ABSTRACT--Aquatic invertebrates, fish (whole body), and birds were collected in 1993 from several locations along the Puerco and Little Colorado Rivers in northeastern Arizona for trace element and radionuclide analysis. Aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc were elevated in fish from several locations on the Little Colorado River. Aluminum, cadmium and mercury were detected in one or more fish samples at concentrations that could cause secondary poisoning of avian predators that consume a large portion of fish in their diet. One fathead minnow sample contained copper (92.34 μg/g wet weight) at four times the highest copper concentration (23.1 μg/g wet weight) detected during the 1976-1984 National Contaminant Biomonitoring Program sampling (Schmitt and Brumbaugh 1990). Arsenic and lead were detected in fish from the Little Colorado River at levels which could possibly limit their reproduction.

Due to natural geographic variations of radioactivity throughout the United States and the lack of background data from our study area with which to compare our findings, radionuclide data interpretation is impractical at this time. The radiological contaminant levels reported in this study will serve as background information for future studies on the effects of radionuclides on fish and wildlife in northeastern Arizona. Additional studies are needed to adequately characterize the effects of contaminants from the Puerco and Little Colorado Rivers on fish and wildlife resources.

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INTRODUCTION

The Puerco River begins in the Chuska and Zuni Mountains in northwestern New Mexico and flows west-southwest to its confluence with the Little Colorado River east of Holbrook, Arizona. With a drainage area of approximately 3,000 square miles, the Puerco River exhibits peak streamflow in response to spring runoff and summer thunderstorms. Between the 1950s and the mid-1980s, flows of the Puerco River changed from ephemeral to perennial in the upper part of the basin downstream to at least the New Mexico-Arizona border and possibly as far as a few miles downstream from Chambers, Arizona (Shuey 1982). The sources of perennial flows were effluent from dewatering activities associated with uranium mines and mills northeast of Gallup, New Mexico and from effluent discharges from a wastewater treatment plant in Gallup. Flows were reduced after February 1986 when the Church Rock mill operations ceased. Effluent from the mining activities and natural runoff contained “environmentally significant” amounts of radioactive lead-210, radium-226, radium-228 uranium, sulfates and several trace elements including lead, molybdenum, and selenium (Arizona Department of Health Services 1986).

In July 1979, a tailings-pond dam failed at the United Nuclear Corporation’s uranium mill facility at Church Rock, New Mexico. Most of the estimated 94 million gallons of highly contaminated effluent and 1,100 tons of tailings eroded from the bottom of a holding pond and flowed down a wash and into the Puerco River. Large amounts of thorium-230, thorium-232, radium-226, radium-228, uranium, and sulfates were released into the Puerco River (Weimer et al. 1981). This spill represents the largest known single release of water contaminated by uranium tailings in the United States (Fisk et al. 1994). Humpback chub (*Gila cypha*) and channel catfish (*Ictalurus punctatus*) tissue samples collected in 1988 from the Little Colorado River above its confluence with the Colorado River in Grand Canyon National Park contained radium-226 and thorium-232 (U.S. Fish and Wildlife Service [FWS] unpub. data). Thorium-232 and uranium-238 were detected in sediments and uranium-238 was present in water (FWS unpub. data).

Information is available (Arizona Department of Health Services 1986, Fisk et al. 1994, Shuey 1982, Webb et al. 1987a, Webb et al. 1987b, Weimer et al. 1981, and Wirt et al. 1991) on radionuclides and trace elements in ground and surface water and sediment along the Puerco and Little Colorado Rivers. However, little information is available on levels and effects of these contaminants on fish and wildlife resources of those rivers. This study was designed to assess radionuclide and trace element loading of biota associated with the Puerco and Little Colorado Rivers and to identify ecological “hot spots” where fish and wildlife resources may be most affected.

STUDY AREAS

The study area includes the Puerco River from its confluence with United Nuclear Corporation's Church Rock Mill drainage downstream to and including the Little Colorado River to approximately 30 km south of Cameron, Arizona. The study area encompass portions of McKinley County in New Mexico, and Apache, Navajo, and Coconino Counties in Arizona. Ten sites were pre-selected from a map as collecting locations based on equidistant geographic distribution along the Puerco and Little Colorado Rivers and on site accessibility. Because of the ephemeral nature of the Puerco River, it was anticipated that not all sites would contain water. On-site investigations revealed that only five of the ten pre-selected sites contained sufficient water to support communities of fish and aquatic invertebrates. The sites that were xeric and/or depauperate of species available for collection will be referred to in this report as observation sites (Figure 1).

The Little Colorado River and its tributaries provide important aquatic and riparian habitat for a variety of species. Two federally listed species of fish, Apache trout (*Oncorhynchus apache)* and Little Colorado spinedace (*Lepidomeda vittata*), as well as several candidate species, occur in the mainstem and tributaries of the Little Colorado River (Minckley 1985). A portion of the Little Colorado River in Apache County, Arizona, upstream of its confluence with the Puerco River, is designated critical habitat for the threatened Little Colorado spinedace (52 FR 35034; September 16, 1987). The Puerco and Little Colorado Rivers are used extensively by citizens of the Navajo Nation for domestic purposes and watering of livestock.

METHODS

One reconnaissance trip was made to the study area in September 1992, but no samples were collected during that period. Biota were collected at five sites on the Puerco and Little Colorado Rivers in August 1993 (Figure 1, Table 1). Because of permit limitations, no samples were taken within the Navajo Nation. Invertebrates were sampled at sites 1 and 2 on the Puerco River, and site 3 on the Little Colorado River near its confluence with the Puerco. Fish and birds were collected at sites 3, 4, and 5 on the Little Colorado River.

Fish were sampled using a seine, dip nets, and a Smith-Root Model 12 backpack electroshocker. Whole bodies (n=4-65) were weighed, measured, and cornposited by species at each site and analyzed for radionuclides and trace elements. Carp (*Cyprinus carpio*) and green sunfish (*Lepomis cyanellus*) were analyzed only for radionuclide levels due to limited sample mass. Other species collected include fathead minnow (*Pimephales promelas*), plains killifish *(Fundulus zebrinus*), and Little Colorado River sucker (*Catostomus sp.*). Least sandpiper (*Calidris minutilla*), semipalmated plover (*Charadrius semipalmatus*), and killdeer (*Charadrius vociferus*) were collected by shotgun using steel shotshells. The bill, legs, wings, feathers, and gastrointestinal (GI) tract were removed from the birds. Carcass remainders were cornposited (n= 1-6) by site for radionuclide and metalloid analyses. The GI tract from the least sandpiper samples collected at sites 3 and 4 were submitted for radionuclide analyses. Invertebrates were collected by dip net, cornposited by site, and analyzed for radionuclides. Invertebrate samples included water boatment, (Corixidae), aquatic beetles, and several species of armelids. All samples were weighed and wrapped in aluminum foil and placed on wet ice until they were transferred to a commercial freezer and stored frozen until shipped for chemical analysis. Fish and bird samples were analyzed for selected trace elements including aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc at Research Triangle Institute, Research Triangle Park, North Carolina. Mercury concentrations were analyzed by cold vapor atomic absorption, arsenic and selenium were analyzed by hydride generation atomic absorption spectrophotometry. All other elements were analyzed by using inductively coupled plasma emission spectroscropy (ICP) following preconcentration to lower detection limits. Element concentrations in all samples are reported in $\mu g/g$ wet weight. Percent moisture (Table 2) is used to facilitate wet weight to dry weight conversions. Wet weight values can be converted to dry weight equivalents by dividing the wet weight values by one minus percent moisture. This is illustrated in the following equation:

$$\text{Dry weight} = \frac{\text{wet weight}}{1 - \text{percent moisture}}$$

Whenever possible, element concentrations of fish were compared with those reported in the National Contaminant Biomonitoring Program (NCBP) for fish collected in 1976-1984 from 109 stations nationwide (Schmitt and Brumbaugh 1990). Concentrations of an element were considered elevated when they exceeded the 85th percentile of the nationwide geometric mean. The 85th percentile was not based on toxicity hazard to fish, but provides a frame of reference to identify elements of potential concern.

Invertebrate, fish and bird samples were analyzed at IT Analytical Services, Richland, Washington, for radionuclides including thorium-230, thorium-232, thorium-228, uranium-234, uranium-235, and uranium-238 using an alphaspectrometry process. Analytical methodology and reports met or exceeded Patuxent Analytical Control Facility, Laurel, Maryland, Quality Assurance and Quality Control standards.

RESULTS AND DISCUSSION

Trace Elements

Fourteen trace elements were recovered in fish and bird tissues (Table 2). Aluminum was detected in all fish and bird samples. Concentrations ranged from 158.0 to 3126 μg/g wet weight in whole body fish and 18.0 to 48 μg/g in birds (Table 2). Aluminum in fathead minnows from site 3 was considerably higher than concentrations in other species from the same site. No comparable data are available to assess whether aluminum concentrations in fish reported in this study were elevated or within the normal background range. Aluminum is one of the elements most likely to be toxic to birds and mammals that prey on fish. The maximum tolerable aluminum concentrations in the diet of domestic animals varies from 200 to 1,000 μg/g dry weight (National Research Council 1980). Flycatchers feeding on insects that contained 1,230 μg/g dry weight aluminum experienced severe eggshell defects, reduced clutch size, and a high incidence of mortality (Nyholm and Myhrberg 1977, Nyholm 1981). However, juvenile doves fed up to 1,500 μg/g dry weight aluminum for 63 days demonstrated no growth impairments. Aluminum was detected at 1208, 1265, 2221, and 4171 μg/g dry weight in four fish samples (Table 2). These levels are near or above the concentrations associated with reproductive failure of flycatchers. Aluminum at concentrations detected in fish from the Little Colorado River may present ecological risks, including survival and reproduction of resident fish-eating birds.

Arsenic concentrations in whole body fish ranged from $<$ 0.27 to 2.87 μg/g wet weight (Table 2). Arsenic in six of seven whole body fish samples exceeded the NCBP 85th percentile of 0.27 μg/g wet weight (Schmitt and Brumbaugh 1990). The only fish sample which contained less than the detection limit was the Little Colorado River sucker from site 3. All killifish and fathead minnow samples exceeded 0.5 μg/g wet weight which is considered a high level that could harm fish (Walsh et al. 1977). Arsenic was not recovered in either least sandpiper sample.

Beryllium was detected in only the fathead minnow samples from sites 3 and 5 at 0.18 and 0.12 μg/g wet weight respectively (Table 2). Background concentrations of beryllium in fish tissues have not been established, therefore interpretation of data is not yet possible.

Boron was recovered in six of nine fish and bird samples. Boron concentrations ranged from $<$0.44 to 3.42 μg/g wet weight in whole body fish (Table 2). The plains killifish sample from site 3 and the bird samples from sites 3 and 4 contained less than the detection limit.

Cadmium was detected in only the fathead minnow sample from site 3 at a level three times higher (0.15 μg/g wet weight) than the NCBP 85th percentile of 0.05 μg/g (Schmitt and Brumbaugh 1990).

Chromium was present in all fish and bird samples (Table 2). Chromium concentrations in fish ranged from 1.83 to 6.45 μg/g wet weight. Available data suggest that >4.0 μg/g dry weight chromium in fish tissues should be viewed as evidence of chromium contamination (Eisler 1986.). All fathead minnow samples as well as the Little Colorado River sucker sample contained chromium >4.0 μg/g dry weight. The least sandpiper samples contained 0.28 μg/g and 2.28 μg/g wet weight. Little information is available on chromium concentrations in sandpipers. None of 14 western sandpiper carcass samples collected in coastal Texas in 1986 contained >2 μg/g wet weight chromium (King unpub. data). Chromium concentrations in double-crested cormorants (*Phalacrocorax auritus*), red-winged blackbirds (*Agelaius phoeniceus*), and killdeer collected from polluted areas in southern Arizona averaged 2.53, 3.30, and 3.45 μg/g wet weight, respectively (Rector unpub. data). Chromium concentrations in the least sandpiper samples from the Little Colorado River are lower than those detected in other aquatic bird species from Arizona.

Copper concentrations in all fish samples ranged from 4.91 to 92.34 μg/g wet weight (Table 2) and were elevated above the NCBP 85th percentile of 1.0 μg/g wet weight. Some samples contained extremely elevated levels; fathead minnows from site 3 contained copper concentrations (92.34 μg/g wet weight) four times higher than the highest copper concentration (23.1 μg/g wet weight) detected in fish sampled nationwide (Schmitt and Brumbaugh 1990). Effects of high concentrations of copper on fish are not well established; however, when young rainbow trout were fed invertebrates containing between 14 and 50 μg/g wet weight copper, the fish experienced 60% mortality after 90 days of exposure. The surviving fish had reduced growth rates when compared to fish fed a non-contaminated diet (Woodward et al. 1994). Therefore, it is possible that predatory fish that feed on minnows containing copper concentrations as elevated as those reported here, could experience toxicity. There are no comparable data available to assess whether copper concentrations reported in sandpipers in this study (3.61 and 9.08 μg/g wet weight) were elevated or within normal background range.

Iron, magnesium, and manganese are essential nutrients and were present in all fish and bird samples (National Research Council 1980). Concentrations varied from 65.9 to 2504 μg/g, 334.0 to 3134.4 μg/g, and 1.9 to 296.5 μg/g wet weight, respectively (Table 2). Background levels for these trace elements in fish and birds and their tendency to bioaccumulate through the aquatic food chain to predators are not well known.

Lead was detected in all fish samples and ranged from 0.57 to 8.8 $\mu g/g$ wet weight (Table 2), but was not present in either bird sample. The highest lead concentration recorded in this study was nearly double the maximum lead concentration (4.88 $\mu g/g$ wet weight) detected during the 1976-1984 NCBP sampling (Schmitt and Brumbaugh 1990). All fish samples contained lead that exceeded the NCBP 85th percentile of 0.22 $\mu g/g$. Lead is highly toxic to aquatic organisms, especially fish (Rompala et al. 1984). The biological effects of sublethal concentrations of lead include delayed embryonic development, suppressed reproduction, inhibition of growth, increased mucous formation, neurological problems, enzyme inhibition, and kidney disfunction (Leland and Kuwabara 1985, Rompala et al. 1984). Lead concentrations in whole body fish exceeding 0.5 $\mu g/g$ wet weight have the potential to harm fish reproduction and survival (Walsh et al. 1977). All fish collected from the Little Colorado River contained lead concentrations in excess of the 0.5 $\mu g/g$ threshold level.

Mercury was detected in all fish and bird samples (Table 2). Four of seven fish samples exceeded the NCBP 85th percentile of 0.17 $\mu g/g$ wet weight (Schmitt and Brumbaugh 1990). The highest mercury concentration (0.52 $\mu g/g$) occurred in the fathead minnow sample from site 5. Mercury in the other fish samples ranged from 0.09 to 0.51 $\mu g/g$ wet weight. Mercury in six of seven fish samples exceeded the 0.1 $\mu g/g$ wet weight concern level, above which mercury may have adverse effects on fish-eating birds (Eisler 1987). In an extensive review of the chronic toxicity of mercury in birds, Scheuhammer (1987) reported that the lowest level of mercury in food items to adversely affect birds was 0.3 to 0.4 $\mu g/g$ wet weight. Only the killifish sample from site 4 and the fathead minnow sample from site 5 contained mercury in excess of Scheuhammer's concern level. Least sandpiper samples contained 0.29 and 0.30 $\mu g/g$ wet weight mercury. These levels exceed the reported range (<0.01-0.2 $\mu g/g$ wet weight) from the 1973 National Pesticide Monitoring Program (NPMP) sampling of starlings (White et al. 1977) and suggest that least sandpipers from the Puerco and Little Colorado Rivers are contaminated with mercury.

Nickel was recovered in all fish samples and one of two bird samples (Table 2). The fish samples contained nickel ranging from 0.49 to 3.40 $\mu g/g$ wet weight. Nickel concentrations >0.9 $\mu g/g$ wet weight in fish can be considered elevated (Irwin 1988). Five fish samples contained nickel that exceeded the 0.9 $\mu g/g$ wet weight concern level. Nickel was detected in one of two least sandpiper samples at 0.95 $\mu g/g$ wet weight. Little information is available on the effects of nickel body burdens on fish and wildlife, however, experimental doses of nickel on some small mammals have induced cancer (Environmental Protection Agency 1980).

Selenium concentrations in all fish samples exceeded the NCBP 85th percentile of 0.73 $\mu g/g$ wet weight (Schmitt and Brumbaugh 1990). Selenium levels ranged from 0.97 to 2.00 $\mu g/g$ wet weight in fish and 0.65 to 0.96 $\mu g/g$ wet weight in birds (Table 2). Dry weight conversions of the fish selenium levels varied from 1.67 to 2.32 $\mu g/g$, which are lower than the 3.0 μg/g dry weight value considered potentially lethal to fish and aquatic birds that consume them (Lemly 1993). Concentrations of 3 to 8 μg/g dry weight selenium in food items could cause adverse reproductive effects in sensitive aquatic bird species (Heinz et al 1987, Hoffman et al. 1991, Lemley and Smith 1987, Skorupa and Ohlendorf 1991). "Normal" food chain selenium levels in an aquatic environment are usually ≤ 2.0 μg/g dry weight (Ohlendorf et al. 1990). Only two fish samples contained concentrations that slightly exceeded 2.0 μg/g dry weight.

Strontium was present in all bird and fish samples and ranged from 3.0 to 238.0 μg/g wet weight (Table 2). The lowest concentrations were in the two bird samples at 3.0 and 10.0 μg/g wet weight. Vanadium was also recovered in all fish samples and ranged from 0.57 to 5.08 μg/g wet weight. The bird samples contained less than the detection limit. No comparable data are available to assess whether strontium and vanadium concentrations reported in this study were elevated or within the normal background range.

Zinc was recovered at elevated (> 34.2 μg/g, NCBP 85th percentile) concentrations in all fish samples. The fathead minnow sample from site 3 had the highest zinc concentration (202.22 μg/g wet weight). The other fish samples ranged from 85.76 to 164.58 μg/g (Table 2). Although zinc is an essential element, it is known to be toxic to fish, causing mortality, growth retardation, and reproductive impairments (Sorenson 1991). Little information is available on the level of toxicity in whole body fish that will cause these detrimental effects. The two sandpiper samples contained residues of 19.92 and 28.52 μg/g wet weight. Little is known about bioaccumulation of zinc through the aquatic food chain to predators such as fish-eating birds.

Radionuclides

Many areas throughout the United States are known to have high amounts of natural radioactivity in rock, ground water, streams, and the sediment in streams. The Colorado Plateau of Arizona and New Mexico has higher than average levels of radioactivity from natural sources, and this region contains more than half of all uranium mineral reserves in the Nation (Wirt 1994). Due to natural geographic variations of radioactivity throughout the United States and because there are no radionuclide background data for fish and wildlife from our study area, we are reluctant to formulate interpretations from the radiological data reported for the specimens that we collected. Our data are presented in Tables 3 and 4 in units of picocuries per gram (pCi/g) for thorium-230, thorium-232, thorium-228, uranium-234, uranium-235, and uranium-238. The data acquired in this study can serve as background values for future radionuclide studies of fish and wildlife in the Puerco and Little Colorado drainages.

Residue Implications for Fish and Wildlife

Residue implications for fish - Although no comparable data are available to assess whether aluminum concentrations in fish reported in this study were elevated or within the normal background range, we suspect that aluminum residues in some samples were elevated. We compared the highest aluminum concentration in this study to the highest reported aluminum concentrations in fish from other sites in Arizona. Aluminum concentrations in fish collected from the Puerco and Little Colorado Rivers average about 4-times higher than other fish samples in the state (Baker and King 1994, King et al. 1991, 1993, Ring and Baker 1995). Arsenic concentrations in all killifish and fathead minnow samples exceeded the NCBP 85th percentile (Schmitt and Brumbaugh 1990) as well as the 0.5 $\mu g/g$ wet weight threshold level above which arsenic is possibly toxic to fish (Walsh et al. 1977). Arsenic in all killifish and fathead minnows exceeded this concern level. Lead was detected in all fish samples with concentrations that greatly exceeded the NCBP 85th percentile. Our data suggest that lead is accumulating in fish in the Little Colorado River and may affect fish and wildlife resources. Although selenium concentrations detected in all whole body fish from the Little Colorado River were above background levels, concentrations were below the 4 $\mu g/g$ dry weight level associated with selenium-induced reproductive failure of fish (Lemly 1993).

Residue implications for fish-eating birds - The elements in diets of birds that are most likely to cause reproductive and survival problems are aluminum, arsenic, cadmium, mercury, and selenium (Eisler 1985, 1987, 1988, Ohlendorf et al. 1986, 1988, Scheuhammer 1987)). The chronic toxicity of food chain ingested aluminum on the breeding impairment of birds in not well understood. Our study suggests that aluminum at concentrations detected in fish from the Little Colorado River could affect survival and reproduction of resident fish-eating birds. While the acute effects of arsenic have been investigated, little is known about its sublethal chronic effects except that arsenic is readily accumulated by aquatic organisms. Based on data summarized by Eisler (1988), arsenic at concentrations recovered in Little Colorado River fish apparently poses little hazard of secondary poisoning to avian predators. Secondary hazards of cadmium poisoning to avian predators might be expected if dietary intake averages 0.1 $\mu g/g$ wet weight (Eisler 1985). Only one composite fish sample, fathead minnows from site 3, contained cadmium that exceeded this threshold level. The minimum dietary concentration of mercury which may cause effects on predatory fish-eating birds is 0.1 $\mu g/g$ (Eisler 1987). Mercury levels in all but one fish sample from the Little Colorado River exceeded this concern level. Schuhammer (1987), however, reported that mercury concentrations of 0.3 to 0.4 $\mu g/g$ wet weight could adversely affect birds. Only the killifish sample from site 4 and the fathead minnow sample from site 5 exceed this concern level. Since mercury bioaccumulates and biomagnifies through the food chain, even low concentrations of mercury can still be dangerous to upper trophic level predators. The accumulation of mercury is rapid, but unlike selenium, depuration is slow (Stickel et al. 1977).

Therefore, birds which consume predominantly fish from the study area in their diet may be in danger of bioaccumulating potentially hazardous concentrations of mercury. Least sandpipers consume primarily aquatic invertebrates (Ehrlich et al. 1988) and may not bioaccumulate mercury to the same degree as a top level predator such as a fish-eating bird species. "Normal" food chain selenium levels in an aquatic environment are usually ≤ 2.0 $\mu g/g$ dry weight (Ohlendorf et al. 1990). Only two of seven fish samples contained selenium that slightly exceeded this level. Organisms containing selenium concentrations of 3 $\mu g/g$ dry weight or more should be viewed as potentially lethal to fish and aquatic birds that consume them (Lemly 1993). None of our samples approached the 3.0 $\mu g/g$ selenium concern level, therefore, selenium appears to be within tolerable limits for piscivorous fish and birds in this study area.

RECOMMENDATIONS

It is recommended that further sampling be done to adequately characterize the effects of contaminants from the Puerco and Little Colorado Rivers on fish and wildlife resources. Many variables modify radionuclide concentrations in biota. In general, lower trophic levels of aquatic organisms usually have greater concentrations of radionuclides than higher trophic levels (Bowen et al. 1971). Furthermore, radionuclide concentrations in biota are modified significantly by an organism's age, size, sex, tissue, season of collection, and other variables which have to be considered when interpreting radiological analysis (Eisler 1994). Based on the inconclusive radionuclide data, we recommend that the Puerco and Little Colorado Rivers be re-sampled for radionuclides at the earliest possible date, preferably during the latter half of seasonal high water levels in order to enhance the chances of finding water at each site and collecting specimens that have been in the area for the longest period of time. It is imperative that a control site be included in additional studies. The control site should be in the vicinity of the study area yet not associated with anthropogenic activities such as direct effluent discharges.

Based on the current high aluminum, cadmium, and mercury residues in fish from the Little Colorado River and the potential effects on fish-eating birds that consume them, we recommend regular monitoring of fish and birds of the Puerco and Little Colorado Rivers on a three-year basis. Since copper, lead, and arsenic concentrations exceeded the level known to harm fish, we also recommend additional monitoring and intensive research to determine if elevated levels are adversely affecting fish populations. Endangered species concerns, specifically the Little Colorado spinedace and Apache trout which occupy the Little Colorado River and some tributaries, give impetus to the need for continued study. Study areas should include various locations on the rivers including, but not limited to, areas of mining activity and wastewater release sites, to possibly determine point sources of elevated elements. Once the sources of contamination are identified, management practices can be undertaken to limit and possibly remediate the pollution.

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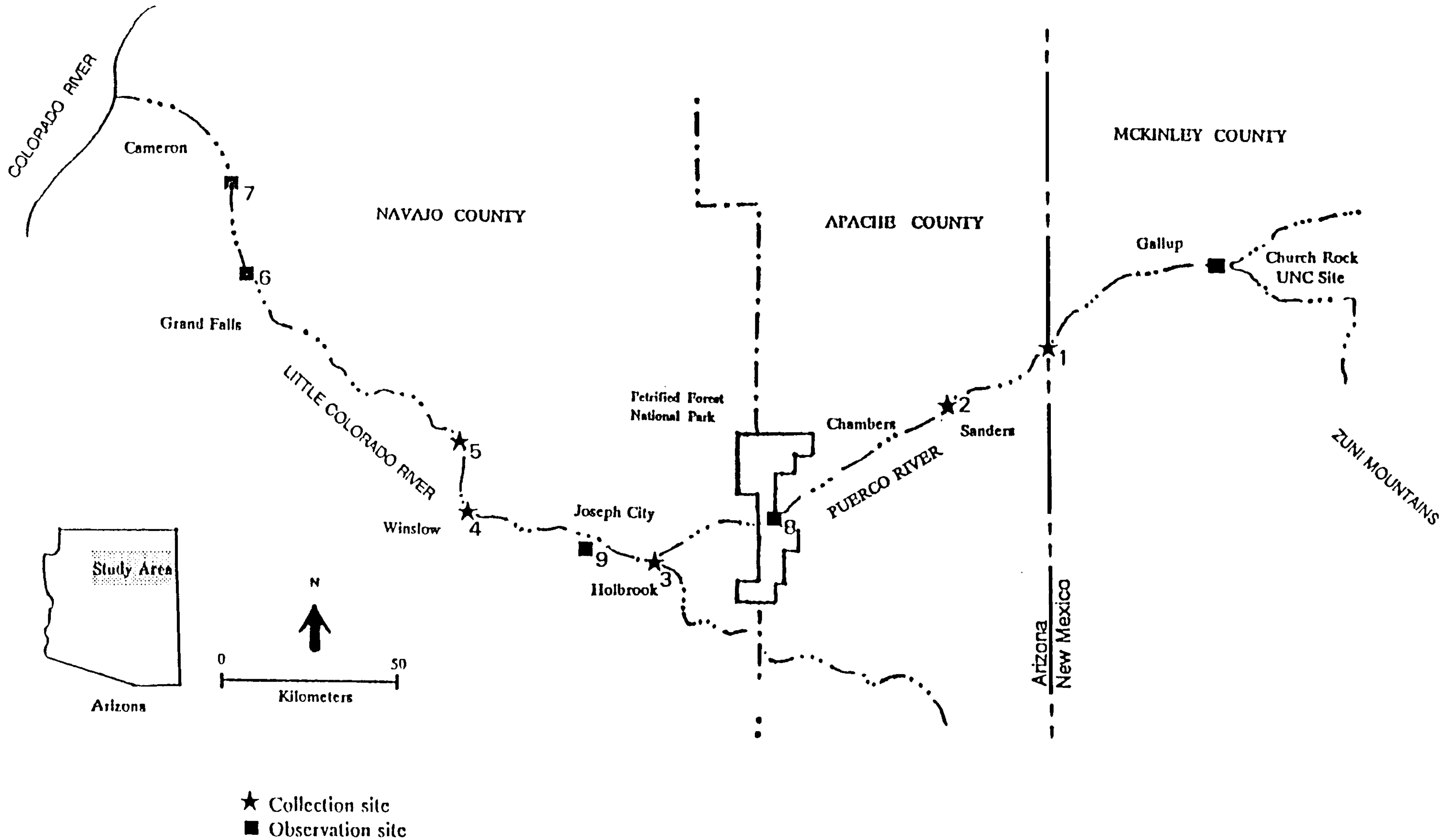

Figure 1. Puerco and Little Colorado River basin study site locations in northeastern Arizona.

Table 1. List of study sites within the Puerco and Little Colorado River basin.
(See also Figure 1)

1. Puerco River at Arizona/New Mexico border.
2. Puerco River at Sanders, Arizona.
3. Little Colorado River approximately 100 meters downstream of confluence with the Puerco River, Arizona.
4. Little Colorado River at Winslow, Arizona.
5. Little Colorado River approximately 30 kilometers downstream of Winslow, Arizona.
6. Little Colorado River at Wupatki National Monument, Arizona.
7. Little Colorado River approximately 30 kilometers upstream of Cameron, Arizona.
8. Puerco River within Petrified National Forest, Arizona.
9. Little Colorado River at Joseph City, Arizona.
10. Puerco River/United Nuclear Corporation's Church Rock Mill drainage, New Mexico.

TRACE ELEMENT CONCENTRATIONS (μg/g wet weight) IN BIRDS AND WHOLE BODY FISH COLLECTED FROM THE LITTLE COLORADO RIVER, ARIZONA 1993

Table 2

Sample	Site	Al	As	B	Cr	Cu	Hg	Ni	Pb	Se	Sr	V	Zn	% Moisture
NCBP 85'	#	NA[2]	0.27	NA	NA	1.0	0.17	NA	0.22	0.73	NA	NA	34.20	NA
Fathead minnow[3]	5	1619.	2.87	3.42	4.35	4.91	0.52	1.27	1.11	1.66	238.	2.82	109.23	27.0
Fathead minnow[4]	3	3126.	1.49	2.15	5.75	92.34	0.11	3.40	8.82	1.46	131.	5.08	202.22	25.0
Fathead minnow	4	807.	1.06	1.77	3.84	27.43	0.38	1.04	2.24	1.12	157.	1.30	127.93	33.2
Killifish	3	158.	0.80	<0.44	3.16	24.70	0.14	0.91	1.23	2.00	74.	0.81	164.58	13.7
Killifish	4	307.	0.90	0.33	2.01	12.40	0.51	0.49	0.57	1.00	65.	0.57	87.68	41.3
Killifish	5	723.	1.99	1.83	1.83	13.57	0.27	0.67	1.30	1.06	177.	2.12	95.98	42.9
LCR[6] sucker	3	352.	<0.27	1.17	6.45	9.67	0.09	1.11	1.35	0.97	90.	0.69	85.76	46.4
Sandpiper	3	18.	<0.25	<0.25	0.28	3.61	0.30	<0.25	<0.25	0.96	3.	<0.25	19.92	50.1
Sandpiper	4	48.	<0.18	<0.18	2.28	9.08	0.29	0.95	<0.19	0.65	10.	co.19	28.52	63.1

'National Contaminant Biomonitoring Program 85th Percentile (Schmitt and Brumbaugh 1990).
*Data not available.
[3]Beryllium was detected in the fathead minnow sample from site 5 at 0.12 μg/g.
[4]Fathead minnow sample from site 3 contained 0.15 μg/g cadmium and 0.18 μg/g beryllium.

[6] LCR - Little Colorado River

RADIONUCLIDE LEVELS IN INVERTEBRATES AND FISH OF THE PUERCO AND LITTLE COLORADO RIVERS, ARIZONA 1993

Table 3

Species	Site #	pCi/g Overall Error [ ]*					
		TH 230	TH 232	228	U-234	U-235	U-238
Invertebrates	1	2.37E-02 [1.08E-02 (2S)]	1.66E-02 [8.99E-03(2S)]	2.05E-02 [1.08E-02(2S)]	3.14E-02 [1.86E-02(2S)]	-1.44E-03** [1.65E-03(2S)]	1.37E-02 [1.32E-02(2S)]
Invertebrates	2	5.14E-02** [3.38E-02(2S)]	2.11E-02 [2.12E-02(2S)]	2.80E-02 [2.67E-02(2S)]	7.21 E-03” [3.54E-02(2S)]	-8.39E-03** [8.47E-03(2S)]	2.05E-02** [3.84E-02(2S)]
Invertebrates	3	NA	NA	NA	6.85E-03** [1.38E-02(2S)]	-2.55E-03** [2.77E-03(2S)]	3.21 E-03” [8.87E-03(2S)]
Plains killifish	3	NA	NA	NA	1.37E-02 [1.32E-02(2S)]	4.08E-03** [6.50E-03(2S)]	1.82E-02 [1.30E-02(2S)]
Plains killifish	5	1.58E-02 [1.06E-02(2S)]	1.01E-02 [8.69E-03(2S)]	1.16E-02 [9.54E-03(2S)]	8.39E-02 [3.20E-02(2S)]	2.83E-03** [9.35E-03(2S)]	3.95E-02 [2.22E-02(2S)]
Plains killifish	4	8.37E-03 [6.88E-03(2S)]	3.83E-03** [4.89E-03(2S)]	2.00E-02 [1.15E-02(2S)]	3.82E-03** [1.49E-02(2S)]	2.11 E-03” [1.08E-02(2S)]	6.04E-03** [1.48E-02(2S)]
LCR*** sucker	3	1.67E-02** [2.37E-02(2S)]	8.33E-03** [1.67E-02(2S)]	1.41E-02** [2.75E-02(2S)]	1.49E-02 [1.23E-02(2S)]	7.76E-04** [4.96E-03(2S)]	1.49E-03** [6.92E-03(2S)]
Common carp	3	8.25E-03 [6.28E-03(2S)]	7.78E-03 [6.35E-03(2S)]	3.40E-02 [1.40E-02(2S)]	8.51 E-03” [1.29E-02(2S)]	2.53E-03** [5.93E-03(2S)]	1.67E-03** [5.78E-03(2S)]
Fathead minnow	5	7.19E-03 [7.13E-03(2S)]	1.09E.02 [8.34E-03(2S)]	1.14E-02 [9.30E-03(2S)]	9.03E-02 [3.19E-02(2S)]	-5.68E-04** [6.66E-03(2S)]	7.12E-02 [2.58E-02(2S)]
Fathead minnow	3	1.33E-02 [7.77E-03(2S)]	2.85E-02 [1.12E-02(2S)]	4.39E-02 [1.50E-02(2S)]	3.53E-02 [2.02E-02(2S)]	5.16E-03** [8.72E-03(2S)]	3.00E-02 [1.82E-02(2S)]
Fathead minnow	4	1.18E-02** [1.35E-02(2S)]	1.31 E-02” [1.32E-02(2S)]	2.25E-02 [1.98E-02(2S)]	2.54E-02 [1.73E-02(2S)]	-5.76E-04** [7.82E-03(2S)]	2.09E-02 [1.60E-02(2S)]
Green sunfish	3	0.00E+00** [1.85E-02(2S)]	-7.41 E-03” [8.60E-03(2S)]	2.46E-02** [2.80E-02(2S)]	1.59E-02” [1.93E-02(2S)]	1.05E-03** [1.30E-02(2S)]	1.06E-02** [1.52E-02(2S)]

* [ ] denotes the value of the overall error.
** Denotes a result less than the overall error.
*** LCR - Little Colorado River

RADIONUCLIDE LEVELS IN BIRDS OF THE PUERCO
AND LITTLE COLORADO RIVERS, ARIZONA 1993

Table 4

Species	Site #	pCi/g Overall Error [ ]*					
		TH 230	TH 232	TH 228	U-234	U-235	U-238
Killdeer	5	0.00E+00** [4.03E-02(2S)]	2.69E-02** [3.83E-02(2S)]	5.45E-02** [6.25E-02(2S)]	8.85E-03** [1.53E-02(2S)]	-9.91E-05** [5.77E-03(2S)]	8.46E-03** [1.16E-02(2S)]
Least sandpiper GI tract	3	0.00E+00** [4.69E-02(2S)]	-6.26E-03** [1.26E-02(2S)]	3.56E-03** [4.10E-02(2S)]	2.14E-02 [1.75E-02(2S)]	2.93E-03** [6.57E-03(2S)]	1.16E-02** [1.22E-02(2S)]
Least sandpiper GI tract	4	1.95E-02** [2.78E-02(2S)]	1.95E-02** [2.78E-02(2S)]	8.90E-03** [3.51E-02(2S)]	1.01E-02** [1.30E-02(2S)]	2.12E-04** [6.65E-03(2S)]	-4.13E-03** [5.55E-03(2S)]
Least sandpiper	4	9.97E-03** [1.16E-02(2S)]	3.32E-03** [6.66E-03(2S)]	1.05E-05** [1.59E-02(2S)]	4.77E-03** [7.30E-03(2S)]	-2.69E-04** [2.84E-03(2S)]	-1.77E-03** [4.17E-03(2S)]
Least sandpiper	3	3.87E-03** [4.49E-03(2S)]	-5.16E-04** [1.03E-03(2S)]	2.91E-04** [3.34E-03(2S)]	4.41E-03** [8.65E-03(2S)]	5.72E-05** [4.64E-03(2S)]	6.21 E-03” [7.15E-03(2S)]
Spotted sandpiper	5	6.55E-03** [1.80E-02(2S)]	0.00E+00** [2.62E-02(2S)]	4.43E-02** [4.50E-02(2S)]	7.64E-03** [1.19E-02(2S)]	3.70E-03** [7.03E-03(2S)]	1.81 E-03” [6.24E-03(2S)]
Semipalmated plover	4	1.07E-02 [7.39E-03(2S)]	1.32E-02 [8.19E-03(2S)]	3.31E-02 [1.38E-02(2S)]	8.30E-03** [9.51E-03(2S)]	1.85E-03** [3.54E-03(2S)]	5.29E-03** [6.17E-03(2S)]

* [ ] denotes the value of the overall error.
** Denotes a result less than the overall error.