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Contaminants in Oil Field Produced Waters Discharged into the Loch Katrine Wetland Complex, Park County, Wyoming and Their Bioconcentration in the Aquatic Bird Food Chain

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Environmental Contaminants Program

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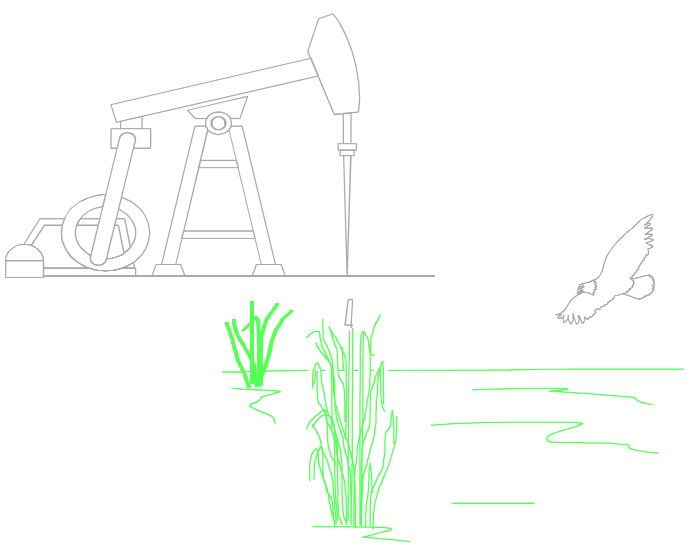

Contaminants in Oil Field Produced Waters Discharged into the Loch Katrine Wetland Complex, Park County, Wyoming and Their Bioconcentration in the Aquatic Bird Food Chain

By

Pedro Ramirez, Jr.

ABSTRACT

The 866-acre Loch Katrine wetland complex in Park County, Wyoming provides habitat for many species of aquatic birds. However, the complex is sustained primarily by oil field produced waters. This study was designed to determine if constituents in oil field produced waters discharged into Loch Katrine pose a risk to aquatic birds inhabiting the wetlands. Trace elements, hydrocarbons and radium-226 concentrations were analyzed in water, sediment and biota collected from the complex during 1992. Boron and radium-226 were present in the produced water discharge and are bioaccumulating in the food chain. Although not present in acute concentrations, elevated boron in aquatic vegetation may cause chronic effects to aquatic birds such as reduced growth in ducklings or altered metabolism. The 93.7 pCi/l radium-226 concentration recorded at the Sidney Battery Discharge in July exceeded the Wyoming Department of Environmental Quality's (WDEQ) 60 pCi/l standard for the protection of aquatic life (WDEQ 1990). The radium-226 concentration in aquatic vegetation from Custer Lake, 29.5 pCi/g, exceeded the 2.9 pCi/g average concentration found in plants growing in uranium mill tailings in South Dakota (Rumble and Bjugstad 1986). The presence of radium-226 in aquatic vegetation suggests that this radionuclide is available to aquatic birds. The water quality criterion for the protection of aquatic organisms from acute effects was exceeded for arsenic at Custer Lake in July and for zinc at the Sidney Battery Discharge in April. Arsenic and zinc concentrations were also elevated in sediment but not in aquatic vegetation and invertebrates. Oil and grease concentrations in water from Sidney Battery Discharge exceeded the maximum 10 mg/l permitted by the WDEQ (1990). Total aliphatic and aromatic hydrocarbon concentrations in sediments were highest at the Sidney Battery Discharge, 6.376 µg/g, followed by Custer Lake, 1.104 µg/g. The higher levels of hydrocarbons found at Custer Lake, compared to Loch Katrine, may be explained by Custer Lake's closer proximity to the Sidney Battery Discharge. Benzo(a)pyrene was not detected in bile from gadwalls collected at Loch Katrine but was detected in bile from northern shovelers collected at Custer Lake. Benzo(a)pyrene concentrations in northern shoveler bile ranged from 500 to 960 ng/g (ppb) wet weight. The presence of benzo(a)pyrene in the shovelers indicates exposure to petroleum hydrocarbons. Nesting failure in aquatic birds was attributed to flooding and predation rather than contaminants. Contaminants from oil field produced water discharge are probably not affecting nesting success because trace element concentrations in bird eggs were not present in levels known to cause embryo mortality and because no oil was observed on the egg shells. The risk to peregrine falcons and bald eagles feeding on aquatic birds from the Loch Katrine wetland complex is minimal because trace element and hydrocarbon concentrations in aquatic birds were low. Periodic monitoring of Loch Katrine for radium-226, arsenic, zinc and metabolized polycyclic aromatic hydrocarbons is warranted to determine trends and effects in the aquatic bird food chain.

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INTRODUCTION

In arid areas of Wyoming, oil field produced waters are commonly discharged into depressions and drainages for disposal. The discharges often create wetlands and provide habitat for wildlife. However, a myriad of trace elements and hydrocarbon compounds can occur in oil field produced waters (Kemmer 1988). Seemingly innocuous levels of contaminants in oil field brines can accumulate in sediments and the food chain and can adversely affect aquatic birds. Waterfowl ingesting sublethal doses of oil can experience impaired reproduction (Grau et al. 1977). Female aquatic birds returning to their nests with oil on their feathers can inadvertently apply the oil to their eggs (King and Le Fever 1979). Microliter amounts of oil applied externally to eggs are extremely toxic to bird embryos (Leepen 1976, Szaro 1979).

Low discharges of produced water combined with dry weather can lower the water level at Loch Katrine and disrupt aquatic bird nesting. The Bureau of Land Management (BLM) proposes to maintain a consistent water level at Loch Katrine to enhance aquatic bird production by constructing water control structures and dikes. A long-term proposal includes diverting water from Buffalo Bill Reservoir along an existing freshwater pipeline to Loch Katrine. BLM is investigating this proposal in coordination with the Bureau of Reclamation, the U.S. Fish and Wildlife Service (Service), Marathon Oil Company, Ducks Unlimited, Wyoming Game and Fish Department and the Wyoming State Engineer. Trace element and/or petroleum hydrocarbon compounds could be affecting aquatic birds nesting at the Loch Katrine wetland complex; therefore, data are needed to determine potential effects of oil field produced waters to aquatic birds.

In July 1985, the BLM measured an oil and grease concentration of 74.1 mg/l in a water sample collected from the discharge to Custer Lake. In 1987 and 1988, total dissolved solids in the discharge exceeded 5,000 mg/l, the maximum allowed by the WDEQ (1978). In 1989, the Service collected water, sediment and biota from the Loch Katrine wetland complex at the request of BLM biologist Eric Greenquist. The limited number of samples analyzed did not provide conclusive evidence of adverse affects to aquatic birds but indicated potential problems that deserved a more in-depth investigation. Boron concentrations in water collected from the Sidney Battery Discharge and Custer Lake ranged from 2,520 µg/l to 3,830 µg/l. These levels are below the 100,000 to 300,000 µg/l concentrations suspected to cause adverse effects to aquatic organisms (Eisler 1990). Aliphatic and polycyclic aromatic hydrocarbons were not detected in water samples from the Sidney Battery Discharge or Custer Lake, but several aliphatic and aromatic hydrocarbon compounds were detected in sediments from Loch Katrine and Custer Lake. Sediments from Custer Lake had the highest concentration of total hydrocarbons (14.6 µg/g wet weight or 34.9 µg/g dry weight) and oil and grease (5,450 µg/g wet weight or 13,038 µg/g dry weight).

Boron concentrations in aquatic vegetation samples collected from Loch Katrine were greater than the 300 µg/g concentration suspected of causing reduced growth in mallard ducklings (Eisler 1990). None of the vegetation samples exceed the 1,000 µg/g concentration suspected to cause embryo mortality in mallards (Eisler 1990). Selenium concentrations in pondweed (*Potamogeton* spp.) samples from Loch Katrine did not exceed the 3 µg/g level of concern for bioconcentration in the food chain reported by Lemly and Smith (1987). A duckling carcass from Custer Lake that died of unknown causes was submitted for polycyclic aromatic hydrocarbon (PAH) analyses. Aromatic hydrocarbons detected in the carcass included chrysene at 0.02 µg/g and benzo(e)pyrene at 0.01 µg/g wet weight and 11 aliphatic hydrocarbons. The carcass had a total hydrocarbon concentration of 1.11 µg/g wet weight (5.41 µg/g dry weight). Pristane was not detected in the carcass; but the, phytane concentration of 0.04 µg/g wet weight, indicated that these were petrogenic hydrocarbons.

In 1992, the BLM provided funds to study the effects of oil field produced waters discharged into the Loch Katrine wetland complex. The objectives of this study were to:

1. determine organic and inorganic contaminants in oil field produced waters discharged into wetlands supporting breeding waterfowl and shorebirds;
2. determine if contaminants in oil field produced waters are bioconcentrating in the food chain at levels adverse to aquatic avifauna;
3. determine if pathways exist for contaminants to affect threatened and endangered species.

Acknowledgements - Joni Armstrong, Mike Lessard and Steve Oddan of the Service collected samples for this study. Yuman Lee, BLM, conducted bird and nesting surveys and collected bird eggs. Chuck Neal, BLM, also assisted with bird surveys. The manuscript was reviewed by George T. Allen, Kirke King, Rick Roy and Sandy Spon of the Service, Tom Hare, BLM, and Jeff Lucero, U.S. Bureau of Reclamation. Eric Greenquist, BLM, initiated efforts to fund the study. The study was funded by BLM and the Service. Thanks are extended to these individuals for their assistance.

STUDY AREA DESCRIPTION

The 350-hectare (866-acre) Loch Katrine wetland complex, on BLM land near Cody, Wyoming, is sustained primarily by oil field produced waters generated by Marathon Oil Company at its Oregon Basin Oil Field. The produced water originates from the Madison Formation approximately 2,100 meters (7,000 feet) below the surface and is discharged during oil recovery operations into Custer Lake, an artificial wetland created by the discharge.. The water at the Sidney Battery discharge is discharged at temperatures greater than 32ºC (>90ºF) and is cooled to ambient temperatures at Custer Lake before it flows to Loch Katrine through a canal.

Nesting species of waterfowl at Loch Katrine include: Canada goose (*Branta canadensis*), redhead (*Aythya americana*), lesser scaup (*A. affinis*), mallard (*Anas platyrhynchos*), pintail (*A. acuta*), gadwall (*A. strepera*), American wigeon (*A. americana*), northern shoveler (*A. clypeata*), and green-winged (*A. crecca*), blue-winged (*A. discors*) and cinnamon teal (*A. cyanoptera*). Shorebirds and other aquatic birds nesting at Loch Katrine include: eared grebe (*Podiceps nigricollis*, American coot (*Fulica americana*), black-necked stilt (*Himantopus mexicanus*), American avocet (*Recurvirostra americana*), sandhill crane (*Grus canadensis*), white-faced ibis (*Plegadis chihi*), long-billed curlew (*Numenius americanus*), killdeer (*Charadrius vociferus*), black tern (*Chlidonias niger*) and Wilson's phalarope (*Phalaropus tricolor*). Two threatened and endangered species, peregrine falcon (*Falco peregrinus*) and bald eagle (*Haliaeetus leucocephalus*), have been observed in the area.

METHODS

Water and sediment samples were collected at the discharge pipe, Custer Lake and Loch Katrine (Figure 1).

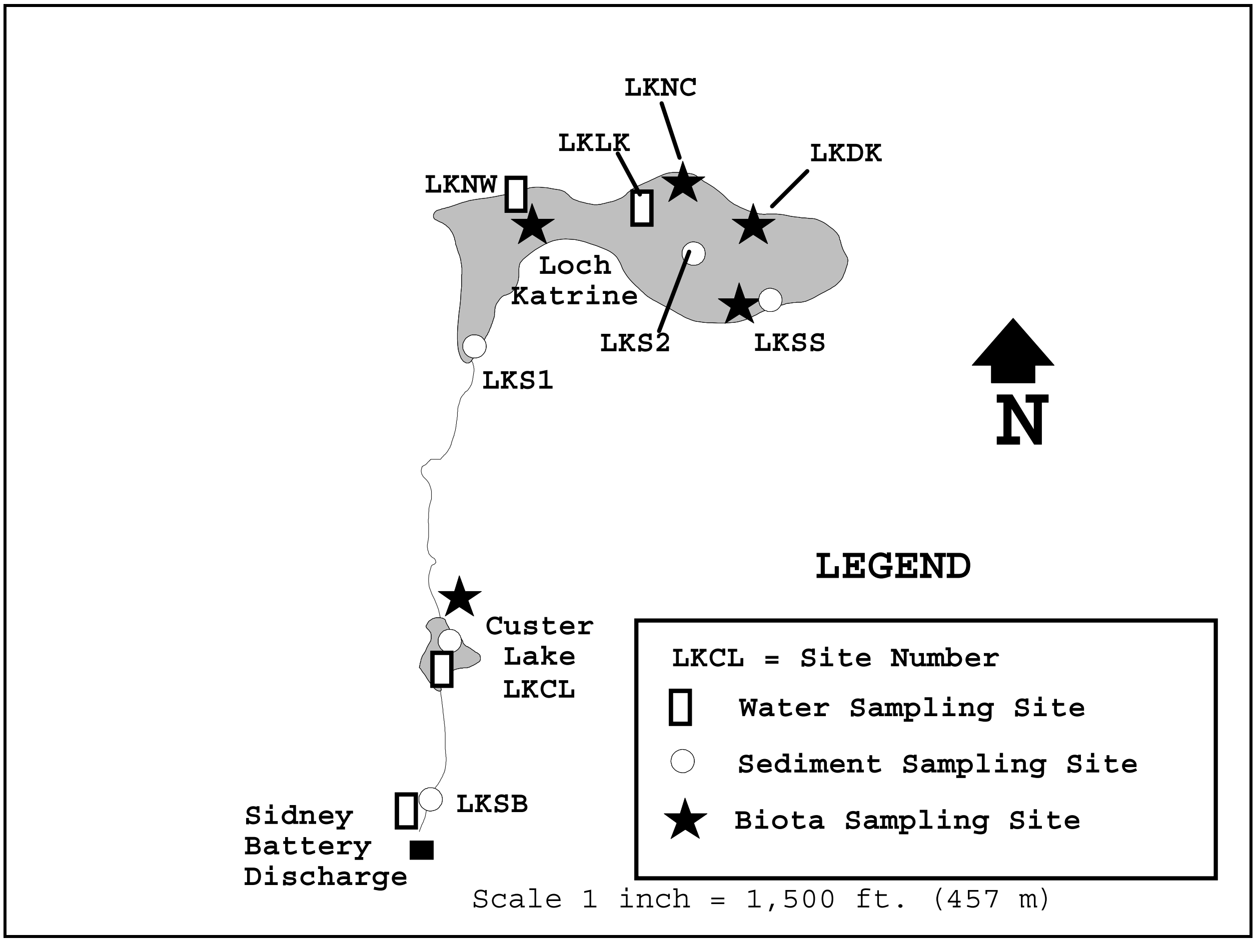

Figure 1. Sampling locations for water, sediment and biota collected at the Loch Katrine wetland complex, Park County, Wyoming.

We collected two water samples for chemical analyses at each site in April 1992 during the pre-nesting period for aquatic birds and in July 1992 during the fledging period. Water samples were collected in 1 liter chemically-clean polyethylene jars with teflon-lined lids for trace element and radium-226 analyses. The pH in the water samples collected for chemical analyses was lowered to approximately 2.0 with laboratory grade nitric acid. Water samples for oil and grease analyses were collected in 950 ml chemically-clean amber glass jars with teflon-lined lids and kept chilled at 4ºC. Sediment samples were analyzed for trace elements, radium-226, oil and grease, and aliphatic and aromatic hydrocarbon compounds. One composite sediment sample was collected at the Sidney Battery Discharge and at Custer Lake. Three composite sediment samples were collected at various points in Loch Katrine to determine if hydrocarbon concentrations decrease with increasing distance from the oil field produced water inflow point. Water and sediment samples were also collected from Alkali Lake, a reference site near Cody. Sediment and biota samples were placed in chemically-clean glass jars with teflon-lined lids and frozen as soon as possible. Samples collected for hydrocarbon analyses were placed in chemically-clean amber glass jars or vials. Aquatic invertebrates and submerged aquatic vegetation were collected at Custer Lake and Loch Katrine and analyzed for trace elements and hydrocarbons. Addled aquatic bird eggs were collected and dissected and the contents were submitted for trace element and hydrocarbon analyses. Embryos were aged and examined for deformities.

To quantify nesting success, the BLM conducted nest searches one day each week in May for waterfowl and late June and July for other aquatic birds. Nests were marked using wire survey flags placed 4 m north of the nest. Nest identification numbers were recorded on the flags. The exact nest location was plotted on a map. After recording waterfowl nest data, the observer covered the eggs with down to conceal them from avian predators. A small strip of yarn was placed over the covered nest so that a returning hen could be detected on a subsequent visit. No special effort was made to conceal grebe and shorebird nests after each nest inspection. Eggs in a nest were numbered consecutively using a waterproof marker. A hatching date was estimated based on the incubation period for the species. The nests were revisited during the estimated hatching period to determine the fate of the eggs and nesting success. Data recorded at each nest followed methods recommended by Klett et al. (1986). Additionally, egg shells were examined for any signs of oil.

Fresh carcasses were wrapped in aluminum foil, frozen and submitted to the Wyoming Game and Fish Department's veterinary diagnostic lab in Laramie for necropsy. Bird liver samples were analyzed for trace elements and hydrocarbons. Pre-fledged aquatic birds were collected during late July using a shotgun and steel shot. Target species included: gadwall, northern shoveler, American avocet and eared grebe. Liver and bile samples from each species were submitted for trace element and hydrocarbon analyses, respectively. Aquatic bird surveys were conducted weekly at Loch Katrine and Custer Lake to determine species and abundance between April and November.

Water, sediment and biota samples were submitted to the Service's Patuxent Analytical Control Facility (PACF) or designated contract laboratories for trace element and hydrocarbon analyses. Trace element analysis included scans for: arsenic, mercury, and selenium using atomic absorption spectroscopy. Inductively Coupled Plasma Emission Spectroscopy was used to scan for a variety of elements including boron, barium, copper, lead, vanadium and zinc. Radium Water and sediment samples were analyzed for radium-226 by co-precipitation with barium sulfate and counted by alpha spectrometry. An extended scan for aromatic hydrocarbons was conducted on sediment and bird liver samples. Bird bile was analyzed for polycyclic aromatic hydrocarbon metabolites using high performance liquid chromatography. Quality assurance and quality control was provided by PACF. Chemical residues are expressed in Fg/g (ppm) dry weight unless otherwise specified.

RESULTS

Trace Elements

Arsenic

Arsenic in water samples from Custer Lake ranged from 33.1 µg/l in April to 423 µg/l in July and are above the 10 to 48 µg/l concentrations demonstrated to adversely affect some aquatic species (Eisler 1988a). Arsenic in water samples from Loch Katrine ranged from 7.3 µg/l in July to 35.6 in April. Arsenic concentrations in sediments from Loch Katrine ranged from 5.71 to 10.4 µg/g exceeding the 5.5 µg/g mean concentration reported in soils and other surficial materials in the western United States (Shacklette et al. 1971). Arsenic concentrations in aquatic vegetation ranged from 2.49 µg/g in algae collected at Custer Lake to 15.6 µg/g in widgeongrass collected at Loch Katrine. Arsenic concentrations in aquatic invertebrates collected from Custer Lake and Loch Katrine ranged from 2.75 to 7.31 µg/g and averaged 5.46 µg/g. Eisler (1988) reported that background arsenic concentrations in biota are usually less than 1 µg/g wet weight (3 to 4 µg/g dry weight). Jenkins (1981) suggests the potential for bioaccumulation or bioconcentration of arsenic is moderate for mammals, birds, fish, mosses, lichens, and algae, but high to very high for mollusks, crustacea, lower animals, and higher plants. Uptake of arsenic by phytoplankton can be significant (Lindsay and Sanders 1990). Although concentrations in water were elevated and arsenic in sediment, aquatic vegetation and aquatic invertebrates was above background, arsenic was not detected in bird eggs. Arsenic in a liver sample from a juvenile eared grebe collected at Loch Katrine was elevated at 7.41 µg/g. Eisler (1988) reported that arsenic concentrations in bird livers above 2 to 10 µg/g wet weight (6 to 33 µg/g dry weight) are considered elevated. Although biota can accumulate arsenic from the water, there is no evidence of magnification of this element along the food chain (Eisler 1988a).

Boron

Boron concentrations in widgeongrass from Loch Katrine ranged from 309 to 554 µg/g, exceeding the 300 µg/g dietary level associated with reduced growth in ducklings (Eisler 1990).

Cadmium

One widgeongrass sample from loch Katrine had a cadmium concentration of 0.322 µg/g. Eisler (1985) recommended that dietary cadmium concentrations greater than 0.3 µg/g dry weight should be viewed with caution.

Copper

Copper is listed by the Environmental Protection Agency as one of 129 priority pollutants (Keith and Telliard 1979). Copper concentrations in gadwalls collected from Loch Katrine ranged from 104 to 166 µg/g, above the 86 µg/g level considered normal, but were below the 186 µg/g level associated with copper toxicosis (Henderson and Winterfield 1975).

Radium-226

Radium-226 is a radionuclide produced by uranium and thorium decay (Hem 1985). Radium can be found in groundwater and surface waters in undissolved and dissolved states (Wagner 1980). Radium levels below 1.0 pCi/l can be expected in river water but concentrations as high as 720 pCi/l have been recorded in areas receiving oilfield produced waters (Hem 1985). Radium-226 was detected in water samples from Loch Katrine, Custer Lake and the Sidney Battery Discharge (Figure 2). Radium-226 was present at 9.31 pCi/l in one water sample collected in April 1992 from Loch Katrine but was below detection limits in a sample collected in July 1992. Radium-226 was below detection limits in one water sample collected from the Sidney Battery Discharge in April 1992 but was recorded at 93.7 pCi/l in July 1992. Radium-226 in water from Custer Lake was below detection limits in April 1992 but was detected at 14.8 pCi/l in July 1992. The radium-226 concentration recorded at the Sidney Battery Discharge in July exceeded the 60 pCi/l standard for the protection of aquatic life (Wyoming Department of Environmental Quality 1990).

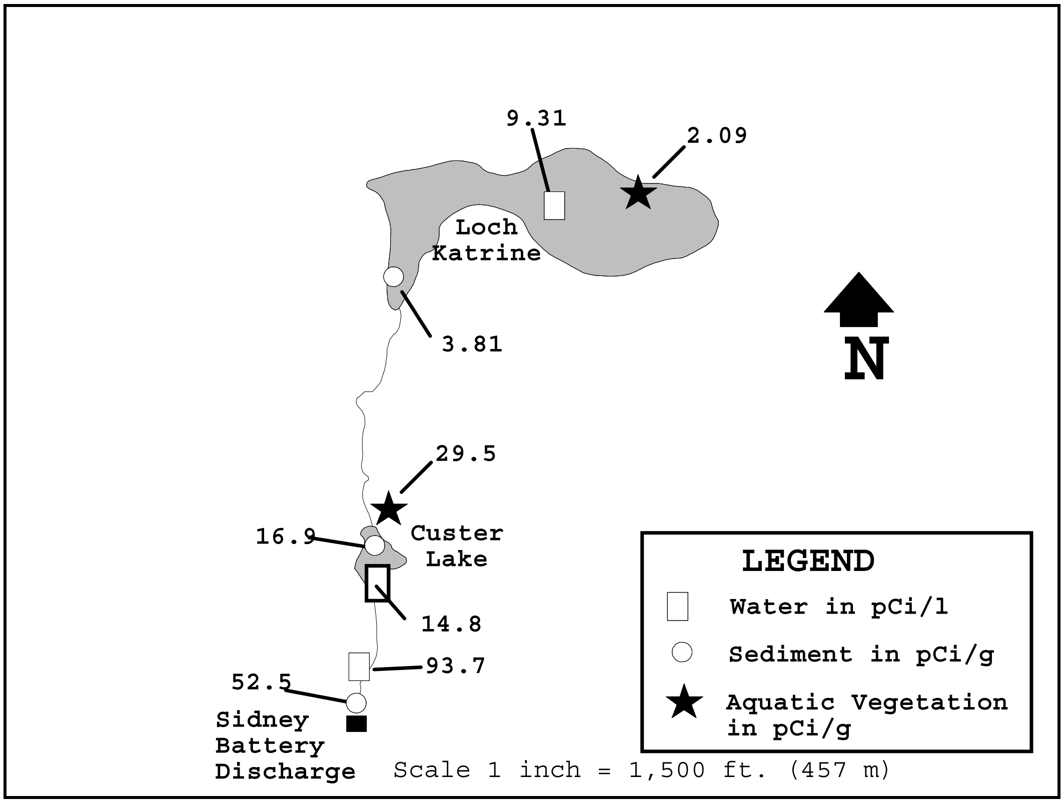

Figure 2. Radium-226 concentrations in water, sediment and aquatic vegetation at the Loch Katrine wetland complex, Park County, Wyoming.

In sediments, radium-226 concentrations were highest at the Sidney Battery Discharge (52.5 pCi/l), followed by Custer Lake (16.9 pCi/l) and Loch Katrine (3.81 pCi/l). In aquatic vegetation, radium-226 concentrations ranged from 2.09 pCi/g at Loch Katrine to 29.5 pCi/g at Custer Lake. Radium-226 was below detection limits in aquatic invertebrates collected at Custer Lake and Loch Katrine.

Selenium

Selenium is generally associated with Cretaceous marine shale formations which are prevalent throughout Wyoming. Selenium is readily mobilized and bioaccumulated in aquatic food chains

(Lemly and Smith 1987). Selenium concentrations in water collected from Loch Katrine and Custer Lake in April 1992 were 8.3 and 3.7 µg/l, respectively but were below detection limits in July. Selenium concentrations in water greater than 3 µg/l may pose a bioaccumulation risk to birds and could cause impaired reproduction and embryo deformities (Skorupa and Ohlendorf 1991).

Vanadium

Vanadium is found in soil, often in formations with uranium (Hem 1985), and is deposited in water from air pollution fallout (Jenkins 1981). Plants absorb vanadium from soil, groundwater, surface water, and air pollution (Jenkins 1981). Animals assimilate vanadium from contaminated air, water, and food (Jenkins 1981). Limited data suggests that the potential for bioaccumulation or bioconcentration of vanadium is low or limited for mammals, and birds, high to very high for aquatic invertebrates and moderate for higher plants, and algae (Jenkins 1981). Waterborne vanadium concentrations are typically at 1 µg/l (Jenkins 1981). Vanadium concentrations in water were below detection limits at all sites except Loch Katrine where it occurred at 4 µg/l. Vanadium in sediment ranged from below detection limits at Custer Lake to 44.5 µg/g at Loch Katrine and 57.3 µg/g at Alkali Lake, the reference site. Vanadium concentrations in aquatic vegetation ranged from 4.83 at Custer Lake to 25.3 µg/g at Loch Katrine. Vanadium in aquatic invertebrates ranged from below detection to 9.65 µg/g. Dietary vanadium has been shown to suppress egg production of laying hens (Rompala et al. 1984) and dietary levels as low as 0.5 µg/g have been shown to alter metabolism in mallards (White et al. 1980). Vanadium concentrations in bird eggs and livers were below detection limits at all sites.

Zinc

Zinc is an EPA priority pollutant (Keith and Telliard 1979), but in low concentrations is an essential element in plant and animal life. Elevated concentrations of zinc in water are particularly toxic to many species of algae, crustaceans, and salmonids (Leland and Kuwabara 1985) and have especially strong effects on macroinvertebrates such as molluscs, crustaceans, odonates, and ephemeropterans (Gore and Bryant 1986). Sediments with zinc concentrations less than 90.0 mg/kg were classified as non-polluted (Ingersoll and Nelson 1989). Sediments having concentrations higher than 200 mg/kg dry weight were classified as heavily polluted (Ingersoll and Nelson 1989). Typically, waterborne zinc concentrations average 20µg/l, but streams affected by mine drainage can have zinc concentration greater than 100 µg/l (Hem 1985). Zinc concentrations in water ranged from below detection limits to 3,181 ug/l. The highest concentration was recorded at the Sidney Battery Discharge in April 1992, but the zinc concentration in July 1992 was 17 µg/l. Zinc concentrations in water greater than 30 µg/l are toxic to freshwater algae and concentrations as low as 10 µg/l will inhibit growth (Wong and Chau 1990). Zinc concentrations in sediments ranged from 18.4 µg/g at Custer Lake to 123 µg/g at Loch Katrine. In uncontaminated areas, zinc concentrations in sediments are generally less than 50 µg/g (Moore and Ramamoorthy 1984a). Zinc concentrations in aquatic vegetation from Custer Lake and Loch Katrine ranged from 22.6 to 113 µg/g. Aquatic invertebrates had zinc concentrations ranging from 109 to 143 µg/g. These concentrations are below dietary levels considered adverse to birds (Gasaway 1972, Johnson et al. 1962, Roberson and Schaible 1960).

Other Trace Elements

Other trace elements at all sites were either below detection limits or were present in concentrations not associated with adverse effects to aquatic birds.

Hydrocarbons

Oil and Grease

Oil and grease concentrations in water from the Sidney Battery Discharge were 2 µg/l (0.002 mg/l) in April and 12,620 µg/l (12.62 mg/l) in July. The July sample exceeded the 10 mg/l water quality criterion required by the WDEQ (1990). Oil and grease concentrations in water collected from Custer Lake and Loch Katrine in July were 490 µg/l (0.49 mg/l) and 220 µg/l (0.22 mg/l), respectively. Oil and grease concentrations in sediment were highest at the Sidney Battery Discharge with 1,253 µg/g. Oil and grease concentrations in sediments from Custer Lake and Loch Katrine ranged from 8 µg/g to 48 µg/g. The highest concentrations in sediments from these two wetlands were found at Custer Lake, 35 µg/g, and at the inlet to Loch Katrine, 48 µg/g.

Aliphatic Hydrocarbons

Aliphatic hydrocarbons occur naturally in oil and gas deposits and are discharged into the environment with oil field produced waters. Most of the aliphatics do not significantly concentrate in aquatic organisms (Moore and Ramamoorthy 1984b). Total aliphatic hydrocarbons were highest in sediments from the Sidney Battery Discharge, 3.638 µg/g wet weight, followed by sediments from Custer Lake, 0.994 µg/g wet weight. Aliphatic hydrocarbon concentrations in sediments from Loch Katrine ranged from 0.539 to 0.647 µg/g wet weight.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAH's) originate from both natural and anthropogenic sources. Several PAH compounds are known or suspected carcinogens. PAH's are commonly found in water and concentrations are usually less than 1 µg/l in unpolluted areas (Moore and Ramamoorthy 1984b). Concentrations of PAH's in unpolluted sediments are generally 1 to 500 µg/g (Moore and Ramamoorthy 1984b) Total PAH's in sediments were 2.738 µg/g wet weight at the Sidney Battery Discharge and less than 1 µg/g wet weight at Loch Katrine and Custer Lake.

Metabolized PAH Compounds in Bird Bile

Metabolized PAH compounds were detected in bile from birds collected at Custer Lake and Loch Katrine. Benzo(a)pyrene concentrations ranged from 500 to 960 ng/g (ppb) wet weight in bile from northern shovelers collected from Custer Lake and was below detection limits in gadwalls collected at Loch Katrine. Benzo(a)pyrene was 110 and 160 ng/g in bile from two of four American avocets collected at Loch Katrine and below detection limits in the remaining two birds. Naphthalene and phenanthrene were detected in bile from gadwall, shoveler and American avocet and were highest in shovelers collected from Custer Lake.

Aquatic Bird Nesting

Twenty-eight nests were monitored from May to July 1992 and included the following species:

American coot; eared grebe; gadwall; mallard; pintail and redhead (Appendix Table 12). Three nests were flooded, eight were destroyed by predators and 11 failed.. Embryo mortality occurred in 10 eggs from five nests; however, none of these embryos were deformed. The cause of the mortality was unknown. Predation and nest flooding caused low (< 80 %) hatching success for all species surveyed except the redhead.

Aquatic Bird Survey

Total number of aquatic birds ranged from 107 to 1,370 during any single observation period at Loch Katrine from April 26 to November 15 (Figure 3). Bird surveys were not conducted from September 13 through October 10. During the breeding season, May 3 through August 2, shorebirds were present in greater numbers than waterfowl (Figure 4). Dabbling ducks (*Anas* spp.) were more numerous than diving ducks (*Aythya* spp.) (Figure 5).

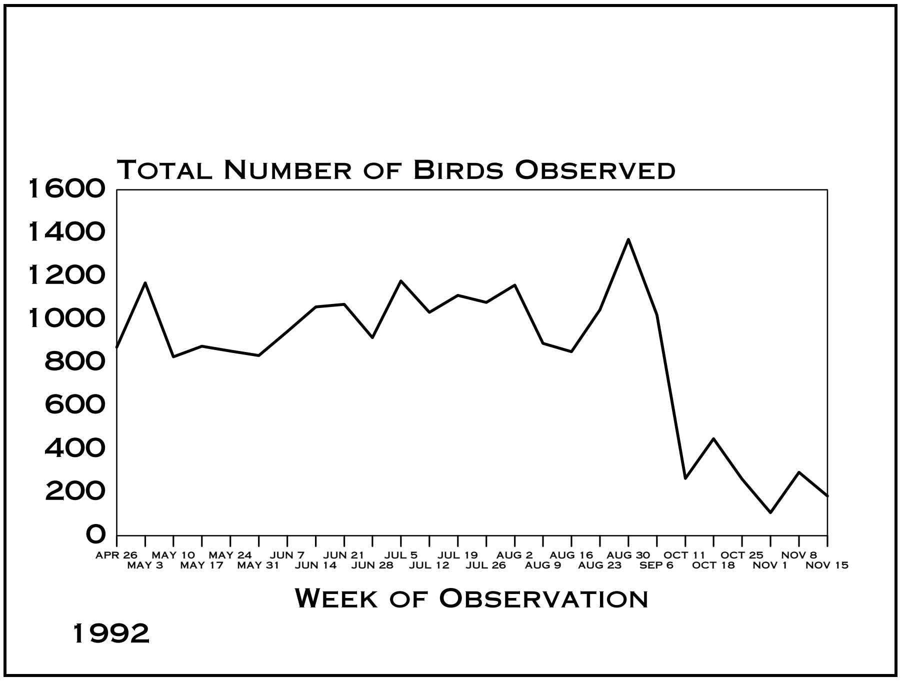

Figure 3. Total number of aquatic birds observed at Loch Katrine, Park County, Wyoming, April through November 1992.

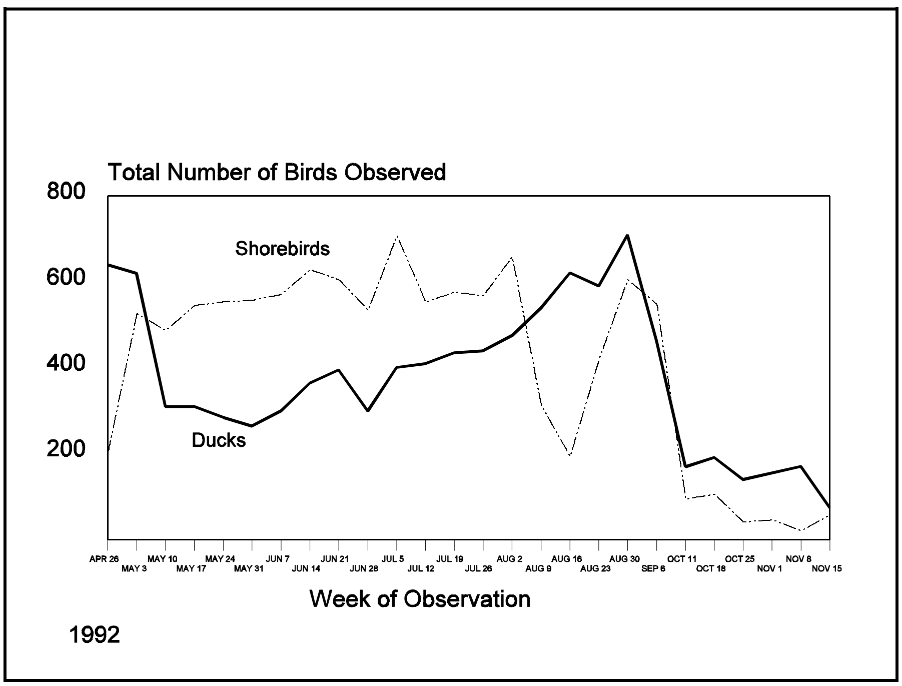

Figure 4. Total number of shorebirds and ducks observed at Loch Katrine, Park County, Wyoming, April through November 1992.

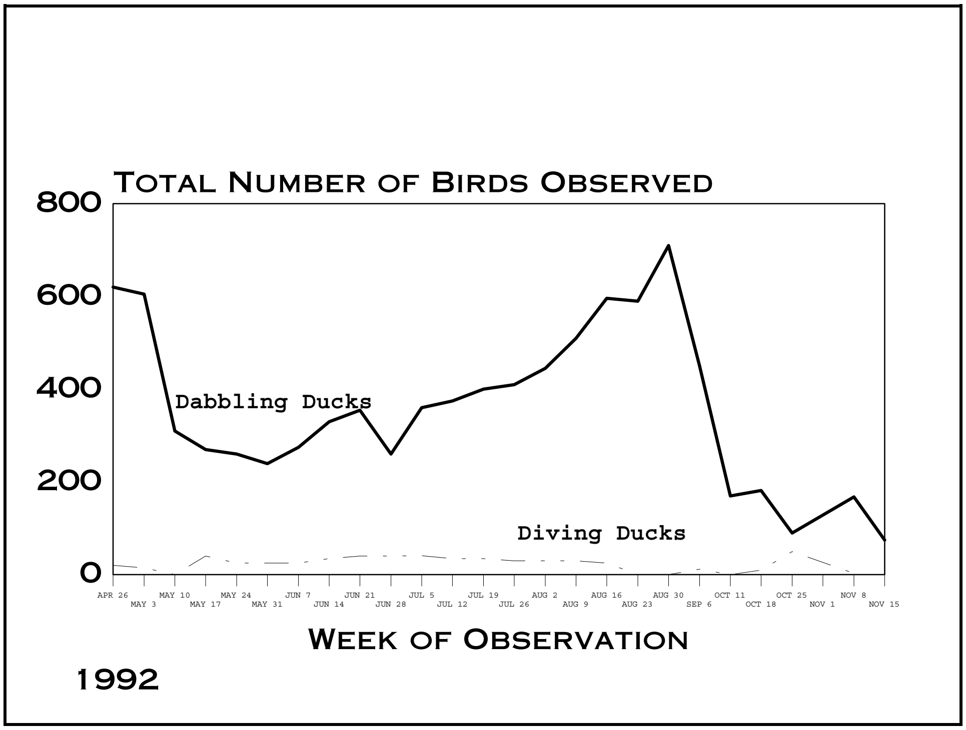

Figure 5. Total number of dabbling and diving ducks observed at Loch Katrine, Park County, Wyoming, April through November 1992.

DISCUSSION

Boron and radium-226 in the produced water discharge appear to be bioaccumulating in the food chain. Although not present in acute concentrations, elevated boron in aquatic vegetation from Loch Katrine may cause chronic effects to aquatic birds such as reduced growth in ducklings or altered metabolism. The radium-226 concentration recorded at the Sidney Battery Discharge in July, 93.7 pCi/l, exceeded the WDEQ (1990) 60 pCi/l criterion for the protection of aquatic life. Radium-226 concentrations in sediments from Custer Lake, Loch Katrine inlet and the Sidney Battery Discharge ranged from 16.9 to 52.5 pCi/g, exceeding the 5 pCi/g concentration which is the criterion for identifying hazardous wastes (Wagner 1980, EPA 1990); however, there are no criteria for sediment toxicity due to radium-226. As a comparison, radium-226 in sediments from phosphate settling basins in central Florida averaged 23.8 pCi/g (Montalbano et al. 1983). The radium-226 concentration in aquatic vegetation from Custer Lake, 29.5 pCi/g was ten times higher than the 2.9 pCi/g average concentration found in terrestrial plants growing in uranium mill tailings in South Dakota (Rumble and Bjugstad 1986). The presence of radium-226 in aquatic vegetation suggests that this radionuclide may be available to aquatic birds. Radium-226 mimics calcium in vertebrates and can be incorporated into bone tissue. In another study, the University of Wyoming Red Buttes Environmental Biology Laboratory analyzed water and sediment from the Sydney Battery Discharge and bone tissue from waterfowl collected at Loch Katrine for radium-226. Concentrations of radium-226 ranged from 31 to 105.9 pCi/l in water from the Sydney Battery discharge, 29.7 pCi/l in water from the northern edge of Loch Katrine, 64.8 pCi/g in sediment from the Sydney Battery Discharge and 1 pCi/g in waterfowl bone tissue (Bill Herrera, personal communications, July 1993). Radium-226 in water and sediment from the Sidney Battery Discharge and Custer Lake is higher than at Loch Katrine and this radionuclide is accumulating in aquatic vegetation. Continued discharge of oil field produced waters could eventually result in higher radium-226 concentrations in the food chain at Loch Katrine. Radium-226 should be monitored in the food chain to determine if it is increasing. Water quality criteria for the protection of aquatic organisms from acute effects was exceeded for arsenic at Custer Lake in July and for zinc at the Sidney Battery Discharge in April. Arsenic and zinc concentrations were also elevated in sediment from Loch Katrine. Arsenic and zinc in aquatic vegetation and invertebrates were not elevated to levels considered adverse to aquatic birds. Trace elements in bird livers were not present at levels considered adverse to aquatic birds.

Oil and grease concentrations in water from the Sidney Battery Discharge exceeded the 10 mg/l permitted maximum established by the WDEQ (1990) but were below this criterion at Custer Lake and Loch Katrine. Total hydrocarbon (aliphatic and aromatic) concentrations in sediments were highest at the Sidney Battery Discharge, 6.376 µg/g, followed by Custer Lake, 1.104 µg/g. Total aliphatic hydrocarbon concentrations in sediments were also higher at the Sidney Battery Discharge, 3.638 µg/g, followed by Custer Lake, 0.994 µg/g. Concentrations of aliphatic hydrocarbons are higher at Custer Lake than Loch Katrine.

Metabolized PAH compounds were detected in bile from birds collected at Custer Lake and Loch Katrine. Benzo(a)pyrene, a known carcinogen, was not detected in gadwalls collected at Loch Katrine but was detected in northern shovelers collected at Custer Lake. Benzo(a)pyrene concentrations in northern shoveler bile ranged from 500 to 960 ng/g (ppb) wet weight. The benzo(a)pyrene concentrations in the shovelers is indicative of exposure to petroleum hydrocarbons (Sue McDonald, Texas A & M University, Geochemical and Environmental Res. Group, College Station, Texas, personal communications, February 24, 1993). The benzo(a)pyrene concentration was 110 and 160 ng/g in bile from two of four American avocets collected at Loch Katrine but was below the detection limit in the remaining two birds. Naphthalene and phenanthrene were detected in bile from gadwall, shoveler and American avocet and were highest in shovelers collected from Custer Lake.

Although PAH's in sediments from Custer Lake were low, these birds could have ingested oil at nearby separator waste pits in the oilfield.

Nesting failure was attributed primarily to flooding and predation. Contaminants resulting from the oil field produced water discharge are probably not affecting nesting success because trace element concentrations in bird eggs were not present in levels known to cause embryo mortality and no oil was observed on egg shells.

The risk to peregrine falcons and bald eagles feeding on aquatic birds from the Loch Katrine wetland complex is suspected to be minimal because trace element and hydrocarbon concentrations in aquatic birds were low. Periodic monitoring of radium-226, arsenic, zinc and metabolized PAH's is warranted to determine trends in the aquatic bird food chain.

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APPENDIX

Table 1. Hydrocarbon concentrations in sediment (in µg/g wet weight) collected from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

SITE	LKAL	LKCL	LKLK	LKLK	LKLK	LKSB
SITE NAME	ALKALI LAKE	CUSTER LAKE	LOCH KATRINE	LOCH KATRINE	LOCH KATRINE	SIDNEY BATTERY DISCHARGE
ANALYTE						
OIL & GREASE	17	35	48	14	8	1253
AROMATIC HYDROCARBONS						
NAPHTHALENE	0.002	0.002	0.002	0.001	0.001	0.007
2-METHYLNAPHTHALENE	0.003	0.005	0.004	0.002	0.002	0.012
1-METHYLNAPHTHALENE	0.013	0.016	0.02	0.007	0.006	0.133
BIPHENYL	0.002	0.002	0.003	0.002	0.002	0.042
2,6 DIMETHYLNAPHTHALENE	0.011	0.01	0.013	0.007	0.006	0.106
ACENAPHTHYLENE	0	0	0	0	0	0
ACENAPHTHENE	0.001	0.001	0.001	0.001	0	0.015
2,3,4-TRIMETHYLNAPHTHALENE	0.038	0.032	0.044	0.025	0.02	0.702
FLUORENE	0.003	0.005	0.004	0.003	0.002	0.128
PHENANTHRENE	0.006	0.009	0.005	0.003	0.003	0.632
ANTHRACENE	0	0.001	0	0	0	0.043
1-METHYLPHENANTHRENE	0.003	0.009	0.002	0.002	0.001	0.486
FLUORANTHRENE	0.004	0.001	0	0	0	0.014
PYRENE	0.005	0.004	0.001	0.001	0.001	0.115
BENZO(A)ANTHRACENE	0.002	0	0	0	0	0.027
CHRYSENE	0.006	0.006	0.002	0	0	0.161
BENZO(B)FLUORANTHRENE	0.003	0.001	0.001	0	0	0.008
BENZO(K)FLUORANTHRENE	0.001	0	0	0	0	0.016
BENZO(E)PYRENE	0.003	0.002	0.003	0	0	0.017
BENZO(A)PYRENE	0.002	0.001	0	0	0	0.025
PERYLENE	0.001	0.001	0.001	0	0	0.042
INDENOPYRENE	0.001	0.001	0.001	0	0	0.002
DIBENZOANTHRACENE	0	0	0	0	0	0.003
BENZO(GHI)PERYLENE	0.001	0.001	0.001	0	0	0.002
TOTAL AROMATIC HYDROCARBONS	0.111	0.11	0.108	0.054	0.044	2.738

SITE	LKAL	LKCL	LKLK	LKLK	LKLK	LKSB
SITE NAME	ALKALI LAKE	CUSTER LAKE	LOCH KATRINE	LOCH KATRINE	LOCH KATRINE	SIDNEY BATTERY DISCHARGE
ALIPHATIC HYDROCARBONS						
N-C12	0.007	0.008	0.019	0.01	0.012	0.002
N-C13	0.013	0.015	0.03	0.017	0.018	0.003
N-C14	0.044	0.055	0.087	0.056	0.056	0.01
N-C15	0.048	0.073	0.083	0.062	0.059	0.03
N-C16	0.024	0.031	0.032	0.034	0.148	0.081
N-C17	0.136	0.111	0.034	0.148	0.088	1.07
PRISTANE	0.04	0.203	0.141	0.045	0.056	0.097
N-C18	0.045	0.035	0.017	0.022	0.015	1.95
PHYTANE	0.124	0.419	0.097	0.075	0.03	0.076
N-C19	0.086	0.028	0.036	0.052	0.042	0.185
N-C20	0.08	0.016	0.019	0.02	0.015	0.134
TOTAL ALIPHATICS	0.647	0.994	0.595	0.541	0.539	3.638
TOTAL PAH S	0.758	1.104	0.703	0.595	0.583	6.376

Table 2 . Hydrocarbon concentrations (in ng/g) in bile from aquatic birds collected at the Loch Katrine wetland complex, Park County, Wyoming, 1992.

SITE	SPECIES	NAPHTHALENE	PHENANTHRENE	BENZO(A)PYRENE
LOCH KATRINE	AM. AVOCET	36,000	7,300	110
LOCH KATRINE	AM. AVOCET	52,000	12,000	100
LOCH KATRINE	AM. AVOCET	96,000	20,000	100
LOCH KATRINE	AM. AVOCET	130,000	28,000	160
CUSTER LAKE	SHOVELER	210,000	92,000	620
CUSTER LAKE	SHOVELER	240,000	120,000	960
CUSTER LAKE	SHOVELER	180,000	88,000	500
LOCH KATRINE	GADWALL	58,000	11,000	100
LOCH KATRINE	GADWALL	39,000	7,100	100
LOCH KATRINE	GADWALL	36,000	4,200	100
LOCH KATRINE	GADWALL	28,000	4,000	100
LOCH KATRINE	GADWALL	61,000	7,100	100

Table 3. Trace elements in water (in mg/l) from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

SITE #	SITE	Al	As	B	Ba
LKCL	Custer Lake	0.416	0.0331	1.87	0.011
LKCL	Custer Lake	0.432	0.4230	2.20	0.021
LKLK	Loch Katrine - Middle	0.195	0.0356	5.46	0.003
LKNW	Loch Katrine - Northwest	0.227	0.0073	9.79	0.015
LKSB	Sidney Battery Discharge	0.312	0.0092	2.20	0.020
LKSB	Sidney Battery Discharge	0.362	0.0146	1.77	0.014

SITE #	SITE	Be	Cd	Cr	Cu
LKCL	Custer Lake	0.0005	<0.0005	<0.005	0.010
LKCL	Custer Lake	<0.0005	<0.0005	<0.005	<0.005
LKLK	Loch Katrine - Middle	0.0005	<0.0005	<0.005	<0.005
LKNW	Loch Katrine - Northwest	<0.0005	<0.0005	<0.005	0.005
LKSB	Sidney Battery Discharge	<0.0005	<0.0005	<0.005	0.005
LKSB	Sidney Battery Discharge	0.0005	<0.0005	<0.005	0.008

SITE #	SITE	Fe	Hg	Mg	Mn
LKCL	Custer Lake	0.032	<0	209	0.005
LKCL	Custer Lake	0.308	<0.0011	194	0.008
LKLK	Loch Katrine - Middle	0.070	<0	681	0.039
LKNW	Loch Katrine - Northwest	0.153	<0.0011	715	0.023
LKSB	Sidney Battery Discharge	0.071	<0.0011	120	0.015
LKSB	Sidney Battery Discharge	<0.02	<0	20	0.002

SITE #	SITE	Mo	Ni	Pb	Se
LKCL	Custer Lake	<0.004	<0.005	0.011	0.0037
LKCL	Custer Lake	<0.004	<0.005	0.007	<0.0056
LKLK	Loch Katrine - Middle	<0.004	<0.005	0.009	0.0083
LKNW	Loch Katrine - Northwest	<0.004	<0.005	0.009	<0.0055
LKSB	Sidney Battery Discharge	<0.004	<0.005	<0.005	<0.0056
LKSB	Sidney Battery Discharge	<0.004	<0.005	0.005	<0.0001

SITE #	SITE	Sr	V	Zn
LKCL	Custer Lake	8.12	<0.004	<0.010
LKCL	Custer Lake	11.90	<0.004	0.010
LKLK	Loch Katrine - Middle	2.65	<0.004	0.018
LKNW	Loch Katrine - Northwest	19.70	0.004	0.044
LKSB	Sidney Battery Discharge	9.94	<0.004	0.017
LKSB	Sidney Battery Discharge	8.13	<0.004	3.181

Table 4. Radium-226 concentrations (in pCi/l) in water from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

SITE #	SITE	Ra-226
LKCL	Custer Lake	<26.0
LKCL	Custer Lake	14.8
LKLK	Loch Katrine - Middle	9.31
LKNW	Loch Katrine - Outer	<4.03
LKSB	Sidney Battery Discharge	<11.0
LKSB	Sidney Battery Discharge	93.7

Table 5. Trace element concentrations (in µg/g dry weight) in sediment collected from the Loch Katrine wetland complex and a reference site (Alkali Lake), Park County, Wyoming in 1992.

SITE #	SITE	% Moisture	Al	As	B
LKAL	Alkali Lake	54.8	29300	4.79	89.8
LKCL	Custer Lake	34.0	5000	3.95	9.4
LKS1	Loch Katrine near Inlet	43.5	25100	10.40	63.0
LKS2	Loch Katrine - Middle	49.1	18500	5.71	12.8
LKS3	Loch Katrine - outer site	42.8	12800	6.30	23.4
LKSB	Sidney Battery Discharge	45.2	3060	5.06	8.5

SITE #	SITE	Ba	Be	Cd	Cr
LKAL	Alkali Lake	270.0	0.996	<0.1942	28.4000
LKCL	Custer Lake	54.5	0.599	<0.1965	<4.9116
LKS1	Loch Katrine near Inlet	212.0	0.955	0.4530	24.9000
LKS2	Loch Katrine - Middle	176.0	0.963	0.5160	17.1000
LKS3	Loch Katrine - outer site	115.0	0.942	0.8030	14.0000
LKSB	Sidney Battery Discharge	37.3	0.700	<0.1957	<4.8924

SITE #	SITE	Cu	Fe	Hg	Mg
LKAL	Alkali Lake	15.5000	17900	<0.0971	10700
LKCL	Custer Lake	<4.9116	3070	<0.0982	3480
LKS1	Loch Katrine near Inlet	16.7000	20900	<0.0952	11700
LKS2	Loch Katrine - Middle	20.0000	17600	<0.0936	12700
LKS3	Loch Katrine - outer site	17.9000	14600	<0.0960	10500
LKSB	Sidney Battery Discharge	<4.8924	1770	<0.0978	4160

SITE #	SITE	Mn	Mo	Ni	Pb
LKAL	Alkali Lake	543.0	<4.8544	19.3000	25.0000
LKCL	Custer Lake	37.2	<4.9116	<4.9116	6.0200
LKS1	Loch Katrine near Inlet	438.0	<4.7619	25.5000	17.1000
LKS2	Loch Katrine - Middle	388.0	<4.6816	24.6000	19.8000
LKS3	Loch Katrine - outer site	279.0	<4.7985	19.8000	16.9000
LKSB	Sidney Battery Discharge	48.9	<4.8924	<4.8924	<4.8924

SITE #	SITE	Se	Sr	V	Zn
LKAL	Alkali Lake	5.4400	954	57.3000	67.5
LKCL	Custer Lake	0.2750	1850	<4.9116	18.4
LKS1	Loch Katrine near Inlet	0.2860	1870	44.5000	123.0
LKS2	Loch Katrine - Middle	<0.0468	726	19.8000	120.0
LKS3	Loch Katrine - outer site	0.3940	494	20.3000	83.2
LKSB	Sidney Battery Discharge	0.3910	3580	12.1000	30.6

Table 6. Radium-226 concentrations (in pCi/g) in sediment from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

SITE #	SITE	Ra-226
LKAL	Alkali Lake	na
LKCL	Custer Lake	16.9
LKS1	Loch Katrine near Inlet	38.1
LKS2	Loch Katrine - Middle	na
LKS3	Loch Katrine - outer site	na
LKSB	Sidney Battery Discharge	52.5

Table 7. Trace element concentrations (in µg/g dry weight) in aquatic invertebrates from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

Analyte	Daphnids	Waterboatmen (n=5)		
	Custer Lake	Loch Katrine		
	(n=1)	Minimum	Maximum	Geometric Mean
% Moisture	79.49	69.95	88.62	82.50
Al	452	62.2	3600	311.01
As	2.75	5.14	7.31	5.96
B	5.17	19.2	82.2	32.98
Ba	6.23	<1.14	27	2.64
Be	<0.2439	<0.2294	0.783	0.17
Cd	<0.2439	<0.2294	1.04	0.22
Cr	<1.2195	1.1468	6.97	1.25
Cu	15.30	11.6	23.7	16.72
Fe	544	133	2190	358.31
Hg	<0.2392	<0.2404	0.4269	0.18
Mg	1530	1960	4100	2841.31
Mn	10.3	23.8	85.7	36.11
Mo	<1.2195	<1.1468	<1.2195	0.60
Ni	<1.2195	<1.1468	7.5	1.22
Pb	<1.2195	<1.1468	4.29	0.89
Se	4.09	1.49	3.79	2.30
Sr	71.6	85.4	480	148.31
V	<1.2195	<1.1468	9.65	1.31
Zn	130	109	143	134.30

Table 8. Trace element concentrations (in µg/g dry weight) in aquatic vegetation from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

Analyte	Widgeongrass (n=5)			Algae (n=1)
	Loch Katrine			Custer Lake
	Minimum	Maximum	Geo. Mean	
% Moisture	75.75	83.97	80.94	84.83
Al	2250	14000	5106.64	3040
As	6.47	15.6	10.04	2.49
B	309	554	435.51	4.4
Ba	20.9	67.1	38.30	44.4
Be	<0.2392	<0.2463	BDL	<0.2326
Cd	<0.2392	0.322	0.17	<0.2326
Cr	4.78	16.4	9.13	3.03
Cu	5.41	20.3	11.69	2.56
Fe	2790	7180	4799.46	2810
Hg	<0.2358	<0.2451	BDL	<0.2463
Mg	7160	15400	10838.34	4580
Mn	354	838	473.53	113
Mo	<1.1962	<1.2315	BDL	<1.1628
Ni	3.9	11.9	7.97	11.4
Pb	2.49	8.13	4.36	9.09
Se	<0.7075	<0.7840	BDL	<0.7389
Sr	634	817	704.62	3160
V	7.2	25.3	11.28	4.83
Zn	40.5	113	71.65	22.6

Table 9. Radium-226 concentrations (in pCi/g) in aquatic vegetation and aquatic invertebrates from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

SITE #	Species	Site	Radium-226
LKCL	Daphnids	Custer Lake	<1.43
LKDK	Waterboatmen	Loch Katrine	<0.825
LKCL	Widgeongrass	Custer Lake	29.5
LKDK	Widgeongrass	Loch Katrine	2.09

Table 10. Trace element concentrations (in µg/g dry weight) in livers from aquatic birds collected at the Loch Katrine wetland complex, Park County, Wyoming, 1992.

Analyte	American Avocet (n=4)			Northern Shoveler (n=5)		
	Loch Katrine			Custer Lake		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
% Moisture	69.91	72.24	71.04	69.31	71.53	70.28
Al	6.41	43.4	12.35	<4.7529	6.52	3.41
As	<0.4902	0.81	0.52	<0.4780	<0.4970	BDL
B	0.708	4.46	1.68	<0.4753	1.8	0.59
Ba	<0.4826	<0.4960	BDL	<0.4753	<0.4960	BDL
Be	<0.0965	0.122	0.06	<0.0951	<0.0980	BDL
Cd	<0.0965	2	0.30	<0.0951	<0.0980	BDL
Cr	<0.4826	0.587	0.30	<0.4753	0.497	0.28
Cu	10.5	14.5	11.81	3.87	8.83	5.45
Fe	860	2750	1408.17	1290	2930	1942.01
Hg	0.3805	1.267	0.64	0.2803	0.4326	0.34
Mg	542	692	602.55	473	683	615.81
Mn	10	12.2	11.09	3.34	6.77	4.53
Mo	1.74	2.25	1.96	1.37	2.3	1.94
Ni	<0.4826	0.531	0.30	<0.4753	<0.4902	BDL
Pb	<0.4826	0.589	0.30	<0.4753	<0.4902	BDL
Se	10.18	30.41	21.60	6.53	9.44	7.34
Sr	1.17	3.3	1.83	1.1	4.74	1.76
V	<0.4826	<0.4960	BDL	<0.4753	<0.4902	BDL
Zn	62.7	72.1	66.94	53.2	75.9	66.50

Table 10. Trace element concentrations (in µg/g dry weight) in livers from aquatic birds collected at the Loch Katrine wetland complex, Park County, Wyoming, 1992 (Continued).

	Eared Grebe (n=2)			Gadwall (n=5)		
	Loch Katrine			Loch Katrine		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
% Moisture	65.07	67.25	66.16	69.13	75.41	71.65
Al	<4.9310	10.4	6.43275	<4.8077	6.47	2.97163
As	4.83	7.41	6.12	0.65	4.15	1.82507
B	2.2	3.5	2.85	3.12	5.04	3.86535
Ba	<0.4873	<0.4931	BDL	<0.4808	<0.5000	BDL
Be	<0.0975	<0.0986	BDL	<0.0962	<0.1000	BDL
Cd	<0.0986	0.903	0.47615	<0.0962	<0.1000	BDL
Cr	<0.4873	<0.4931	BDL	<0.4912	0.542	0.38616
Cu	15.9	43.5	29.7	104	166	126.66
Fe	288	1070	679	886	2510	1324.72
Hg	0.4094	4.512	2.4607	<0.0951	0.7782	0.22405
Mg	491	710	600.5	530	810	689.032
Mn	11.2	19.5	15.35	5.95	11.5	8.66382
Mo	<0.4931	0.913	0.57978	0.874	1.64	1.15557
Ni	<0.4931	0.527	0.38678	<0.4808	<0.5000	BDL
Pb	<0.4931	<0.598	BDL	<0.4892	0.654	0.39872
Se	3.79	18.69	11.24	2.32	6.38	4.16805
Sr	0.488	1.34	0.914	0.985	1.43	1.19417
V	<0.4873	<0.4931	BDL	<0.4808	<0.5000	BDL
Zn	72.2	89	80.6	125	213	167.315

Table 11. Trace element concentrations (in µg/g dry weight) in waterfowl eggs collected from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

Analyte	Mallard (n=3)			Eared Grebe (n=5)		
	Custer Lake			Loch Katrine		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
% Moisture	69.5	71.2	70.16	74.74	79.64	77.01
Al	7.93	9.5	8.86	7.51	35.5	12.77
As	<0.2907	<0.2959	BDL	<0.2941	<0.3000	BDL
B	<0.4941	3.19	1.70	0.911	20	4.42
Ba	0.732	2.28	1.5906667	<0.4912	0.876	0.48
Be	<0.0986	<0.1000	BDL	<0.0982	<0.1000	BDL
Cd	<0.0986	<0.1000	BDL	<0.0982	<0.1000	BDL
Cr	<0.4931	<0.5000	BDL	<0.4912	0.565	0.34
Cu	2.18	3.68	2.73	2.15	3.47	2.77
Fe	96.8	127	114.93	136	215	163.93
Hg	<0.0969	<0.0986	BDL	0.2402	0.5076	0.31
Mg	245	297	270	508	1180	774.77
Mn	<0.3945	<0.40	BDL	2.89	3.95	3.24
Mo	<0.4931	<0.5000	BDL	<0.4912	<0.5000	BDL
Ni	<0.4931	<0.5000	BDL	<0.4912	<0.5000	BDL
Pb	<0.4931	<0.5000	BDL	<0.4912	<0.5000	BDL
Se	1.46	1.94	1.63	2.68	4.79	3.50
Sr	14.8	26.1	20.5	19.1	66.7	44.72
V	<0.4931	<0.5000	BDL	<0.4912	<0.5000	BDL
Zn	50.9	60.4	54.7	42.2	58.9	51.00

Table 11. Trace element concentrations (in µg/g dry weight) in waterfowl eggs collected from the Loch Katrine wetland complex, Park County, Wyoming (Continued).

Analyte	Redhead (n=4)		
	Loch Katrine		
	Minimum	Maximum	Mean
% Moisture	65.03	76.26	70.52
Al	11.8	21.1	14.90
As	<0.2799	<0.2924	BDL
B	6.08	11	8.12
Ba	0.951	3.74	2.03
Be	<0.0928	<0.0980	BDL
Cd	<0.0928	<0.0980	BDL
Cr	0.721	1.29	1.06
Cu	3.59	5.08	4.40
Fe	116	151	139.50
Hg	<0.0962	0.233	0.13
Mg	427	624	515.75
Mn	1.53	1.86	1.75
Mo	<0.4638	<0.4902	BDL
Ni	<0.4638	<0.4902	BDL
Pb	<0.4638	<0.4902	BDL
Se	0.867	1.27	1.13
Sr	58.1	145	99.30
V	<0.4638	<0.4902	BDL
Zn	46.8	68.9	60.68

Table 12. Aquatic bird nesting data from the Loch Katrine wetland complex, Park County, Wyoming, 1992.

Species	Number of Nests	Avg. Clutch Size	Total # of Eggs	Number of Eggs Hatched	Egg Loss*	Embryo Mortality	Percent Hatch
Am. Coot	3	3	10	4	6		40%
Eared Grebe	2	2	5	1		2	20%
Gadwall	1	9	9	0	9		0
Mallard	18	8	154	90	23	2	58%
Pintail	1	7	7	3		4	43%
Redhead	3	8	25	22		2	88%

* Egg losses due to nest flooding and predation.