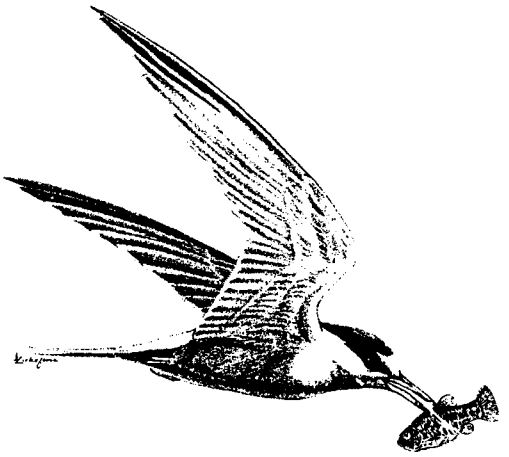
CAFB97

U.S. Department of the Interior
Fish and Wildlife Service
Region 2

LIBRARY COPY

JUL 1997
RECEIVED

AN EXAMINATION OF THE SUITABILITY OF WASTEWATER TREATMENT PLANT EFFLUENT FOR CREATION OF ARTIFICIAL WETLANDS IN EASTERN NEW MEXICO, 1992-1993



Environmental Contaminants Program

New Mexico Ecological Services Field Office
2105 Osuna NE
Albuquerque, New Mexico 87113

June 1997

U.S. Department of the Interior
Fish and Wildlife Service
Region 2

AN EXAMINATION OF THE SUITABILITY OF WASTEWATER TREATMENT PLANT EFFLUENT FOR CREATION OF ARTIFICIAL WETLANDS IN EASTERN NEW MEXICO, 1992-1993

Project Number: 2F26

Report Prepared by: Russ MacRae

New Mexico Ecological Services Field Office
Environmental Contaminants Program
2105 Osuna NE
Albuquerque, New Mexico 87113

TABLE OF CONTENTS

Page

List of Figures and Tables iii

Abbreviations and Conversion Factors iv

Acknowledgments 1

Executive Summary 2

Introduction 3
- Background 3
- Objective 4

Study Area and Methods 5
- Sample Collection Sites 5
- Water 12
- Sediment 13
- Biological 13

Results and Discussion 15
- Contaminants in Water 15
- Contaminants in Sediments 19
- Contaminants in Aquatic Biota 25
- Contaminants in Birds 28

Conclusions and Recommendations 36

Literature Cited 41

LIST OF FIGURES AND TABLES

Page

Figure 1. Map of playa wetlands, discharge basins, and discharges sampled in 1992 and 1993. 10

Table 1. Sites, location, and samples collected in 1992 and 1993. 11

Table 2. Radium (pCi/L) and conventional pollutants (mg/L) in selected waters. 16

Table 3. Metals and trace-metals in water samples (mg/L).. 18

Table 4. Detectable concentrations of organophosphate or organochlorine pesticides found in sediments (μg/kg wet weight) 20

Table 5. Metals and trace-metals in sediment samples (mg/kg wet weight). 22

Table 6. Criteria used to evaluate the potential hazard of metals in sediments and potential food items to birds and aquatic organisms, expressed as mg/kg wet or dry weight (ww or dw). 23

Table 7. Trace-metals concentrations in aquatic organisms and vegetation, which could be potential food items for birds (μg/g wet weight). 27

Table 8a. Organochlorine pesticide and PCB residues in adult duck tissues from Cannon AFB and Clovis WWTP playa lakes (μg/kg wet weight).. 29

Table 8b. Organochlorine pesticide and PCB residues in whole-body duckling samples and killdeer eggs from Cannon AFB and Clovis WWTP playa lakes (μg/kg wet weight). 31

Table 9. Metals and trace-metals in mallards sampled at the Cannon AFB playa lake (μg/g wet weight).. 33

Table 10. Metals and trace-metals in ducks (μg/g wet weight).. 34

Table 11. Metals and trace-metals in ducklings and eggs (μg/g wet weight).. 35

Table 12. Summary of contaminants of potential concern for each site sampled. 40

ABBREVIATIONS AND CONVERSION FACTORS

Abbreviations

liter	L
milliliter	mL
kilogram	kg
gram	g
parts per million	ppm
parts per billion	ppb
picocuries per liter	pCi/L
milligram per kilogram	mg/kg
micrograms per gram	ug/g
micrograms per milliliter	ug/mL
micrograms per liter	ug/L
Centigrade or Celsius	C
Method Detection Limit	MDL
Dietary Threshold Concentration	DTC
Not analyzed	n/a
Not Available	NA
Not Detected	ND

Conversion Factors

micrograms per gram (μg/g)	ppm
micrograms per milliliter (μg/mL)	ppm
milligrams per liter (mg/L)	ppm
milligrams per kilogram (mg/kg)	ppm
micrograms per liter (μg/L)	ppb
micrograms per kilogram (μg/kg)	ppb
1 Degree Fahrenheit	$(C \div 5/9) + 32$

ACKNOWLEDGMENTS

Assistance in preparation of the study design and selection of collection sites and species was provided by Laurie Shomo Brown. Data preparation and analysis assistance was provided by many individuals within the Fish and Wildlife Service, including: Joy Winkle, Sky Bristol, Mary Orms, Chuck Mullins, Mark Wilson, and Joel Lusk. This report was reviewed by Kathy Wood and Sky Bristol at the Fish and Wildlife Service Region 2 Office, and Dave Haukus at the Texas A&M University Fish and Wildlife Cooperative Research Unit. Thanks to everyone for their helpful comments and suggestions.

ABSTRACT

Sediment, water, bird tissues, and potential bird food items (plants, invertebrates, and fish) were sampled at 15 eastern New Mexico playas that receive secondary treated wastewater effluent. In addition to standard measures of water and sediment quality, metals (metals, trace-metals, and metalloids), radium, organochlorine and organophosphate pesticides, and arochlor-PCB concentrations were determined. Analytical results were compared to data available in the literature. Concentrations of most contaminants analyzed for were less than water and sediment quality criteria, typical background concentrations, and avian dietary thresholds of adverse effects. However, polychlorinated biphenyls (PCBs), were elevated in ducklings and killdeer eggs at the Cannon AFB Playa, at concentrations that may be toxic to the eggs. Also, at all three sites where ducks were sampled (Cannon AFB, Clovis WWTP, and Ladd Gordon playas) copper was elevated to potentially toxic concentrations in their livers, and lead was elevated in a duck ovum at Cannon AFB and ducklings at the Ladd Gordon playa. Based on the results of this study, trace metal contamination, particularly copper, at playas receiving treated sewage effluent should be examined more thoroughly. Although some sediment and aquatic organism metal concentrations exceeded avian dietary thresholds and/or sediment quality criteria, none were concurrently elevated in bird tissues. Many of these elevated metals likely reflect geologic sources in this region. Region-specific criteria for water, sediment, and tissue metals concentrations would be helpful to better understand metal toxicity risks to birds and aquatic organisms in the Southwest.

INTRODUCTION

Background:

Playa lakes are natural surface depressions which serve as watershed catchment basins. New Mexico has an estimated 1,700 playa lakes that provide breeding and wintering habitat for many waterfowl and shorebird species. As many as 15 million birds may migrate through the region each year, with perhaps a third stopping to winter. Playa lakes usually have no external drainage and often, in New Mexico, develop clay-rich bottom sediments which limit groundwater seepage or upwelling. Most water loss is therefore due to evapotranspiration, which can concentrate natural salts and contaminants, and in some basins, groundwater recharge. Depending on the size of the playa, the size of its watershed, rainfall, and temperature, a playa may hold water year-round or only for a few weeks. This lack of dependable water creates challenges for wildlife managers who may be interested in managing playas for waterfowl, shorebirds, neotropical migrants or resident upland birds.

To focus attention on management of playas in the Southern High Plains and Southern Great Plains, and to point out the importance of this habitat to migrating and resident birds, the Playa Lake Joint Venture (PLJV) was formed. The PLJV is a consortium of public and private organizations, including the New Mexico Department of Game and Fish, Colorado Division of Wildlife, Kansas Department of Wildlife and Parks, Oklahoma Department of Wildlife Conservation, Texas Parks and Wildlife Department, Ducks Unlimited Inc., Phillips Petroleum Company, The Nature Conservancy, National Wildlife Federation, and the U.S. Fish and Wildlife Service (FWS).

To enhance the value of playas for migrating and resident birds in the playa region of eastern New Mexico, the U.S. Fish and Wildlife Service's New Mexico Ecological Services Field Office (NMESFO) proposed a playa-water management option that involved the use of secondary treated sewage water from municipal wastewater treatment plants (WWTP) across eastern New Mexico. However, prior to any serious consideration of the use of treated sewage effluent in playa management, a

contaminant survey of the water and its environs was considered necessary to ensure that harmful toxicants were not present. The PLJV agreed to assist the NMESFO in sampling the municipal wastewater treatment plant effluents of 15 eastern New Mexico communities, contributing the funding for collecting and analyzing samples of water, vegetation, soil, vertebrates and invertebrates. The NMESFO agreed to provide the labor and a report interpreting the analytical data.

Objective:

The objective of this study was to screen water, sediment, and biological samples, collected from eastern New Mexico playas receiving secondary treated effluent, for potentially toxic contaminant concentrations. All of the playa lakes sampled receive or have received some form of domestic or industrial waste water. Several avian, sediment, water and invertebrate samples were collected and screened for some or all of the following: nutrients, metals (includes metals, trace-metals, and metalloids), organochlorine and organophosphate pesticides, PCB's, and radium 226/228.

The broad sampling scheme was intended to survey a large area for potential contaminant problems. Acknowledged limitations to this study include: (1) the low sample size prevented statistical inferences about local population level effects; (2) the single sampling date for most sites represents a "snapshot in time" of wetland status; (3) for water and sediments, a single sampling location or composite sample would not detect a heterogeneous distribution of contaminants; and (4) water, sediment, birds, and potential bird food items were not all sampled at every site, so little can be inferred about contaminant sources, pathways, or bioaccumulation pathways. Nonetheless, this study provides a screening-level analysis to focus future research on specific contaminants at identified locations.

STUDY AREA AND METHODS

Fifteen municipalities in the playa region of eastern New Mexico were selected for sampling of treated sewage effluent, sediments, bird tissues, and aquatic plants and animals potentially used by birds as food items (Figure 1 and Table 1). The criteria for a municipality selection were that the community was located in proximity to numerous playas or basins suitable for wetland habitat and the sewage plant produced quantities of treated effluent sufficient for potential water management options in playas and discharge basins.

Sample Collection Site Descriptions:

1) **Cannon Air Force Base, Curry County**

Wastewater effluent enters two wastewater stabilization ponds (32 acres combined surface area) before discharge to an adjoining 13-acre playa lake. Final effluent disposal is via evaporation, infiltration, and irrigation of local farmlands. Another playa lake at the southwest corner of the Base (not sampled) receives the majority of stormwater runoff from the Base (USAF 1990).

2) **Clovis WWTP, Curry County**

Clovis WWTP uses an activated sludge treatment system. Treated municipal wastewater effluent is pumped from clarifier ponds to an adjacent 40-acre playa lagoon. Water is then used for irrigation of surrounding farmland, and a portion is often diverted to the Barry Williams Wildlife Management Playa. Samples were collected near the effluent input to the lagoon.

3) **Barry Williams Playa, Curry County**

As part of the Williams Playa Management Area, this playa receives biologically treated sewage water from the Clovis Municipal WWTP to grow moist-soil plants for wildlife and flood the

basin for migrating or wintering waterfowl. In addition, the City of Clovis is enhancing 200 acres of land surrounding the sewage treatment plant to benefit wintering waterfowl. Highlighted as a demonstration New Mexico playa for the Playa Lakes and Gulf Coast Joint Ventures initiative, the management scheme for Barry Williams Playa is currently funded by the USFWS Partners for Wildlife Program. Migratory birds typically present included waterfowl, avocets, sandpiper species, red-winged blackbirds, black terns, black-necked stilts, great horned owls and hawks. Water and sediment were collected from within the playa.

4) **Ladd S. Gordon Management Area, Quay County**

Located in Tucumcari, and is managed by the New Mexico Department of Game and Fish. WWTP effluent was at one time released into the management area. Duck hunting was also allowed, so lead shot is likely present in the sediments and surrounding soils. The management area receives significant stormwater runoff from a nearby highway and the city.

5) **Tucumcari - Breen Pond, Quay County**

Breen Pond receives 500,000 gallons/day of municipal wastewater effluent from the Tucumcari WWTP. Two major industries, the grain elevator and a packing company, had previously used the WWTP but were shut down several years prior to sampling for this investigation. Overflow from Breen Pond flows to Pajarito Creek and then to the Canadian River. Water was collected from the effluent inflow pipe and algae from near the pipe.

6) **Portales - Playa Lake, Curry County**

WWTP effluent is collected and diverted to an irrigation water holding pond during irrigation season, located next to the city landfill. When irrigation season is over, the effluent is sent to a

nearby playa lake. When dry, this lake is used for cattle grazing. Water was collected from the irrigation pond inflow, and sediment (soil) from the dry playa lake.

7) **Fort Sumner WWTP, De Baca County**

Fort Sumner mechanically treats their sewage. The treated effluent is then discharged directly into the Pecos River. Samples were destroyed during shipping, and therefore no analyses were performed.

8) **Santa Rosa WWTP, Guadalupe County**

Santa Rosa discharges into lagoons, then into El Rito Creek, which flows a few hundred yards to the Pecos River. Surface water flows are used to dilute the effluent. Wastewater is chlorinated/dechlorinated. Water samples were collected from a manhole near the effluent outfall pipe.

9) **Tatum WWTP- Tatum Final Lagoon, Lea County**

Discharges approximately 40,000 gallons per day of mostly domestic wastewater. The town uses a constructed wetland for treatment, consisting of 2 aerated lagoons to filter/pre-treat water, before delivery to several ponds consisting of a rock substrate, with bulrush, cattails, and other plants. The water trickles through the rock substrate, and is then discharged into a 1-2 acre pond, at a depth of approximately 2-4.5 feet. Black-necked stilts, red-winged blackbirds, grackles, mourning doves and coots were seen in the pond area. Water and sediment were collected from within the pond.

10) **Hobbs WWTP, Lea County**

Total discharge is approximately 3.2-3.5 million gallons per day. All discharge water is sold for irrigation (City Cemetery, Jr. College, and S&H Agriculture) and oil drilling/processing (e.g., Amoco, Conoco). Water was collected from the final runway leading to the main pipeline.

11) **Carlsbad WWTP, Eddy County**

The Carlsbad WWTP is an activated sludge treatment facility that discharges directly into the Pecos River. Domestic and commercial water is accepted. The plant chlorinates and dechlorinates effluent prior to discharge. It discharges approximately 2.5-3.5 million gallons per day. Water only was collected directly from the outfall into the Pecos River.

12) **Artesia WWTP, Eddy County**

The Artesia WWTP receives primarily domestic sewage, has a rock substrate, and uses a trickling-filter water system. It discharges approximately 7-900,000 gallons per day into a lined lagoon just off-site. The plant uses Roundup to control vegetation around the lagoon and passes most of its water to the city parks. However, 3-4 times a year it does discharge into the Pecos River. Water was collected from the outfall at the lagoon.

13) **Capitan WWTP, Lincoln County**

The Capitan WWTP was in the process of building a constructed wetland to treat its domestic sewage at the time of this study. Although the town is not within the Playa Lake Joint Venture boundary, there was a possibility the two abandoned evaporative ponds may be used for moist soil management, and therefore, were tested. Water was sampled from the outfall at one of the lagoons.

14) **Raton - CS Ranch Pond, Colfax County**

Effluent is either discharged to Chicarica Creek, a tributary to the Canadian River, or is pumped to CS Ranch Pond (2 acres). Water samples were taken from the WWTP effluent pipe and sediment was collected from the CS Ranch Pond.

15) **Clayton - Dillinger Pond, Union County**

Effluent is discharged into four cement-lined lagoons; the fourth lagoon discharges into a pond on D. Dillinger's land year-round and is used for irrigation. Water and salamanders were collected from the fourth lagoon. Sediment and invertebrates were collected from Dillinger's pond.

Table 1 . Sites, location, and samples collected in 1992 and 1993.

Site Name	Location(s)	Collection Date(s)	Samples Collected	Analyses Performed
Cannon Air Force Base	T2N, R35E, Sec. 17 & 20	4/27-28/92, 5/11-12/92, 6/9/92	water, sediment, waterfowl, egg	metals, organochlorine, organophosphates
Clovis WWTP	T2N, R36E, Sec. 20 & 21	4/27-28/92, 5/12-13/92	water, sediment, waterfowl	metals, organochlorine, organophosphates
Barry William's Playa	T2N, R36E	5/12/92, 5/19-20/93	water, sediment, invertebrates, egg	metals, organochlorine, organophosphates
Ladd S. Gordon Management Area	T11N, R30E, Sec. 13 and T11N, R31E, Sec.7 & 18	5/19-20/92, 6/8/92	water, sediment, fish, waterfowl	metals, organochlorine, organophosphates
Tucumcari WWTP	T11N, R30E, Sec. 12	5/19/93	water, sediment, plant	metals, organochlorine, organophosphates
Portales WWTP	T2N, R34E, Sec. 1 & 12	5/19/93	water, sediment	metals, organochlorine, organophosphates
Fort Sumner WWTP	T3N, R26E, Sec. 32	5/20/93	water (destroyed during shipping)	metals (not tested)
Santa Rosa WWTP	T8N, R21E, Sec. 11	5/20/93	water	metals
Tatum WWTP	T12S, R36E, Sec. 27	5/25/93	water, sediment, plant, fish, invertebrates	metals, organochlorine, organophosphates
Hobbs WWTP	T19S, R38E, Sec. 2	5/26/93	water	metals
Carlsbad WWTP		5/26/93	water	metals
Artesia WWTP	T17S, R26E, Sec. 9	5/26/93	water	metals
Capitan Lagoons		5/27/93	water	metals
Raton WWTP	T31N, R24E	6/8/93	water, sediment	metals, organochlorine, organophosphates
Clayton WWTP	T25N, R35E, Sec. 1 & 2	6/10/93	water, sediment, invertebrates, salamander	metals, organochlorine, organophosphates

Samples of birds, fish, sediment, water, invertebrates, aquatic plants, and eggs were collected in 1992 and 1993. Collection of birds and other species proved difficult, therefore the sample sizes were limited to a few birds and ducklings from each of three playas. Although an attempt was made to sample all available organisms at several of the playas, birds and/or potential avian food items were frequently absent during the sampling visits. Actual samples collected are listed in Table 1. Separate sample aliquots were collected for nutrients, metals, radium, purgeable organics, organophosphate and organochlorine pesticides, and phytoplankton. Samples were collected, processed, and preserved as follows:

Water

- Nutrients and metals: collected using a Nalgene® plastic bucket, filtered through 0.45μm Millipore polycarbonate membrane filters into a 1-L HDPE cubitainer, preserved with either H_2SO_4 (nutrients) or HNO_3 (metals), then transported on ice to the laboratory. Although some WWTPs in this study chlorinate/dechlorinate before discharge to the playas, residual chlorine was not measured. Residual chlorine readily evaporates after discharge, and therefore is probably a minor hazard to waterfowl and aquatic organisms.

- Radium water samples: collected as above, then transferred directly into a 1-gallon cubitainer and preserved with 20-mL HNO_3. Samples were transported at ambient temperature.

- Purgeable organics: collected directly into 40-mL glass septum vials and transported on ice.

- Organophosphate, organochlorine pesticides and PCBs: collected directly into 500-mL glass container, preserved with vinegar and iodine. Samples were transported at ambient temperature.

Sediment

- Purgeable organics: composite samples (individual samples collected from various points around the playa) transferred to 40-mL glass vials using a dredge or stainless steel spoon, 2 vials partially filled and preserved with methyl alcohol, and a third filled. Samples were transported on ice.

- Metals: composite samples (individual samples collected from various points around the playa) of the top 2 inches of sediment sampled with a dredge or stainless steel spoon, placed in a 500-mL glass jar, and transported on ice.

- Organophosphate, organochlorine pesticides and PCBs: same procedure as for metals.

Biological

- Plants, Phytoplankton: composite scrapings placed into 500-mL glass jar with site-water. Composite samples of aquatic plants were collected by hand or with forceps; focused on known waterfowl food.

- Fish, Invertebrates: Fish, invertebrates and salamanders were collected using fine mesh seines and dip nets.

- Birds: Birds were collected by shotgun (steel shot); one or more of the following tissues were removed: liver, kidney, ova, stomach (stomach contents), and breast muscle. Carcasses to be analyzed for organochlorine compounds were individually wrapped in aluminum foil, stored on

ice, then placed in a freezer. All other samples placed in chemically clean jars and stored on ice in the field until frozen.

Samples collected were analyzed for one or more of the following parameters: metals, trace elements, radium 226/228, nutrients, PCBs, and organochlorine and organophosphate pesticides. Samples were analyzed by the New Mexico Department of Health, Scientific Laboratory Division (SLD) in Albuquerque, New Mexico. Except for arsenic, mercury, and selenium, metal analyses were conducted using Inductively Coupled Plasma Emission Spectroscopy (ICP). Mercury was analyzed by Cold Vapor Atomic Absorption (CVAA), and arsenic and selenium by Hydride Generation Atomic Absorption (HGA). Organochlorine compounds were analyzed by Gas Chromatography (GC). Organic chemical analysis of tissue and sediment was done using Gas-Liquid Chromatography and Gas Chromatography-Mass Spectrophotometry (GC-MS).

All analytical methods conformed to approved methods in "APHA Standard Methods for the Examination of Water and Wastewater", "EPA methods for Chemical Analyses of Water and Wastes", or "Guidelines for Establishing Test Procedures for the Analysis of Pollutants under the Clean Water Act" (40 CFR Part 136). All environmental measurements were validated according to procedures in "Quality Assurance Project Plan for Water Pollution Control Programs" (NMED 1993- revised annually).

RESULTS AND DISCUSSION

Contaminants in Water

Conventional Pollutants (Nitrogen and Phosphorous Compounds; Table 2)-

Nitrate and nitrite (NO_3/NO_2) were well below the 10 mg/L New Mexico domestic drinking Water Quality Criteria (WQC) at all sites sampled and would likely not be a risk to wildlife (NMWQCC 1995). Ammonia (NH_3), total nitrogen (TKN), and ortho and total phosphorous (ortho-P and total-P), however, are not regulated under New Mexico Drinking WQC, but were elevated in Clovis WWTP and Cannon AFB during the 4/28/92 sampling, indicating possible insufficient wastewater treatment. Using an average pH and temperature from the Bitter Lake National Wildlife Refuge (NWR) in nearby Roswell, New Mexico (pH= ~8.1, Temperature= ~20°C; temperature and pH were not measured at sites in this study), the Clovis WWTP ammonia concentrations exceeded acute NH_3 WQC, and Cannon AFB playa exceeded chronic NH_3 WQC for warmwater fisheries, and could therefore adversely impact some wildlife aquatic food resources (e.g., invertebrates, and at some sites, fish) if regularly elevated.

Radium (Table 2)- Radium was well below New Mexico domestic drinking WQC at all sites sampled (NMWQCC 1995). Therefore, it is not a contaminant of concern for wildlife inhabiting the playas and discharge ponds examined in this study.

Table 2. Radium (pCi/L) and conventional pollutants (mg/L) in selected waters (n/a= not analyzed).

Sample Site Sample Date	Cannon AFB 04/28/92	Cannon AFB 05/12/92	Clovis 04/28/92	Clovis 05/12/92	Ladd Gordon 05/19/92	Ladd Gordon 05/20/92
Ra-226	n/a	0.15	n/a	0.06	n/a	0.26
Ra-228	n/a	0	n/a	-0.1	n/a	0.8
Total Organic Carbon	<200	n/a	<200	n/a	n/a	n/a
Nitrate + Nitrite as N	0.1	n/a	0.12	n/a	0.08	n/a
Ammonia	1.29	n/a	17.8	n/a	n/a	n/a
Total Kjeldahl Nitrogen	15.6	n/a	20.2	n/a	n/a	n/a
Ortho Phosphate	2.87	n/a	2.73	n/a	<.01	n/a
Total Phosphorus	4.05	n/a	4.53	n/a	0.01	n/a

Organophosphate and organochlorine pesticides, and PCBs-

All pesticide concentrations were below analytical Method Detection Limits (MDL). Because sediment and tissue sample pesticide concentrations were also below MDLs, hazardous water concentrations of pesticides are probably not present. PCBs were not measured in water, but PCBs are generally insoluble in water and therefore would most likely be associated with sediments. Overall, pesticides and PCBs in the water do not appear to be of concern for wildlife inhabiting the playa wetlands examined in this study.

Metals (Table 3)-

Aluminum (Al) in the Clovis WWTP playa was elevated (2.9 mg/L) and exceeded the New Mexico fisheries acute WQC (0.75 mg Al/L; NMWQCC 1995) and therefore could be toxic to fish and invertebrate food items eaten by waterfowl. High concentrations of aluminum found in algae collected from Tucumcari WWTP suggest that this playa also had elevated water aluminum concentrations (actual water measurements are not available for this site) that would exceed fisheries acute WQC. Thus, while

aluminum is not likely a direct hazard to birds (based on dietary criteria; see discussion in Contaminants in Sediments section), it could be an indirect hazard, by adversely impacting the bird's food base.

Dissolved boron (B) concentrations were elevated in several playas above recommended concentrations for crop irrigation, and therefore, may adversely affect plant growth. Boron at these concentrations in surface water should not, however, directly injure aquatic invertebrates or waterfowl (Eisler 1990).

Dissolved selenium (Se) and mercury (Hg) were below MDLs (5 μg/L and 0.5 μg/L, respectively) in all sites sampled, but risk from these metals to wildlife can not be determined because: (1) WQC are based on total, not dissolved Hg and Se, and (2) New Mexico Wildlife Use WQC for total Se and Hg are 2 μg/L and 0.012 μg/L respectively (NMWQCC 1995), less than the MDLs of this study. Potential hazards from these metals must therefore be assessed relative to sediment, food, and body residue concentrations.

Silver (Ag), cadmium (Cd), copper (Cu), & lead (Pb) are all reported as less than the MDL (100 μg/L), but toxic effects are possible to aquatic biota at concentrations less than 100 μg/L. Thus, even though metal concentrations below 100 μg/L are not directly toxic to waterfowl (see Contaminants in Sediment, below), birds could still be at risk if their food resources were adversely impacted.

Table 3. Metals and trace metals in water samples (mg/L). A "<" symbol indicates the element was below the analytical detection limit

Sample Site	Cannon AFB	Clovis	Ladd Gordon	Portales	Santa Rosa	Tatum	Hobbs	Carlsbad	Artesia	Capitan	Raton	Clayton
Ag	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Al	<.1	2.9	<.1	0.2	0.1	<.1	0.1	<.1	0.1	0.1	<.1	<.1
As	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Ba	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Be	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Bo	<.1	0.6	1.8	0.2	0.3	0.6	0.4	0.3	0.3	0.3	0.3	0.4
Ca	51	47	57	35	210	93	110	180	200	130	55	35
Cd	<.001	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Co	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Cr	<.005	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Cu	<.1	<.1	<.1	<.1	<.1	<.1	<1	<.1	<.1	<.1	<.1	<.1
Fe	<.1	1.7	<.1	0.2	<.1	<.1	0.2	<.1	<.1	0.1	0.3	0.2
Hg	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005
Mg	47	14	140	17	31	29	<21	72	59	43	37	18
Mn	<.05	0.06	<.05	<.05	0.09	<.05	<.05	<.05	0.05	<.05	0.07	<.05
Mo	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Ni	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Pb	<.005	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Sb	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Se	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Si	2.5	0.9	1	1	0.7	1.4	0.9	0.7	0.7	0.6	0.3	0.4
Sr	1.5	1.4	2.4	0.7	2.7	0.9	0.9	1.8	2.8	1.5	0.7	0.5
V	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Zn	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1

Contaminants in Sediments

Conventional Pollutants (Nitrogen and Phosphorous Compounds) & Radium- not measured in sediments.

Organophosphate and organochlorine pesticides, and PCBs (Table 4)-

In addition to standard organophosphate and organochlorine pesticides, base/neutral extractables, base/neutral/acid extractables, triazine herbicides, and chlorophenoxy acid herbicides were also analyzed for at Cannon AFB, Barry Williams, Clovis, and Tucumcari. No pesticide or PCB residues were detected at any sites above MDLs (MDL= 0.10 μg/kg for dieldrin, endrin, DDE, DDT; 0.50 μg/kg for chlordane; 0.5-1.0 μg/kg arochlor PCBs). Trace amounts of organophosphate pesticides (diazinon, triadimefon) were detected at a few sites (Table 6) but at concentrations less than the analytical laboratory's "Practical Quantitation Limit" (PQL) of 10.0 μg/kg (PQL ~10x MDL). Based on the results of this study, pesticides and PCBs in the playa sediments do not appear to be contaminants of concern for wildlife inhabiting the playa wetlands examined in this study.

However, a more intensive assessment of sediments conducted at the Cannon AFB playa in 1994 (RCRA facility investigation) indicated one of ten sediment sample locations did contain elevated organochlorine pesticide and PCB concentrations that could present a risk to resident waterfowl (Cannon AFB 1995). This suggests that there could be isolated "hot spots" of contamination that this study's sampling scheme missed. The elevated concentrations of organic compounds in sediment from the Cannon AFB playa, concurrent with elevated tissue concentrations of PCBs in ducklings and killdeer eggs (see below), suggests that (1) adult birds feeding the ducklings and/or the ducklings may be gathering food from these "hot spots", and (2) that there may be other, as yet unmeasured, contaminant "hot spots" (both within and surrounding the playa) where birds are feeding. Alternatively, adult birds may have transferred pesticides to their eggs, derived from the Cannon AFB playa or an external source.

With the exception of the Cannon AFB playa, though, most tissue samples did not show evidence of organic contaminant bioaccumulation, which supports our conclusion that organics are not an issue at other playas examined in this study.

Table 4. Detectable concentrations of organophosphate or organochlorine pesticides found in sediments (μg/kg wet weight; n/a = not analyzed).

Sample Site	Cannon AFB	Barry-Williams	Clovis	Portales	Tucumcari	Tatum	Raton	Clayton
Diazinon	<10	<10	8	6	20	<10	<10	<10
Diazinon	<10	<10	<10	20	6	8	n/a	n/a
Triadimefon	<10	<10	<50	10	<50	<10	<10	<10
Triadimefon	<10	<10	<10	<50	10	<50	n/a	n/a

Metals (Table 5)-

Aluminum (Al), barium (Ba), chromium (Cr), iron (Fe), magnesium (Mg), vanadium (V), and zinc (Zn) exceeded avian Dietary Threshold Concentrations (DTC) for adverse effects in some playas (Table 6). Waterfowl normally ingest some soil and/or sediment while feeding, so if significant amounts of contaminated sediment are ingested, adverse effects could result.

Aluminum, barium, iron, and magnesium are normally elevated in New Mexico soils, but the Raton, Portales, and Clovis WWTP sites were still above Rio Grande geometric means of 3736 mg aluminum/kg dry weight and 123 mg barium/kg dry weight (O'Brien 1990; playa sediment metal concentrations are expressed on a wet weight basis, but were converted to dry weights assuming an average 25% sediment moisture content). Raton, Portales, Clovis WWTP, and Ladd Gordon playas were above Rio Grande geometric means of 2168 mg magnesium/kg dry weight and 6164 mg iron/kg dry weight. Because aluminum, iron, magnesium, and barium were elevated at several sites, and are common

constituents of New Mexico soils, the elevated concentrations were most likely a consequence of local geologic sources. Chromium, vanadium, and zinc, however, could originate from natural and/or anthropogenic sources. Anthropogenic inputs may include treated wastewater, storm runoff, roads, and other non-point sources. Further sampling is required to assess natural background concentrations and potential anthropogenic sources of chromium, vanadium, and zinc near these playas.

Table 5. Metals and trace metals in sediment samples (mg/kg wet weight). A "<" symbol before a value means the element concentration was below this value (i.e., < Method Detection Limit (MDL)).

Sample Site	Cannon AFB	Clovis	Clovis	Barry Williams	Ladd Gordon	Tucumcari	Portales	Raton	Clayton
Ag	<5	<5	<5	<.1	<5	<4.3	<4.30	<5	<2.90
Al	6690	6550	19580	750	8430	2600	18500	22880	2340
As	0.55	1	<.25	1.4	1.4	0.43	10.9	<1.25	0.49
Ba	45	170	84	3	370	60	150	190	55
Be	<5	<5	<5	<.1	<5	<4.3	<4.30	<5	<2.90
Bo	8	9	11	0.14	13	<4.3	28	<5	<2.90
Ca	34000	79100	6130	107	12370	11500	101000	9930	25300
Cd	0.1	0.11	<5	<.1	<5	<4.3	<4.30	<5	<2.90
Co	<2.5	<2.5	3.93	0.15	<2.5	<2.2	3.8	6.4	<1.5
Cr	5	<5	13	0.47	6.5	4.5	11	14	<2.90
Cu	65	<5	11	0.98	<5	9.8	9.2	35	<2.90
Fe	4420	3630	12200	450	6590	2770	11900	19310	2370
Hg	<.25	<.25	<.15	<.21	<.2	<.14	<.17	<.025	<.025
Mg	1830	3460	4130	117	3450	1350	51500	5300	960
Mn	32	32	120	4	110	68	190	180	30
Mo	<5	<5	<5	<.1	<5	<4.3	<4.30	<5	<2.90
Ni	<5	<5	8.1	0.34	<5	<4.3	8.2	12	<2.90
Pb	7.4	6.3	<5	0.12	<5	<4.3	<4.30	<5	<2.90
Sb	6	<5	<5	<.1	<5	<4.3	<4.30	<5	<2.90
Se	<.25	<.25	<.25	0.43	0.34	0.236	<.5	0.2	<.25
Si	580	410	260	2.5	180	230	310	310	140
Sr	59	130	98	2.9	130	110	1640	100	27
V	9	12	23	0.8	13	5.2	52	31	4.9
Zn	31	11	43	1.5	12	22	28	80	4.4

Table 6. Criteria used to evaluate the potential hazard of metals in sediments and potential food items to birds and aquatic organisms, expressed as mg/kg wet or dry weight (ww or dw; NA = not available).

Metal	DTC (ww)[a]	Ontario MME Lowest Observable Effect Level (dw)[b]	Other Sediment Quality Criteria (dw)[c]	Rio Grande Geometric Mean-Background (dw)[d]
Ag	NA	NA	0.5	NA
Al	200.0	NA	NA	3735.0
As	30.0	6.0	---	1.90
Ba	20.0	NA	20.0	123.01
Be	NA	NA	NA	0.30
Bo	30.0	NA	NA	2.63
Cd	0.1	0.6	---	0.24
Cr	5.1	26.0	---	4.83
Co	NA	NA	50.0	NA
Cu	300.0	16.0	---	5.53
Fe	NA	21,200 (2.0%)	---	6164.9
Hg	0.1	0.2	---	0.00
Pb	50.0	31.0	---	6.74
Mg	3,000.0	NA	NA	2168.0
Mn	2,000.0	460.0	---	840.8
Mo	100.0	NA	4.0	1.78
Ni	100.0	16.0	---	4.69
Se	0.8	NA	5.0	0.30
Sr	3,000.0	NA	NA	72.67
Sb	NA	NA	NA	NA
V	10.0	NA	NA	NA
Zn	44.5	120.0	---	24.46

a Dietary Threshold Concentration; derived from various sources (NRC 1980, Eisler (USFWS Contaminant Report Series) 1985-94, Lemly and Smith 1987, and International Joint Commission 1993).

b Ontario Ministry of the Environment and Energy, Ontario, Sediment Quality Guidelines (1993).

c Derived from various sources cited in MacDonald (1994).

d From USFWS, Contaminants Investigation of Bitter Lake NWR, Roswell, NM (O'Brien 1990).

Chromium does not usually biomagnify, so the elevated sediment concentrations are probably not a risk to birds (Eisler 1986). Cadmium and mercury (Hg) MDLs are too high to assess if these metals exceed DTC, and DTC are not available for silver, beryllium (Be), cobalt (Co), and tin (Sb). Boron (28 mg/kg in Portales) approaches, but does not exceed, the DTC for avian species of 30 mg/kg.

Silver, beryllium, and tin MDLs were also too high to compare to various background concentration references (Boergen and Shacklette 1981, O'Brien 1990, Horowitz et al. 1993). Most other sediment metals were not elevated above typical sediment background concentrations and should pose little risk to waterfowl and aquatic organisms.

Of those metals that were above typical background concentrations, most are not directly hazardous to waterfowl (i.e., do not exceed DTC). For instance, arsenic (As; Portales, 10.9 mg/kg), boron (Portales, 28 mg/kg), copper (Raton, 35 mg/kg; Cannon AFB, 65 mg/kg) and selenium (Barry Williams, 0.43 mg/kg; Ladd Gordon, 0.34 mg/kg) were elevated above typical regional background values, but did not exceed the DTC for avian species. But others that are not directly hazardous to waterfowl are potentially hazardous to benthic invertebrates and other aquatic organisms on which waterfowl feed. Arsenic in Portales WWTP and copper in Raton and Cannon AFB WWTP exceeded Ontario MEE (1993) lowest observable effect levels for aquatic organisms. The MDLs are again too high for silver, cadmium, and molybdenum (Mo; 5 mg/kg), and mercury (0.5 mg/kg) to assess if they exceeded sediment screening criteria, but if they were elevated above various sediment quality criteria, they would pose a threat to aquatic organisms.

Overall, birds may be at risk from some sediment metals (Table 6) if: (1) sediment metals are bioaccumulating in food items or bird tissues, (2) a significant percentage of the bird's diet includes ingested sediment (ingested while feeding on benthic invertebrates and plants), and (3) the metals are in a bioavailable, and thus toxic, form (see following sections).

Contaminants in Aquatic Biota

Contaminant residues in aquatic biota and vegetation are an indicator of the bioaccumulation potential for birds eating fish, invertebrates, and vegetation. Fish metal residues can be compared to National Contaminant Biomonitoring Program (NCBP) 85th percentile U.S. background concentrations (Schmitt and Brumbaugh 1990). Few data are available, however, to interpret the toxic potential of contaminant residues in plants, invertebrates, and amphibians. Lethal or sublethal effects of elevated tissue metals concentrations in aquatic biota may translate to an indirect risk to waterfowl by way of reduction in the available food base. Adverse effects on the food base available to the birds must, therefore, be assessed by comparison to water and sediment quality criteria, or, by actual assessment of the biota present in each playa.

Organophosphate and organochlorine pesticides- organic contaminant residues in potential food items (various invertebrates, salamander, fish, and plants/algae) were not determined.

Metals (Table 7)-

All potential avian food items from each wetland were not sampled, so elevated aquatic biota contaminant concentrations serve only as indicators that further sampling is required. Because both birds and their potential food items were not sampled together at the same playa, actual food chain transfer of contaminants cannot be assessed. Thus, no definitive conclusions regarding contaminant risks to waterfowl ingesting contaminated prey items can be drawn from these results.

Aluminum, boron, cadmium, and selenium were slightly elevated in some samples, but most other tissue metal residues did not exceed DTC and should not pose a risk to waterfowl ingesting them. Aluminum was elevated in an invertebrate sample from Clayton, and an algae sample from Tucumcari, and exceeded the recommended DTC for birds (200.00 μg/g). This was not surprising given the elevated

aluminum concentrations found in the sediments. The elevated aluminum concentration found in the algae sample in Tucumcari WWTP playa suggests surface water trace metal concentrations were also elevated. Boron concentrations in plants sampled at Tatum WWTP (48.6 μg/g) also exceed the DTC for birds (30.0 μg/g). The boron concentration in Tatum WWTP surface water was among the highest of the 15 playas sampled, but boron in an invertebrate sample was not elevated, indicating the primary exposure pathway for birds would be via water and plant consumption, rather than ingestion of contaminated invertebrates. Cadmium exceeded the DTC for birds (0.1μg/g) in an invertebrate from Barry Williams and in algae sampled at Tucumcari. Selenium in a fish from Tatum WWTP is at the DTC of 0.8 μg Se/kg, and could result in adverse affects to piscivorus birds. No other metal concentrations in potential food items exceeded DTC or NCBP criteria, although some may still present a risk to aquatic organisms.

Table 7. Trace-metal concentrations in aquatic organisms and vegetation. which could be potential food items for birds (µg/g wet weight). A "<" symbol before a value means the element concentration was below this value (i.e., < Method Detection Limit (MDL)).

Sample Site	Clovis	Barry Williams	Ladd Gordon	Tucumcari	Tatum	Tatum	Tatum	Clayton	Clayton
Sample Matrix	Salamander	Invertebrate	Fish	Algae	Fish	Invertebrate	Vegetation	Salamander	Invertebrate
Al	<2	205	12	484	2	4.7	9.6	111	539
As	<0.2	0.59	<0.1	0.099	<0.05	0.17	0.052	0.07	0.19
Ba	3	1.78	7	16.5	2.2	0.2	0.528	1.53	12.9
Be	<2	0.0087	<2	0.017	<.002	<.002	0.00078	0.0049	0.027
Bo	<2	0.59	<2	2.4	0.5	1.4	48.6	<0.3	0.7
Cd	<2	0.12	<2	0.12	0.005	0.017	0.026	0.069	0.09
Cr	<2	0.2	<2	1.27	0.11	0.17	0.062	0.28	0.63
Cu	<2	0.78	<2	7.58	0.89	2.6	0.15	1.4	4.49
Fe	7	114	20	422	16	12	7.18	96.4	461
Hg	<0.05	0.021	<0.05	0.036	0.034	0.021	<.0003	0.003	0.013
Mg	430	185	330	369	316	149	116	146	415
Mn	<1	2.75	5	45.5	2.3	1.1	3.2	1.5	10.7
Mo	<2	<0.1	<2	0.2	<0.2	<0.2	<0.03	<0.1	<0.2
Ni	<2	0.21	<2	0.52	<0.02	0.43	0.086	0.18	0.7
Pb	<2	<0.04	<2	1.3	<0.1	<0.09	<0.01	<0.07	0.43
Se	0.5	0.27	0.96	0.46	0.75	0.41	0.042	0.17	0.2
Sr	<2	37.2	84	51.3	18.6	2.52	7.85	3.61	10.6
V	<2	0.6	<2	1.1	<0.07	1.3	0.24	0.52	1.2
Zn	27	6.9	25	17.4	30.4	13	0.75	9.1	20.8

Contaminants in Birds

Elevated contaminant body burdens may be due to ingestion of water, food items, sediments, and surrounding soils (not measured in this study) within and surrounding the playas, and/or from outside sources. It is beyond the scope of this study, however, to assess contaminant exposure pathways, and contaminant body burdens acquired from sites outside those sampled here. The presence of nests, eggs, and ducklings suggest many birds are residents, and are likely feeding in or near the playas sampled. Also, playa lakes represent one of the few waterfowl habitats in the area, so birds are more likely to be near a playa than elsewhere. In general, egg and duckling tissue residues probably reflect contaminants acquired within the playas, whereas adult tissue residues may reflect contaminants acquired within the playas or sources along a migratory route. Tissue residues in ducklings and eggs may be interpreted in two ways: (1) in terms of adverse effects to the birds themselves, or (2) as potential food items (and contaminant exposure source) for raptors and other predatory wildlife.

Organophosphate and organochlorine pesticides, and PCBs (Tables 8a & 8b)-

Organophosphates and organochlorine in avian tissues were either not detected, or found at concentrations similar to control birds in various laboratory studies (< 1μg/g). Total Arochlor-PCB concentrations, however, were elevated in 83% of the duckling tissue samples from the Cannon Air Force Base WWTP playa. Egg PCB concentrations exceeded the DTC for raptors consuming contaminated eggs or ducklings, and depending on the type of PCB present, may exceed the dose demonstrated to kill laboratory chicken eggs (Eisler and Belisle 1996). No other screening levels were exceeded, but the presence of detectable PCB concentrations in eggs and ducklings is reason for concern. The absence of detectable PCBs in the sediments sampled in this study suggests the source of tissue PCB residues was not from the playa, although the elevated PCBs in an egg and duckling indicates there may be some nearby PCB source from which parent birds are gathering food (i.e., "hot spots" within the

wetland sediments [see discussion in Contaminants in Sediments] or other nearby sources not sampled in this study).

Table 8a. Organochlorine pesticide and PCB residues in adult duck tissues from Cannon AFB and Clovis WWTP playa lakes (µg/kg wet weight; ND = not detected).

Sample Site	**Cannon AFB**		**Clovis**		
Species	**Mallard**	**Mallard**	**Teal &Shoveler**	**Teal**	**Shoveler**
Tissue	**Liver**	**Liver**	**Liver**	**Breast**	**Breast**
Aldrin	6	5.2	ND	ND	ND
4,4' - DDE	25	7.4	ND	ND	11
4,4' - DDT	ND	ND	ND	ND	ND
beta-BHC	ND	ND	ND	ND	ND
Arochlor PCB Mix	ND	ND	ND	ND	ND
Endosulfan I	ND	ND	ND	ND	ND

Metals (Tables 9-11)-

Several metals were elevated in stomach content samples (aluminum, barium, copper, iron, manganese, lead, and vanadium), but aluminum, barium, manganese, and vanadium were not bioaccumulating to concentrations of concern. These elevated concentrations corresponded to concentrations found in the sediments and aquatic biota that the birds may be consuming. Aluminum, barium, iron, selenium, and zinc were present at concentrations greater than the DTCs in bird stomach content samples from some playas, but are not bioaccumulating. Iron tissue concentrations were less than starlings sampled within the San Juan Basin (O'Brien 1990). The cadmium MDL was too high to assess if it exceeded a DTC.

Copper, lead, and cadmium, however, were bioaccumulating within some birds. Liver copper concentrations were elevated above background tissue concentrations reported for birds sampled in the San Juan Basin (O'Brien 1990), at Cannon AFB, Clovis, and Ladd Gordon. Liver copper concentrations of 13.5 μg/g whole-body and 56 μg/g can be toxic to geese (Henderson and Winterfield 1974, Puls 1989). Bird liver copper concentrations in this study were as high as 67 μg/g in Ladd Gordon, 40 μg/g in Clovis, and 37 μg/g in the Cannon AFB playas. One of the four birds and ducklings sampled at Cannon AFB had an elevated ova lead concentration, which could be toxic if similar concentrations existed in the liver. Lead was also elevated in two whole-body duckling samples collected at Ladd Gordon. Lead concentrations this high in mallard livers are considered an indication of lead poisoning (Longcore et al. 1974). Whether whole-body lead concentrations can be interpreted similarly is unknown.

The source(s) of the elevated copper and lead in these samples are unknown. Copper and lead were not elevated in water, sediments or other potential food items, so these elevated copper and lead residues could be due to isolated copper/lead "hot spots," previous copper/lead exposure at other locations (adults), ingestion of stray lead shot (and/or copper-coated lead shot), or, sample contamination. Although copper, lead, and vanadium were elevated in stomach content samples, they did not exceed DTC. Nonetheless, elevated concentrations in the stomach suggest these birds could be slowly accumulating low concentrations from sediments and/or some unknown source. Copper and lead concentrations found in several duck livers and within the whole-body duckling samples are reason for concern, and could be considered toxic when compared to toxic liver tissue concentrations reported in the literature.

Kidney cadmium concentrations were above background concentrations reported by DiGiulio and Scanlon (1984) and Blus et al. (1993), but below the no-effect level of 50 μg/g determined by White et al. (1978) and DiGiulio and Scanlon (1984). The cadmium concentrations found in the birds sampled

Table 8b. Organochlorine pesticide and PCB residues in whole-body duckling samples and killdeer eggs from Cannon AFB and Clovis WWTP playa lakes (µg/kg wet weight; ND= not detected).

Sample Site	**Cannon AFB**						**Clovis**		
Sample Matrix	**Duckling**	**Duckling**	**Duckling**	**Egg**	**Egg**	**Egg**	**Duckling**	**Duckling**	**Duckling**
Species	**Unknown**	**Unknown**	**Unknown**	**Killdeer**	**Killdeer**	**Killdeer**	**Unknown**	**Unknown**	**Unknown**
Tissue	**Whole Body**	**Whole Body**	**Whole Body**	**Embryo**	**Embryo**	**Embryo**	**Whole Body**	**Whole Body**	**Whole Body**
Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4' - DDE	8	ND	ND	241	ND	15	2	6.2	ND
4,4' - DDT	ND	ND	ND	9	ND	ND	ND	1	ND
beta-BHC	ND	ND	ND	13	ND	ND	ND	ND	ND
Arochlor PCB Mix	80	ND	800	200	250	69	ND	ND	ND
Endosulfan I	ND	ND	ND	ND	ND	ND	ND	1.6	ND

in this study should not be hazardous, but more birds should be analyzed before this contaminant is dismissed as a concern.

Silver, arsenic, beryllium, boron, cobalt, chromium, mercury, molybdenum, nickel, tin, selenium, strontium, and zinc in tissues were either not detected, similar to concentrations found in birds from other playa studies, or at concentrations below those known to cause adverse effects in various animals (O'Brien 1990, King and Andrews 1997, U.S.EPA 1997). In general, waterbirds, ducklings, and eggs do not appear at risk from these metals in any of the playas sampled. But, whereas selenium and mercury concentrations in duckling whole-body tissues are not toxic to the ducklings themselves, they do exceed DTCs, and thus raptors eating these ducklings could be at risk from these metals.

Table 9. Metals and trace-metals in four mallards sampled at the Cannon AFB playa lake (µg/g wet weight). A "<" symbol before a value means the element concentration was below this value (i.e., < Method Detection Limit (MDL), and n/a= not analyzed).

Tissue	Ova	Kidney	Stomch Cnts	Kidney	Stomch Cnts	Ova	Liver	Stomch Cnts	Kidney	Ova	Kidney	Liver	Kidneys	Stomch Cnts	Livers
Ag	<2	<2	<2	<2	<2	n/a	<2	<2	<2	n/a	<2	<2	<2	<2	<2
Al	3	<2	880	2	320	n/a	<2	300	<2	n/a	<2	<2	47	300	<2
As	<.2	<.1	1	<.1	0.08	<.25	<.1	0.29	<.1	<.5	<.1	<.1	<.2	0.3	<.1
Ba	<2	<2	43	<2	25	n/a	<2	57	<2	n/a	<2	<2	4	26	<2
Be	<2	<2	<2	<2	<2	n/a	<2	<2	<2	n/a	<2	<2	<2	<2	<2
Bo	<2	<2	<2	<2	<2	n/a	<2	<2	<2	n/a	<2	<2	2	<2	<2
Ca	160	110	23000	81	17500	n/a	59	20700	120	n/a	52	43	130	19100	60
Cd	<2	<2	<2	3	<2	n/a	<2	<2	<2	n/a	<2	<2	3	<2	<2
Co	<1	<1	<1	<1	<1	n/a	<1	<1	<1	n/a	<1	<1	<1	<1	<1
Cr	<2	<2	<2	<2	<2	n/a	<2	<2	<2	n/a	<2	<2	<2	<2	<2
Cu	5	5	3	7	<2	n/a	37	3	9	n/a	19	34	5	<2	29
Fe	1060	120	1370	140	53	n/a	1950	1670	150	n/a	610	1180	180	660	2710
Hg	<.05	0.06	<.05	0.08	<.05		0.11	<.05	0.1		<.05	0.06	0.12	<.05	0.12
Mg	150	200	470	210	670	n/a	260	280	190	n/a	230	200	190	350	200
Mn	<1	3	58	<1	11	n/a	5	41	3	n/a	4	4	1.9	11	3.5
Mo	<2	<2	<2	<2	<2	n/a	2	<2	<2	n/a	<2	<2	<2	<2	2
Ni	<2	<2	<2	<2	<2	n/a	<2	<2	<2	n/a	<2	<2	<2	<2	<2
Pb	45	0.14	1.2	0.22	0.14	<.3	0.61	0.49	0.84	<.3	0.06	0.12	0.24	0.32	0.11
Sb	<2	<2	<2	<2	<2	n/a	<2	<2	<2	n/a	<2	<2	<2	<2	<2
Se	1.4	2.8	2.3	5.5	0.12	1.8	2.6	0.23	3.1	1.9	4.2	2.1	1.6	0.17	2.1
Si	8	9	3	4	7	n/a	7	74	3	n/a	12	5	9	3	7
Sr	<2	<2	59	<2	20	n/a	<2	19	<2	n/a	<2	<2	<2	26	<2
V	<2	<2	7	<2	<2	n/a	<2	4	<2	n/a	<2	<2	<2	<2	<2
Zn	23	21	66	25	8	n/a	54	6	23	n/a	55	44	26	4	38

Table 10. Metals and trace-metals in ducks (µg/g wet weight). A "<" symbol before a value means the element concentration was below this value (i.e., < Method Detection Limit (MDL), and n/a= not analyzed).

Sample Site	Clovis						Ladd Gordon								
Species	Teal, Shoveler	Teal	Shoveler	Teal, Shoveler	Teal	Teal, Shoveler	Mallrd, Redhd	Mallard	Mallrd, Redhd	Redhd	2 Redhds	B-WingTeal	B-Wing Teal	Mallrd, Redhd	2 Redhds
Tissue	Livers	Breast	Breast	Kidneys	Ova	Stomach Cnts	Kidneys	Ova	Stomach Cnts	Ova	Stomach Cnts	Liver	Kidney	Livers	Livers
Ag	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Al	3	3.2	<2	<2	n/a	75	4	n/a	4	8	590	<2	<2	<2	2
As	<.2	<.2	<.2	<.2	n/a	0.12	<.10	n/a	<.1	<.1	0.79	<.2	<.2	<.2	<.1
Ba	<2	6.1	2	<2	n/a	8	<2	n/a	<2	<2	20	<2	<2	<2	<2
Be	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Bo	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Ca	60	7900	6780	67	n/a	750	93	n/a	130	470	6500	33	75	45	95
Cd	<2	<2	<2	<2	n/a	<2	4	n/a	<2	<2	<2	<2	<2	<2	<2
Co	<1	<1	<1	<1	n/a	<1	<1	n/a	<1	<1	<1	<1	<1	<1	<1
Cr	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Cu	40	11	9	8	n/a	<2	5	n/a	4	<2	<2	2	2	38	67
Fe	1230	100	84	100	n/a	200	170	n/a	130	74	500	940	110	1820	490
Hg	0.41	0.13	0.34	0.6	0.12	<.05	0.13	0.13	0.07	<.05	<.05	0.13	0.09	0.2	0.12
Pb	0.11	0.99	<.1	0.07	n/a	0.23	0.12	n/a	0.21	<.04	0.8	0.06	0.14	0.09	0.07
Mg	250	330	350	200	n/a	36	210	n/a	190	130	450	220	210	240	220
Mn	5.7	<1	1	3	n/a	8	3	n/a	2	<1	23	5	2	6	4
Mo	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Ni	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Sb	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	<2	<2	<2	<2	<2
Se	4.4	1	1.5	5.1	n/a	<.1	2.5	n/a	1.4	0.4	0.17	0.97	1.4	3.5	1.4
Si	7	10	3	3	n/a	8	11	n/a	7	11	4	2	2	6	7
Sr	<2	10	11	<2	n/a	<2	<2	n/a	<2	5	61	<2	<2	<2	<2
V	<2	<2	<2	<2	n/a	<2	<2	n/a	<2	<2	2	<2	<2	<2	<2
Zn	67	17	18	23	n/a	13	30	n/a	22	21	8	29	20	38	55

Table 11. Metals and trace-metals in ducklings and eggs (µg/g wet weight). A "<" symbol before a value means the element concentration was below this value (i.e, < Method Detection Limit (MDL); n/a= not analyzed).

Sample Site	Cannon AFB						Clovis					Ladd Gordon	
Sample Matrix	duckling	duckling	Egg	Egg	Egg	Duckling	Duckling	Duckling	Duckling	Duckling	Duckling	Duckling	Duckling
Species	unknown	unknown	Killdeer	Killdeer	Killdeer	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Tissue	whole body	whole body	Embryo	Embryo	Embryo	Whole Body	Whole Body	Whole Body	Whole Body	Whole Body	Whole Body	Whole Body	Whole Body
Ag	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Al	34	23	<2	<2	3	26	4	2	17	5	5	16	12
As	<.1	<.2	<.1	<.1	<.1	<.1	<.2	<.2	<.1	<.2	<.1	<.1	<.2
Ba	2	<2	<2	7	12	5	4	<2	4	5	<2	4	6
Be	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Bo	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ca	4420	3440	2130	41000	87800	7840	6870	1860	9000	15000	1440	10300	9990
Cd	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Co	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cr	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cu	2	3	<2	<2	<2	8	3	<2	3	3	2	5	14
Fe	100	66	27	26	22	79	64	21	74	54	45	46	57
Hg	<.05	<.05	0.06	<.05	0.05	<.05	<.05	<.05	<.05	<.05	<.05	0.24	0.13
Pb	<.1	<.1	<.5	<.4	<.3	0.12	1.3	3.4	0.13	2.3	1.2	12	21
Mg	250	250	110	460	910	320	300	110	370	450	210	420	340
Mn	1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	5	3
Mo	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ni	<2	<2	<2	<2	<2	3	<2	<2	<2	<2	<2	<2	<2
Sb	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Se	1.3	1.3	1	0.65	1.1	2	1.8	2.1	1.9	1.8	2.1	1	1.3
Si	55	39	2	4	6	22	8	3	7	18	8	21	10
Sr	20	19	5	87	200	22	23	7	27	51	5	50	62
V	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Zn	22	23	9	9	8	31	24	9	28	30	24	29	35

CONCLUSIONS AND RECOMMENDATIONS

1. Organic contaminants:

Organic contaminants were not detected in water and sediments of any of the sampled playas (Tables 4 and 12). Although detection limits were too high in water samples to assess if chronic water quality criteria are met, the lack of any significant bioaccumulation of organochlorine pesticides and PCBs (with the exception of Cannon AFB) suggests any trace concentrations that may be present are not hazardous. The 1995 Cannon AFB sediment screening (Cannon AFB 1995), which found elevated organochlorine pesticide concentrations, suggests that there could be an isolated "hot spot(s)" within this playa that was not detected in this study. The finding of elevated PCBs in ducklings and killdeer eggs from this site (Tables 8 and 12) suggests there may also be a PCB "hot spot(s)" from which adult birds and ducklings are feeding.

2. Nutrient and metal contaminants:

In all of the sites where sediment was sampled (8 of 15), one or more metals were elevated (Tables 5 and 12). If the elevated concentrations of aluminum, barium, iron, and magnesium are attributed to natural, geological sources, then only 5 of the 8 sites where sediment was sampled (Cannon AFB, Clovis WWTP, Ladd Gordon, Portales, and Raton) contain one or more potentially anthropogenically derived metals. Nonetheless, several sediment metals were elevated above dietary threshold concentrations (DTC) and sediment screening criteria (SSC), and birds from all three sites sampled had liver copper concentrations that exceeded toxicity screening levels. Because copper was not elevated in sampled sediments, but was in bird tissues, the source of this copper should be determined. Lead was also slightly elevated in ducklings at the Cannon AFB playa, but it is uncertain if these whole-body lead concentrations would result in adverse effects.

Furthermore, while most other metals are not bioaccumulating in waterfowl (Tables 7, 9-11, and 12), there still could be adverse effects to aquatic organisms that are one of the primary food resources for many waterfowl. Any adverse effects to lower trophic levels in the aquatic food chain could cause an indirect adverse effect on waterfowl. For instance, copper concentrations in the Cannon AFB and Raton playas, and arsenic in the Portales playa exceed Ontario MME (1993) sediment quality criteria.

Several other metals (Tables 3 and 12), including silver, cadmium, copper, mercury, lead, and selenium may also exceed New Mexico Water Quality Criteria (WQC). Method detection limits (MDLs) in this study were too high to compare silver, cadmium, mercury, and molybdenum in sediments to DTC and various sediment screening criteria (SSC). Once accurate concentrations are determined, these elements may also exceed WQC and SSC. Further biological-based testing, such as standardized laboratory toxicity evaluations, is recommended to screen for food-base impacts to waterfowl.

3. General conclusions:

The use of secondary-treated wastewater to enhance playa bird habitat should not be adopted as a widespread management alternative until the risk to birds from trace-metals is examined more thoroughly. Although organic contaminants do not appear to be a hazard to birds and aquatic organisms in the sites sampled in this study, several do have sediment and food metal concentrations that exceed avian DTCs. Nonetheless, except for copper and lead in two ducklings at Cannon AFB, tissue metal concentrations are not concurrently elevated, suggesting that birds are not ingesting a high percentage of contaminated sediment and food items and/or these metals are not bioavailable.

Because the studies used to establish the DTC in Table 6 usually do not consider the influence of site-specific factors on the bioavailability of these metals, local acclimation and/or adaptation to naturally elevated metals, such as aluminum or barium, and competitive interactions in calcium-rich soils, may render these metals less bioavailable and less toxic. For instance, laboratory studies of lead ingestion by

birds have demonstrated that high calcium concentrations and nutrient-rich diets can reduce lead toxicity and accumulation (Pain 1996, Scheuhammer 1996), possibly by lowering the metal's bioavailability. Thus, the high calcium concentrations present in the playas examined in this study might explain the lack of tissue metal bioaccumulation, even though DTC criteria are exceeded, and, may reduce the adverse impacts of copper and lead accumulated in some birds. This topic needs to be examined further.

In general, most avian laboratory toxicity and bioaccumulation reference data are generated at much lower calcium concentrations than those encountered in the arid southwest. So until metal screening criteria are generated which are more appropriate to this region, it will be difficult to determine metal risks to birds.

4. Specific recommendations:

- *Use of WWTP effluent for bird habitat management*: Until the risk from trace metals to birds, particularly copper, is examined further, use of WWTP effluent to create bird habitat should be limited. The key question is: Do the benefits of increased habitat outweigh the risks from metal contaminants?

- *Repeated sampling locations*: Sites where only water was sampled should be reanalyzed for sediment metal concentrations. If sediment metals are elevated, then aquatic organisms and birds should be analyzed to see if these metals are bioaccumulating.

- *Required analytical Method Detection Limits (MDL)*: Re-sample and re-analyze for silver, cadmium, copper, mercury, lead, and selenium in water, and silver, cadmium, and mercury in sediments, using lower MDLs. No definitive conclusions can be drawn for

these metals regarding potential harmful effects to birds and aquatic biota until MDLs are below screening criteria.

- *Suggested additional studies*: This survey study points to the need for a more focused study, preferably with fewer sites and a "control" site, and upon contaminants that seem to present ubiquitous potential toxicity problems in the region examined in this study. Copper and lead in sediments and bird tissues, and effects of metals on aquatic organisms, including fish, and benthic and aquatic invertebrates, should be examined more closely at the more intensively managed playas. If birds are sampled, then any potential food items should also be sampled to help determine potential exposure and bioaccumulation pathways. At sites where sediment or water metal concentrations exceed chronic WQC, the health and composition of fish and invertebrate populations should be assessed in terms of food resource requirements for birds. This assessment may take the form of laboratory or in-situ toxicity testing and/or an U.S. EPA Rapid Bioassessment type of approach. Lastly, a thorough literature review of existing WWTP constructed wetland projects throughout the southwest may yield valuable data regarding metals risks to birds and aquatic organisms.

- *Effluent toxicity testing:* If New Mexico WQC require toxicity testing of treated effluent at the locations surveyed, the results should be examined and factored into decisions pertaining to the use of effluent for the creation of wildlife habitat.

Table 12. Summary of contaminants of potential concern for each site sampled. Elements where MDLs are too high to compare to allow comparison to various screening criteria were not included, even though these elements may also be COPCs.

	Organics[a]			Trace-metals						
Wetland	**Sediment**	**Water**	**Tissues**	**Sediment**		**Water**	**Tissues**			
				DTC[e]	**SSC[f]**		**Ducklings**	**Eggs**	**Adults**	**Bird Food Items & Stomach Contents[g]**
Cannon Air Force Base	ND[b]	ND	PCBs- ducklings & eggs	Al, Ba, Cr, Fe	Ba, Cu	BSL	BSL	BSL	Cd, Cu, Fe, Pb, V	Al, Ba, Fe, Se, Zn
Clovis WWTP	ND	ND	BSL[d]	Al, Ba, Fe, Mg, V	Ba	Al	BSL	--	Cd, Cu, Fe	--
Barry William's Playa	ND	ND	--	Al	BSL	BSL	--	BSL	--	Al, Cd
Ladd S. Gordon Management Area	--[c]	ND	--	Al, Ba, Cr, Fe, Mg, V	Ba	BSL	Pb	--	Cd, Cu, Fe	Al, Ba, Fe
Tucumcari WWTP	ND	ND	--	Al, Ba, Fe	Ba	Al	--	--	--	Al, Cd
Portales WWTP	ND	ND	--	Al, Ba, Cr, Fe, Mg, V	As, Ba	BSL	--	--	--	--
Santa Rosa WWTP	--	ND	--	--	--	BSL	--	--	--	--
Tatum WWTP	ND	ND	--	--	--	BSL	--	--	--	Bo
Hobbs WWTP	--	--	--	--	—	BSL	--	--	--	--
Carlsbad WWTP	--	—	—	--	—	BSL	--	--	--	--
Artesia WWTP	--	--	--	--	—	BSL	--	--	--	--
Capitan Lagoons	--	--	--	--	—	BSL	--	--	--	--
Raton WWTP	ND	ND	--	Al, Ba, Cr, Fe, Mg, V, Zn	Ba, Cu	BSL	--	--	--	--
Clayton WWTP	ND	ND	--	Al, Ba, Fe	Ba	BSL	--	--	--	Al

[a] Organics include pesticides and PCBs. [b] ND= Not Detected (below MDLs). [c] "--" = Parameter not measured. [d] BSL= Below Screening Level (the concentration which may cause adverse effects). [e] exceed Dietary Threshold Concentration (DTC; ingestion of this concentration may cause adverse effects). [f] SSC= Sediment Screening Criteria (the concentration which may cause adverse effects to benthic organisms). [g] Food items include: invertebrates, vegetation, algae, fish, and salamanders.

LITERATURE CITED

Blus, L.J., C.H. Henny, D.J. Hoffman, and R.A. Grove. 1993. Accumulation and effects of lead and cadmium on wood ducks near a mining and smelting complex in Idaho. Ecotox. 2: 139-154.

Boerngen, J.G., and H.T. Shacklette. 1981. Chemical analyses of soils and other superficial materials of the conterminous United States. U.S. Geological Survey, Open-File Report 81-197, 18pp.

Cannon AFB. 1995. Volume 1A, Draft RCRA facility investigation, Appendix III, SWMUs-Phase II risk assessment, Cannon Air Force Base, New Mexico, C3M11MM.

DiGiulio, R.T., and P.F. Scanlon. 1984. Heavy metals in tissues of waterfowl from the Chesapeake Bay, USA. Environ. Pollut. Ser. A, 35:29-48.

Eisler, R. 1985. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.2). 46 pp.

Eisler, R. 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.6). 60 pp.

Eisler, R. 1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.10). 90 pp.

Eisler, R. 1990. Boron hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep 85(1.20). 32 pp.

Eisler, R. 1993. Zinc hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep 85(1.). pp.

Eisler, R. 1994. Arsenic hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep 85(1.). pp.

Eisler, R. and A.A. Belisle. 1996. Planar PCB hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep 31. 75 pp.

Henderson, B.M. and R.W. Winterfield. 1974. Acute copper toxicosis in the Canada goose. Avian Diseases 19:385-387.

Horowitz, A.J., K.A. Elrick, and R.B. Cook. 1993. Effect of mining and related activities on the sediment trace element geochemistry of Lake Coeur D'Alene, Idaho, USA. Part I: Surface Sediments. Hydrol. Process. 7:403-423.

International Joint Commission. 1993. A strategy for virtual elimination of persistent toxic substances: Volume 1. Report of the virtual elimination task force. Windsor, Ontario. 72pp.

King, K.A., and B.J. Andrews. 1997. Environmental contaminants in ducks collected from wastewater treatment plant ponds, Nogales, Arizona 1996. U.S. Fish and Wildlife Service, Arizona Ecological Services Field Office Report, February 1997, 13 pp.

Lemly, A.D. and G.J. Smith. 1987. Aquatic cycling of selenium: Implications for fish and wildlife. U.S. Fish and Wildlife Service leaflet No. 12, Washington, D.C. 10pp.

Longcore, J.R., L.N. Locke, G.E. Bagley, and R. Andrews. 1974. Significance of Pb residues in mallard tissues. U.S. Fish and Wildlife Service Special Science Report No. 182.

MacDonald, D.D. 1994. Fraser River action plan: A review of environmental quality criteria and guidelines for priority substances in the Fraser River Basin. Environment Canada, Environmental Conservation Branch, North Vancouver, BC. DOE FRAP 1994-30.

National Research Council. 1980. Mineral tolerance of domestic animals. National Academy Press, National Academy of Sciences, Washington, D.C. 577 pp.

NMED (New Mexico Environment Department). 1993 (updated annually). Laboratory quality assurance/quality control plan.

NMWQCC (New Mexico Water Quality Control Commission). 1995. State of New Mexico standards for interstate and intrastate streams. 51 pp.

O'Brien, T.F. 1990. Organochlorine and heavy metal contaminant investigation for Bitter Lake National Wildlife Refuge, Roswell, New Mexico, 1986. U.S. Fish and Wildlife Service, New Mexico Ecological Services Field Office Contaminant Report, April 1990, 24 pp.

Ontario MME (Ontario Ministry of the Environment and Energy). 1993. Development of the Ontario Provincial sediment quality guidelines for arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc. August 1993. 24 pp.

Puls, R. 1989. Mineral levels and animal health: Diagnostic data. Sherpa International, Clearbrook, B.C.

Scheuhammer, A. M. 1996. Influence of reduced dietary calcium on the accumulation and effects of lead, cadmium, and aluminum in birds. Environ. Pollution: 94(3): 337.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National Contamiant Biomonitoring Program: concentratiosn of arsenic, cadmium, copper, lead, mercury, slenium, and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19:731-747.

USAF. 1990. Realignment of Cannon Air Force Base, Curry County, New Mexico. Final environmental impact statement. May 1990.

USEPA. 1980. Ambient water quality criteria for DDT. EPA 440/5-80-038, Washington, D.C.

USEPA. 1997 (database updated monthly). IRIS2: Integrated Risk Information System. Office of Health and Environmental Assessment, Office of Research and Development, U.S. EPA.

White, D.H., M.T. Finley, and J.F. Ferrell. 1978. Histopathological effects of dietary cadmium on kidneys and tissues of mallard ducks. J. Toxicol. Environ. Health 4:551-558.