eight out of 62 avocet embryos (13 percent) examined contained deformities. The occurrence of embryo terata in wild uncontaminated bird populations is normally less than 1 percent (Austin 1969, Gilbertson et al. 1976, Hill and Hoffman 1984, Pomeroy 1962, Smith and Diem 1971, and Threlfall 1968). Selenium concentrations in 29 Canada goose eggs collected in 1993 ranged from 3.75 to 29.9 ug/g with a median of 7.7 ug/g. All of the 29 Canada goose eggs collected in 1993 were addled. Eight of the 29 were embryonated and the remainder were infertile.

Goose Lake

Selenium concentrations in all pondweed and aquatic invertebrate samples exceeded the 3 ug/g dietary threshold for aquatic birds reported by Lemly and Smith (1987) and Lemly (1993) and significantly increased from 1988 to 1996 (p=.05) (Table 3).

Table 3. Selenium concentrations in ìg/g in pondweed and aquatic invertebrates from Goose Lake in the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

Pondweed

Year	n	Minimum	Maximum	Median	Mean
1992	3	28.9	29.1	29	29
1993	5	18.2	67.5	51.4	46.2
1994	5	33.8	47.7	35.4	37.6
1995	5	26.8	46.8	39.6	36.6
1996	5	55.6	63.6	61.9	60.9

Table 3 (continued). Selenium concentrations in ug/g in pondweed and aquatic invertebrates from Goose Lake in the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

Aquatic Invertebrates

Year	n	Minimum	Maximum	Median	Mean
1992	9	50.6	136	66	87.2
1993	5	62.8	104	75.4	81.6
1994	5	34	68.2	62.2	52.6
1995	5	79.4	89.8	82.8	83.4
1996	5	122.3	130.1	124.6	125.2

Mean dietary selenium levels in pondweed and aquatic invertebrates from this closed basin ranged from 10 to 20 times and 17 to 41 times the dietary threshold, respectively, during the monitoring period. A change in aquatic invertebrate species composition was observed at Rasmus Lee Lake during the monitoring period. Species collected in 1988 and 1989 during the detailed investigation by See et al. (1992) included damselfly (Odonata) and midge fly (Chironomidae) larvae, waterboatmen (*Arctocorixa interrupta*), and amphipods (Amphipoda). Although no relative abundance estimates of aquatic invertebrates were made at this site, it appears that densities of amphipods, copepods and midge fly larvae were lower than those observed during the detailed study (See et al. 1992). This change may be due to increases in total dissolved solids as measured by conductivity.

Eared grebe eggs were only collected in 1994 and 1995 as grebes did not nest at Goose Lake in 1992, 1993 and 1996. Lower water levels and a possible change in the species composition and abundance of aquatic invertebrates could have contributed to the lack of nesting; however, the actual cause is unknown. Selenium concentrations in eared grebe eggs exceeded the levels shown by Skorupa and Ohlendorf (1991) to cause embryo toxicity (> 8 ug/g) and teratogenesis (> 13 ug/g). Selenium concentrations in 10 eared grebe eggs collected in 1994 ranged from 40.8 ug/g to 111 ug/g with a median of 76.6 ug/g. Five of the 10 grebe eggs were addled and embryonated, one was infertile and the remainder were fertile. Four eared grebe eggs collected in 1995 had selenium concentrations ranging from 59.4 to 111 ug/g with a median of 75.5 ug/g. All four eggs were fertile; however, no deformities were observed.

33-Mile Reservoir

Selenium concentrations in all aquatic invertebrate samples exceeded the 3 ug/g dietary threshold for aquatic birds reported by Lemly and Smith (1987) and Lemly (1993); however, the concentrations were not as high as those reported for Rasmus Lee and Goose Lakes (Table 4). Median selenium concentrations in pondweed ranged from 11.6 ug/g in 1992 down to 0.5 ug/g in 1994. Pondweed samples collected in 1992 and 1996 all exceeded the 3 ug/g dietary threshold; however, all of the samples collected in 1993 and 1995 were below this threshold.

Table 4. Selenium concentrations in ug/g in pondweed, aquatic invertebrates and carp from 33-Mile Reservoir in the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

Pondweed

Year	n	Minimum	Maximum	Median	Mean
1992	3	11	12	12	11.6
1993	5	1.2	2.7	1.6	1.9
1994	5	0.5	5	0.5	1.6
1995	5	1	2.7	2.1	1.8
1996	5	5.7	8.6	7.1	7.2

Aquatic Invertebrates

Year	n	Minimum	Maximum	Median	Mean
1992	5	11.6	20.7	15.8	16
1993	5	6.3	12.8	9.5	9.5
1994	5	11.5	18.8	17.2	16.4
1995	5	16.2	18.4	17.1	17
1996	5	13.4	18.7	16.6	16.5

Carp

Year	n	Minimum	Maximum	Median	Mean
1992	5	32.2	61.8	48.7	47.2
1993	5	23.7	38.2	29.7	30.3
1994	5	9.1	11.3	10.3	10.4
1995	5	20.4	37.2	27.4	28
1996	5	33.6	45.9	41.3	41.5

Selenium concentrations in carp ranged from a high of 40.37 ug/g in 1992 to a low of 7.94 ug/g in 1994 (Table 4). Lemly (1993) indicated a reproductive impairment threshold of 4 ug/g whole-body selenium in sensitive species of fish. There are no statistically discernible trends in selenium concentrations in pondweed, aquatic invertebrates or carp at 33-Mile Reservoir.

Illco Pond

Mean selenium concentrations in pondweed and aquatic invertebrate samples exceeded the 3 ug/g dietary threshold for aquatic birds reported by Lemly and Smith (1987) and Lemly (1993); however, the concentrations were not as high as those reported for Rasmus Lee and Goose Lakes (Table 5). There are no statistically discernible trends in selenium concentrations in biota for this site.

Table 5. Selenium concentrations in ug/g in pondweed, aquatic invertebrates and carp from Illco Pond in the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

Pondweed

Year	n	Minimum	Maximum	Median	Mean
1992	3	4.8	6.3	5	5.3
1993	5	2.6	7.7	3.4	4.6
1994	5	4.2	6.4	4.5	4.8
1995	5	4.4	5.9	5.4	5.1
1996	5	5.3	7.6	6.6	6.6

Aquatic Invertebrates

Year	n	Minimum	Maximum	Median	Mean
1992	7	12	29.1	20.3	18.6
1993	5	4.1	33.4	21	22.4
1994	5	7.4	39	19.9	23.1
1995	5	16.9	18	17.6	17.5
1996	5	25	25.7	25.4	25.4

Carp

Year	n	Minimum	Maximum	Median	Mean
1992	5	28.9	40.6	32.5	33.5
1993	5	14.4	25.4	20	21
1994	5	4.7	6.8	5.1	5.5
1995	0	No Carp Collected in 1995			
1996	5	16.9	26.8	24.1	23.4

Other Sites

Selenium concentrations in pondweed and aquatic invertebrates from Poison Spider Creek and Poison Spring Creek, Ohnstad Pond and Oxbow Pond exceeded the 3 ug/g dietary threshold for aquatic birds reported by Lemly and Smith (1987) and Lemly (1993)(Table 6). Although pondweed from Lang Pond was below 3 ug/g, aquatic invertebrates from this pond were above this threshold.

Table 6. Selenium concentrations in ug/g in pondweed and aquatic invertebrates from tributaries and other impoundments in the Kendrick Reclamation Project, Natrona County, Wyoming. (n = number collected)(BDL=Below Detection Limits)

Pondweed

Site	Year	n	Minimum	Maximum	Median	Mean
Casper Creek	1994	5	6.58	7.9	6.98	7.07
Poison Spider Creek	1993	1	3.94	3.94	--	--
Poison Spider Creek	1994	5	2.52	6.86	4.26	3.22
Poison Spring Creek	1995	5	5.60	9.54	7.16	7.48
Lang Pond	1994	5	BDL	0.85	0.545	0.61
Lang Pond	1995	5	BDL	1.00	1.0	1.0
Ohnstad Pond	1993	5	BDL	8.76	7.31	5.84

Aquatic Invertebrates

Site	Year	n	Minimum	Maximum	Median	Mean
Oxbow Pond	1993	5	5.8	7.11	6.21	6.29
Lang Pond	1994	5	3.62	6.18	5.67	5.06
Lang Pond	1995	5	3.86	4.44	4.25	4.13
Poison Spider Creek	1993	3	6.7	8.49	7.73	7.64
Poison Spring Creek	1993	2	1.95	2.19	2.07	2.07

All creek chub samples collected from Kendrick tributaries had selenium concentrations exceeding the 4 ug/g threshold known to cause reproductive impairment (Table 7). The highest mean selenium concentrations were observed in samples collected from Poison Spring Creek (32.1 ug/g) and Six Mile Draw (41.88 ug/g).

Table 7. Selenium concentrations in ug/g in Creek chubs collected from streams in the Kendrick Reclamation Project, Natrona County, Wyoming in 1996 (n = number collected).

Site	n	Minimum	Maximum	Median	Mean
Casper Creek	5	15.2	23.4	19.4	19.6
Poison Spider Creek	5	9.7	16.6	12.9	12.6
Poison Spring Creek	5	16.7	43.9	35.3	32.1
Six Mile Draw	5	15.7	66.6	41.88	41.4

Other biota collected from Kendrick included crayfish (Order Decapoda) and leopard frogs (*Rana pipiens*) from Ohnstad Pond and Poison Spider Creek, a plains killifish (*Fundulus kansae*) from Lang Pond and a minnow (Family Cyprinidae) from Ohnstad Pond. One crayfish was collected from both Ohnstad Pond and Poison Spider Creek and they each had selenium concentrations of 3.6 and 3.4 ug/g, respectively. One leopard frog collected from Ohnstad Pond had a selenium concentration of 6 ug/g. Four leopard frogs collected from Poison Spider Creek had selenium concentrations ranging from 11.34 to 13.55 ug/g and a mean concentration of 12.45 ug/g. The one minnow collected from Ohnstad Pond had a selenium concentration of 24.9 ug/g. The killifish from Lang Pond had a selenium concentration of 5.74 ug/g.

North Platte River

Whole-body selenium concentrations in rainbow trout collected from the Bessemer Bend and Casper reaches of the North Platte River exceeded the 4 ug/g level associated with reproductive impairment (Table 8). Selenium concentrations in rainbow trout collected from the reference site at the Grey Reef reach of the North Platte River were slightly above the 4 ug/g level and ranged from 4.8 to 9.5 ug/g. There is no statistically discernible trend in selenium concentrations in rainbow trout.

Table 8. Selenium concentrations in ug/g in rainbow trout collected from the North Platte River adjacent to the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

North Platte River Reach below Grey Reef Dam

Year	n	Minimum	Maximum	Median	Mean
1992	5	4.3	6.5	4.9	5.1
1993	Fish Collections Not Conducted in 1993				
1994	5	6.4	11.4	9.5	9.4
1995	5	3.6	4.2	4	3.9
1996	5	6.6	12.1	8.3	9.3

Table 8 (continued). Selenium concentrations in ug/g in rainbow trout collected from the North Platte River adjacent to the Kendrick Reclamation Project, Natrona County, Wyoming (n = number collected).

North Platte River Reach below Bessemer Bend

Year	n	Minimum	Maximum	Median	Mean
1992	5	8.8	13.4	10.7	11.2
1993	Fish Collections Not Conducted in 1993				
1994	5	10.8	18	15.6	15
1995	7	3.9	15.2	11.9	9.5
1996	Site Not Sampled in 1996				

North Platte River Reach below Casper Creek

Year	n	Minimum	Maximum	Median	Mean
1992	5	11.1	14.5	12.4	12.7
1993	Fish Collections Not Conducted in 1993				
1994	4	9.7	17.9	16.9	15.3
1995	No Rainbow Trout Collected in 1995				
1996	5	8.3	29.4	13	15.6

Trends

Selenium data from pondweed, aquatic invertebrates and aquatic bird eggs collected from 1992 through 1996 were compared to data collected in 1988 and 1989 and reported in See et al. (1992). There are no statistically discernible trends in selenium concentrations in pondweed and aquatic invertebrates from Rasmus Lee Lake, 33-Mile Reservoir and Illco Pond (Figures 3 and 4) and in carp from 33-Mile Reservoir and Illco Pond (Figure 5). However, selenium concentrations in pondweed and aquatic invertebrates from Goose Lake significantly increased from 1988 to 1996 (Kruskall-Walis, p=.05). There is no statistically discernible trend in selenium concentrations in rainbow trout from the North Platte River along the Kendrick Project (Figure 6).

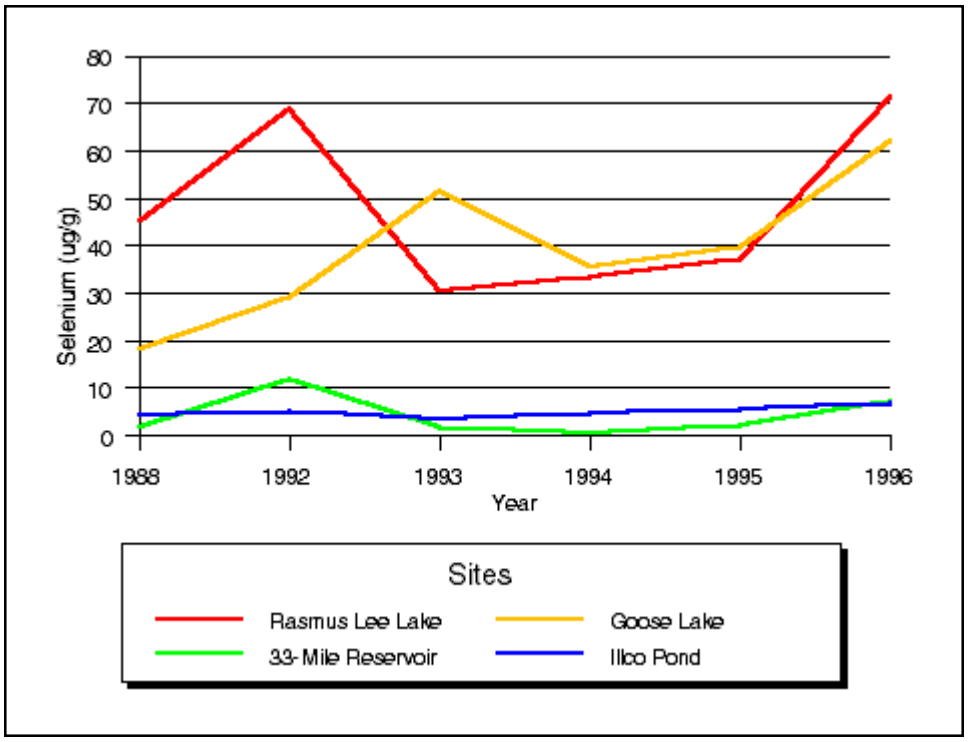

Figure 3. Selenium concentrations in ug/g in pondweed from the Kendrick Reclamation Project, Natrona County, Wyoming.

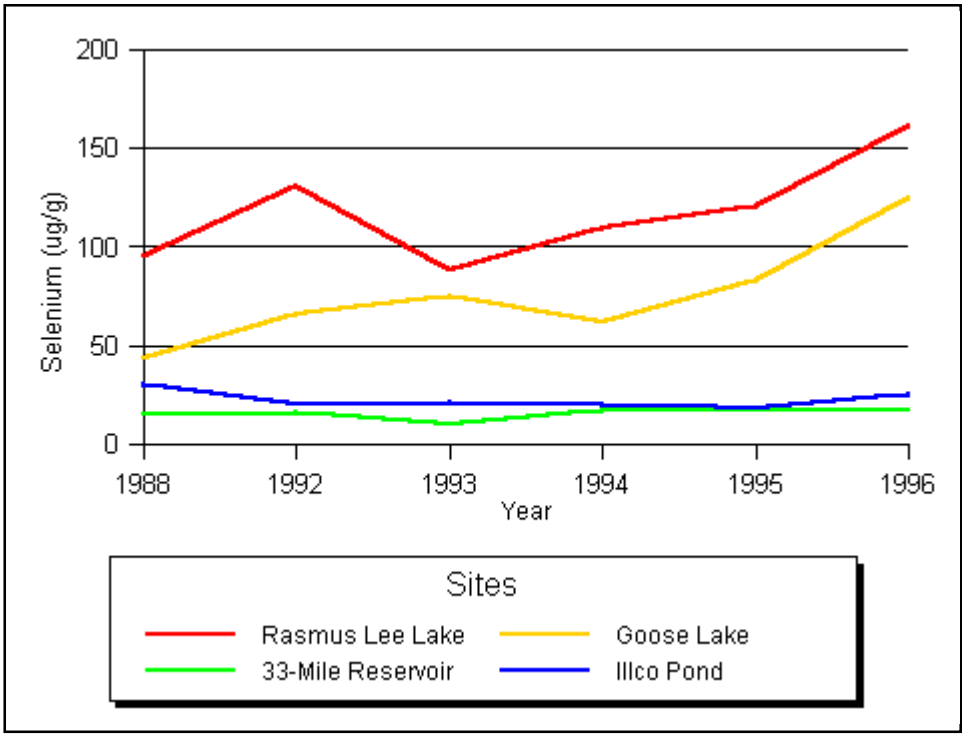

Figure 4. Selenium concentrations in ug/g in aquatic invertebrates from the Kendrick Reclamation Project, Natrona County, Wyoming.

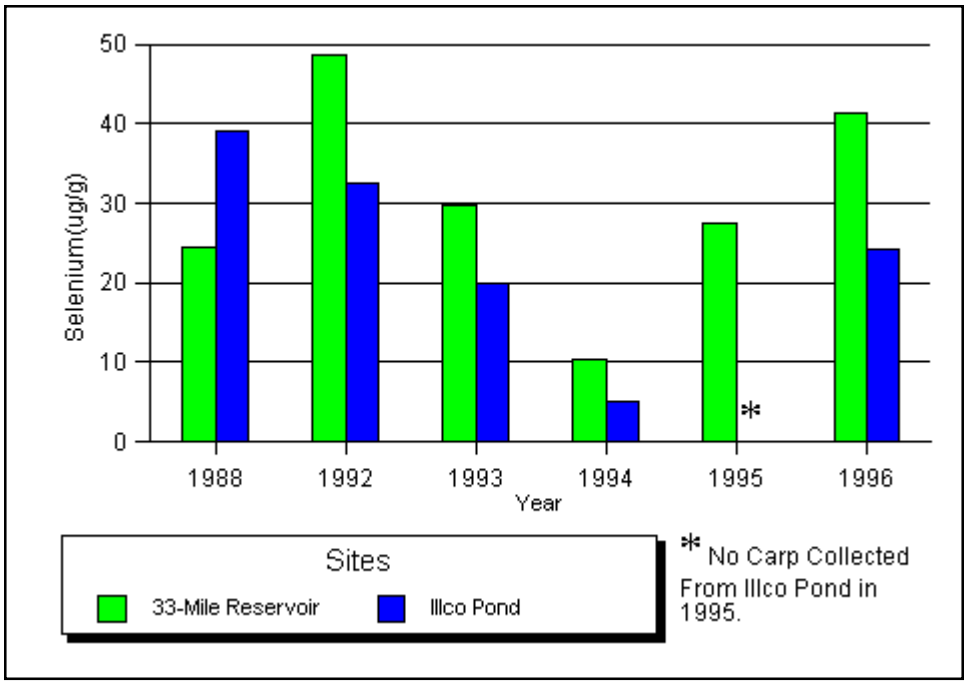

Figure 5. Selenium concentrations in ug/g in whole-body carp from the Kendrick Reclamation Project, Natrona County, Wyoming.

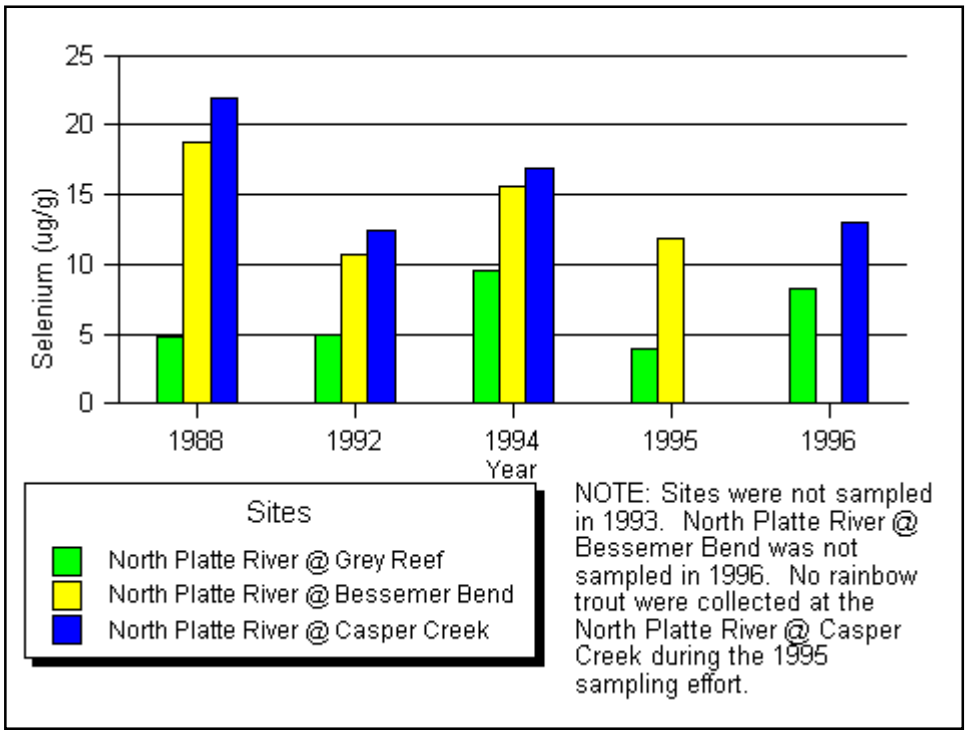

Figure 6. Selenium concentrations in ug/g in whole-body rainbow trout collected from the North Platte River near the Kendrick Reclamation Project, Natrona County, Wyoming.

SUMMARY

Selenium concentrations in biota remain elevated at the four major wetlands at Kendrick. Selenium concentrations in pondweed and aquatic invertebrates at Goose Lake are in an upward trend ($p=0.05$). The increase may be due to lower water levels and an increase in the evaporative concentration of selenium. Impaired reproduction and embryo deformities were documented for American avocets nesting at Rasmus Lee Lake. Selenium concentrations declined in 1995 and 1996 in avocet eggs. The cause for decline is unknown as selenium concentrations in aquatic invertebrates did not significantly change during those years. Eared grebes did not nest at Goose Lake in 1992, 1993 and 1996. Lower water levels may have contributed to the lack of nesting. Eared grebe eggs collected in 1994 and 1995 had elevated selenium concentrations comparable to those found in 1988 by See et al. (1992) and at levels known to cause impaired reproduction.

LITERATURE CITED

Austin, O.L. 1969. Extra toes on a Sooty Tern chick. Auk. 86:352.

Espinosa, L.R. and W.E. Clark. 1972. A polypropylene light trap for aquatic invertebrates. Calif. Fish Game. 58:149-152.

Gilbertson, M.; R.D. Morris; and R.A. Hunter. 1976. Abnormal chicks and PCB residue levels in eggs of colonial birds in the lower Great Lakes (1971-73). Auk. 93:434-442.

Hill, E.F. and D.J. Hoffman. 1984. Avian models for toxicity testing. Jour. Am. College of Toxicol. 3(6):357-376.

Lemly, A.D. 1993. Guidelines for evaluating selenium data from aquatic monitoring and assessment studies. Environ. Monitor. Assess. 28:83-100.

Lemly, A.D. and G.J. Smith. 1987. Aquatic cycling of selenium: implications for fish and wildlife. Fish and Wildlife Leaflet 12. U.S. Fish Wildl. Serv. Washington, DC. 10 pp.

Naftz, D.L.; R.B. See; and P. Ramirez. 1993. Selenium source identification and biogeochemical processes controlling selenium in surface water and biota, Kendrick Reclamation Project, Wyoming, U.S.A. Applied Geochemistry. 8:115-126.

Peterson, D.A.; W.E. Jones; and A.G. Morton. 1988. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Kendrick Reclamation Project Area, Wyoming, 1986-87. U.S. Geol. Survey Water Res. Invest. Rep. 87-4255. 57 pp.

Pomeroy, D.E. 1962. Birds with abnormal bills. Brit. Birds. 55(2):49-72.

Presser, T.S. 1994. “The Kesterson Effect”. Environ. Manage. 18(3):437-454.

See, R.B.; D.L. Naftz; D.A. Peterson; J.G. Crock; J.A. Erdman; R.C. Severson; P. Ramirez, Jr. and J.A. Armstrong. 1992. Detailed study of selenium in soil, representative plants, water, bottom sediment, and biota in the Kendrick Reclamation Project Area, Wyoming, 1988-90. U.S. Geol. Surv Water Res. Invest. Rep. 91-4131. 142 pp.

Skorupa, J.P. and H.M. Ohlendorf. 1991. Contaminants in drainage water and avian risk thresholds. *in* A. Dinar and D. Zilberman (eds.), The Economics and Management of Water and Drainage in Agriculture. Kluwer Academic Publishers, Dordrecht and Boston. pp. 345-368.

Smith, J. and K.L. Diem. 1971. Incidence of deformed bills in California gulls (*Larus californicus*). Auk. 88:435.

Threlfall, W. 1968. A herring gull chick (*Larus argentatus*) with an abnormal bill. Auk. 85:506-508.

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