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CONTAMINANTS PROGRAM

Trace Elements and Petroleum Hydrocarbons in the Aquatic Bird Food Chain Of Process Water Evaporation Ponds at the Little America Refinery, Casper, Wyoming

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ABSTRACT

This study determined the nature and extent of trace elements, metals, and petroleum hydrocarbons in evaporation ponds used for the disposal of process water from Sinclair Oil Corporation's LARCO oil refinery in Evansville, Wyoming. This study was conducted to determine if contaminants are causing adverse effects or have the potential to adversely affect aquatic migratory birds inhabiting the evaporation ponds. The discharge of refinery process water into relict dune basins created a series of ponds that provide habitat for 39 species of aquatic migratory birds. Several aquatic bird species nest at the evaporation ponds and the adjacent natural marsh complex. Migrating waterfowl and shorebirds also use the ponds as a stop-over with peak numbers (between 1,000 and 2,000 birds) occurring in mid-September during the fall migration. The refinery evaporation ponds are highly eutrophic and contain elevated concentrations of arsenic, chromium, copper, mercury, nickel, lead, selenium, and zinc in bottom sediments. Sediments from the nearby Russian Olive Pond contained elevated concentrations of arsenic, chromium, mercury and nickel. Polycyclic aromatic hydrocarbons (PAHs) were also present in high concentrations in sediments from the three evaporation ponds. Although these trace elements and PAHs are elevated in the bottom sediments, eutrophication is likely limiting the availability of these contaminants to the food chain and aquatic migratory birds. Some trace elements such as selenium are accumulating in the food chain and PAHs are present in algae and aquatic invertebrates. Selenium bioaccumulation was documented in aquatic birds nesting at the ponds. Selenium concentrations in black-necked stilt eggs (mean = 13.6 μg/g) exceeded the 6 to 7 μg/g threshold associated with impaired egg hatchability in black-necked stilts. Selenium concentrations in livers from prefledged juvenile American avocets (mean = 13.8 μg/g) and blue-winged teal (mean = 20.1 μg/g) exceeded background for avian livers of 10 μg/g level. Other species of waterfowl, such as widgeon, gadwall, and Northern shoveler, feeding on algae and aquatic invertebrates in the evaporation ponds are probably also bioaccumulating selenium at levels of concern. PAH bile metabolites and analysis of the liver detoxification enzyme ethoxyresorufin-O-dealkylase (EROD) shows that aquatic birds feeding in the evaporation ponds are exposed to petroleum hydrocarbons; however, it is not known if this exposure is resulting in adverse effects. The eutrophic nature of these ponds is precluding the establishment of macrophytic aquatic vegetation as well as limiting the density and diversity of aquatic invertebrates, both dietary items consumed by aquatic migratory birds. Eutrophication and its contribution of organic matter onto the surficial sediments is likely limiting the bioavailability of trace elements and petroleum hydrocarbons as these contaminants are strongly bound to the organic matter within the sediment. Although eutrophication is limiting the availability of chemical contaminants in the food chain, the potential exists for the presence of cyanotoxins produced by cyanobacteria in the evaporation ponds.

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INTRODUCTION

Oil refineries use large quantities of water to remove salts from the crude oil, and in coking, catalytic and other refining processes (55 gallons of water per barrel of crude oil) (US EPA 1995). Refinery process water comes into contact with crude oil and thus becomes contaminated with hydrocarbons, metals, hydrogen sulfide, ammonia and other contaminants (US EPA 1995). Refinery process water is typically treated on-site prior to discharge. Most refineries use large ponds to contain their process water. The Little America refinery has existed since the early 1920's and is located adjacent to the North Platte River in Evansville, Wyoming, a suburb of Casper. The process water evaporation ponds were placed into service in the 1950's while under the ownership of Mobil Oil. The Little America Refining Company (LARCO) purchased the refinery in 1968 and it is still known as the LARCO refinery even though it is now owned by the Sinclair Oil Corporation. The refinery produces motor gasoline, distillates, jet fuel, heavy fuel oil, asphalt, propane, and mixed butanes. It refines approximately 24,500 barrels of crude oil per day (ThermoRetec Consulting Corp. 2000).

At the LARCO refinery, the process water is treated at an Aggressive Biological Treatment Unit (ABTU) which consists of a dual cell, synthetically-lined surface impoundment. The ABTU treats the process wastewater by aeration to remove organics, such as benzene. Following treatment at the ABTU, the wastewater is discharged via a pipeline to the evaporation ponds for disposal. The LARCO refinery discharges approximately 6.5 million gallons of process water per month (Jerry Breed, Wyoming Department of Environmental Quality, personal communications, February 12, 2007).

Contaminants in the process water can accumulate in sediments and the food chain. Oil present in refinery process waters can adversely affect aquatic birds. Waterfowl ingesting sub-lethal doses of oil can experience impaired reproduction (Grau et al. 1977), and female aquatic birds returning to their nests with oil on their feathers can inadvertently apply the oil to the eggs (King and Le Fever 1979). Microliter amounts of oil applied externally to eggs are extremely toxic to bird embryos (Leepen 1976, Szaro 1979). Trace elements, such as selenium (Se), also can be present in refinery process water ponds and can bioaccumulate to toxic levels in migratory aquatic birds (Ramirez 1997).

A study of the LARCO Refinery process water evaporation ponds by Golder Associates, Inc. (1991), a consultant to Sinclair, documented high concentrations of several contaminants in sediments. Golder Associates, Inc. (1991) reported the following maximum concentrations of these contaminants in the sediment: chromium (Cr), 7,610 µg/g; lead (Pb), 190 µg/g; mercury (Hg), 9.53 µg/g; selenium (Se), 200 µg/g; vanadium (V), 68 µg/g; chrysene, 13,000; µg/g phenanthrene, 110,000 µg/g; and pyrene, 36,000 µg/g.

The presence of metals and hydrocarbons led to the U.S. Fish and Wildlife Service's (Service) Environmental Contaminants (EC) Program field study of the LARCO Refinery process water evaporation ponds. Access to the process water evaporation ponds was granted to the Service by Sinclair Oil Corporation. Funding for the study was provided by the Service's EC program. The study was designed to determine the extent of bird use at the ponds, the nature and extent of contaminants in the ponds, and to determine if contaminants are causing adverse effects or have the potential to adversely affect aquatic migratory birds inhabiting the ponds.

SITE DESCRIPTION

The evaporation ponds were created by the discharge of refinery process water into natural depressions located in Quaternary sand dunes underlain by bedrock of the Mesaverde Formation with an average elevation of 5,100 ft (Love and Christiansen 1985) (Figure 1). Pond 1 is approximately 14 acres with depths ranging from 1.9 to 9.2 ft. Pond 2 is about 6 acres with depths ranging from 4 to 6.1 ft. Pond 3 is roughly 43 acres in size and 4.5 to 5.5 ft in depth. The three evaporation ponds are located approximately 1.25-1.5 miles from the refinery (Figure 2).

Refinery process water is discharged via pipeline into a small inlet pond (Inlet Pond). Water then flows from the Inlet Pond into Pond 1, then into Pond 2, and finally into Pond 3, a closed basin and the largest of the three ponds. These wetlands provide habitat used by a variety of migratory aquatic birds. In the semi-arid environment of Wyoming where annual precipitation averages about 12.5 inches per year, any open water draws aquatic birds.

A freshwater marsh wetland is present immediately to the northwest of the evaporation ponds (Figure 2). This freshwater marsh wetland, referred to as the Natural Marsh, does not directly receive refinery process water and was selected as a reference site for this study. A closed-basin pond is located immediately to the southeast of Pond 1 and is referred to as the Russian Olive Pond. It is not presently known if the Natural Marsh and the Russian Olive Pond have a hydrologic connection to the evaporation ponds or if the Natural Marsh and the Russian Olive Pond are down gradient of the evaporation ponds. Other nearby ponds include Pasture Pond, and Windmill Pond.

Figure 1. LARCO refinery process water evaporation ponds are located in relict sand dunes.

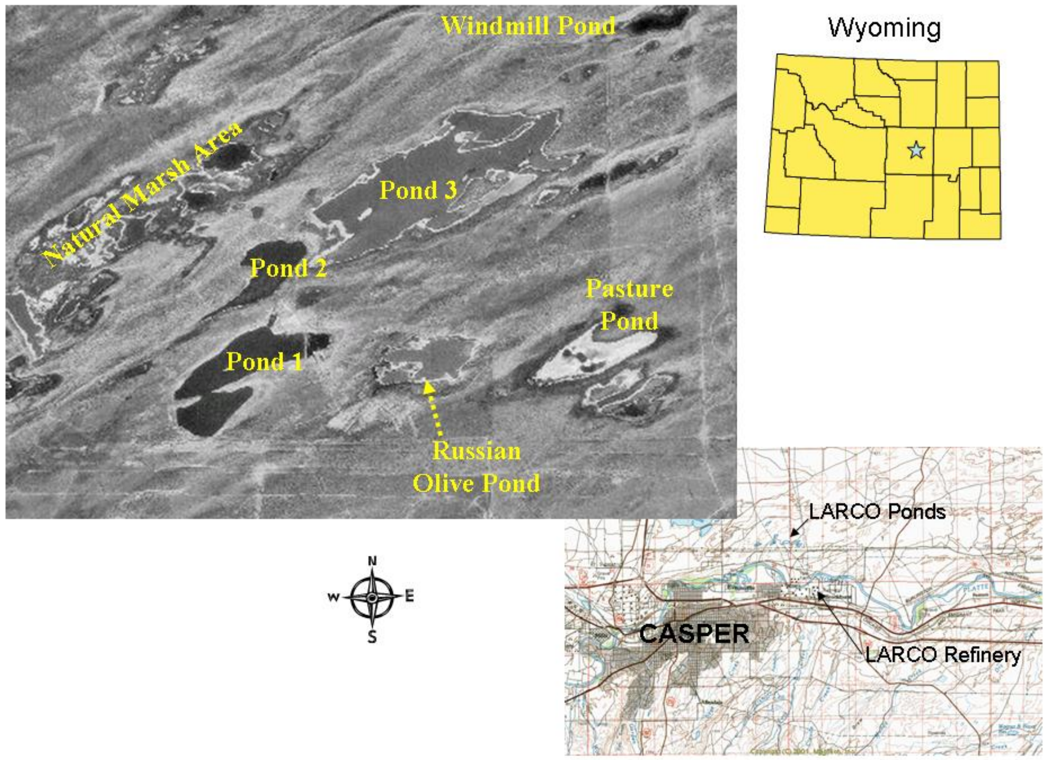

Figure 2. Location of LARCO Refinery process water ponds and adjacent ponds and wetlands, Casper, Wyoming.

The LARCO Refinery process water evaporation ponds are highly eutrophic. Eutrophication results from an increase in nutrients and is evident by the algal community structure and abundance (Harper 1992). The eutrophication of the evaporation ponds is likely due to high levels of ammonia (NH_3) produced by the ABTU process. Maximum daily ammonia concentrations in the process water discharged from the ABTU ranged from 7 to 39 μg/L in 2003 (LARCO ABTU Monthly Reports to Wyoming Department of Environmental Quality).

METHODS

Weekly bird surveys were conducted to determine migratory bird use at the study site. Water and sediment samples were collected for trace element and hydrocarbon analysis to determine the presence of contaminants at the process water ponds. Phytoplankton, aquatic invertebrate, bird egg, and bird liver samples were collected for chemical analysis to determine the potential effects of contaminants in the process water ponds on the food chain. Sample locations were determined using a Garmin™ hand-held GPS unit. Samples collected for aliphatic and polycyclic aromatic hydrocarbon (PAH) analysis were submitted to the Geochemical and Environmental Research Group (GERG) Laboratory, Texas A&M University, College Station, Texas and TDI Brooks International (TDI), College Station, Texas. Samples collected for trace element analysis were submitted to Research Triangle Institute (RTI), Research Triangle Park, North Carolina and Laboratory and Environmental Testing (LET), Columbia, Missouri. These laboratories are under contract with the Service's Analytical Control Facility (ACF) in Shepherdstown, West Virginia. Trace element analysis included scans for arsenic (As), mercury, and selenium using atomic absorption spectroscopy. Inductively Coupled Plasma Emission Spectroscopy was used to scan a variety of elements including boron (B), barium (Ba), chromium, copper (Cu), lead, selenium, vanadium, and zinc (Zn). Mercury samples were digested under reflux in nitric acid. Other samples were digested under reflux in nitric and perchloric acids. An extended scan for aromatic hydrocarbons was conducted on sediment, phytoplankton, and aquatic invertebrate samples. ACF conducted Quality Assurance/Quality Control on all samples analyzed by GERG, TDI and RTI. All procedural blank results, duplicate results, spike recoveries, and standard reference material results were generally within normal limits. Quality control samples in the form of procedural blanks, matrix spikes, duplicates, and standard reference materials were analyzed at a frequency of 1 to every 10 samples. Analytical laboratory results for sediment and biota are reported in μg/g dry weight unless otherwise noted.

Water Sampling

Water samples were collected from the three evaporation ponds and the Russian Olive Pond. Reference water samples were also collected from the Natural Marsh, Windmill Pond, and Pasture Pond. Water samples were collected in 1-liter chemically-clean polyethylene jars with Teflon-lined lids. Conductivity, Total Dissolved Solids (TDS), and pH of water samples were measured with an Oakton® TDS/conductivity meter and an Orion® pH meter. The pH was then lowered to < 2.0 with laboratory-grade nitric acid, allowing the samples to be stored at room temperature. Water samples were also collected for basic water chemistry analysis (cations, anions, total dissolved solids, etc.), kept chilled in ice and submitted within 48 hours to the Colorado State University Soil, Water & Plant Testing Laboratory at Fort Collins, Colorado.

Sediment Sampling

Sediment samples were collected at the three ponds and reference sites. GPS coordinates (in decimal degrees) of sampling locations are shown in the Appendix. Sediment samples were randomly collected at five locations per pond from Ponds 1, 2, 3, the Natural Marsh, and Russian Olive Pond (Figures 3, 4, 5, 6, 7). One sample was collected from the Inlet Pond which is the first pond receiving refinery process water. Sediment was collected using an Eckman dredge and then placed into chemically-clean amber-colored glass jars with Teflon-lined lids for hydrocarbon analysis and in Whirl-Pak® bags for trace element analysis. The Eckman dredge and stainless-steel implements used in sample collection were washed with distilled water and rinsed with acetone before each use.

Sediment samples were frozen immediately following collection. In 2004, additional sediment samples were collected from Ponds 1, 2, and 3 for analysis of Total Organic Carbon (TOC) and to confirm elevated trace element and total petroleum hydrocarbon (TPH) concentrations.

Algal Sampling

Algal samples were collected with a Wisconsin net towed using a canoe powered with a trolling motor. Plankton tows were performed for approximately one hour at Ponds 1, 2, and 3. Algal-laden water samples were collected from Russian Olive Pond in wide-mouth jars. All plankton samples were placed on ice until they could be centrifuged to further separate the algal from the water. Following centrifugal-separation, the water was decanted and the algae was transferred to chemically-clean 40-ml glass vials and frozen. Algal samples were also submitted to Dr. Paul Kugrens, Colorado State University, Fort Collins, Colorado for taxonomic identification on September 2004.

Aquatic Invertebrates

Aquatic invertebrates were collected at the evaporation ponds and the Natural Marsh using light traps, as described by Espinosa and Clark (1972). Light traps were set at three locations per pond until sufficient sample was collected, thus the amount of effort per pond varied. On July 1, 2004 a daphnia (*Daphnia* sp.) bloom occurred in Pond 2, thus offering an opportunity to collect these organisms with a dip net. Daphnia were collected and the samples submitted for trace element and hydrocarbon analysis. Aquatic invertebrate samples were placed in chemically-clean, clear glass vials, frozen immediately and submitted for trace element analysis. In 2004, aquatic invertebrates and algae were collected from Ponds 1, 2 and 3 and submitted for hydrocarbon analysis. Although the ponds are eutrophic, minnow traps were set to confirm the absence of fish.

Bird Surveys

Bird surveys were conducted weekly using a spotting scope and binoculars. Surveys were conducted for 17 weeks in 2003, beginning May 15 and ending September 25, and for 22 weeks in 2004 beginning May 8 and ending September 30. During 2003, bird surveys were not conducted during the last two weeks of May and the second week of August. The amount of time required to identify and count all birds present was recorded for each pond. Total survey effort in hours of observation for 2003 was: 3 hours for Pond 1, 2.7 hours for Pond 2, 10.45 hours for Pond 3, and 9.6 hours for the Natural Marsh. Total survey effort in hours of observation for 2004 was: 2.3 hours for Pond 1, 2 hours for Pond 2, 10.5 hours for Pond 3, and 9.3 hours for the Natural Marsh. Species presence and abundance were recorded.

Nest Searches and Egg Collections

Nest searches were conducted in an effort to quantify nesting success. Searches were conducted in May for waterfowl and through late June and July for shorebirds. Nests were located by actively searching islands, peninsulas, and pond perimeters. Once located, nests were marked with a wooden stake (labeled with the nest identification number), eggs were numbered, a GPS coordinate was recorded, and field notes were taken to assist in relocating the nest for monitoring purposes. Addled and randomly selected viable eggs were collected from waterfowl and shorebird nests. Eggs were dissected to determine embryo age, viability, and examined for deformities. Egg contents were frozen immediately following dissection and submitted for trace element analysis. Based on species incubation information and aged embryos, nests were revisited during the estimated hatching period to determine the fate of the eggs and nesting success. Data recorded at each nest followed the recommendations by Klett et al. (1986). During nest searches and monitoring activities, areas were also surveyed for bird carcasses. Bird mortality was documented, but carcasses were too decomposed to submit for necropsy.

Bird Collections

Juvenile pre-fledged Canada geese (*Branta canadensis*), American avocets (*Recurvirostra americana*), and Blue-winged teal (*Anas discors*) were collected from the LARCO evaporation ponds during mid-July and early August 2003 using a shotgun and steel shot. Additionally, reference specimens were collected in 2003 from the following areas: Canada geese were collected from Table Mountain Recreation Area in Goshen County, American avocets were obtained from Steamboat Lake in Pathfinder National Wildlife Refuge (NWR) in Natrona County, and Blue-winged teal from Hutton Lake NWR in Albany County. Liver and bile samples from pre-fledged birds of each species were submitted for trace element and hydrocarbon analyses, respectively. Bile was extracted using Vacutainers® and livers were placed in chemically-clean glass jars. Additionally, 0.3 to 1 g of liver tissue from each specimen was placed in a cryotube and immediately frozen in liquid nitrogen for ethoxyresorufin-O-dealkylase (EROD) activity analysis. EROD analysis was performed by Dr. Mark Melancon of the U.S. Geological Survey, Patuxent Wildlife Research Center following the procedures described in Melancon (1996). The use of EROD in bird livers is an indicator of petroleum contamination (Stegeman et al. 1992). The EROD is a liver detoxification enzyme and part of the protein family of cytochrome P450 monooxgenases or mixed function oxygenase (MFO). The EROD activity can be used as a sensitive indicator of PAH exposure while reproductive parameters (including hatching success, percent deformities, etc.) are used to document adverse effects. Gizzard contents were also collected from the LARCO pre-fledged birds, placed in chemically-clean glass jars, frozen and submitted for trace element analysis.

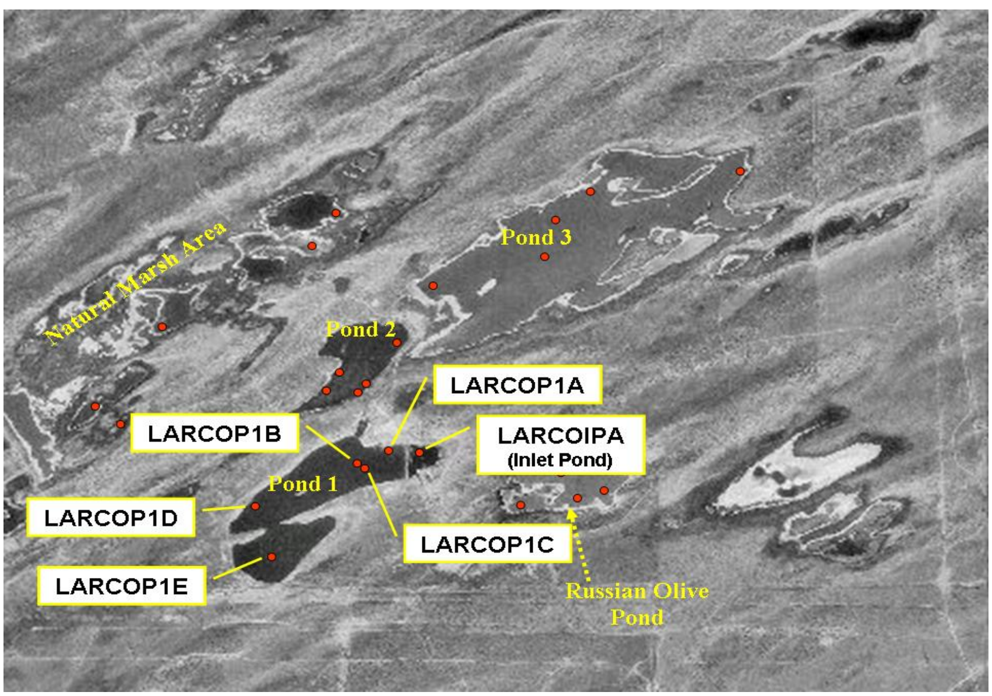

Figure 3. Sediment sampling locations at the LARCO process water evaporation ponds (Pond 1 and the Inlet Pond).

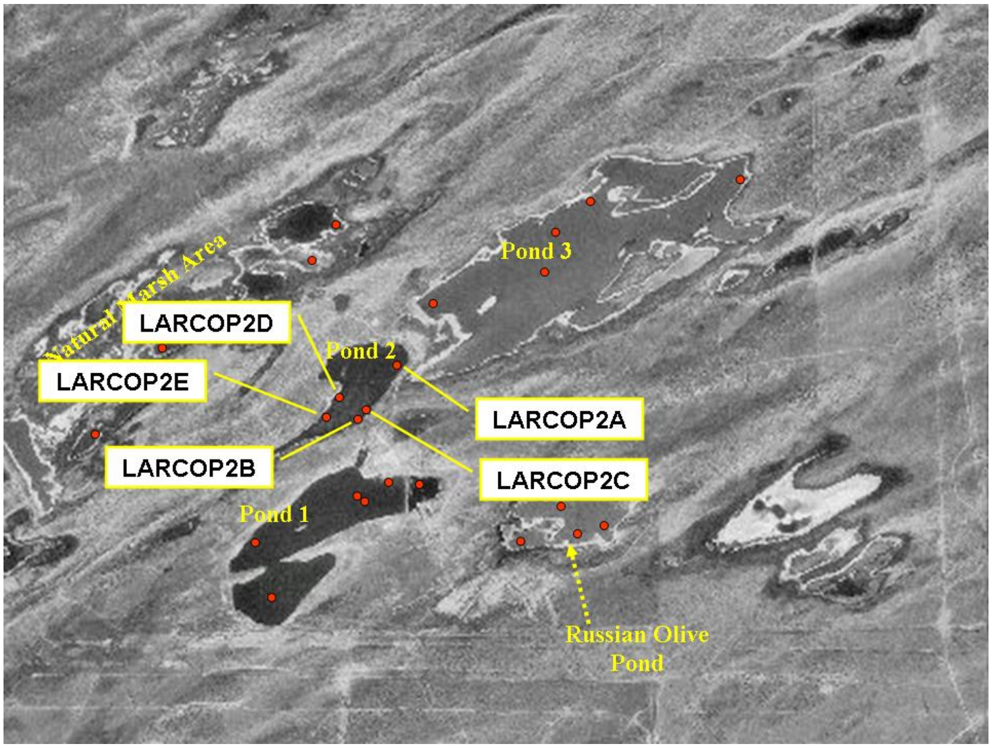

Figure 4. Sediment sampling locations at the LARCO process water evaporation ponds (Pond 2).

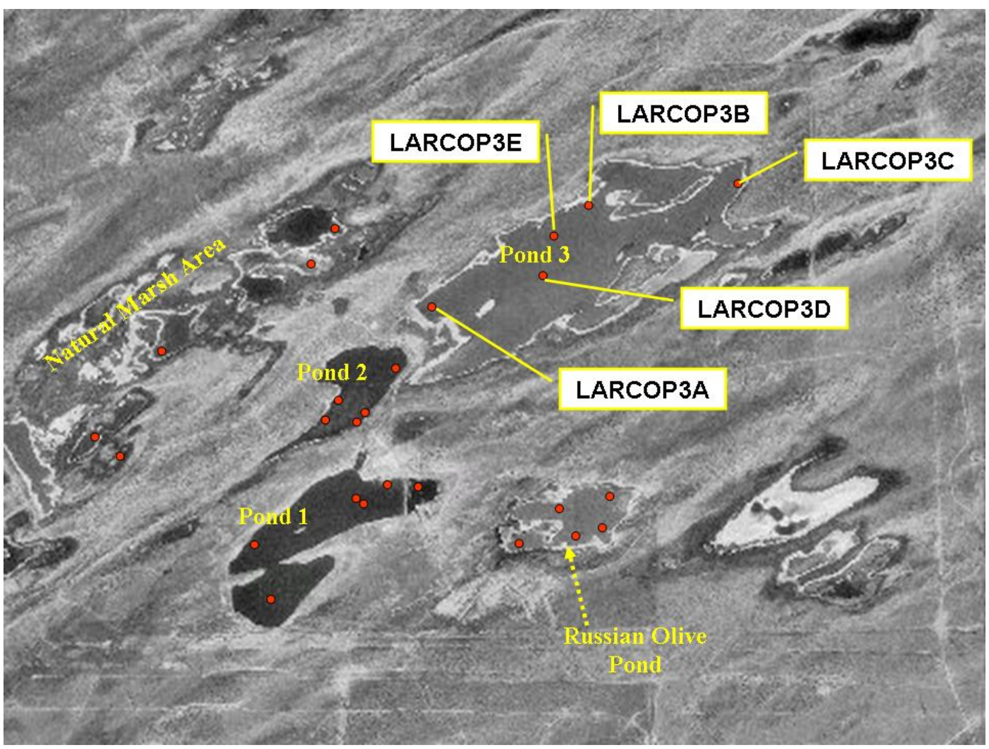

Figure 5. Sediment sampling locations at the LARCO process water evaporation ponds (Pond 3).

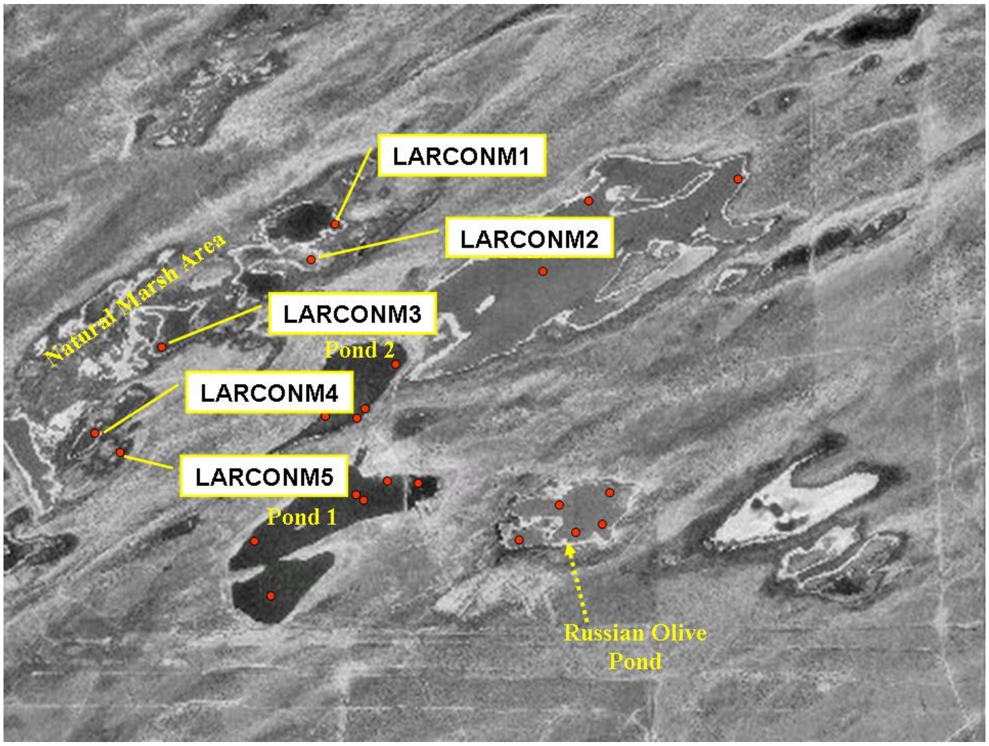

Figure 6. Sediment sampling locations at the LARCO process water evaporation ponds (Natural Marsh - reference site).

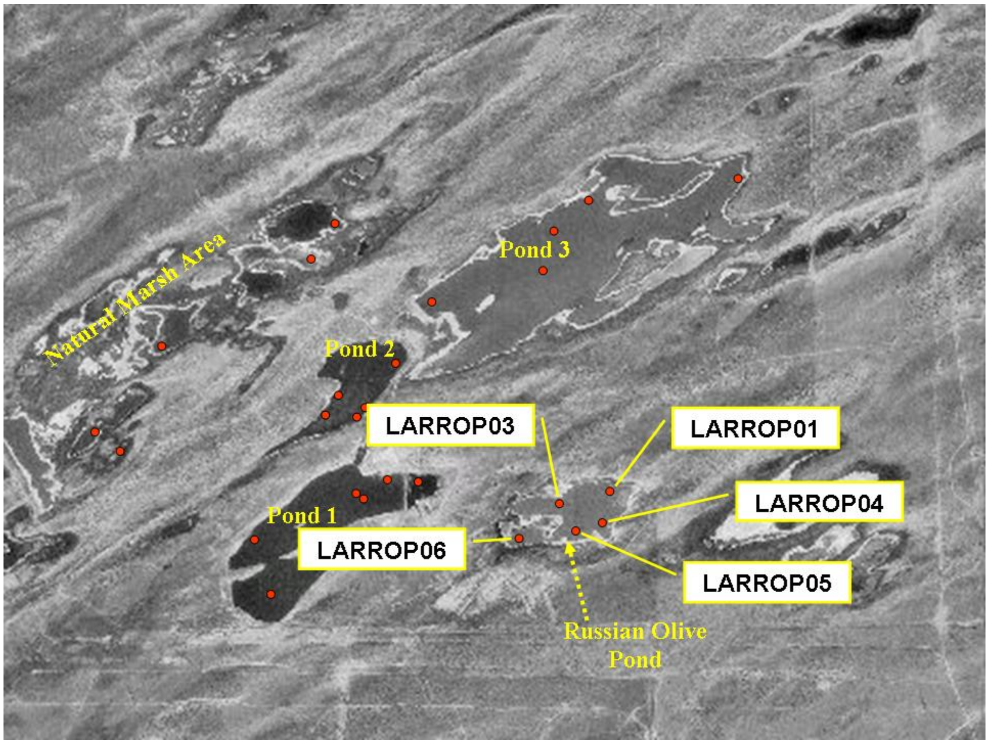

Figure 7. Sediment sampling locations at the LARCO process water evaporation ponds (Russian Olive Pond).

RESULTS

Analytical data for trace elements, aliphatic hydrocarbons and PAHs are shown in the Appendix.

Basic Water Chemistry

Total dissolved solids (TDS), specific conductance, pH, cations, anions, sulfates, chlorides, and other water quality parameters are shown in Table 1. Specific conductance, TDS, sulfates (SO_4), chlorides (Cl), and boron (B) are higher in the terminal pond (Pond 3).

Table 1. Basic chemistry of water collected from the LARCO refinery process water ponds, Casper, Wyoming.

Sample ID	pH	Specific Conductance (umhos/cm)	B	SO_4	Cl	Total Dissolved Solids	Ammonia NH_4	Ammonium Nitrate NH_4-N
Inlet Pond	7.3	1450	0.3	296	185	1063	33.5	26.2
Pond 1	9.1	3280	0.5	830	485	1565	17.9	14
Pond 2	8.9	3670	0.6	846	715	2515	7.4	5.8
Pond 3	9.7	21800	2.4	5140	3690	13939	0.2	0.2

Selenium concentrations in water from the Inlet Pond, Pond 1 and Pond 2 exceeded the 2 µg/L threshold which may create a risk for bioaccumulation in sensitive species of aquatic birds (Hamilton 2002)(Table 2). The water-borne selenium concentration in the Inlet Pond was 61 µg/L and exceeded the acute and chronic criteria for selenium of 20 µg/L and 5 µg/L, respectively. Water-borne selenium concentrations in Pond 1 ranged from 5.2 to 10.6 µg/L, exceeding the chronic criterion for selenium. Selenium in one of three water samples collected from Pond 2 was at 9 µg/L and exceeded the chronic criterion for selenium. Selenium in water samples from Pond 3, the Natural Marsh, Russian Olive Pond, Windmill Pond and Pasture Pond were below detection limits. Mercury was detected in the water samples from the Inlet Pond and Pond 1 (0.3 µg/L) but was below detection limits in all other ponds sampled (Table 2).

Table 2. Selenium and mercury concentrations (in µg/L) in water from the LARCO refinery process water ponds, the natural marsh reference site, and other nearby ponds, Casper, Wyoming.

Site	Hg	Se
Inlet Pond		
n=1	0.3	61
Pond 1		
n=3	0.13[a] [<0.1 - 0.3][b] (0.145)[c]	7.53 [5.2 - 10.6] (2.77)
Pond 2		
n=3	<0.1 [<0.1 - <0.1] 0	5.8 [3.5 - 9] (2.8)
Pond 3		
n=3	<0.1	<2.2
Natural Marsh		
n=3	<0.1	<2.2
Russian Olive Pond		
n=1	<0.1	<2.2
Windmill Pond		
n=1	<0.1	<2.2
Pasture Pond		
n=1	<0.1	<2.2

a = mean
b = range
c = standard deviation

<u>Sediment Quality</u>

Trace elements exceeding probable effects concentrations (PECs) (levels above which biological effects are likely to occur according to Ingersoll and MacDonald (2002) include: arsenic, chromium, copper, mercury, and zinc (Tables 3 and 4). Trace elements exceeding threshold effects concentrations (TECs) (levels below which biological effects are unlikely to occur) but below PECs include: nickel (Ni), and lead. Selenium concentrations ranged from below detection limits at the Natural Marsh (reference site) to 140 µg/g in Pond 1. Mean selenium concentrations were significantly higher ($p<0.05$) in Ponds 1 and 2, 49.2 and 41.2 µg/g, respectively, than in Pond 3 (mean Se 6.8 µg/g). Selenium concentrations above 4 µg/g in sediment have the potential for bioaccumulation in the food chain and adverse effects on sensitive fish and aquatic bird species (Lemly 1993). Trace elements exceeding background concentrations for soils and other surficial materials in the Western United States as defined by Shacklette and Boerngen (1984) included: boron, molybdenum (Mo) and strontium (Sr).

Table 3. Mean trace element concentrations (in µg/g) in sediment collected in 2003 from the LARCO refinery process water ponds and natural marsh reference site, Casper, Wyoming.

Site	As	Cr	Cu	Hg	Ni	Pb	Se	Zn
Inlet Pond								
n=1	15	62	221	3	20	31	40	734
Pond 1								
n=5	14.9[a] [4.4 - 38][b] (13.35)[c]	1354.4 [231 - 3920] (1517.3)	121.4 [67 - 258] (79.4)	2.09 [0.75 - 3.9] (1.26)	21.2 [7 - 42] (14.23)	54.8 [32 - 76] (20.57)	49.2 [2.2 - 140] (54.7)	884 [203 - 1810] (687.7)
Pond 2								
n=5	11.8 [3.2 - 19] (5.73)	618 [92 - 1680] (645.8)	54.98 [9.9 - 89] (28.8)	1.04 [0.2 - 2.1] (0.69)	21.6 [7 - 33] (9.3)	41.6 [10 - 64] (19.88)	41.2 [8.1 - 65] (21.2)	543 [74 - 875] (294.14)
Pond 3								
n=5	6.06 [2.7 - 9.8] (3.11)	20.82 [3.1 - 48] (17.9)	8.2 [2 - 21] (7.6)	0.1 [<0.1 - 0.3] (0.11)	10.6 [<5 - 24] (9.3)	23 [7 - 36] (13.6)	6.8 [0.6 - 21] (8.49)	50.3 [7.5 - 150] (57.6)
Natural Marsh								
n=5	10.54 [5.6 - 16] (5.06)	5.76 [4.4 - 7.9] (1.49)	5.08 [3 - 9.4] (2.74)	<.100 [<.1 - <.1] (0)	22.4 [9 - 35] (12.3)	23.6 [19 - 28] (4.5)	0.62 [<0.6 - 1] (0.31)	17 [10 - 26] (6.4)
Background	5.5	41	21	0.046	15	17	0.23	55
TEC	9.79	43.4	31.6	0.18	22.7	35.8		121
PEC	33	111	149	1.06	48.6	128		459

a = mean
b = range
c = standard deviation
TEC = threshold effects concentration (level below which adverse biological effects are likely to occur
PEC = probable effects concentration (level above which adverse biological effects are likely to occur

Table 4. Total organic carbon and trace element concentrations (in µg/g) in sediment collected in 2004 from the LARCO refinery process water ponds, Casper, Wyoming.

Site & Sample ID	Total Organic Carbon	As	Cr	Cu	Hg	Ni	Pb	Se	Zn
Pond 1									
4LP1S01	14.8	9.2	279	55	1.2	18	37	32	406
4LP1S02	28.5	12	1630	101	3.9	23	73	80	967
Pond 2									
4LP2S01	0.2	1	7	2	<0.1	<5	5	2	7.5
4LP2S02	2.6	2.3	106	10	0.2	<5	9	7.7	67
Pond 3									
4LP3S01	5.5	3.5	28	8.4	0.1	10	17	4.4	46
4LP3S02	16.6	7.8	57	18	0.48	20	28	17	130
	Background	5.5	41	21	0.05	15	17	0.23	55
	TEC	9.79	43.4	31.6	0.18	22.7	35.8		121
	PEC	33	111	149	1.06	48.6	128		459

TEC = threshold effects concentration (level below which adverse biological effects are likely to occur
PEC = probable effects concentration (level above which adverse biological effects are likely to occur

During sediment collections from the Inlet Pond, Pond 1, Pond 2, and Russian Olive Pond, there was a visible sheen on the water surface when the unused portion of the sample was returned to the water and/or when the bottom was agitated by the Eckman dredge. Additionally, these samples had a strong hydrocarbon odor, lacked vegetation and benthic invertebrates, and were highly reduced.

Petroleum hydrocarbon concentrations were highest in Pond 1 followed by Pond 2. All sediment samples collected from the Inlet Pond, Pond 1 and Pond 2 exceeded the upper effects levels as defined by Buchman (1999) for the following aromatic hydrocarbons: benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene (Table 5). In Pond 3, benzo(a)pyrene, chrysene, phenanthrene, and pyrene exceeded the threshold effects level as defined by Buchman (1999) in three of the five sediment samples (Table 6). All sediment samples collected from the Russian Olive Pond exceeded the upper effects levels as defined by Buchman (1999) for the following aromatic hydrocarbons: chrysene, phenanthrene, and pyrene and exceeded the threshold effects level for benzo(a)pyrene. All sediment samples from Pond 1 and Pond 2 and one sample from Pond 3 exceeded the PEC for total PAHs.

Table 5. Mean concentrations of polycyclic aromatic hydrocarbons (PAHs) (in µg/g) in sediment from the LARCO refinery process water ponds, Casper, Wyoming.

Site	benzo(a)pyrene	chrysene	fluoranthene	phenanthrene	pyrene	Total PAHs
Inlet Pond						
n=1	3.54	13.4	1.9	32.1	16.5	1, 334.87
Pond 1						
n=5	4.49[a] [1.16 - 12.6][b] (4.71)[c]	26.6 [8.03 - 83.4] (31.9)	14.6 [3.0 - 58.6] (24.5)	273.8 [30.6 - 1,119] (472.9)	93.98 [17.3 - 380] (159.9)	4,393 [978 - 14,340] (5,614)
Pond 2						
n=5	4.76 [0.79 - 7.26] (2.88)	24.2 [6.03 - 37.5] (12.74)	8.93 [2.07 - 14.5] (5.51)	126.4 [37.3 - 252] (94.33)	65.3 [12 - 103] (38.27)	2,469 [1,156 - 3,403] (1,157)
Pond 3						
n=5	0.028 [0.004 - 0.046] (0.02)	0.193 [0.017 - 0.51] (0.201)	0.053 [0.006 - 0.113] (0.04)	0.146 [0.028 - 0.24] (0.107)	0.357 [0.028 - 1] (0.39)	10.67 [0.749 - 29.97] (11.8)

a = mean
b = range
c = standard deviation

Arsenic, chromium, mercury, and nickel in sediment samples from the Russian Olive Pond exceeded TECs (Table 6). Two of five sediment samples exceeded PECs for chromium. Three of the five samples were analyzed for aliphatic and aromatic hydrocarbons and had total PAHs ranging from 163.8 to 953.2 µg/g, with a mean of 441.1 µg/g and were higher than those found in Pond 3.

Table 6. Mean trace element concentrations (in µg/g) in sediment from the Russian Olive Pond located near the LARCO refinery process water ponds, Casper, Wyoming.

n=5	As	Cr	Hg	Ni
	6.938[a] [4.46 - 11.2][b] (2.96)[c]	188.36 [55.4 - 442] (168.93)	0.17 [<0.0519 - 0.279] (0.12)	18.04 [11.1 - 26.6] (6.41)
Background	5.5	41	0.046	15
TEC	9.79	43.4	0.18	22.7
PEC	33	111	1.06	48.6

a = mean
b = range
c = standard deviation
TEC = threshold effects concentration (level below which adverse biological effects are likely to occur
PEC = probable effects concentration (level above which adverse biological effects are likely to occur

Algae

Algal samples from Ponds 2 and 3 were identified as *Arthrospira maxima*, *Planktothrix mougeoti, and P. agardhii*. Concentrations of chromium, copper, lead, nickel, selenium, and zinc were significantly higher in Pond 1 than in Ponds 2 and 3 and the Russian Olive Pond ($p < 0.05$) (Table 7). Mercury in algae from Pond 1 and the Russian Olive Pond were not significantly different; however, mercury in algae from these two ponds was significantly higher than in algae from Ponds 2 and 3 ($p < 0.05$). Mercury concentrations in algae from Ponds 1, 2 and 3 did not exceed the 0.05 µg/g wet weight dietary threshold recommended by Eisler (1987) for the protection of birds. Wet weight concentrations in algae from Ponds 1, 2, and 3 ranged from 0.007 to 0.03 ppm with moisture concentrations ranging from 92 to 98 percent. Mercury in one of five algae samples from the Russian Olive Pond was 2.91 µg/g (0.754 µg/g wet weight) and exceeded the 0.05 µg/g wet weight dietary threshold recommended by Eisler (1987) for the protection of birds. Selenium concentrations in algae from all three refinery process water ponds exceed the 3 µg/g dietary threshold for sensitive species of aquatic migratory birds (Lemly 1993). The highest selenium concentrations occurred in algae collected from Pond 1 and ranged from 20 to 30 µg/g. Selenium in algae from uncontaminated sites typically average less than 0.5 µg/g (USDOI 1998).

Ninety-five percent of the aromatic hydrocarbon compounds were detected in algal samples from Pond 1. Fifty percent and 61 percent of the aromatic hydrocarbon compounds were detected in algal samples from Pond 2 and Pond 3, respectively.

Aquatic Invertebrates

Two of five waterboatmen samples from Pond 1 had mercury concentrations of 0.2 and 0.3 µg/g (0.05 and 0.06 µg/g wet weight), at or slightly above the 0.05 µg/g wet weight dietary threshold recommended by Eisler (1987) for the protection of birds. One waterboatmen sample from Pond 3 also had mercury at the dietary threshold for the protection of birds (0.2 µg/g dry weight). However, mean mercury concentrations in waterboatmen from all three ponds were below the 0.05 µg/g wet weight dietary threshold (Table 8). Mercury concentrations in waterboatmen samples from the Natural Marsh were below detection limits (<0.1 µg/g).

Table 7. Mean trace element concentrations (in µg/g) in algae from the LARCO refinery process water ponds and Russian Olive Pond located near the LARCO refinery process water ponds, Casper, Wyoming.

Site	Cr	Cu	Hg	Ni	Pb	Se	Zn
Pond 1							
n=5	10.8[a]	86.8	1.28	18.2	14.6	24.8	92.8
	[9.2 - 14][b]	[61 - 115]	[1.1 - 1.5]	[17 - 20]	[12 - 19]	[20 - 30]	[68.3 - 121]
	(1.9)[c]	(86.8)	(0.148)	(1.3)	(2.88)	(3.63)	(21.12)
Pond 2							
n=5	1.96	41.6	0.378	13.4	2.5	5	35
	[1 - 2.6]	[20 - 75]	[0.36 - 0.4]	[13 - 14]	[2 - 3.8]	[4.2 - 6.5]	[27 - 45]
	(0.87)	(23.3)	(0.018)	(0.548)	(0.748)	(0.892)	(7.61)
Pond 3							
n=5	3.08	42.8	0.28	9.48	40.8	4.98	36.06
	[2.7 - 3.3]	[19 - 122]	[0.2 - 0.3]	[9.1 - 9.8]	[39 - 44]	[4.8 - 5.4]	[25 - 74.3]
	(0.228)	(44.34)	(0.045)	(0.277)	(1.924)	(0.249)	(21.44)
Russian Olive Pond							
n=5	2.7	3.297	0.606	7.67	0.552	0.298	5.52
	[<0.492 - 8.48]	[<0.492 - 9.75]	[<0.0442 - 2.91]	[6.13 - 8.55]	[0.304 - 1.12]	[0.227 - 0.499]	[3.18 - 10.8]
	(3.47)	(4.179)	(1.288)	(0.931)	(0.326)	(0.115)	(3.32)

a = mean
b = range
c = standard deviation

Selenium concentrations in waterboatmen from all three refinery process water ponds exceed the 3 µg/g dietary threshold for sensitive species of aquatic migratory birds (Lemly 1993). Mean selenium concentrations in waterboatmen collected from Ponds 1 and 2 were 5.6 and 6.2 µg/g, respectively and were significantly higher than the mean concentration in waterboatmen from Pond 3 (4.2 µg/g). Selenium concentrations in waterboatmen collected from the Natural Marsh were below the 3 µg/g dietary threshold.

Table 8. Mean mercury and selenium concentrations (in µg/g) in aquatic invertebrates collected from the LARCO refinery process water ponds and natural marsh reference site, Casper, Wyoming.

Site	Hg	Se
Pond 1 - Waterboatmen		
n=5	0.17	5.64
	[<0.1 - 0.3]	[4.6 - 7.1]
	(0.097)	(1.246)
Pond 2 - Waterboatmen		
n=5	0.14	6.2
	[<0.1 - 0.2]	[5.6 - 7.5]
	(0.055)	(0.748)
Pond 3 - Waterboatmen		
n=5	0.16	4.28
	[0.1 - 0.2]	[3 - 7.9]
	(0.055)	(2.04)

Site	Hg	Se
Pond 1 - Dobson Flies		
n=3	0.334	14.73
	[0.303 - 0.38]	[14 - 16.1]
	(0.041)	(1.185)
Pond 2 - Backswimmers		
n=3	0.461	12.66
	[0.411 - 0.527]	[11.6 - 14.1]
	(0.06)	(1.29)
Natural Marsh - Waterboatmen		
n=5	<0.1	1.12
	[<0.1]	[1 - 1.2]
	(0)	(0.08)

a = mean
b = range
c = standard deviation

Mercury concentrations in all three backswimmer (Family Notonectidae) samples from Pond 2 exceeded the 0.05 µg/g wet weight dietary threshold and ranged from 0.41 to 0.52 µg/g (0.12 to 0.16 µg/g wet weight). Two of three Dobson fly samples (Family Corydalidae, *Corydalus* sp.) from Pond 1 had mercury concentrations of 0.3 µg/g (0.05 µg/g wet weight), at the 0.05 µg/g wet weight dietary threshold recommended by Eisler (1987) for the protection of birds. Dobson flies and backswimmers had selenium concentrations ranging from 11.6 to 16.1 µg/g, exceeding the 3 µg/g dietary threshold for sensitive species of aquatic migratory birds (Lemly 1993).

In general, most PAH compounds were detected in all three waterboatmen samples from Pond 2 and in 2 out of 3 waterboatmen samples from Pond 3.

All five Daphnia samples collected from Pond 2 had selenium concentrations of 15 µg/g, exceeding the 3 µg/g dietary threshold for sensitive species of aquatic migratory birds (Lemly 1993). Aromatic and aliphatic hydrocarbons were detected in Daphnia.

Bird Livers and Bird Eggs

The mean selenium concentration in three black-necked stilt eggs was 13.6 µg/g and exceeded the 6 to 7 µg/g threshold reported by Ohlendorf (2003) associated with impaired egg hatchability in black-necked stilts (Table 9). Selenium concentrations in Canada goose, American avocet, and mallard eggs were below levels associated with impaired egg hatchability for those species.

Table 9. Mean selenium concentrations (in µg/g) in black-necked stilt, American avocet, Canada goose, and mallard eggs collected from the LARCO refinery process water ponds, Casper, Wyoming.

	Se
Black-necked Stilt	
n=3	13.6[a] [11 - 19][b] (0.351)[c]
American Avocet	
n=7	7.9 [2.5 - 18] (5.1)

	Se
Canada Goose	
n=5	2.5 [1.5 - 3.4] (0.86)
Mallard	
n=4	5.05 [3.5 - 7.6] (1.96)

a = mean
b = range
c = standard deviation

Selenium concentrations in American avocet livers ranged from 12 to 17 µg/g with a mean of 13.8 µg/g, above the 10 µg/g considered background for avian livers (Ohlendorf 2003)(Table 10). Blue-winged teal had selenium concentrations ranging from 9.5 to 37 µg/g with a mean of 20.1 µg/g, above the 10 µg/g considered background for avian livers (Ohlendorf 2003) and above the 15 µg/g level associated with reduced growth in ducklings (Hoffman 2002).

Table 10. Mean selenium concentrations (in µg/g) in livers from pre-fledged juvenile blue-winged teal, American avocets, and Canada geese collected from the LARCO refinery process water ponds, Casper, Wyoming.

Blue-winged teal	
n=5	**Se**
	20.1
	[9.5 - 37]
	(1.5)

American Avocet	
n=5	**Se**
	13.8
	[12 - 17]
	(2.16)

Canada Goose	
n=5	**Se**
	4.56
	[4.2 - 4.9]
	(0.548)

a = mean
b = range
c = standard deviation

Mark J. Melancon (personal communications, U.S. Geological Survey, Patuxent, MD, October 9, 2003) found that liver samples from American avocets collected from the refinery process water ponds have more microsomal protein/g of liver, more EROD activity/mg of microsomal protein and more EROD activity/g liver than American avocet livers from birds collected at Pathfinder NWR (Table 11). Statistical analysis of the EROD data showed significantly higher ($p < 0.05$) EROD activity in American avocets from the LARCO refinery process water evaporation ponds than in avocets from the reference site, Pathfinder NWR.

PAH bile metabolites in pre-fledged blue-winged teal, Canada geese, and American avocets collected from the LARCO refinery process water evaporation ponds are shown in Table 12. PAH bile metabolite (benzo(a)pyrene, naphthalene, and phenanthrene) concentrations were higher in pre-fledged blue-winged teal collected from Ponds 1 and 2 than those collected from Pond 3 although the sample size was too small to perform a statistical comparison. PAH bile metabolites in pre-fledged blue-winged teal collected from Ponds 1 and 2 ranged as follows: benzo(a)pyrene, 1.7 to 4.1 µg/g; naphthalene, 160 to 490 µg/g; and phenanthrene, 98 to 320 µg/g. PAH bile metabolites in pre-fledged blue-winged teal collected from Pond 3 ranged as follows: benzo(a)pyrene, 0.4 to 2 µg/g; naphthalene, 12 to 72 µg/g; and phenanthrene, 15 to 120 µg/g.

<u>Bird Observation Data</u>

The LARCO evaporation ponds and adjacent Natural Marsh complex attract a variety of spring and fall migratory birds and also provide nesting habitat for several species, including Canada geese, dabbling ducks, American avocets, black-necked stilts (*Himantopus mexicanus*) and other shorebirds. Peak numbers of aquatic birds were observed in mid-September (Figure 8). Wilson's phalarope (*Phalaropus tricolor*), dabbling ducks, American avocet, and American coot (*Fulica americana*) comprised the majority of birds observed during weekly bird surveys. Table 13 lists the aquatic migratory birds observed at the LARCO evaporation ponds and adjacent Natural Marsh complex. Northern shoveler's (*Anas clypeata*) comprised 78 percent of the dabbling ducks observed (Figure 9). Waterfowl made up over half of the birds observed in 2003 and 2004 with Wilson's phalaropes and American avocets comprising 18 and 8 percent of the observations, respectively (Figure 10).

Table 11. EROD activity in American avocets and Canada goose pre-fledged young collected from the LARCO refinery process water ponds, Casper, Wyoming and reference sites.

American Avocet							
Sample ID	Microsomal Protein mg/mL	pmol produced per minute per mg microsomal protein	pmol produced per minute per g liver	Total Liver Weight (g)	Body Weight (g)	pmol produced per minute per liver	pmol produced per minute per g body weight
LARCO Pond 3							
LP3AAL1	8.80	37	646	3	102	1937	18.99
LP3AAL2	5.65	132	1489	7	153	10421	68.11
LP3AAL3	8.48	129	2180	7	216	15260	70.65
LP3AAL4	6.83	248	3380	4	100	13522	135.22
LP3AAL5	9.17	101	1861	5	98	9307	94.97
Reference Site (Pathfinder NWR)							
PFRAAL1	3.56	11	80	8	244	641	2.63
PFRAAL2	3.94	4	28	12	268	338	1.26
PFRAAL3	5.33	12	124	14	320	1729	5.40
PFRAAL4	5.46	0	0	10	319	0	0.00
PFRAAL5	4.96	0	0	8	334	0	0.00
Canada Goose							
Sample ID	Microsomal Protein mg/mL	pmol produced per minute per mg microsomal protein	pmol produced per minute per g liver	Total Liver Weight (g)	Body Weight (g)	pmol produced per minute per liver	pmol produced per minute per g body weight
LARCO Pond 3							
LP3CGL1	3.79	13	100	68	1545	6197	4.01
LP3CGL2	3.56	11	78	74.2	1300	4693	3.61
LP3CGL3	4.77	41	389	63.4	2000	31894	15.95
LP3CGL4	2.29	29	135	61	2000	12125	6.06
LP3CGL5	5.17	110	1139	94	2000	75147	37.57
Reference Site (Table Mountain WMA)							
REFCGL1	2.85	41	233	62	2720	15810	5.81
REFCGL2	5.21	22	226	60	2720	16768	6.16
REFCGL3	5.15	21	213	82	2720	13501	4.96
REFCGL4	6.02	49	589	90	2720	35920	13.21
REFCGL5	4.49	22	198	66	2720	18587	6.83

Table 12. Polycyclic aromatic hydrocarbon metabolites in bile from blue-winged teal, Canada geese, and American avocets collected from the LARCO refinery process water ponds, Casper, Wyoming and from American avocets collected from a reference site at Steamboat Lake, Pathfinder National Wildlife Refuge, Wyoming.

	benzo(a)pyrene	naphthalene	phenanthrene
Blue-winged teal			
n=5	2.2	222.8	148.6
	[0.4 - 4.1]	[12 - 490]	[15 - 320]
	(1.369)	(204.4)	(148.6)
American Avocet			
n=5	0.64	39.6	10.6
	[0.3 - 1.3]	[26 - 48]	[7 - 14]
	(0.397)	(8.62)	(2.6)
Canada Goose			
n=4	3.2	62.25	8.75
	[0.3 - 6]	[50 - 80}	[7 - 11]
	(3.23)	(13.426)	(1.7)

a = mean
b = range
c = standard deviation

Northern shovelers made up 21 percent of the dabbling ducks observed in the Natural Marsh (Figure 11). Waterfowl made up 37 percent of all aquatic birds observed in the Natural Marsh (Figure 12). Wilson's Phalaropes and American avocets made up 30 and 17 percent of all birds observed in the Natural Marsh.

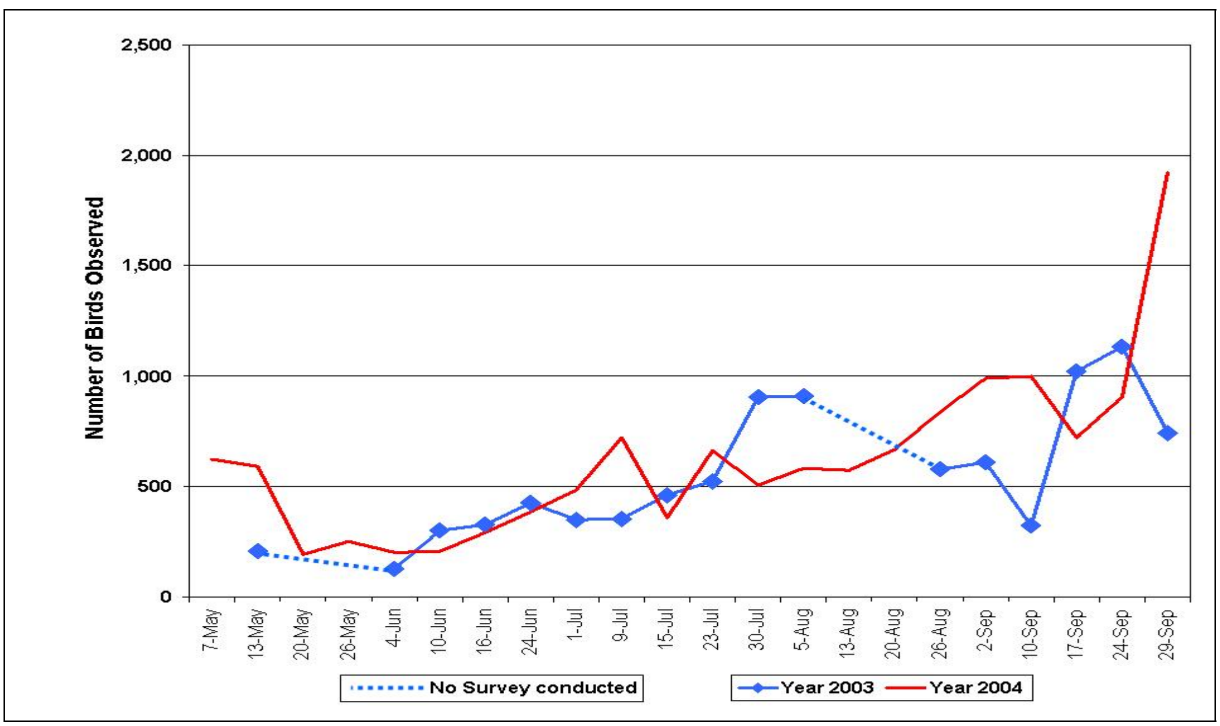

Figure 8. Total number of aquatic birds observed at the LARCO ponds and natural marsh area during weekly surveys (May - Sept 2003 and 2004).

Table 13. Migratory aquatic bird species observed at the LARCO evaporation ponds and adjacent natural marsh complex during weekly surveys, May – September 2003 and 2004, Casper, Wyoming.

Common Name	Scientific Name
Canada Goose	(*Branta canadensis*)
Gadwall	(*Anas strepera*)
American Wigeon	(*Anas americana*)
Mallard	(*Anas platyrhynchos*)
Blue-winged Teal	(*Anas discors*)
Cinnamon Teal	(*Anas cyanoptera*)
Northern Shoveler	(*Anas clypeata*)
Northern Pintail	(*Anas acuta*)
Green-winged Teal	(*Anas crecca*)
Canvasback	(*Aythya valisineria*)
Redhead	(*Aythya americana*)
Lesser Scaup	(*Aythya affinis*)
Ruddy Duck	(*Oxyura jamaicensis*)
Pied-billed Grebe	(*Podilymbus podiceps*)
Eared Grebe	(*Podiceps nigricollis*)
American Coot	(*Fulica americana*)
Sandhill Crane	(*Grus canadensis*)
Semipalmated Plover	(*Charadrius semipalmatus*)
Killdeer	(*Charadrius vociferus*)
Black-necked Stilt	(*Himantopus mexicanus*)
American Avocet	(*Recurvirostra americana*)
Yellowlegs	(*Tringa sp.*)
Solitary Sandpiper	(*Tringa solitaria*)
Willet	(*Catoptrophorus semipalmatus*)
Spotted Sandpiper	(*Actitis macularia*)
Long-billed Curlew	(*Numenius americanus*)
Marbled Godwit	(*Limosa fedoa*)
Semipalmated Sandpiper	(*Calidris pusilla*)
Western Sandpiper	(*Calidris mauri*)
Least Sandpiper	(*Calidris minutilla*)
Pectoral Sandpiper	(*Calidris melanotos*)
Dunlin (FL)	(*Calidris alpina*)
Stilt Sandpiper	(*Calidris himantopus*)
Long-billed Dowitcher	(*Limnodromus scolopaceus*)
Wilson's Phalarope	(*Phalaropus tricolor*)
California Gull	(*Larus californicus*)
Black-bellied Plover	(*Pluvialis squatarola*)
Ruddy Turnstone	(*Arenaria interpres*)
Least Tern	(*Sterna antillarum*)

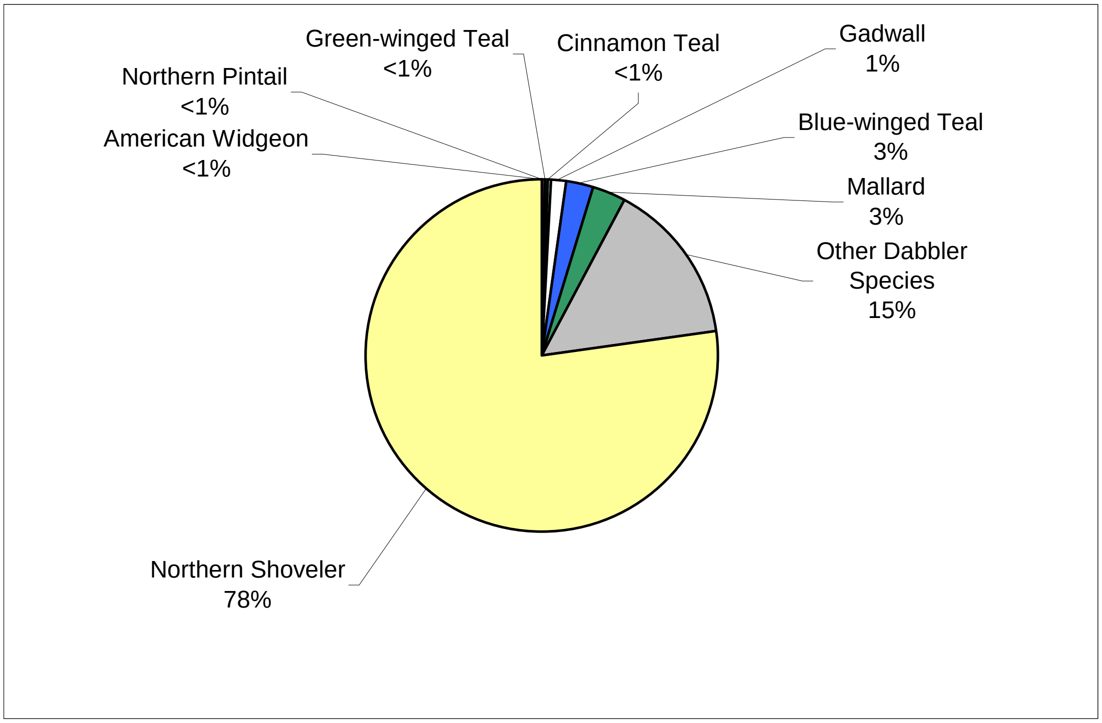

Figure 9. Dabbling duck species composition (in percent) observed at the LARCO process water ponds, Casper, Wyoming.

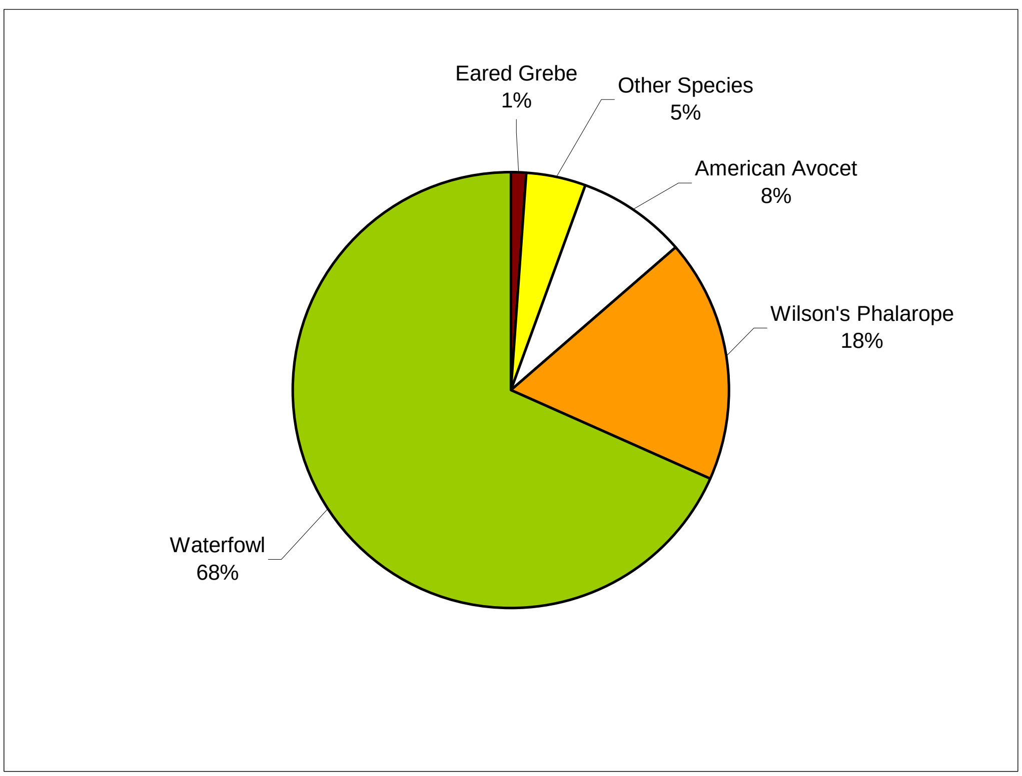

Figure 10. Aquatic migratory bird species composition (in percent) observed at the LARCO process water ponds, Casper, Wyoming.

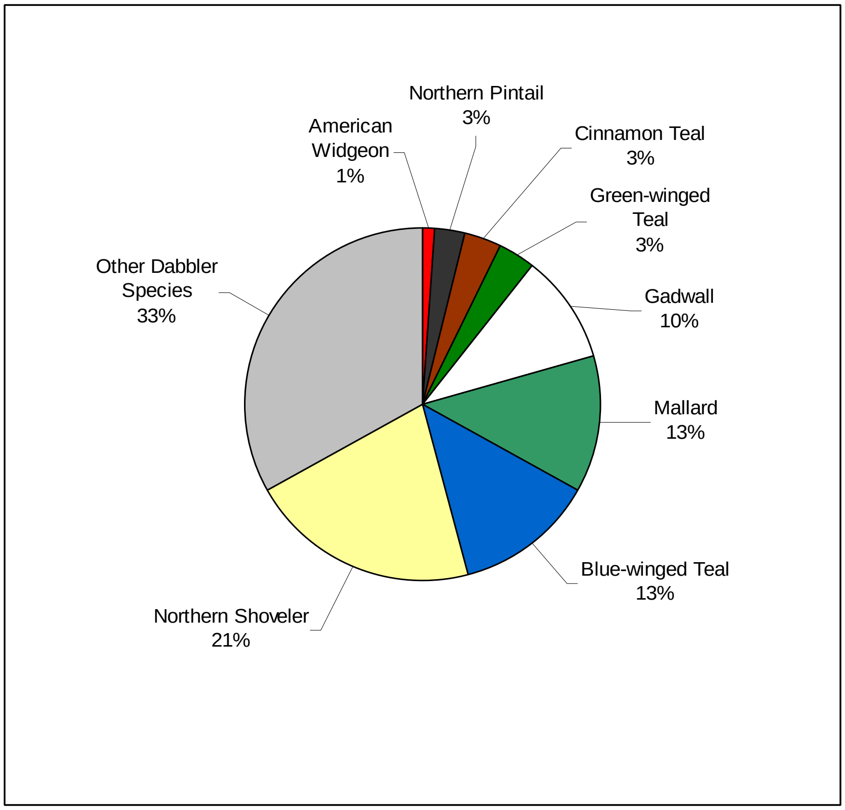

Figure 11. Dabbling duck species composition (in percent) observed at the natural marsh area (LARCO ponds study site), Casper, Wyoming.

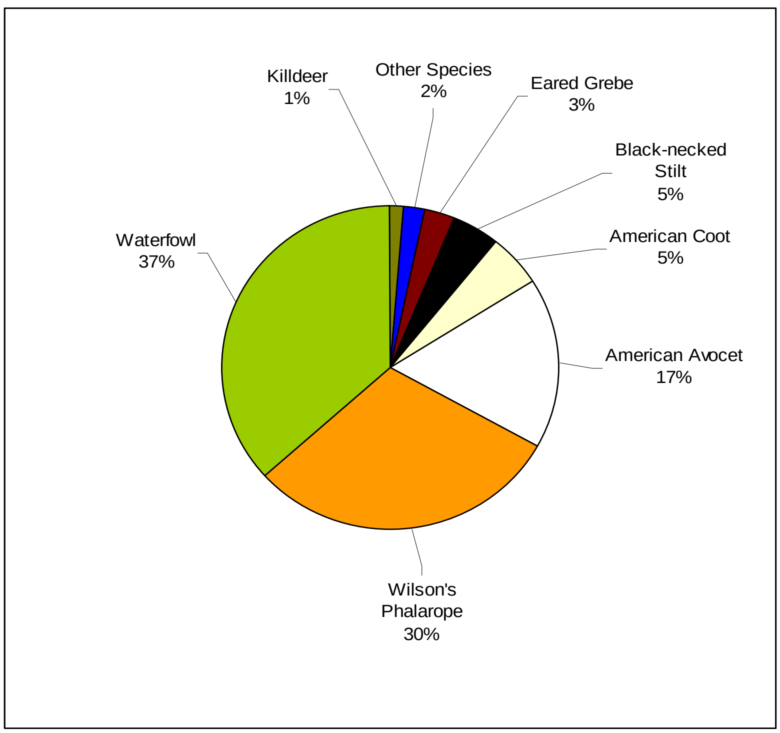

Figure 12. Aquatic bird species composition (in percent) observed at the natural marsh area (LARCO ponds study site), Casper, Wyoming.

Nesting Data

Figure 13 shows the nesting areas for Canada geese, dabbling ducks, American avocets, and black-necked stilts. Canada geese nested on Pond 3's north and south islands and the Natural Marsh. Nesting surveys of Canada geese were not conducted in the Natural Marsh during 2003 and 2004 and were not conducted in Pond 3 during 2004. During 2003, 21 Canada goose nests were observed on the north and south islands in Pond 3 and 25 Canada goose eggs were collected. Of the 25 Canada goose eggs collected, 15 were fertile and 10 were infertile. Of the 15 fertile eggs, one embryo was malpositioned, two were good, and the remaining 12 eggs were rotten.

American avocets created scrape nests on islands and peninsulas, building them in sandy areas or mud flats (Ehrlich 1988). Nest searches in 2003 revealed 14 American avocet nests on the island of Pond 1 and nine nests on Pond 3 (islands and west end of Pond 3). Based on the nesting surveys, it was determined that all 14 nests probably hatched and were probably successful in 2003 in Pond 1. On Pond 3, two avocet nests were documented as successful, three probably hatched and were probably successful, and the fate of four nests was unknown. Seven avocet eggs were collected from the island on Pond 1 in 2003. Six of the seven eggs were fertile and ranged from 8 to 17 days old. Five of the seven embryos were alive. Five American avocet eggs were collected from Pond 3 and were all fertile and alive. In 2004, 12 American avocet nests were observed on the island of Pond 1 and 12 nests were observed on Pond 3 (islands and west end of Pond 3) of which two were successful, 14 were recorded as a possible hatch, and the fate of eight nests was unknown.

Five and six black-necked stilt nests were observed on Pond 3 (islands and west end of Pond 3) in 2003 and 2004, respectively. During 2003 and 2004, four of the stilt nests were probably successful. During 2004, the fate of one stilt nest was unknown and two were destroyed by predation. During 2003, three black-necked stilt eggs were collected from Pond 3. All three of the eggs were fertile.

Twelve avocet and one stilt nest were found on the islands and peninsulas at Russian Olive Pond. Five avocet eggs were collected from the nests and submitted for trace element analysis. American avocet and black-necked stilts appeared abundant in the Natural Marsh, but due to the size of the area and the dense vegetation, it was difficult to locate their cryptic nests. We monitored two nests in the complex, collecting one egg from each nest and submitting them for trace metal analysis. The avocet nest was successful and the stilt nest was a possible hatch.

Other Observations

During sediment collections from the Inlet Pond, Pond 1, Pond 2, and Russian Olive Pond, there was a visible sheen on the water surface when the unused portion of the sample was returned to the water and/or when the bottom was agitated by the Eckman dredge. Additionally, these samples had a strong volatile hydrocarbon odor, lacked vegetation and benthic invertebrates, and were highly reduced, hence their dark color. Wading in the back bay of Pond 1 and in the Russian Olive Pond also caused a sheen on the water surface.

Waterboatmen were the most common aquatic invertebrates in the evaporation ponds and Natural Marsh. Backswimmers were present in lower densities in all three evaporation ponds. Waterboatmen were visible and easily collected with a sweep net in the Natural Marsh. The Natural Marsh required 3 trap nights, plus sweep net collections to obtain adequate samples (71g total). The evaporation ponds required 14 to 18 trap nights per pond, collecting less than half that number of water boatmen

(17g to 27g)(Figure 14). Waterboatmen relative abundance was higher (2X) in the Natural Marsh than in all three evaporation ponds (Figure 15).

Aquatic birds feed on algae and aquatic invertebrates in the ponds. Although aquatic invertebrates were not abundant in the evaporation ponds, the nearby Natural Marsh provided an easily accessible food source for adult birds. The evaporation ponds are highly eutrophic probably due to the presence of ammonia in the process water. The overproduction of algae provides algae-consuming birds with an abundant food source. However, aquatic bird production at the evaporation ponds may be limited by aquatic invertebrate availability to juvenile birds. Submerged aquatic vegetation was absent in the evaporation ponds, but present in the Natural Marsh and other natural ponds in the study area.

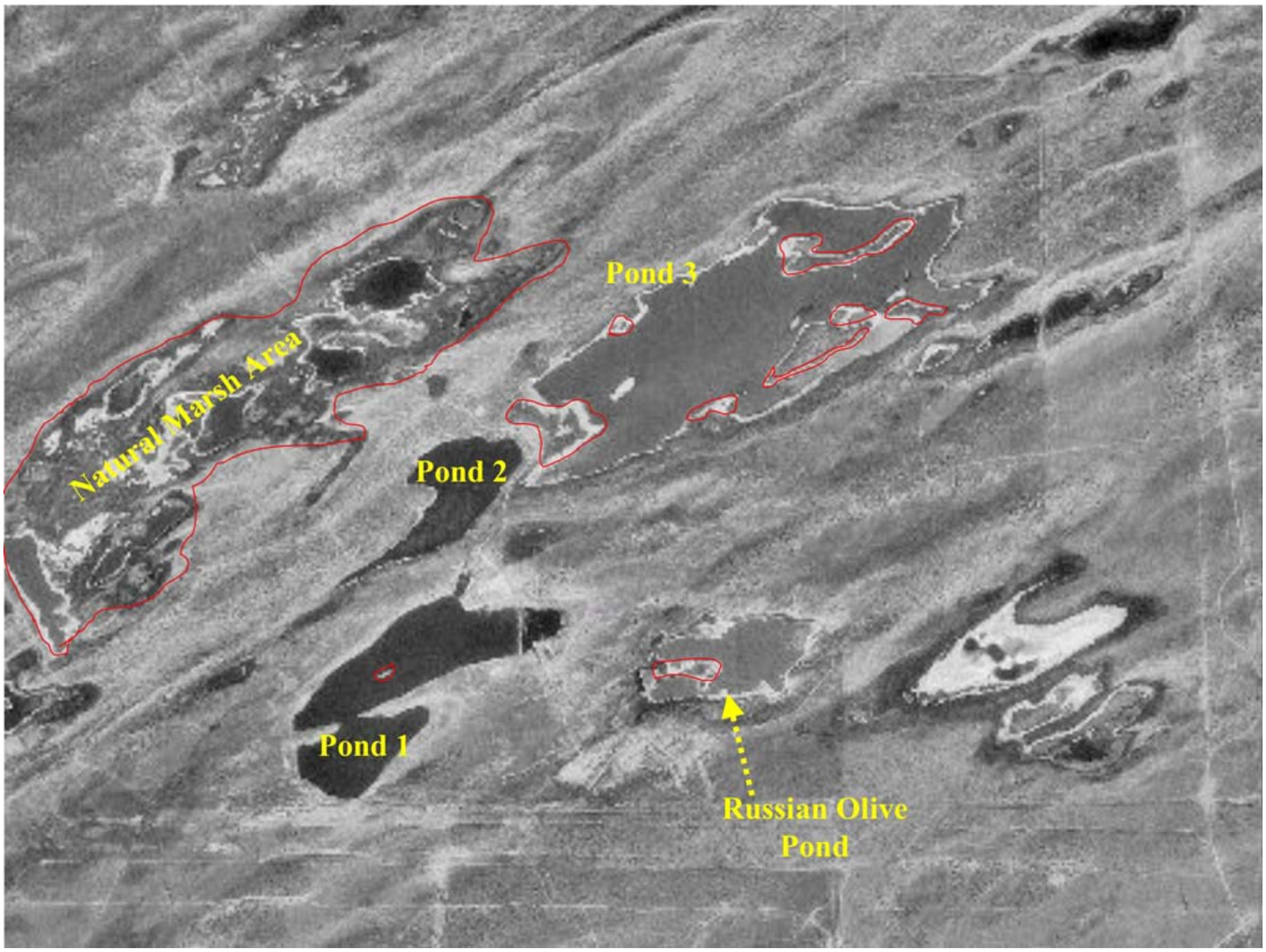

Figure 13. Aquatic migratory bird nesting areas (delineated in red) at the LARCO process water ponds and natural marsh area, Casper, Wyoming.

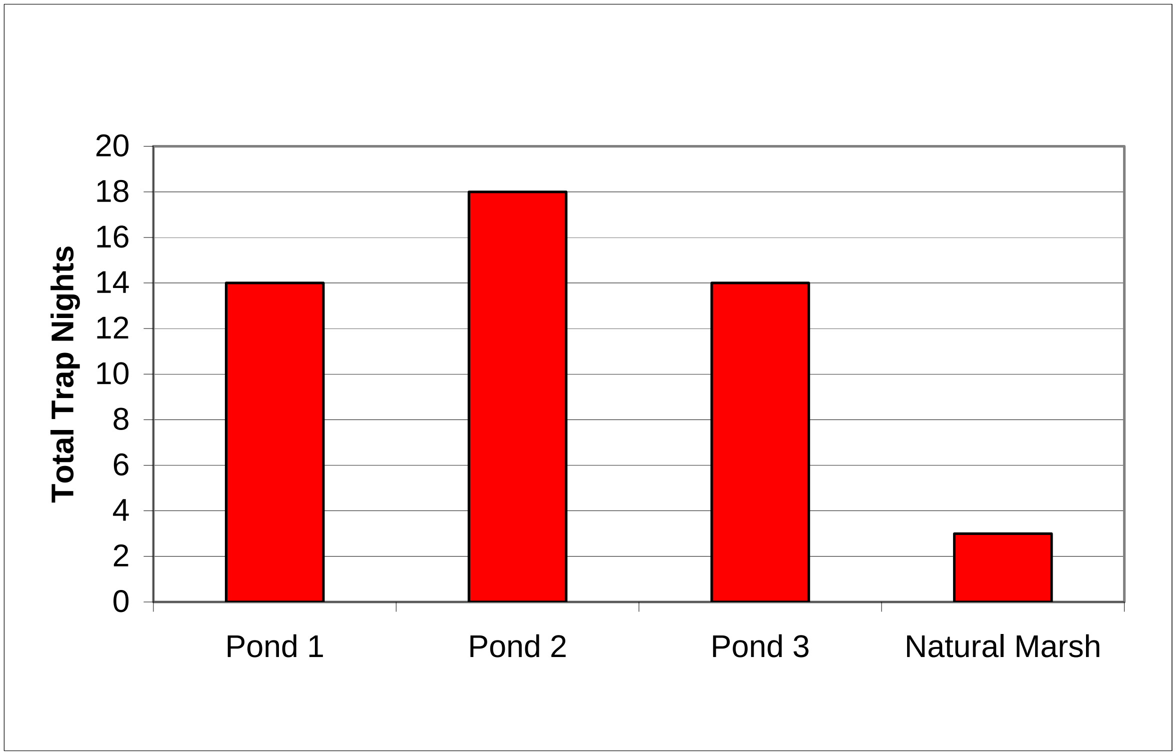

Figure 14. Aquatic invertebrate collection effort (in trap nights) at the LARCO refinery process water ponds, Casper, Wyoming.

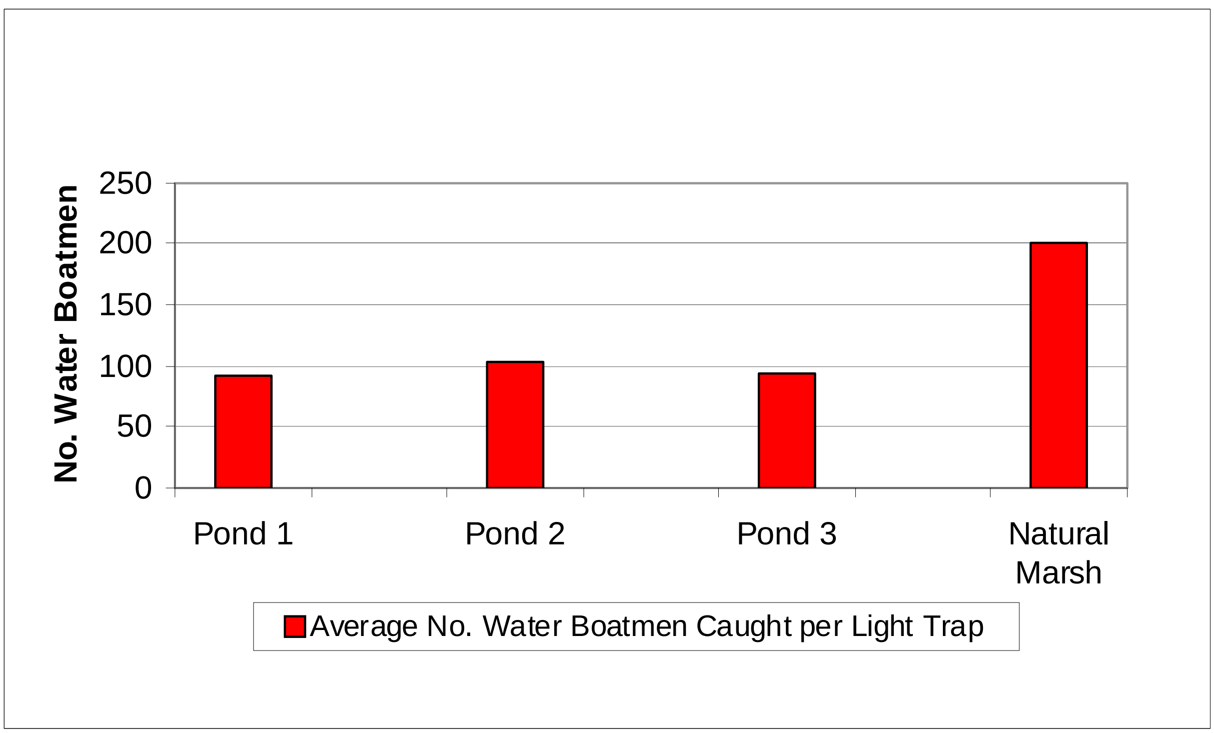

Figure 15. Relative abundance of waterboatmen (Family Corixidae) in the LARCO refinery process water ponds and natural marsh area, Casper, Wyoming.

Wildlife mortality documented at the study area included a pronghorn (*Antilocapra americana*) fawn found partially submerged in Pond 2 on July 15, 2003. The carcass was partially submerged approximately 2 to 3 feet from the shoreline. A necropsy conducted by the Wyoming State Veterinary Laboratory in Laramie, Wyoming diagnosed the cause of death as pneumonia; however, the cause of pneumonia was unknown. A jackrabbit carcass (*Lepus* sp.) was found partially submerged in the south shoreline of Pond 2 on Man 18, 2004. The jackrabbit carcass was too decomposed for necropsy. A male pronghorn carcass was observed near the north shore of Pond 3 on July 15, 2004. The carcass was approximately 30 to 40 feet from the shoreline. No obvious external injuries were observed. The cause of death was unknown.

DISCUSSION

The discharge of refinery process water into the relict dune basins has created a series of ponds that provide habitat for 39 species of aquatic migratory birds. Additional wetland habitat exists to the north and northwest of the process water evaporation ponds; however, it is not clear if this "natural marsh" complex was created by subsurface flow of water from the nearby evaporation ponds. Several aquatic bird species nest at the evaporation ponds and the natural marsh complex. Migrating waterfowl and shorebirds also use the ponds as a stop-over with peak numbers (between 1,000 and 2,000 birds) occurring in mid-September during the fall migration. Approximately 1,600 Northern shovelers were counted on September 27, 2004 on Pond 3. The migrating Northern shovelers feed on the abundant algae on the surface of the eutrophic ponds. Bellrose (1980) states that Northern shovelers "are prone to gather in sizable numbers" on eutrophic sewage lagoons to feed on plankton.

This study documents trace elements in the evaporation ponds typically found in refinery process water: arsenic, cadmium (Cd), chromium, copper, mercury, nickel, lead, selenium, vanadium and zinc. We also found elevated concentrations of arsenic, chromium, copper, mercury, nickel, lead, selenium, and zinc in bottom sediments from the three evaporation ponds. Sediments from the nearby Russian Olive Pond contained elevated concentrations of arsenic, chromium, mercury and nickel. PAHs were also present in high concentrations in sediments from the three evaporation ponds.

Although these trace elements and PAHs are elevated in the bottom sediments, eutrophication is likely limiting the availability of these contaminants to the food chain and aquatic migratory birds. Eutrophication influences the sequestration of metals in sediments (Lithner et. al. 2000). Additionally, eutrophic aquatic systems contain high levels of dissolved organic matter and particulate organic matter which will bind organic and inorganic contaminants, thus resulting in lower dissolved contaminant concentrations in the water (McCarthy and Bartell 1988). Consequently, the highly eutrophic conditions at the three process water evaporation ponds and the Russian Olive Pond have probably resulted in sequestering metals and hydrocarbons in the sediments and reduced the availability of these contaminants to biological organisms using these ponds.

Even though bioavailability is limited by the sequestration in sediments, some trace elements such as selenium are accumulating in the food chain and PAHs are present in algae and aquatic invertebrates. PAH bile metabolites and EROD analysis shows that aquatic birds feeding in the evaporation ponds are exposed to petroleum hydrocarbons; however, it is not known if this exposure is resulting in adverse effects.

Selenium

Selenium is present in crude oil and can range from 500 to 2,200 µg/L (Lemly 2002). Selenium in the crude oil can be transferred to the process water during the refining process. Generally, selenium concentrations in refinery process water can range from 15 to 75 µg/L (Lemly 2002). Although selenium is naturally-occurring and typically associated with marine Cretaceous shale, the evaporation ponds are not located on selenium-bearing formations. Waterborne selenium concentrations in all evaporation ponds, except the terminal pond (Pond 3) exceeded the 2 µg/L threshold which may create a risk for bioaccumulation in sensitive species of aquatic birds (Hamilton 2002). Waterborne selenium concentrations in all other waterbodies sampled were below detection limits. Selenium levels in sediment and algae from the Russian Olive Pond and sediment and aquatic invertebrates from the Natural Marsh were below levels of concern for food chain organisms.

We documented the highest selenium concentration in sediment from Pond 1 (140 µg/g), exceeding the maximum concentration reported in sediment from Goose Lake at the Kendrick irrigation project (43 µg/g) where selenium-induced reproductive impairment and embryonic deformities were documented in American avocets and eared grebes (See et. al. 1992). Golder Associates, Inc. (1991) reported a maximum concentration of 200 µg/g of selenium in sediment from Pond 2. Bottom sediment in Ponds 1 and 2 may be acting as a sink for selenium; hence, the higher concentrations in the sediment from these two ponds. This may also account for the lower selenium levels in water and sediment in the terminal pond (Pond 3).

Algae in Pond 1 is bioaccumulating selenium from the water column as reflected in the significantly higher levels (20 to 30 µg/g) than those in algae from Ponds 2 and 3 (4.2 to 6.5 µg/g). Differences in selenium speciation and the cycling of this element may explain why the algae in Pond 2 did not have higher selenium concentrations given that the mean waterborne selenium was 5.8 µg/L and why algae from Pond 3 had higher selenium concentrations than algae from Pond 2 given that waterborne selenium in Pond 3 was below detection limits. The mean waterborne selenium concentration in Pond 1 was 7.5 µg/L. Differences in the speciation of waterborne selenium may account for the differences as organoselenium bioaccumulates to higher levels than equivalent concentrations of inorganic forms (Lemly 2002). Differences in algal selenium in the three ponds may result from the removal (bioaccumulation) of organic selenium by algae in Pond 1; thus, making less selenium available for bioaccumulation by algae in Ponds 2 and 3. Differences in algal selenium could also be due to a higher rate of selenium cycling in Pond 1 and the presence of the organoselenium. Subtle differences in primary productivity and microbial activity (the rate of production and decomposition of organic matter) and associated transfer of organic selenium from the sediments back into the water in Pond 1 could account for the higher bioaccumulation of selenium in algae from Pond 1. Selenium concentrations in algae from all three refinery process water ponds exceed the 3 µg/g dietary threshold for sensitive species of aquatic migratory birds (Lemly 1993) and exceed the background concentration (<0.5 µg/g) typically found in algae from uncontaminated sites (Ohlendorf 2003). The selenium concentrations are below levels known to affect cell replication and Chlorophyll-a concentrations in algae (Lemly 2002). Aquatic birds, such as Northern shovelers and American coots, that feed on algae were observed in all three ponds but were most numerous in Pond 3.

Mean selenium concentrations (4.2 to 5.6 µg/g) in aquatic invertebrates from all three refinery process water ponds exceed the 3 µg/g dietary threshold for sensitive species of aquatic migratory birds (Lemly 1993). The highest selenium concentrations were found in Daphnia, Dobson flies, and backswimmers. Algae are an important food item for Daphnia (Dodson and Frey 1991); thus, algae are probably the source of selenium for this species. Dobson flies and backswimmers are predatory (Dodson and Frey 1991), feeding on other aquatic invertebrates, and probably are accumulating selenium through their diet. Waterboatmen feed on algae and cyanobacteria and accumulate selenium through their diet (Ohlendorf 2003). The background concentration of selenium in aquatic invertebrates from uncontaminated sites typically averages less than 2 µg/g (Ohlendorf 2003).

Elevated selenium in dietary items such as algae and aquatic invertebrates is resulting in the bioaccumulation of selenium in aquatic birds inhabiting the ponds. American avocets and black-necked stilts feed on waterboatmen and Daphnia (Robinson et. al. 1997 and 1999) and probably ingest small quantities of sediment and algae while foraging in the evaporation ponds. Selenium concentrations in black-necked stilt eggs exceeded the 6 to 7 μg/g threshold reported by Ohlendorf (2003) associated with impaired egg hatchability in black-necked stilts. Selenium concentrations in livers from prefledged juvenile American avocets and blue-winged teal exceeded the 10 μg/g level considered background for avian livers (Ohlendorf 2003). Blue-winged teal ducklings had selenium concentrations above the 15 μg/g level associated with reduced growth in ducklings (Hoffman 2002). Blue-winged teal feed on aquatic invertebrates and algae (Bellrose 1980). Other species of waterfowl, such as widgeon, gadwall, and Northern shoveler, feeding on algae and aquatic invertebrates in the evaporation ponds are probably also bioaccumulating selenium at levels of concern. Selenium bioaccumulation by migrating Northern shovelers feeding in Pond 3 should be assessed to determine if this species is accumulating adverse levels of selenium during their stop-over.

Mercury

Sources of mercury in aquatic systems include atmospheric deposition from natural activities such as volcanism and from industrial sources such as the burning of fossil fuels (Eisler 1987). Mercury can occur in crude oil in small quantities. Shur and Stepp (1993 as cited in Jones and Slotton 1996) reported an average of 0.41 μg/g of mercury in crude oil. Magaw et. al. (2001) analyzed 26 crude oils from various global regions including North America and reported mercury concentrations ranging from below detection levels to a maximum of 1.56 μg/g and an average of 0.06 μg Hg/g of oil. Mercury was detected in one water sample from the Inlet Pond and in one of three water samples from Pond 1 (0.3 μg/L) but was below detection limits in all other waterbodies sampled. Wiener et. al. (2003) report that total mercury in waters "influenced by industrial pollution" range from 0.01 to 0.04 μg/L or 10 to 40 nanograms per liter (ng/L). The detection of mercury in only two water samples could be attributed to sampling contamination in the field or laboratory; however, when evaluated in context with sediment quality, the refinery process water cannot be discounted as a source. If atmospheric deposition of mercury was the sole source, then mercury concentrations in sediment from all the evaporation ponds would be fairly comparable. However, mercury concentrations were higher in sediments from the Inlet Pond, Pond 1 and Pond 2 and were below detection in Pond 3 and the Natural Marsh. Mean total mercury concentrations in sediments from Ponds 1 and 2 were 1 and 2 μg/g, respectively, and one sediment sample from the Inlet Pond had 3 μg/g total mercury. Golder Associates, Inc. (1991) reported mercury concentrations in sediments from Ponds 1 and 2 ranging from 1.13 to 6.34 μg/g. These mercury concentrations are at or above the 1 μg/g level considered "heavily polluted" (Baudo and Muntau 1990). Mercury is cycling through the food chain as evidenced by concentrations in algae and aquatic invertebrates from the evaporation ponds; however, bioaccumulation of mercury to adverse levels was not observed in aquatic bird livers and eggs.

Other Trace Elements

Arsenic, chromium, copper, and zinc concentrations in sediments from Ponds 1 and 2 exceeded levels above which biological effects are likely to occur (Ingersoll and MacDonald 2002). The mean arsenic concentration (13.7 μg/g) in sediment from Pond 1 was higher than the 7 μg/g concentration reported by Golder Associates, Inc. (1991). Chromium, mercury and lead concentrations in sediment for Ponds 1, 2, and 3 reported by Golder Associates, Inc. (1991) were higher than the levels found in this study. Chromium in sediments from the Russian Olive Pond also exceeded above which biological effects are likely to occur (Ingersoll and MacDonald 2002). Although these trace elements were elevated in sediments, they were below detection limits in bird eggs and in liver samples from prefledged juvenile birds. Sequestration of these metals in the sediments probably limits their availability in the food chain.

PAHs

Petroleum hydrocarbon concentrations in sediments were highest in Pond 1 followed by Pond 2. All sediment samples collected from the Inlet Pond, Pond 1 and Pond 2 exceeded the upper effects levels as defined by Buchman (1999) for several aromatic hydrocarbons. In Pond 3, benzo(a)pyrene, chrysene, phenanthrene, and pyrene exceeded the threshold effects level as defined by Buchman (1999) in three of the five sediment samples. All sediment samples collected from the Russian Olive Pond exceeded the upper effects levels as defined by Buchman (1999) for aromatic hydrocarbons. Aromatic hydrocarbons were also detected in algae, waterboatmen, and Daphnia collected from the three process water evaporation ponds; however, effects on the food chain are unknown.

Perturbation of the bottom sediments in the Inlet Pond, Ponds 1 and 2, and the Russian Olive Pond resulted in the release of hydrocarbons and a visible sheen on the water surface. It is possible that shorebirds feeding and wading in these ponds could disturb the contaminated sediments and release minute quantities of hydrocarbons onto the water surface. Feeding and wading birds could then ingest or come into contact with these hydrocarbons.

Eutrophication

Eutrophication is typically caused by excessive nutrients in water (Harper 1992). Ammonia in the process water is more than likely the chief contributor of nutrients and eutrophication in the evaporation ponds. Maximum daily ammonia (NH_3) concentrations in the process water discharged from the ABTU ranged from 7 to 39 µg/L in 2003 (LARCO ABTU Monthly Reports to WDEQ).

Inorganic and organic contaminant levels in evaporation pond sediments as well as eutrophication probably account for the paucity of water column aquatic invertebrates and the lack of benthic invertebrates. Eutrophication has resulted in the deposition of large quantities of organic matter (primarily dead algae) onto the bottom sediment. Sediments are highly reduced and anoxic in the three ponds and the Russian Olive Pond.

Cyanobacteria

Cyanobacteria are organisms with characteristics of bacteria and algae and are also termed "blue-green algae." According to information provided by Steve Pate, Environmental Coordinator, LARCO Refinery, (personal communications, May 2003), algal species identified in plankton surveys conducted in July and August 1997 included the following genera: *Scendesmus, Selenestrum, Chloroccoccum, Oscillatoria (Planktothrix) and Actinastrum*. Of these genera, *Planktothrix* is classified as cyanobacteria and the species *Planktothrix agardhi* identified in Ponds 2 and 3 can produce hepatotoxic microcystins (Tonk et. al. 2005). Microcystins can cause liver damage (Tonk et. al. 2005) and have been implicated in aquatic bird mortalities in the United States (Carmichael and Li 2006, Creekmore 1999). Many species of cyanobacteria form gas-filled cavities that allow vertical movement through the water column to attain ligh for photosynthesis. Cyanobacteria blooms become quite dense and acquire a "gelatinous consistency" (WHO 2003).

These blooms form scums on the water surface and get pushed by the prevailing winds to the leeward shores. Bacterial decomposition of this scum causes rapid putrefaction. These inshore deposits of decomposing scum can be quite toxic. A pronghorn fawn carcass recovered from the edge of Pond 2 was diagnosed with pneumonia as the probable cause of death. Pneumonia is one illness attributable to the inhalation or aspiration of the microcystin toxin (WHO 2003).

MANAGEMENT RECOMMENDATIONS

Refinery process water is contributing trace elements, metals, and petroleum hydrocarbons into a series of evaporation ponds which are providing habitat and are used extensively by migratory aquatic birds. However, the eutrophic nature of these ponds is precluding the establishment of macrophytic aquatic vegetation and is limiting the density and diversity of aquatic invertebrates, both dietary items consumed by aquatic migratory birds. The contribution of organic matter onto the surficial sediments is limiting the bioavailability of trace elements and petroleum hydrocarbons as these contaminants are strongly bound to the organic matter within the sediment. Sequestration of these contaminants is not all encompassing as some food chain transfer of selenium and petroleum hydrocarbons is occurring. Although eutrophication is limiting the availability of chemical contaminants in the food chain, the potential exists for the presence of cyanotoxins produced by cyanobacteria in the evaporation ponds. Refinery environmental management staff should consider the following recommendations to minimize or prevent adverse impacts to aquatic migratory birds and other wildlife inhabiting the LARCO process water evaporation ponds and adjacent habitats.

- Monitor the process water evaporation ponds for large-scale aquatic migratory bird die-offs. Algal blooms in the evaporation ponds could result in the presence of cyanotoxins, such as microcystins, and the potential for waterfowl mortality. Periodic monitoring should especially be conducted during the fall migration (after August) when peak numbers of waterfowl occur at the evaporation ponds. Aquatic bird die-offs should be reported to the Service so that the agency can determine the cause of death.

- Identify cyanobacteria present in scum accumulated along the shorelines of the ponds and periodically assess the algal blooms for the presence of cyanotoxins.

- Conduct hydrological studies to determine if subsurface flows from the evaporation ponds are contributing water and contaminants to the adjacent Natural Marsh area and the Russian Olive Pond.

- Remediate oil-contaminated soils along the shoreline of the Russian Olive Pond and between Ponds 2 and 3 to prevent chronic oiling of the ponds.

- Evaluate the use of constructed wetlands to treat the process water and reduce contaminants prior to discharge into the evaporation ponds.

- Assess remediation options for contaminated sediments in the evaporation ponds.

The LARCO process water ponds and the surrounding upland area have become a haven for migratory aquatic birds as well as terrestrial wildlife such as pronghorn and mule deer. Water and sediment quality in the pond complex could be improved by using constructed wetlands. Contaminated sediments could be remediated in stages by bypassing the discharge from one pond to another and allowing the targeted pond to dry. For example, water from the constructed wetland would bypass Pond 1 and flow directly to Pond 2; thus, allowing Pond 1 to dry for sediment remediation. After sediment remediation, water would be allowed back into Pond 1 but flows would then bypass Pond 2 so that Pond 2 could dry up. The same scenario would then be applied to Pond 3 for sediment remediation. Remediation of contaminated sediments and reduction of nutrients into these ponds would result in improvement in wetland habitat quality, establishment of submergent and emergent aquatic vegetation, a potential increase in the diversity and density of aquatic invertebrates, and better habitat for aquatic migratory birds. The ideal situation would result in meeting the needs of the LARCO refinery for discharge of process water and clean, high quality wetlands for migratory birds attracted to these ponds created by the refinery discharge.

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APPENDIX
(Data Tables)

Appendix - Table A 1. GPS coordinates (in decimal degrees) of sediment sampling locations at the LARCO Refinery process water evaporation ponds.

Natural Marsh		
Sample #	**Lat-DD**	**Long-DD**
LARCONM1	42.887167	-106.267250
LARCONM2	42.886778	-106.268500
LARCONM3	42.885417	-106.271861
LARCONM4	42.885056	-106.273083
LARCONM5	42.884472	-106.272889

Pond 2		
Sample #	**Lat-DD**	**Long-DD**
LARCOP2A	42.885222	-106.265083
LARCOP2B	42.884211	-106.266333
LARCOP2C	42.884500	-106.266056
LARCOP2D	42.884667	-106.266861
LARCOP2E	42.884167	-106.267139

Pond 1		
Sample #	**Lat-DD**	**Long-DD**
LARCOP1A	42.882861	-106.265167
LARCOP1B	42.882556	-106.266028
LARCOP1C	42.882472	-106.265917
LARCOP1D	42.881417	-106.269222
LARCOP1E	42.880444	-106.268722

Pond 3		
Sample #	**Lat-DD**	**Long-DD**
LARCOP3A	42.886278	-106.264583
LARCOP3B	42.888806	-106.260111
LARCOP3C	42.889111	-106.255444
LARCOP3D	42.887333	-106.260694
LARCOP3E	42.887944	-106.260444

Inlet Pond		
Sample #	**Lat-DD**	**Long-DD**
LARCOIPA	42.882889	-106.264500

LARCO Russian Olive Pond		
Sample #	**Lat-DD**	**Long-DD**
LARROP01	42.9661111	-106.2591667
LARROP03	42.88250000	-106.2608333
LARROP04	42.8816667	-106.2594444
LARROP05	42.8816667	-106.2600000
LARROP06	42.8816667	-106.2619444

Appendix - Table A 2. Basic chemistry of water collected from the LARCO refinery process water ponds, Casper, Wyoming.

Sample ID	pH	E.C. umhos/cm	Ca	Mg	Ka
Inlet Pond	7.3	1450	63.5	31.8	220
Pond 1	9.1	3280	95.7	54	572
Pond 2	8.9	3670	108.2	61.3	658
Pond 3	9.7	21800	373	200.1	4097

Sample ID	K	B	CO3	HCO3	SO4
Inlet Pond	10.6	0.3	<0.1	256.2	296
Pond 1	22.2	0.5	<0.1	226.9	830
Pond 2	24.9	0.6	<0.1	101.3	846
Pond 3	162	2.4	34.8	239.1	5140

Sample ID	Cl	Nitrates NO_3	Nitrate Nitrogen NO_3-N	Hardness as $CaCO_3$	Alkalinity as CaCO3
Inlet Pond	185	<0.1	<0.1	289	210
Pond 1	485	<0.1	<0.1	461	186
Pond 2	715	<0.1	<0.1	461	83
Pond 3	3690	<0.1	<0.1	1753	254

Sample ID	Total Dissolved Solids	Ammonia NH_4	Ammonium Nitrate NH_4-N
Inlet Pond	1063	33.5	26.2
Pond 1	1565	17.9	14
Pond 2	2515	7.4	5.8
Pond 3	13939	0.2	0.2

Appendix - Table A 3. Trace element concentrations (in μg/L) in water from the LARCO refinery process water ponds, the natural marsh reference site, and nearby ponds, Casper, Wyoming.

Sample ID	Collection Date	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Inlet Pond																				
LARCOWIA	14-May-03	92.3	15.9	365	68.9	<0.6	0.6	2.6	19.2	1420	0.3	44500	86.3	252	6	<5.6	61	990	8.9	47.1
Pond 1																				
LARCOW1A	14-May-03	34.4	14.3	497	73.6	<0.6	0.7	2.6	12.8	754	<0.1	48700	96.7	195	5.7	<5.6	10.6	1110	6	32.6
LARCOW1B	10-Jul-03	11.2	16.6	486	80.2	<0.6	0.6	2.8	3.7	416	0.3	50300	102	144	4.6	<5.6	5.2	1210	4.5	57.4
LARCOW1C	5-Sep-03	<5.6	18.7	628	84.8	<0.6	0.7	2.2	4.3	154	<0.1	63300	145	128	5.7	<5.6	6.8	1510	2.3	27
Pond 2																				
LARCOW2A	14-May-03	20.6	17.2	519	75	<0.6	0.6	2.1	8.4	513	<0.1	50200	111	148	5	<5.6	9	1140	4.3	54.8
LARCOW2B	10-Jul-03	7.4	17.2	591	88.9	<0.6	0.6	2.2	2.3	296	<0.1	59300	112	116	4.3	<5.6	5	1350	2.5	54.9
LARCOW2C	5-Sep-03	<5.6	16.8	664	99.8	<0.6	0.6	1.6	2.4	160	<0.1	68000	141	101	5.8	<5.6	3.5	1590	1.6	58.5
Pond 3																				
LARCOW3A	14-May-03	<5.6	55.6	2360	73.4	<0.6	2.1	1.4	3	259	<0.1	342000	790	125	8.7	<5.6	<2.2	8210	5.7	66.3
LARCOW3B	10-Jul-03	<5.6	55.6	2470	73.2	<0.6	1.7	1.1	1.9	54.5	<0.1	352000	109	125	7.4	<5.6	<2.2	8510	2.4	67.3
LARCOW3C	5-Sep-03	<5.6	68.2	3180	106	<0.6	1.7	1.4	3.1	127	<0.1	439000	600	101	7.5	<5.6	<2.2	10300	<1.1	74.7
Natural Marsh																				
LARCOWR1	14-May-03	17	60.8	1020	30.3	<0.6	1.5	1.6	2.7	290	<0.1	366000	780	<1.1	12.9	<5.6	<2.2	7520	1.4	60.1
LARCOWR2	31-Jul-03	<5.6	78.8	1840	44.5	<0.6	1.7	1.7	1.6	68.4	<0.1	633000	624	<1.1	11.6	<5.6	<2.2	11700	<1.1	80.8
LARCOWR3	5-Sep-03	<5.6	38.3	2570	65.9	<0.6	1.9	2.7	1.3	76.7	<0.1	922000	1160	<1.1	12.7	<5.6	<2.2	17500	<1.1	106
Russian Olive Pond																				
LARCOWO2	5-Sep-03	9.1	116	4090	178	<0.6	1.2	2.3	1.3	117	<0.1	585000	151	3.5	27.6	<5.6	<2.2	7030	7.7	75.6
Windmill Pond																				
LARCOWMB	5-Sep-03	<5.6	<2.2	542	42.5	<0.6	0.9	<1.1	<1.1	153	<0.1	185000	46	<1.1	3.7	<5.6	<2.2	8400	<1.1	36
Pasture Pond																				
LARCOWP2	5-Sep-03	<5.6	<2.2	2170	16.5	<0.6	1.6	1.6	1.2	169	<0.1	751000	762	<1.1	6.4	<5.6	<2.2	12900	<1.1	77.4

Appendix - Table A 4. Trace element concentrations (in µg/g) in sediment collected in 2003 from the LARCO refinery process water ponds and natural marsh reference site, Casper, Wyoming.

Site	Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Inlet Pond																				
	LARCOIPA	5830	15	10	160	0.3	0.84	62	221	10600	3	2310	81	78	20	31	40	87	37	734
Pond 1																				
	LARCOP1A	6490	8.4	10	127	0.3	0.4	340	69	8420	1.1	2780	100	62	10	36	20	93	28	254
	LARCOP1B	2780	4.4	20	182	0.2	0.4	1490	67	11300	0.75	15300	170	<5.00	7	32	2.2	562	4.4	203
	LARCOP1C	11200	9.8	33	268	0.5	1.1	3920	121	11300	2.7	18700	247	22	19	76	25	776	34	1300
	LARCOP1D	11700	38	36	236	0.5	0.81	231	258	36500	3.9	5430	180	270	42	56	140	141	84	1810
	LARCOP1E	9150	14	20	175	0.4	0.91	791	92	13000	2	4120	120	150	28	74	59	233	51	855
Pond 2																				
	LARCOP2A	6020	11	10	130	0.3	0.4	331	53	10300	0.87	2950	85	89	24	46	40	76	38	515
	LARCOP2B	4380	14	20	117	0.3	0.2	768	66	11500	1.2	2650	110	74	22	49	53	98	31	653
	LARCOP2C	7380	12	20	121	0.3	0.2	219	57	13200	0.84	2660	87	65	22	39	40	68	41	598
	LARCOP2D	4860	3.2	10	55.1	<.200	0.3	92	9.9	4910	0.2	1570	41	17	7	10	8.1	27	19	74
	LARCOP2E	7330	19	20	174	0.4	0.62	1680	89	13100	2.1	3580	130	83	33	64	65	101	45	875
Pond 3																				
	LARCOP3A	7870	2.7	30	104	0.3	0.3	23	6.8	6650	<.100	4130	180	10	8	28	3.7	122	25	40
	LARCOP3B	8720	8.9	80	193	0.4	0.7	48	21	7680	0.3	8120	532	51	24	36	21	626	39	150
	LARCOP3C	6140	9.8	33	126	0.3	0.61	24	8.2	6160	<.100	9740	1370	6	16	34	8.1	2370	25	40
	LARCOP3D	3130	4.8	10	38	<.200	0.2	6	3	3200	<.100	1870	120	6	<5.00	10	0.6	191	10	14
	LARCOP3E	1980	4.1	<10.0	16	<.200	0.3	3.1	2	2470	<.100	930	71	6	<5.00	7	0.7	64	6.2	7.5
Natural Marsh																				
	LARCONM1	3490	8.1	20	70	<.200	0.5	5.2	3.8	4030	<.100	7460	1450	<5.00	10	24	<.600	1160	12	17
	LARCONM2	2930	7	10	43	<.200	0.3	4.4	3	2770	<.100	3410	723	<5.00	9	19	0.7	630	11	10
	LARCONM3	4840	16	20	104	<.200	0.73	6.7	6.2	5150	<.100	10200	2810	<5.00	33	28	1	1910	28	20
	LARCONM4	5660	16	39	114	0.2	0.6	7.9	9.4	5680	<.100	15100	2490	<5.00	35	28	0.8	2240	34	26
	LARCONM5	3430	5.6	<10.0	48	<.200	0.4	4.6	3	3860	<.100	2890	1190	<5.00	25	19	<.600	366	14	12
	Background	5.80%	5.5	23	580	0.68		41	21	2.10%	0.046	0.74%	380	0.85	15	17	0.23	200	70	55
	TEC		9.79				0.99	43.4	31.6		0.18				22.7	35.8				121
	PEC		33				4.98	111	149		1.06				48.6	128				459

TEC = threshold effects concentration (level below which adverse biological effects are likely to occur)

PEC = probable effects concentration (level above which adverse biological effects are likely to occur)

Appendix - Table A 5. Total organic carbon and trace element concentrations (in µg/g) in sediment collected in 2004 from the LARCO refinery process water ponds, Casper, Wyoming.

Sample #	Total Organic Carbon	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Pond 1																				
4LP1S01	14.8	8190	9.2	20	142	0.3	0.2	279	55	7770	1.2	2410	58	100	18	37	32	51	42	406
4LP1S02	28.5	7300	12	10	256	0.4	0.5	1630	101	7910	3.9	3100	85	95	23	73	80	185	58	967
Pond 2																				
4LP2S01	0.2	2690	1	<10	37	<0.2	<0.2	7	2	2060	<0.1	590	25	<5	<5	5	2	15	6	7.5
4LP2S02	2.6	3430	2.3	20	38	<0.2	<0.2	106	10	3500	0.2	970	30	10	<5	9	7.7	23	14	67
Pond 3																				
4LP3S01	5.5	5980	3.5	30	96	0.3	0.4	28	8.4	5860	0.1	3020	256	10	10	17	4.4	179	28	46
4LP3S02	16.6	8740	7.8	61	179	0.4	0.2	57	18	7800	0.48	5720	399	48	20	28	17	419	40	130
	Background	5.80%	5.5	23	580	0.68		41	21	2.10%	0.046	0.74%	380	0.85	15	17	0.23	200	70	55
	TEC		9.79				0.99	43.4	31.6		0.18				22.7	35.8				121
	PEC		33				4.98	111	149		1.06				48.6	128				459

TEC = threshold effects concentration (level below which adverse biological effects are likely to occur

PEC = probable effects concentration (level above which adverse biological effects are likely to occur

Appendix - Table A 6. Polycyclic aromatic hydrocarbons (in µg/g) in sediment from the LARCO refinery process water ponds, Casper, Wyoming.

	Inlet Pond	*Pond 1*				
Aromatics	**Sample 1**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
1,6,7-Trimethyl-naphthalene	21.8	3.04	69.9	40	11.6	24.7
1-methylnaphthalene	7.63	5.14	249	70.1	5.15	9.24
1-methylphenanthrene	22.8	17.5	306	40	18.7	39.1
2,6-dimethylnaphthalene	28.5	19.2	532	149	23.3	43.1
2-methylnaphthalene	6.74	2.27	551	67.3	6.27	5.59
acenaphthalene	0.554	0.2	4.42	2.32	0.128	0.306
acenaphthene	1.12	0.7	22.8	5.15	0.569	2.22
anthracene	1.33	2.56	82.7	1.73	2.71	3.86
benzo(a)pyrene	3.54	3.54	12.6	1.17	3.99	1.16
benzo(b)fluoranthene	1.88	1.66	5.68	0.713	2.35	0.943
benzo(e)pyrene	8.11	7.07	12	1.77	7.35	2.52
benzo(g,h,i)perylene	2.25	2.09	3.67	0.615	2.17	0.678
benzo(k)fluoranthene	0.311	0.348	1.09	0.13	0.619	0.228
biphenyl	1.3	0.359	11.3	6	0.843	1.22
C1-chrysenes	37.2	34.5	200	16.9	42.9	23.8
C1-dibenzothiophenes	50.4	32.4	290	142	44.1	110
C1-Fluoranthenes & Pyrenes	48.4	55.6	596	31.8	57.9	44.7
C1-fluorenes	37.9	19.9	360	81.8	31.1	55.8
C1-naphthalenes	14.4	7.41	800	137	11.4	14.8
C1-Phenanthrenes & Anthracenes	97.2	113	2456	185	97.9	211
C2-chrysenes	34.8	27	99.1	12.4	42.6	17.7
C2-dibenzothiophenes	68.6	39.6	276	153	72.2	165
C2-fluorenes	54.5	28.2	449	109	61.2	94
C2-naphthalenes	65.9	35.6	875	332	47.1	109
C2-Phenanthrenes & Anthracenes	124	115	1758	185	136	251
C3-chrysenes	22.9	17.6	28.2	5.83	24.5	8.57
C3-dibenzothiophenes	59.3	35.2	162	98.1	63.5	119
C3-fluorenes	47.1	32.7	325	79.9	67.4	94.3
C3-naphthalenes	128	41.8	623	410	107	229
C3-Phenanthrenes & Anthracenes	78.1	73.2	670	102	110	140
C4-chrysenes	2.53	1.52	0.901	0.522	2.32	0.716
C4-naphthalenes	108	34.9	286	267	134	236
C4-Phenanthrenes & Anthracenes	52.7	38.1	215	41.6	58.2	56.8
chrysene	13.4	13.5	83.4	8.03	17.6	10.5
dibenzothiophene	16.1	9.3	113	51.7	11.2	40.5
fluoranthene	1.9	4.33	58.6	3.05	3.36	3.97
fluorene	8.05	3.41	112	21.9	3.32	7.44
indeno(1,2,3-cd)pyrene	0.61	0.602	0.761	0.165	0.705	0.237
naphthalene	0.849	0.779	79	6.75	1.24	0.912
perylene	1.43	1	2.24	<.310	1.46	<.354
phenanthrene	32.1	64.5	1119	88.4	30.6	66.5
pyrene	16.5	26	380	17.3	23.8	22.8
Benzo(a)anthracene	3.17	5.26	58	3.13	6.09	3.04
Dibenz(a,h)anthracene	0.966	0.634	0.883	0.158	0.762	0.209
Total PAHs	1334.87	978.222	14340.245	2977.433	1397.206	2272.159

Appendix -Table A 6 (continued). Polycyclic aromatic hydrocarbons (in µg/g) in sediment from the LARCO refinery process water ponds, Casper, Wyoming.

	Pond 2				
Aromatics	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
1,6,7-Trimethyl-naphthalene	20.4	25	22.9	11.7	9.39
1-methylnaphthalene	30.7	14.1	28.2	7.36	14.2
1-methylphenanthrene	56.2	53.9	59.1	20.3	19.2
2,6-dimethylnaphthalene	83.2	68.4	87.1	20	25.1
2-methylnaphthalene	53.6	16.4	46.3	0.325	24.2
acenaphthalene	0.866	0.894	0.395	0.274	0.32
acenaphthene	4.8	3.37	4.5	0.841	1.31
anthracene	7.24	6.12	7.04	3.34	1.3
benzo(a)pyrene	7.26	7.06	6.03	2.68	0.798
benzo(b)fluoranthene	4.22	3.78	3.85	1.7	0.687
benzo(e)pyrene	9.55	10.9	9.21	3.94	1.96
benzo(g,h,i)perylene	3.43	3.13	2.99	1.71	0.599
benzo(k)fluoranthene	0.867	0.896	0.857	0.243	0.151
biphenyl	1.88	1.2	2.11	0.415	0.831
C1-chrysenes	80.8	77.2	78.9	33.6	16.6
C1-dibenzothiophenes	81.7	141	102	42.3	60.2
C1-Fluoranthenes & Pyrenes	164	135	160	67.6	26.3
C1-fluorenes	80.2	73.9	85.7	31	26.6
C1-naphthalenes	84.3	30.5	74.5	7.68	38.4
C1-Phenanthrenes & Anthracenes	424	325	456	118	87.1
C2-chrysenes	53.3	47.3	48.9	25.5	10.7
C2-dibenzothiophenes	114	194	126	63.4	71.6
C2-fluorenes	108	116	114	57.8	38.3
C2-naphthalenes	172	154	184	48.2	57.8
C2-Phenanthrenes & Anthracenes	397	321	360	150	101
C3-chrysenes	19	23.7	21.4	9.5	5.43
C3-dibenzothiophenes	89.8	145	108	49.8	59.1
C3-fluorenes	112	112	100	56.7	46.1
C3-naphthalenes	197	249	221	92.5	109
C3-Phenanthrenes & Anthracenes	189	202	210	82.6	69.5
C4-chrysenes	1.06	1.86	1.02	0.541	0.36
C4-naphthalenes	160	212	176	75	113
C4-Phenanthrenes & Anthracenes	74	89.5	83	38.8	28.8
chrysene	37.5	29.4	31.7	16.5	6.03
dibenzothiophene	28.9	45.3	29.2	14.2	16.9
fluoranthene	14.5	10.4	13.4	4.28	2.07
fluorene	22.5	14.6	22.5	6.24	5.26
indeno(1,2,3-cd)pyrene	0.832	0.796	0.753	0.327	0.15
naphthalene	4.5	1.97	4.84	0.254	8.9
perylene	1.24	1.17	1.11	0.472	<.214
phenanthrene	252	110	192	40.9	37.3
pyrene	92.7	79.1	103	39.7	12
Benzo(a)anthracene	17.8	14.1	13.6	6.79	1.78
Dibenz(a,h)anthracene	0.664	0.666	0.591	0.268	0.13
Total PAHs	3358.509	3172.612	3403.696	1255.28	1156.456

Appendix -Table A 6 (continued). Polycyclic aromatic hydrocarbons and total petroleum hydrocarbons (TPH) (in µg/g) in sediment from the LARCO refinery process water ponds, Casper, Wyoming.

	Pond 3				
Aromatics	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
1,6,7-Trimethyl-naphthalene	0.0298	0.0308	0.0448	0.005	0.0032
1-methylnaphthalene	0.0242	0.0471	0.0275	0.0091	0.006
1-methylphenanthrene	0.0754	0.308	0.118	0.0234	0.033
2,6-dimethylnaphthalene	0.0647	2.29	0.466	0.445	0.0275
2-methylnaphthalene	0.0427	0.0467	0.04	0.0124	0.0114
acenaphthalene	0.0029	0.005	0.0042	<.00116	<.00136
acenaphthene	0.0049	0.0189	0.0118	<.000796	<.000929
anthracene	0.0452	0.0899	0.0428	0.0098	0.0027
benzo(a)pyrene	0.0388	0.0459	0.0404	0.0088	0.004
benzo(b)fluoranthene	0.0439	0.0809	0.0509	0.0123	0.0049
benzo(e)pyrene	0.104	0.208	0.115	0.0311	0.0094
benzo(g,h,i)perylene	0.0537	0.0697	0.046	0.0126	0.0054
benzo(k)fluoranthene	0.0113	0.017	0.0132	0.0037	<.00164
biphenyl	0.007	0.0442	0.0319	0.0094	0.0022
C1-chrysenes	0.339	1.12	0.508	0.104	0.0262
C1-dibenzothiophenes	0.165	0.888	0.656	0.0403	0.0223
C1-Fluoranthenes & Pyrenes	0.411	1.63	0.679	0.13	0.0427
C1-fluorenes	0.106	0.267	0.13	<.00239	0.0112
C1-naphthalenes	0.0669	0.0938	0.0675	0.0215	0.0174
C1-Phenanthrenes & Anthracenes	0.523	1.11	0.539	0.0964	0.0699
C2-chrysenes	0.195	0.702	0.316	0.0762	0.0212
C2-dibenzothiophenes	0.364	2.31	1.35	0.0796	0.0414
C2-fluorenes	0.22	0.687	0.255	<.00239	0.0255
C2-naphthalenes	0.139	2	0.79	0.362	0.0312
C2-Phenanthrenes & Anthracenes	1.07	3.18	1.44	0.123	0.0409
C3-chrysenes	0.107	0.371	0.16	0.0381	<.00250
C3-dibenzothiophenes	0.346	2.07	0.784	0.0983	0.0366
C3-fluorenes	0.3	1.1	0.573	<.00239	0.0154
C3-naphthalenes	0.224	0.994	0.539	0.0615	0.047
C3-Phenanthrenes & Anthracenes	0.519	2.87	0.925	0.188	0.0404
C4-chrysenes	0.0263	0.045	0.026	<.00214	<.00250
C4-naphthalenes	0.263	1.41	0.674	0.0518	0.0212
C4-Phenanthrenes & Anthracenes	0.241	1.55	0.469	0.103	0.0215
chrysene	0.124	0.515	0.255	0.0548	0.0173
dibenzothiophene	0.0627	0.183	0.215	0.0135	0.0071
fluoranthene	0.0714	0.113	0.0626	0.0139	0.006
fluorene	0.0147	0.0346	0.0236	0.0038	0.0037
indeno(1,2,3-cd)pyrene	0.0234	0.022	0.0196	0.006	0.0028
naphthalene	0.022	0.0332	0.0325	0.0146	0.0089
perylene	<.00896	0.0104	<.0101	<.00845	<.00986
phenanthrene	0.223	0.24	0.208	0.0318	0.0282
pyrene	0.271	1	0.407	0.0799	0.0282
Benzo(a)anthracene	0.0528	0.108	0.0566	0.0085	0.0042
Dibenz(a,h)anthracene	0.0107	0.0111	0.0099	0.0029	0.0011
Total PAHs	7.0494	29.9702	13.2228	2.386	0.7492

Appendix - Table A 7. Aliphatic hydrocarbons (in µg/g) in sediment from the LARCO refinery process water ponds, Casper, Wyoming.

	Inlet Pond	*Pond 1*					*Pond 2*					*Pond 3*				
Aliphatics	**Sample 1**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
n-decane	4.45	0.28	18.3	39.2	6.07	1.19	0.93	1.1	0.64	0.51	0.35	0.14	0.18	0.15	0.08	0.23
n-docosane	29.5	7.25	264	206	77.8	57.3	34.8	63.1	57.4	4.23	15.8	0.29	1.1	0.58	0.22	0.22
n-dodecane	22.7	2.31	166	198	50.5	8.76	6.58	18.7	5.75	4.03	2.04	0.35	0.58	0.48	0.29	0.34
n-dotriacontane	5.56	1.13	3.32	8.09	32.9	4.96	1.42	3.89	2.93	2.81	3.04	1.67	1.01	0.7	0.36	0.93
n-eicosane	44.4	48.4	546	409	135	115	35.8	128	109	10.6	21.6	0.75	2.94	1.07	0.41	0.28
n-heneicosane	37.4	12.3	378	290	124	100	63.7	96.2	87.5	7.76	21.6	1.29	1.53	1.12	0.35	0.26
n-hentriacontane	6.8	17.8	8.15	15	72.2	7.86	2.44	6.87	10.5	2.89	9.99	4.49	1.34	2.62	1.04	0.53
n-heptacosane	10.3	5.86	35.6	29.4	27.6	9.18	6.56	13.3	11	1.4	3.43	1.03	3.7	2.16	0.95	0.31
n-heptadecane	87.6	27.3	561	697	327	130	58.1	117	134	15.7	46.7	1.69	8.68	1.46	6.77	0.7
n-hexacosane	10.8	0.86	43.4	40.9	25	12.3	6.94	14.3	10.2	0.55	4.01	0.31	0.61	0.62	0.17	0.21
n-hexadecane	101	20	663	729	312	103	101	139	95	47.3	12	0.5	1.28	0.79	0.34	0.33
n-nonacosane	7.03	6.24	11.7	17	17.1	5.01	2.99	6.82	5.05	0.6	3.8	1.64	3.25	3.47	1.14	0.45
n-nonadecane	56.7	7.49	481	480	189	125	68.4	151	106	13	79.9	0.53	2.31	0.76	0.45	0.25
n-octacosane	8.13	2.26	20.5	20.8	17.7	6.08	4.81	9.22	7.09	1.09	3.21	0.31	0.82	0.49	0.17	0.13
n-octadecane	72.7	25.4	731	628	223	130	75.9	134	159	15.7	40.2	0.57	3.85	1.32	0.3	0.38
n-pentacosane	15.4	2.7	70	60.6	30.2	19	10.5	23	17.8	0.77	6.69	0.45	1.71	1.18	0.2	<.100
n-pentadecane	76.7	17.1	455	612	265	60	58.9	81.7	45.6	19	7.1	0.6	1.03	0.68	0.19	0.25
n-tetracosane	21.3	4.62	189	103	52	31.1	29.1	45.9	46	0.91	9.97	0.42	1.25	0.83	0.29	0.47
n-tetradecane	69	15.9	350	571	181	37	61.6	50.2	35.4	35.2	8.49	0.3	0.79	0.33	0.14	0.22
n-tetratriacontane	6.13	0.76	2.52	7.49	17.2	3.92	2.9	5.12	3.42	1.3	3.59	0.12	0.77	0.51	0.19	0.47
n-triacontane	7.47	1.92	8.63	15.1	17.3	5.33	2.77	6.67	4.49	0.65	2.6	0.31	0.87	0.63	0.16	0.14
n-tricosane	22	4.4	156	134	51.4	37.5	22.8	41.2	35.3	2.32	10.9	0.3	1.91	0.98	0.26	0.36
n-tridecane	40.4	10.1	253	333	104	20.5	23.8	32.6	20.5	9.84	5.21	0.19	0.64	0.34	0.12	0.22
n-tritriacontane	5.62	2.01	3.11	8.86	18.7	3.95	1.88	4.62	2.48	0.74	2.46	1.58	1.91	2.14	0.97	0.28
n-undecane	10.4	0.48	64.9	87.2	17.7	2.39	1.53	3.07	1.65	0.94	0.76	0.21	0.29	0.2	0.15	0.25
phytane	92	110	260	489	280	327	161	222	354	104	220	2.13	19.8	4.98	1.78	0.45
pristane	141	133	381	620	397	410	203	283	442	137	282	2.2	15	3.63	1.1	0.26

Appendix - Table A 8. Total petroleum hydrocarbons (TPH) (in µg/g) in sediment the LARCO refinery process water ponds, Casper, Wyoming.

Year 2003	
Inlet Pond	
Sample #	**TPH**
LARCOIPA	15,012
Pond 1	
Sample #	**TPH**
LARCOP1A	25,380
LARCOP1B	50,752
LARCOP1C	64,176
LARCOP1D	41,575
LARCOP1E	36,599
Pond 2	
Sample #	**TPH**
LARCOP2A	19,602
LARCOP2B	28,632
LARCOP2C	43,284
LARCOP2D	12,165
LARCOP2E	24,145
Pond 3	
Sample #	**TPH**
LARCOP3A	392
LARCOP3B	2,534
LARCOP3C	928
LARCOP3D	295
LARCOP3E	17

Year 2004	
Pond 1	
Sample #	**TPH**
4LP1S01	94,671
4LP1S02	144,954
Pond 2	
Sample #	**TPH**
4LP2S01	736
4LP2S02	18,573
Pond 3	
Sample #	**TPH**
4LP3S01	12,721
4LP3S02	5,132

Appendix - Table A 9. Trace element concentrations (in µg/g) in sediment from the Russian Olive Pond located near the LARCO refinery process water ponds, Casper, Wyoming.

Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
LARROP01	1290	4.75	19.2	49.2	<0.0216	<0.0539	80.9	4.07	3230	0.069	6260	338	1.52	12.3	5.5	0.58	280	4.95	8.42
LARROP03	1730	4.46	20.8	61.2	<0.0207	0.067	55.4	4	3710	<0.0519	6960	362	1.2	11.1	7.28	0.54	294	6.32	13.9
LARROP04	2040	11.2	60.3	118	<0.0214	<0.0535	80.5	6.5	4220	0.063	21800	991	2.64	26.6	7.4	1.09	909	9.46	14.6
LARROP05	2090	8.86	36.9	120	<0.0220	0.104	283	13.5	5100	0.258	11800	624	2.96	19.2	12.5	1.59	644	9.19	40.5
LARROP06	2690	5.42	17.2	106	<0.0219	0.0616	442	16.8	7860	0.279	5820	665	3.06	21	9.37	1.13	819	9.2	31.6
Background	5.80%	5.5	23	580	0.68		41	21	2.10%	0.046	0.74%	380	0.85	15	17	0.23	200	70	55
TEC		9.79				0.99	43.4	31.6		0.18				22.7	35.8				121
PEC		33				4.98	111	149		1.06				48.6	128				459

TEC = threshold effects concentration (level below which adverse biological effects are likely to occur

PEC = probable effects concentration (level above which adverse biological effects are likely to occur

Appendix - Table A 10. Polycyclic aromatic hydrocarbons (in µg/g) in sediment from Russian Olive Pond located near the LARCO refinery process water, Casper, Wyoming.

	LARROP01	LARROP03	LARROP06
1,6,7-Trimethyl-naphthalene	0.705	0.698	17.4
1-methylnaphthalene	0.158	0.404	32
1-methylphenanthrene	2.86	4.61	20.4
2,6-dimethylnaphthalene	1.28	1.59	56.5
2-methylnaphthalene	0.128	0.0712	32.9
acenaphthalene	<.000766	<.000642	<.000361
acenaphthene	0.0429	0.0645	1.83
anthracene	0.459	0.429	1.55
benzo(a)pyrene	0.13	0.108	0.231
benzo(b)fluoranthene	0.395	0.442	0.268
benzo(e)pyrene	0.925	0.992	0.581
benzo(g,h,i)perylene	0.186	0.207	0.165
benzo(k)fluoranthene	0.0449	0.0565	0.0325
biphenyl	0.0144	0.0286	2.07
C1-chrysenes	4.73	6.6	5.99
C1-dibenzothiophenes	3.6	3.88	12.6
C1-Fluoranthenes & Pyrenes	11.1	12.3	18.3
C1-fluorenes	2.94	3.08	30
C1-naphthalenes	0.286	0.475	64.9
C1-Phenanthrenes & Anthracenes	19.6	26.5	85.7
C2-chrysenes	3.54	3.82	3.49
C2-dibenzothiophenes	7.48	8.69	17.3
C2-fluorenes	7.91	9.11	36.4
C2-naphthalenes	2.09	2.71	113
C2-Phenanthrenes & Anthracenes	26.8	36.4	80.5
C3-chrysenes	1.22	1.45	1.35
C3-dibenzothiophenes	5.88	7.12	10.9
C3-fluorenes	9.3	10.8	28.6
C3-naphthalenes	3.85	3.69	94.4
C3-Phenanthrenes & Anthracenes	15.8	21.1	40
C4-chrysenes	0.122	0.138	0.054
C4-naphthalenes	3.44	3.66	51.7
C4-Phenanthrenes & Anthracenes	8.07	10.6	19
chrysene	4.06	4.41	3.67
dibenzothiophene	0.695	0.902	5.01
fluoranthene	0.989	1.4	2.36
fluorene	0.465	0.631	10.3
indeno(1,2,3-cd)pyrene	0.044	0.0452	0.0337
naphthalene	0.0139	0.0217	3.34
perylene	0.0275	0.0241	<.0537
phenanthrene	5.04	8.4	36.3
pyrene	6.79	8.31	10.9
Benzo(a)anthracene	0.572	0.443	1.21
Dibenz(a,h)anthracene	0.0404	0.0327	0.0328
Total Petroleum Hydrocarbons (TPH)	7029	6967	6772

Appendix - Table A 11. Aliphatic hydrocarbons (in µg/g) in sediment from Russian Olive Pond located near the LARCO refinery process water, Casper, Wyoming.

	LARROP01	LARROP03	LARROP06
n-decane	0.12	0.0739	0.342
n-docosane	4.79	2.19	4.28
n-dodecane	0.56	0.206	3.33
n-dotriacontane	0.833	0.828	0.0902
n-eicosane	6.67	4.81	8.49
n-heneicosane	2.86	0.976	4.03
n-hentriacontane	1.69	0.617	0.028
n-heptacosane	0.766	0.206	0.414
n-heptadecane	5.97	3.95	8.57
n-hexacosane	0.706	0.311	0.871
n-hexadecane	3.78	1.84	4.27
n-nonacosane	0.66	0.475	0.156
n-nonadecane	6.24	7.03	7.58
n-octacosane	0.8	0.644	0.268
n-octadecane	9.76	7.18	15.2
n-pentacosane	1.5	2.17	1.51
n-pentadecane	3.22	2.77	3.19
n-tetracosane	4.17	4.34	3.16
n-tetradecane	0.973	1.56	5.8
n-tetratriacontane	0.886	0.839	0.143
n-triacontane	0.613	0.232	0.103
n-tricosane	2.29	0.739	2.66
n-tridecane	0.667	0.259	2.71
n-tritriacontane	0.893	0.179	0.162
n-undecane	0.227	0.0739	1.21
phytane	83.6	83.6	73.1
pristane	64.8	63.9	90.9

Appendix - Table A 12. Trace element concentrations (in µg/g) in algae from the LARCO refinery process water ponds, Casper, Wyoming.

Site	Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Pond 1																				
	LARP1PL1	627	8.8	92	176	<.100	0.68	11	103	4370	1.3	5540	9910	40	17	15	26	180	9.9	107
	LARP1PL2	439	8.7	89	112	<.100	0.2	9.2	61	2780	1.2	5470	5140	28	20	12	20	145	7	68.3
	LARP1PL3	777	9.1	80	209	<.100	0.72	14	115	4930	1.5	5120	10700	44	17	19	30	185	12	121
	LARP1PL4	518	9.1	120	132	<.100	0.47	9.2	81	3230	1.1	5600	7530	35	19	12	24	150	7.4	87.7
	LARP1PL5	571	8.8	120	146	<.100	0.34	11	74	3420	1.3	5420	7300	35	18	15	24	158	9.2	80.1
Pond 2																				
	LARP2PL1	52	3.6	58	10	<.100	0.3	1	54	354	0.39	4250	50.6	6.9	14	2.4	4.5	69.5	<.500	41
	LARP2PL2	43	3.7	110	10	<.100	0.37	1	38	357	0.36	4340	54.1	7.1	13	2	4.2	70.3	0.6	31
	LARP2PL3	85	3.5	110	13	<.100	0.42	2.6	75	439	0.4	4280	52.7	7.9	13	3.8	5	72.6	0.9	45
	LARP2PL4	262	3.4	87	10	<.100	<.100	2.6	21	500	0.38	3580	50.4	8.6	14	2	4.8	51.7	1.8	27
	LARP2PL5	244	3.3	63	12	<.100	<.100	2.6	20	540	0.36	3710	57	9.9	13	2.3	6.5	57.7	1.7	31
Pond 3																				
	LARP3PL1	614	6.2	40	12	<.100	0.49	3.2	25	691	0.3	5450	100	4	9.1	39	5.4	131	2.9	29
	LARP3PL2	1210	6.1	37	21.4	<.100	0.73	3.3	122	778	0.3	5500	102	4	9.8	44	4.8	131	3.4	74.3
	LARP3PL3	1220	6.4	38	21.5	<.100	0.51	3.1	25	755	0.2	5670	105	4	9.6	41	4.8	138	3.4	27
	LARP3PL4	1320	6.3	33	21.3	<.100	0.52	3.1	19	769	0.3	5510	103	4	9.3	40	4.9	137	3.5	25
	LARP3PL5	575	6.4	33	12	<.100	0.5	2.7	23	707	0.3	5540	99.8	4	9.6	40	5	133	2.9	25

Appendix - Table A 13. Aromatic hydrocarbon concentrations (in µg/g) in algae from the LARCO refinery process water ponds, Casper, Wyoming.

	Pond 1			Pond 2		
Aromatics	**4LP1PP01**	**4LP1PP02**	**4LP1PP03**	**4LP2PP01**	**4LP2PP02**	**4LP2PP03**
1,6,7-Trimethyl-naphthalene	0.119501	0.27	0.16934	0.061856	<0.040816	<0.027031
1-methylnaphthalene	0.05113	0.052222	0.105169	0.058419	<0.061224	0.054422
1-methylphenanthrene	0.228894	0.413333	0.108734	0.151203	0.122449	0.07483
2,6-dimethylnaphthalene	8.323424	9.011111	14.367201	9.484536	8.72449	7.653061
2-methylnaphthalene	0.030321	0.037778	0.067736	<0.047477	<0.071429	0.047619
Benzo(a)anthracene	0.039239	0.054444	0.083779	<0.020347	<0.030612	<0.020273
C1-Fluoranthenes & Pyrenes	0.731272	1.005556	1.144385	0.209622	0.193878	0.170068
C1-Phenanthrenes & Anthracenes	0.731272	1.522222	1.11943	0.271478	0.265306	0.180272
C1-chrysenes	0.52497	0.746667	0.916221	0.202749	0.173469	0.193878
C1-dibenzothiophenes	0.453032	0.89	0.648841	0.065292	0.061224	0.057823
C1-fluorenes	0.220571	0.508889	0.354724	<0.047477	<0.071429	<0.047304
C1-naphthalenes	0.043401	0.047778	0.092692	<0.088171	<0.132653	<0.08785
C2-Phenanthrenes & Anthracenes	0.862069	1.688889	1.254902	0.089347	0.091837	0.068027
C2-chrysenes	0.315696	0.465556	0.518717	<0.054259	<0.081633	0.098639
C2-dibenzothiophenes	0.743163	1.411111	0.994652	0.079038	0.086735	0.071429
C2-fluorenes	0.522592	1.211111	0.889483	<0.047477	<0.071429	<0.047304
C2-naphthalenes	3.870392	4.222222	6.559715	4.295533	3.928571	3.435374
C3-Phenanthrenes & Anthracenes	0.6956	1.104444	0.802139	0.130584	0.147959	0.112245
C3-chrysenes	0.193817	0.295556	0.286988	<0.054259	<0.081633	<0.054061
C3-dibenzothiophenes	0.570155	0.955556	0.684492	0.085911	<0.061224	<0.040546
C3-fluorenes	0.545779	1.025556	0.720143	<0.047477	<0.071429	<0.047304
C3-naphthalenes	0.677765	1.533333	1.14082	0.223368	<0.163265	<0.108123
C4-Phenanthrenes & Anthracenes	0.317479	0.456667	0.388592	0.065292	<0.05102	0.05102
C4-chrysenes	0.016647	0.044444	<0.028053	<0.054259	<0.081633	<0.054061
C4-naphthalenes	1.307967	2.411111	2.477718	<0.108519	<0.163265	<0.108123
Dibenz(a,h)anthracene	0.009512	0.013333	0.014026	<0.02713	<0.040816	<0.027031
acenaphthalene	0.009512	0.011111	0.012478	<0.020347	<0.030612	<0.020273
acenaphthene	0.010107	0.018889	0.024955	<0.020347	<0.030612	<0.020408
anthracene	0.016647	0.03	0.019608	<0.013565	<0.020408	<0.013515
benzo(a)pyrene	0.012485	0.016667	0.019608	<0.02713	<0.040816	<0.027031
benzo(b)fluoranthene	0.037455	0.054444	0.064171	0.020619	<0.030612	<0.020273
benzo(e)pyrene	0.260999	0.363333	0.454545	0.14433	0.117347	0.115646
benzo(g,h,i)perylene	0.023781	0.032222	0.035651	<0.027491	<0.040816	<0.027031
benzo(k)fluoranthene	0.008323	0.01	0.019608	<0.020347	<0.030612	<0.020273
biphenyl	0.011296	<0.013333	<0.02104	<0.040695	<0.061224	<0.040546
chrysene	0.642093	0.818889	1.110517	0.340206	0.30102	0.302721
dibenzothiophene	0.112961	0.197778	0.180036	0.027491	<0.030612	0.020408
fluoranthene	0.027348	0.031111	0.053476	<0.020347	<0.030612	<0.020273
fluorene	0.030321	0.065556	0.055258	<0.020347	<0.030612	<0.020273
indeno(1,2,3-cd)pyrene	<0.007111	<0.013201	<0.02104	<0.040695	<0.061224	<0.040546
naphthalene	0.020214	0.023333	0.048128	<0.054259	<0.081633	<0.054061
perylene	<0.005926	<0.011001	<0.017533	<0.033912	<0.05102	<0.033788
phenanthrene	0.181926	0.355556	0.299465	0.054983	0.066327	0.05102
pyrene	0.257432	0.352222	0.41533	0.164948	0.147959	0.129252

Appendix -Table A 13 (continued). Aromatic hydrocarbon concentrations (in µg/g) in algae from the LARCO refinery process water ponds, Casper, Wyoming.

Aromatics	Pond 3		
	4LP3PL1	4LP3PL2	4LP3PL3
1,6,7-Trimethyl-naphthalene	<0.014868	<0.014246	<0.012943
1-methylnaphthalene	0.101695	0.079137	0.07329
1-methylphenanthrene	0.077213	0.106115	0.053746
2,6-dimethylnaphthalene	15.499058	11.258993	9.869707
2-methylnaphthalene	0.056497	0.044964	0.039088
Benzo(a)anthracene	0.013183	0.01259	<0.009772
C1-Fluoranthenes & Pyrenes	0.165725	0.115108	0.104235
C1-Phenanthrenes & Anthracenes	0.175141	0.17446	0.127036
C1-chrysenes	0.205273	0.154676	0.149837
C1-dibenzothiophenes	0.082863	0.059353	0.02443
C1-fluorenes	<0.026018	<0.024931	<0.02265
C1-naphthalenes	0.084746	0.066547	0.060261
C2-Phenanthrenes & Anthracenes	0.101695	0.080935	0.061889
C2-chrysenes	0.096045	0.079137	0.078176
C2-dibenzothiophenes	0.129944	0.100719	0.089577
C2-fluorenes	<0.026018	<0.024931	<0.02265
C2-naphthalenes	6.93032	5.233813	4.625407
C3-Phenanthrenes & Anthracenes	0.112994	0.109712	0.068404
C3-chrysenes	<0.029735	<0.028492	<0.025886
C3-dibenzothiophenes	0.109228	0.086331	0.070033
C3-fluorenes	<0.026018	<0.024931	<0.02265
C3-naphthalenes	<0.059471	<0.056984	<0.051772
C4-Phenanthrenes & Anthracenes	0.071563	0.05036	0.043974
C4-chrysenes	<0.029735	<0.028492	<0.025886
C4-naphthalenes	<0.059471	<0.056984	<0.051772
Dibenz(a,h)anthracene	<0.014868	<0.014246	<0.012943
acenaphthalene	<0.011151	<0.010685	<0.009707
acenaphthene	<0.011151	<0.010685	<0.009707
anthracene	<0.007434	<0.007123	<0.006472
benzo(a)pyrene	<0.014868	<0.014246	<0.012943
benzo(b)fluoranthene	0.020716	0.019784	0.016287
benzo(e)pyrene	0.077213	0.061151	0.053746
benzo(g,h,i)perylene	<0.014868	<0.014246	<0.012943
benzo(k)fluoranthene	<0.011299	0.014388	<0.009707
biphenyl	<0.022302	<0.021369	<0.019415
chrysene	0.214689	0.152878	0.151466
dibenzothiophene	0.018832	0.019784	0.011401
fluoranthene	0.016949	0.014388	0.011401
fluorene	<0.011151	<0.010685	<0.009707
indeno(1,2,3-cd)pyrene	<0.022302	<0.021369	<0.019415
naphthalene	0.043315	0.032374	0.032573
perylene	<0.018585	<0.017808	<0.016179
phenanthrene	0.022599	0.017986	0.017915
pyrene	0.111111	0.084532	0.070033

Appendix - Table A 14. Aliphatic hydrocarbon concentrations (in µg/g) in algae from the LARCO refinery process water ponds, Casper, Wyoming.

	Pond 1			Pond 2			Pond 3		
Aliphatics	4LP1PP01	4LP1PP02	4LP1PP03	4LP2PP01	4LP2PP02	4LP2PP03	4LP3PL1	4LP3PL2	4LP3PL3
n-decane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-docosane	<0.312911	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-dodecane	<0.118511	<0.220022	1.697649	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-dotriacontane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-eicosane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-heneicosane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-hentriacontane	1.564553	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-heptacosane	1.01696	1.160862	1.06103	2.898191	<1.020408	<0.95813	<1.070022	<0.356151	<0.323576
n-heptadecane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-hexacosane	<0.234683	<0.497512	<0.636618	<1.242082	<1.020408	3.353454	<0.428009	<0.382673	<.588674
n-hexadecane	<0.118511	<0.220022	48.38299	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-nonacosane	0.782277	1.160862	1.273237	<1.242082	<1.020408	<0.95813	<0.371692	<0.356151	<0.323576
n-nonadecane	<0.118511	<0.220022	<0.350662	3.312218	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-octacosane	1.095187	1.160862	1.909855	<1.242082	<1.020408	<0.95813	<0.856018	<0.356151	<0.323576
n-octadecane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-pentacosane	1.486326	1.824212	2.122061	4.5543	<1.020408	4.790649	3.85208	4.592071	3.139594
n-pentadecane	<0.237022	<0.440044	8.063832	<1.356484	<2.040816	<1.351534	<0.743384	<0.712301	<0.647151
n-tetracosane	0.391138	1.492537	2.546473	<0.678242	<1.020408	<0.675767	1.712036	1.339354	0.981123
n-tetradecane	<0.118511	<0.220022	<0.848824	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-tetratriacontane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-triacontane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-tricosane	0.782277	1.824212	2.334267	3.312218	<1.020408	<0.675767	5.564116	7.270779	3.924493
n-tridecane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-tritriacontane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
n-undecane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
phytane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576
pristane	<0.118511	<0.220022	<0.350662	<0.678242	<1.020408	<0.675767	<0.371692	<0.356151	<0.323576

Appendix - Table A 15. Trace element concentrations (in µg/g) in waterboatmen (Family Corixidae) from the LARCO refinery process water ponds and natural marsh reference site, Casper, Wyoming.

Site	Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Natural Marsh																				
	LARNMAI1	36.0	2.90	5.0	1.80	<.100	<.100	<.500	6.4	170	<.100	1770	41.0	<2.00	<.500	<.200	1.10	41.1	<.500	101.0
	LARNMAI2	20.0	2.00	2.0	1.30	<.100	<.100	<.500	7.0	150	<.100	1390	28.0	<2.00	<.500	<.200	1.00	30.2	<.500	104.0
	LARNMAI3	17.0	2.10	7.8	1.20	<.100	<.100	<.500	7.0	140	<.100	1620	26.0	<2.00	<.500	0.2	1.20	32.9	<.500	103.0
	LARNMAI4	39.0	2.50	6.9	2.00	<.100	<.100	2.7	6.6	180	<.100	1720	32.0	<2.00	1	<.200	1.20	36.0	<.500	105.0
	LARNMAI5	37.0	3.70	12.0	2.00	<.100	<.100	<.500	7.9	180	<.100	2480	44.0	<2.00	4	0.2	1.10	54.8	<.500	102.0
Pond 1																				
	LARP1AI2	14.0	<.400	56.0	1.10	<.100	0.1	<.500	14.0	120	0.2	963	13.0	<2.00	<.500	<.200	4.80	12.0	<.500	124.0
	LARP1AI3	11.0	<.400	36.0	1.10	<.100	<.100	<.500	12.0	110	0.1	1030	13.0	<2.00	<.500	<.200	7.10	9.5	<.500	124.0
	LARP1AI4	6.0	<.400	42.0	0.80	<.100	<.100	<.500	12.0	110	<.100	1030	12.0	<2.00	<.500	<.200	6.90	8.6	<.500	125.0
	LARP1AI5	9.3	0.80	40.0	1.10	<.100	0.2	<.500	17.0	120	0.2	976	11.0	<2.00	<.500	<.200	4.60	12.0	<.500	124.0
	LARP1AI6	10.0	<.400	37.0	1.10	<.100	0.2	<.500	18.0	120	0.3	958	12.0	<2.00	<.500	<.200	4.80	12.0	<.500	118.0
Pond 2																				
	LARP2AI3	22.0	0.90	24.0	0.88	<.100	<.100	0.6	12.0	110	0.2	1040	14.0	<2.00	<.500	<.200	5.60	13.0	<.500	122.0
	LARP2AI5	9.3	<.400	27.0	0.88	<.100	<.100	<.500	10.0	99	0.2	1080	13.0	<2.00	<.500	<.200	7.50	11.0	<.500	127.0
	LARP2AI6	20.0	0.30	33.0	1.40	<.100	<.100	0.7	13.0	120	0.1	1010	14.0	<2.00	<.500	0.3	6.10	15.0	<.500	126.0
	LARP2AI7	9.7	0.30	23.0	1.20	<.100	<.100	<.500	12.0	120	0.1	1000	13.0	<2.00	<.500	<.200	5.90	14.0	<.500	125.0
	LARP2AI8	5.0	0.20	24.0	1.10	<.100	<.100	<.500	12.0	120	0.1	1010	13.0	<2.00	<.500	<.200	5.90	15.0	<.500	122.0
Pond 3																				
	LARP3AI1	140.0	1.20	23.0	2.60	<.100	<.100	0.7	15.0	200	0.2	1710	79.7	<2.00	<.500	<.200	7.90	52.4	<.500	128.0
	LARP3AI2	70.0	0.80	22.0	1.40	<.100	<.100	1.0	9.1	140	0.2	1570	49.0	<2.00	<.500	<.200	3.00	30.0	<.500	93.1
	LARP3AI3	44.0	0.70	29.0	1.00	<.100	<.100	<.500	10.0	120	0.1	1450	38.0	<2.00	<.500	<.200	3.70	28.4	<.500	95.7
	LARP3AI4	35.0	0.80	36.0	1.20	<.100	<.100	1.6	11.0	120	0.1	1610	38.0	<2.00	<.500	<.200	3.20	31.6	<.500	93.4
	LARP3AI5	35.0	1.00	8.0	2.30	<.100	<.100	<.500	8.9	120	0.2	1790	50.7	<2.00	<.500	<.200	3.60	35.7	<.500	91.5

Appendix - Table A 16. Aromatic hydrocarbon concentrations (in µg/g) in waterboatmen (Family Corixidae) from the LARCO refinery process water ponds, Casper, Wyoming.

	Pond 2			Pond 3		
Aromatics	**4LP2AI1**	**4LP2AI3**	**4LP2AI6**	**4LP3AI1**	**4LP3AI3**	**4LP3AI4**
1,6,7-Trimethyl-naphthalene	0.029	<0.004	0.039	<0.003	0.011	0.129
1-methylnaphthalene	0.024	0.011	0.057	<0.005	0.030	0.179
1-methylphenanthrene	0.085	0.027	0.036	0.009	0.068	0.602
2,6-dimethylnaphthalene	0.182	<0.004	0.211	<0.004	0.110	0.359
2-methylnaphthalene	0.010	<0.006	0.062	<0.006	<0.014	0.015
Benzo(a)anthracene	0.063	0.012	0.011	<0.002	0.029	1.124
C1-Fluoranthenes & Pyrenes	0.301	0.138	0.187	<0.004	0.581	20.679
C1-Phenanthrenes & Anthracenes	0.473	0.120	0.154	0.026	0.277	3.075
C1-chrysenes	0.228	0.107	0.132	<0.006	0.271	7.466
C1-dibenzothiophenes	0.161	0.048	0.093	0.022	0.194	1.676
C1-fluorenes	0.160	<0.006	0.118	<0.006	<0.014	0.521
C1-naphthalenes	0.021	<0.011	0.073	<0.010	<0.026	0.119
C2-Phenanthrenes & Anthracenes	0.830	0.318	0.330	0.058	0.804	19.300
C2-chrysenes	0.186	0.096	0.107	<0.006	0.214	6.299
C2-dibenzothiophenes	0.355	0.121	0.156	<0.005	0.470	12.089
C2-fluorenes	0.284	<0.006	0.154	<0.005	<0.014	4.093
C2-naphthalenes	0.171	<0.014	0.292	<0.013	0.144	0.509
C3-Phenanthrenes & Anthracenes	0.700	0.431	0.234	<0.004	0.881	22.375
C3-chrysenes	0.107	0.051	0.050	<0.006	0.084	2.937
C3-dibenzothiophenes	0.278	<0.005	0.106	<0.005	0.466	15.164
C3-fluorenes	0.219	<0.006	0.185	<0.006	<0.014	7.190
C3-naphthalenes	0.196	<0.014	0.259	<0.013	0.073	0.968
C4-Phenanthrenes & Anthracenes	0.260	0.189	0.188	<0.004	0.344	10.414
C4-chrysenes	<0.006	<0.007	<0.007	<0.006	<0.016	0.133
C4-naphthalenes	0.158	<0.014	0.193	<0.013	0.092	2.598
Dibenz(a,h)anthracene	0.003	<0.004	<0.003	<0.003	<0.008	0.094
acenaphthalene	0.008	<0.003	0.004	<0.002	<0.006	0.011
acenaphthene	0.004	<0.003	0.009	<0.002	<0.006	0.022
anthracene	0.005	0.004	0.006	<0.002	0.016	0.441
benzo(a)pyrene	0.010	0.015	0.014	0.007	0.023	0.788
benzo(b)fluoranthene	0.018	0.014	0.022	<0.002	0.021	0.622
benzo(e)pyrene	0.063	0.042	0.060	0.006	0.062	1.676
benzo(g,h,i)perylene	0.009	0.008	0.007	<0.003	0.014	0.459
benzo(k)fluoranthene	0.014	0.006	0.011	0.004	<0.006	0.122
biphenyl	<0.004	<0.005	0.006	<0.005	<0.012	<0.013
chrysene	0.159	0.103	0.110	<0.003	0.164	2.609
dibenzothiophene	0.024	0.008	0.022	0.009	0.026	0.078
fluoranthene	0.019	0.007	0.007	0.004	0.033	0.664
fluorene	0.015	0.004	0.022	<0.002	0.010	0.069
indeno(1,2,3-cd)pyrene	<0.004	<0.005	<0.005	<0.005	<0.012	0.107
naphthalene	0.007	0.008	0.011	<0.006	<0.016	0.027
perylene	0.006	0.006	<0.004	0.006	<0.010	0.093
phenanthrene	0.101	0.031	0.068	0.022	0.062	0.164
pyrene	0.109	0.028	0.050	0.010	0.302	11.559

Appendix - Table A 17. Aliphatic hydrocarbon concentrations (in µg/g) in waterboatmen (Family Corixidae) from the LARCO refinery process water ponds, Casper, Wyoming.

Aliphatics		Pond 1		
		4LP1AI1	4LP1AI4	4LP1AI6
n-decane	C10	0.102583	<0.092107	<0.097116
n-docosane	C22	34.826942	30.676965	37.919114
n-dodecane	C12	0.564207	0.345239	0.956949
n-dotriacontane	C32	1.487454	0.937078	0.478475
n-eicosane	C20	15.233582	12.921808	12.859005
n-heneicosane	C21	49.342443	229.337437	184.093111
n-hentriacontane	C31	4.821403	1.874155	37.500449
n-heptacosane	C27	7.796311	4.636069	13.815955
n-heptadecane	C17	2.821034	1.430276	6.638835
n-hexacosane	C26	1.846495	1.085037	3.229704
n-hexadecane	C16	0.871956	0.394559	1.016759
n-nonacosane	C29	2.205535	1.578236	4.904365
n-nonadecane	C19	5.077861	3.403072	4.665128
n-octacosane	C28	3.898156	6.066345	1.016759
n-octadecane	C18	0.718081	0.789118	1.375615
n-pentacosane	C25	52.368642	46.064767	56.10115
n-pentadecane	C15	1.743912	0.887758	1.495233
n-tetracosane	C24	8.411809	12.37929	12.978624
n-tetradecane	C14	1.69262	1.232997	3.169894
n-tetratriacontane	C34	0.410332	0.443879	2.870848
n-triacontane	C30	1.436163	0.986398	0.538284
n-tricosane	C23	56.01034	262.579035	233.13676
n-tridecane	C13	0.974539	0.443879	1.136377
n-tritriacontane	C33	0.307749	0.887758	1.674661
n-undecane	C11	<0.094346	<0.092107	0.299047
phytane		4.667528	2.416674	7.416357
pristane		4.359779	2.564634	8.253687

Appendix -Table A 17 (continued). Aliphatic hydrocarbon concentrations (in μg/g) in waterboatmen (Family Corixidae) from the LARCO refinery process water ponds, Casper, Wyoming.

Aliphatics		Pond 2		
		4LP2AI1	4LP2AI3	4LP2AI6
n-decane	C10	0.07191	<0.086722	<0.085317
n-docosane	C22	33.724079	28.624105	31.040696
n-dodecane	C12	0.202669	0.248473	0.09792
n-dotriacontane	C32	0.64854	1.540533	1.468803
n-eicosane	C20	6.323265	9.889231	8.763856
n-heneicosane	C21	24.968789	237.341536	183.257608
n-hentriacontane	C31	1.378147	55.707676	34.761662
n-heptacosane	C27	4.093909	6.609385	7.246093
n-heptadecane	C17	0.689074	2.03748	3.672007
n-hexacosane	C26	1.175479	0.944198	2.643845
n-hexadecane	C16	0.405337	<0.086722	0.293761
n-nonacosane	C29	0.932276	2.484731	1.175042
n-nonadecane	C19	3.485902	3.677402	4.749129
n-octacosane	C28	4.134442	0.894503	1.615683
n-octadecane	C18	0.526939	0.546641	0.293761
n-pentacosane	C25	35.46703	35.929215	44.45576
n-pentadecane	C15	0.567472	0.844809	0.342721
n-tetracosane	C24	8.714756	7.851751	11.4077
n-tetradecane	C14	0.526939	0.447252	0.342721
n-tetratriacontane	C34	0.486405	0.347862	0.783361
n-triacontane	C30	0.364804	0.298168	0.293761
n-tricosane	C23	29.589636	209.611935	226.293526
n-tridecane	C13	0.162135	0.149084	0.14688
n-tritriacontane	C33	1.418681	0.894503	0.979202
n-undecane	C11	<0.07191	<0.086722	<0.085317
phytane		0.97281	1.043587	0.881282
pristane		0.689074	0.894503	0.636481

Appendix -Table A 17 (continued). Aliphatic hydrocarbon concentrations (in μg/g) in waterboatmen (Family Corixidae) from the LARCO refinery process water ponds, Casper, Wyoming.

Aliphatics		Pond 3		
		4LP3AI1	4LP3AI3	4LP3AI4
n-decane	C10	0.078324	<0.202061	<0.209989
n-docosane	C22	33.588947	21.238728	25.804171
n-dodecane	C12	0.0845	<0.202061	<0.209989
n-dotriacontane	C32	2.661766	0.830565	<0.209989
n-eicosane	C20	15.29459	7.237779	16.024508
n-heneicosane	C21	40.179986	91.955387	119.241192
n-hentriacontane	C31	33.631198	15.424775	38.058207
n-heptacosane	C27	8.069797	2.610346	5.537881
n-heptadecane	C17	4.605277	8.898908	14.021445
n-hexacosane	C26	3.38002	1.067869	2.003064
n-hexadecane	C16	0.211251	0.474608	1.413927
n-nonacosane	C29	2.408264	2.135738	6.716154
n-nonadecane	C19	5.408032	2.610346	3.8883
n-octacosane	C28	1.267507	0.711913	2.827854
n-octadecane	C18	0.253501	0.355956	1.885236
n-pentacosane	C25	21.589877	18.153773	25.686344
n-pentadecane	C15	0.464753	0.949217	1.2961
n-tetracosane	C24	7.098042	7.475083	9.89749
n-tetradecane	C14	0.211251	0.355956	0.589136
n-tetratriacontane	C34	1.267507	0.593261	<0.209989
n-triacontane	C30	0.802755	0.355956	0.471309
n-tricosane	C23	36.377464	94.565733	115.706374
n-tridecane	C13	<0.078324	<0.202061	<0.209989
n-tritriacontane	C33	1.73226	0.593261	<0.209989
n-undecane	C11	0.0845	<0.202061	<0.209989
phytane		0.380252	0.949217	7.7766
pristane		0.760504	1.067869	5.1844

Appendix - Table A 18. Trace element concentrations (in μg/g) in Daphnia (*Daphnia sp.*) from Pond 2, LARCO refinery process water, Casper, Wyoming.

Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
4LP2DAP4	39	6	11	27.1	<0.1	<0.1	0.7	6.1	453	0.32	1950	43	5	0.9	0.3	15	51.3	<0.5	63.5
4LP2DAP5	26	6	8.8	25.8	<0.1	<0.1	0.7	6.3	430	0.3	1960	41	4	1	<0.2	15	51	<0.5	64.1
4LP2DAP6	27	6.1	7.7	25.3	<0.1	<0.1	0.8	6.4	438	0.3	2000	41	4	1	<0.2	15	51.4	<0.5	65.1
4LP2DAP7	20	5.8	9.3	25	<0.1	<0.1	0.7	6.2	419	0.3	1950	39	4	0.9	<0.2	15	49.4	<0.5	64.4

Appendix - Table A 19. Aromatic hydrocarbon concentrations (in μg/g) in Daphnia (*Daphnia sp.*) from Pond 2, LARCO refinery process water ponds, Casper, Wyoming.

Aromatics	4LP2DAP1	4LP2DAP2	4LP2DAP3
1,6,7-Trimethyl-naphthalene	<0.02712	<0.01356	<0.013819
1-methylnaphthalene	0.064626	0.037415	0.051993
1-methylphenanthrene	0.085034	0.037415	0.038128
2,6-dimethylnaphthalene	<0.033901	<0.01695	<0.017273
2-methylnaphthalene	<0.047461	<0.02373	<0.024183
Benzo(a)anthracene	0.098639	<0.01017	<0.010364
C1-Fluoranthenes & Pyrenes	0.319728	0.136054	0.199307
C1-Phenanthrenes & Anthracenes	0.251701	0.095238	0.140381
C1-chrysenes	0.42517	<0.02712	0.261698
C1-dibenzothiophenes	0.088435	<0.02034	<0.020728
C1-fluorenes	<0.047461	<0.02373	<0.024183
C1-naphthalenes	<0.088142	<0.044071	<0.044911
C2-Phenanthrenes & Anthracenes	<0.033901	<0.01695	<0.017273
C2-chrysenes	0.687075	<0.02712	0.362218
C2-dibenzothiophenes	<0.040681	<0.02034	<0.020728
C2-fluorenes	<0.047461	<0.02373	<0.024183
C2-naphthalenes	<0.108482	<0.054241	<0.055275
C3-Phenanthrenes & Anthracenes	<0.033901	<0.01695	<0.017273
C3-chrysenes	0.316327	<0.02712	<0.027638
C3-dibenzothiophenes	<0.040681	<0.02034	<0.020728
C3-fluorenes	<0.047461	<0.02373	<0.024183
C3-naphthalenes	<0.108482	<0.054241	<0.055275
C4-Phenanthrenes & Anthracenes	<0.033901	<0.01695	<0.017273
C4-chrysenes	<0.054241	<0.02712	<0.027638
C4-naphthalenes	<0.108482	<0.054241	<0.055275
Dibenz(a,h)anthracene	<0.02712	<0.01356	<0.013819
acenaphthalene	0.02381	<0.01017	<0.010364
acenaphthene	<0.02034	<0.01017	<0.010364
anthracene	0.068027	0.022109	0.043328
benzo(a)pyrene	0.064626	0.02551	0.048527
benzo(b)fluoranthene	0.047619	0.018707	0.025997
benzo(e)pyrene	0.316327	0.151361	0.202773
benzo(g,h,i)perylene	0.088435	0.039116	0.053726
benzo(k)fluoranthene	<0.02034	<0.01017	<0.010364
biphenyl	<0.040681	<0.02034	<0.020728
chrysene	0.622449	0.404762	0.54766
dibenzothiophene	0.064626	0.030612	0.039861
fluoranthene	0.037415	0.018707	0.017331
fluorene	<0.02034	<0.01017	<0.010364
indeno(1,2,3-cd)pyrene	<0.040681	<0.02034	<0.020728
naphthalene	<0.054241	<0.02712	<0.027638
perylene	<0.034014	<0.01695	<0.017273
phenanthrene	0.173469	0.057823	0.093588
pyrene	0.139456	0.071429	0.098787

Appendix - Table A 20. Aliphatic hydrocarbon concentrations (in μg/g) in Daphnia (*Daphnia sp.*) from Pond 2, LARCO refinery process water, Casper, Wyoming.

Aliphatics		4LP2DAP1	4LP2DAP2	4LP2DAP3
n-decane	C10	<0.678012	<0.339006	<0.345469
n-docosane	C22	<0.678012	<0.339006	<0.345469
n-dodecane	C12	<0.678012	<0.339006	<0.345469
n-dotriacontane	C32	<0.678012	<0.339006	<0.345469
n-eicosane	C20	5.26401	2.570796	2.038944
n-heneicosane	C21	<0.678012	<0.339006	<0.345469
n-hentriacontane	C31	<0.678012	<0.339006	<0.345469
n-heptacosane	C27	0.809848	0.395507	<0.345469
n-heptadecane	C17	350.259151	188.459105	199.612601
n-hexacosane	C26	1.214772	0.791014	<0.345469
n-hexadecane	C16	6.073858	3.164056	3.26231
n-nonacosane	C29	<0.678012	<0.339006	<0.345469
n-nonadecane	C19	3.239391	4.152824	4.689571
n-octacosane	C28	<0.678012	<0.339006	<0.345469
n-octadecane	C18	16.601879	8.503401	9.990825
n-pentacosane	C25	2.834467	0.593261	<0.345469
n-pentadecane	C15	13.767412	7.119127	7.136303
n-tetracosane	C24	<0.678012	0.593261	<0.345469
n-tetradecane	C14	2.024619	0.988768	1.223366
n-tetratriacontane	C34	<0.678012	<0.339006	<0.345469
n-triacontane	C30	<0.678012	<0.339006	<0.345469
n-tricosane	C23	<0.678012	0.593261	0.611683
n-tridecane	C13	<0.678012	<0.339006	<0.345469
n-tritriacontane	C33	<0.678012	<0.339006	<0.345469
n-undecane	C11	<0.678012	<0.339006	<0.345469
Phytane		29.154519	13.644993	13.253135
Pristine		29.964367	14.436007	14.068712

Appendix - Table A 21. Trace element concentrations (in µg/g) in Dobson flies (Family Corydalidae, *Corydalus* sp.) from Pond 1 and backswimmers (Family Notonectidae) from Pond 2, LARCO refinery process water, Casper, Wyoming.

Site	Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se
Pond 1 - Dobson Flies																	
	4LP1AI5	5.36	1.23	10.8	2.1	<0.106	<0.106	0.902	7.24	104	0.303	1280	24.9	3.04	<0.317	<0.528	14.1
	4LP1AI6	54.8	1.81	12.7	3.88	<0.108	<0.108	1.52	8.97	131	0.38	1730	21.5	3.27	<0.324	<0.54	14
	4LP1AI7	6.09	1.61	6.14	2.09	<0.102	<0.102	0.43	7.38	97.2	0.318	1220	26.6	2.5	<0.307	<0.512	16.1
Pond 2 - Backswimmers																	
	4LP2AI2	7.93	<0.505	12	2.46	<0.101	0.205	<0.404	14.1	163	0.527	1710	24.4	3.33	<0.303	<0.505	12.3
	4LP2AI4	11.4	<0.519	6.17	2.89	<0.104	<0.104	<0.415	14.7	119	0.411	1700	24.5	5.08	<0.311	<0.519	11.6
	4LP2AI8	9.11	1.01	11.6	2.92	<0.0987	<0.0987	<0.395	14.4	190	0.445	1890	24	3.82	<0.296	<0.493	14.1

Site	Sample #	Sr	V	Zn
Pond 1 - Dobson Flies				
	4LP1AI5	28.2	0.577	108
	4LP1AI6	30.4	0.652	112
	4LP1AI7	26.7	0.556	117
Pond 2 - Backswimmers				
	4LP2AI2	62.4	0.45	224
	4LP2AI4	57.7	0.439	195
	4LP2AI8	84.7	0.401	214

Appendix - Table A 22. Trace element concentrations (in µg/g) in Canada goose, mallard, American avocet, and black-necked stilt eggs collected from the LARCO refinery process water ponds, Casper, Wyoming.

Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Canada Goose																			
LARCOCG1	<2.00	<.200	2	4.5	<.100	<.100	<.500	3.9	94	<.100	368	1.9	<2.00	<.500	<.200	1.7	5.2	<.500	54.5
LARCOCG2	<2.00	<.200	<2.00	1.5	<.100	<.100	<.500	3.9	130	<.100	415	2.3	<2.00	<.500	<.200	3.4	6.7	<.500	56.4
LARCOCG3	<2.00	<.200	<2.00	6.6	<.100	<.100	<.500	4.1	98	<.100	522	1.9	<2.00	<.500	<.200	1.5	17	<.500	64.5
LARCOCG4	<2.00	<.200	<2.00	1.2	<.100	<.100	<.500	3.7	120	<.100	384	2	<2.00	<.500	<.200	3.1	3.2	<.500	58
LARCOCG5	<2.00	<.200	<2.00	3.6	<.100	<.100	<.500	3.9	130	<.100	401	2.2	<2.00	<.500	<.200	2.9	10	<.500	59.2
Mallard																			
LARCOME2	<2.00	<.200	<2.00	3.7	<.100	<.100	<.500	4.5	100	0.3	404	6.6	<2.00	<.500	<.200	3.5	24.1	<.500	58.7
LARCOME3	<2.00	<.200	<2.00	2.1	<.100	<.100	<.500	3.9	120	0.2	405	7.2	<2.00	<.500	<.200	5.6	20.1	<.500	60.4
LARCOME4	<2.00	<.200	<2.00	1.8	<.100	<.100	<.500	5.4	140	0.3	618	6.2	<2.00	<.500	<.200	7.6	54.7	<.500	61.3
LARCOME5	<2.00	0.3	<2.00	3.1	<.100	<.100	<.500	4.5	110	0.2	365	6.7	<2.00	<.500	<.200	3.5	21.6	<.500	54.7
American Avocet																			
LP1N1AA1	6.4	0.3	<2.00	1.3	<.100	<.100	<.500	3.5	110	0.33	586	2.7	<2.00	<.500	<.200	9.2	21.5	<.500	51.1
LP1N2AA2	4	<.200	<2.00	1.1	<.100	<.100	0.8	4.1	100	0.2	404	3.4	<2.00	<.500	<.200	2.5	33.1	<.500	52.2
LP1N3AA3	2	0.2	<2.00	0.6	<.100	<.100	0.5	3.4	94	0.61	523	3.4	<2.00	<.500	<.200	3.7	26.6	<.500	43
LP1N4AA4	<2.00	0.3	<2.00	0.5	<.100	<.100	<.500	4.9	120	0.1	494	3	<2.00	<.500	<.200	7.3	28.2	<.500	60.8
LP1N5AA5	<2.00	<.200	<2.00	0.6	<.100	<.100	<.500	5.9	110	0.3	613	1	<2.00	<.500	<.200	5.5	40.2	<.500	52.1
LP1N6AA6	<2.00	<.200	<2.00	0.3	<.100	<.100	<.500	3.6	120	0.2	388	2.5	<2.00	<.500	<.200	18	16	<.500	49
LP3AA01	<2.00	0.2	<2.00	0.3	<.100	<.100	<.500	3.4	94	0.2	393	3.7	<2.00	<.500	<.200	9.4	14	<.500	51.6
Black-necked Stilt																			
LP3BS01	<2.00	<.200	<2.00	3.1	<.100	<.100	<.500	3.9	120	0.48	386	1.6	<2.00	<.500	<.200	11	29.8	<.500	50.7
LP3BS02	<2.00	<.200	<2.00	2	<.100	<.100	<.500	4.6	91	0.74	620	1.6	<2.00	<.500	<.200	19	68.4	<.500	62.9
LP3BS03	<2.00	<.200	<2.00	1.3	<.100	<.100	<.500	4.2	120	0.48	406	1.5	<2.00	<.500	<.200	11	25.2	<.500	61.4

Appendix - Table A 23. Trace element concentrations (in µg/g) in livers from pre-fledged juvenile Canada geese, blue-winged teals, American avocets, and black-necked stilts collected from the LARCO refinery process water ponds, Casper, Wyoming.

Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Blue-winged Teal																			
LP1BWTL3	<2.00	<.200	<2.00	0.3	<.100	<.100	<.500	30.7	2430	0.41	804	15	6	<.500	<.200	37	0.92	<.500	141
LP1BWTL5	<2.00	<.200	<2.00	<.200	<.100	<.100	<.500	22	587	0.42	841	12	3	<.500	<.200	23	0.92	<.500	106
LP2BWTL4	<2.00	<.200	<2.00	0.4	<.100	<.100	<.500	16	2930	0.2	836	17	4	<.500	<.200	21	0.88	<.500	116
LP3BWTL1	<2.00	0.3	3	<.200	<.100	<.100	<.500	24	1060	0.3	752	8.1	3	<.500	<.200	9.5	0.5	<.500	156
LP3BWTL2	<4.00	<.700	2	0.3	<.100	<.100	<.500	6.4	629	0.1	942	10	2	<.500	<.400	10	1.1	<.500	166
American Avocet																			
LP3AAL1	<2.00	0.5	3	<.200	<.100	<.100	<.500	13	609	0.32	926	12	<2.00	<.500	<.200	12	1.2	<.500	120
LP3AAL2	<2.00	0.4	4	<.200	<.100	<.100	<.500	9.3	834	0.2	828	12	<2.00	<.500	<.200	15	0.96	<.500	74.3
LP3AAL3	<2.00	0.2	<2.00	<.200	<.100	<.100	<.500	13	874	0.47	830	14	3	<.500	<.200	17	0.69	<.500	107
LP3AAL4	<2.00	<.200	3	<.200	<.100	<.100	<.500	9	367	0.3	907	13	<2.00	<.500	<.200	12	0.63	<.500	113
LP3AAL5	5	0.3	3	<.200	<.100	<.100	<.500	9.4	555	0.2	884	13	<2.00	<.500	<.200	13	0.88	<.500	114
Canada Goose																			
LP3CGL1	<2.00	<.200	2	0.2	<.100	<.100	<.500	54.8	319	<.100	644	9.1	2	<.500	<.200	4.6	1.2	<.500	145
LP3CGL2	<2.00	<.200	3	<.200	<.100	<.100	<.500	44.1	343	<.100	579	7.1	<2.00	<.500	<.200	4.8	0.2	<.500	148
LP3CGL3	4	<.200	3	<.200	<.100	<.100	<.500	28	706	<.100	619	9.5	<2.00	<.500	<.200	4.2	0.3	<.500	138
LP3CGL4	<2.00	<.200	3	<.200	<.100	<.100	<.500	39.8	527	<.100	614	9.3	2	<.500	<.200	4.9	0.2	<.500	196
LP3CGL5	<2.00	<.200	3	<.200	<.100	<.100	<.500	48.7	454	<.100	602	8.6	2	<.500	<.200	4.3	<.200	<.500	122

Appendix - Table A 24. Trace element concentrations (in µg/g) in gastrointestinal tract contents from pre-fledged juvenile Canada geese, blue-winged teals, and American avocets collected from the LARCO refinery process water ponds, Casper, Wyoming.

Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Blue-winged Teal																			
LP1BWGI5	267	0.258	18.7	1.81	<.0833	<.0250	0.832	1.96	302	<.0417	124	2.81	0.682	1.14	0.362	1.21	1.16	0.642	3.46
LP2BWGI4	249	0.227	4.92	3.19	<.0893	<.0268	<.446	<.446	238	<.0446	96.6	2.8	0.544	0.376	0.612	0.544	1.49	0.532	1.95
LP3BWGI1	248	0.33	10.8	2.78	<.0906	<.0272	0.787	<.453	375	<.0453	140	3.38	0.107	0.297	0.465	0.516	1.28	0.564	1.83
LP3BWGI2	319	0.455	12.9	3.42	<.0980	<.0294	<.490	<.490	463	<.0490	196	5.62	0.102	0.461	0.612	0.669	4.07	0.653	3.01
American Avocet																			
LP3AAGI1	370	1.07	28.1	2.7	<.0936	0.038	0.655	1.19	561	<.0468	521	15.2	0.718	0.551	0.695	0.694	16.3	1.01	7.55
LP3AAGI2	503	1.16	92.8	4.95	<.124	0.084	0.996	3.08	409	<.0622	437	23.6	1.21	0.947	2.04	2.35	13.6	1.34	13.6
LP3AAGI3	106	0.534	13.5	3.23	<.0936	<.0281	<.468	0.881	227	<.0468	131	4.07	0.33	0.557	0.477	0.619	6.26	0.386	5.54
LP3AAGI4	240	0.463	13.7	3.98	<.0862	<.0259	0.644	0.811	242	<.0431	205	7.43	0.227	0.28	0.672	0.763	7.31	0.462	2.32
LP3AAGI5	370	0.371	13.6	24.1	<.0909	<.0273	0.468	<.454	466	<.0455	164	6.54	0.106	0.239	1.28	0.73	14.3	0.633	2.07
Canada Goose																			
LP3CGGI3	883	0.61	1.27	33.8	<.0856	<.0257	0.769	2.38	494	<.0461	133	7.84	0.203	0.828	1.38	0.719	2.71	1.33	3.34
LP3CGGI4	1151	0.756	1.94	56.8	<.0893	<.0268	0.831	0.883	752	<.0446	177	15	0.31	0.819	1.96	1.04	8.5	1.92	4.51
LP3CGGI5	276	0.355	2.18	6.35	<.0996	<.0299	0.553	0.605	326	<.0498	223	6.99	0.412	0.599	0.759	0.788	2.18	0.604	2.78

Appendix - Table A 25. Polycyclic aromatic hydrocarbon metabolites in bile from blue-winged teal, Canada geese, and American avocets collected from the LARCO refinery process water ponds, Casper, Wyoming and from American avocets collected from a reference site at Steamboat Lake, Pathfinder National Wildlife Refuge, Wyoming.

Sample ID	Site	benzo(a)pyrene	naphthalene	phenanthrene
Blue-winged Teal				
LP1BWTB3	LARCO Pond 1	4.1	490	320
LP1BWTB5	LARCO Pond 1	2.8	380	190
LP2BWTB4	LARCO Pond 2	1.7	160	98
LP3BWTB1	LARCO Pond 3	0.4	72	15
LP3BWTB2	LARCO Pond 3	2	12	120
Canada Goose				
LP3CGB2	LARCO Pond 3	6	80	11
LP3CGB3	LARCO Pond 3	0.5	50	7
LP3CGB4	LARCO Pond 3	0.3	54	8
LP3CGB5	LARCO Pond 3	6	65	9
American Avocet				
LP3AAB1	LARCO Pond 3	0.5	45	10
LP3AAB2	LARCO Pond 3	0.4	48	14
LP3AAB3	LARCO Pond 3	1.3	37	10
LP3AAB4	LARCO Pond 3	0.7	42	12
LP3AAB5	LARCO Pond 3	0.3	26	7
American Avocet (Reference Site)				
PFRAAB2	Pathfinder NWR	0.1	120	23
PFRAAB4	Pathfinder NWR	0.4	230	18
PFRAAB5	Pathfinder NWR	0.2	190	16