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Evaluation of Contaminant Concentrations in Water, Sediment, and Biota at Bear Lake National Wildlife Refuge from Historical Phosphate Mining and Agricultural Return Flows

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EXECUTIVE SUMMARY

Bear Lake National Wildlife Refuge (Refuge) sits at the north end of a large lake called Bear Lake, and is located in southeast Idaho, seven miles southwest of the town of Montpelier. It is in the Bear Lake Valley at an elevation of approximately 5,925 feet. This region of Idaho contains 15 phosphate mines owned by 6 different companies, as well as numerous "orphaned" mine sites primarily of underground design. One of the inactive, underground phosphate mines, Hot Springs Mine, is located on the southeast corner of the Refuge, across from Mud Lake (Figure 1). Two other sites, the Bloomington Canyon Mine, and Paris Canyon Mine are located upstream of two creeks that flow into the Refuge. Concerns developed over the potential movement of contaminants from these sites into the Refuge when investigations at other phosphate mines in the region indicated that elevated concentrations of contaminants, and in particular selenium, were being released into the environment. In addition, the Refuge is heavily influenced by agricultural return flows and acts as a sediment trap for the Bear River, which is often diverted through the Refuge and into Bear Lake, a natural waterbody now often used for irrigation storage and power generation. This study was undertaken to assess the potential risk to fish and wildlife from contaminants associated with mining and agricultural activities within the Bear Lake Refuge drainage.

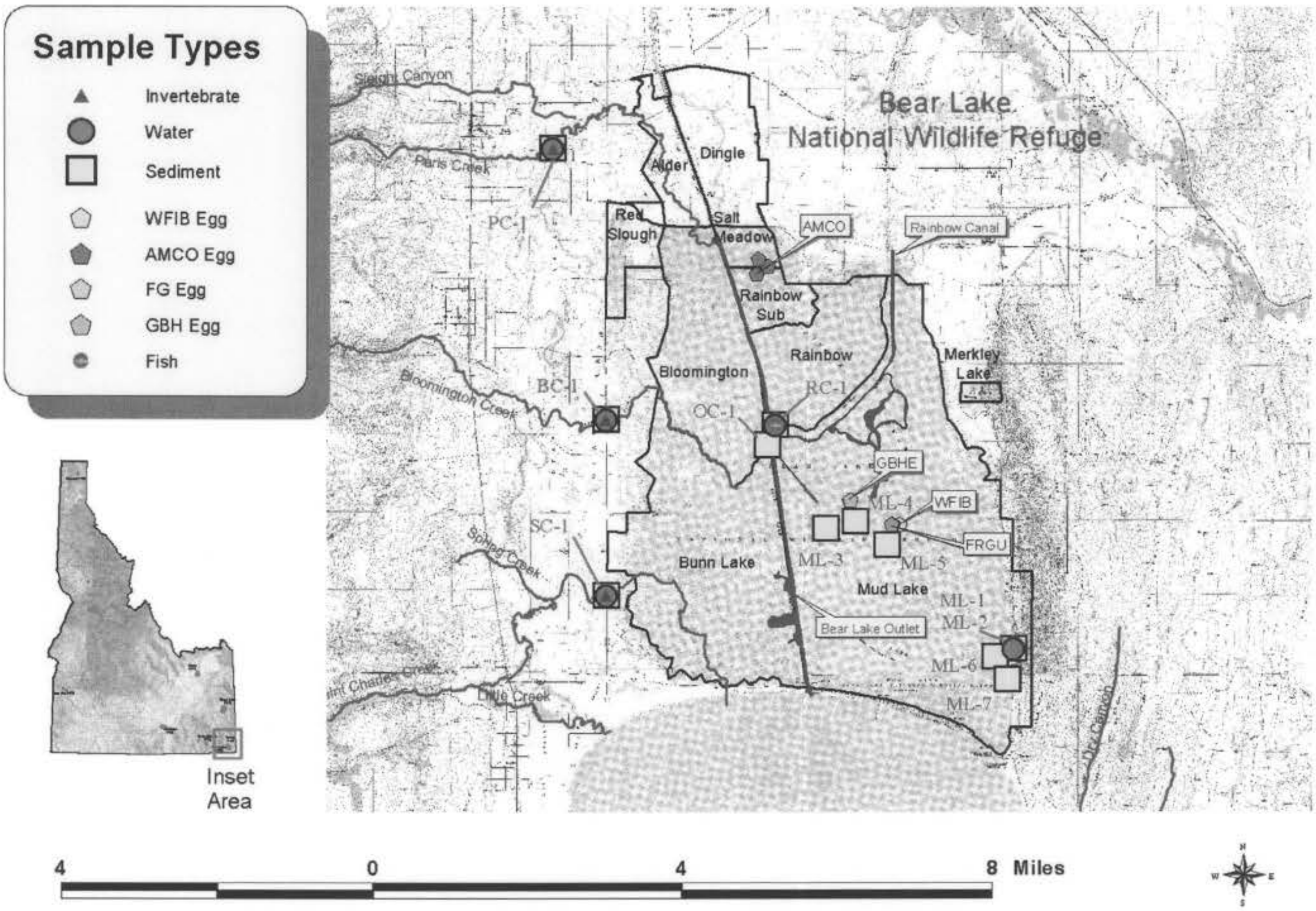
Several matrices were evaluated for contamination, including: water, sediment, plants, invertebrates, fish, and bird eggs. Sampling sites included surface water inflows to and outflows from the refuge, and several locations within Mud Lake (Figure 1). Chemical analyses included scans for inorganics and organochlorine compounds (OCs) to determine whether contaminants associated with both agricultural with its legacy pollutants, and mining activities are accumulating in sediment and biota on the Refuge.

The Bear River and its tributaries entering the Bear Lake National Wildlife Refuge have a designated beneficial use of coldwater aquatic life and salmonid spawning. Most water quality parameters (i.e. temperature, dissolved oxygen, etc.) were within the range of criterion to support aquatic life.

Organochlorine concentrations in sediment, plants, fish, and bird eggs did not appear to be at levels harmful to aquatic resources. No OCs were detected in sediment or plant samples, two OCs were detected at low concentrations in fish tissues (p,p'-DDD and p,p'-DDE), and four OCs were detected at low concentrations in eggs (heptachlor epoxide, p,p'-DDE, total PCBs, and trans-nonachlor).

Inorganic concentrations were analyzed in sediment, water, invertebrates, fish, and bird eggs. As with organochlorine compounds, bird egg tissue had low levels of inorganics. However, arsenic, cadmium, chromium, copper, manganese, and strontium, were elevated in sediments and exceeded guidelines and/or effects thresholds. Concentrations of lead in invertebrates from Paris Creek were within the range known to cause dietary effects to fish, and zinc levels in fish tissue were well above what is considered to be background and exceeded concentrations reported to cause effects in birds.

Figure 1: Location and types of samples collected on Bear Lake NWR, 2002-2003.



INTRODUCTION

Bear Lake National Wildlife Refuge (Refuge) is located in southeast Idaho, seven miles southwest of the town of Montpelier. It is in the Bear Lake Valley at an elevation of approximately 5,925 feet. The 18,000 acre refuge is a sprawling complex of wetlands at the north end of Bear Lake. It is comprised mainly of a bulrush-cattail marsh, open water, and flooded meadows of sedges, rush, and grasses. Portions of the Refuge include scattered grasslands and brush-covered slopes. The Refuge provides valuable habitat for 12 colonial-nesting bird species including: white-faced ibis (*Plegadis chihi*), snowy egret (*Egretta thula*), great blue heron (*Ardea herodias*), black-crowned night heron (*Nycticorax nycticorax*), double-crested cormorant (*Phalacrocorax auritus*), California gull (*Larus californicus*), Franklin's gull (*Larus pipixcan*), Caspian tern (*Sterna caspia*), Forster's tern (*Sterna forsteri*), black tern (*Chlidonias niger*), Clark's grebe (*Aechmophorus clarkii*), western grebe (*Aechmophorus occidentalis*), and eared grebe (*Podiceps nigricollis*). The Refuge also is important for waterfowl; in a typical breeding season the Refuge will support approximately 4,500 ducks and 1,800 geese (USFWS 1996).

The general land use for the watershed is primarily rangeland (~140,000 acres) with agriculture and forest lands comprising about 23,000 acres. The Refuge acts as a sediment trap for flows from Big St. Charles Creek, Bloomington Creek, Bear River (Rainbow Canal), and Telluride canal (Figure 1). In a complex water management system, water from the Bear River is diverted at Stewart Dam into the Rainbow Canal, which flows through the Refuge and is stored in Bear Lake for irrigation use, and power generation. Water from this canal often flows through Mud Lake and exits into Bear Lake through the Bear Lake Causeway. Telluride Canal also enters the Refuge with agricultural return flows laden with sediment and nutrients. Previous studies have shown that Mud Lake may filter as much as 95% of water in the Bear River (Bear Lake Regional Commission 1983, Idaho Cooperative Fish and Wildlife Research Unit 1989). When water is released from Bear Lake at the Lifton Pump Station, it travels northwest through the Refuge via the Bear Lake Outlet (Figure 2).

Figure 2.

Phosphate has been mined in southeastern Idaho throughout most of the 20th century. In 1996, livestock losses associated with excessive dietary selenium from past and present phosphate mining operations prompted concern regarding the potential ecological and health impacts from selenium contamination. Investigations were initiated by the Idaho Mining Association's Selenium Subcommittee within the 6,500-square kilometer area that comprises portions of Caribou, Bear Lake, Bonneville, and Bingham counties. Fifteen phosphate mines owned by six different companies are in this region, as well as numerous "orphaned" mine sites primarily of underground design. One of the inactive, underground phosphate mines, Hot Springs Mine, is located on the Refuge.

In 1999, the Fish and Wildlife Service (Service) Snake River Fish and Wildlife Office (SRFWO), in cooperation with the Service's Sacramento Fish and Wildlife Office and the University of California at Davis, collected water and bird eggs from areas within the region, known to be heavily influenced by phosphate mining. Selenium concentrations in surface water at four of these sites indicated water selenium concentrations ranged between 8.7 to 68.5 µg/L [parts per billion (ppb)]. The chronic water quality criterion for selenium is 5 µ/L and the acute criterion is 20 µg/L (EPA 1980a). Concentrations of selenium in coot eggs collected from the same sites ranged from 12.9 to 79.8 mg/kg [parts per million (ppm)] dry weight. Literature values indicate embryo teratogenesis may occur at about 13 mg/kg dry weight.

Limited data has been collected on the influence that historical phosphate mines may be having on fish and wildlife resources on the Refuge. Of particular concern is the Hot Springs Mine located on the Refuge and within 40 meters of wetlands and open water. In addition, Paris Creek and Bloomington Creek discharge into the Refuge and both watersheds contain historical phosphate mines.

A study by the U.S. Geological Survey (USGS, Piper *et al.* 2000) at the Hot Springs Mine examined the major-element oxides and inorganics of the Phosphoria Formation. High concentrations of several inorganics throughout the deposit, such as arsenic, cadmium, selenium, and uranium have raised concern about their introduction into the environment and onto the Refuge via weathering, and the degree to which mining and waste rock from this deposit might be accelerating that process. For perspective, the concentration of selenium in source rocks which have impacted the avian population in the San Joaquin Valley of California are roughly an order of magnitude less than the concentrations in the Formation which occurs in Idaho (Piper *et al.* 2000). Background concentrations of selenium in the Phosphoria Formation are above levels of concern for the protection of wildlife (Piper *et al.* 2000). Background concentrations of selenium-normal environments are 0.2 to 2.0 mg/kg, and typically less than 1.0 mg/kg (NIWQP 1998). The minimum total response boundary (EC100, effective exposure concentration of a toxicant estimated to cause a designated effect other than lethality in 100% of the test organisms within a designated time) for effects of selenium in sediment for birds nesting at shallow terminal ponds (population basis) is 1.0 mg/kg (NIWQP 1998). Studies have reported sedimentary selenium is a reliable predictor of adverse biological effects and that a preliminary toxic threshold exists at about 2.5 mg/kg (NIWQP 1998).

The purpose of this Refuge study was to assess the risk that environmental contaminants pose to the Service's trust resources in and around the Refuge. Our objectives were the following:

(1) determine whether contaminants of potential ecological concern (COPEC) were present in the Hot Springs Mine slag piles on the Refuge,
(2) determine whether COPECs are entering the Refuge from known mine sites,
(3) determine whether organochlorine agricultural chemicals from surrounding land uses are entering the Refuge,
(4) determine whether any of these compounds are present in water, sediment, and biota on the Refuge, and
(5) determine whether these contaminants are accumulating in the food chain to levels likely to cause adverse effects.

METHODS

Sample Collection

We collected water, sediment, plant, invertebrate, and fish samples during July and August 2002, and egg samples during May and June 2003, with assistance of Refuge personnel (Figure 1). Sample collections were conducted as previously discussed in the study proposal and detailed in the appropriate standard operating procedures (SOPs) available from the SRFWO.

Water Samples

Water samples were taken at Bloomington Creek, Paris Creek, Spring Creek, Rainbow Canal, and at one location in Mud Lake near the location of the Hot Springs Mine. Briefly, water quality parameters (conductivity, pH, dissolved oxygen, and temperature) were measured at the beginning of each site visit. One water sample was collected from each of the sample sites directly into chemically cleaned amber glass jars (with a Teflon® lined lid). Hardness values were calculated from calcium and magnesium concentrations measured in water samples. All inorganic analytes were measured as total recoverable and were compared to literature values for total recoverable analytes.

Sediment Samples

Two sediment samples were collected into chemically cleaned glass jars from each of the same sample sites (Paris Creek, Bloomington Creek, Spring Creek, Rainbow Canal, Outlet Canal), plus six additional sites in Mud Lake; one was analyzed for inorganics and one for organics. Each sediment sample was a composite of three surficial grab samples collected at the sample site. Both water and sediment samples were transported on ice to the SRFWO lab; water was refrigerated and sediment was frozen until submitted to a laboratory for chemical analyses.

Biological Samples

Biological samples were collected in Paris Creek, Spring Creek, and Bloomington Creek at the same locations as water and sediment samples. Various methods were used to collect biota samples. Dip nets were used to collect invertebrates and plants. Invertebrate samples were sorted into whirlpacks at both Bloomington Creek and Paris Creek. Samples were sorted by species; one composite sample was made from damselflies (Zygoptera), the other sample was a composite of all other species of invertebrates collected. Only one composite sample of invertebrates (mixed species) was collected at Spring Creek. Only one plant sample was collected from Paris Creek; that sample was a composite of plants taken from several locations at the sample site. Gill nets were used to collect fish samples. Fish (*Cyprinus carpio*) were only collected from Mud Lake at the confluence of the Rainbow Canal and Outlet Canal.

Waterbird eggs were randomly collected from the nest by hand. All fish and waterbird egg samples were analyzed separately, no composites were made. A 16 foot Panther airboat was used to access the bird colonies and fish sampling locations. All biota samples were transported to the SRFWO lab on ice, processed, and frozen until submitted for chemical analyses.

Sample Processing, Transport, and Analyses

At the SRFWO lab, length and weight measurements were obtained for each fish sample, and length, breadth, mass, and volume were measured for each egg. Eggs were opened at the equator and contents were placed into chemically cleaned jars. Invertebrate samples were weighed prior to shipping for chemical analyses. Sediment and biota samples were sent to analytical labs in securely padded coolers on dry ice. Water samples were sent in securely padded coolers on blue ice. Mississippi State Chemical Laboratory conducted the organic analyses of all samples and Trace Element Research Laboratory conducted the inorganic analyses of all samples collected. Sample spikes, blanks, and duplicates were run with samples for quality control. Table 1 details the analyses that were performed on each sample.

Table 1. Analyses performed on water, sediment, and tissue samples collected in 2002 and 2003 from Bear Lake National Wildlife Refuge, Idaho.

Matrix	Analytes		
	Metal/Trace Element Scan	Organochlorine Scan	Grain Size
Water	x		
Sediment	x	x	x
Plant tissue		x	
Invertebrate tissue	x		
Fish tissue (whole body)	x	x	
Bird eggs	x	x	

Samples were prepared for inorganic analysis using nitric acid digestion. With the exception of mercury and selenium, concentrations of all inorganics were determined via inductively coupled plasma analysis. Cold vapor atomic absorption spectroscopy was used to determine mercury concentrations, and an atomic fluorescence spectrometer was used to determine selenium concentrations in all matrices.

Sediment samples were prepared for organic analysis using an accelerated solvent extractor with a 33 ml cell and petroleum ether digestion. Florisil and silica columns were used for sample cleanup, and OC concentrations were determined via electron capture gas chromatography (GC) using a Varian 3600 GC equipped with dual 30M megabore columns. Polychlorinated biphenyls (PCBs) were separated from other OCs using a silicic acid chromatographic column. Residues were concentrated to the appropriate volume and quantified using a GC. Total PCBs were determined by adding the GC peaks associated with Aroclors 1242, 1248, 1254, and 1260. OCs in biota were soxhlet extracted with hexane and concentrated to dryness for lipid determination. The lipid sample was then extracted with acetonitrile saturated with petroleum ether, and eluted using a florisil chromatographic column and diethyl and petroleum ethers. PCB congeners were determined using a Varian 3350 GC equipped with a 60M DB-5 capillary column. See Table A of the Appendix for method detection limits.

Data Interpretation

Compounds that were not detected were assigned the value of one-half of the detection limit. A geometric mean value was calculated for analytes with a sample size of three or greater, and if more than half of the samples had concentrations above the detection limit. For analytes where a mean was not calculated, only the range of concentrations was reported. Concentrations of inorganics in water samples were reported as total recoverable analyte. Contaminant concentrations detected in this study were compared to published literature, Environmental Protection Agency guidelines (EPA), and other research, to determine potential adverse effects on fish and wildlife.

RESULTS

Water Quality

Water quality measurements of pH, temperature, conductivity, dissolved oxygen (DO), and hardness are provided in Table 2. Hardness values were calculated from calcium and magnesium concentrations measured in the water samples at the analytical laboratory. All waterbodies had neutral to alkaline pH, which ranged from 7.88 in Paris Creek to 8.48 in the Mud Lake sample. Temperature was between 17.8 and 20.2 °C for all waters except Spring Creek. The temperature in Spring Creek was markedly higher at 23.8 °C.

Electrical conductivity (a measurement of dissolved solids such as calcium, magnesium, bicarbonate, and chloride), was similar between the Rainbow Canal, Outlet Canal, and Mud Lake, and ranged from 600 to 810 µS/cm. Paris Creek, Bloomington Creek, and Spring Creek had markedly lower conductivities ranging from 271 to 390 µS/cm. Likewise hardness values were elevated in the Mud Lake and Rainbow Canal samples (328 to 339 mg/L as $CaCO_3$); but lower in Spring Creek, Bloomington Creek, and Paris Creek (205 to 222 mg/L). Concentrations of DO were variable, ranging from 5.89 mg/L at Mud Lake site 4 to 10.24 mg/L in Spring Creek, but generally higher in the flowing streams (versus ponded water in Mud Lake).

Table 2. Water quality in and around Bear Lake National Wildlife Refuge, July 2002. Mud Lake sample locations are shown in Figure 2.

Site	Collection Time	pH	Temperature (EC)	Hardness [1] mg/L as $CaCo_3$	Conductivity (ΦS/cm)	Dissolved Oxygen (mg/L)
Rainbow Canal	1042	8.16	20.2	339	750	6.35
Outlet Canal	1125	8.31	18.2	----	600	6.88
Mud Lake 3	1144	8.32	19.1		620	6.77
Mud Lake 4	1200	8.33	19.2		710	5.89
Mud Lake 5	1216	8.35	19.5		780	6.02
Mud Lake 6 [2]	1239	8.45	19.7	328	810	7.29
Mud Lake 7	1256	8.48	19.9		805	7.73
Paris Creek	1414	7.88	17.8	222	299	9.95
Bloomington Creek	1441	8.28	19.9	215	271	8.99
Spring Creek	1505	7.99	23.8	205	390	10.24

[1] Hardness values are calculated from calcium and magnesium concentrations measured in water samples at the lab.
[2] This water sample was collected from Mud Lake near the Hot Springs Mine site.

Inorganics

Water samples

An inorganic scan was conducted on all matrices except plant tissue. Results of analyses in water samples for inorganic compounds of potential concern are reported in Table 3. No single location clearly had elevated or decreased concentrations. However, Rainbow Canal had the largest number of elevated compounds: aluminum, arsenic, calcium, cadmium, iron, manganese, and selenium. Boron, magnesium, sodium, and strontium were elevated in the Mud Lake sample (next to the mine site), but Bloomington Creek had the highest concentration of lead. The Paris Creek sample had the only detectable level of zinc of all the sites.

According to Piper (2000), the highest concentration of trace elements found in the Phosphoria Formation at the Hot Springs Mine, include arsenic, cadmium, selenium, thallium, and uranium. Thallium and uranium were not analyzed in this study. The water sample from Mud Lake did not show the same elevated trace elements detected in the Hot Springs Mine.

Table 3. Inorganic concentrations (total recoverable, µg/L) in water collected during July 2002 from Bear Lake National Wildlife Refuge, Idaho.

	Location				
Analyte [1]	Bloomington Cr (N = 1) [2]	Mud Lake (N = 1)	Paris Cr (N = 1)	Rainbow Canal (N = 1)	Spring Cr (N = 1)
Aluminum	650	90	450	790	180
Arsenic	2.5	2.0	1.4	3.9	1.0
Boron	40	190	30	100	40
Calcium	41,200	40,300	59,200	61,100	44,400
Cadmium	0.08	0.08	0.06	0.1	0.06
Iron	636	40	502	818	157
Lead	1.86	0.6	0.7	1.0	0.4
Magnesium	27,100	55,400	18,000	45,300	22,700
Manganese	18	4	43	87	3
Selenium	0.16	0.11	< dl [3]	0.29	0.11
Sodium	7,000	54,700	5,000	41,200	3,000
Strontium	134	781	267	638	71.7
Zinc	< dl	< dl	10	< dl	< dl

[1] All samples of beryllium, chromium, cobalt, copper, mercury, molybdenum, nickel, and vanadium had concentrations below the detection limit.
[2] N = number of samples.
[3] dl = detection limit.

Sediment Samples

Twenty-eight inorganic compounds were analyzed in sediment samples. With the exception of mercury, molybdenum, silver, and sodium, all inorganics were detected in all sediment samples. Inorganic compounds that are of potential concern are listed in Table 4. Concentrations tended to be higher in samples collected from Bloomington Creek and Mud Lake.

Aluminum, beryllium, cadmium, chromium, cobalt, iron, lead, nickel, vanadium, and zinc concentrations were highest in the sample taken at Mud Lake 3. Mud Lake site 5 had the greatest concentration of arsenic at 8.14 µg/g, and Mud Lake site 4 had the highest of manganese (662 µg/g). All three sites (Mud Lake 3, 4, and 5) are located down gradient of the Rainbow Canal and accounted for nearly half of the highest concentrations of trace elements measured in sediments.

Boron, mercury, and selenium concentrations were elevated at Mud Lake site 1 when compared to the other sample sites. Mercury was also high in the samples collected from Mud Lake 2, Outlet Canal, Paris Creek, and Spring Creek. Mud Lake 1 and 2 are sites closest to Hot Springs Mine. The copper concentration in the Mud Lake 7 sample was as much as six times higher than sediments collected from the other sites. This site also had detectable levels of molybdenum, and elevated concentrations of strontium. It should also be noted that Mud Lake 7 sediment had dramatically higher concentrations of sodium and sulphur over the other sample sites. This site is also very close and down gradient from the Hot Springs Mine, and near the location of the geothermal spring from which the mine gets its name. The sediment sample taken from Spring Creek contained the highest concentration of silver; however there was not much difference in concentrations between sites.

Table 4. Inorganic concentrations (µg/g dry weight) in sediment collected during July 2002 from Bear Lake National Wildlife Refuge, Idaho.

	Location					
Analyte	Bloomington Cr (N = 1) [1]	Paris Cr (N = 1)	Mud Lake (N = 7)	Rainbow Canal (N = 1)	Outlet Canal (N = 1)	Spring Cr (N = 1)
Aluminum	21,300	8,190	7,800 [2] (3,820 – 24,600)	18,900	14,700	5,670
Arsenic	6.39	2.63	6.53 (5.09 – 8.14)	5.52	5.12	2.49
Beryllium	1.01	0.42	0.47 (0.27-1.15)	0.92	0.71	0.29
Boron	10.8	7.76	30.5 (16.3 – 60.9)	13.8	11.6	5.87
Cadmium	0.61	0.45	0.68 (0.42 – 1.01)	0.68	0.56	0.19
Chromium	25.5	11.6	9.58 (4.46 – 27.8)	22.2	18.2	7.5
Cobalt	6.28	4.15	2.22 (< dl – 6.85) [3]	5.86	4.77	2.69
Copper	10.2	5.82	38.3 (18.8 – 65.2)	12.6	10.5	4.41
Iron	17,000	7,140	6,890 (2,810 – 19,000)	16,600	13,800	4,970
Lead	11.3	5.63	12.71 (8.86 - 14.8)	10.7	8.85	5.20
Manganese	275	150	276 (148 - 662)	550	458	110
Mercury	< dl	0.05	0.04 (0.03 – 0.06)	0.02	0.04	0.04
Molybdenum	< dl	< dl	1.65 (< dl – 1.98)	< dl	< dl	< dl
Nickel	15.5	6.34	8.24 (2.86 – 18.4)	14.2	11.1	5.18
Selenium	0.22	0.27	1.00 (0.19 – 2.09)	0.39	0.40	0.20
Silver	< dl	0.22	< dl – 0.30 [4]	< dl	0.22	0.35
Sodium	< dl	< dl	706 (447 – 916)	14.2	11.1	5.18
Sulphur	320	612	6,490 3,710 – 9,940)	718	967	428

Table 4. Inorganic concentrations (µg/g dry weight) in sediment collected during July 2002 from Bear Lake National Wildlife Refuge, Idaho.

	Location					
Analyte	Bloomington Cr (N = 1) [1]	Paris Cr (N = 1)	Mud Lake (N = 7)	Rainbow Canal (N = 1)	Outlet Canal (N = 1)	Spring Cr (N = 1)
Strontium	78	69.9	1,069 (235 – 3,050)	211	177	50.9
Vanadium	30.7	12.4	13.9 (7.66 – 34.3)	27.8	22.0	8.97
Zinc	64.4	33.0	38.0 (17.4 – 89.6)	64.1	50.9	19.6

[1] N = number of composite samples.
[2] Values presented represent the mean; values in parenthesis represent the range of concentrations detected.
[3] dl = detection limit.
[4] Less than half of the samples analyzed had a concentration above the detection limit; therefore, no mean was calculated.

Biological Samples

Invertebrate samples were collected in Bloomington Creek, Paris Creek, and Spring Creek. Fish samples were collected for analysis in Mud Lake. Both the invertebrate and fish tissue samples were analyzed for inorganic compounds (Table 5). Beryllium, molybdenum, and silver were not detected in any of the fish or invertebrate samples.

In general, concentrations of trace elements in invertebrates were evenly distributed among the three creeks. Exceptions were manganese, which was three times higher in invertebrates collected from Paris Creek than other sites; mercury, which was lower in samples from Bloomington Creek (< dl to 0.01µg/g), than from Paris Creek (0.08 to 0.15 µg/g) and Spring Creek (0.13 µg/g); and strontium that was four times higher in concentration in one sample collected at Paris Creek than from the other two sites.

Boron, cobalt, and vanadium were not detected in samples from Bloomington Creek. Vanadium was the only constituent not detected in samples collected from Paris Creek. Arsenic, chromium, and nickel, were detected in only one of the two invertebrate samples collected at Bloomington and Paris creeks. Of the trace elements that were detected in invertebrates and are of environmental concern, arsenic concentrations ranged from 0.52 µg/g (Bloomington Creek) to 1.69 µg/g (Spring Creek). Cadmium levels were from 0.30 µg/g (Paris Creek) to 0.60 (Spring Creek); copper ranged from 12.3 µg/g (Paris Creek) to 23.5 µg/g (Bloomington Creek); lead ranged from a low of 0.23 µg/g (Bloomington Creek) to a high of 1.01µg/g (Paris Creek). Ranges of selenium in tissue were from 1.48 µg/g in Bloomington Creek to 2.45 µg/g in Paris Creek. Zinc concentrations ranged from a low of 81.2 µg/g in one sample from Paris Creek, to a high concentration of 162 µg/g in one sample from Bloomington Creek. However, the invertebrate sample collected from Spring Creek (157 µg/g) was close to the high concentration measured in the sample collected from Bloomington Creek.

Table 5. Inorganic concentrations (μg/g dry weight) in invertebrate and common carp samples collected during 2002 from Bear Lake National Wildlife Refuge, Idaho.

Analyte [1]	Invertebrate Sample Locations			Carp Sample Location
	Bloomington Ck [2] (N = 2) [3]	Paris Ck [2] (N = 2)	Spring Ck (N = 1)	Mud Lake [2] (N = 12)
Aluminum	564.5 (220-909)	742 (732 – 752)	853	36.3 (11.4 - 572)
Arsenic	< dl [4] – 0.52 [5]	< dl – 1.57 [5]	1.69	2.18 (1.35 – 3.36)
Boron	< dl	< dl – 1.63 [5]	1.09	< dl
Cadmium	0.45 (0.43 – 0.47)	0.38 (0.30 – 0.49)	0.60	0.07 (<dl – 0.13)
Chromium	< dl – 0.72 [5]	< dl – 0.77 [5]	0.86	< dl – 1.43 [5]
Cobalt	< dl	< dl – 0.72 [5]	1.27	< dl – 0.51 [5]
Copper	18 (12.5 – 23.5)	16.6 (12.3 – 22.5)	19.5	3.39 (1.82 – 5.93)
Lead	0.46 (0.23 – 0.69)	0.85 (0.72 – 1.01)	0.73	0.24 (0.11 – 0.57)
Magnesium	1,195 (1,110 - 1,280)	1,260 (1,250 – 1,270)	1,740	1,360 (993 – 1,680)
Manganese	33.3 (26.9 - 39.7)	115 (93.1 - 141)	29.8	11.1 (5.26 – 49.4)
Mercury	< dl – 0.01 [5]	0.11 (0.08 – 0.15)	0.13	0.16 (0.07 – 0.41)
Nickel	< dl – 0.57 [5]	< dl – 0.71 [5]	0.89	< dl – 0.89 [5]
Selenium	1.81 (1.48 – 2.14)	2.09 (1.79 – 2.45)	2.03	1.36 (0.99 – 1.85)
Strontium	7.84 (7.19 – 8.49)	19.6 (9.99 – 38.3)	7.76	109 (34.3 - 206)
Vanadium	< dl	< dl	1.19	< dl – 1.09 [5]
Zinc	123 (83.5 – 162)	92.8 (81.2 - 106)	157	157 (38.8 - 350)

[1] All samples of beryllium, molybdenum, and silver had concentrations below the detection limit.
[2] Values presented represent the mean; values in parenthesis represent the range of concentrations detected.
[3] N = number of composite samples.
[4] dl = detection limit.
[5] Less than half of the samples analyzed had a concentration above the detection limit; therefore, no mean was calculated.

The geometric mean and range of concentrations for inorganic elements measured in 12 whole body fish samples are reported in Table 5. Fish were only collected from Mud Lake and not from the other sample sites. Likewise, invertebrates were not collected in Mud Lake.

Boron was the only inorganic compound not detected in any of the fish samples. Means were not calculated for chromium, cobalt, nickel and vanadium, since less than half of the samples had concentrations above the detection limit. Of the constituents found to be elevated in the Hot Springs Mine (Piper *et al.* 2000), arsenic concentrations ranged from 1.35 to 3.36 μg/g (mean of 2.18 μg/g), cadmium ranged from below detection limit to 0.13 μg/g (mean of 0.07 μg/g), and selenium concentrations in fish tissue ranged from 0.99 to 1.85 μg/g (mean concentration of 1.36

μg/g). Other trace elements of environmental concern include copper, with concentrations in fish tissue ranging from 1.82 to 5.93 μg/g (mean of 3.39 μg/g); and lead, with levels measured from 0.11 to 0.57 μg/g (mean of 0.24 μg/g). Mercury concentrations ranged from 0.07 to 0.41 μg/g, with a mean of 0.16 μg/g; and zinc with a range of 38.8 to 350 μg/g (mean of 157 μg/g).

Of the inorganics analyzed in bird eggs, 36% were not detected (Table 6). All of the eggs were collected from sites within the Mud Lake area (Figure 1). Lead and molybdenum had an insufficient number of detects to allow calculation of a mean. Of the remaining inorganic compounds, American coot eggs tended to have the highest concentrations of boron, copper, iron, strontium, and zinc. In contrast, eggs of white-faced ibis and Franklin's gulls tended to have the lowest concentrations of the trace elements of potential environmental concern. However, no clear trend in the concentration of inorganics was apparent among bird species.

Boron copper, mercury, molybdenum, selenium, and zinc are known to be of concern in irrigation return flows (NIWQP 1998). Boron was only detected in eggs of the white faced-ibis and the American coot. The range of concentrations was a low of 0.22 μg/g in ibis to 0.35 μg/g in coot eggs. Geometric means of copper concentrations were fairly uniform across species ranging from a low of 0.66 μg/g in eggs of the white-faced ibis, to 0.84 μg/g in American coot eggs. Mercury geometric means ranged from 0.03 μg/g in coot eggs to 0.13 μg/g in eggs of the great blue heron. Molybdenum was only detected in eggs of the great blue heron, and selenium geometric mean concentrations ranged in value from 0.25 μg/g in American coot eggs, to 1.02 μg/g in eggs of Franklin's gulls. The pattern is similar for zinc with the geometric mean ranging from a low of 8.38 μg/g in great blue heron eggs, and a high of 14.5 μg/g in coot eggs.

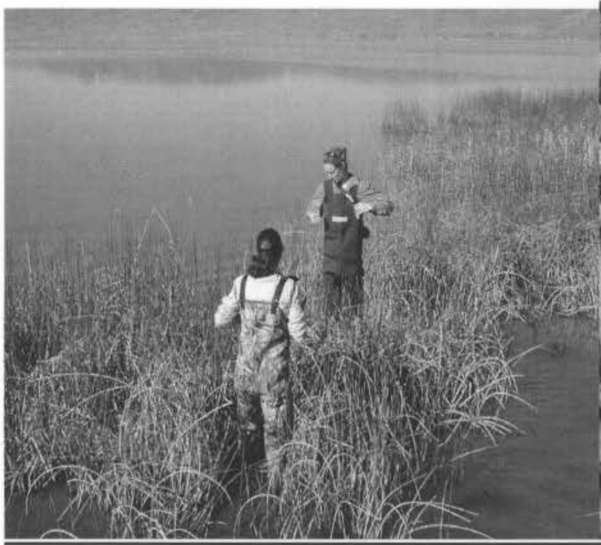



Table 6. Inorganic concentrations (µg/g wet weight) in Franklin=s gull, great blue heron, white-faced ibis, and American coot eggs collected during 2003 from Bear Lake National Wildlife Refuge, Idaho.

Analyte [1]	Franklin's Gull (N = 5) [2]	Great Blue Heron (N = 6)	White-Faced Ibis (N = 5)	American Coot (N = 3)
Boron	< dl	< dl	< dl [4] – 0.22 [5]	0.30 (0.26 – 0.35)
Copper	0.71 (0.54 – 0.85)	0.77 (0.71 – 0.87)	0.66 (0.57 – 0.88)	0.84 (0.74 – 0.92)
Lead	<dl – 0.01 [5]	< dl	<dl – 0.46 [5]	< dl
Manganese	0.54 (0.39 – 0.72)	0.18 (0.15 – 0.21)	0.29 (0.21 – 0.48)	0.29 (0.24 – 0.34)
Mercury	0.07 (0.03 – 0.09)	0.13 (0.06 – 0.42)	0.07 (0.03 – 0.12)	0.03 (0.01 – 0.05)
Molybdenum	< dl	< dl – 0.24 [4]	< dl	< dl
Selenium	1.02 (0.91 – 1.22)	0.84 (0.59 – 1.55)	0.83 (0.72 – 0.95)	0.25 (0.22 – 0.28)
Strontium	1.33 (0.85 – 1.83)	0.46 (0.27 – 0.62)	1.26 (0.83 – 2.22)	3.95 (2.67 – 5.62)
Zinc	13.1 (11.7 – 14.5)	8.38 (7.42 – 9.69)	9.11 (9.63 – 10.6)	14.5 (13.1 – 16.6)

[1] All samples of aluminum, arsenic, beryllium, cadmium, chromium, cobalt, nickel, silver, titanium and vanadium had concentrations below the detection limit.
[2] N = number of composite samples.
[3] Values in parenthesis represent the range of concentrations detected.
[4] dl = detection limit.
[5] Less than half of the samples analyzed had a concentration above the detection limit; therefore, no mean was calculated.

Organochlorine Compounds

Organochlorine compounds were below detection limits in all sediment and plant samples.

Biota Samples

Of the 22 OCs analyzed, only 2 (p,p'-DDD and p,p'-DDE) were above detection limits in fish tissue. Five fish samples had detectable concentrations of p,p'-DDD (range: 8 ng/g (ppb) – 15.9 ng/g) and 10 fish samples had detectable concentrations of p,p'-DDE (range: 11 ng/g – 34 ng/g).

Bird eggs were collected in 2003, the year following collections of water, sediment, fish, and invertebrates. In bird eggs, 7 of the 22 OCs were detected at low concentrations (Table 7).

Oxychlordane was present in eggs of all bird species. Concentrations of oxychlordane above the detection limit occurred in 1 of 5 gull eggs, 2 of 6 heron eggs, and 1 of the 5 ibis eggs. Dieldrin, hexachlorobenzene (HCB), and heptachlor epoxide were occasionally present in eggs. Detectable concentrations of dieldrin occurred in 2 out of 5 gull eggs, 1 of 6 heron eggs, and 2 of 5 ibis eggs. Detectable concentrations of HCB occurred in 1 of 5 gull eggs, 2 of 6 heron eggs, and 1 of 5 ibis eggs. Detectable heptachlor epoxide concentrations occurred in 2 of the 6 heron eggs, and 1 of the 5 ibis eggs. Of the OCs analyzed, p,p'-DDE concentrations were greatest and were detected in all samples.

Table 7. Organochlorine compound concentrations (ng/g fresh wet weight) in Franklin's gull, great blue heron and white-faced ibis eggs collected during 2003 from Bear Lake National Wildlife Refuge, Idaho.

Analyte [1]	Franklin=s gull (N = 5) [2]	Great blue heron (N = 6)	White-faced ibis (N = 5)
Dieldrin	< dl [3] - 22.8 [4]	dl - 1.67 [4]	< dl - 9.89 [4]
HCB	< dl - 1.84 [4]	< dl - 4.52 [4]	< dl - 13.5 [4]
Heptachlor Epoxide	16.3 (9.79 - 27.9) [5]	< dl - 28.0 [4]	< dl - 32.9 [4]
Oxychlordane	< dl - 9.01 [4]	< dl - 22.6 [4]	< dl - 16.9 [4]
p,p=-DDE	159 (84.0 - 320)	681 (106 - 6,475)	112 (40.9 - 216)
Total PCBs	< dl – 424 [4]	< dl – 814 [4]	< dl
Trans-nonachlor	10.3 (7.96 - 12.6)	< dl - 19.0 [4]	7.62 (< dl - 32.0)

[1] All samples of alpha BHC, alpha chlordane, beta BHC, cis-nonachlor, delta BHC, endrin, gamma BHC, gamma chlordane, mirex, o,p'-DDD, o,p'–DDE, o,p'-DDT, p,p'-DDD, p,p'-DDT, and toxaphene had concentrations below the detection limit.
[2] N = number of composite samples.
[3] dl = detection limit.
[4] Less than half of the samples analyzed had a concentration above the detection limit; therefore, no mean was calculated.
[5] Values in parenthesis represent the range of concentrations detected.

DISCUSSION

Water Quality

The Bear River and its tributaries entering the Bear Lake National Wildlife Refuge have a designated beneficial use of coldwater aquatic life and salmonid spawning. In the State of Idaho the water quality standard for the protection of coldwater aquatic life is 22 °C or less with a maximum daily average of no greater than 19 °C (IDAPA 58.01.02). Temperature for most of the sites was within an acceptable range; there was only one location (Spring Creek) that had a markedly elevated temperature of 23.8 °C.

The range of pH considered by IDEQ to be acceptable is 6.5 to 9. All pH values measured at the Refuge were within that standard, but tended to be on the higher end of the range meaning the water was more basic than acidic (7.88 - 8.48). The DO standard is 6 mg/L; all sites met or exceeded the criteria with the exception of one sample obtained from Mud Lake (DO = 5.89 mg/L).

Within Mud Lake (including the Rainbow and Outlet Canals), conductivity was fairly elevated (600 – 810 μS/cm), whereas conductivity levels in Bloomington, Paris, and Spring Creeks were 2 to 3 times lower (271 – 390 μS/cm). Likewise, hardness values calculated from calcium and magnesium concentrations measured in water samples at the analytical laboratory, tended to be higher in samples collected in the canals and in Mud Lake than in waters entering from the creeks. Toxicities of several contaminants detected in water samples are hardness dependent (e.g. cadmium, copper, lead, zinc), with toxicity generally decreasing with increasing hardness. Dissolved oxygen also appeared to be lower in samples collected from the Rainbow canal, Outlet Canal, and the three Mud Lake sites (Mud Lake 3, 4, 5) that are potentially influenced from the Rainbow canal. These factors of lower DO, elevated conductivity and hardness in areas in and around Mud Lake, would suggest water quality is being degraded from the sediment-laden irrigation return flows of the Rainbow and Telluride Canals, and to a lesser extent the Outlet Canal. However, DO concentrations are likely higher in the streams where water is faster and more turbulent, and thus more oxygenated, than in a shallow lake like Mud Lake.

Inorganics

Water Samples

Beryllium, chromium, cobalt, copper, mercury, molybdenum, nickel, and vanadium concentrations were below detection limits at all sites. Additionally, zinc was detected at only one site (Paris Creek).

Arsenic concentrations were below 4 µg/L (ppb) at all sites, well below the typical background concentration of 10 µg/L reported by Eisler (1988a) and well below Idaho's chronic aquatic life criteria of 190 µg/L (Table 3). Boron concentrations at all sites sampled at the Refuge were well below the predicted boron effects level range of 500 µg/L for catfish and trout embryos, to 600 µ/L for aquatic invertebrates (NIWQP 1998).

Likewise, cadmium, lead, selenium, and zinc were below nationally recommended criteria by EPA (2002). Water quality criteria for cadmium ranges from about 1 (chronic) to 2 µg/L (acute) at a hardness of 100 mg/L $CaCO_3$. The greatest cadmium concentration measured in water at the Refuge was 0.1 µg/L, at a hardness range of 215 – 328 mg/L $CaCO_3$. Criteria adjusted for hardness would be higher than 1 µg/L, additionally, as hardness increases, toxicity generally decreases. Lead concentrations on the Refuge did not exceed EPA's (2002) recommended criterion of 2.5 (chronic), and 65 µg/L (acute) for protection of aquatic organisms. However, adverse effects on aquatic biota have been documented at lead concentrations of 1.0 to 5.1 µg/L in water (Eisler 1988b); the hardness concentration in these studies is unknown. Two sample locations within the Refuge had lead concentrations in the lower range of effects reported by Eisler; these included Bloomington Creek (1.86 µg/L) and Rainbow Canal (1.0 µg/L). A NIWQP (1998) report cites that concentrations of selenium below 1 µg/L produce no discernable adverse effects on fish or wildlife and are typical of background concentrations in uncontaminated environments. Water selenium concentrations at the Refuge never exceeded 0.3 µg/L, well below the threshold for effects. The water sample collected from Paris Creek had the only detection of zinc at 10 μg/L. Similarly, this value is less than the no effect chronic value of 30 μg/L presented in the NIWQP report (1998), and EPA's 2002 recommended water quality criterion of 100 μg/L for both acute and chronic toxicity.

Sediment Samples

Generally, trace elements measured in sediments collected from the 12 sample sites were below levels of concern to the Service's trust resources.

Arsenic concentrations ranged from 2.49 μg/g in Spring Creek to 8.14 μg/g at Mud Lake site 5 (south of Rainbow Canal). All sites in Mud Lake, and samples collected from Paris Creek and Bloomington Creek exceeded the Lowest Effect Level (LEL) guideline for arsenic of 6 μg/g as established by the Ontario Ministry of the Environment and Energy (1993), but were well below the Limit of Tolerance Level of 33 μg/g.

Of the inorganic analytes analyzed in sediment, cadmium and copper had concentrations that exceeded the EPA sediment screening value Threshold Effects Level (TEL) (EPA 1998). The sediment sample collected from Rainbow Canal had a cadmium concentration of 0.68 μg/g (ppm), and a sample collected from Mud Lake (Mud Lake 3), south of the Rainbow Canal, had a concentration of 1.01 μg/g (mean for 7 Mud Lake samples = 0.68 μg/g). Copper concentrations in sediment samples ranged from 4.41 μg/g in Spring Creek to 65.2 μg/g at sample site Mud Lake 7 (south of Hot Springs Mine portal). The mean of 7 Mud Lake samples was 38.3 μg/g. The TEL for cadmium and copper are 0.68 μg/g and 18.7 μg/g, respectively. Additionally, the National Oceanic and Atmospheric Administration (1999) calculated sediment Effects Ranges for nine inorganics. Copper concentrations from five of the seven Mud Lake sediments (Mud Lake sites 1, 2, 5, 6, and 7) exceeded the Effects Range – Low (ERL) of 34 μg/g. The ERL is indicative of concentrations at which adverse effects rarely occur. Four of these sites occur immediately next to, or just south of, the Hot Springs Mine site. No samples collected exceeded the Effects Range – Medium (ERM) for copper, which is indicative of concentrations at which adverse effects frequently occur.

Concentrations of lead in sediment were generally low (range of 5.20 (Spring Creek) to 14.8 μg/g (Mud Lake 3)), and well below the 91 μg/g Canadian sediment Probable Effects Level (PEL) guideline (2002). Similarly, mercury and nickel concentrations were also low (mercury: <dl – 0.06 μg/g; nickel: 2.86 – 18.4 μg/g). Both elements were below the TEL benchmarks established by the Massachusetts (1996) of 0.18 μg/g for mercury, and 22.7 μg/g for nickel. Literature also indicate that silver and zinc concentrations measured in sediments from the Refuge (silver: <dl – 0.30 μg/g; zinc: 17.4 – 89.6 μg/g) are at levels considered to be in the range of background (Moore 1991, Andren and Bober 2002, NIWQP 1998).

Selenium concentrations in sediments from most sites were similar to background averages of 0.2 to 2.0 μg/g reported by the NIWQP (1998). Mud Lake samples had a mean sediment selenium concentration of 1.0 μg/g, with a range of 0.19 (Mud Lake site 7) to 2.09 μg/g (Mud Lake sites 1 and 2). Sediment collected from the Rainbow Canal had a selenium concentration of 0.39 μg/g which is within background averages; however, water collected from the Rainbow Canal had the highest concentration among samples at 0.29 μg/L.

Although water quality standards do not exist for compounds such as sulfur, it is an element often associated with acidification of surface waters, and the buildup of decaying material and production of hydrogen sulfide. It complexes with many toxic metals and organic materials, and limits the movement of these pollutants into the environment. The pH of waters entering and within Bear Lake Refuge are alkaline and do not indicate acidification of surface waters to be a threat. Elevated sulfur is not unexpected since waters in Mud Lake are ponded and an accumulation of organic material is likely, unlike faster moving waters of the streams.

Comparing sediment concentrations from the Refuge to EPA (1977) harbor pollution classifications reveals several inorganics in the category designation of "moderately polluted". Chromium concentration in sediment from Mud Lake 3, and manganese in Mud Lake, Rainbow Canal, and Outlet Canal, all exceed the 400 μg/g criteria. Strontium concentrations in sediments from all sites exceeded the Great Lakes background concentration of 49 μg/g. However, manganese itself is not usually acutely toxic to the majority of freshwater species, but is often associated with other metals; especially iron (Moore 1991). Unfortunately, additional interpretive guidelines for these inorganics are not readily available.

Biota Samples

Inorganic contaminant concentrations were generally low in invertebrate and most fish samples, and were low or not detected in many of the bird egg samples.

Arsenic concentrations in invertebrate samples collected during this study were well below levels that have been documented to cause effects in rainbow trout and birds (Eisler 1998; NIWQP 1998). However, arsenic in fish tissue is considered to be at "levels of concern" and just above the 85^{th} percentile concentration for freshwater fish (Schmitt and Brumbaugh 1990), but well below toxicity thresholds (NIWQP 1998).

Cadmium concentrations in whole body fish samples collected from Mud Lake (range of <dl to 0.13 μg/g) are within background levels reported by Eisler (1985), and were below concentrations reported in livers of arctic char (2.3 μg/g dry weight) from an unpolluted high Arctic Lake (Bohn and Fallis 1978 *as cited in* Moore and Ramamoorthy 1984). Such a comparison is valid since cadmium tends to accumulate in body organs instead of muscle tissue (Moore and Ramamoorthy 1984).

Concentrations of copper in invertebrates from Bloomington Creek, Paris Creek, and Spring Creek ranged from 12.3 to 23.5 μg/g. As with arsenic and cadmium, these levels of copper in the diets of fish and birds have not been shown to cause adverse effects (NIWQP 1998). Copper in fish tissue are also well below concentrations that are of concern to fish and birds. The geometric mean of fish tissue collected from the Refuge was 3.39 μg/g. The whole body fish tissue "No Effect" level cited in the NIWQP report (1998) is 9.8 μg/g, and the toxic dietary level for ducks is estimated to be greater than 200 μg/g.

Lead levels in aquatic invertebrates range from 0.23 to 1.01 μg/g, and in fish tissue from 0.11 to 0.57 μg/g. Lead has been shown to bioconcentrate in aquatic species, and invertebrates tend to have higher bioconcentration factors than vertebrates. Fish exposed to lead as part of their diet

(0.86 – 1.77 µg/g) for 21 days experienced increased scale loss and accumulation of lead in their guts (Farag *et al.* 1994). There is a slight chance that fish from Paris Creek could experience some adverse effects from lead since concentrations of lead in invertebrates ranged from 0.72 to 1.01 µg/g. However, it is not clear in the literature that lead is transferred through the food chain from concentrations of lead in prey (Eisler 1988b). It should be noted that the highest concentration of lead in water was in Bloomington Creek and not Paris Creek. Waterfowl feeding on the Refuge would likely not experience adverse effects from lead concentrations in biota, but have a greater likelihood of ill effects due to ingestion of lead shot from hunting activities.

Eisler (1987) lists background concentrations of mercury in any biological sample is usually less than 1.0 µg/g wet weight. Both invertebrate and fish tissue samples collected in Mud Lake and the streams had wet weight concentrations well below this background value. Mercury concentrations in carp samples from Mud Lake were well below concentrations of 1 to 5 µg/g reported to be the chronic effects estimate for rainbow trout (Niimi and Kissoon 1994). Furthermore, concentrations in fish tissue were about 20 times lower than the 2.7 µg/g mercury concentration reported to cause reproductive impairment in brook trout (McKim *et al.* 1976). Similar to invertebrate and fish tissue samples, mercury concentrations in eggs were well below 4 µg/g (ppm), the concentration reported to cause adverse effects in mallard ducks (Heinz 1976).

Concentrations of selenium in invertebrate and fish samples collected from the Refuge were within reported background concentrations (NIWQP 1998). Selenium in invertebrates collected from Bloomington Creek, Paris Creek, and Spring Creek on the Refuge ranged from 1.48 to 2.45 µg/g, with the highest concentrations in Bloomingtion Creek and Paris Creek (2.14 and 2.45 µg/g, respectively). The NIWQP report cites background concentrations for aquatic invertebrates is typically < 2, but can range from 0.4 – 4.5 µg/g. Monitoring has revealed that most fish species average less than 4 µg Se/g on a whole body basis (Schmitt and Brumbaugh 1990), but typically concentrations are less than 2 µg/g. Selenium in carp collected from Mud Lake ranged from 0.99 to 1.85 µg/g. Lemly (1996) reported 3 µg/g as the selenium concentration threshold in food-chain organisms (e.g., invertebrates) that may cause reproductive failure in fish and wildlife.

Tissue residues are not yet a reliable indicator of zinc contamination (NIWQP 1998). However, zinc concentrations in fish averaged 157 µg/g; however, concentrations as high as 350 µg/g were detected in some samples. These upper-end concentrations in nine fish samples are above what is considered normal background (88 µg/g) for whole fish (Schmitt and Brumbaugh 1990), and exceeded the 178 µg/g dietary concentration reported to cause marginal sublethal effects in birds (Eisler 1993).

Concentrations of inorganics were low or not detected in many bird egg samples. There are few studies available on the toxicity of copper to birds, but it appears that they tolerate copper better than most aquatic organisms do. The National Academy of Sciences (1980) reported that 300 mg Cu/kg in the diet is the maximum tolerable level for poultry. This value may be used to estimate the safety levels for avian wildlife with the use of safety factors (NIWQP 1998). Levels of copper measured in bird eggs ranged from 0.54 to 0.92 µg/g wet weights. A concentration of 5.5 µg/g dry weight is considered to be the "no effect" level (NIWQP 1998).

Selenium concentrations in eggs collected from the Refuge ranged from 0.22 – 1.55 µg/g, well below the concentration associated with reproductive impairment. It is selenium in the egg, rather than in the parent bird, that causes developmental abnormalities and death of avian embryos; therefore, selenium in the egg gives the most sensitive measure for evaluating hazards to birds. Additionally, given the rapid accumulation and loss patterns of selenium in birds, selenium concentrations in eggs also probably best represent contamination of the local environment (Heinz 1996). Based on the compilation of data from other studies, 3 µg/g (ppm) of selenium in bird eggs is the reported threshold for reproductive impairment (Heinz 1996).

Organics

Concentrations of legacy pollutants such as organochlorine pesticides were below detection limits in plant and sediment samples.

Biota Samples

Organochlorine compounds do not appear to be present on the Refuge at levels that will impact fish and wildlife. These chemicals have been largely phased out and no longer used, but are widely known to remain in the environment for decades and cause adverse effects to birds. Other organic compounds commonly used today in agriculture were not evaluated in this study.

Only p,p'-DDD and p,p'-DDE concentrations were above the detection limit in all fish samples collected. Concentrations were low, however, with maximum concentrations of p,p'-DDD at 0.016 µg/g) and maximum concentrations of p,p'-DDE at 0.034 µg/g. Lake trout in Cayuga Lake, New York, had tissue residues of 3.06 µg/g p,p'-DDE for 6 year old fish and 10 µg/g for 12 year old fish (Gutenmann *et al* 1992). It is not clear from the literature if adverse effects were occurring at these levels.

Concentrations of OCs were also low in eggs. No more than two eggs (and in some cases only one egg) from each species had concentrations of dieldrin, HCB, or oxychlordane above the detection limit. Similarly, only Franklin's gull eggs had a mean concentration of heptachlor epoxide (0.016 µg/g) above the detection limit; however, concentrations in heron and gull eggs were below the detection limit in all but 2 eggs.

Concentrations of p,p'-DDE, total PCBs, and trans-nonachlor, were below those reported to cause adverse effects. Eggshell thinning of 10 – 13 % has been documented in eggs of great blue herons with concentrations of 4 – 5 µg/g DDE (Blus 1996). Maximum concentrations of p,p'-DDE in great blue heron eggs collected from the Refuge were 0.68 µg/g. Similarly, Henry *et al.* (1985) reported reduced clutch size and egg breakage in white-faced ibis eggs with DDE concentrations of 3.0 µg/g. Maximum concentrations of p,p'-DDE in ibis eggs collected from the Refuge were 0.22 µg/g.

Many studies have reported effects of exposure to varying concentrations of total PCBs. Gilbertson et al. (1991) reported embryo mortality and reproductive success in gulls following exposure to 6 to 180 µg/g total PCBs. Reproductive impairment also was identified in tern eggs following exposure to between 6 to 26 µg/g total PCBs (Kubiak *et al.* 1989) and 5 to 24 µg/g total PCBs (Hoffman et al. 1993). For comparison, total PCB concentrations in gull eggs collected from the Refuge ranged from less than the detection limit to 0.424 μg/g, while heron eggs had concentrations ranging from less than detection to 0.814 μg/g. Total PCBs were not detected in any white-faced ibis eggs.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Historical Phosphate Mining

Bear Lake National Wildlife Refuge is located in southeast Idaho and sits at the north end of Bear Lake. There are numerous inactive, underground phosphate mines within this region of Idaho. One of these mines, the Hot Springs Mine, is located on the southeast corner of the Refuge across from Mud Lake (Figure 1). Two other inactive mine sites, the Bloomington Canyon Mine and Paris Canyon Mine, are located upstream of two creeks that flow into the Refuge. Concerns developed over the potential movement of contaminants from these sites into the Refuge, when investigations at other phosphate mines in the region indicated that elevated concentrations of contaminants, and in particular selenium, were being released into the environment (IDEQ, 2004). In addition, the Refuge is heavily influenced by agricultural return flows and acts as a sediment trap for the Bear River, which is often diverted through the Refuge and into Bear Lake (Bear Lake Regional Commission 1983, Idaho Cooperative Fish and Wildlife Research Unit 1989).

Mercury and selenium were highest in sediments collected on the Refuge near the Hot Springs Mine site (Mud Lake sites 1 and 2), but were within concentrations considered to be background (Massachusetts Department of Environmental Protection 1996). Boron, copper, molybdenum, silver, and strontium were highest in the sediment sample from Mud Lake 7. Copper concentrations exceeded EPA screening thresholds (1998) in five of seven sediment samples, while manganese is considered to be moderately polluted using EPA's harbor pollution classification (1977). These sites are closest to, and just south of the Hot Springs Mine site. It is likely that elevated trace elements in these sites are not associated with agricultural return flows, but due to migration of tailings from the Hot Springs Mine, and influence from the thermal hot spring located just south of the Refuge.

In May and July of 2002, the IDEQ led an interagency team to conduct an "orphan mine site screening". The intent of the screening activity was to ensure that all historical mining sites, (not being evaluated through other means), had been inspected and evaluated. The interagency team's primary objectives were to identify potential release pathways, conduct limited sampling of various site media, and evaluate regulatory risk concerns existing at the sites. In April 2004, IDEQ released their final Orphan Mine Site Preliminary Assessment Screening Report (Orphan Mine Report). Conclusions from the Orphan Mine Report indicate three sites have the potential for direct input of contaminants into the Refuge. These consist of the Bloomington Canyon Mine (via Bloomington Creek), Paris Canyon Mine (via Paris Creek), and the Hot Springs Mine.

Sampling results within the Orphan Mine Report (IDEQ 2004) for Bloomington Canyon Mine indicate transport of contaminants to soil and vegetation around the mine site, which exceed Area Wide action levels set by IDEQ and supporting agencies. Analyses of data collected from our study indicate that a few inorganics appear in Bloomington Creek samples (within the Refuge boundary) at slightly elevated concentrations. At this time, contaminant loads do not appear to be reaching the Refuge at levels shown to cause adverse effects to Service trust resources.

Paris Canyon Mine, which has direct input into Paris Creek and thus, the Refuge, has a similar risk evaluation associated with it as that described above for Bloomington Canyon Mine (IDEQ 2004). Volumes of mine waste were small at Paris Canyon Mine, but also showed significant erosion and disturbances. Sampling indicated a minimal amount of migration to surrounding surface water features, although waste deposition was evident. Concentrations of trace elements within Paris Creek do not appear to be at levels that would cause adverse impacts to fish and wildlife. Given that movement of mine material from Paris Canyon Mine into Paris Creek is minimal, it is unlikely that waste material would migrate to the Refuge in large enough amounts to cause adverse affects.

Of the historical phosphate mines identified within the drainage of the Refuge, the Hot Springs Mine has the largest potential to impact trust resources, since it is located immediately adjacent to Mud Lake. IDEQ sampling results indicate significant pathways of migration originating from the waste materials, the largest of which actually resides on Refuge land (IDEQ 2004). The Orphan Mine Report identified the Hot Springs Mine waste piles as having elevated concentrations of selenium, as well as other COPECs such as cadmium, copper, and zinc. Our data indicate that while adverse effects appear to be unlikely at this point, there is an on-going migration of contaminants into Mud Lake, as evidenced from the slightly elevated selenium, and high copper concentrations in the sediments collected from sites in Mud Lake (sites 1, 2, and 7) which are immediately adjacent to, or just south of the Hot Springs. This movement of contaminants into Mud Lake is expected to continue unless reclamation of the site occurs. Because of this, in June 2004, Service personnel met with IDEQ, the company responsible for the mine, and the Bureau of Land Management to discuss reclamation options. Several options for site reclamation are being considered, however a definitive approach to reclaiming the site and for monitoring have not yet been finalized. It is anticipated that reclamation work will begin in 2005.

Boron and strontium were higher in the water sample collected from Mud Lake near the Hot Springs Mine site than from other sites. Likewise, mercury and selenium were highest in sediments collected on the Refuge near the Hot Springs Mine site (Mud Lake sites 1 and 2), but were within concentrations considered to be background (Massachusetts Department of Environmental Protection 1996). Boron, copper, molybdenum, silver, and strontium were highest in the sediment sample from Mud Lake 7. Copper concentrations exceeded EPA screening thresholds (1998) in five of seven sediment samples, while manganese is considered to be moderately polluted using EPA's harbor pollution classification (1977). These sites are closest to, and just south of the Hot Springs Mine site. It is likely that elevated trace elements in these sites are not associated with agricultural return flows, but due to migration of tailings from the Hot Springs Mine, and influence from the thermal hot spring located just south of the Refuge.

Agricultural Influence

Although trace elements are often associated with mining, these pollutants can also be transported and concentrated in the environment from human activities such as agriculture. Sample sites that are less likely to be influenced by the historical phosphate mines are discussed within this section. These include Bloomington Creek, Paris Creek, Spring Creek, Outlet Canal, Rainbow Canal, and Mud Lake sites 3, 4, and 5.

The highest concentrations of trace elements in water that are of potential concern to trust resources were collected from the Rainbow Canal. The Bear River is diverted at Stewart Dam into the Rainbow Canal, which then joins with the Telluride Canal and passes through Mud Lake to Bear Lake. By the time the river is diverted into the Refuge, it is laden with nutrients and sediment (Utah Non Point Source Water Quality Conference & Bear River Watershed Symposium 2003). Depending upon the flow of water through Mud Lake and how much of the Refuge is flooded, Mud Lake often acts as a "sink" for sediment (Utah Non Point Source Water Quality Conference & Bear River Watershed Symposium 2003). Trace elements elevated in water from the Rainbow Canal included aluminum, arsenic, cadmium, manganese, and selenium. Lead was highest in water from Bloomington Creek, and the only detection of zinc was at Paris Creek.

Sediment collected from Mud Lake sites 3, 4, and 5 had the highest concentrations of arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, nickel, vanadium, and zinc. These three sites are located down-gradient from the Rainbow Canal (Figure 1). Arsenic and cadmium levels exceeded the Lowest Effect Level guideline established by Canada (Ontario Ministry of the Environment and Energy 1993) and EPA's Threshold Effects Level (1998), respectively. Chromium in sediment from Mud Lake 3 would be classified as moderately polluted using EPA Guidelines for classifying sediments of Great Lakes harbors (1977).

Biota samples generally had low concentrations of inorganic elements. Although arsenic in fish tissues were at "levels of concern" and slightly above the 85th percentile concentration for freshwater fish (Schmitt and Brumbaugh 1990), concentrations were still well below toxicity thresholds (NIWQP 1998). One invertebrate sample from Paris Creek had a lead concentration that has been documented to cause adverse effects in fish; however, the literature is not clear on the transfer of lead through the food web (Farag *et al.* 1994, Eisler 1988b). Zinc concentrations in fish tissue were of primary concern. Nine of the 12 samples had elevated levels over what is considered normal background for fish, and were at concentrations reported to cause sublethal effects in bird diets (Schmitt and Brumbaugh 1990, Eisler 1993).

Organochlorine compounds were detected in fish and bird samples, but were not at levels of concern. These chemicals are largely legacy pollutants as many have been banned from use. Other organic compounds (i.e. carbamates, organophosphates) used in agriculture were not evaluated in this study but should be considered for a future investigations.

In summary, our study results indicate that trace elements occur in water, sediment, and biota collected from the Bear Lake Refuge. Several trace element concentrations were at or slightly above guidelines, but the pattern of contamination did not point to any one source – historical phosphate mining or agriculture. There is evidence that both have had an influence on resources within the Refuge and that there may be additional inputs of trace elements from the geothermal hot springs located at the lower edge of the Refuge. Overall, concentrations are not at levels to be of concern to the Service's trust resources; however, there are several constituents that warrant continued monitoring, such as arsenic, lead, and zinc.

Current efforts are underway by several State and Federal agencies to reclaim disturbed ground that was previously mined for phosphate ore. Once these actions have been completed it is anticipated that pollutants identified from mines in the IDEQ Orphan Mine Report will no longer be a potential source of trace elements onto the Refuge.

Management Recommendations

We recommend three investigations to address water quality at the Refuge, with an emphasis on the agricultural/Bear River flows, which would include the following items.

- Intensive monitoring of water quality parameters including, but not limited to hardness, conductivity, dissolved oxygen, total suspended solids, pH, and alkalinity. In addition, in cooperation with other State, Federal, and local agencies/groups, measurements of the seasonal sediment and nutrient loading occurring from the Rainbow and Telluride canals entering the Refuge/Mud Lake area, and as it exits the Refuge into Bear Lake. Trace elements should be included in the analysis to further evaluate the potential effects of metals to the Service's trust resources.
- Research leading into a sampling plan to assess the use of agricultural chemicals within the Bear River basin that may influence resources on the Refuge, which were not analyzed as part of this study. Sampling of sediments and possibly biota for these agricultural chemicals would be included to determine if concentrations are at levels that may cause effects to fish and wildlife.
- Evaluate the influence of the geothermal hot springs on sediment and biological resources of the Refuge. Our investigation indicated that mercury may be entering the Refuge and accumulating in sediments in the vicinity of the hot springs. Further investigation and sampling should be done to determine if total and methyl mercury and other metals are present in concentrations that could affect the Service's trust resources.

REFERENCES

Andren A.W. and T.W. Bober, editors. 2002. Silver in the Environment: Transport, Fate, and Effects. Research Findings of the Argentum International Conference Series, 1993-2000. Pensacola, FL, USA: Society of Environmental Toxicology and Chemistry (SETAC). 192 p.

Blus, L.J. 1996. DDT, DDD, and DDE in birds. Pages 49-71 *in* Beyer, W.N., G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental contaminants in wildlife: Interpreting tissue concentrations. Lewis Publishers, New York, New York.

Eisler, R. 1985. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85 (1.2), Contaminant Hazard Reviews Report 2. 46 p.

Eisler, R. 1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85 (1.10), Contaminant Hazard Reviews Report 10. 90 p.

Eisler, R. 1988a. Arsenic hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service Biological Report 85 (1.12). 92 p.

Eisler, R. 1988b. Lead hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service Biological Report 85 (1.14). 134 p.

Eisler, R. 1993. Zinc hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 10, Contaminant Hazard Reviews Report 26. 106 p.

Environment Canada. 2002. The Canadian sediment quality guidelines for the protection of aquatic life. Summary table, 12 p.

EPA. 1977. USEPA Region 5 harbor classification. Chicago, Illinois.

EPA. 1980a. Ambient water quality criteria for selenium. U.S. Environ. Protection Agency Rep. 440/5-80-070. 123 p.

EPA. 1998. Sediment quality guidelines: National sediment inventory, appendix D – Screening values for chemicals evaluated. 19 p.

EPA. 2002. National Recommended Water Quality Criteria: 2002. EPA-822-R-02-047.

Farag, A.M., Boese, C.J., Woodward, D.F., Bergman, H.L. 1994. Physiological changes and tissue metal accumulation in rainbow trout exposed to foodborne and waterborne metals. Environmental Toxicology and Chemistry. 13(12):2021-2029.

Gilbertson, M., T. Kubiak, J. Ludwig, and G. Fox. 1991. Great Lakes embryo mortality, edema, and deformities syndrome (GLEMEDS) in colonial fish-eating birds: similarity to chick-edema disease. Journal of Toxicology and Environmental Health 33:455-520.

Gutenmann, W.H., J.G. Ebel, H.T. Kuntz, K.S. Yourstone, and D.J. Lisk. 1992. Residues of *p,p'*DDE and mercury in lake trout as a function of age. Archives of Environmental Contaminants and Toxicology. 22:452-455.

Heinz, G.H. 1976. Methylmercury: second-year feeding effects on mallard reproduction and duckling behavior. Journal of Wildlife Management 40:82-90.

Heinz, G.H. 1996. Selenium in birds. Pages 447-458 *in* Beyer, W.N., G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental contaminants in wildlife: Interpreting tissue concentrations. Lewis Publishers, New York, New York.

Henry, C.J., L.J. Blus, and C.S. Hulse. 1985. Trends and effects of organochlorine residues on Oregon and Nevada wading birds, 1979-1983. Colonial Waterbirds 8:117-128.

Hoffman, D.J., G.J. Smith, and B.A. Rattner. 1993. Biomarkers of contaminant exposure in common terns and black-crowned night herons in the Great Lakes. Journal of Environmental Toxicology and Chemistry 12:1095-1103.

IDEQ. 2004. Orphan Mine Site Preliminary Assessment Screening Report. Prepared by: Idaho Department of Environmental Quality, Idaho Department of Lands, U.S. Bureau of Land Management, and U.S. Forest Service. 34 p.

Kubiak, T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.I. Stalling, J.A. Trick, L. Sileo, D.E. Docherty, and T.C. Erdman. 1989. Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan – 1983. Archives of Environmental Contamination and Toxicology 18:706-727.

Lemly, D.A. 1996. Selenium in aquatic organisms. Pages 427-445 *in* Beyer, W.N., G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental contaminants in wildlife: Interpreting tissue concentrations. Lewis Publishers, New York, New York.

Massachusetts Department of Environmental Protection. 2002. Freshwater Sediment Screening Benchmarks for Use Under the Massachusetts Contingency Plan. Update to: Section 9.4 of *Guidance for Disposal Site Risk Characterization – in Support of the Massachusetts Contingency Plan* (1996). Technical Update. Office of Research and Standards.

McKim, J.M., G.F. Olson, G.W. Holcombe, and E.P. Hunt. 1976. Long-term effects of methylmercuric chloride on three generations of brook trout (*Salvelinus fontinalis*): toxicity, accumulation, distribution, and elimination. Journal of the Fisheries Research Board of Canada 34:1148-1154.

Moore, J.W. and S. Ramamoorthy. 1984. Heavy metals in natural waters: applied monitoring and impact assessment. Springer-Verlag New York, Inc. New York. 268 p.

Moore, J.W. 1991. Inorganic contaminants of surface water: research and monitoring priorities. Springer-Verlag New York, Inc. 334 p.

National Academy of Sciences. 1980. Mineral tolerance of domestic animals. National Academy of Science. U.S. National Research Council. Washington. 577p.

National Irrigation Water Quality Program (NIWQP). 1998. Guidelines for the interpretation of the biological effects of selected constituents in biota, water, and sediment. Information Report No. 3. 198 p.

National Oceanic and Atmospheric Administration. 1999. Sediment quality guidelines developed for the National Status and Trends Program. 12 p.

Niimi, A.J. and G.P. Kissoon. 1994. Evaluation of the critical body burden concept based on inorganic and organic mercury toxicity to rainbow trout (*Oncorhynchus mykiss*). Archives of Environmental Contamination and Toxicology 26:169-178.

Persaud, D., R. Jaagumagi, and A. Hayton. 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of the Environment and Energy. Toronto. 27 p.

Piper, D.Z., Skorupa, J.P., Presser, T.S., Hardy, M.A., Hamilton, S.J., Huebner, M., and R.A. Gulbrandsen. 2000. The Phosphoria formation at the Hot Springs Mine in southeast Idaho: A source of selenium and other trace elements to surface water, ground water, vegetation, and biota. Open File Report 00-050. 34 p.

Schmitt, C.J., and W.G. Brumbaugh. 1990. National Contaminant Biomonitoring Program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984. Archives of Environmental Contaminants and Toxicology 19:731-747.

USFWS. 1996. Bear Lake National Wildlife Refuge, Idaho. U.S. Department of Interior, Fish and Wildlife Service, Montpelier, Idaho. Visitor's pamphlet. RF14613, January.

Utah Non-Point Source Water Quality Conference & Bear River Watershed Symposium. 2003. Meeting Notes.

APPENDICES

Appendix A. Method detection limits for organochlorine compounds in sediment, plant, fish, and bird egg tissue collected from Bear Lake National Wildlife Refuge, Idaho, in 2002 and 2003. DDD = dichlorodiphenyldichloroethane, DDE = dichlorodiphenyldichloroethylene, DDT = dichlorodiphenyltrichloroethane, PCB = polychlorinated biphenyl, BHC = benzene hexachloride, HCB = hexachlorobenzene.

Analyte	Method Detection Limit		
	Sediment (Φg/g) dry weight	Plant Tissue (Φg/g) wet weight	Fish and Bird Egg Tissue (Φg/g) wet weight
Aluminum	0.002	0.002	0.002
Alpha Chlordane	0.002	0.002	0.002
Beta BHC	0.002	0.002	0.002
Cis-Nonachlor	0.002	0.002	0.002
Delta BHC	0.002	0.002	0.002
Dieldrin	0.002	0.002	0.002
Endrin	0.002	0.002	0.002
Gamma BHC	0.002	0.002	0.002
Gamma Chlordane	0.002	0.002	0.002
HCB	0.002	0.002	0.002
Heptachlor Epoxide	0.002	0.002	0.002
Mirex	0.002	0.002	0.002
o,p'-DDD	0.002	0.002	0.002
o,p'-DDE	0.002	0.002	0.002
o,p'-DDT	0.002	0.002	0.002
Oxychlordane	0.002	0.002	0.002
p,p'-DDD	0.002	0.002	0.002
p,p'-DDE	0.002	0.002	0.002
p,p'-DDT	0.002	0.002	0.002
Total PCB	0.02	0.02	0.02 [1]
Toxaphene	0.05	0.05	0.05
Trans-nonachlor	0.002	0.002	0.002

1 Method detection limit of Total PCB for bird eggs is 0.01 Φg/g.

Appendix B. Method detection limits for inorganic compounds in samples collected from Bear Lake National Wildlife Refuge, Idaho, in 2002 and 2003. NA=Not Analyzed.

Analyte	Method Detection Limit				
	Sediment (Φg/g) dry weight	Invertebrate (Φg/g) dry weight	Water (Φg/L) wet weight	Fish Tissue (Φg/g) dry weight	Bird Egg Tissue (Φg/g) wet weight
Aluminum	5.0	10	0.05	5.0	1.0
Arsenic	0.5	1.0	0.00025	0.5	0.1
Barium	0.1	0.2	0.001	0.1	0.2
Beryllium	0.5	0.1	0.0005	0.5	0.1
Boron	2.0	2.0	0.01	1.0	0.2
Calcium	2.0	3.0	0.02	2.0	1.0
Cadmium	0.05	0.1	0.00005	0.05	0.1
Chromium	0.2	1.0	0.005	0.5	0.1
Cobalt	0.5	1.0	0.005	0.5	0.1
Copper	0.2	1.0	0.005	0.5	0.1
Iron	0.5	2.0	0.01	1.0	0.2
Lead	0.5	0.1	0.00005	0.05	0.005
Magnesium	1.0	2.0	0.01	1.0	0.5
Manganese	0.1	0.5	0.002	0.2	0.5
Mercury	0.02	0.05	0.00002	0.02	NA
Molybdenum	1.0	2.0	0.01	1.0	0.2
Nickel	0.5	1.0	0.005	0.5	0.1
Phosphorus	5.0	100	NA	50	10
Potassium	10	20	0.1	10	2.0
Selenium	0.02	1.0	0.0001	0.05	0.005
Silicon	NA	20	0.1	10	2.0
Silver	1.0	2.0	NA	1.0	0.2
Sodium	200	300	2.0	200	45
Strontium	0.1	1.0	0.0005	0.05	0.1
Sulphur	10	100	NA	50	10
Titanium	0.1	1.0	0.005	0.5	0.1
Vanadium	0.5	2.0	0.01	1.0	0.2
Zinc	0.2	1.0	0.005	0.5	0.2