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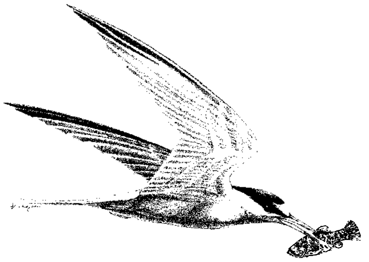
Fish and Wildlife Service
Region 2

Investigation of the Role of Environmental Contaminants upon Ecological Sentinel Species and Their Habitats at Bitter Lake National Wildlife Refuge, New Mexico



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DISCLAIMER

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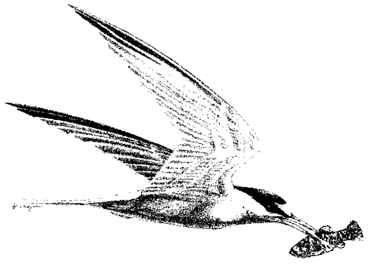
Investigation of the Role of Environmental Contaminants upon Ecological Sentinel Species and Their Habitats at Bitter Lake National Wildlife Refuge, New Mexico.

MacRae, R. K., J.D. Lusk, and W.R. Radke.

EXECUTIVE SUMMARY



During the summers of 1996 and 1997, the U.S. Fish and Wildlife Service, New Mexico Ecological Services Field Office collected 139 biologic and substrate samples, and 27 filtered water samples for a variety of inorganic and organic chemical analyses. Our objectives were to identify chemicals in the environment that may reduce reproductive success of interior least terns, and provide baseline contaminant data at Bitter Lake National Wildlife Refuge (Refuge) in southeastern New Mexico. We analyzed water, sediment, and biota for inorganics, aliphatic hydrocarbons, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and organochlorine insecticides.

Aluminum, cadmium, lead, selenium, and mercury concentrations were elevated in water samples when compared to regional averages. Aluminum, boron, mercury, selenium, and zinc were the only elements in plants, invertebrates, fish, or eggs that exceeded literature-based thresholds for adverse health effects. Lake St. Francis contained biota that had greater concentrations of copper, selenium, and zinc than at other sites, although sediment metal concentrations were low. Hunter Marsh, which historically received municipal wastewater, contained sediment and biota with elevated concentrations of lead and mercury.

No organic chemicals were detected in water, but several organics were found in sediments from the mouth of Lost River at Bitter Creek and in Hunter Marsh, and in fish collected at Hunter Marsh. The remaining areas of the Refuge were relatively contaminant free. Although PCBs and organochlorines were not measured in Lost River sediments, fish contained only trace concentrations of these compounds. Several PAHs were measured in sediments in Hunter Marsh at concentrations as high as 20 mg/kg dry weight (parts per million, ppm), which could adversely impact invertebrate communities and wildlife that forage there regularly. Fish from Hunter Marsh also contained total PCBs at concentrations up to 5 ppm dry weight. A diet that contains greater than 0.1 ppm total PCBs can have adverse effects on wildlife. Hunter Marsh contains contaminated sediments, invertebrates, and fish that when consumed regularly by local wildlife could result in adverse health effects. Additional sampling is required in Hunter Marsh to determine the extent of contamination, and if remedial action is warranted.

INTRODUCTION

The Refuge is located approximately 10 miles (mi) (16 kilometers) [km] northeast of Roswell, in Chaves County, New Mexico, in the Lower Pecos Valley (Figure 1)[1]. The 24,536 acre (ac) (9,929 hectare) [ha] Refuge was established by Executive Order 7724, dated October 8, 1937 "...as a refuge and breeding ground for migratory birds and other wildlife." The Refuge is divided into three special management areas along the Pecos River (Figure 2). On the North Unit, the 9,620-acre (3,893- hectare) Salt Creek Wilderness was established to protect native grasses, sand dunes, brush bottomlands, and a deeply eroded red bluff along its northern boundary.

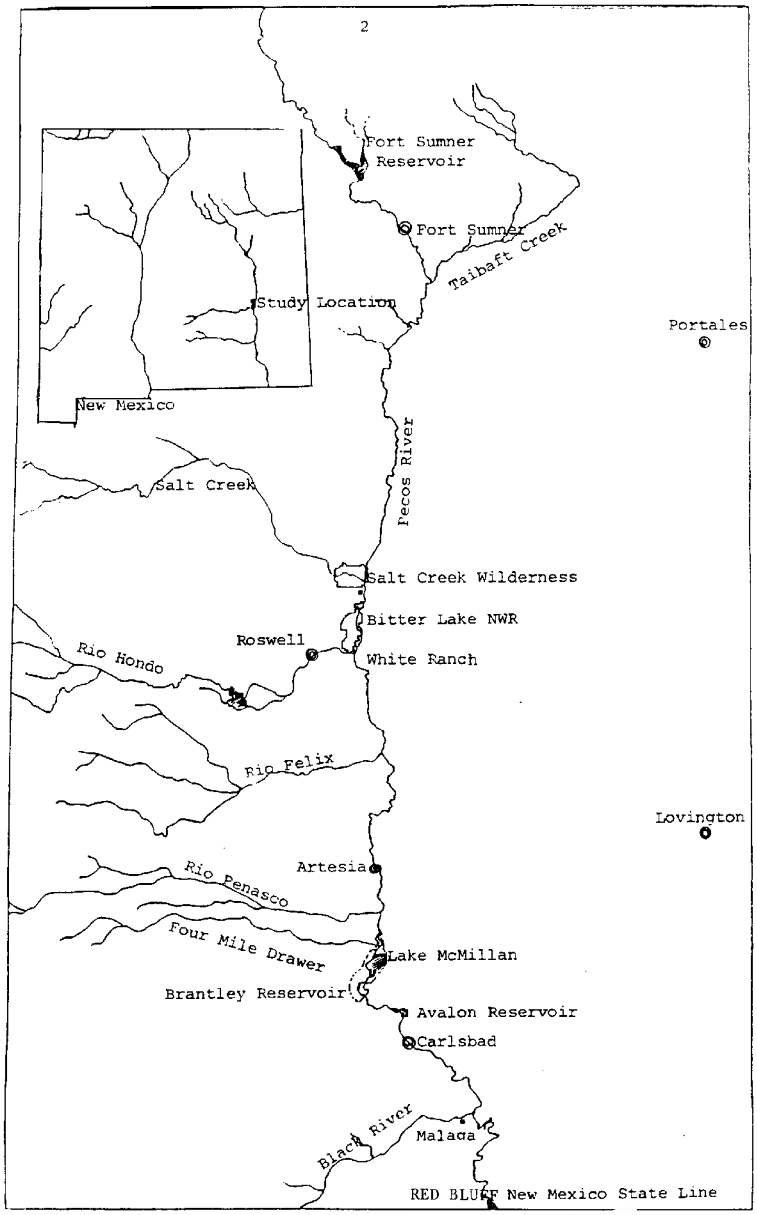


Figure 1. Map of Pecos River watershed in New Mexico.

The Middle Unit contains several impoundments and natural wetlands, desert upland, riparian areas, and agricultural croplands. The 300-acre (121- hectare) Bitter Lake Research Natural Area is located one mile north-northwest of Refuge headquarters, and is dominated by the Bitter Lake playa. In winter, large numbers of waterfowl, cranes, and migratory shorebirds inhabit the lake, and species such as the snowy plover (*Charadrius alexandrinus*) and federally-listed endangered interior least tern (*Sterna antillarum*) nest there. These aquatic systems, along with several associated sinkholes, provide unique habitat for three uncommon native fish species: the federally-listed endangered Pecos gambusia (*Gambusia nobilis*), the greenthroat darter (*Etheostoma lepidum*), and the Pecos pupfish (*Cyprinodon pecosensis*). Koster's spring snail (*Tyronia kosteri*), Roswell pyrg snail (*Pyrgulopsis roswellensis*), Pecos assiminea (*Assiminea pecos*), and Noel's amphipod (*Gammarus desperatus*) are relict species once associated with Permian shallow seas, which covered the area. Some of these species are now found only on the Refuge.

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[1] Unless noted otherwise, the background information presented here is from the 1997 Bitter Lake National Wildlife Refuge (NWR) Annual Report (BLNWR 1997).

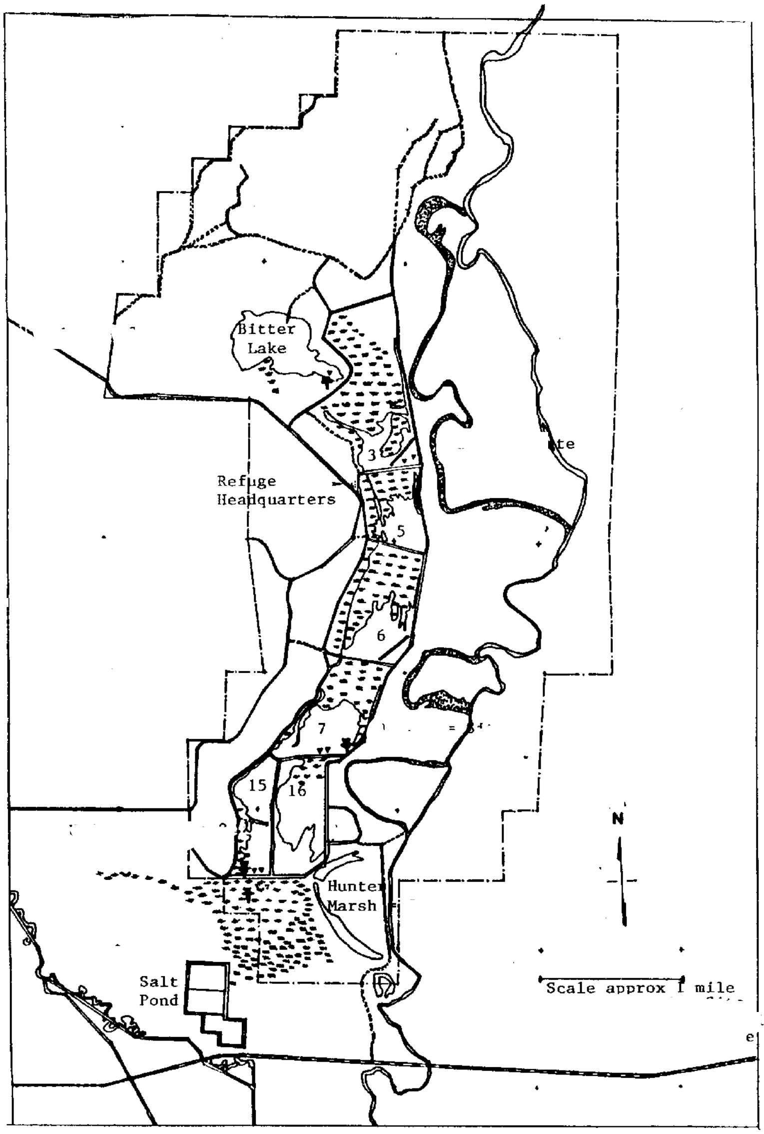


Figure 2. Bitter Lake National Wildlife Refuge middle management units.

Hunter Marsh is a shallow wetland located at the south end of the Middle Unit. Here, emergent vegetation such as reed (*Phragmites australis*), alkali bulrush (*Scirpus maritimus*), the federally-listed threatened Pecos sunflower (*Helianthus paradoxus*), and salicornia is bisected by numerous shallow, sediment-rich stream channels which begin as springs and ultimately flow east into the Pecos River. There are two historical contaminant sources to Hunter Marsh. Effluent from the City of Roswell's Water Treatment Facility was discharged into Hunter Marsh until 1981, and lead shotgun shells were used to hunt birds until 1986, when nontoxic shells were required for hunting on national wildlife refuges nationwide.

The South Unit is closed to public access, and serves as a major food production area for wildlife in the Pecos Valley. It is surrounded by private lands used for agricultural production, dairy farming, and cattle grazing. Here, Refuge cropland and seasonally flooded ponds are managed to provide food and shelter for a variety of fish and wildlife. While the Refuge was originally established to conserve wetlands vital to the migratory birds, the isolated gypsum springs, seeps, and associated wetlands protected by the Refuge have been recognized as the last known habitats in the world for several unique species (discussed below). Other special management areas include the 10,090-acre (4083-hectare) Bitter Lake Group National Natural Landmark, the 700-acre (283-hectare) Lake St. Francis Research Natural Area, and the 2-acre (0.8-hectare) Inkpot Research Natural Area. Overall, the management emphasis on the Refuge is the protection and enhancement of habitat for imperiled species.

Study Management Objective(s)

- Identify chemicals that may contribute to reduced hatching and fledgling success of the federally-listed endangered interior least tern, which nests along the shorelines of alkaline playa lakes at the Refuge.

- Identify chemicals that may contribute to adverse health effects in piscivorous raptors.

- Provide baseline data concerning the whole-body concentrations of contaminants in Pecos pupfish.

- Provide data for the Pecos Ecosystem Team concerning contaminant concentrations in various physical and biological media as benchmark references for the development of a management plan for the Pecos Ecosystem. These data will establish baseline conditions prior to any gas and petroleum development in the area.

Scientific/Technical Objective(s)

- Document contaminant concentrations in primary food items (small fish) that adult interior least terns feed their hatchlings.

- Document contaminant concentrations in habitats used by native species, and in representative components of the ecological food chain (e.g., water, sediment, plants, invertebrates, fish) that contribute to the quality of fish consumed by piscivorous birds.

- Determine if contaminants in the diet of interior least tern nestlings at the Refuge correlate with observed poor fledgling success.

Geology and Hydrology

Upstream of the Refuge, the Pecos River enters a basin dominated by evaporitic sedimentary rocks. Salinity in the Pecos River and Refuge water bodies greatly increases below this point due to geologic-based salt loading and high evaporation rates. Refuge water bodies include isolated oxbow lakes, a large playa lake, several developed impoundments, artesian springs, and 60 sinkholes formed by the dissolution of underlying carbonate formations. To help control salinity, and manage Refuge waters for a diversity of fish and wildlife, lake levels have been manipulated since 1994 to flush accumulated salts and concentrate forage for migratory birds. For example, many of the lakes are purposely kept low during hot summer months to expose mud flats for shorebird forage and for nesting. Some are also kept low during winter months to provide shallow roosting areas for cranes and geese.

At the northern end of the Refuge is the Salt Creek Wilderness. Historically, this area had a higher water table, Salt Creek flowed perennially into the Pecos River, seasonal wetlands were more expansive, and at least some of the area's sinkholes overflowed to create additional wetland acreage. Water levels in many of the sinkholes have drastically declined from 1950 to the late 1970s, concentrating salts, selenium (Se), and other contaminants. For example, water levels in the Inkpot, a vertical-walled sinkhole 150 feet (46 meters) in diameter, have declined to approximately 18 feet (5.5 meters) below the rim. Interestingly, the Inkpot contains rare populations of the marine algae *Bataphora oerstedii* and endangered Pecos gambusia. Farther to the south is the 700-acre (283-hectare) Lake St. Francis Research Natural Area, which contains the refuge's largest sinkhole, Lake St. Francis (200 feet [61 meters] wide and 60 feet [18 meters] deep). Water levels in some of the sinks are slowly rising due to reduced groundwater withdrawals (Balleau Groundwater Inc. 1999).

The Bitter Lake Research Natural Area in the Refuge Middle Unit is dominated by Bitter Lake, which ranges from 0 - 4 feet (0 - 1.2 meters) deep. It receives water from Bitter Creek, Lost River, Dragonfly Spring, and Sago Spring on its west side. Bitter Creek is especially important ecologically due to the large number of rare and endemic species within its drainage. As in most water-bodies in this part of the Refuge, water levels depend on local groundwater flows, which in turn depend upon precipitation and water use many miles to the west and north. Although some of the small sinkholes in the west part of the Research Natural Area have dried up and flow from springs and creeks decreased, recent salt cedar (*Tamarix spp.)* removal has resulted in rising water levels in many areas.

Land Uses

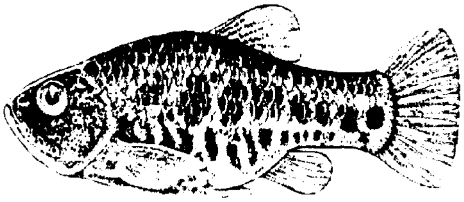
Refuge land-management activities emphasize the control of salt cedar, a non-native invader of wetlands, grasslands, and riparian areas. The primary objectives of salt cedar removal are: (1) restoration of historical water levels, and (2) protection and enhancement of native plant and animal species abundance and diversity. Integrated Pest Management techniques (e.g., planting different crop/plant species together to discourage large-scale pest invasion) are used extensively to minimize pesticide application, and cow manure is used as the primary fertilizer (liquid fertilizers were used prior to 1995). Commercial dairy farming occurs adjacent to the west and south boundaries of the Refuge's South Unit, while livestock grazing is the dominant use on private and federally-owned lands adjacent to all other Refuge boundaries. The Bureau of Land Management (BLM) permits extensive natural gas extraction in the Pecos River flood plain just north of the boundary of the Refuge's Middle Tract.

Fire

Fires in the Southwest are a natural part of a grassland ecosystem, and most species within this ecosystem are adapted to periodic fire disturbance. However, a March 2000, wildfire burned roughly 1,000 acres (405 hectares) of the Refuge, including several sensitive habitats with species at the verge of extinction. The fire extended from Bitter Creek Road on to the southwest side of Bitter Lake, and resulted in a near complete burn of vegetation bordering Bitter Creek from Dragonfly Spring to Bitter Lake (the area around Sago Spring did not burn). Bitter Creek provides key habitat for Koster's tyronia springsnail, Pecos gambusia, the Roswell springsnail, Pecos assiminae snail, and Noel's amphipod. The fire itself had only limited impacts. However, ash, sediment, and salts flushed into the system by heavy precipitation events have caused decreases in dissolved oxygen and increases in turbidity, sedimentation, salinity, and temperature. Although vegetation is returning and moderating stream siltation and water chemistry changes, water quality and biological monitoring of Bitter Creek is ongoing.

Biodiversity

The Refuge provides habitat for at least 351 bird species, 57 mammal species, 50 reptile and amphibian species, and 24 fish species. Along with common, abundant species, the Refuge harbors five species federally listed species: Pecos bluntnose shiner (Notropis simus pecosensis),.Pecos gambusia, interior least tern, bald eagle (Haliaeetus leucocephalus), brown pelican (Pelicanus occidentalis) (Table 1). An additional 16 plant and animal species on the Refuge are listed by the State of New Mexico as endangered. These include Noel's amphipod, Pecos assiminea, Roswell pyrg snail, Koster's spring snail, Mexican tetra (*Astyanax mexicanus*), Pecos pupfish, greenthroat darter, river cooter (*Pseudemys gorzugi*), ribbon snake (*Thamnophis proximus*), American peregrine falcon (*Falco peregrinus anatum*), neotropic cormorant (*Phalacrocorax brasilianus*), Baird's sparrow (*Ammodramus bairdi*), Bell's vireo (*Vireo bellii*), least shrew (*Cryptotis parva*), and the Pecos sunflower (*Helianthus paradoxus*).



Cyprinodon pecosensis

Fish & Invertebrates

The system of springs, sinkholes, and other wetlands on the Refuge support the most significant remaining populations of Pecos pupfish, Pecos gambusia, greenthroat darter, rainwater killifish (*Luciana parva*), roundnose minnow (*Dionda episcopa*), plains killifish (*Fundulus zebrinus*) and numerous rare and/or endemic species of aquatic snails. Four of these species, the Say's pond snail (*Stagnicola caperata*), Pecos assiminea, Roswell pyrg snail, and Koster's spring snail, have been documented on the Refuge. Say's pond snail was documented in the northwest portion of Hunter marsh as recently as the 1980s, but now appears to be locally extinct. This area of the Refuge is where treated municipal wastewater historically entered Refuge wetlands. Mosquitofish (*Gambusia affinis*), which are native to the Refuge, are the primary prey taken by smaller piscivorous birds such as belted kingfisher (*Caryle alcyon*) and least terns (*Sterna antillarum*).

Reptiles and Amphibians

At least 12 species of amphibians and 40 species of reptiles have been documented on the Refuge. Contaminant-related deformity among amphibians is unknown. The most common amphibian species on the Refuge is the Texas toad (*Bufo speciosus).* Fourteen snake species were identified from 1996 to1997, with coachwhips (*Masticophis flagellum*) being the most common and widespread.

Table 1. Federal and State listed species that occur at the Refuge.

Status	**Common Name**	**Scientific Name**	**Occurrence**
T	Pecos sunflower	*Helianthus paradoxus*	resident
NME	Wrinkled marsh snail	*Stagnicola caperata*	resident
CA/NME	Pecos assiminea snail	*Assiminea pecos*	resident
CA/NME	Koster's tryonia	*Tryonia kosteri*	resident
CA/NME	Roswell Pyrg snail	*Pyrgulopsis roswellensis*	resident
NME	Noel's amphipod	*Gammarus desperatus*	resident
NMT	Mexican tetra	*Astyanax mexicanus*	resident
T/NMT	Pecos bluntnose shiner	*Notropis simus pecosensis*	resident
CA	Pecos pupfish	*Cyprinodon pecosensis*	resident
End/NME	Pecos gambusia	*Gambusia nobilis*	resident
NMT	Greenthroat darter	*Etheostoma lepidum*	resident
NMT	Western river cooter	*Pseudemys gorzugi*	resident
NMT	Arid land ribbon snake	*Thamnophis proximus*	resident
End/NME	Brown pelican	*Pelicanus occidentalis*	migrant
NMT	Neotropic cormorant	*Phalacrocorax olivaceus*	migrant
NMT	Am. peregrine falcon	*Falco peregrinus anatum*	migrant
End/NMT	American bald eagle	*Haliaeetus leucocephalus*	migrant
End/NME	Interior least tern	*Sterna antillarum athalassos*	breeding
CA	Mountain plover	*Charadrius montanus*	migrant
End/NME	Southwest willow flycatcher	*Empidonax traillii*	migrant
NMT	Bell’s vireo	*Vireo bellii*	migrant
NMT	Baird's sparrow	*Ammodramus bairdi*	migrant
NMT	Least shrew	*Cryptotis parva*	resident

Key: End - federally endangered, T - federally threatened, CA - Federal candidate species, NME - New Mexico endangered, NMT - New Mexico threatened, PE - proposed listing as federally endangered.

Mammals

The Refuge is situated within the transition zone between the Chihuahuan Desert and Great Plains, and has a high diversity, but low density, of small mammals. At least 57 mammal species have been documented on the Refuge, including the state endangered least shrew (*Cryptotis parva*). Raccoons (*Procyon lotor*), bobcats (*Lynx rufus*), and coyotes (*Canis latrans*) are abundant, while mustelids of all species appear rare.

Migratory Birds

The Refuge lies within the Central Flyway and is part of a complex of several thousand playa lakes found in New Mexico, Colorado, Texas, and Chihuahua, Mexico. The Refuge provides a staging area for thousands of migrating waterfowl during winter, and supports hundreds of nesting shorebirds in summer. Among the several significant species the Refuge supports are globally significant numbers of interior least tern, western snowy plover, snow geese (*Chen caerulescens*) and sandhill cranes *(Grus canadensis*). The largest breeding colony of snowy plovers in New Mexico occurs at the Refuge.

The Refuge and adjacent public lands are the only known sites in New Mexico where interior least terns nest, and Refuge management has emphasized recovery of this species. This species was federally listed as endangered in 1985 due to serious population declines throughout their geographic range. Three of the problems impacting least terns at the Refuge have been overall low numbers of nesting birds, low nesting success, and low fledgling survival. Recruitment has been documented at less than or equal to 50 percent, and tern chicks have been found dead on at least one occasion. Since 1994, least tern management emphasis has been on manipulating water levels to concentrate small forage fish during nesting and fledgling periods. Refuge biologists are concerned that contaminants may also contribute to poor reproductive success.

At least 34 waterfowl species have been regularly documented, including the snow goose (*Chen caerulescens),* Ross' goose (*Chen rossii),* Northern pintail (*Anas acuta*), ruddy duck (*Oxyura jamaicensis*), American wigeon (*Anas americana*), and green-winged teal (*Anas crecca*). Mallard (*Anas platyrhynchos*), and gadwall (*Anas strepera*) are common nesting species. Waterfowl feed on aquatic invertebrates (e.g., bloodworms, amphipods, snails), and vegetation (e.g., salicornia (*Salicornia spp.**), alkali bulrush (*Schoenoplectus maritimus*), smartweed (*Polygonum lapathifolium*).

A total of 26 raptor species have been documented. Common species include the osprey, turkey vulture (*Cathartes aura*), Northern harrier (*Circus cyaneus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*), American kestrel (*Falco sparverius*), barn owl (*Tyto alba*), Cooper's (*Accipiter cooperii*) and sharp-shinned hawks (*Accipter striatus*), and great horned owl (*Bubo virginianus*). American peregrine falcons are seen on the Refuge during the spring and fall, and bald eagles are occasional visitors during fall and winter. The lack of roost sites and large reservoirs in the vicinity of the Refuge limit bald eagle and other large raptor nesting.

The Refuge provides some of the most important habitat in New Mexico for approximately 36 different species of migrating shorebirds, with as many as 2,500 birds in the spring and autumn. Common species include the western sandpiper (*Calidris mauri*), least sandpiper (*Calidris minutilla*), long-billed dowitcher (*Limnodromus scolopaceus*), white-faced ibis (*Plegadis chihi*), neotropic cormorants, American white pelicans (*Pelecanus erythrorhynchos*), and large populations of snowy egrets (*Egretta thula*) (373 in August 23, 1997). Numerous other marsh and water birds are also common, including cranes, egrets, gulls, herons, ducks, and grebes. Nesting species include the American avocet (*Recurvirostra americana*), black-necked stilt (*Himantopus mexicanus*), and snowy plover. A key food item eaten by migrating shorebirds is chironomid larva (bloodworms), which are abundant in wetland sediments.

Plants

Some of the sinkholes, including Lake St. Francis, contain the only known inland population of the marine green algae *(Bataphora oerstedii)*. The occurrence of this algae demonstrate the significance of this area as relict habitat for species common when shallow seas covered this part of New Mexico. Terrestrial vegetation on the Refuge is mixed Chihuahuan shrub/grassland, and grasslands comprise nearly half of all Refuge lands. Riparian vegetation is confined to a narrow band adjacent to water courses, and is composed primarily of willows and exotic salt cedar, and cottonwoods (*Populus spp.*) and cattails (*Typha spp.*) in scattered patches near freshwater springs. The federally listed Pecos sunflower is common on the Refuge and competes well with other vegetation in burned areas or lands recently cleared of salt cedar.

Historical and Ongoing Water Quality Monitoring

Basic Water Chemistry

Since 1996, temperature, salinity, and conductivity have been measured monthly at 14 Refuge wetlands (Table 2). Water management techniques have dramatically reduced the salinity of every impoundment, and removal of salt cedar from sinkholes and riparian corridors has increased flow and helped remove surface salt encrustations.

Table 2. Monthly salinity (in part per thousand [PPT]) during 1997 at 14 Refuge wetlands.

SITE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S20	7.3	6.9	7.2	6.9	6.5	6.9	6.6	7.6	6.1	6.5	5.4	1.7
LR	5.2	6.0	5.3	5.3	5.4	5.4	5.1	4.6	3.5	5.2	2.6	1.7
BC	5.3	6.0	5.3	5.1	4.8	5.5	4.1	5.2	3.8	4.6	2.7	1.4
BL	32.5	19.2	15.4	29.9	24.4	28.8	32.6	19.7	>	>	13.6	10.2
U-3	5.1	7.1	6.4	11.2	12.3	12.2	5.2	4.4	5.1	5.8	2.4	1.0
U-5	4.0	4.4	4.8	8.1	8.5	9.1	9.4	8.3	7.7	5.4	2.6	0.8
U-6	4.4	5.4	4.8	7.3	8.1	6.8	2.9	3.2	5.5	5.5	3.1	0.8
U-7	4.5	5.1	5.5	6.0	6.9	7.6	7.9	7.8	6.6	5.0	3.7	0.7
U15	4.1	5.5	5.3	4.5	5.3	6.2	5.7	4.2	4.4	3.8	5.2	0.8
U16	7.1	7.1	7.6	6.9	7.6	7.6	14.1	16.9	7.3	7.2	5.5	1.1
HM	4.4	5.9	5.8	8.0	5.6	6.5	5.7	4.3	4.2	3.9	4.9	0.9
SW	5.4	6.9	5.9	7.1	7.0	7.4	5.6	5.1	7.4	4.3	5.1	1.0
WE	3.8	4.0	3.9	3.8	3.8	4.0	3.9	3.7	3.7	3.4	2.0	1.3
OX	11.3	9.5	11.3	11.1	11.9	12.3	16.0	10.4	11.1	10.1	2.9	1.5

Key: S20 = Sinkhole 20, LR = Lost River, BC = Bitter Creek Weir, BL = Bitter Lake, U-3 = Unit-3, HM = Hunter Marsh, SW = South Weir, WE = Well 4691 Outflow, OX = Isolated Pecos River Oxbow East of HQ, > = salinity too great to measure.

Water quality readings were also taken from 69 Refuge sinkholes on both the North Tract and

Middle Tract during June and July of 1997 by an AmeriCorps biologist and various Youth Conservation Corps staff. A Hydrolab Scout-2 water quality system was used to document temperature, conductivity, dissolved oxygen (DO), pH, salinity, and the percent saturation of DO from each sinkhole. On the North Tract, salinity ranged from a low of 4.7 ppt (sinkhole #W9) to a high of 62.7 ppt (sinkhole #W12); DO ranged from 2.56 mg/L (sinkhole #W7) to 8.06 mg/L (sinkhole #W16); and pH ranged from 7.52 (sinkhole #W6) to 8.58 (sinkhole #W14). On the Middle Tract, salinity ranged from 4.1 ppt (sinkhole #38) to 60.5 ppt (sinkhole #21); DO ranged from 0.16 mg/L (sinkhole #44) to 10.21 mg/L (sinkhole #28); and pH ranged from 7.11 (sinkhole #34) to 8.92 (sinkhole #28). About 50 percent of all sinkholes on both the North Tract and the Middle Tract contain fish. Sinkhole #W9 is the only sinkhole on the entire Refuge having cattails growing in it, indicating a fresh water influence.

Groundwater samples were collected in 1997 by GeoScience Technologies of Roswell, New Mexico, from Lost River, Sago Spring, and Well RA-4691, and analyzed at the New Mexico Bureau of Mines and Technology Chemistry Lab in Soccorro, New Mexico (Table 3).

Table 3. Water chemistry of three sites on Bitter Lake NWR.

ANALYSIS	LOST RIVER	SAGO SPRING	RA-4691
pH	6.97	7.05	7.04
TDS (ppm)	6830	5100	4590
Conductivity (umhos/cm^2)	8200	6000	6000
Hardness ($CaCO_3$) (ppm)	2584	2416	1602
Bicarbonate (HCO_3) (ppm)	167	169	185
Chloride (Cl) (ppm)	2168	1588	1580
Sulfate (SO_4) (ppm)	2290	1770	1365
Nitrate (NO_3) (ppm)	3.4	4.5	<1.5
Sodium (Na) (ppm)	1320	760	960
Potassium (K) (ppm)	6.3	3.8	4.5
Magnesium (Mg) (ppm)	197	150	110
Calcium (Ca)(ppm)	710	720	460
Iron (Fe) (ppm)	0.09	0.06	0.13
Silica (SiO_2) (ppm)	48	19	17

Documented Contaminant Concerns

Potential contaminant sources in the area include irrigated agriculture, oil and gas production wells and pipelines, and historic municipal wastewater discharges to Hunter Marsh. A 1986 contaminants investigation conducted by the U.S. Fish and Wildlife Service (O'Brien 1990), identified elevated concentrations of selenium (Se) throughout the Refuge. Concentrations of Se in fish were high enough to suggest possible reproductive difficulties and health risks to birds consuming those fish. Polychlorinated biphenols (PCB) were detected in Hunter Marsh sediments at concentrations that may be high enough to pose a risk to fish and wildlife using this area. The organochlorine derivative of DDT, p,p'DDE, was detected in low to trace concentrations in fish from 4 of the 5 sites sampled. The parent compound, DDT, was not detected, suggesting that there are no continuing sources of DDT to the Refuge. Cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), and zinc (Zn) were elevated in Hunter Marsh sediment and biologic samples.

Oil and Gas Exploration and Production

There are three active oil wells and three active natural gas wells on the Refuge. Three of the six oil wells that were in production when the Service acquired the "Bitter Lake Oil Field" from the BLM in the late 1960s are still producing. The BLM continues to permit extensive natural gas development in the Pecos River flood plain just north of the boundary of the Refuge Middle Tract. In the summer of 1997, M.E.W. Enterprises of Midland, Texas (which has the oil lease on the Refuge Middle Tract), installed a gathering system to transport produced water and oil from leases located on the Refuge onto private property south of the Refuge. Fluids are now pumped to a central battery located off-Refuge, which greatly reduces the chance of any future spills and associated habitat damage on the Refuge. Three produced water storage tanks were also removed from the Refuge.

Minor oil spills within the holding berm of the oil tanks have, for the most part, been infrequent, with only one significant incident on November 22, 1997. Approximately 11 barrels of crude oil leaked from a broken pipe onto the Refuge in the NE 1/4 of Section 27. Since this spill was not a direct threat to a wetland area, it was simply plowed into surrounding soils and amended with "oil gator," a mixture of shredded paper, straw, and microorganisms that promote natural hydrocarbon breakdown. This same affected area has received spills in the past that were approximately 2-4 times larger than the current spill, with no record or sign of cleanup. Consequently, this area has crusted oil in spots that is void of vegetation. These prior spills were attributed to an old abandoned delivery line that was removed during the 1997 spill cleanup.

Other contaminant sources

Arroyo del Macho- Irrigated agriculture, grazing, oil, and natural gas wastes drain to Salt Creek.

Salt Creek- Natural gas pipeline, power line, and gas well.

Bitter Creek- Lowered water tables and subsequent increases in salinity, Se, and As.

Lost River- Same as Bitter Creek, plus nutrient inputs from septic tanks and feedlots.

Rio Hondo- Wastewater treatment point-source inputs, and agricultural, grazing, and oil and gas.

Feedlot/Dairy farms- Adjacent to south Refuge tract.

METHODS AND SAMPLE COLLECTION

During the summers of 1996 and 1997, the New Mexico Ecological Services Field Office collected 139 biologic or substrate samples and 27 0.45 µm filtered water samples for a variety of inorganic and organic chemical analyses. Of those collected, 33 samples were soil or sediment, 87 were animal tissue (fish, avian eggs, aquatic invertebrates), 19 were aquatic plants, and 27 were water.

Composite samples of sediment, plants, aquatic invertebrates (Physa snails or amphipods), water, whole-body fish, and avian eggs were collected from seven aquatic habitat locations (six study sites and two reference sites) (Figure 3, Table 4). At sample locations where many species of fish were available, composite samples of different species (e.g., common carp, mosquitofish, plains killifish) were collected. At the sites where unique and native fish were found, and Pecos pupfish predominate (Lake St. Francis, Sago Spring, Lost River, and Bitter Lake), all three whole-body fish samples consisted of ten adult Pecos pupfish within the same study site. Five of the seven study sites were identified as traditional interior least tern feeding areas.

Table 4. Samples collected and analytes measured.

	Water	Sediment	Plants	Inverts	Fish
Hunter Marsh	IN, A, OC, PAH	IN, A, PAH	IN	IN	IN, A, OC, PAH, PCB
Unit 16	IN, A, OC, PAH	IN, A, OC, PAH, PCB	IN	IN	IN
East Ditch	IN, A, OC, PAH	IN	IN	IN	IN, A, PAH
West Ditch	IN, A, OC, PAH	IN, A, PAH	IN	IN	IN, A, PAH
Bitter Lake	IN, A, OC, PAH	IN	IN	IN	IN, A, PAH
Sago Spring	IN, A, OC, PAH	IN	IN	IN	IN, A, PAH
Lost River	IN, A, OC, PAH	IN, A, OC, PAH, PCB	IN	IN	IN, A, OC, PAH, PCB
Lake St. Francis	IN, A, OC, PAH	IN, A, PAH, PCB	IN	IN	IN, A, OC, PAH, PCB

IN = inorganics (e.g., major cations, metals); A = aliphatics; OC = organochlorines; PAH = polycyclic aromatic hydrocarbons; PCB = polychlorinated biphenyls.

The two reference sites selected were Lake Saint Francis and the confluence of Bitter Creek and Lost River, on the basis that they were: (1) unique aquatic systems isolated from the other Refuge wetland units; (2) had a diversity of native species; and (3) were vulnerable to anthropogenic and hydrologic alterations (spills, pollution, ground water withdrawal), but were presumably not yet contaminated. These reference sites were also important because they had large populations of the endangered Pecos gambusia, so they would provide valuable baseline information.

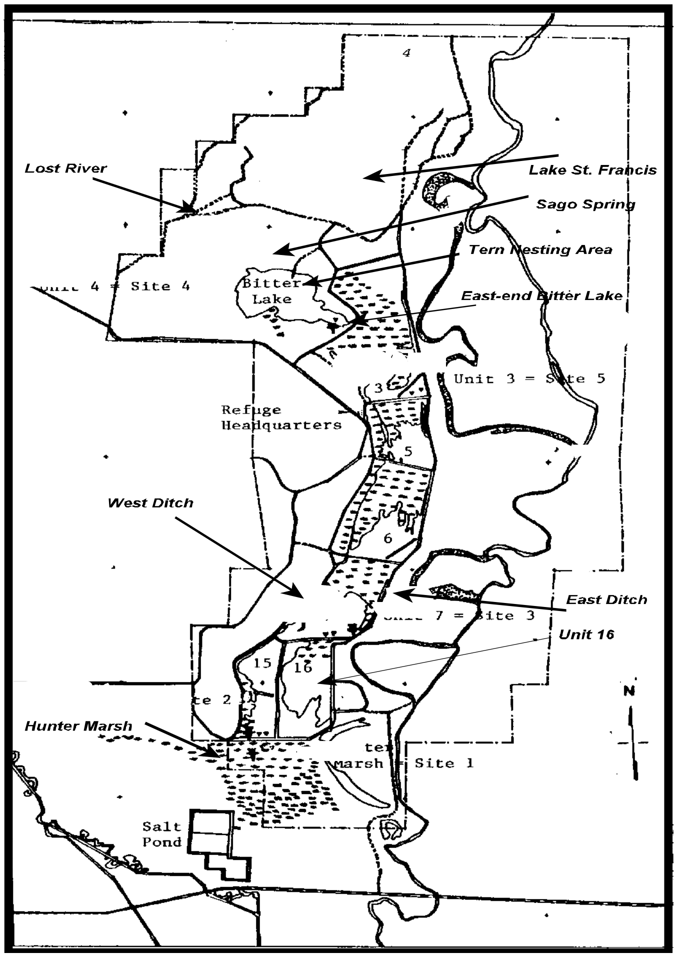


Figure 3. Sampling locations at the Refuge in 1996 and 1997.

Chemical Analyses

Water, sediment, fish, and eggs were scanned for inorganic compounds (major cations, trace elements, including aluminum (Al), iron (Fe), magnesium (Mg), arsenic (As), beryllium (Be), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn)), aliphatic compounds (long chain oils, waxes), polycyclic aromatic hydrocarbons (PAHs, coal resins, semivolatiles), polychlorinated biphenyls (PCBs), and organochlorine insecticides (DDT, DDE, Dieldrin, etc). All analytical work was conducted by laboratories contracted by the Service's Patuxent Analytical Control Facility. All elements excluding Hg, As, and Se were analyzed using Inductively Coupled Plasma Spectroscopy (ICP). Hg was analyzed using Cold Vapor Atomic Absorption (CVAA). As and Se were analyzed using Graphite Furnace Atomic Absorption (GFAA). Percent moisture was determined by oven-drying at 100° centigrade (C) for approximately 12 to 18 hours. A more detailed description of analytical methods for inorganics can be acquired from the Patuxent Analytical Laboratory, Laurel, Maryland. Quality assurance/quality control analyses included procedural blanks, duplicate sampling of a random set of samples, and an analysis of spike recoveries. In addition, an analysis of standard reference materials was also conducted for the inorganic results. All results reported and included in data analyses met laboratory quality assurance criteria.

Collection Methods

Sediment was collected using a stainless-steel spoon and mixing bowl at five locations within a site and composited. Sediment sampling also captured many small, indigenous spingsnails (see below). At some sites, there was such a local abundance of snails at these sites, that the shells of these snails made up a substantial portion of the sediment composition. Water was collected with a Geopump fitted with a 0.45 µm polycarbonate filter. Filtered water was placed in a container appropriate for the selected analysis (plastic containers for metal scans, colored glass containers for hydrocarbon scans, etc.), acidified with high purity nitric acid (if necessary) and chilled to 4°C. Plants were hand collected, washed in site water, then rinsed with distilled water in stainless steel bowls to remove any attached invertebrates or sediments.

Avian Egg Sampling

Eggs from avocets (6), interior least terns (3), and western snowy plovers (2) were collected from areas surrounding Bitter Lake, and three additional tern eggs were collected from the Unit 16 wetland. Eggs were weighed and measured, then placed in pre-cleaned glass containers.

Interior Least Tern Diet Sampling Methods

Sampling was based on observations of tern feeding behavior and habitats, including nesting locations, bird movements, and prey-base makeup. Small fish were the most frequently taken food item, so they were sampled for chemical analysis. Ecological risk to the terns was then calculated (see below) based on the contaminant concentrations measured in these dietary items. When terns were no longer actively feeding in an area, and moved on to new feeding locations, the abandoned area was seined or set with minnow traps to capture forage fish.

Pecos Pupfish and Pecos Gambusia Sampling Methods

Three samples of up to 20 pupfish each were weighed, measured, and composited. While these fish are rare regionally, they are locally abundant in the springs and pools on the Refuge. Live-catch methods were employed to minimize harm to non-target fish. Collection of Pecos pupfish was with baited minnow traps. To avoid the inadvertent capture of the Pecos gambusia (mosquitofish), we took advantage of the substrate-specific behavior of the pupfish. Pupfish prefer substrate whereas mosquitofish tend to stay at the water surface, so traps were submerged below the water surface to selectively capture pupfish. In addition, traps were deployed in the day, and checked regularly (about every 2 hours), to minimize inadvertent mosquitofish mortality. Fish were handled with nets and/or clean, wet hands to protect the fishes' slime layer.

Koster's tryonia, Pecos assiminea snail, and Roswell springsnail Sampling Methods

Spring snails were collected during sediment sampling. Other invertebrates collected included *Physa spp.* snails and amphipods. Invertebrates were collected by hand from either aquatic vegetation or sediments, using stainless steel forceps. Non-targeted species were released.

Ecological Risk Assessment

For both the osprey (a representative raptor species) and interior least terns, fish are primary prey items. Therefore, health risks from contaminants on the Refuge were evaluated by comparing mean, 95th percentile, and maximum metal and organic concentrations in fish tissues to published Toxicity Reference Values (TRVs) for adverse health effects in similar surrogate species (Table 5; USEPA 1998b). Food consumption rates and bird body weights were derived from the U.S. Environmental Protection Agency (USEPA) Wildlife Exposure Handbook (USEPA 1993). Assuming a “worst-case scenario” in which exposure duration is 365 days/year and 100 percent fish consumption, a contaminant intake rate was calculated, expressed as mg/kg/day.

Dividing the contaminant intake rate by the TRV yields a Hazard Quotient (HQ), where a HQ greater than 1.0 indicates a potential risk to that organism (see Equation 1). The HQ is an individual characterization of risk for a particular element. These individual characterizations can be excellent indicators of potential contaminant-related problems, but do not adequately express the combined risk from all elements. Therefore, from these individual element HQs, an aggregate Hazard Index (HI) was obtained, which shows the combined effect of contaminants, by adding together the individual element hazard quotients. If a HI is less than one, chronic adverse effects from ingestion of fish are unlikely to occur. The HI assumes that a threshold exists (i.e., HI greater than or equal to 1) below which exposure does not cause adverse effects. The HI used here assumes elements act additively, and does not take into account synergistic or antagonistic interactions between elements, or other more complex biological processes, such as organ transport.

Equation 1. Equation used to estimate daily contaminant intakes due to ingestion of fish.

$$\text{Intake} = \frac{C_m \times \text{FDIET} \times \text{EF}}{\text{BW} \times \text{AT}}$$

where:

Intake	contaminant intake rate (mg/kg-day)
C_m	contaminant m concentration in fish (mg/kg)
FDIET	Fraction fish ingestion (0 - 1)
EF	exposure frequency (days/year)
BW	body mass (kg)
AT	averaging time (days/year) - 365

Table 5. Toxicity Reference Values (TRVs) for elements used in risk assessment calculations and reference.

Element	TRV (mg/kg-day)	Reference
Arsenic (total)	5.140	Sample *et al.* 1996
Cadmium	1.450	Sample *et al.* 1996
Chromium (VI)	1.000	Sample *et al.* 1996
Copper	28.000	Chino ERA 1999
Lead	0.450	Sample *et al.* 1996
Mercury	1.130	Sample *et al.* 1996
Selenium	0.500	Sample *et al.* 1996
Vanadium	2.400	Chino ERA 1999
Zinc	14.500	Sample *et al.* 1996
p,p’ DDE	0.002	LANL Draft Ecorisk 1999
PCB- as Arochlor 1242	0.410	Sample *et al.* 1996
PCB- as Arochlor 1254	0.180	Sample *et al.* 1996
PAH- Naphthalene	0.139	LANL Draft Ecorisk 1999

RESULTS AND DISCUSSION

Inorganic Compounds[2]

Water

Concentrations of dissolved Al, Ca, and Mg in water were elevated compared to typical concentrations in other New Mexico freshwater environments. Although Al concentrations often exceeded chronic State of New Mexico Water Quality Criteria (WQC; NMWQCC 2000), and acute WQC in Bitter Lake, little is known about the adverse effects of Al at the very high hardness ([Ca]+[Mg]; approximately 2500 ppm) and pH common in the Southwestern United States. It is possible that the indigenous biota in this area have adapted to these elevated aluminum concentrations, and that as long as concentrations are not further elevated due to irrigation or other anthropogenic means, indigenous biota may not be at risk. Boron and Se in Bitter Lake water were also elevated (approximately 8 - 20 µg/L (ppb)), and could inhibit growth and survival of non-adapted plants, aquatic biota, and birds using this as a primary drinking water source. All other inorganics analyzed were at or below typical background concentrations and/or below levels of concern for fish and wildlife (based on comparisons to adverse effect thresholds in: Haines *et al.*1994, National Oceanic and Atmospheric Administration (NOAA) 1998, USEPA 1998a). Considering the high pH, alkalinity, and sulfate concentrations of these waters, most inorganics (especially metals) will precipitate, and remain suspended in the water-column in a particulate phase (i.e., greater than 0.45 µm), settle into the sediments, or, depending on the bioavailability, accumulate in biota.

Soils and Sediments

With the exception of Hunter Marsh, soils and sediments did not contain elevated concentrations of most inorganic constituents of concern (based on comparisons to adverse effect thresholds in Haines *et al.* 1994, NOAA 1998, MacDonald *et al.* 1999). Even Se in Bitter Lake sediments was less than 1 mg/kg dry weight (ppm dw), despite the elevated water concentration (Figure 4). This suggests that: (1) Se water concentrations are not consistently elevated, or (2) Se is rapidly sequestered in biota. Selenium in sediments from Sago Spring (max 5.6 ppm dw) and Lost River (max 3.0 ppm dw), however, were elevated, despite relatively low water Se concentrations (less than 5 µg/L [ppb]). In this case, there may be: (1) a low, but sustained input of Se, perhaps via groundwater, or (2) a predominance of particulate-bound Se (>0.45 µm). In Hunter Marsh, concentrations of Se and several metals were quite elevated, including Cr (III & VI), Cu, Hg, Pb, V, and Zn (Figures 4 and 5). These elevated concentrations are most likely a consequence of discharges to Hunter Marsh from the City of Roswell wastewater treatment plant (NPDES Outfall NM00203011) until 1981, and waterfowl hunting with Pb shot. These metals, acting individually or in combination, would be hazardous to fish and wildlife using this area on a regular basis (see discussion below in "*Ecological Risk Assessment*").

Soils and sediments from the Pecos River Basin are not known to be underlain with Cretaceous age soils, a known source of Se to biota. However, there is a ring of Se rich soils surrounding an ancient volcano eighty miles to the East. Precipitation infiltrating these Se-rich soils recharges the

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[2] Detailed tables of inorganic analytical results are presented in Appendix I.

Pecos River Basins groundwater, and is transported rapidly through the limestone aquifer where it emerges as springs on the Refuge. Thus, groundwater may play an important role in surface water quality and accumulation of inorganic contaminants in the biota in this region. For other metals, there is no known natural source that could explain the elevated concentrations in Hunter Marsh. This suggests that they are largely anthropogenic in origin.

Biota

Metal concentrations in invertebrates are at or below concentrations found in sediments from the same site (Figures 6 - 8). In general, metals in invertebrates increase proportionately with sediment concentrations. This may be due to bioaccumulation in tissues, and/or residual sediments remaining in the invertebrate gut. In either case, invertebrates represent a primary pathway for metal accumulation to animals feeding on them (e.g., fish, frogs, birds). Hunter Marsh is the only site that contained fish and invertebrates with noticeably elevated metal concentrations (Cr, Cu, Pb, V, Zn) compared to other sites sampled at the Refuge (Figures 9 and 10) and from around the United States (Table 6).

Concentrations of Cr and Pb in Hunter Marsh fish, however, were six times and nine times lower, respectively, than in fish analyzed in 1986 (O'Brien 1990). The reason for this decline is unknown, but may be due to the species, size, or age of fish analyzed, or a decrease in metal bioavailability (e.g., sequestration in deeper sediments). Lead and several other metals are accumulating in invertebrates and some fish in Hunter Marsh at concentrations higher than at any other site sampled, but below thresholds of dietary concern for fish and wildlife (see discussion below in "*Ecological Risk Assessment*").

Table 6. Refuge whole body fish trace-metal concentrations compared to typical concentrations in fish samples from the Southwest and Nationally (mg/kg *wet weight*).

Element	*USFWS[a] Southwest (± 2*Std. Error)*	*NCBP[b] 85th Percentile*	*Adverse Health Effect Threshold[c]*	*Bitter Lake NWR (mean [85th Percentile])*
Al	29.85 (± 11.42)	NA[d]	NA	13.7 (25.5)
As	0.16 (± 0.04)	0.27	0.50 (health impairment)	0.14 (0.22)
Cd	0.02 (± 0.01)	0.05	0.10 (reproductive impairment)	0.01 (0.01)
Cu	1.68 (± 0.32)	1.00	NA	2.39 (5.18)
Pb	0.10 (± 0.04)	0.22	NA	0.07 (0.05)
Hg	ND	0.17	0.50 (health impairment)	0.02 (0.03)
Se	1.04 (± 0.19)	0.73	0.6 (health impairment)[e]	2.64 (6.54)
Zn	23.09 (± 2.16)	34.20	NA	36.0 (47.7)

a Samples collected by Service Contaminant Programs in Nevada, New Mexico, and Utah.

b Schmitt and Brumbaugh (1990), National Contaminant Biomonitoring Program (NCBP).

c Irwin (1998); The "Adverse Effect Threshold" is the approximate concentration that has been associated with various sublethal impairments to the fish, such as decreased reproductive capacity or growth.

d NA = Not Available.
e Lemly (1993).

Zn is also elevated in two samples of water-boatmen collected from Hunter Marsh, and is consistently elevated in most other invertebrates and fish sampled throughout the Refuge (especially Lake St. Francis). Likewise, Cu concentrations in whole body fish are consistently elevated (again, highest in Lake St. Francis). Zn and Cu concentrations in fish are above typical values for trout sampled in New Mexico (Table 6), although still below bird dietary threshold concentrations (Table 7).

Because these elevated metal concentrations appear to be a widespread phenomenon throughout the Refuge, it is likely a consequence of the local geology, and possibly, species-specific metal bioaccumulation mechanisms. Biota in the area may be adapted to these elevated metal body burdens, so there are probably not any significant impacts at a population level. For example, metal concentrations in insectivorous bird eggs (snowy plover, avocet) are low (Cr < 1.5 mg/kg dw; Cu < 3.4 mg/kg dw; and V < 1.1 mg/kg dw), indicating that either bioaccumulation factors are low (especially for those birds feeding in Hunter Marsh), transfer of metals from females to their eggs is low, or diets contain biota from areas of low metal concentrations.

Mercury is accumulating in some fish from Hunter Marsh, Lake St. Francis, and the East Ditch (<0.2 mg/kg dw; Hg concentrations are similar to data collected in 1986 by O’Brien (1990)), but not to levels of concern for the fish or piscivorus wildlife (Figure 11). Mercury concentrations in several least tern eggs, however, are elevated to concentrations ranging from 0.2 - 1.8 mg/kg dw, suggesting birds may be exposed to mercury sources not identified in this study. Two mg/kg dw Hg, is the threshold for decreased egg hatch determined for pheasants, and exceeds the adverse effects threshold of 1.5 ppm dw for reduced number of young osprey fledged. [(National Irrigation Water Quality Program (NIQWP 1998)]. Thresholds for most other birds studied range from 2.5 to 5.0 ppm dw (Eisler 1987; NIWQP 1998).

With the exception of Lake St. Francis, Se concentrations were only slightly elevated in the fish collected from the Refuge and are comparable to O’Brien (1990) (Figure 12; ~3-8 ppm compared to a nationwide average of 3 ppm; Table 6). Selenium concentrations in all fish sampled in Lake St. Francis were unusually elevated (>35 ppm) considering the relatively low water and sediment Se concentrations measured (below detection, ~1ppm, respectively). These tissue concentrations exceeded those associated with adverse reproductive effects (8-12 ppm) in other fish species (i.e., Centrarchids), and would pose a risk to birds consuming them on a regular basis. However, population estimates on sinkhole fish did not indicate reduced recruitment, although a reproductive failure rate of up to 20 percent might not be detected in an isolated population (Hoagstrum, U.S. Fish and Wildlife Service, Pers. Comm. 1997). At Kesterson NWR in California (a highly Se enriched environment), gambusia contained 120 ppm Se yet maintained abundant populations, even though there was a 25 percent stillbirth rate. Many of the stillborn were deformed, indicating that there were some adverse effects from Se, although not severe enough to cause population-level impacts (Skorupa, U.S. Fish and Wildlife Service, Pers. Comm. 1997). Because these fish are accumulating such high whole-body Se concentrations despite relatively low ambient concentrations, they may also be sequestering Se in a biologically inactive form or in insensitive tissues. Further investigation would be necessary to determine the extent and explanation of this phenomena in Lake St. Francis and any other potentially Se-rich environments.

Selenium concentrations in most bird eggs sampled were between 4 and 6 ppm, which is noticeably elevated when compared to the 90th percentile of bird eggs sampled in non-marine wetlands throughout the western United States (2.9 ppm dw; Skorupa and Ohlendorf 1991). One least tern and one snowy plover egg contained nearly 10 ppm Se-- the lowest threshold for adverse effects to an avian embryo (NIWQP 1998). However, species such as the tern and the plover are adapted to saline environments, and tend to be more Se-tolerant than freshwater-adapted species (Skorupa, Pers. Comm. 1997). Therefore, the 10 ppm adverse effects threshold may be overly conservative for species frequenting the more saline basins at the Refuge. In any case, the risk of adverse effects to birds from Se is likely low, considering that several other nearby areas are relatively low in Se concentrations, and most birds will feed in more than one isolated location.

Table 7. Inorganic concentrations in bird diets (invertebrates and fish) compared to thresholds for adverse reproductive effects or harmful bioaccumulation. Values are mg/kg (ppm) dry weight.

Element	*Health Effect Threshold Criteria**	*Invertebrates (range)*	*Fish (range)*	*Reference*
Al	926.4	39.0 - 1892	8.6 - 436	NRC 1980
As	139.0	0.25 - 6.3	0.25 - 1.7	Eisler 1988
Ba	92.6	3.3 - 28.6	0.50 - 11.9	NRC 1980
B	139.0	1.0 - 10.4	1.0 - 8.4	Eisler 1990
Cd	0.5	0.05 - 0.20	0.05 - 0.05	Eisler 1985
Cr	46.3	0.71 - 2.45	0.55 - 15.8	Eisler 1986
Cu	1,389.5	7.6 - 47.2	2.0 - 36.6	NRC 1980
Fe	4,631.8	97.4 - 1375	65.6 - 330	NRC 1980
Pb	231.6	0.25 - 37.7	0.25 - 1.4	NRC 1980
Mn	9,263.5	7.6 - 120	2.6 - 161	NRC 1980
Hg	0.5	0.025 - 0.160	0.025 - 0.190	Eisler 1987
Mo	463.2	1.0 - 2.2	1.0 - 2.6	NRC 1980
Ni	463.2	0.25 - 6.02	0.25 - 2.8	NRC 1980
Se	3.0	1.4 - 3.6	1.5 - 36.4	Lemly 1987
Sr	13,895.3	92.0 - 1257	141 - 596	NRC 1980
V	46.3	0.25 - 4.8	0.25 - 4.4	NRC 1980
Zn	178.0	13.1 - 136	60.7 - 336	Eisler 1993

***** A moisture content of 78.4 % was used to convert wet to dry weight concentrations.

Organic Compounds[3]

Water samples from every site on the Refuge, except the Lost River/Bitter Creek confluence, had no detectable concentrations of aliphatics, PAHs, or organochlorines. At the Lost River site,

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[3] Detailed tables of organic analytical results are presented in Appendix II.

water samples contained approximately 1 µg/L of several aliphatic long chain oils, and sediments contained up to 7 ppm of these same compounds (e.g., n-nonacosane, n-hexacosane, n-pentadecane, n-tritriacontane; Figure 13). Whole body fish samples contained many of the same organics, but at lower concentrations (< 3 mg/kg dw). These organics are most likely naturally-occurring organic compounds from local plants, because the mixture is dominated by odd-numbered aliphatics. Naturally occurring aliphatic mixtures are predominately odd-numbered, whereas those derived from petroleum will have a mixture of both even and odd-numbered compounds (Pete Albers, U.S. Geological Survey, Pers. Comm. 1997). No petroleum derived PAHs were detected at greater than trace concentrations in water, sediment, and whole body fish in Lost River (Figure 13). Overall, most sediments and fish within the Refuge contained relatively low or below detection limit concentrations of anthropogenically-derived organic contaminants. Although sediment PCBs and organochlorines were not measured in Lost River, fish contained no PCBs and only trace concentrations of p,p'DDE, so sediments are probably also free of these contaminants.

Several organics, both plant derived, and anthropogenic (petroleum based PAHs, PCBs) were found in sediments and fish from Hunter Marsh (Figure 14). Naphthalene compounds were present at the highest concentrations (max ~20 ppm C3-naphthalene), and other PAHs (e.g., phenanthrene, anthracene, fluorene) were found at concentrations as high as 7 ppm. Although toxicity criteria are usually based on the base form of the PAH (e.g., naphthalene, *not* C3-naphthalene), adverse effects may be similar, and, microbial activity may strip the core naphthalene of its attached carbon group and return it to its more toxic base-form. Nonetheless, concentrations of even the base-forms of naphthalene, fluorene, phenanthrene, and benzo(a)pyrene all exceed criteria known to cause adverse effects in aquatic organisms.

Hunter Marsh sediments were not analyzed for PCBs or organochlorines in this study, but fish contained up to 5 ppm PCBs (Figure 15). Organochlorine concentrations in fish were trace, and below levels of concern. In a 1986 investigation by O'Brien (1990), PCBs were detected in sediments at 0.5 ppm, and fish contained up to 1.3 ppm (carp; 0.8 ppm in mosquitofish). A diet that is greater than 0.1 ppm total PCBs is considered hazardous to wildlife, so wildlife feeding in Hunter Marsh could be at risk from PCBs. Taken in combination, including base-forms as well as derivatives, the mixture of petroleum-derived PAHs and PCBs in Hunter Marsh sediments could adversely impact invertebrate communities and wildlife that forage there regularly.

Fish from one of seven Refuge areas sampled in 1992 (Roy 1992) contained 2.9 ppm DDE (as p,p'DDE). The only organochlorine found in fish at the Refuge in this 1996 sampling was p,p-DDE, but at concentrations not considered elevated (≤ 0.5 ppm wet weight). These results, combined with the lack of detection of the parent compound DDT, or presence of the less persistent DDE compound, o,p-DDE, suggests that extensive weathering of these organochlorine compounds has occurred and that inputs have ceased.

The majority of eggs sampled contained less than 2.0 ppm p,p'DDE, which is below risk thresholds to developing embryos and other wildlife consuming those eggs (Figure 16). One egg, however, from a snowy plover contained 8.3 ppm p,p'DDE, which is far above the 3.1 ppm threshold criteria for eggshell thinning. Most eggs also contained PCBs, and two avocet eggs sampled in 1996 contained over 5.0 ppm total PCBs. Eggs sampled in 1997 were below 2.0 ppm total PCBs, indicating that the 8.3 ppm PCB detected in 1996 may be unusual. Bird eggs also contain low concentrations of several PAHs, particularly naphthalene compounds (< 0.3 ppm), suggesting some exposure to petroleum in the environment (Figure 17).

Ecological Risk Assessment- Interior Least Tern and Osprey

The primary contaminants of concern to piscivorous birds in Hunter Marsh, based on ecological risk calculations using contaminant concentrations in fish only, are: p,p'DDE > Se > PCB > Zn > Cr > V > Cu > Pb > Hg > As (Table 8; Figure 18). Birds also consuming sediment and invertebrates would be at greater risk due to elevated metal and organic concentrations in sediments and invertebrates, and smaller birds, such as the least tem, would be at greater risk due to their high ingestion rate and relatively small size. Most metal concentrations in fish are comparable to those in sediment or invertebrates. Lead concentrations, however, are up to 26 times greater in snails collected in Hunter Marsh than fish collected from the same area. Wildlife consuming these snails, and other invertebrates from Hunter Marsh with elevated Pb concentrations, could be at significant risk (HIs exceed 20).

The ecological risk assessment calculations indicate that, in a worst-case scenario, p,p'DDE, Se, PCBs, Zn, and Cr (VI) in fish contribute the most risk to piscivorous birds at the Refuge. Cr, Zn, and PCBs are primarily associated with fish in Hunter Marsh. Maximum Se and p,p'DDE concentrations in fish were measured in Lake St. Francis. Calculations assume that Cr is in its most toxic form of Cr (VI). Although only total Cr was measured in this study, it is unlikely that the Cr (VI) form would predominate. Conservatively assuming that 50 percent is in the Cr (VI) form, the hazard index would decrease to less than 1.0 based on mean Cr concentrations at the Refuge. Birds feeding primarily in Hunter Marsh would still be at risk from Cr ingestion.

Considering all contaminants in combination, multiple exposure pathways (drinking water, incidental and/or intentional sediment ingestion, consumption of contaminated biota, and the baseline stresses of living in a highly-saline environment), contaminants in Lake St. Francis, and especially Hunter Marsh, could have population-level effects on the least tem and other resident wildlife. Birds hunting regularly for fish in Lake St. Francis would be exposed to hazardous concentrations of Se and p,p'DDE. However, because Lake St. Francis is one of many potential feeding areas for terns and other birds in the area, the risks from Lake St. Francis are diminished (assuming other sinkholes and feeding areas on the Refuge are relatively contaminant-free). Hunter Marsh, however, contains numerous contaminants of unknown distribution. Because of the marsh's high productivity, food items would likely be plentiful and thus exposure to a variety of wildlife to contaminants could be significant. Even if birds fed in Hunter Marsh for one half year (i.e., 182 days rather than the worst-case estimate of 365 days), the HQ from the combination of contaminants in Hunter Marsh would still exceed 1, indicating possible adverse health effects.

While ecological risk calculations are useful in predicting potential risks to wildlife in a particular area, actual field observation of adverse effects is most informative. Decreases in population size, irregularities in age-class distributions, or other indicators of disease or deformity, can confirm effects predicted from an ecological risk assessment. Likewise, reduced reproductive success can be an indicator of contaminant exposure. In birds, one measure of potential reproductive

Table 8. Parameters considered in calculating ecological risk to osprey and least terns from inorganic and organic chemicals in fish at the Refuge, and calculated hazard quotients (HQ) and aggregate hazard indices (HI) based on Toxicity Reference Values (TRV).

Osprey

Element	***Fish conc mg/kg (Mean)***	***Fish conc mg/kg (95th %ile)***	***Fish conc mg/kg (Max)***	***Intake Mean (mg/kg-day)***	***Intake 95th (mg/kg-day)***	***Intake Max (mg/kg-day)***	***TRV***	***Mean HQ***	***95th HQ***	***Max HQ***
As (total)	0.648	1.500	1.700	0.139	0.322	0.365	5.140	0.027	0.063	0.071
Cd	0.050	0.050	0.050	0.011	0.011	0.011	1.450	0.007	0.007	0.007
Cr (VI)	1.895	2.640	15.750	0.407	0.567	3.383	1.000	0.407	0.567	3.383
Cu	11.059	32.050	36.640	2.376	6.885	7.871	28.000	0.085	0.246	0.281
Hg (Total)	0.070	0.170	0.190	0.015	0.037	0.041	0.450	0.034	0.081	0.091
Pb	0.337	0.900	1.400	0.072	0.193	0.301	1.130	0.064	0.171	0.266
Se	12.224	34.200	36.400	2.626	7.346	7.819	0.500	5.252	14.693	15.638
V	1.097	3.430	4.440	0.236	0.737	0.954	2.400	0.098	0.307	0.397
Zn	166.759	294.390	336.490	35.821	63.237	72.281	14.500	2.470	4.361	4.985
PCB- Arochlor 1242	NA	NA	4.971	NA	NA	1.068	0.410	NA	NA	5.932
PCB- Arochlor 1254	NA	NA	4.971	NA	NA	1.068	0.180	NA	NA	2.604
p,p’ DDE	NA	NA	0.203	NA	NA	0.044	0.002	NA	NA	21.803
Naphthalene	NA	NA	0.041	NA	NA	0.009	0.139	NA	NA	0.063
							HI	8.444	20.496	55.523

Least Tern

Element	***Fish conc mg/kg (Mean)***	***Fish conc mg/kg (95th %ile)***	***Fish conc mg/kg (Max)***	***Intake Mean (mg/kg-day)***	***Intake 95th (mg/kg-day)***	***Intake Max (mg/kg-day)***	***TRV***	***Mean HQ***	***95th HQ***	***Max HQ***
As (total)	0.648	1.500	1.700	0.456	1.057	1.198	5.140	0.089	0.206	0.233
Cd	0.050	0.050	0.050	0.035	0.035	0.035	1.450	0.024	0.024	0.024
Cr (VI)	1.895	2.640	15.750	1.335	1.860	11.097	1.000	1.335	1.860	11.097
Cu	11.059	32.050	36.640	7.791	22.581	25.815	28.000	0.278	0.806	0.922
Hg (Total)	0.070	0.170	0.190	0.050	0.120	0.134	0.450	0.110	0.266	0.297
Pb	0.337	0.900	1.400	0.237	0.634	0.986	1.130	0.210	0.561	0.873
Se	12.224	34.200	36.400	8.613	24.095	25.645	0.500	17.225	48.191	51.291
V	1.097	3.430	4.440	0.773	2.417	3.128	2.400	0.322	1.007	1.303
Zn	166.759	294.390	336.490	117.489	207.411	237.073	14.500	8.103	14.304	16.350
PCB- Arochlor 1242	NA	NA	4.971	NA	NA	3.502	0.410	NA	NA	19.457
PCB- Arochlor 1254	NA	NA	4.971	NA	NA	3.502	0.180	NA	NA	8.542
p,p’ DDE	NA	NA	0.203	NA	NA	0.143	0.002	NA	NA	71.511
Naphthalene	NA	NA	0.041	NA	NA	0.029	0.139	NA	NA	0.208
							HI	27.697	67.226	182.11

impairment is the degree of eggshell thinning (which is directly related to hatching success). The Ratcliffe Index (RI) is used to quantify this relationship, and is calculated as: RI = eggshell mass (g) / (egg length (mm) * egg girth (mm)), where an index greater than 1 indicates a "normal" egg.

A significant multiple regression relationship was identified ($p = 0.007$, $r^2 = 0.909$) among Hg, Se, PCB, and p,p'DDE concentrations in tern eggs and the RI, with Hg as the primary contributor. A correlation matrix among all the variables examined is outlined in Table 9. Surprisingly, PCB and p,p'DDE concentrations were weakly *positively* correlated with the RI. This is likely a statistical artifact of the small sample size and low contaminant concentrations present in the eggs. When examined individually, correlations between p,p'DDE and PCB with the RI were far less distinct ($R^2 < 0.030$) than the correlation between Hg and the RI ($R^2 = 0.654$, Figure 19), indicating that among the contaminants elevated within the eggs, Hg is most likely responsible for eggshell thinning.

Table 9. Correlations between Ratcliffe Index and various contaminant concentrations.

Correlation Matrix- All Bird Eggs

	WEIGHT	MOISTURE	PPDDE	PCB	HG	SE	RATCLIFFE
WEIGHT	1.000	0.568	-0.203	-0.134	-0.794	-0.187	0.839
MOISTURE	0.568	1.000	-0.534	-0.199	-0.363	-0.063	0.143
PPDDE	-0.203	-0.534	1.000	0.605	0.269	-0.153	0.204
PCB	-0.134	-0.199	0.605	1.000	-0.116	-0.151	0.172
HG	-0.794	-0.363	0.269	-0.116	1.000	-0.170	-0.769
SE	-0.187	-0.063	-0.153	-0.151	-0.170	1.000	-0.110
RATCLIFFE	0.839	0.143	0.204	0.172	-0.769	-0.110	1.000

Correlation Matrix- Terns Only

	WEIGHT	MOISTURE	PPDDE	PCB	HG	SE	RATCLIFFE
WEIGHT	1.000	0.530	-0.789	-0.421	-0.192	0.312	-0.118
MOISTURE	0.530	1.000	-0.637	-0.483	0.433	-0.128	-0.726
PPDDE	-0.789	-0.637	1.000	0.338	0.142	0.084	0.416
PCB	-0.421	-0.483	0.338	1.000	-0.459	-0.316	0.500
HG	-0.192	0.433	0.142	-0.459	1.000	-0.487	-0.811
SE	0.312	-0.128	0.084	-0.316	-0.487	1.000	0.608
RATCLIFFE	-0.118	-0.726	0.416	0.500	-0.811	0.608	1.000

Moisture and the RI were also highly correlated in tern eggs, although it is unclear if decreased moisture is a consequence of a thinner shell, or, if lack of moisture causes a thinner shell. Nonetheless, neither egg mercury nor moisture content are factors controllable through Refuge-specific management actions.

Other than some areas of Hunter Marsh, mercury contamination is not a localized phenomena within the Refuge food-chain. And aside from Hunter Marsh, there is no specific area to "remediate." Elevated Hg concentrations in biota may be due to international, or other, more local off-Refuge exposures. For example, studies conducted by the U.S. Army Corps of Engineers, the Service, and the New Mexico Environment Department have documented that sediments in the Pecos watershed are relatively high in mercury compared with other watersheds in New Mexico. Sumner Reservoir, upstream of the Refuge, also accumulates mercury, and is a methyl-mercury generation source for the Pecos River. Mercury is also commonly spread via dust and precipitation, often great distances from its original source.

There are, however, other contaminants that pose a risk to wildlife that are localized in Hunter Marsh, that may not impair hatching success. Even if eggs hatch, young hatchlings are highly sensitive to environmental contaminants delivered via their food. As discussed above, ecological risk calculations indicate that food-borne concentrations of organics, and inorganics such as Pb and Cr, may also cause hatchling mortality. In addition to a thorough evaluation of the extent and magnitude of contamination of Hunter Marsh, investigations may be necessary to determine if there are actual adverse effects to biota in and around Hunter Marsh. If these effects are severe enough to impact individual threatened, endangered, and sensitive species, or populations of other wildlife, remedial action may be necessary in Hunter Marsh.

CONCLUSIONS AND RECOMMENDATIONS

1) Evaluate the extent of contamination in Hunter Marsh. A randomized sampling design should be developed for water and sediment, extending outward from the areas sampled thus far. Depending on the extent and severity of contamination discovered from this sampling, more detailed remediation and/or management plans may be necessary.

2) Determine wildlife use of contaminated regions in Hunter Marsh, so appropriate species can be selected for a more comprehensive ecological risk determination, and possible adverse effects can be documented.

3) Verify impacts to fish reproduction, then, depending on impacts, quantify Se input sources to Lake St. Francis. Groundwater sources and recharge zones, and/or other potential Se input sources to Lake St. Francis can then be appropriately managed.

4) Monitor weekly impacts to water quality and biota due to the March 2000, Sandhill fire:

   a) Fire acts as a mineralizing agent, releasing nutrients from soils and from ash to surface water by overland flow and by wind deposition. Water and sediment should be analyzed twice monthly for pH, nutrients (nitrate, total nitrogen, phosphate, total phosphorus), sulfate, total suspended solids (TSS), turbidity, alkalinity, hardness, major cations (Ca, Mg, K, Na), Si, trace elements (Al, Fe, Hg, and Se) and organic combustion byproducts in ash (aliphatic hydrocarbons [waxes, oils, terpenes, etc.] and polycyclic aromatic hydrocarbons [PAHs- anthracene, napthalene]). Basic water quality parameters (e.g., temperature, DO, pH, specific conductivity) should be monitored hourly at several locations based on habitat (pool, run, glide, spring head) along the Bitter Creek and similar habitat locations at the reference site (Sago Spring wetland complex) until conditions return to pre-fire parameters or stabilize.

   b) Monitor all of the parameters described in (a) in conjunction with a major storm event.

   c) Evaluate erosion, and changes in sediment loading and water turbidity. Episodic or intense storm events produce overland flow and increase erosion. Channel scouring, mass erosion, and sediment delivery to the stream can have detrimental effects to aquatic fauna. Sediment texture, concentration of total suspended solids, turbidity, and sediment yield are likely to change over time. The invertebrate and fish community as well as the characteristics of their habitat are influenced by stream bed instability associated with erosion as well as decreased light due to turbidity.

   d) Monitor the instantaneous discharge and average discharge at several locations based on habitat (pool, run, glide, spring head) in conjunction with a major storm event, and daily along the Bitter Creek and similar habitat locations at the reference site (Sago Spring wetland complex) to evaluate habitat stability.

5) Request/evaluate the following information prior to initiation of new oil and gas activities that could potentially impact the Refuge:

a) Determine existing groundwater flow patterns, including connectivity of the aquifers, and sources of water in each of the biologically crucial springs and sinkholes, as they relate to groundwater impacts in the project area.

b) Model possible alterations in groundwater flows, quantity, and quality resulting from a proposed project.

c) Analyze oil/gas raw material, and any by-products (e.g., produced water, hydrostatic testing fluids) prior to full-scale operations. These chemical "fingerprints" for a facility should be kept on record so any future spills or groundwater contamination can be traced to their source.

d) Determine cumulative impacts of a proposed oil and gas action. Significant cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time and space.

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FIGURES

APPENDICES

APPENDIX I-
INORGANIC SAMPLE RESULTS

APPENDIX II-
ORGANIC SAMPLE RESULTS