SAN JUAN RIVER BASIN WATER QUALITY AND CONTAMINANTS REVIEW

VOLUME I

APRIL 1994

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EXECUTIVE SUMMARY

The San Juan River Seven Year Research Plan included among its goals a long-term water-quality program, the first step of which was a water quality and contaminants review. The review was intended to synthesize existing water quality and contaminants information on the San Juan River and its tributaries in order to identify future research needs. This report constitutes the first portion of the review, the compilation of existing information for the New Mexico, Colorado, and Utah portions of the San Juan River basin. All studies, reviews, unpublished data sets, and communications that were available by 1 July 1993 were included. Over 85 individuals from more than 25 agencies and organizations were consulted in the research process.

The San Juan River from Navajo Reservoir to the confluence of the Mancos River, and the Animas and La Plata Rivers, have been investigated fairly extensively for the presence of contaminants. Reaches or lakes where little contaminants research has been conducted included the San Juan River above Navajo Reservoir; the Navajo River; the Piedra River; Navajo Reservoir; Los Pinos River; the Florida River; Chinde Wash; the San Juan River from Cottonwood Wash to Mexican Hat; Cottonwood Wash; Chinle Creek; and the San Juan River from Mexican Hat to the San Juan arm of Lake Powell.

Major sources of contaminants identified in the basin were irrigation and mineral extraction, processing, and use. Irrigation projects sponsored by the Department of the Interior have been thoroughly studied through reconnaissance investigations aimed at determining the extent of toxic irrigation return flows; unfortunately, only one of three reconnaissance investigations was available for inclusion in the review. Irrigation return flows that would be generated by the proposed Animas-La Plata Project have also been examined. Selenium is the major contaminant associated with irrigation return flows, and it has been suggested that flows may also serve to transport other contaminants such as pesticides and polycyclic aromatic hydrocarbons (PAHs).

Mineral extraction, processing, and use were abundant and widespread activities in the basin. Oil, natural gas, and coal operations dominated, while the mining and milling of uranium and other metals have been historically important. None of the activities has been investigated to the extent necessary to determine their effects on basin water quality or fish health. Contaminants of the greatest concern associated with these activities are PAHs, selenium, and certain metals.

Sources of selenium have been widely investigated, but effects of selenium on rare basin fish are unknown. There was minimal information on either the sources or effects of PAHs. The presence of disease in fish was highly correlated with contamination, but a small amount of disease data has been collected from only the San Juan and Animas rivers. In general, there exists a surplus of abiotic data identifying potential contaminants and a dearth of biotic data linking those contaminants to fish health.

Future research efforts by federal and state government agencies should be coordinated so that information generated on contaminants, sources, and effects can be connected to make management recommendations. The determination of toxicities of various contaminants to fish species is crucial, but management recommendations cannot be made without first identifying contaminants sources. Because resources are limited, priorities for research should be established before further investigations are begun.

ACKNOWLEDGMENTS

This review could not have been written without the generous assistance of people in a variety of agencies and private organizations. The author would especially like to thank Steven Platania (UNM) and Mark Wilson, Jennifer-Fowler Propst, Mike Donahoo, and Matt Custer (FWS) for their time and effort. Additionally, the following people provided valuable information:

From the U.S. Geological Survey offices in New Mexico, Colorado, Utah, and Arizona: Dave Allen, Paul Blanchard, Bob Broshears, Dave Butler, Bill Carey, Jerry Carr, Dan Chafin, Dave Naftz, Kim Ong, Doyle Stevens, and John Turk.
From the U.S. Fish and Wildlife Service state and regional offices and at NCBP substations: Andrew Archuleta, Paul Baumann, Barbara Campbell-Osmundson, Kristie DeBois, Jim Dwyer, Steve Hamilton, Richard Lee Herman, Clark Johnson, Rick Krueger, Frank Pfieffer, Richard Roy, Patty Schraeder, Carol Shanks, Bruce Waddell, John Wegrzyn, and Carol Wiens.
From the Bureau of Indian Affairs: Jim Formea, Bob Krakow, and Ernest Teller.
From the U.S. Bureau of Reclamation in Salt Lake City and Durango: Ken Beck, Larry Crist, Errol Jensen, Kirk Lashmett, Jerry Miller, Stan Powers, and Tom Strain.
From the U.S. Bureau of Land Management offices in New Mexico and Colorado: Elizabeth Araki, Joel Farrell, John Hanson, Eric Janes, Mark Kelley, and Bob Moore.
From the U.S. Environmental Protection Agency in Dallas: Greg Lyssy and Tina Wooten.
From the Southern Ute Tribe: Cindy Crist and Mike Frost.
From the Utah Department of Environmental Quality offices in Salt Lake City: Chris Horting, Bill Moellmer, Dave Rupp, and Tom Toole.
From the Utah Division of Oil, Gas, and Mining offices in Salt Lake City: Joelle Burns, Ron Firth, and Pam Grubaugh-Littig.
From the Utah Geological Survey in Salt Lake City: Bob Blackett and Bryce Tripp.
From the Colorado Division of Wildlife: Mike Japhet and Tom Nesler.
From the Colorado Department of Health offices: Dennis Anderson, Jim Harvey, and Leslie Simpson.
From the Colorado Division of Minerals and Geology offices: Dan Hernandez, Shirley Just, Harry Ranney, John Reilly, Kim Roberts, and Jim Stevens.
From the Colorado Oil and Gas Conservation Commission: Jim Kenney.
From the Colorado Public Utilities Commission: Steve Pott.
From the New Mexico Energy, Minerals and Natural Resources Department offices: Bill Olson, Kathy Brown, and Doug Bland.
From the New Mexico Environmental Improvement Division: Dennis McQuillan.
From the New Mexico Department of the Environment offices: Diane Barnes, Peter Monahan, John Pittenger, Larry Smolka, and Anne Young.
From the Office of Information Transfer: Dawn Jennings and Darrell York.
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1. INTRODUCTION

The San Juan River Seven Year Fisheries Research Plan was initiated in 1990 to guide the collection of data believed necessary for the conservation of the San Juan River's native fish fauna. Included among the Plan's goals was a long-term water-quality program, the first step of which was a water quality and contaminants review. The review was to synthesize existing water quality and contaminants information for the San Juan River and its tributaries in order to identify research needs. Specifically, the review was designed to meet the following objectives:

1) To compile and interpret existing water quality and contaminants information into a single document to guide investigations of chemical hazards to San Juan River endemic fishes.

2) To determine any geographic variation in water quality parameters and contaminants in the San Juan River basin.

3) To identify important water quality and contaminant data gaps as a focus for determining needed water quality and contaminant assessments in the San Juan River basin.

The review was undertaken as a joint effort between the University of New Mexico (UNM) and the New Mexico Ecological Services Office of the U.S. Fish and Wildlife Service (FWS). UNM assumed responsibility for the compilation of data related to contaminants and water quality, while the FWS was responsible for interpreting the data, identifying any important water quality and contaminants needs, and providing advice which may direct future research in this area. This report constitutes the first portion of the review, the compilation of existing information.

2. STUDY AREA

Data included in this review were collected in the San Juan River basin, which is located within the Upper Colorado River basin and comprises a drainage area of 24,900 mi^2 (Figure 1) (Iorns et al. 1965, Melancon et al. 1979). For this report, the basin included the area drained by the San Juan River from its headwaters to Lake Powell, as well as all of the river's tributary streams. Major tributaries are Navajo, Piedra, Los Pinos, Animas, La Plata, Chaco, and Mancos rivers; McElmo, Montezuma, and Chinle creeks; and Cottonwood Wash (Figure 2) (Bureau of Reclamation et al. 1992). The states from which data were included are New Mexico, Colorado, and Utah; Arizona contains only the headwaters of Chinle Creek, whose effect on the basin's water quality was deemed negligible.

It is important to note that the watershed termed the San Juan River basin is not equivalent to the geologic San Juan basin, which is a larger structural depression covering approximately 30,000 mi^2 of northwest New Mexico and southwest Colorado (Figure 3) (Melancon et al. 1979, Stone et al. 1983). In this report all references to the basin will refer to the San Juan River basin unless otherwise noted.

2.1 SOILS AND GEOLOGY

The soils of the San Juan River basin have been principally developed by weathering of the underlying rocks. As a result of the arid climate, the soils are poorly developed, retaining many of the geochemical characteristics of the parent rocks. The San Juan Mountains, where the San Juan, Animas, Los Pinos, Piedra, and Navajo rivers head, are composed chiefly of Tertiary age volcanic rocks. The rest of the basin is principally underlain by late Paleozoic to Recent sedimentary rocks (Iorns et al. 1965).

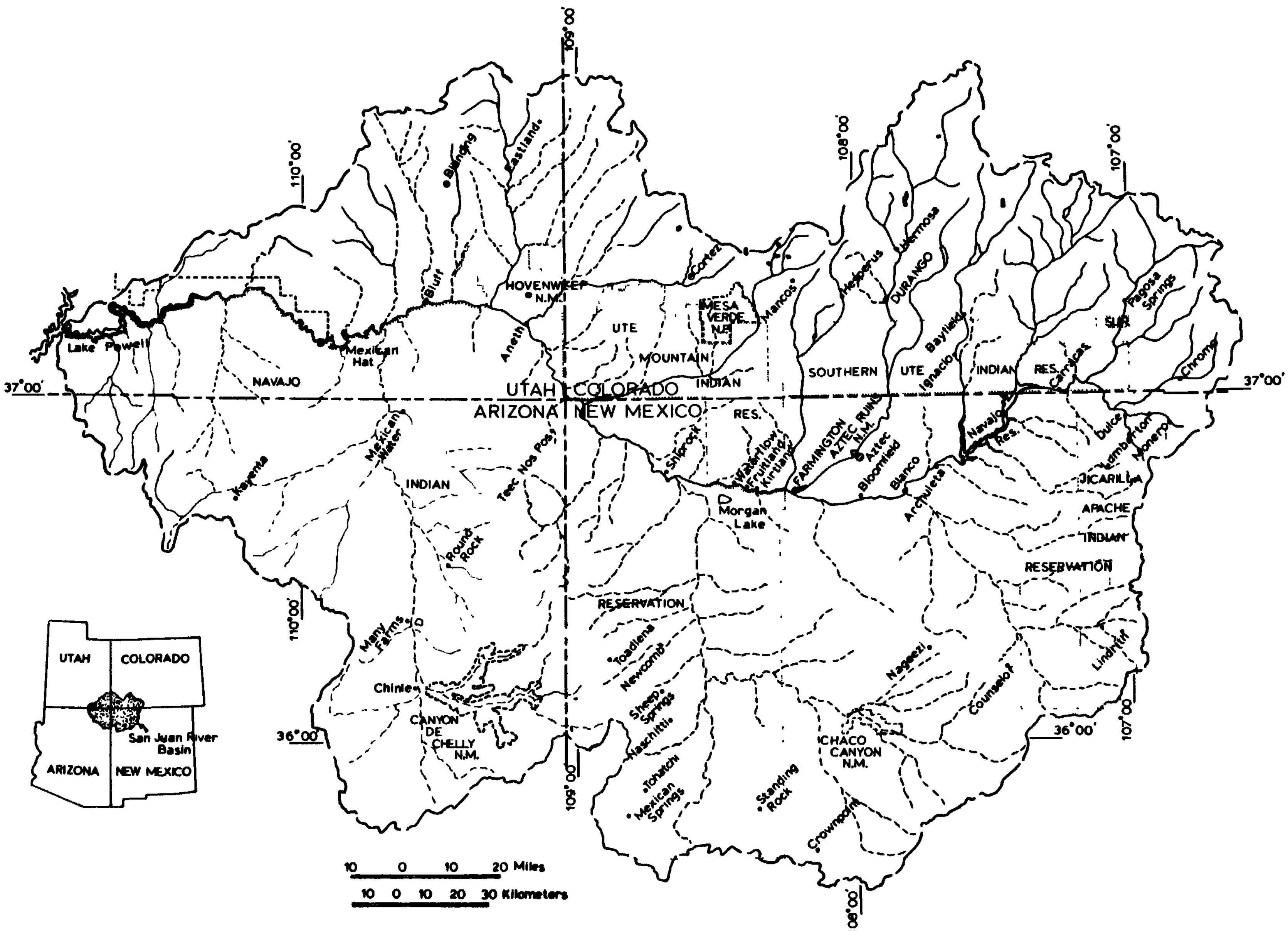

Figure 1. The San Juan River basin. (Taken from Melancon et al. 1979)

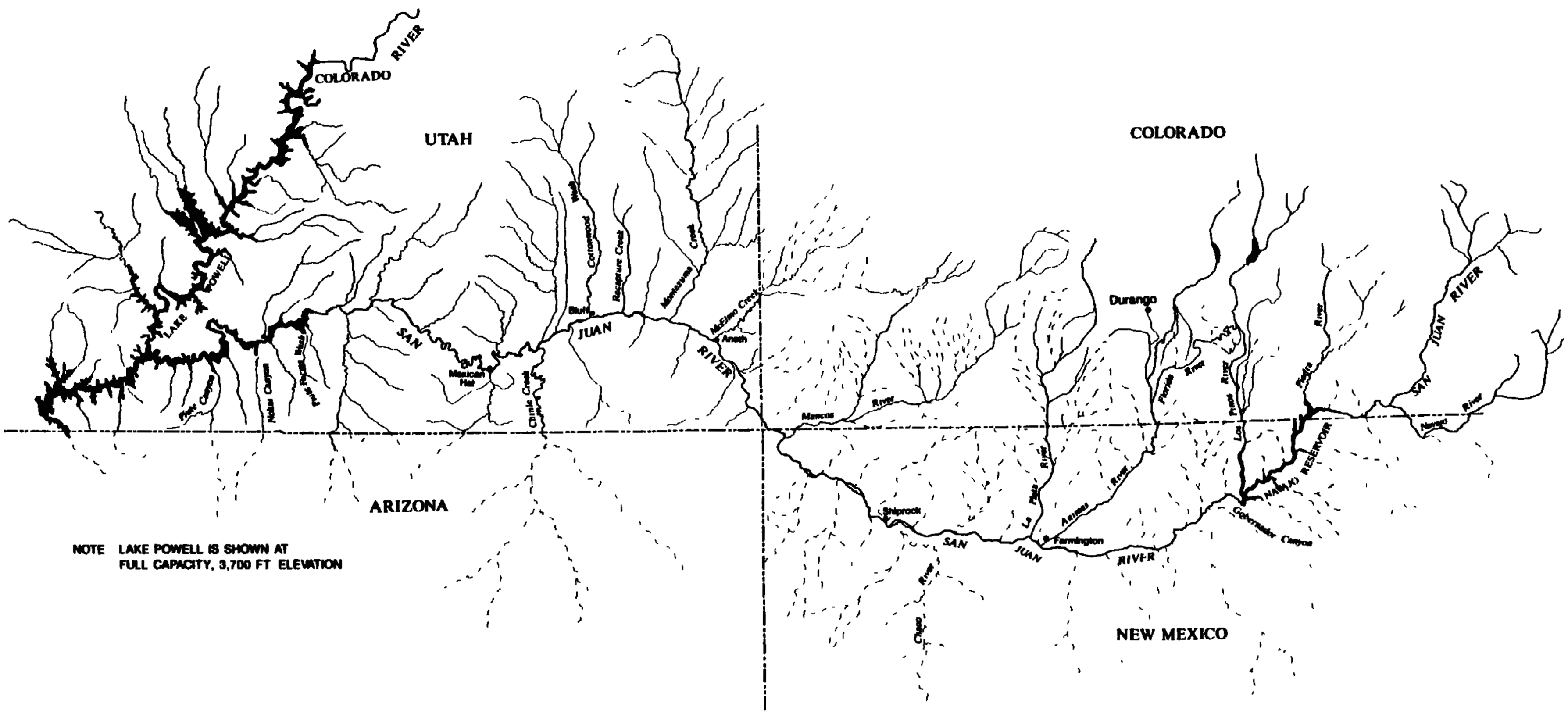

Figure 2. The San Juan River and major tributaries. (Taken from U.S. Bureau of Reclamation et al. 1992)

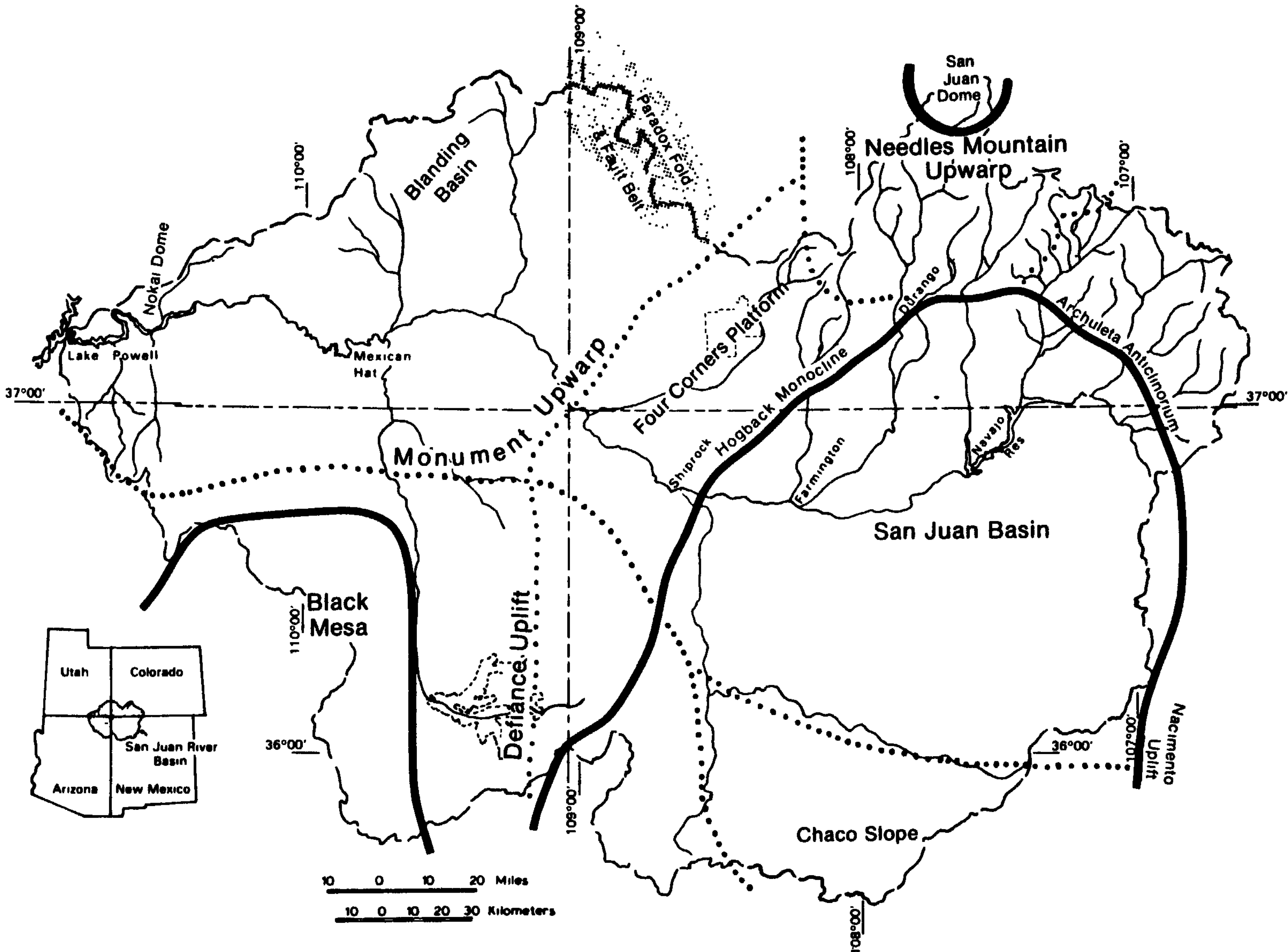

Figure 3. Geologic structure of the San Juan basin. (Taken from Melancon et al. 1979)

2.2 MINERAL RESOURCES

The basin's geologic history has resulted in rich deposits of extractable petroleum, coal, and non-fuel minerals (Figures 4 and 5) (Melancon et al. 1979, Roybal et al. 1983). The basin's coal fields are primarily found in New Mexico and Colorado and its oil and gas fields are concentrated in New Mexico and Utah. In the past, uranium was also heavily mined in Utah and in the southernmost portion of the basin in New Mexico.

2.3 LAND OWNERSHIP

The most recent compilation of land ownership statistics for the basin is from 1974 (Melancon et al. 1979, Roybal et al. 1983). In that year, 25% of the basin land was federally owned and administered by the U.S. Bureau of Land Management (BLM), the National Park Service (NPS), or the Forest Service. Non-Indian private property accounted for 13% of the land, and state and local governments owned and managed 3% of the basin's area. The remaining portion, nearly 60% of the land, was owned by four Indian reservations. The Navajo Reservation held 30,000 km^2 in New Mexico, Arizona, and Utah; the Ute Mountain Ute Indian Reservation owned 2300 km^2 in Colorado, New Mexico, and Utah; the Jicarilla Apache Reservation had 2485 km^2 in New Mexico, and the Southern Ute Indian Reservation had 1214 km^2 in Colorado (Figure 1) (Melancon et al. 1979).

2.4 POPULATION

Within the basin, small population centers are scattered along perennial river valleys and ephemeral streams and arroyos, as well as at widely dispersed locations within the Indian reservations (Tables 1 and 2) (New Mexico Water Quality Control Commission 1976). The principal municipalities in the basin are Durango and Cortez in Colorado; Aztec, Bloomfield, Farmington, and Shiprock in New Mexico; and Blanding, in Utah.

It is difficult to arrive at population estimates for the study area because basin and county boundaries do not coincide. In an analysis of a portion of the basin, Goetz and Abeyta (1987) compiled census statistics for that part of the watershed upstream from Shiprock and reported the 1950 population as 46,000. A population boom occurred, largely in the subsequent decade, and by 1980 the population had nearly tripled to reach 120,000 (Figure 6) (Goetz 1981).

San Juan County, New Mexico, is the most densely populated area within the basin. By 1990, the county's population was 91,605, and New Mexico's total population within the basin was 107,381 (U.S. Department of Commerce, 1992; Wilson 1992). At that time, approximately 62% of all New Mexicans in the basin were living in urban centers (Wilson 1992).

2.5 IRRIGATION

Irrigated agriculture is present on the San Juan River plateau as part of the Navajo Indian Irrigation Project as well as in perennial stream valleys of the basin, while dry farming is nearly nonexistent (Stone et al. 1983, Goetz and Abeyta 1987). Along the San Juan River there are currently five Department of the Interior (DOI) sponsored irrigation projects: the Hammond Irrigation Project, Fruitland Irrigation Project, Hogback Irrigation Project, Cudei Irrigation Project, and Navajo Indian Irrigation Project (NIIP) (Figure 7) (Blanchard et al. 1993). Other irrigation projects within the basin include the Dolores Project, which transports water from the Dolores River to the San Juan basin to irrigate Colorado lands; the Pine River Project, which distributes Los Pinos River water, stored in Vallecito Reservoir, to lands located primarily on the Southern Ute Reservation, Colorado; the Florida Project, located on the Florida River in Colorado; and the proposed Animas-La Plata Project, which if developed would irrigate Colorado lands using water from the Animas and La Plata rivers (U.S. Water and Power Resources Service 1981). No statistics are available for the total area of irrigated land in the basin.

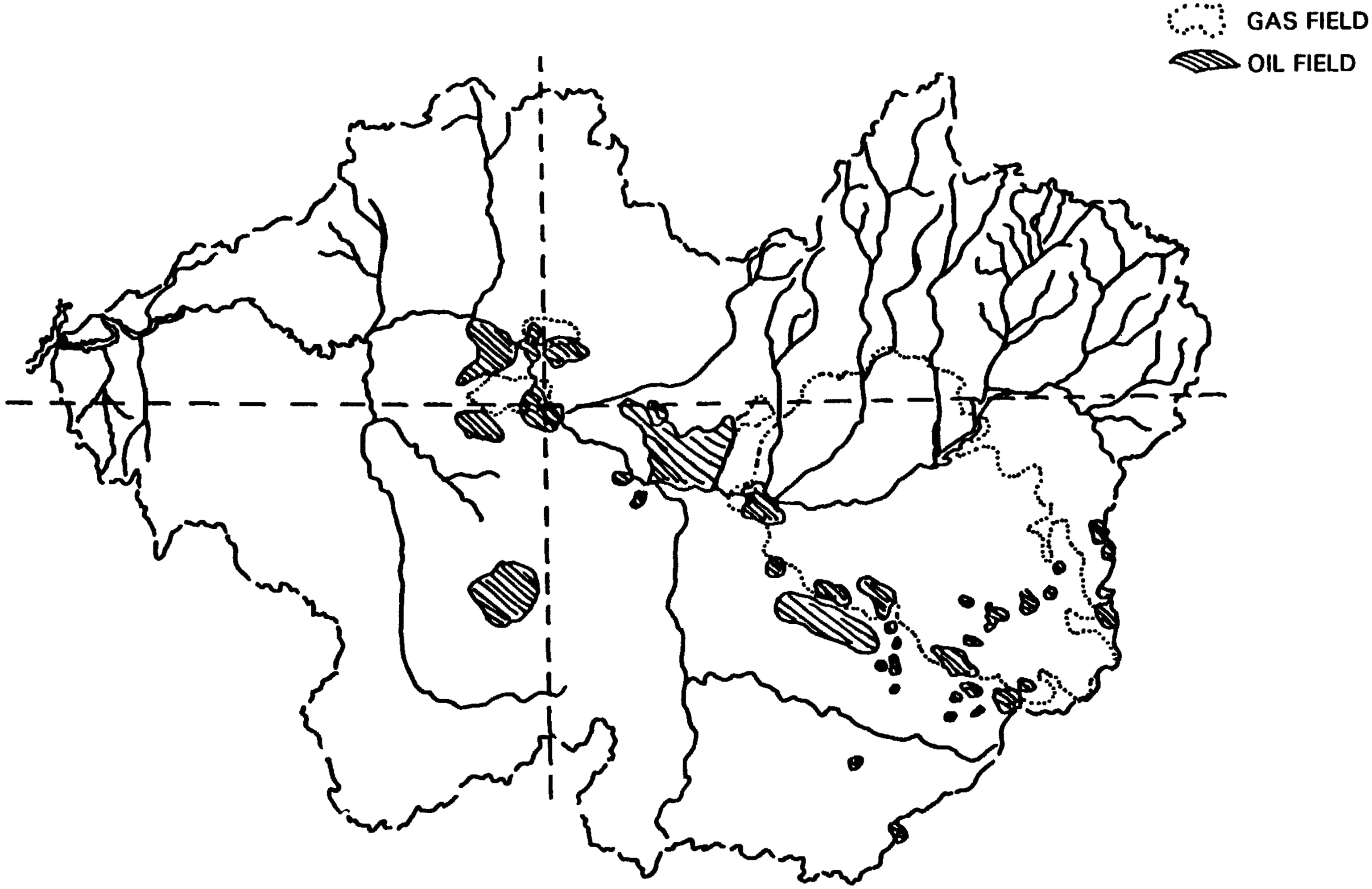

Figure 4. San Juan basin petroleum fields. (Modified from Melancon et al. 1979)

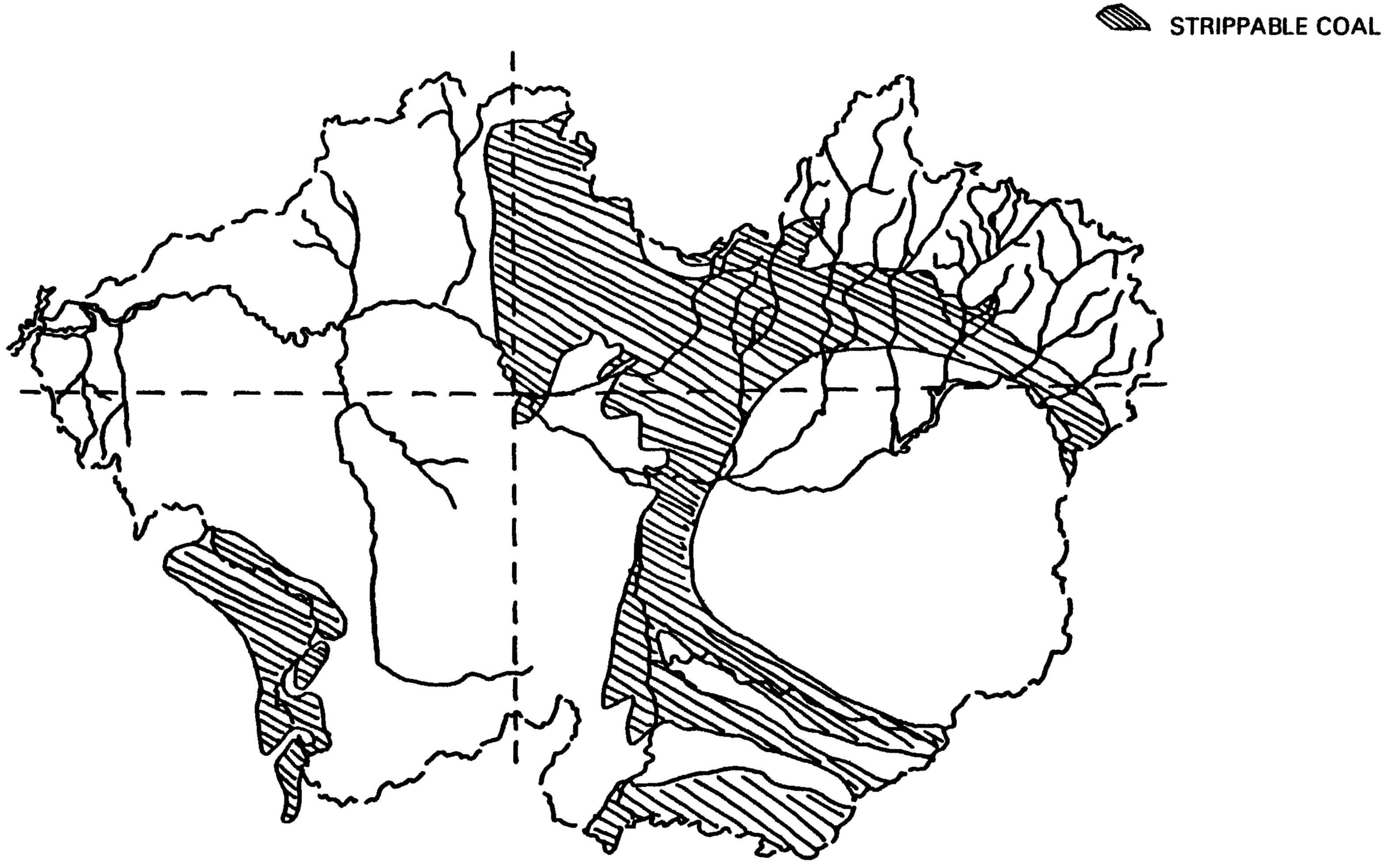

Figure 5. San Juan basin coal deposits. (Modified from Melancon et al. 1979)

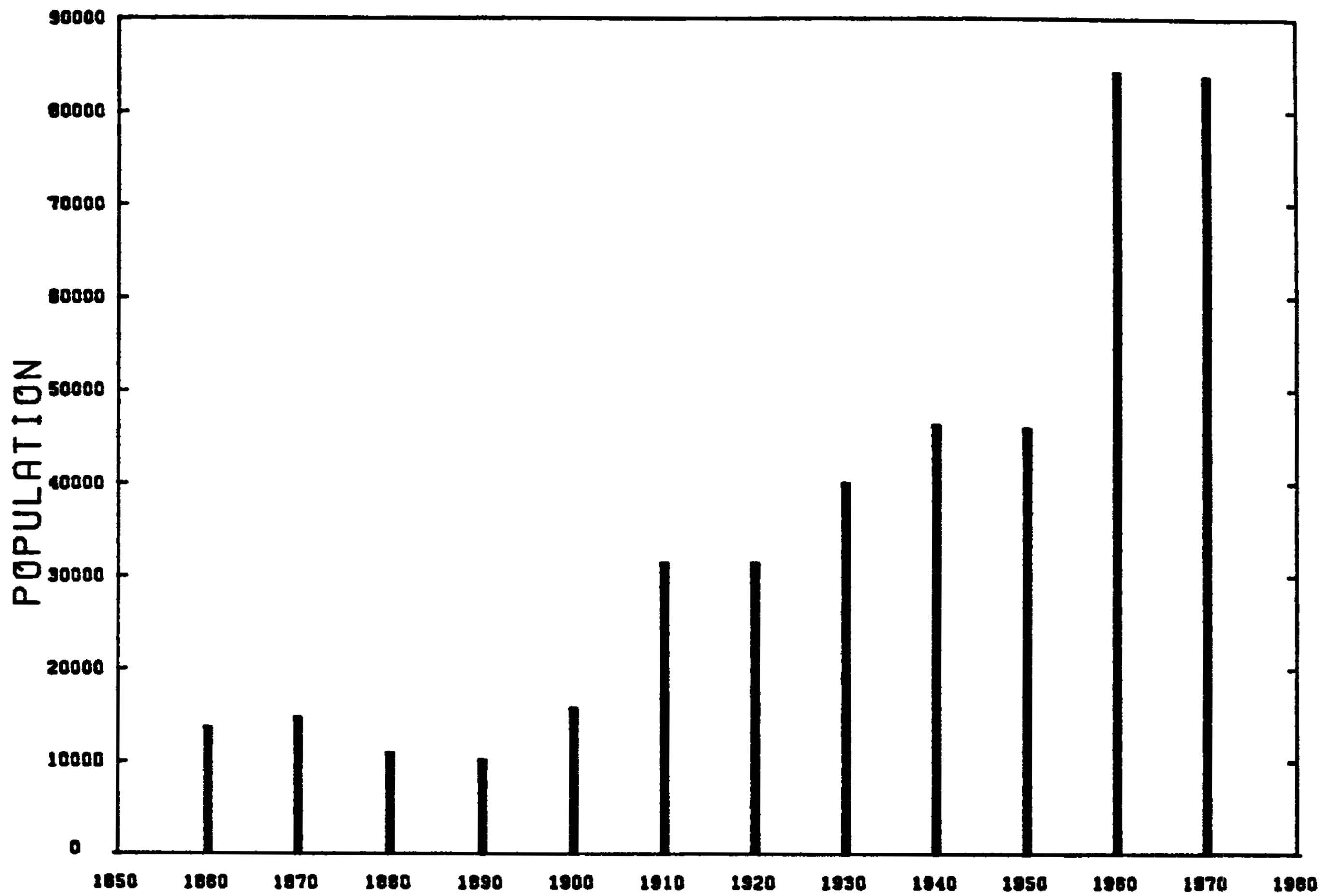

Figure 6. Population in the San Juan basin above Shiprock, 1860-1970. (Taken from Goetz 1981)

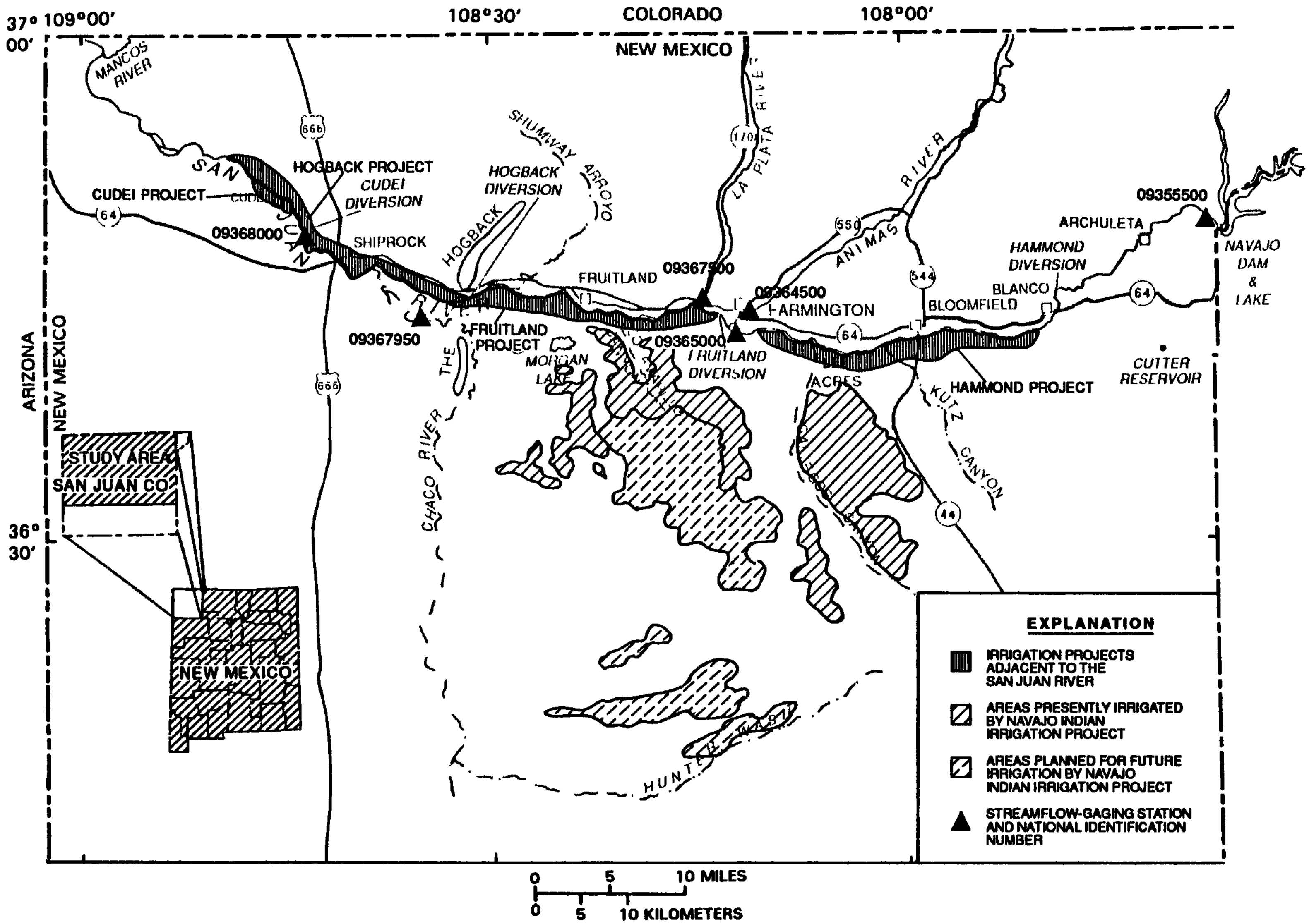

Figure 7. Location of DOI-sponsored irrigation projects, San Juan basin. (Taken from Blanchard et al. 1993)

Table 1: Population of selected towns, San Juan River basin, 1990

New Mexico		Colorado		Utah	
Aztec	5,479	Bayfield	1,090	Blanding	3,162
Bloomfield	5,214	Cortez	7,284	Monticello	1,806
Crownpoint*	2,108	Dolores	866		
Dulce*	2,438	Durango	12,430		
Farmington	33,997	Pagosa Springs	1,207		
Shiprock*	7,687	Telluride	1,309		

* Census-Designated Place: population not within incorporated area

Taken from U.S. Department of Commerce 1990

Table 2: Population of Indian reservations, San Juan River basin, 1990

New Mexico		Colorado		Utah	
Jicarilla Apache	2,617	S. Ute Reservation	7,804	Navajo Reservation	5,500
Navajo Reservation & Trust Lands	51,987	Ute Mountain Ute Reservation & Trust Lands	1,069	Ute Mountain Ute Reservation & Trust Lands	251
Ute Mountain Ute	0				

Taken from U.S. Department of Commerce 1990

2.6 WATER USE

Water use statistics for the basin as a single unit were unavailable. The best data, approximated here, exist for New Mexico. In 1992, 497,414 acre-feet (about 613 million m^3) of water were withdrawn for use in the basin within New Mexico; 99% of these depletions were surface water. Water depletions totaled 337,760 acre-feet (about 417 million m^3). Irrigation consumed the most water, with 78% of withdrawals and 74% of depletions. Mining and power generation constituted the next largest users of water, together accounting for 10% of basin withdrawals in New Mexico and 12% of depletions. Of these depletions, nearly 100% were of surface water. Livestock, commercial, and industrial uses of water totaled less than 1% of basin withdrawals, with 73% of withdrawals from surface water sources; these uses resulted in 1% of basin depletions in New Mexico (Wilson 1992).

Goetz et al. (1987) determined water use statistics for the New Mexico and Colorado portion of the basin upstream from Shiprock, NM. In 1965 agriculture accounted for almost 93% of water depletions in the area and was projected to equal 77% by 1980. Power generation alone totaled 4% of depletions in 1965 and was projected to reach 16% by 1980. These projections closely match the 1992 New Mexico statistics, suggesting that water use is fairly uniform in the basin, at least throughout New Mexico and Colorado.

2.7 BIOTA

Within the New Mexico portion of the basin, Meneely and Duzan (1979) documented 99 species of mammals, 311 species of birds, 14 species of amphibians, 34 species of reptiles, and 50 species of fish. This review focuses on those species of fish that are native and especially those that are considered rare. Colorado squawfish (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) are both listed as federally endangered species. Roundtail chub (*Gila robusta*) and flannelmouth sucker (*Catostomus latipinnis*) are federal candidate species, and the roundtail chub is on the New Mexico state list of endangered species. Other native fish in the basin include speckled dace (*Rhinichthys osculus*), bluehead sucker (*Catostomus discobolus*), and mottled sculpin (*Cottus bairdi*).

Factors identified in the decline of San Juan basin native fish include habitat alteration, fragmentation, and degradation from dam construction as well as competition and predation from exotics (U.S. Bureau of Indian Affairs 1991). Navajo Reservoir, which was built in 1962 as part of the Colorado River Storage Project (CRSP), eliminated 35 miles of endangered fish habitat in the San Juan River by inundation and an additional 40 miles by changing the water quality (U.S. Bureau of Reclamation 1992a). In recent years the Colorado squawfish has only been verified in the San Juan River main channel below Shiprock, and the razorback sucker has been verified in the San Juan arm of Lake Powell and near Bluff, Utah. Roundtail chub have not been identified in the Animas River since the 1970s but have been taken in the Florida River and the San Juan River at its confluence with the Animas (Figures 8a-c) (Platania 1990, U.S. Fish and Wildlife Service 1993).

3. METHODS

Three questions guided the collection of information for this review: 1) What are the contaminants and water quality problems in the San Juan River basin? 2) What are the sources of the contaminants and problems? 3) What are the effects of these contaminants and problems on the basin's native fish fauna? Documents that attempted to answer these questions were considered for inclusion in this review. For the purposes of this report, a contaminant is considered any material with the potential, directly or indirectly, to impair fish health or reproduction. Water quality parameters identified as potential threats to fish health include temperature, pH, dissolved oxygen, salinity, and sediment. No distinction has been made between anthropogenic and natural contamination, as the mandate of the San Juan River Fisheries Seven Year Research Plan was to identify any and all threats to the native fish fauna.

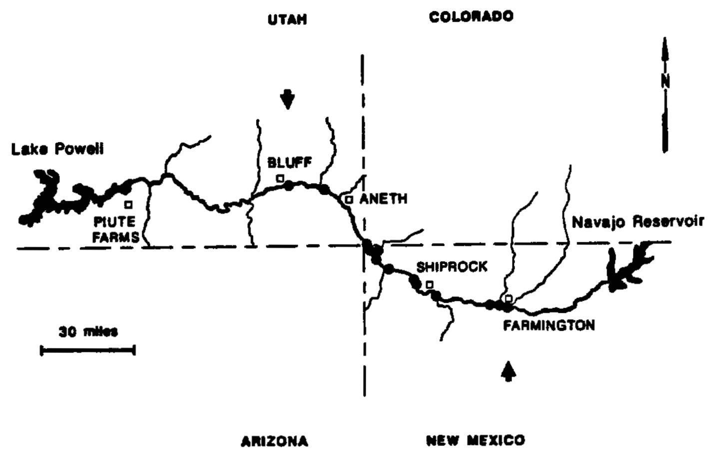

Figure 8a. Collection records of roundtail chub in the San Juan River, New Mexico and Utah, 1987-1989. (Taken from Platania 1990)

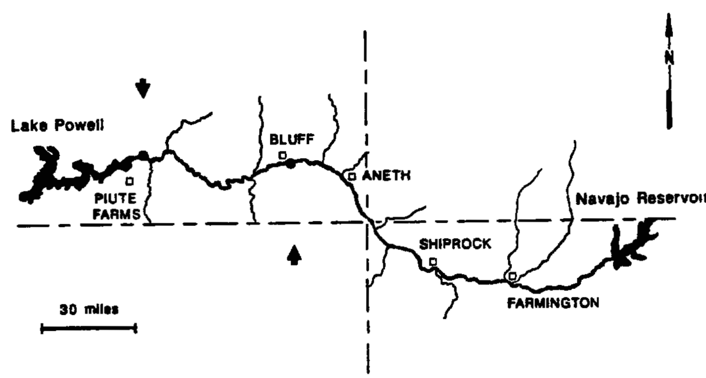

Figure 8b. Collection records of razorback sucker in the San Juan River, New Mexico and Utah, 1987-1989. (Taken from Platania 1990)

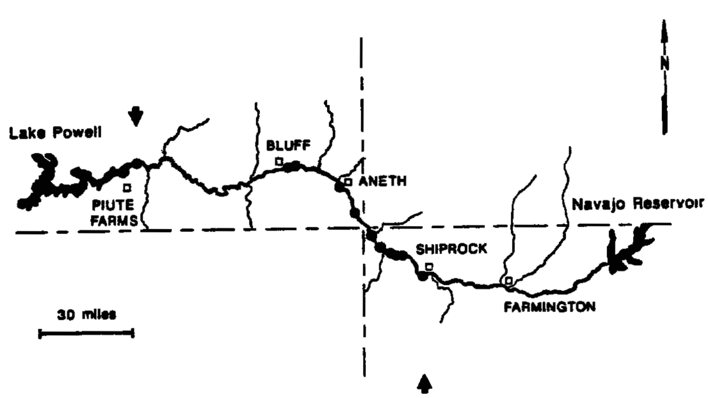

Figure 8c. Collection records of Colorado squawfish in the San Juan River, New Mexico and Utah, 1987-1989. (Taken from Platania 1990)

This review was organized mainly by contaminant source, as sources primarily define the more substantial studies discussed herein. The RESULTS section begins with background information concerning San Juan River fish, disease, and standards, that is important to understanding the discussions that follow. Background information is included elsewhere in the RESULTS section where pertinent. Raw data from studies are generally located in a separately bound volume of appendices (Volume II, Appendices 4-16), while discussion of the data is found in the body of this review under RESULTS. The review attempts to give a reader who has little or no prior knowledge of contaminants the tools necessary for a basic evaluation of the data that have been included.

Few studies have collected data from the entire San Juan basin, with the vast majority of research stopping at state boundaries. An attempt was made to obtain parallel information for each of the three states, but in many cases this was not possible; therefore, the quality of information varies for a given category and in some instances was not available for one or more states. Additionally, little information was available for the Indian reservations. As the purpose of the report was to identify gaps in information, these discontinuities are only a problem insomuch as it makes an overall evaluation of the basin difficult for a given contaminant or contaminant source. Maps were included liberally in this review to facilitate evaluation of where geographic gaps in data exist.

An attempt was made to convert units of measurement to standard forms to simplify the comparison of data, but in many cases such conversions were not possible. For example, tissue sample analyses measure the concentrations of contaminants in either wet or dry weight, but to convert one to the other involves the use of a mathematical formula which requires the percent moisture of the samples. The percent moisture of samples is often not collected at the analytical laboratory, and when collected it is usually not included in the data set. Additionally, some older reports do not specify the type of measurement; in these cases, the data were selectively included. To facilitate other data comparisons, a conversion table listing the concentrations of various unit measurements has been provided (Appendix 3).

Within the text, conversions have been supplied between English and metric units. The number given first is that which appeared in the reference cited; the number in parentheses is the conversion. Similarly, when available, both common and scientific names are given for species. The first time a species is mentioned its scientific name is given in parenthesis, and thereafter only the common name is used.

Because surface water quality is a function not only of direct inputs but also of groundwater, soils, and even air quality, the volume of information regarding the basin is quite large. Therefore, for this review it was necessary to prioritize information according to its potential importance to San Juan basin native fishes. The highest priority was given to water quality, sediment, and biota studies from the San Juan River and its tributaries. Secondary priority was assigned to groundwater and soils if there was evidence that they affected surface water quality in the river or its tributaries. Studies on reservoirs were considered according to their applicability to San Juan basin water quality. Proposed projects such as the Animas-La Plata Project, although as yet undeveloped, received fairly high priority because of the magnitude of their potential effects on the basin's water quality.

More recent information was given priority over older documents, but in many cases the only available information was a decade or more old. If the information was not obviously outdated, it was incorporated into the review. Conversely, only the most recent water quality data were included based on the assumption that older information would not normally be pertinent to the health of present-day fish populations.

Research for this review has made use of as many types of documents as possible. Using CD-ROMs, the federal government documents depository at UNM was searched for pertinent items, while the general library holdings were used to provide background information on various topics. The depository contained only published documents, but there was also a wealth of unpublished information on contaminants and water quality. For this information, government agencies were visited and, where possible, unpublished data and communications were obtained for use in this review. These agencies included the Bureau of Indian Affairs, Farmington; Bureau of Reclamation, Durango; and Fish and Wildlife Service Ecological Services in Albuquerque, Grand Junction, and Salt Lake City. Other offices, particularly those of state agencies and consulting firms, were contacted by telephone for information. In several cases the authors of unpublished material have asked that it not be included until it has been approved and published.

This review was compiled beginning in February 1993 and includes studies, reviews, data sets, and communications available by July 1, 1993. All information gathered for the review is archived at the New Mexico Ecological Services Office of the U.S. Fish and Wildlife Service. All future inquiries regarding the review should be directed to the contaminants specialist at that office.

4. RESULTS

4.1 NATIVE FISH FAUNA CHARACTERISTICS

The San Juan basin native fish fauna, as a result of their life histories, physiologies, and habitat preferences, are in certain ways particularly vulnerable to contaminants and the suite of water quality changes that have occurred in the basin.

The native fishes rely heavily on backwater areas and low-flow channels as habitat for larvae, young-of-the-year (YOY), and juveniles, and it is in these areas that contaminants tend to concentrate, especially if a contaminant enters the system as a surface water input (Petty et al. 1992). In the Upper Colorado River basin, Colorado squawfish occur in a variety of habitats, but YOY, juveniles, and subadults prefer quiet backwaters with little or no current (Seethaler 1978, Tyus et al. 1982, Tyus 1987). Tyus (1991) found that young squawfish moved in and out of backwaters as temperatures fluctuated, locating the warmest water. Subadult and adult Colorado squawfish were also found in backwaters, although they did not rely on them exclusively (Seethaler 1978, Meneely et al. 1979). During peak runoff, adults have been observed to move to backwaters where there were warmer temperatures (Colorado Fishes Recovery Team 1991). Likewise, adult roundtail chub have been found in a variety of habitats and have seemed to prefer deeper pools of large streams, but larvae of the species have preferred backwaters for their habitat (Meneely et al. 1979, Petty et al. 1992). Razorback sucker have been found to prefer backwaters of rivers or impounded waters (Holden and Stalnaker 1975). Like the Colorado squawfish and roundtail chub, razorback sucker larvae depend on backwaters, with older fish showing a preference for backwaters of rivers or impounded waters. Young bluehead and flannelmouth suckers have also been found in backwaters associated with main channels (Meneely et al. 1979).

When contaminants concentrate in backwater habitats, fish inhabiting them are exposed to the contaminants through several pathways. If adult fish move into the nursery areas prior to reproduction, they may ingest food items in which contaminants have already accumulated to greater than background concentrations (National Fisheries Contaminant Research Center et al. 1991). Adult fish may then transfer accumulated levels of contaminants to their offspring. Larval, YOY, and juvenile fish may also accumulate contaminants by direct uptake from the water or through feeding. In Colorado squawfish and razorback sucker, for whom critical life stages are from fertilized eggs through the first year (Miller et al. 1982), increased exposure to contaminants in backwaters has the potential to reduce reproductive success (National Fisheries Contaminant Research Center et al. 1991). Evidence from recent larval fish studies has shown that, at least for the Colorado squawfish, recruitment of young is exceptionally low (Platania 1991).

The endangered fishes of the basin are also at high risk of contamination as a result of their life history strategies. Colorado squawfish and razorback sucker are long-lived, require several years to reach sexual maturity, and may reproduce infrequently after reaching maturity (Seethaler et al. 1979, Roy and Hamilton 1992). The females of these species carry their eggs and precursor materials for years before shedding them during spawning, allowing an extended period of time for contaminant accumulation in the ovaries and eggs (Roy and Hamilton 1992). As predaceous piscivores, Colorado squawfish face the additional risk of biomagnification of contaminants (Seethaler et al. 1979).

4.2 SAN JUAN RIVER BASIN FISH DISEASE DATA

San Juan River researchers have, in the course of their work, noted what seems to be an unusually high occurrence of abnormal growths on fishes (Shanks 1993a). The New Mexico Water Quality Control Commission (1992) has stated that "to date, no fish abnormalities have been identified which are attributable to man-induced pollutants." This is true to the extent that abnormalities have not been positively traced to specific pollutant sources. There is, however, limited but strong evidence suggesting a correlation between contaminants and abnormalities.

In 1992, in response to repeated observations of abnormalities, Carol Shanks of the Pinetop Fish Health Center, FWS, undertook a preliminary histopathological survey of San Juan River fish. Samples from diseased and healthy fish were collected from the San Juan River between the Hogback diversion and Mexican Hat (October 1992), and from secondary channels of the river between Shiprock and Bluff (May 1993). A total of 31 apparently diseased and 11 healthy fish was sampled in October and 15 diseased and 3 healthy fish were collected in May (Appendix 5) (Shanks 1993b). Fish were examined in the field and tissue samples were transferred to the Pinetop Fish Health Center for pathogen identification (Shanks 1993a).

Of the diseased fish taken in October 1992, 77% (N=24) were flannelmouth sucker, common carp (*Cyprinus carpio*) was 10% (N=3), channel catfish (*Ictalurus punctatus*) was 6% (N=2), and both roundtail chub and bluehead sucker were 3% (N=1). Of diseased fish collected in May 1993, flannelmouth sucker constituted 47% (N=7), channel catfish were 27% (N=4), and both common carp and bluehead sucker were 13% (N=2) (Shanks 1993).

Skin lesions, which occurred primarily near the dorsal fin, identified the presence of disease. Three species of bacteria were isolated from the lesions of fish collected in May 1993: *Aeromonas hydrophila* (also isolated in October 1992), *Citrobacter freundii*, and *Acinetobacter* sp. According to Shanks (1993a), "these bacterial species have been designated as fish pathogens but usually require stressors such as high contaminant levels or malnutrition to invade the host."

A Colorado squawfish taken in May 1993 appeared healthy, but *Acinetobacter* sp. was isolated from its skin. Shanks hypothesized that either Colorado squawfish are less susceptible than flannelmouth sucker to contaminants stress and subsequent bacterial invasion, or the fish was in an early stage of infection and tissue abnormalities had not yet occurred (Shanks 1993a).

The results of the fish surveys indicate that disease is a problem in San Juan River fish, particularly in flannelmouth sucker. Histological examinations of the fish sampled are currently being performed by a researcher at Bozeman Technical Center to determine what contaminants, if any, caused the abnormalities (Shanks 1993).

In the San Juan DOI Irrigation Drainage Study, discussed in greater detail under the IRRIGATION section (4.10), high percentages of abnormalities were found in flannelmouth sucker and channel catfish. A total of 49 fish from 7 species was sampled from the San Juan River in the spring and fall of 1990 (Blanchard et al. 1993). Of these, 28% of flannelmouth sucker and 35% of channel catfish had external lesions. In the Shiprock to Cudei reach of the river, 50% of flannelmouth sucker and 37% of channel catfish sampled had lesions. It was suggested that the lesions were the result of exposure to polycyclic aromatic hydrocarbons (PAHs) and that the physiological stress caused by the lesions could exacerbate or synergistically work with other contaminants, further weakening the fish (U.S. Fish and Wildlife Service 1991b).

Hepato-histological examinations have also been performed on San Juan River fish. In one sampling, the livers from 36 flannelmouth sucker from the San Juan River were examined, and 77% of them exhibited large numbers of eosinophillic granulocytes (U.S. Fish and Wildlife Service 1991b, Herman 1991a). At the time of the analysis, the condition, as manifested in inflammatory tissues around the bile ducts, was interpreted as either being normal and age-related or an abnormality due to accumulation of toxic substances (Herman 1991a). A sample of six livers from flannelmouth sucker collected from Alkali Creek in Colorado suggested that the San Juan River flannelmouth sucker livers had experienced unusual tissue breakdown and that the large number of granulocytes in the fish was abnormal (Herman 1991b).

The San Juan River sample also included a black bullhead (*Ameiurus melas*) with a papilloma, a type of skin lesion, that showed an unusual number of mucous cells. Papillomas are rare in this species, and the condition has been reported to be related to water quality. Conversely, papillomas have been found on brown bullheads (*Ameiurus natalis*) from apparently clean water (Herman 1991a).

The remaining fish disease data from the San Juan River basin comes from the lower Animas River. In July 1992 the Colorado Department of Wildlife (CDOW), the U.S. Bureau of Reclamation (BR), the FWS, and the Southern Ute Tribe conducted an electrofishing survey of the Animas from the Purple Cliffs area, four miles south of Durango, to the New Mexico state line (Japhet 1993). Diseased bluehead, flannelmouth, and bluehead x white hybrid suckers were first sighted approximately 0.3 miles upstream of a large natural gas well located within 300 feet of the river high water line at T33N, R10W, S36 (Figure 9) (Walker 1992, Japhet 1993). Two of the fish had large tumors protruding from their bodies, and an estimated 5% of the suckers had large lesions, ulcers, and open sores (Japhet 1993). That percentage can be considered to represent a major feral fish disease outbreak (Walker 1992, Japhet 1993).

Pete Walker, a CDOW fish pathologist, examined the aforementioned fish and reported that he suspected *Aeromonas salmonicida nova*, a bacteria, of causing furunculosis (Walker 1992). Furunculosis is a stress-mediated disease arising in poor water quality. Because the affected fish were found only in the immediate vicinity of the gas well, there is strong evidence to support that water quality indirectly caused the outbreak of furunculosis (Walker 1992).

Following the diagnosis of furunculosis, an additional nine suckers were collected from the Animas River near Bondad, Colorado. Five of the fish had open sores or lesions, while the remaining four had no external signs of disease. When tested, the five fish with lesions and two without showed evidence of exposure to PAHs (Japhet 1993).

The above-mentioned studies represent all disease research that has been performed on San Juan River basin fish. With the exception of the hepato-histological investigations and the PAH analyses, the studies have relied on external expressions of disease, which were the most obvious clues of contamination. When such clues have not been available, researchers have often compared tissue, food item, water, or sediment concentrations of a given contaminant with criteria derived from toxicity studies.

4.3. WATER QUALITY STANDARDS

4.3.1 EPA WATER QUALITY STANDARDS

Once sampling data have been generated, researchers must decide to which standards the numbers should be compared. When evaluating water quality data, many researchers look to the criteria set by the Environmental Protection Agency (EPA); these standards are officially published in the Federal Register. These standards are often considered high, especially for sensitive species, but in the absence of better standards for certain contaminants they are generally used. Below are the EPA criteria for a number of common parameters, trace elements, and organics. All EPA criteria, except where otherwise stated, are from the 1 July 1993 edition of the Federal Register (Table 3) (Office of the Federal Register 1993).

Alkalinity - The EPA criterion for freshwater aquatic life is a minimum of 20 mg/l as $CaCo_3$ except where natural concentrations are less.

Ammonia - The EPA found that acute toxicity of ammonia for 29 species of freshwater fish from 9 families and 18 genera was 0.083-1.09 mg/l NH_3. The 96-hour LC_{50} (concentration that resulted in death of half the test population over the course of 96 hours) was 0.083-1.09 mg/l for salmonids and

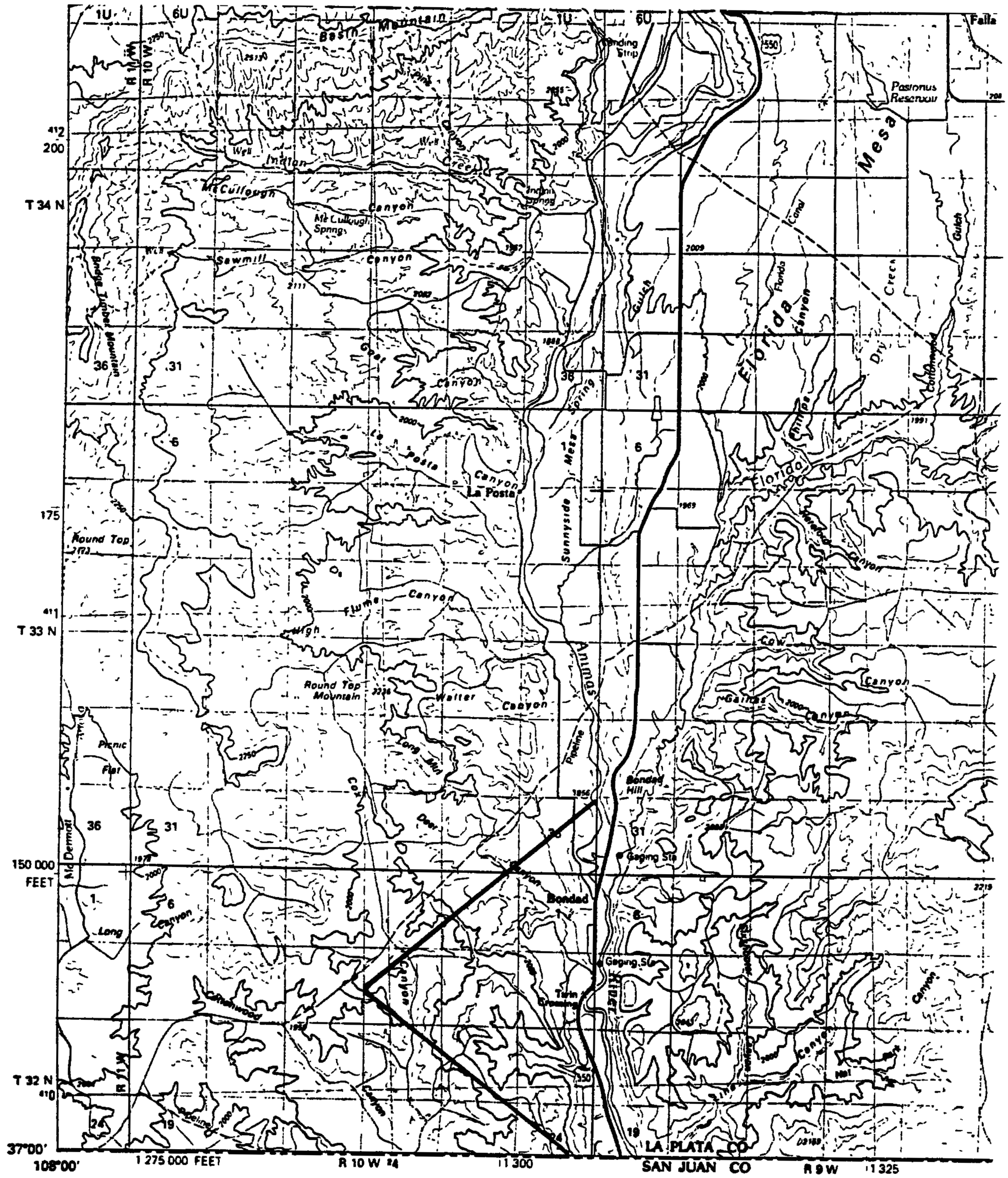

Figure 9. Location of diseased fish collected from the Animas River, 1992.
(Source Japhet, personal communication)

Table 3: EPA water quality criteria for selected trace elements, freshwater

Element	Acute (CMC)*	Chronic (CCC)*
Arsenic	360 a	190 a
Cadmium	3.9 a,b	1.1 a,b
Chromium (III)	1700 a,b	210 a,b
Chromium (IV)	16 a	11 a
Copper	18 a,b	12 a,b
Lead	82 a,b	3.2 a,b
Mercury	2.4 a	0.012 c
Nickel	1400 a,b	160 a,b
Selenium	20	5
Silver	4.1 a,b	
Zinc	120 a,b	110 a,b

* CMC - criteria maximum concentration - the water quality criteria to protect against acute effects in aquatic life and is the highest instream concentration of a priority toxic pollutant consisting of a one-hour average not to be exceeded more than once every three years on the average
CCC - criteria continuous concentration - the water quality criteria to protect against chronic effects in aquatic life and is the highest instream concentration of a priority toxic pollutant consisting of a 4-day average not to be exceeded more than once every three years on the average

a Criteria for these metals are expressed as a function of the water effect ratio, WER, as defined in 40 CFR 131.36(c)

b Freshwater aquatic life criteria for these metals are expressed as a function of total hardness (mg/L), and as a function of the pollutant's WER Values displayed in the above table correspond to a total hardness of 100 mg/L and a WER of 1 0.

c If the CCC for total mercury exceeds 0.012 µg/L more than once in a 3-year period in the ambient water, the edible pportion of the aquatic species of concern must be analyzed to determine whether the concentration of methyl mercury exceeds the FDA action level (1.0 mg/kg).

Modified from Office of the Federal Register 1993

0.14-4.60 mg/l for non-salmonids. Toxicity of ammonia varies with temperature and pH (Valdez et al. 1993).

Dissolved Oxygen (DO) - The EPA criteria for non-salmonid fisheries for dissolved oxygen is 6.5 mg/l for early life stages and 6.0 mg/l for all other life stages. The criteria for salmonid fisheries is 11 mg/l for early life stages and 8 mg/l for other life stages.

Nitrate - No EPA criteria exist for nitrate. Westin (1974) found the 7-day LC_{50} for fingerling rainbow trout (*Oncorhynchus mykiss*) to be 1060 mg/l. Nitrate nitrogen levels at or below 90 mg/l have been found not to adversely affect warmwater fish (Valdez et al. 1992).

pH - The European Inland Fisheries Advisory Commission (1969) determined that a pH of 5-9 was not directly lethal to freshwater fish. However, the toxicity of several common pollutants is markedly affected by pH changes within this range (Valdez et al. 1992). The EPA criterion for freshwater aquatic life is 6.5-9.0.

Phosphate - No EPA criteria exist for phosphate. In general, phosphate is an indicator of pollution but is not considered a pollutant itself except for its effect on plant growth (Toole 1992).

Sulfates - No EPA criteria exist for sulfates.

Total suspended solids (TSS) and settleable solids - The EPA states that settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life.

Total dissolved solids (TDS) - The EPA reports that, in general, water systems with TDS levels in excess of 15,000 mg/l are unsuitable for most freshwater fish; however, the EPA has set no criteria for TDS. In experiments several common freshwater species have survived exposure to 10,000 mg/l TDS (Valdez et al. 1992). Pimentel and Bulkley (1983) found that Colorado squawfish avoided TDS concentrations greater than 4,000 mg/l.

Aluminum - No EPA criteria exist for aluminum.

Arsenic - The EPA states that freshwater organisms should not be affected unacceptably if the 4-day average concentration of arsenic (III) does not exceed 190 μg/l more than once every three years on average and if the 1-hour average concentration does not exceed 360 μg/l more than once every three years on average. Inorganic arsenic (IV) is acutely toxic to freshwater animals at concentrations as low as 850 μg/l. For inorganic arsenic, an acute:chronic ratio of 28 has been obtained for fathead minnow (*Pimephales promelas*).

Cadmium - Cadmium toxicity is affected by water hardness. The EPA states that, except where a locally important species is very sensitive, freshwater aquatic organisms should not be affected unacceptably if the 4-day average concentration of cadmium (in μg/l) does not exceed the numerical value given by $e^{(0.7852[\ln(\text{hardness})]-3.490)}$ more than once every three years on the average and if the 1-hour average concentration (in μg/l) does not exceed the numerical value given by $e^{(1.128[\ln(\text{hardness})]-3.828)}$ more than once every three years on the average.

Copper - Copper toxicity is affected by water hardness. The EPA states that, except where a locally important species is very sensitive, freshwater aquatic organisms should not be affected unacceptably if the 4-day average concentration of copper (in μg/l) does not exceed the numerical value given by $e^{(0.8545[\ln(hardness)]-1.465)}$ more than once every three years on the average and if the 1-hour average concentration (in μg/l) does not exceed the numerical value given by $e^{(0.9422[\ln(hardness)]-1.464)}$ more than once every three years on the average. At a hardness of 50 mg/l the acute toxicity for *Ptychocheilus* was found to be 16.74 μg/l (EPA 1986).

Iron - The EPA criterion for iron is 1.0 mg/l.

Lead - The acute toxicity of lead in several species has been shown to decrease as water hardness increases. The EPA states that, except where a locally important species is very sensitive, freshwater aquatic organisms should not be affected unacceptably if the 4-day average concentration of lead (in μg/l) does not exceed the numerical value given by $e^{(1.273[\ln(hardness)]-4.705)}$ more than once every three years on the average and if the 1-hour average concentration (in μg/l) does not exceed the numerical value given by $e^{(1.273[\ln(hardness)]-1.460)}$ more than once every three years on the average.

Mercury - The EPA states that the acute toxicity of mercury (II) for fishes ranges from 30 μg/l for guppies to 1,000 μg/l for *Tilapia* spp. The chronic toxicity level of mercury (II) in fathead minnow has been shown to be 0.26 μg/l. According to the EPA, freshwater organisms should not be affected unacceptably if the 4-day average concentration of mercury (II) does not exceed 0.012 μg/l more than once every three years and if the 1-hour average concentration does not exceed 2.4 μg/l more than once every three years on average. Methylmercury is the most chronically toxic, with values of less than 0.07 μg/l.

Radionuclides - No EPA criteria exist for radionuclides (uranium, thorium, radium-226).

Selenium - In 1987 the EPA lowered the permissible level of waterborne selenium from 35 μg/l to 5 μg/l as a 24-hour average. Lemly (in press) recommends that waterborne selenium concentrations of 2 μg/l or greater be considered highly hazardous to the health and long-term survival of fish and wildlife. The EPA's acute criterion for selenium is 20 μg/l (U.S. Environmental Protection Agency 1993). The EPA acute criterion for selenite is 260 μg/l. Acute toxicity of inorganic selenate can occur as low as 760 μg/l and may be lower for more sensitive fish (U S. Environmental Protection Agency 1986).

Silver - The EPA criterion for total silver is based on water hardness. The EPA states that the concentration of total recoverable silver (in μg/l) should not exceed the numerical value given by $e^{(1.72[\ln(hardness)]-6.52)}$ at any time. Chronic toxicity to freshwater aquatic life may occur at concentrations as low as 0.12 μg/l.

Zinc - The EPA criterion for zinc is based on water hardness. The EPA states that for total recoverable zinc, the concentration (in μg/l) should not exceed the numerical value given by $e^{(0.83[\ln(hardness)]+1.95)}$ at any time. The chronic criterion is given by $e^{(0.8473[\ln(hardness)]+8604)}$.

Hydrocarbons - The EPA has not set any acute or chronic criteria for PAHs as a group. It states that acute and chronic toxicity of naphthalene occurs at concentrations as low as 2,300 μg/l and 620 μg/l, respectively, and could occur at lower concentrations among sensitive species. The EPA also states that acute toxicity of benzene and toluene to freshwater life occurs at concentrations as low as 5,300 μg/l and 17,500 μg/l, respectively; there are no chronic toxicity standards for either compound.

The above standards are only for surface water quality. The EPA has not issued standards for trace elements or organics in soils, sediment, food items, or fish tissue. (The Food and Drug Administration regulates trace elements and organics in fish, but these standards are based on concerns for human rather than fish health.) Data collected for these components are normally compared with data or baseline data or criteria accepted within the research community. Such criteria will be discussed in further detail under sections dealing with specific contaminants.

4.3.2 STATE SURFACE WATER QUALITY STANDARDS

The federal Clean Water Act, as amended (33 U.S.C. 466 et seq.), declares that "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983..." (Senate Committee on Environment and Public Works 1982). In accordance with this Act, each state must designate the uses for which its surface waters shall be protected and must prescribe the water quality standards necessary to sustain the designated uses (New Mexico Water Quality Control Commission 1991). Each of the three states of the San Juan River basin has therefore assigned designated uses and standards to the San Juan River and its tributaries (New Mexico Water Quality Control Commission 1991, New Mexico Water Quality Control Commission 1992, Utah Department of Environmental Quality 1992, Toole 1992, Colorado Water Quality Control Commission 1993a, Colorado Water Quality Control Commission 1993b).

Each state has approached the task of assigning use designations and standards in a somewhat different manner, making a comparison of all standards for the basin cumbersome. In general, each state has three sets of information that need to be referenced in order to determine the standards for a given section of river or stream. The first set lists the water use classifications that a state has chosen, the second lists the water quality standards that apply to each classification, and the third assigns a classification to each section of water. Depending on the state, these three sets of information may be combined or given in separate tables. A particular stretch of water may have multiple use classifications, with the most stringent standards taking precedence; fisheries standards are normally, though not always, the most restrictive. The following sections list the classifications and standards for each state.

New Mexico - New Mexico has chosen 11 use classifications for its waters (Table 4). In assigning classifications to its surface waters, the state has divided the San Juan basin into seven broad sections (Table 5), each with its own standards for pH, dissolved oxygen, temperature, and fecal coliform. All New Mexico waters within the San Juan basin have been designated as fisheries and as such must meet the standards for trace elements, chlordane, and cyanide that have been prescribed for the protection of aquatic life (section 3-101-J. of Table 6). All waters within the basin are also classified for livestock and wildlife watering and therefore must meet the radium-226 + radium-228 limit of 30.0 picocuries per liter (pCi/l) in addition to trace element requirements (New Mexico Water Quality Control Commission 1991).

In accordance with section 305(b) of the Clean Water Act (Appendix 6) (Senate Committee on Environment and Public Works 1982), New Mexico has evaluated its surface waters to determine which sections do not support their use classifications. The state's assessment of its water depends primarily on ambient physical and chemical data. The state also uses fish tissue data from a study begun in 1991, but data from biological surveys and biomonitoring tests have not yet been formally incorporated into New Mexico's assessment protocol (New Mexico Water Quality Control Commission 1992).

The EPA recommends that even a single exceedance of a chronic criterion in a three-year period indicates that aquatic uses are "not supported." New Mexico, though, has chosen to designate uses as "partially supported" when waters show exceedances of chronic criteria for toxicants, unless exceedances of other criteria indicate that impairment is serious enough to warrant the designation of "not supported" (New Mexico Water Quality Control Commission 1992).

New Mexico has compiled a list of those sections of rivers and streams within the San Juan basin whose uses are not fully supported (Table 7). The table also includes the toxicants that have been found at acute or chronic levels within these waters, as well as the probable sources of these toxicants. According to the New Mexico Water Quality Control Commission's evaluation, none of the surface

Table 4a: New Mexico surface water use classications

HQCWF	=	high quality coldwater fishery	DWS	=	domestic water supply
CWF	=	coldwater fishery	IRR	=	irrigation
MCWF	=	marginal coldwater fishery	L&WW	=	livestock and wildlife watering
WWF	=	warmwater fishery	PCR	=	primary contact recreation
LWWF	=	limited warmwater fishery	SCR	=	secondary contact recreation
			IS	=	irrigation storage

Table 4b: New Mexico codes for sources of nonsupport

0100		**Industrial point sources**
0200		**Municipal point sources**
	0201	Domestic point sources
0400		**Combined sewer overflows**
1000		**Agriculture**
1100		Nonirrigated crop production
1200		Irrigated crop production
	1201	Irrigation return flows
1300		Specialty crop production (e.g truck farming and orchards)
1400		Pastureland
1500		Rangeland
1600		Feedlots - all types
1700		Aquaculture
1800		Animal holding/management areas
1900		Manure lagoons
2000		**Silviculture**
2100		Harvesting, restoration, residue mgmt
2200		Forest management
2300		Road construction maintenance
3000		**Construction**
3100		Highway/road bridge
3200		Land development
	3201	Resort development
3300		Hydroelectric
4000		**Urban runoff/storm sewers**
5000		**Resource extraction**
5100		Surface mining
5200		Subsurface mining
5300		Placer mining
5400		Dredge mining
5500		Petroleum activities
	5501	Pipelines
5600		Mill tailings
5700		Mine tailings
5800		Road construction/maintenance
5900		Spills
6000		**Land Disposal**
6100		Sludge
6200		Wastewater
6300		Landfills
6400		Industrial land treatment
6500		Onsite wastewater systems (septic tanks, etc)
6600		Hazardous waste
6700		Septage disposal
6800		UST Leaks
7000		**Hydromodification**
7100		Channelization
7200		Dredging
7300		Dam construction/repair
7400		Flow regulation/modification
7500		Bridge construction
7600		Removal of riparian vegetation
7700		Streambank modification/destabilization
7800		Draining/filling of wetlands
8000		**Other**
8010		Vector control activities
8100		Atmospheric deposition
8200		Waste storage/storage tank leaks
8300		Highway maintenance and runoff
8400		Spills
8500		In-place contaminants
8600		Natural
8700		Recreational activities
	8701	Road/parking lot runoff
	8702	Off-road vehicles
	8703	Refuse disposal/littering
	8704	Spills
	8705	Ski slope runoff
8800		Upstream impoundment
8900		Salt storage sites
9000		**Source unknown**

Taken from New Mexico Water Quality Control Commission 1992

Table 5: Designated uses and standards for the San Juan basin, New Mexico

2-400. SAN JUAN RIVER BASIN

2-401. The main stem of the San Juan River from the point where the San Juan leaves New Mexico and enters Colorado upstream to U.S. Highway 64 at Blanco, and any flow which enters the San Juan River from the Mancos and Chaco River.

A. Designated Uses: municipal and industrial water supply, irrigation, livestock and wildlife watering, secondary contact recreation, marginal coldwater fishery, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-402. La Plata River from its confluence with the San Juan River upstream to the New Mexico-Colorado line.

A. Designated Uses: irrigation, limited warmwater fishery, marginal coldwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-403. The Animas River from its confluence with the San Juan upstream to U.S. Highway 550 at Aztec.

A. Designated Uses: municipal and industrial water supply, irrigation, livestock and wildlife watering, marginal coldwater fishery, secondary contact recreation, and warmwater fishery.

Table 5 (cont): Designated uses and standards for the San Juan basin, New Mexico

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 27 C (80.6 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 mg; no single sample shall exceed 400/100 ml (see 1-103.B).

2-404. The Animas River from U.S. Highway 550 upstream to the New Mexico-Colorado line.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total phosphorus (as P) shall be less than 0.1 mg/l, and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-405. The main stem of the San Juan River from U.S. Highway 64 at Blanco upstream to the Navajo Dam.

A. Designated Uses: high quality coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 400 μmhos/cm (at 25 C); dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen shall be less than 1.0 mg/l (as N); pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less then 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

Table 5 (cont): Designated uses and standards for the San Juan basin, New Mexico

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-406. Navajo Reservoir in New Mexico

A. Designated Uses: coldwater fishery, warmwater fishery, irrigation storage, livestock and wildlife watering, municipal and industrial water storage, and primary contact recreation.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total phosphorus (as P) shall be less than 0.1 mg/l, total chlorine residual shall be less than 0.002 mg/l, and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-407. The Navajo and Los Pinos Rivers in New Mexico

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total phosphorus (as P) shall be less than 0.1 mg/l; and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

Taken from the New Mexico Water Quality Control Commission 1991

3-101. STANDARDS[1] APPLICABLE TO ATTAINABLE OR DESIGNATED USES UNLESS OTHERWISE SPECIFIED IN TABLE 5.

A. Coldwater Fishery: Un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, temperature shall be less than 20 C (68 F), total chlorine residual shall not exceed 0.004 mg/l, and pH shall be within the range of 6.6 to 8.8. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

B. Domestic Water Supply: Waters designated for use as domestic water supplies shall not contain substances in concentrations that create a lifetime cancer risk of more than one cancer per 100,000 exposed persons. The following numeric standards shall not be exceeded:

Dissolved arsenic	0.05	mg/l
Dissolved barium	1.	mg/l
Dissolved cadmium	0.010	mg/l
Dissolved chromium	0.05	mg/l
Dissolved lead	0.05	mg/l
Total mercury	0.002	mg/l
Dissolved nitrate (as N)	10.	mg/l
Dissolved selenium	0.05	mg/l
Dissolved silver	0.05	mg/l
Dissolved cyanide	0.2	mg/l
Dissolved uranium	5.0	mg/l
Radium-226 + radium-228	30.0	pCi/l

C. High Quality Coldwater Fishery: Dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; temperature shall be less than 20 C (68 F); pH shall be within the range of 6.6 to 8.8; un-ionized ammonia (as N) shall not exceed 0.02 mg/l; total chlorine residual shall not exceed 0.004 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l;[2] total inorganic nitrogen (as N) shall be less than 1.0 mg/l;[2] total organic carbon shall be less than 7 mg/l; turbidity shall be less than 10 NTU (25 NTU in certain reaches where natural background prevents attainment of lower turbidity); and conductivity (at 25 C) shall be less than a limit varying between 300 μmhos/cm and 1,500 μmhos/cm depending on the natural background in particular stream reaches (the intent of this standard is to prevent excessive increases in dissolved solids which would result in changes in stream community structure). The acute and chronic standards set out in Section 3-101.J are applicable to this use.

D. Irrigation (or Irrigation Storage): The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml. The following numeric standards shall not be exceeded:

Dissolved aluminum	5.0 mg/l
Dissolved arsenic	0.10 mg/l
Dissolved boron	0.75 mg/l
Dissolved cadmium	0.01 mg/l
Dissolved chromium	0.10 mg/l
Dissolved cobalt	0.05 mg/l
Dissolved copper	0.20 mg/l
Dissolved lead	5.0 mg/l
Dissolved selenium	0.13 mg/l
Dissolved selenium in presence of >500 mg/l SO_4	0.25 mg/l
Dissolved vanadium	0.1 mg/l
Dissolved zinc	2.0 mg/l

E. Limited Warmwater Fishery: Standards are the same as for "Warmwater Fishery" except on a case by case basis, the dissolved oxygen may reach a minimum of 4.0 mg/l or maximum temperatures may exceed 32.2 C. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

F. Marginal Coldwater Fishery: Standards are the same as for "Coldwater Fishery" except on a case by case basis, the dissolved oxygen may reach a minimum of 5.0 mg/l or maximum temperatures may exceed 25 C and the pH may range from 6.6 to 9.0. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

G. Primary Contact Recreation: The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml, no single sample shall exceed 400/100 ml; the open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders; pH shall be within the range of 6.6 to 8.8; and turbidity shall be less than 25 NTU.

H. Warmwater Fishery: Un-ionized ammonia (as N) shall not exceed 0.06 mg/l, dissolved oxygen shall be greater than 5 mg/l, temperature shall be less than 32.2 C (90 F), and pH shall be within the range of 6.0 to 9.0 and total chlorine residual shall not exceed 0.008 mg/l. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

Table 6 (cont.): Standards applicable to designated uses, New Mexico

I. Fish culture and municipal and industrial water supply and storage are also designated in particular stream reaches where these uses are actually being realized. However, no numeric standards apply uniquely to these uses. Water quality adequate for these uses is ensured by the general standards and numeric standards for bacterial quality, pH, and temperature which are established for all stream reaches listed in Part 2 of the standards.

J. The following schedule of numeric standards and equations for the substances listed shall apply to the subcategories of fisheries identified in Section 3-101:

Chronic Criteria[3]

Dissolved aluminum	87.0	(10^{-3}) mg/l
Dissolved beryllium	5.3	(10^{-3}) mg/l
Total mercury	0.012	(10^{-3}) mg/l
Dissolved selenium	5.0	(10^{-3}) mg/l
Dissolved silver	0.12	(10^{-3}) mg/l
Total cyanide	5.2	(10^{-3}) mg/l
Total chlordane	0.0043	(10^{-3}) mg/l
Dissolved cadmium[5]	$e^{(0.7852[\ln(hardness)]-3.49)}$	(10^{-3}) mg/l
Dissolved chromium[6]	$e^{(0.819[\ln(hardness)]+1.561)}$	(10^{-3}) mg/l
Dissolved copper	$e^{(0.8545[\ln(hardness)]-1.465)}$	(10^{-3}) mg/l
Dissolved lead	$e^{(1.273[\ln(hardness)]-4.705)}$	(10^{-3}) mg/l
Dissolved nickel	$e^{(0.846[\ln(hardness)]+1.1645)}$	(10^{-3}) mg/l
Dissolved zinc	$e^{(0.8473[\ln(hardness)]+0.761)}$	(10^{-3}) mg/l

Acute Criteria[4]

Dissolved aluminum	750	(10^{-3}) mg/l
Dissolved beryllium	130	(10^{-3}) mg/l
Total mercury	2.4	(10^{-3}) mg/l
Dissolved selenium	20.0	(10^{-3}) mg/l
Dissolved silver	$e^{(1.72[\ln(hardness)]-6.52)}$	(10^{-3}) mg/l
Total cyanide	22.0	(10^{-3}) mg/l
Total chlordane	2.4	(10^{-3}) mg/l
Dissolved cadmium	$e^{(1.128[\ln(hardness)]-3.828)}$	(10^{-3}) mg/l
Dissolved chromium[6]	$e^{(0\ 819[\ln(hardness)]+3.688)}$	(10^{-3}) mg/l
Dissolved copper	$e^{(0.9422[\ln(hardness)]-1.464)}$	(10^{-3}) mg/l
Dissolved lead	$e^{(1.273[\ln(hardness)]-1.46)}$	(10^{-3}) mg/l
Dissolved nickel	$e^{(0.76[\ln(hardness)]+4.02)}$	(10^{-3}) mg/l
Dissolved zinc	$e^{(0.8473[\ln(hardness)]+8604)}$	(10^{-3}) mg/l

K. Livestock and Wildlife Watering: The following numeric standards shall not be exceeded:

Dissolved aluminum	5.0	mg/l
Dissolved arsenic	0.02	mg/l
Dissolved boron	5.0	mg/l
Dissolved cadmium	0.05	mg/l
Dissolved chromium[6]	1.0	mg/l
Dissolved cobalt	1.0	mg/l
Dissolved copper	0.5	mg/l
Dissolved lead	0.1	mg/l
Total mercury	0.01	mg/l
Dissolved selenium	0.05	mg/l
Dissolved vanadium	0.1	mg/l
Dissolved zinc	25.0	mg/l
Radium-226 + radium-228	30.0	pCi/l

[1]For waters with more than a single attainable or designated use the applicable criteria are those which will protect and sustain the most sensitive use.

[2]As the need arises, the State shall determine for specified stream segments or relevant portions thereof whether the limiting nutrient for the growth of aquatic plants is nitrogen or phosphorus. Upon such a determination the waters in question shall be exempt from the standard for the nutrient found to be not limiting. Until such a determination is made, standards for both nutrients shall apply. If co-limitation is found, the waters in question shall be exempt from the total inorganic nitrogen standard. The State shall make available a list of those waters for which the limiting nutrient has been determined.

[3]The chronic criteria shall be applied to the arithmetic mean of four samples collected on each of four consecutive days. Chronic criteria shall not be exceeded more than once every three years.

[4]The acute criteria shall be applied to any single grab sample. Acute criteria shall not be exceeded.

[5]For numeric standards dependent on hardness, hardness (as mg $CaCO_3$/l) shall be determined as needed from available verifiable data sources including, but not limited to, the U.S. Environmental Protection Agency's STORET water quality database.

[6]The criteria for chromium shall be applied to an analysis which measures both the trivalent and hexavalent ions.

Modified from New Mexico Water Quality Control Commission 1991

Table 7: Assessed river reaches not fully supporting designated uses, San Juan basin, New Mexico

Water Body (Basin, segment)	Uses Not Fully Supported (see Table 4a)	Probable Cause of Nonsupport	Toxics at Acute Levels*	Toxics at Chronic Levels*	Probable Sources of Nonsupport (see Table 4b)	Total Size Affected (Miles)
San Juan River from Canon Largo to Navajo Dam (San Juan River, 2-405)	HQCWF	Metals, turbidity, siltation, reduction of riparian vegetation, streambank destabilization		Hg	Agriculture (1500) Resource extraction (5500)	11 1
San Juan River from Chaco River to Animas River (San Juan River, 2-401)	MCWF, WWF	Metals, pesticides, siltation, salinity, reduction of riparian vegetation, streambank destabilization		Al	Agriculture (1200, 1500) Resource extraction (5500, 5900)	31 2
San Juan River from Animas River to Canon Largo (San Juan River, 2-401)	MCWF, WWF, IRR	Siltation, salinity, pathogens, reduction of riparian vegetation, streambank destabilization			Agriculture (1200, 1500) Resource extraction (5500)	26 0
San Juan River from New Mexico-Colorado border to Chaco River (San Juan River, 2-401)	MCWF, WWF, IRR	Metals, pesticides, pathogens, salinity, siltation, un-ionized ammonia, reduction of riparian vegetation, streambank destabilization		Ag, Hg, Cd, Al	Agriculture (1200, 1500) Resource extraction (5500)	33 4
Chaco River from mouth on the San Juan River to Chinle Wash (San Juan River, 2-401)	MCWF**, WWF**, L&WW	Metals, pH, siltation, dissolved oxygen		Pb, Se, Hg	Agriculture (1500) Resource extraction (5100, 5500, 5800)	18 9
Animas River from mouth on San Juan River to Estes Arroyo (San Juan River, 2-403)	MCWF, WWRF	Metals, total phosphorus, siltation		Ag, Hg, Al	Resource extraction (5500, 5800)	16 5
Animas River from Estes Arroyo to New Mexico-Colorado border (San Juan River, 2-404)	CWF	Temperature, siltation, reduction of riparian vegetation, streambank destabilization			Agriculture (1200, 1500) Resource extraction (5500)	19 9
La Plata River from mouth on the San Juan River to New Mexico-Colorado border (San Juan River, 2-402)	LWWF	Metals, nutrients, siltation, pathogens		Hg	Agriculture (1500) Resource extraction (5100, 5500, 5800)	24 7

* Conclusions concerning attainment of fishery uses are largely based on water quality analysis, where available, biological data are used to verify these results
** All toxins for which the EPA has prepared a 304(a) guidance document were reviewed as required by the EPA

Taken from New Mexico Water Quality Control Commission 1992

waters of the San Juan basin in New Mexico has fully supported uses. Agriculture and resource extraction activities are the most common sources of nonsupport, with metals and siltation as the most common causes of nonsupport (New Mexico Water Quality Control Commission 1992). The only San Juan basin lake whose uses are not fully supported is Navajo Reservoir (Table 8).

Colorado - Colorado has eight surface water use classifications, one of which is for wetlands (Table 9) (Colorado Water Quality Control Commission 1993a). All river and stream segments within the San Juan basin are designated fisheries with the exception of single segments along the Animas River, Cement Creek, and Mineral Creek.

Individual river basins in Colorado have their own surface water quality standards. The standards for the San Juan basin and the Dolores River basin are grouped together (Table 10) (Colorado Water Quality Control Commission 1993b). The significance of the Dolores River to the San Juan basin is discussed in Section 4.10.3. Standards pertaining to the entire state for organics (Table 11), physical and biological parameters (Table 12), inorganics (Table 13), and metals (Table 14) have also been promulgated (Colorado Water Quality Control Commission 1993a). All waters in the San Juan basin are subject to the following temperature standard: temperature shall maintain a normal pattern of diurnal and seasonal fluctuations with no abrupt changes and shall have no increase in temperature of magnitude, rate, and duration deemed deleterious to resident aquatic life (Colorado Water Quality Control Commission (1993b). In addition to the general standards set for the state and the San Juan basin, most segments within the basin have also been assigned standards specific to their designated uses. The segments, their classifications, and corresponding standards are listed by subbasin (Table 15) (Colorado Water Quality Control Commission 1993b).

The Colorado Water Quality Control Commission (1993b) warns that although none of the water quality standards are set below detectable limits, routine methodology may not achieve a low enough detection limit for certain parameters. This warning applies to several of the New Mexico and Utah standards as well, particularly for the more toxic parameters such as mercury and many of the organics.

The classifications for upstream segments of streams generally are the same or higher than downstream segments. In a few cases, tributaries have been assigned lower classifications than mainstems where flow from the tributaries does not threaten the mainstem water and the lower classification is appropriate (Colorado Water Quality Control Commission 1993b).

The three segments that have not been designated as fisheries are Segments 2, 6, and 7 of the Animas River basin (Table 15). The justification for the Segment 2 classification is that:

> Although there is some evidence of insect life at points in the segment, the evidence regarding the presence of aquatic life is contradictory, and there is no evidence of fish life being present. In the absence of sufficient data to support the classification of any portion of this segment for aquatic life, the current status is being retained and no aquatic life use is assigned.

The justification for the Segment 6 classification is that:

> Since Cement Creek and its tributaries are degraded by abandoned mine drainage and past discharges, the Commission did not assign aquatic and agricultural classifications to the segments as had been proposed. The segment does not currently have an aquatic life classification, and thus the status quo is maintained.

Table 8: Assessed lakes not fully supporting designated uses, San Juan basin, New Mexico

Water Body (Basin, segment) Evaluated or Monitored (E/M)	Trophic Status*	Uses Not Fully Supported or Uses Threatened** (see Table 4a)	Probable Cause of Nonsupport	Toxics at Acute Levels***	Toxics at Chronic Levels***	Probable Sources of Nonsupport (see Table 4b)	Total Size Affected (Acres)	Status of Support****
Navajo Reservoir (San Juan River, 2-406) M	OM	CWF, WWF	Metals, fish tissue mercury		Hg (fish)	Unknown (9000)	15,000	PS

* Trophic status based on Carlson trophic state index

** Conclusions concerning attainment of fishery uses are largely based on water quality analysis; where available, biological data are used to verify these results.

*** All toxins for which the EPA has prepared a 304(a) guidance document were reviewed as required by the EPA

**** Use support summary for assessed New Mexico lakes

FST = Fully supporting but threatened

PS = Partially supporting

NS = Not supporting

U = Unknown/lake of current data precludes adequate evaluation

Taken from New Mexico Water Quality Control Commission 1992

Table 9: Colorado surface water state use classifications

3.1.13 STATE USE CLASSIFICATIONS

Waters are classified according to the uses for which they are presently suitable or intended to become suitable. In addition to the classifications, one or more of the qualifying designations described in paragraph 3.1.13(2), may be appended. Classifications may be established for any state surface waters, except that water in ditches and other manmade conveyance structures shall not be classified.

(1) Classifications

(a) Recreation

(i) Class 1 - Primary Contact

These surface waters are suitable or intended to become suitable for recreational activities in or on the water when the ingestion of small quantities of water is likely to occur. Such waters include but are not limited to those used for swimming, rafting, kayaking and water-skiing.

(ii) Class 2 - Secondary Contact

These surface waters are suitable or intended to become suitable for recreational uses on or about the water which are not included in the primary contact subcategory, including but not limited to fishing and other streamside or lakeside recreation.

(b) Agriculture

These surface waters are suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock.

(c) Aquatic life

These surface waters presently support aquatic life uses as described below, or such uses may reasonably be expected in the future due to the suitability of present conditions, or the waters are intended to become suitable for such uses as a goal:

(i) Class 1 - Cold Water Aquatic Life

These are waters that (1) currently are capable of sustaining a wide variety of cold water biota, including sensitive species, or (2) could sustain such biota but for correctable water quality conditions. Waters shall be considered capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species.

Table 9 (cont.): Colorado surface water state use classifications

(i) Class 1 - Cold Water Aquatic Life

These are waters that (1) currently are capable of sustaining a wide variety of cold water biota, including sensitive species, or (2) could sustain such biota but for correctable water quality conditions. Waters shall be considered capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species.

(ii) Class 1 - Warm Water Aquatic Life

These are waters that (1) currently are capable of sustaining a wide variety of warm water biota, including sensitive species, or (2) could sustain such biota but for correctable water quality conditions. Waters shall be considered capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species.

(iii) Class 2 - Cold and Warm Water Aquatic Life

These are waters that are not capable of sustaining a wide variety of cold or warm water biota, including sensitive species, due to physical habitat, water flows or levels, or uncorrectable water quality conditions that result in substantial impairment of the abundance and diversity of species.

(d) Domestic Water Supply

These surface waters are suitable or intended to become suitable for potable water supplies. After receiving standard treatment (defined as coagulation, flocculation, sedimentation, filtration, and disinfection with chlorine or its equivalent) these waters will meet Colorado drinking water regulations and any revisions, amendments, or supplements thereto.

(e) Wetlands

(i) The provisions of this section do not apply to constructed wetlands.

(ii) Compensatory wetlands shall have, as a minimum, the classifications of the segment in which they are located.

Taken from Colorado Water Quality Control Commission 1993a

Table 10: Table value standards for the San Juan and Dolores River basins, Colorado

PARAMETER	TABLE VALUE STANDARDS[2][3] (in μg/l unless otherwise noted)
Ammonia	Cold Water Acute = 0.43/FT/FPH/2[4] in mg/l Warm Water Acute = 0.62/FT/FPH/2[4] in mg/l
Cadmium	Acute = $e^{(1.128[\ln(hardness)]-2.905)}$ Chronic = $e^{(0.7852[\ln(hardness)]-3.490)}$ (Trout) = $e^{(1.128[\ln(hardness)]-3.828)}$
Chromium III	Acute = $e^{(0.819[\ln(hardness)]+3.688)}$ Chronic = $e^{(0.819[\ln(hardness)]+1.561)}$
Chromium VI	Acute = 16 Chronic = 11
Copper	Acute = $e^{(0.9422[\ln(hardness)]-1.4634)}$ Chronic = $e^{(0.8545[\ln(hardness)]-1.465)}$
Lead	Acute = $e^{(1.6148[\ln(hardness)]-2.8736)}$ Chronic = $e^{(1.417[\ln(hardness)]-5.167)}$
Nickel	Acute = $e^{(0.76[\ln(hardness)]+3.33)}$ Chronic = $e^{(0.76[\ln(hardness)]+1.06)}$
Selenium	Acute = 135 Chronic = 17
Silver	Acute = $e^{(1.72[\ln(hardness)]-7.21)}$ Chronic = $e^{(1.72[\ln(hardness)]-9.06)}$ (Trout) = $e^{(1.72[\ln(hardness)]+10.51)}$
Uranium	Acute = $e^{(1\ 102[\ln(hardness)]+2.7088)}$ Chronic = $e^{(1.102[\ln(hardness)]+2.2382)}$
Zinc	Acute = $e^{(0.8473[\ln(hardness)]+0.8604)}$ Chronic = $e^{(0.8473[\ln(hardness)]+0.7614)}$

Taken from Colorado Water Quality Control Commission 1993b

Table 10 (cont.): Table value standards for the San Juan and Dolores River basins, Colorado

FOOTNOTES

(1) Metals are stated as dissolved unless otherwise specified.

(2) Hardness values to be used in equations are in mg/l as calcium carbonate. The hardness values used in calculating the appropriate metal standard should be based on the lower 95 per cent confidence limit of the mean hardness value at the periodic low flow criteria as determined from a regression analysis of site-specific data. Where insufficient site-specific data exists to define the mean hardness value at the periodic low flow criteria, representative regional data shall be used to perform the regression analysis. Where a regression analysis is not appropriate, a site-specific method should be used. In calculating a hardness value, regression analyses should not be extrapolated past the point that data exist.

(3) Both acute and chronic numbers adopted as stream standards are levels not to be exceeded more than once every three years on the average.

(4) $FT = 10^{.03\,(20-TCAP)}$;
<u>TCAP</u> less than or equal to <u>T</u> less than or equal to <u>30</u>

$FT = 10^{.03\,(20-T)}$;
<u>0</u> less or equal to <u>T</u> less than or equal to <u>TCAP</u>

TCAP = 20° C cold water aquatic life species present

TCAP = 25° C cold water aquatic life species absent

FPH = 1; <u>8</u> less than <u>pH</u> less than or equal to <u>9</u>

$FPH = \frac{1 + 10^{(7.4-pH)}}{1.25}$; <u>6.5</u> less than or equal to <u>pH</u> less than or equal to <u>8</u>

FPH means the acute pH adjustment factor; defined by the above formulas.

FT means the acute temperature adjustment factor, defined by the above formulas.

T means the temperature measured in degrees Celsius

TCAP means temperature CAP; the maximum temperature which affects the toxicity of ammonia to salmonid and non-salmonid fish groups.

NOTE: If the calculated acute value is less than the calculated chronic value, then the calculated chronic value shall be used as the acute standard.

Taken from Colorado Water Quality Control Commission 1993b

Table 11: Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute :	 Chronic	PQL[5]
Acenapthene 83-32-9	---	---	1,700	520	10
Acenapthylene (PAH) 208-96-8	---	0.0028	---	---	10
Acrolein 107-02-8	---	320	68	21	10
Acrylonitrile[C] 107-13-1	---	0.058	7,500	2,600	5
Aldicarb 116-06-3	10	---	---	---	10**
Aldrin[C] 309-00-2	0.002	0.00013	1.5	---	0.1*
Anthracene (PAH) 120-12-7	---	0.0028	---	---	1.0*
Benzene[C] 71-43-2	1.0	1.0	5,300	---	1.0*
Benzidine[C] 92-87-5	0.0002	0.00012	2,500	---	10
Benzo(a)anthracene (PAH)[C] 56-55-3	---	0.0028	---	---	10
Benzo(a)pyrene (PAH)[C] 50-32-8	---	0.0028	---	---	10
Benzo(b)fluoranthene (PAH)[C] 205-99-2	---	0.0028	---	---	10
Benzo(k)fluoranthene (PAH)[C] 207-08-9	---	0.0028	---	---	10
Benzo(g,h,i)perylene (PAH) 191-24-2	---	0.0028	---	---	10
BHC Hexachlorocyclohexane 608-73-1	---	---	100	---	0.05*
Bromodichloromethane (HM) 75-27-4	0.3	0.3	---	---	1.0

Table 11 (cont.): Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute :	 Chronic	 PQL[5]
Bromoform (HM)[C] 75-25-2	4	4	---	---	1.0
Butyl benzyl phthalate 85-68-7	---	3000	---	---	10
Carbofuran 1563-66-2	36	---	---	---	
Carbon tetrachloride[C] 56-23-5	0.3	0.25	35,200	---	1.0*
Chlordane[C] 57-74-9	0.03	0.00058	1.2	0.0043	1.0
Chlorethyl ether (BIS-2) 111-44-4	0.03	0.03	---	---	10
Chlorobenzene 108-90-7	100	100	---	---	1.0
Chloroform (HM)[C] 67-66-3	6	6	28,900	1,240	1.0
Chloroisopropyl ether (BIS-2) 39638-32-9	---	1,400			10
4-Chloro-3-methylphenol 59-50-7	---	---	30	---	50
Chlorophenol 2 95-57-2	---	---	4,380	2,000	50
Chloropyrifos 2921-88-2	---	---	0.083	0.041	0.1*
Chrysene (PAH) 218-01-9	---	0.0028	---	---	10
DDD[C] 72-54-8	---	0.00083	0.6	---	0.1*
DDE[C] 72-55-9	0.1	0.00059	1,050	---	0.1*
DDT[C] 50-29-3	0.1	0.00059	0.55	0.001	0.1*

Table 11 (cont.): Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute :	 Chronic	PQL[5]
Demeton 8065-48-3	---	---	---	0.1	1.0*
Dibenzo(a,h)anthracene (PAH) 50-70-3	---	0.0028	---	---	10
Dibromochloromethane (HM) 124-48-1	14	6	---	---	1.0
Dichlorobenzene 1,2 95-50-1	620	620	---	---	1.0
Dichlorobenzene 1,3 541-73-1	620	400	---	---	1.0
Dichlorobenzene 1,4 106-37-6	75[M]	75	---	---	1.0
Dichlorobenzidine[C] 91-94-1	---	0.039	---	---	10
Dichloroethane 1,2[C] 107-06-2	0.4	0.4	118,000	20,000	1.0
Dichloroethylene 1,1 75-35-4	7	0.057	---	---	1.0*
Dichloroethylene 1,2-cis 156-59-2	70	---	---	---	1.0
Dichloroethylene 1,2-trans 156-60-5	100	---	---	---	1.0
Dichlorophenol 2,4 120-83-2	21	21	2,020	365	50
Dichlorophenoxyacetic acid (2,4-D) 94-75-7	70	---	---	---	1.0
Dichloropropane 1,2[C] 78-87-5	0.56	0.56	23,000	57,000	1.0
Dichloropropylene 1,3 542-75-6	---	10	6,060	244	1.0*
Dieldrin[C] 60-57-1	0.002	0.00014	1.3	0.0019	0.1*

Table 11 (cont.): Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute :	 Chronic	PQL[5]
Diethyl phthalate 84-66-2	---	23,000	---	---	10
Dimethylphenol 2,4 105-67-9	---	---	2,120	---	50
Demethyl phthalate 131-11-3	---	313,000	---	---	10
Di-n-butyl phthalate 84-74-2	---	2,700	---	---	10
Dinitrophenol 2,4 51-28-5	14	14	---	---	50
Dinitro-o-cresole 4,6 534-52-1	---	13	---	---	50
Dinitrotoluene 2,4 121-14-2	---	0.11	---	---	10
Dinitrotoluene 2,6 606-20-2	---	---	330	230	10
Dioxin (2,3,7,8 TCDD)[C] 1746-01-6	$2.2x10^{-7}$	$1.3x10^{-8}$	0.01	0.00001	
Diphenylhydrazine 1,2[C] 122-66-7	0.05	0.04	270	---	
Endosulfan 115-29-7	---	0.93	0.11	0.056	0.1*
Endosulfan sulfate 1031-07-8	---	0.93	---	---	0.1*
Endrin 72-20-8	0.2	---	0.09	0 0023	0.1*
Endrin aldehyde 7421-93-4	0.2[M]	0.2	---	---	0.1
Ethylbenzene 100-41-4	680	3,100	32,000	---	1.0
Ethylhexyl pthalate (BIS-2)[C] 117-81-7	---	1.8	---	---	10

Table 11 (cont.): Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute :	 Chronic	PQL[5]
Fluoranthene (PAH) 206-44-0	---	42	3,980	---	10
Fluorene (PAH) 86-73-7	---	0.0028	---	---	10
Guthion 86-50-0	---	---	---	0.01	1.5
Heptachlor[C] 76-44-8	0.008	0.00021	0.26	0.0038	0.05*
Heptachlor epoxide[C] 1024-57-3	0.09	0.0001	0.26	0.0038	0.05*
Hexachlorobenzene[C] 118-74-1	6	0.00072	---	---	10
Hexachlorobutadiene 87-68-3	1.0	0.45	90	9.3	10
Hexachlorocyclohexane, Alpha[C] 319-84-6	0.006	---	0.0039	---	0.05*
Hexachlorocyclohexane, Beta 319-85-7	---	0.014	---	---	0.05*
Hexachlorocyclohexane, Gamma (Lindane) 58-89-9	0.2	0.019	1.0	0.08	0.05*
Hexachlorocyclohexane, Technical[C] 608-73-1	---	0.012	---	---	0.2*
Hexachlorocyclopentadiene 77-47-4	---	240	7	5	10
Hexachloroethane 67-72-1	---	1.9	980	540	10
Ideno(1,2,3-cd)pyrene(PAH)[C] 193-39-5	---	0.0028	---	---	10
Isophorone 78-59-1	1,050	8.4	117,000	---	10
Malathion 121-75-4	---	---	---	0.1	0.2*

Table 11 (cont.): Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute	 Chronic	PQL[5]
Methoxychlor 72-43-5	40	---		0.03	0.5*
Methyl bromide (HM) 74-83-9	---	48	---	---	1.0
Methyl chloride (HM)[C] 74-87-3	---	5.7	---	---	1.0
Methylene chloride (HM)[C] 75-09-2	---	4.7	---	---	1.0
Mirex 2385-85-5	---	---	---	0.001	0 1*
Naphthalene (PAH) 91-20-3	---	0.0028	2,300	620	10
Nitrobenzene 98-95-3	3.5	3.5	27,000	---	10
Nitrosodibutylamine N	---	0.0064	---	---	10
Nitrosodiethylamine N	---	0.0008	---	---	10
Nitrosodimethylamine N[C] 62-75-9	---	0.00069	---	---	10
Nitrosodiphenylamine N[C] 86-30-6	---	4.9	---	---	10
Nitrosopyrrolidine N	---	0.016	---	---	10
N-Nitrosodi-n-propylamine[C] 621-64-7	---	0.005	---	---	10
PCBs[C] 1336-36-3	0.005	0.000044	2.0	0.014	1.0
Pentachlorobenzene 608-93-5	6	---	---	---	10
Pentachlorophenol[C] 87-86-5	200	---	9[6]	5.7[6]	50
Phenanthrene (PAH) 85-01-8	---	0.0028	---	---	10

Table 11 (cont.): Basic standards for organic chemicals, Colorado

Parameter CAS No.	Human Health Based[1] Water Supply[2]	 Water + Fish[3]	Aquatic Life Based[4] Acute :	 Chronic	PQL[5]
Phenol 108-95-2	---	21,000	10,200	2,560	50
Pyrene (PAH) 129-00-0	---	0.0028	---	---	10
Tetrachlorobenzene 1,2,4-5 95-94-3	2	---	---	---	10
Tetrachloroethane 1,1,2,2[C] 79-34-5	---	0.17	---	2,400	1.0*
Tetrachloroethylene 127-18-4	5	0 8	5,280	840	1.0*
Toluene 108-88-3	1,000	1,000	17,500	---	1.0
Toxaphene[C] 8001-35-2	0.03	0.00073	0.73	0.0002	5.0
Trichloroethane 1,1,1 71-55-6	200	200	---	---	1 0
Trichloroethane 1,1,2 79-00-5	3	0.6	9,400	---	1.0
Trichloroethylene[C] 79-01-6	5	2.7	45,000	21,900	1.0
Trichlorophenol 2,4,6[C] 88-06-2	2	2	---	970	50
Trichlorophenoxyproprionic acid (2,4,5-tp) 93-72-1	50	---	---	---	0.5
Vinyl Chloride[C] 75-01-4	2[M]	2	---	---	2

Taken from Colorado Water Quality Control Commission 1993a

Table 11 (cont.): Basic standards for organic chemicals, Colorado

[1] All standards are chronic or 30-day standards. They are based on information contained in EPA's Integrated Risk Information System (IRIS) and/or EPA lifetime health advisories for drinking water using a 10^{-6} incremental risk factor unless otherwise noted.

[2] Only applicable to segments classified for water supply.

[3] Applicable to all Class 1 aquatic life segments or Class 2 aquatic life segments designated by the Commission after rulemaking hearing.

[4] Applicable to all aquatic life segments.

[5] PQL's are detection levels based on the Colorado Department of Health's laboratories best judgement for Gas Chromotography/Mass Spectrophotometry (GC/MS) unless otherwise noted.

[6] Standards are pH dependent. Those listed are calculated for pH =7.0. Acute = $e^{[1.005(pH)-4.83]}$; Chronic = $e^{[1.005(pH)-5.29]}$.

[C] Carcinogens classified by the EPA as A, B1, or B2.

[D] Total trihalomethanes are considered the sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane (bromoform) and trichloromethane (chloroform).

[M] Drinking water MCL

* Gas Chromotrography (GC) PQL

** High Pressure Liquid Chromotography (HPLC) PQL

CAS No. - Chemical Abstracts Service Registry Number

(HM) - Halomethanes

(PAH) - Polymer Aromatic Hydrocarbons

Taken from Colorado Water Quality Control Commission 1993a

Table 12: Physical and biological parameters, Colorado

Parameter	Recreational: Class 1 Primary Contact	Recreational: Class 2 Secondary Contact	Aquatic Life: Class 1 Cold Water Biota	Aquatic Life: Class 1 Warm Water Biota	Aquatic Life: Class 2	Agriculture	Domestic Water Supply
D.O. (mg/l)(1)(8)	3 0	3 0	6 0(2) 7 0 (spawning)	5 0	*	3 0	3.0
pH (Std. Units)(3)	6.5-9.0		6 5-9.0	6.5-9 0	*		5 0-9.0
Suspended Solids(4)							
Temperature (C)			Max 20 C, with 3 C Increase(5)	Max 30 C, with 3 C Increase(5)	*		
Fecal Coliforms per 100 ml (Geometric Mean)	200(6)	2000(6)			*		2000

* To be established on a case-by-case basis

(1) Standards for dissolved oxygen are 1-day minima, unless specified otherwise For the purposes of permitting, dissolved oxygen may be modeled for average conditions of temperature and flow for the worst case time period Where dissolved oxygen levels less than these levels occur naturally, a discharge shall not cause a further reduction in dissolved oxygen in receiving water

(2) A 7.0 mg/liter standard (minimum), during periods of spawning of cold water fish, shall be set on a case-by-case basis as defined in the NPDES permit for those dischargers whose effluent would affect fish spawning

(3) The pH standards of 6.5 (or 5 0) and 9 0 are an instantaneous minimum and maximum, respectively to be applied as effluent limits

(4) Suspended solid levels will be controlled by Effluent Limitation Regulations, Basic Standards, and Best Management Practices (BMPs)

(5) Temperature shall maintain a normal pattern of diurnal and seasonal fluctuations with no abrupt changes and shall have no increase in temperature of a magnitude, rate, and duration deemed deleterious to the resident aquatic life Generally, a maximum 3 degrees Celsius increase over a minimum of a four-hour period, lasting for 12 hours maximum, is deemed acceptable for dischargers fluctuating in volume or temperature. Where temperature increases cannot be maintained within this range using BMP, BATEA and BPWTT control measures, the Division will determine whether the resulting temperature increases preclude an aquatic life classification

(6) Fecal coliform is an indicator only. It may indicate the presence of pathogenic organisms, however, fecal coliform counts from agriculture or urban runoff may not indicate organisms detrimental to human health. The bacteria standard is based on the geometric mean of representative stream samples

(7) For drinking water with or without disinfection

(8) The dissolved oxygen criteria is intended to apply to the epilimnion and metalimnion strata of lakes and reservoirs Dissolved oxygen in the hypolimnion may, due to the natural conditions, be less than the table criteria No reductions in dissolved oxygen levels due to controllable sources is allowed

Taken from Colorado Water Quality Control Commission 1993a

Table 13: Inorganic parameters for designated uses, Colorado

PARAMETER	AQUATIC LIFE CLASS 1 Cold Water Biota	AQUATIC LIFE CLASS 1 Warm Water Biota	AQUATIC LIFE CLASS 2	AGRICULTURE	DOMESTIC WATER SUPPLY
Ammonia (mg/l as N) (Un-ionized unless otherwise noted)	chronic = 0.2 acute = 0.43/FT/FPH/2[4]	chronic = 0.06 acute = 0.62/FT/FPH/2[4]	acute: see [1] chronic: Cold = 0.02 Warm = 0.06-0.10[1]		0.5 total[2] (30-day)
Total residual chlorine (mg/l)	0.019 (1-day) 0.011 (30-day)	0.019 (1-day) 0.011 (30-day)			
Cyanide - Free (mg/l)	0.005 (1-day)	0.005 (1-day)		0.2 (1-day)	0.2 (1-day)
Fluoride (mg/l)					2.0[5] (1-day)
Nitrate (mg/l as N)				100[3]	10[6] (1-day)
Nitrite (mg/l as N)	*(5)	*(5)		10[3] (1-day)	1.0[2][6] (1-day)
Sulfide as H_2S (mg/l)	0.002 undisassociated (30-day)	0.002 undisassociated (30-day)			0.5 (30-day)
Boron (mg/l)				0.75 (30-day)	
Chloride (mg/l)					250 (30-day)
Sulfate (mg/l)					250 (30-day)
Asbestos					30,000 fibers/l

* To be established on a case-by case basis

Taken from Colorado Water Quality Control Commission 1993a

Table 13 (cont.): Inorganic parameters for designated uses, Colorado

(1) For class 2 warm water aquatic life segments, where table value standards are to be applied, a specific chronic standard in the 0.06 to 0.10 mg/l range for un-ionized ammonia shall be selected based upon the aquatic life present or to be protected and whether the waters have been adversely impacted by factors other than ammonia. The Commission may consider a standard higher than 0.08 mg/l un-ionized ammonia where a higher risk of sublethal effects is justified by habitat limitations or other water quality factors. Where a site-specific study has been conducted, the Commission may apply appropriate alternative chronic standards in accordance with section 3.1.7(1)(b)(iii). Acute standards for cold and warm water class 2 segments generally shall be established at the respective levels listed in table 13 for class 1 segments, except where site-specific information submitted justifies an alternative acute standard.

(2) To be applied at the point of water supply intake.

(3) In order to provide a reasonable margin of safety to allow for unusual situations such as extremely high water ingestion or nitrite formation in slurries, the NO_3-N plus NO_2-N content in drinking waters for livestock and poultry should be limited to 100 ppm or less, and the NO_2-N content alone be limited to 10 ppm or less.

(4) $FT = 10^{0.03\,(20-TCAP)}$;
TCAP less than or equal to T less than or equal to 30

$FT = 10^{0.03\,(20-T)}$;
0 less or equal to T less than or equal to TCAP

TCAP = 20° C cold water aquatic life species present

TCAP = 25° C cold water aquatic life species absent

FPH = 1; 8 less than pH less than or equal to 9

$FPH = \frac{1 + 10^{(7.4-pH)}}{1.25}$; 6.5 less than or equal to pH less than or equal to 8

FPH means the acute pH adjustment factor; defined by the above formulas.

FT means the acute temperature adjustment factor, defined by the above formulas.

T means the temperature measured in degrees Celsius

TCAP means temperature CAP; the maximum temperature which affects the toxicity of ammonia to salmonid and non-salmonid fish groups.

NOTE: If the calculated acute value is less than the calculated chronic value, then the calculated chronic value shall be used as the acute standard.

(5) Salmonids and other sensitive fish species present:

Acute = 0.10 (0.59 * [Cl^-] +3.90) mg/l NO_2-N
Chronic = 0.10 (0.29 * [Cl^-] +0.53) mg/l NO_2-N
(upper limit for Cl^- = 40 mg/l)

Salmonids and other sensitive fish species absent:

Acute = 0.20 (2.00 * [Cl^-] +0.73) mg/l NO_2-N
Chronic = 0.10 (2.00 * [Cl^-] +0.73) mg/l NO_2-N
(upper limit for Cl^- = 22 mg/l)

[Cl^-] = Chloride ion concentration

(6) A combined total of nitrite and nitrate at the point of intake to the domestic water supply shall not exceed 10 mg/l.

Taken from Colorado Water Quality Control Commission 1993a

Table 14: Metal parameters for designated uses, Colorado (in μg/l)

METAL(1)	AQUATIC LIFE(1)(3)(4)	AGRICULTURE(2)	DRINKING WATER SUPPLY(2)
Aluminum	Acute = 750 Chronic = 87		
Antimony			14 (30-day)
Arsenic	Acute = 360 Chronic = 150	100 (30-day)	50 (1-day)
Barium			1,000 (1-day)
Beryllium		100 (30-day)	0.0076 (30-day)
Cadmium	Acute = $e^{(1.28[\ln(\text{hardness})]-2.905)}$ (Trout) = $e^{(1.28[\ln(\text{hardness})]-3.828)}$ Chronic = $e^{(0.7852[\ln(\text{hardness})]-3.490)}$	10 (30-day)	10 (1-day)
Chromium III(5)	Acute = $e^{(0.819[\ln(\text{hardness})]+3.688)}$ Chronic = $e^{(0.819[\ln(\text{hardness})]+1\ 561)}$	100 (30-day)	50 (1-day)
Chromium VI(5)	Acute = 16 Chronic = 11	100 (30-day)	50 (1-day)
Copper	Acute = $\frac{1}{2}e^{(0.9422[\ln(\text{hardness})]-0.7703)}$ Chronic = $e^{(0.8545[\ln(\text{hardness})]-1.465)}$	200	1,000 (30-day)
Iron	Chronic = 1,000 (tot rec.)		300 (dis) (30-day)
Lead	Acute = $\frac{1}{2}e^{(1.6148[\ln(\text{hardness})]-2.1805)}$ Chronic = $e^{(1.417[\ln(\text{hardness})]-5.167)}$	100 (30-day)	50 (1-day)
Manganese	Chronic = 1,000	200 (30-day)	50 (dis) (30-day)
Mercury	Acute = 2.4 Chronic = 0.1 FRV (fish)(6) = 0.01 (Total)		2.0 (1-day)
Nickel	Acute = $\frac{1}{2}e^{(0.76[\ln(\text{hardness})]+4.02)}$ Chronic = $e^{(0.76[\ln(\text{hardness})]+1.06)}$	200 (30-day)	
Selenium	Acute = 135 Chronic = 17	20 (30-day)	10 (30-day)
Silver	Acute = $\frac{1}{2}e^{(1.72[\ln(\text{hardness})]-6.52)}$ Chronic = $e^{(1.72[\ln(\text{hardness})]-9.06)}$ (Trout) = $e^{(1.72[\ln(\text{hardness})]-10.51)}$		50 (1-day)
Thallium	Chronic = 15		0.012 (30-day)
Uranium	Acute = $e^{(1.1021[\ln(\text{hardness})]+2.7088)}$ Chronic = $e^{(1.1021[\ln(\text{hardness})]+2.2382)}$		
Zinc	Acute = $e^{(0.8473[\ln(\text{hardness})]+0.8604)}$ Chronic = $e^{(0.8473[\ln(\text{hardness})]+0.7614)}$	2000 (30-day)	5000 (30-day)

Taken from Colorado Water Quality Control Commission 1993a

Table 14 (cont.): Metal parameters for designated uses, Colorado (in μg/l)

(1) Metals for aquatic life use are stated as dissolved unless otherwise specified.

(2) Metals for agricultural and domestic uses are stated as total recoverable unless otherwise specified.

(3) Hardness values to be used in equations are in mg/l as calcium carbonate. The hardness values used in calculating the appropriate metal standard should be based on the lower 95 percent confidence limit of the mean hardness value at the periodic low flow criteria as determined from a regression analysis of site-specific data. Where insufficient site-specific data exists to define the mean hardness value at the periodic low flow criteria, representative regional data shall be used to perform the regression analysis. Where a regression analysis is not appropriate, a site-specific method should be used. In calculating a hardness value, regression analyses should not be extrapolated past the point that data exist.

(4) Both acute and chronic numbers adopted as stream standards are levels not to be exceeded more than once every three years on the average.

(5) Unless the stability of the chromium valence state in receiving waters can be clearly demonstrated, the standard for chromium should be in terms of chromium VI. In no case can the sum of the instream levels of Hexavalent and Trivalent Chromium exceed the water supply standard of 50 μg/l total chromium in those waters classified for domestic water use.

(6) FRV means Final Residue Value and should be expressed as "Total" because many forms of mercury are readily converted to toxic forms under natural conditions. The FRV value of 0.01 μg/l is the maximum allowed concentration of total mercury in the water that will present bioconcentration or bioaccumulation of methylmercury in edible fish tissue at the U.S. Food and Drug Administration's (FDA) action level of 1 ppm. The FDA action level is intended to protect the average consumer of commercial fish; it is not stratified for sensitive populations who may regularly eat fish.

A 1990 health risk assessment conducted by the Colorado Department of Health indicates that when sensitive subpopulations are considered, methylmercury levels, in sport-caught fish as much as one-fifth lower (0.2 ppm) than the FDA level may pose a health risk.

In waters supporting populations of fish or shellfish with a potential for human consumption, the Commission can adopt the FRV as the stream standard to be applied as a 30-day average. Alternatively, the Commission can adopt site-specific ambient based standards for mercury in accordance with Section 3.1.7(1)(b)(ii) and (iii). When this option is selected by a proponent for a particular segment, information must be presented that (1) ambient water concentrations of total mercury are detectable and exceed the FRV, (2) that there are detectable levels of mercury in the proponent's discharge and that are contributing to the ambient levels and (3) that concentrations of methylmercury in the fish exposed to these ambient levels do not exceed the maximum levels suggested in the CDH Health Advisory for sensitive populations of humans. Alternatively or in addition the proponent may submit information showing that human consumption of fish from the particular segment is not occurring at a level which poses a risk to the general population and/or sensitive populations.

Taken from Colorado Water Quality Control Commission 1993a

Table 15· Stream classifications and water quality standards, Colorado

Basin: San Juan River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l	Metals µg/l	Temporary Modifications Qualifiers
1. Mainstem of the Navajo River and the Little Navajo River, including all tributaries, lakes, and reservoirs, from the boundary of the South San Juan Wilderness Area to the San Juan-Chama diversion.		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7 0 mg/l pH = 6.5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0.005 S = 0.002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
2 Mainstem of the Navajo River from the San Juan-Chama diversion to the Colorado/New Mexico border near Edith, Colorado and from the Colorado/New Mexico border to the confluence with the San Juan River		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6.0 mg/l D O (sp) = 7.0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0.011 CN = 0 005 S = 0 002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ch) = 50 Cd (ch) = 0.4 CrIII (ch) = 50 CrVI (ch) = 25 Cu (ch) = 14 Fe (ch) = 300 (dis) Fe (ch) = 1200 (Trec) Pb (ch) = 5 Mn (ch) = 50 (dis) Mn (ch) = 1000 Hg (ch) = 0 05 Ni (ch) = 50 Se (ch) = 10 Ag (ch) = 0.1 Zn (ch) = 50	All metals are Trec unless otherwise noted.
3 Mainstem of the Little Navajo River from the San Juan-Chama diversion to the confluence with the Navajo River, all tributaries to the Navajo River and the Little Navajo River, including all lakes and reservoirs, from the San Juan-Chama diversions to the confluence with the San Juan River	UP	Aq Life Warm 2 Recreation 2 Agriculture	D O = 5 0 mg/l pH = 6.5-9.0 F. Coli = 2000/100 ml			
4 All tributaries to the San Juan River, Rio Blanco, and Navajo River including all lakes and reservoirs, which are within the Weminuche Wilderness area and South San Juan Wilderness Area		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
5 Mainstem of the San Juan River and the East Fork and West Fork of the San Juan River, from the boundary of the Weminuche Wilderness Area (West Fork) and the source (East Fork) to the confluence with Fourmile Creek, including all tributaries, lakes and reservoirs except for tributaries, lakes and reservoirs included in Segment 4		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.011 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: San Juan River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l	Metals µg/l	Temporary Modifications Qualifiers
6. Mainstem of the San Juan River from the confluence with Fourmile Creek to Navajo Reservoir		Aq Life Cold 1 Recreation 1 Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7 0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0.005 S = 0.002 B = 0.75 NO_2 = 0.05 NO_3 = 100	As (ch) = 50 Cd (ch) = 0.4 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) = 20 Fe (ch) = 2400 Pb (ch) = 10 Mn (ch) = 1000 Hg (ch) = 50 Ni (ch) = 50 Se (ch) = 20 Ag (ch) = 0 1 Zn (ch) = 50	All metals are Trec unless otherwise noted
7 Navajo Reservoir (portion in Colorado)		Aq Life Warm 1 Recreation 1 Water Supply Agriculture	D O. = 5 0 mg/l pH = 6.5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 5 NO_3 = 10 Cl = 250 SO_4 = 250	As (ch) = 50 Cd (ch) = 0.4 CrIII (ch) = 50 CrVI (ch) = 25 Cu (ch) = 5 Fe (ch) = 300 (dis) Fe (ch) = 1000 Pb (ch) = 4 Mn (ch) = 50 (dis) Mn (ch) = 1000 Hg (ch) = 0.05 Ni (ch) = 50 Se (ch) = 10 Ag (ch) = 0 1 Zn (ch) = 50	All metals are Trec unless otherwise noted
9 Mainstem of the Rio Blanco, including all tributaries, lakes, and reservoirs, from the boundary of South San Juan Wilderness Area to the confluence with the San Juan River, except for the specific listing in Segment 10		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6.0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
10 Mainstem of the Rito Blanco River from Echo Ditch to the confluence with the Rio Blanco River.	UP	Aq Life Cold 2 Recreation 2 Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml			
11 All tributaries to the San Juan River in Archuleta County, including all lakes and reservoirs, except for specific listings in Segments 1, 4, 5, and 9	UP	Aq Life Warm 2 Recreation 2 Agriculture	D O = 5 0 mg/l pH = 6 5-9.0 F Coli = 2000/100ml			

Table 15 (CONT). Stream classifications and water quality standards, Colorado

Basin: Piedra River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l	Metals µg/l	Temporary Modifications Qualifiers
1. All tributaries to the Piedra River, including all lakes and reservoirs, which are within the Weminuche Wilderness Area		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7.0 mg/l pH = 6.5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0.005 S = 0.002 B = 0 75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
2 Mainstem of the Piedra River, including the East and Middle Forks, from the boundary of the Weminuche Wilderness Area to the confluence with Indian Creek, except for the specific listing in Segment 3		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O. = 6.0 mg/l D.O. (sp) = 7.0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0.005 S = 0 002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
3 Mainstem of the East Fork of the Piedra River from the Piedra Falls Ditch to the confluence with Pagosa Creek.		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7.0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0.005 S = 0.002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
4 Mainstem of the Piedra River from the confluence with Indian Creek to Navajo Reservoir		Aq Life Cold 1 Recreation 1 Agriculture	D.O. = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 100	As (ch) = 50 Cd (ch) = 0.4 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) =16 Fe (ch) = 1500 Pb (ch) = 4 Mn (ch) = 1000 Hg (ch) = 0 05 Ni (ch) = 50 Se (ch) = 20 Ag (ch) = 0 1 Zn (ch) = 50	All metals are Trec unless otherwise noted
5 All tributaries to the Piedra River, including all lakes and reservoirs, from the boundary of the Weminuche Wilderness Area to a point immediately below the confluence with Devil Creek		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7.0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
6 All tributaries to the Piedra River, including all lakes and reservoirs, from a point immediately below the confluence with Devil Creek to Navajo Reservoir, except for the specific listings in Segment 7	UP	Aq Life Warm 2 Recreation 2 Agriculture	D O = 5 0 mg/l pH = 6 5-9 0 F. Coli = 2000/100ml			

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: Piedra River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l		Metals µg/l			Temporary Modifications Qualifiers
7 "Hatcher Lake, Stevens Lake, Pagosa Lake, Village Lake and Forest Lake "	UP	Aq Life Warm 1 Recreation 2 Water Supply Agriculture	D.O. = 5 0 mg/l pH = 6.5-9.0 F Coli = 2000/100ml	NH_3 (ac) = TVS NH_3 (ch) = 0.06 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0 005	S = 0.002 B = 0 25 NO_2 = 0.5 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac/ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac/ch) = TVS Zn (ac/ch) = TVS	

Basin Los Pinos River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l		Metals µg/l			Temporary Modifications Qualifiers
1 All tributaries to the Los Pinos River, including all lakes and reservoirs, which are within the Weminuche Wilderness Area		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6.0 mg/l D.O (sp) = 7.0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0 005	S = 0.002 B = 0 75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
2a Mainstem of the Los Pinos River from the boundary of the Weminuche Wilderness Area to the U.S Hwy 160 except for the specific listing in Segment 3		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0 005	S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
2b Mainstem of the Los Pinos River from U S Hwy 160 to the Colorado/ New Mexico border.		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005	S = 0 002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
3 Vallecito Reservoir		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0 011 CN = 0.005	S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: Los Pinos River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l	Metals µg/l	Temporary Modifications *Qualifiers*
4. *All tributaries to the Los Pinos River* and Vallecito Reservoir, including all lakes and reservoirs, from the boundary of the Weminuche Wilderness Area to the confluence with Bear Creek (T35N, R7W), except for the specific listing in Segment 5, mainstems of Beaver Creek, Ute Creek, Ute Creek, and Spring Creek from their sources to their confluences with the Los Pinos River.		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O. = 6.0 mg/l D.O. (sp) = 7.0 mg/l pH = 6.5-9.0 F. Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0 011 CN = 0.005 S = 0.002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
5. Mainstem of Vallecito Creek from the boundary of the Weminuche Wilderness Area to Vallecito Reservoir		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O = 6 0 mg/l D.O (sp) = 7.0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = 1 CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
6 All tributaries to the Los Pinos River, including all lakes and reservoirs, *from a point immediately* below the confluence with Bear Creek (T35N, R7W) to the Colorado/ New Mexico border, except for the the specific listing in Segment 4, all tributaries to the San Juan River River in La Plata County	UP	Aq Life Cold 2 Recreation 2 Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 2000/100 ml			

Table 15 (CONT). Stream classifications and water quality standards, Colorado

Basin: Animas and Florida River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l		Metals µg/l			Temporary Modifications Qualifiers
1. All tributaries to the Animas River and Florida River, including all lakes and reservoirs, which are within the Weminuche Wilderness Area.		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O = 6.0 mg/l D O. (sp) = 7.0 mg/l pH = 6.5-9 0 F. Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0 005	S = 0.002 B = 0.75 NO_2 = 0.5 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
2 Mainstem of the Animas River, including all tributaries, from the source to a point immediately above the confluence with Elk Creek, except for specific listings in Segments 1 and 5 through 8a and 8b.		Recreation 2	pH = 6.5-9.0 F Coli = 2000/100 ml						
3 Mainstem of the Animas River from a point immediately above the confluence with Elk Creek to the confluence with Junction Creek.	UP	Aq Life Cold 1 Recreation 2 Water Supply Agriculture	D O = 6 0 mg/l D.O. (sp) = 7 0 mg/l pH = 6.5-9.0 F. Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005	S = 0 002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ch) = 50 Cd (ch) = 0.5 CrIII (ch) = 50 CrVI (ch) = 25 Cu (ch) = 35	Fe (ch) = 300 (dis) Fe (ch) = 1150 Pb (ch) = 43 Mn (ch) = 50 (dis) Mn (ch) = 1000	Hg (ch) = 0.05 Ni (ch) = 50 Se (ch) = 10 Ag (ch) = 0 1 Zn (ch) = 470	All metals are Trec unless otherwise noted.
4 Mainstem of the Animas River from the confluence with Junction Creek to the Colorado/New Mexico border.	UP	Aq Life Cold 1 Recreation 2 Water Supply Agriculture	D O = 6.0 mg/l D O. (sp) = 7 0 mg/l pH = 6.5-9 0 F. Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005	S = 0 002 B = 0.75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ch) = 50 Cd (ch) =1 CrIII (ch) = 50 CrVI (ch) = 25 Cu (ch) = 20	Fe (ch) = 300 (dis) Fe (ch) = 1500 Pb (ch) = 55 Mn (ch) = 50 (dis) Mn (ch) = 1000	Hg (ch) = 0 05 Ni (ch) = 100 Se (ch) = 10 Ag (ch) = 0 1 Zn (ch) = 150	All metals are Trec unless otherwise noted.

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: Animas and Florida River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l	Metals µg/l	Temporary Modifications Qualifiers
5. Mainstem, including all tributaries, lakes and reservoirs, of Cinnamon Creek, Grouse Creek, Picayne Gulch, Minnie Gulch, Maggie Gulch, Cunningham Creek, Boulder Creek, Whitehead Gulch, and Molas Creek from their sources to their confluences with the Animas River.		Aq Life Cold 1 Recreation 2 Water Supply Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7 0 mg/l pH = 6.5-9.0 F Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0.005 S = 0 002 B = 0.75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
6. Mainstem of Cement Creek, including all tributaries, lakes and reservoirs, from the source to the confluence with the Animas River.		Recreation 2	pH = 6 5-9.0 F Coli = 2000/100 ml			
7 Mainstem of Mineral Creek, including all tributaries, from the source to a point immediately above the confluence with South Mineral Creek except for the specific listing in Segment 8a		Recreation 2 Agriculture	pH = 3 5-9.0 F Coli = 2000/100 ml	CN = 0.2 B = 0 75	As (ch) = 0.1 Cd (ch) = 0.005 CrIII (ch) = 0.1 CrVI (ch) = 0.1 Cu (ch) = 0.2 Pb (ch) = 0 035 Hg (ch) = 0.05 Ni (ch) = 0 05 Se (ch) = 0.02 Ag (ch) = 0.1 Zn (ch) = 2 0	All metals are Trec unless otherwise noted
8a Mainstem of South Mineral Creek, including all tributaries, lakes and reservoirs from the source to a point immediately above the confluence with Clear Creek; mainstems, including all tributaries, lakes and reservoirs of Mill Creek, and Bear Creek from sources to confluence with Mineral Creek, all lakes and reservoirs in the drainage areas described in Segments 7 through 9		Aq Life Cold 1 Recreation 2 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
8b Mainstem of South Mineral Creek, including all tributaries, from a point immediately above the confluence with Clear Creek to the confluence with Mineral Creek and the mainstem of Mineral Creek from immediately above the confluence with the South Fork to the confluence with the Animas River		Aq Life Cold 1 Recreation 2 Water Supply	D.O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0 002 B = 0 75 NO_2 = 0.05	As (ch) = 50 Cd (ch) = 2 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) = 5 Fe (ch) = 1000 Pb (ch) = 14 Mn (ch) = 1000 Hg (ch) = 0 05 Ni (ch) = 50 Se (ch) = 20 Ag (ch) = 0.1 Zn (ch) = 50	All metals are Trec unless otherwise noted

Table 15 (CONT)· Stream classifications and water quality standards, Colorado

Basin: Animas and Florida River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l		Metals µg/l			Temporary Modifications Qualifiers
9 Mainstem of Clear Creek from the source to the confluence with South Mineral Creek	UP	Aq Life Cold 1 Recreation 2 Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7.0 mg/l pH = 6 5-9.0 F. Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0 005	S = 0.002 B = 0 75 NO_2 = 0.05	As (ch) = 50 Cd (ch) = 0 4 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) = 150	Fe (ch) = 5000 Pb (ch) = 4 Mn (ch) = 1000 Hg (ch) = 0.05 Ni (ch) = 50	Se (ch) = 20 Ag (ch) = 0 1 Zn (ch) = 480	All metals are Trec unless otherwise noted.
10. Mainstem of the Florida River from the boundary of the Weminuche Wilderness Area to the Florida Farmers Canal Headgate, except for the specific listings in Segment 12b		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7 0 mg/l pH = 6.5-9 0 F. Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0 005	S = 0.002 B = 0.75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
11 Mainstem of the Florida River from the Florida Farmers Canal Headgate to the confluence with the Animas River		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O = 6.0 mg/l D O (sp) = 7.0 mg/l pH = 6.5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0 011 CN = 0.005	S = 0.002 B = 0.75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
12a All tributaries to the Animas River, including all lakes and reservoirs from a point immediately above the confluence with Elk Cr to a point immediately below the confluence with Hermosa Cr except for specific listings in Segment 15 All tributaries to the Florida River including all lakes and reservoirs from the source to the outlet of Lemon Reservoir except the specific listing in Segment 1 Mainstems of the Red and Shearer Creeks from their sources to their confluences with the Florida River		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O = 6.0 mg/l D O (sp) = 7 0 mg/l pH = 6.5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005	S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: Animas and Florida River Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l		Metals µg/l			Temporary Modifications Qualifiers
12b. Lemon Reservoir		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O. = 6.0 mg/l D.O. (sp) = 7 0 mg/l pH = 6 5-9.0 F. Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0.005	S = 0.002 B = 0.75 NO_2 = 0.05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
13a Mainstem of Junction Creek, and including all tributaries, from U.S Forest Boundary to confluence with Animas River	UP	Aq Life Cold 2 Recreation 2 Agriculture	D.O. = 6 0 mg/l D.O. (sp) = 7 0 mg/l pH = 6 5-9.0 F Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005	S = 0 002 B = 0 75 NO_2 = 0.05	As (ac/ch) = TVS Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac/ch) = TVS CrVI (ac/ch) = TVS	Cu (ac/ch) = TVS Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac/sh) = TVS Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	All metals are Trec unless otherwise noted
13b All tributaries to the Animas River, including all lakes and reservoirs, from a point immediately below the confluence with Hermosa Creek to the Colorado/New Mexico border, except for the specific listings in Segments 10, 11, 12a, 12b, 13a and 14, all tributaries to the Florida River, including all lakes and reservoirs, from the outlet of Lemon Reservoir to the confluence with the Animas River, except for specific listings in Segment 12a.	UP	Aq Life Cold 2 Recreation 2 Agriculture	D O = 6.0 mg/l D.O. (sp) = 7.0 mg/l pH = 6 5-9.0 F Coli = 2000/100 ml						
14 Mainstem of Lightner Creek from the source to the confluence with the Animas River		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0 011 CN = 0 005	S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
15 Mainstem of Purgatory Creek from source to Cascade, Cascade Creek, Soulding Creek from the source to Elbert Creek, and Nary Draw from the source to Naviland Lake	UP	Aq Life Cold 2 Recreation 2 Water Supply Agriculture	D O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 2000/100 ml	CN = 0 2 S = 0 05 NO_2 = 1.0	NO_3 = 10 Cl = 250 SO_4 = 250	As (ch) = 50 Cd (ch) = 10 CrIII (ch) = 50 CrVI (ch) = 50	Cu (ch) = 1000 Fe (ch) = 0 3 (dis) Pb (ch) = 50 Mn (ch) = 50	Hg (ch) = 2 Se (ch) = 10 Ag (ch) = 50 Zn (ch) = 5000	All metals are Trec unless otherwise noted

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: La Plata River, Mancos River, McElmo Creek, and San Juan River in Montezuma and Dolores counties Stream Segment Description	Desig	Classifications	Numeric Standards Physical and Biological	Inorganic mg/l		Metals µg/l			Temporary Modifications Qualifiers
1. Mainstem of the La Plata River, including all tributaries, lakes, and reservoirs, from the source to the Hay Gulch diversion south of Hesperus		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O. = 6 0 mg/l D.O. (sp) = 7.0 mg/l pH = 6 5-9.0 F Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0.005	S = 0.002 B = 0.75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0.01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
2 Mainstem of the La Plata River from the Hay Gulch diversion south of Hesperus to the Colorado/New Mexico border	UP	Aq Life Warm 2 Recreation 2 Agriculture	D.O = 5 0 mg/l pH = 6 5-9 0 F Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.1 Cl_2 (ac) = 0.019 Cl_2 (ch) = 0.011 CN = 0.005	S = 0 002 B = 0.75 NO_2 = 0.05	As (ch) = 50 Cd (ch) = 0.1 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) = 10	Fe (ch) = 1000 Pb (ch) = 43 Mn (ch) = 1000 Hg (ch) = 0 05 Ni (ch) = 100	Se (ch) = 20 Ag (ch) = 0.1 Zn (ch) = 140	All metals are Trec unless otherwise noted
3 All tributaries to the La Plata River, including all lakes and reservoirs, from the Hay Gulch diversion south of Hesperus to the Colorado/New Mexico border	UP	Aq Life Warm 2 Recreation 2 Agriculture	D.O = 5 0 mg/l pH = 6.5-9.0 F Coli = 2000/100 ml						
4 Mainstem of the Mancos River, including all tributaries, lakes, and reservoirs, from the source of the East, West and Middle Forks to Hwy 160		Aq Life Cold 1 Recreation 1 Water Supply Agriculture	D.O = 6 0 mg/l D O (sp) = 7 0 mg/l pH = 6 5-9 0 F Coli = 200/100 ml	NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0.005	S = 0 002 B = 0 75 NO_2 = 0 05 NO_3 = 10 Cl = 250 SO_4 = 250	As (ac) = 50 (Trec) Cd (ac) = TVS (tr) Cd (ch) = TVS CrIII (ac) = 50 (Trec) CrVI (ac/ch) = TVS Cu (ac/ch) = TVS	Fe (ch) = 300 (dis) Fe (ch) = 1000 (Trec) Pb (ac/ch) = TVS Mn (ch) = 50 (dis) Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec)	Ni (ac/ch) = TVS Se (ac) = 10 (Trec) Ag (ac) = TVS Ag (ch) = TVS (tr) Zn (ac/ch) = TVS	
5 Mainstem of the Mancos River from Hwy 160 to the Colorado/New Mexico border	UP	Aq Life Warm 2 Recreation 2 Agriculture	D O = 5.0 mg/l pH = 6 5-9 0 F Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0.011 CN = 0.005	S = 0 002 B = 0.75 NO_2 = 0 05	As (ch) = 50 Cd (ch) = 1 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) = 30	Fe (ch) = 5100 Pb (ch) = 25 Mn (ch) = 1000 Hg (ch) = 0 05 Ni (ch) = 100	Se (ch) = 20 Ag (ch) = 0 1 Zn (ch) = 150	All metals are Trec unless otherwise noted.
6 All tributaries to the Mancos River, including all lakes and reservoirs, from Hwy 160 to the Colorado/New Mexico border	UP	Aq Life Warm 2 Recreation 2 Agriculture	D O = 5.0 mg/l pH = 6 5-9 0 F Coli = 2000/100 ml						

Table 15 (CONT): Stream classifications and water quality standards, Colorado

Basin: La Plata River, Mancos River, McElmo Creek, and San Juan River in Montezuma and Dolores counties			Numeric Standards			
Stream Segment Description	Desig	Classifications	Physical and Biological	Inorganic mg/l	Metals µg/l	Temporary Modifications Qualifiers
7. Mainstem of McElmo Creek from the source to the Colorado/Utah border.	UP	Aq Life Warm 2 Recreation 2 Agriculture	D O. = 5.0 mg/l pH = 6.5-9.0 F.Coli = 2000/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0.02 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0 005 S = 0.002 B = 0 75 NO_2 = 0 05	As (ch) = 50 Cd (ch) = 5 CrIII (ch) = 100 CrVI (ch) = 25 Cu (ch) = 19 Fe (ch) = 10400 Pb (ch) = 50 Mn (ch) = 1000 Hg (ch) = 0.05 Ni (ch) = 200 Se (ch) = 20 Ag (ch) = 0.15 Zn (ch) = 100	All metals are Trec unless otherwise noted.
8 All tributaries to McElmo Creek and the San Juan River in Montezuma and Dolores counties, including all lakes and reservoirs, except for specific listings in Segments 2 through 7.	UP	Aq Life Warm 2 Recreation 2 Agriculture	D.O. = 5.0 mg/l pH = 6.5-9.0 F.Coli = 2000/100 ml			
9 Mainstem of the San Juan River in Montezuma County.		Aq Life Warm 1 Recreation 1 Agriculture	D.O. = 5 0 mg/l pH = 6 5-9 0 F.Coli = 200/100 ml	NH_3 (ac) = TVS NH_3 (ch) = 0 06 Cl_2 (ac) = 0 019 Cl_2 (ch) = 0 011 CN = 0.005 S = 0 002 B = 0 75 NO_2 = 0.5	As (ac/ch) = TVS Cd (ac/ch) = TVS CrIII (ac/ch) = TVS CrVI (ac/ch) = TVS Cu (ac/ch) = TVS Fe (ch) = 2200 (Trec) Pb (ac/ch) = TVS Mn (ch) = 1000 (Trec) Hg (ch) = 0 01 (Trec) Se (ac/sh) = TVS Ag (ac/ch) = TVS Zn (ac/ch) = TVS	

Taken from Colorado Water Quality Control Commission 1993b

The justification for the Segment 7 classification is that:

> The Woodling Study indicates that Mineral Creek, from its source to its confluence with South Mineral Creek, is highly toxic due to mineralization and there is not a likelihood that the sources of that toxicity will be corrected in 20 years However, the Commission concluded that there was likely to be aquatic life in that portion of Mineral Creek from below South Fork to Silverton.

All three sections have been severely impacted by anthropogenic pollution from mineral development (Harvey, personal communication), yet Colorado has explicitly chosen to maintain the status quo by prescribing the less stringent standards of a Recreation 2 classification.

In evaluating its surface waters for its 305(b) Report, Colorado has modified the EPA's suggested use support classifications (Tables 16a and 16b) (Colorado Water Quality Control Division 1992). According to the 1992 report, portions of all major tributaries to the San Juan River in Colorado fail to fully support their uses (Table 17). Narraguinnep, McPhee, and Navajo reservoirs were each found to partially support their uses, all due to mercury levels in fish. Of the nineteen river or stream reaches whose uses were impaired, metals were cited as contaminants in twelve, sediment in eight, and salinity in three. Sources of nonsupport are not listed. It should be noted that several stream reaches were designated as Water Quality Limited (WQL), a category in which uses are not measurably impaired but for which there are indications that the potential exists for impairment in the near future (Colorado Water Quality Control Division 1992).

Utah - Utah has a total of 12 water use classifications (Table 18) All river and stream segments within the San Juan basin are designated as fisheries, as is Lake Powell. The use classifications each have been assigned standards (Table 19). For the aquatic wildlife classifications, there are both acute (1 hour) and chronic (4-day) classifications. Criteria for domestic, recreation, and agricultural uses (Table 20), aquatic wildlife (Table 21), and the protection of human health (Table 22) are listed separately (Utah Department of Environmental Quality 1992).

For Utah's 1991 accounting of water quality, one or more violations of acute or chronic toxicity criteria within a three-year period resulted in a determination of nonsupport for a stream classified for aquatic use life support. Use support was determined for stream segments within waterbodies that were monitored (sampled at least quarterly), assessed (sampled less than quarterly), or evaluated (judgements were made whether similar waterbodies within a watershed had the same use support as those monitored or assessed) (Toole 1992)

Within the San Juan basin, the Utah Division of Water Quality sampled two stream segments from October 1, 1988 to September 30, 1991. Water from Montezuma Creek was sampled at a point 1.5 miles upstream from the town of Montezuma Creek; at this station, the creek failed to support its fishery use as a result of temperature, dissolved oxygen, copper, and iron exceedances. Water was also sampled from the San Juan River above Aneth; at this station, the mean iron concentration exceeded the fishery criteria of 1.0000 mg/l, and copper and zinc standards were exceeded in 14.3% and 28.6% samples, respectively (Utah Division of Water Quality 1993)

4.4 RESERVOIRS AND DAMS

Dams and their reservoirs can significantly alter downstream water quality. The following discussion lists a number of effects that may result from the construction and operation of dams. It should be noted that conditions favoring one or more effects might exclude others (Yahnke, personal communication).

As a result of metabolism or other mechanisms, reservoirs can remove nutrients such as nitrogen and phosphorus from the water, reducing their concentrations below dams and effectively lowering the

Table 16a: Designated use impairment conventional pollutants, Colorado

Intensity of Designated Use Impairment	Water Quality Information	Biological Information	Direct Observation/Professional Judgement
FULLY SUPPORTING. Designated uses are not measurably impaired due to water quality.	The water quality standard is exceeded in not more than 10% of the analyses and the mean measured value is less than the standard.	The designated uses of the water body are not impaired due to water quality, and data indicate full supporting of aquatic life, including survival, propagation, production, dispersion, community structure, species diversity within the limits of the physical habitat	The water body is being used as designated, based on observation, and professional judgement indicates no reason why it should not be.
WATER QUALITY LIMITED, ALLOCATED (WQLA): Designated uses not measurably impaired due to water quality, but the assimilative capacity of the segment has been allocated. If additional growth occurs in the areas served by the current treatment facilities or an additional wastewater plant will discharge to the same more restrictive limits will be required for some or all dischargers.	The water quality standard is exceeded in 10-15% of the analyses and the mean measured value is less than the standard and the dischargers are all meeting their permit limits for conventional pollutants	The designated uses of the water body are not impaired, but data indicators indicate a probable downward trend that may impair aquatic life including survival, propagation, production, dispersion, community structure and/or species diversity.	Water quality based effluent limits, which may include an approved wasteload allocation, are in effect on the segment.
WATER QUALITY LIMITED (WQL) Designated uses not measurably impaired due to water quality but assessment information or segment specified water quality based controls indicate the potential for impairment of the designated uses in the near future	The water quality standard is exceeded in 10-15% of the analyses and the mean measured value is less than the standard or data indicate a trend of deteriorating water quality which could impair uses.	The designated uses of the water body are not impaired, but data indicators indicate a probable downward trend that may impair aquatic life including survival, propagation, production, dispersion, community structure and/or species diversity	The segment has been identified as in need of study through a 208 plan, a site application process, or a State permitting process; OR population or industrial siting increases indicate a probable downward trend in water quality which may lead to impairment of uses in the absence of additional management
PARTIAL SUPPORT Some interference with designated uses, but use is not precluded	The standard is exceeded in 15-25% of the analyses and the mean measured value is less than the standard, OR the standard is exceeded in not more than 15% of the analyses and the mean measured value exceeds the standard	The designated uses of the water body are present, but it is uncertain that these are at attainable levels, or some impact on the uses has been noted	The use exists in the water body based on observation, but professional judgement, which may be based on limited data, indicates that the uses are not fully supported
NOT SUPPORTING Designated uses measurably impaired because of water pollution Use may be present but at significantly reduced levels from full support in all or some portion of the water body.	The standard is exceeded in more than 25% of analyses and mean measured value is less than the standard, OR the standard is exceeded in not more than 15% of the analyses and the mean measured value exceeds the standard	There is some certainty that the body can not be fully used as designated because the survival, propagation, production dispersion, community structure, or species diversity of aquatic life is impaired.	No evidence exists that the entire water body can be used as designated; or known or suspected water quality impacts prevent anything but minimal use of all or a major portion of the water body

Taken from Colorado Water Quality Control Division 1992

Table 16b: Designated use impairment toxic pollutants, Colorado

Intensity of Designated Use Impairment	Water Quality Information	Biological Information	Direct Observation/Professional Judgement
FULLY SUPPORTING. Designated uses are not measurably impaired due to water quality	An acute water quality standard is exceeded in not more than one sample in the previous three year period and the mean of all the samples is less than the chronic standard.	The designated uses of the water body are not impaired due to water quality, and data indicate full supporting of aquatic life use, including survival, propagation, production, dispersion, community structure, species diversity within the limits of the physical habitat.	The water body is being used as designated, based on observation, and professional judgement indicates no reason why it should not be.
WATER QUALITY LIMITED, ALLOCATED (WQLA). Designated uses not measurably impaired due to water quality, but the assimilative capacity of the segment has been allocated. If additional growth occurs in the areas served by the current treatment facilities or an additional wastewater plant will discharge to the same more restrictive limits will be required for some or all dischargers.	A chronic water quality standard is exceeded in two or more samples in the past three years, but acute standard exceeded more than once in the last three years, the mean is less than the chronic standard, and all dischargers are meeting the limits specified in their permits	The designated uses of the water body are not impaired, but data indicators indicate a probable downward trend that may impair aquatic life including survival, propagation, production, dispersion, community structure and/or species diversity.	Water quality based effluent limits, which may include an approved wasteload allocation, are in effect on the segment
WATER QUALITY LIMITED (WQL) Designated uses not measurably impaired due to water quality but assessment information or segment specified water quality based controls indicate the potential for impairment of the designated uses in the near future.	A chronic water quality standard is exceeded in two or more samples in the past three years, but an acute water quality standard is not exceeded more than once in the same period, and the mean is less than the chronic standard, OR the data indicate a downward trend toward deteriorations in water quality which could impair use(s)	The designated uses of the water body are not impaired, but data indicators indicate a probable downward trend that may impair aquatic life including survival, propagation, production, dispersion, community structure and/or species diversity	The segment has been identified as in need of study through a 208 plan, a site application process, or a State permitting process, OR population or industrial siting increases indicate a probable downward trend in water quality which may lead to impairment of uses in the absence of additional management
PARTIAL SUPPORT Some interference with designated uses, but use is not precluded	An acute water quality standard is exceeded in two or more samples in the past three years, but the mean measured value is less than the chronic standard	The designated uses of the water body are present, but it is uncertain that these are at attainable levels, or some impact on the uses has been noted	The use exists in the water body based on observation, but professional judgement, which may be based on limited data, indicates that the uses are not fully supported.
NOT SUPPORTING Designated uses measurably impaired because of water pollution Use may be present but at significantly reduced levels from full support in all or some portion of the water body	An acute water quality standard is exceeded in two or more samples in the previous three years and the mean measured value is above the chronic standard	There is some certainty that the body can not be fully used as designated because the survival, propagation, production dispersion, community structure, or species diversity of aquatic life is impaired	No evidence exists that the entire water body can be used as designated; or known or suspected water quality impacts prevent anything but minimal use of all or a major portion of the water body

Taken from Colorado Water Quality Control Division 1992

Table 17: Designated use impairment, San Juan Basin, Colorado

WBID Region/Segment	Segment Description	Evaluated/ Monitored	Status	Criteria*	Constituent(s)
COSJSJ07L	Navajo Reservoir (portion in CO)	M	Partially Supporting	B	Mercury
COSJPI04 9/4	Piedra River Indian Creek/Navajo Reservoir	E	WQL	N	Sediment
COSJPN02B 9/2b	Los Pinos River, Hwy 160/ Stateline	E	WQL	N	Sediment
COSJPN06 9/6	Los Pinos River trib. below Bear Creek	E	Partially Supporting	N	Sediment
COSJAF02 9/2	Animas River source/Elk Creek	E M	Not Supporting Not Supporting	N B	Metals W E T.
COSJAF03 9/3	Animas River, Elk Creek/Junction Creek	E	Partially Supporting	N	Metals
COSJAF04 9/4	Animas Creek Junction Creek/Stateline	E E E	WQL WQL WQL	N N N	Metals Sediment Salinity
COSJAF05 9/5	Animas River tribs above Elk Creek	E	Partially Supporting	N	Metals
COSJAF06 9/6	Cement Creek and tribs	E	Not Supporting	N	Metals
COSJAF07 9/7	Mineral Creek and tribs	E	Not Supporting	N	Metals
COSJAF08A 9/8a	S Mineral Creek above Clear Creek	E	Not Supporting	N	Metals
COSJAF11 9/11	Florida River below Florida Farmers Ditch	E	WQL	N	Sediment
COSJLP01 9/1	La Plata River above Hay Gulch	E	Partially Supporting	N	Metals
COSJLP05 9/5	Mancos River, Hwy. 160/Stateline	E E	Not Supporting Partially Supporting	N N	Sediment Salinity
COSJLP06 9/6	La Plata River, Hay Gulch/Stateline	E E	WQL WQL	N N	Salinity Sediment
COSJLP07 9/7	McElmo Creek, Source/Stateline	E	Not Supporting	N	Sediment
COSJLP08L1	Narraguinnep Reservoir	M	Partially Supporting	B	Mercury
COSJD003 9/3	Dolores River, Horse Creek/Bear Creek	E M	Partially Supporting Not Supporting	N B	Metals W E T
COSJD004 9/4	Dolores River, Bear Creek/Bradfield Ranch	E	WQL	N	Metals
COSJD004L	McPhee Reservoir	M	Partially Supporting	B	Mercury
COSJD006 9/6	Slate Creek and Coke Over Creek	E	WQL	N	Metals
COSJD007 9/7	Coal Creek above Dolores River	E	WQL	N	Metals

* Q indicates chemical or microbiological water quality data, B indicates biological information, J indicates direct observation or professional judgement, N indicates reported in Colorado Nonpoint Assessment Report

Taken from Colorado Water Quality Control Division 1992

Table 18: Surface water classifications, Utah

Class 1	Protected for use as a raw water source for domestic water systems
Class 1A	Reserved
Class 1B	Reserved
Class 1C	Protected for domestic purposes with prior treatment processes as required by the Utah Department of Health
Class 2	Protected for in-stream recreational use and aesthetics
Class 2A	Protected for recreational bathing (swimming)
Class 2B	Protected for boating, water skiing, and similar uses, excluding recreational bathing (swimming)
Class 3	Protected for in-stream use by aquatic life
Class 3A	Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain
Chain 3B	Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food
Class 3C	Protected for nongame fish and other aquatic life, including the necessary aquatic organisms in their food chain
Class 3D	Protected for waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain
Class 4	Protected for agricultural uses including irrigation of crops and stockwatering
Class 5	Reserved
Class 6	Water requiring protection when conventional uses as identified in Section 2.6.1 through 2.6.5 do not apply. Standards for this class are determined on a case-by-case basis

Taken from Utah Department of Environmental Quality 1992

Table 19: Use classifications for the San Juan basin, Utah

San Juan River and tributaries, from Lake Powell to state line except as listed below:	1C	2B	3B	4
Johnson Creek and tributaries, from confluence with Recapture Creek to headwaters	1C	2B	3A	4
Verdure Creek and tributaries, from Highway US-191 crossing to headwaters			3A	4
North Creek and tributaries, from confluence with Montezuma Creek to headwaters	1C		3A	4
South Creek and tributaries, from confluence with Montezuma Creek to headwaters	1C		3A	4
Spring Creek and tributaries, from confluence with Vega Creek to headwaters			3A	4
Montezuma Creek and tributaries, from Highway US-191 to headwaters	1C		3A	4
Lake Powell (Utah Portion)	1C	2A 2B	3B	4

Taken from Utah Department of Environmental Quality 1992

Table 20: Numeric criteria for domestic, recreation, and agricultural uses, Utah

Parameter	Domestic Source 1C	Recreation and Aesthetics 2A	Recreation and Aesthetics 2B	Agriculture 4
BACTERIOLOGICAL (30-day geometric mean) (No./100 ml)				
Max. Total Coliforms	5000	1000	5000	
Max. Fecal Coliforms	2000	200	200	
PHYSICAL				
Min. Dissolved Oxygen (mg/l) (1)	5.5	5.5	5.5	
pH (Range)	6.5-9.0	6.5-9.0	6.5-9.0	6.5-9.0
Turbidity Increase (NTU)		10	10	
METALS (Acid soluble, maximum, mg/l) (2)				
Arsenic	0.05			0.1
Barium	1.0			
Cadmium	0.01			0.01
Chromium	0.05			0.10
Copper				0.2
Lead	0.05			0.1
Mercury	0.002			
Selenium	0.01			0.05
Silver	0.05			
INORGANICS (Maximum mg/l)				
Boron				0.75
Fluoride (3)	1.4-2.4			
Nitrates as N	10			
Total Dissolved Solids (4)				1200
RADIOLOGICAL (Maximum pCi/l)				
Gross Alpha	15			15
Radium 226, 228 (combined)	5			
Strontium 90	8			
Tritium	20,000			
ORGANICS (Maximum μg/l)				
2,4-D	100			
2,4,5-TP	10			
Endrin	0.2			
Hexachlorocyclohexane (Lindane)	4			
Methoxychlor	100			
Toxaphene	5			
POLLUTION INDICATORS (5)				
Gross Beta (pCi/l)	50			50
BOD (mg/l)		5	5	5
Nitrate as N (mg/l)		4	4	
Phosphate as P (mg/l) (6)		0.05	0.05	

Taken from Utah Department of Environmental Quality 1992

Table 20 (cont.): Numeric criteria for domestic, recreation, and agricultural uses, Utah

(1) These limits are not applicable to lower water levels in deep impoundments.

(2) The acid soluble method as used by the State Health Laboratory involves acidification of the sample in the field, no digestion process in the laboratory, filtration, and analysis by atomic absorption spectrophotometry. (Methods of chemical analysis of water and wastes, EPA-600/4-79-020)

(3) Maximum concentration varies according to the daily maximum mean air temperature.

TEMP (C)	MG/L
12.0	2.4
12.1-14.6	2.2
14.7-17.6	2.0
17.7-21.4	1.8
21.5-26.2	1.6
26.3-32.5	1.4

(4) Total dissolved solids (TDS) limits may be adjusted on a case-by-case basis.

(5) Investigations should be conducted to develop more information where these pollution indicator levels are exceeded

(6) Phosphate as P (mg/l) limit for lakes and reservoirs shall be 0.025.

Taken from Utah Department of Environmental Quality 1992

Table 21: Numeric criteria for aquatic wildlife, Utah

Parameter	3A	3B	3C	3D
PHYSICAL				
Total Dissolved Gases	(1)	(1)		
Dissolved Oxygen (mg/l) (2)				
30 Day Average	6.5	5.5	5.0	5.0
7 Day Average	9.5/5.5	6.0/4.0		
1 Day Average	8.0/4.0	5.0/3.0	3.0	3.0
Max. Temperature (C)	20	27	27	
Max. Temperature Change (C)	2	4	4	
pH (Range)	6.5-9.0	6.5-9.0	6.5-9.0	6.5-9.0
Turbidity Increase (NTU)	10	10	15	15
METALS (3)				
(Acid soluble, µg/l) (4)				
Arsenic (Trivalent)				
4 Day Average	190	190	190	190
1 Hour Average	360	360	360	360
Cadmium (5)				
4 Day Average	1.1	1.1	1.1	1.1
1 Hour Average	3.9	3.9	3.9	3.9
Chromium (Hexavalent)				
4 Day Average	11	11	11	11
1 Hour Average	16	16	16	16
Chromium (Trivalent) (5)				
4 Day Average	210	210	210	210
1 Hour Average	1700	1700	1700	1700
Copper (5)				
4 Day Average	12	12	12	
1 Hour Average	18	18	18	18
Cyanide (Free)				
4 Day Average	5.2	5.2	5.2	
1 Hour Average	22	22	22	22
Iron (Maximum)	1000	1000	1000	1000
Lead (5)				
4 Day Average	3.2	3.2	3.2	3.2
1 Hour Average	82	82	82	82
Mercury				
4 Day Average	0.012	0.012	0.012	0.012
1 Hour Average	2.4	2.4	2.4	2.4
Nickel (5)				
4 Day Average	160	160	160	160
1 Hour Average	1400	1400	1400	1400
Selenium				
4 Day Average	5.0	5.0	5.0	5.0
1 Hour Average	20	20	20	20
Silver				
4 Day Average	0.12	0.12	0.12	
1 Hour Average (5)	4.1	4.1	4.1	4.1
Zinc (5)				
4 Day Average	110	110	110	110
1 Hour Average	120	120	120	120
INORGANICS				
(mg/l) (3)				
Ammonia as N (un-ionized) (6)				
4 Day Average	(6a)	(6a)		
1 Hour Average	(6b)	(6b)	(6b)	(6b)
Chlorine (Total Residual) (7)				
4 Day Average	0.011	0.011		
1 Hour Average	0.019	0.019	0.2	(8)

Table 21 (CONT): Numeric criteria for aquatic wildlife, Utah

Parameter	3A	3B	3C	3D
Hydrogen Sulfide				
(Undissociated, Max. µg/l)	2.0	2.0	2.0	2.0
Phenol (Maximum)	0.01	0.01	0.01	0.01
RADIOLOGICAL				
(Maximum pCi/l)				
Gross Alpha (9)	15	15	15	15
ORGANICS				
(µg/l)				
Aldrin (Maximum)	1.5	1.5	1.5	1.5
Chlorane				
4 Day Average	0.0043	0.0043	0.0043	0.0043
1 Hour Average	1.2	1.2	1.2	1.2
DDT and Metabolites				
4 Day Average	0.0010	0.0010	0.0010	0.0010
1 Hour Average	0.55	0.55	0.55	0.55
Dieldrin				
4 Day Average	0.0019	0.0019	0.0019	0.0019
1 Hour Average	1.25	1.25	1.25	1 25
Endosulfan				
4 Day Average	0.056	0.056	0.056	0.056
1 Hour Average	0.11	0.11	0.11	0.11
Endrin				
4 Day Average	0.0023	0.0023	0.0023	0.0023
1 Hour Average	0.09	0.09	0.09	0.09
Guthion (Maximum)	0.01	0.01	0.01	0.01
Heptachlor				
4 Day Average	0.0038	0.0038	0.0038	0.0038
1 Hour Average	0.26	0.26	0.26	0.26
Hexachlorohexane (Lindane)				
4 Day Average	0.08	0.08	0.08	0.08
1 Hour Average	1.0	1.0	1.0	1.0
Methoxychlor (Maximum)	0.03	0.03	0 03	0.03
Mirex (Maximum)	0.001	0.001	0.001	0 001
Parathion (Maximum)	0.04	0.04	0.04	0.04
PCBs				
4 Day Average	0.014	0.014	0.014	0.014
1 Hour Average	2.0	2.0	2.0	2.0
Pentachlorophenol (10)				
4 Day Average	13	13	13	13
1 Hour Average	20	20	20	20
Toxaphene				
4 Day Average	0.0002	0.0002	0.0002	0 0002
1 Hour Average	0.73	0.73	0.73	0 73
POLLUTION INDICATORS				
(9)				
Gross Beta (pCi/l)	50	50	50	50
BOD (mg/l)	5	5	5	5
Nitrate as N (mg/l)	4	4	4	
Phosphate as P (mg/l) (11)	0.05	0.05		

(1) Not to exceed 110% of saturation.

(2) *These limits are not* applicable to lower water levels in deep impoundments. First number in column is for when early life stages are present, second number is for when all other life stages present.

(3) Where criteria are listed as 4-day average and 1-hour average concentrations, these concentrations should not be exceeded more often than once every three years on the average.

(4) The acid soluble method as used by the State Health Laboratory involves acidification of the sample in the field, no digestion process in the laboratory, filtration, and analysis by atomic absoption spectrophometry. (Methods of chemical analysis of water and wastes, EPA-600/4-79-020)

(5) *Hardness dependent criteria. 100 mg/l used.* See table 2.14.3 for complete equation.

(6) Un-ionized ammonia toxicity is dependent upon the temperature and pH of the waterbody. For detailed explanation refer to Federal Register, vol. 50, 30784, July 29, 1985.

(6a) The 4-day average concentration of un-ionized ammonia in mg/l as N (0.80/FT/FPH/RATIO) * 0.822
(6b) The 1-hour average concentration of un-ionized ammonia in mg/l as N (0.52/FT/FPH/2) * 0.822
Where:
FT is a function of temperature which adjusts the criteria concentration for the ambient temperature.
FT = $10^{0.03(20-TCAP)}$; TCAP less than or equal to T less than or equal to 30 = $10^{0.03(20-T)}$; 0 less than or equal to T less than TCAP and FPH is a function of pH which adjusts the criteria concentration for ambient pH.
FPH = 1; 8 less than or equal to pH less than or equal to 9 = $(1+10^{7.4-pH})/1.25$; 6.5 less than or equal to pH less than 8.0 and RATIO is the ratio between acute and chronic criteria and is dependent upon pH.
RATIO = 1.35; 7.7 less than or equal to pH less than or equal to 9 = $20\ (10^{7.7-pH})/(1+10^{7.4-pH})$; 6.5 less than or equal to pH less than 7.7 and TCAP is the maximum temperature that the criteria can be applied and is dependent upon the aquatic community present (i.e., warm water or cold water).
For Class 3A only: TCAP = 15C in equation 6a = 20C in equation 6b
For Class 3B: TCAP = 20C in equation 6a
For Classes 3B, 3C, and 3D: TCAP = 25C in equation 6b
For Tables of values, see following page.

(7) Special case segments and maximum TRC concentrations as follows:

Mill Race from Interstate Highway 15 to the Provo City wastewater treatment plant discharge 0.2 mg/l
Ironton Canal (Utah County), from Utah Lake (Provo Bay) to East boundary of Denver and Rio Grande Western Railroad right-of-way 0.05 mg/l
Beer Creek (Utah County) from 4850 West (in NE1/4NE1/4 sec. 36, T. 8 S., R. 1 E.) to headwaters 0.3 mg/l

(8) Numeric criteria determined on a case-by-case basis.

(9) Investigations should be conducted to develop more information where these levels are exceeded.

(10) *pH dependent criteria. pH 7.8 used in table.* See Table 2.14.4 for equation.

(11) Phosphate as P (mg/l) limit for lakes and reservoirs shall be 0.025.

1-HOUR AVERAGE CONCENTRATION OF UN-IONIZED AMMONIA AS N (MG/L)
FOR CLASS 3A WATERS

Temperature (C)

		0.00	5.00	10.00	15.00	20.00	25.00	30.00
	6.50	0.008	0.011	0.015	0.021	0.030	0.030	0.030
	7.00	0.019	0.027	0.038	0.054	0.076	0.076	0.076
pH	7.50	0.037	0.053	0.075	0.105	0.149	0.149	0.149
	8.00	0.054	0.076	0.107	0.151	0.214	0.214	0.214
	8.50	0.054	0.076	0.107	0.151	0.214	0.214	0.214
	9.00	0.054	0.076	0.107	0.151	0.214	0.214	0.214

4-DAY AVERAGE CONCENTRATION OF UN-IONIZED AMMONIA AS N (MG/L)
FOR CLASS 3A WATERS

Temperature (C)

		0.00	5.00	10.00	15.00	20.00	25.00	30.00
	6.50	0.001	0.001	0.001	0.002	0.002	0.002	0.002
	7.00	0.002	0.003	0.004	0.006	0.006	0.006	0.006
pH	7.50	0.006	0.009	0.013	0.018	0.018	0.018	0.018
	8.00	0.012	0.017	0.024	0.034	0.034	0.034	0.034
	8.50	0.012	0.017	0.024	0.034	0.034	0.034	0.034
	9.00	0.012	0.017	0.024	0.034	0.034	0.034	0.034

1-HOUR AVERAGE CONCENTRATION OF UN-IONIZED AMMONIA AS N (MG/L)
FOR CLASS 3B, 3C, AND 3D WATERS

Temperature (C)

		0.00	5.00	10.00	15.00	20.00	25.00	30.00
	6.50	0.008	0.011	0.015	0.021	0.030	0.042	0.042
	7.00	0.019	0.027	0.038	0.054	0.076	0 107	0.107
pH	7.50	0.037	0.053	0.075	0.105	0.149	0.210	0.210
	8.00	0.054	0.076	0.107	0.151	0.214	0.302	0.302
	8.50	0.054	0.076	0.107	0 151	0.214	0.302	0.302
	9.00	0.054	0 076	0.107	0.151	0.214	0.302	0.302

4-DAY AVERAGE CONCENTRATION OF UN-IONIZED AMMONIA AS N (MG/L)
FOR CLASS 3B WATERS

Temperature (C)

		0.00	5.00	10.00	15.00	20.00	25.00	30.00
	6.50	0.001	0.001	0.001	0.002	0.003	0.003	0.003
	7.00	0.002	0.003	0.004	0.006	0.008	0.008	0.008
pH	7.50	0.009	0.009	0.013	0.018	0.024	0.026	0.026
	8.00	0.012	0.017	0.024	0.034	0.049	0.041	0.041
	8.50	0.012	0.017	0.024	0.034	0.049	0 049	0.049
	9.00	0.012	0.017	0.024	0.034	0.049	0 049	0.049

EQUATIONS FOR PARAMETERS WITH HARDNESS (1) DEPENDENCE

PARAMETER	4-DAY AVERAGE CONCENTRATION ($\mu g/l$)
Cadmium	$e^{(0.7852[\ln(hardness)]-3.490)}$
Chromium (Trivalent)	$e^{(0.8190[\ln(hardness)]+1.561)}$
Copper	$e^{(0.8545[\ln(hardness)]-1.465)}$
Lead	$e^{(1.273[\ln(hardness)]-4.705)}$
Nickel	$e^{(0.8460[\ln(hardness)]+1.1645)}$
Silver	N/A
Zinc	$e^{(0.8473[\ln(hardness)]+0.7614)}$

EQUATIONS FOR PARAMETERS WITH HARDNESS (1) DEPENDENCE

PARAMETER	1-HOUR AVERAGE CONCENTRATION ($\mu g/l$)
Cadmium	$e^{(1.128[\ln(hardness)]-3.828)}$
Chromium (Trivalent)	$e^{(0.8190[\ln(hardness)]+3.688)}$
Copper	$e^{(0.9422[\ln(hardness)]-1.464)}$
Lead	$e^{(1.273[\ln(hardness)]-1.460)}$
Nickel	$e^{(0.8460[\ln(hardness)]+3.3612)}$
Silver	$e^{(1.72[\ln(hardness)]-6.52)}$
Zinc	$e^{(0.8473[\ln(hardness)]+0.8604)}$

(1) HARDNESS AS MG/L $CaCO_3$

EQUATIONS FOR PENTACHLOROPHENOL (pH DEPENDENT)

4-DAY AVERAGE CONCENTRATION ($\mu g/l$)	1-HOUR AVERAGE CONCENTRATION ($\mu g/l$)
$e^{(1.005(pH))-5.290}$	$e^{(1.005(pH))-4.830}$

Taken from Utah Department of Environmental Quality 1992

Table 22: Numeric criteria for the protection of human health, Utah

Pollutant	Maximum Concentration (µg/l) Class 1C (1)	Class 3 (2)
Acenapthene	20 (4)	
Acrolein	320	780
Acrylonitrile (3)	0.058	0.65
Aldrin (3)	0.000074	0.000079
Antimony	146	45000
Arsenic (3)	0.002	0.017
Benzene (3)	0.66	40.0
Benzidene (3)	0.00012	0.00053
Beryllium (3)	0.0037	0.064
Cadmium	10 (5)	
Carbon Tetrachloride (3)	0.40	6.94
Chlordane (3)	0.00046	0.00048
Chlorinated Benzenes		
Hexachlorobenzene (3)	0.00072	0.00074
Chlorobenzene	20 (4)	
Chlorinated Ethanes		
1,2-Dichloroethane (3)	0.94	243
1,1,1-Trichloroethane	200 (5)	1030000
1,1,2-Trichloroethane (3)	0.60	41.8
1,1,2,2-Tetrachloroethane (3)	0.17	10.7
Hexachloroethane (3)	1.9	8.74
Chlorinated Phenols		
2,4,6-Trichlorophenol (3)	1.2	3.6
p-Chloro-m-cresol	3000 (4)	
Chloroalkyl ethers		
Bis (2-chloroethyl) ether (3)	0.03	1.36
Bis (2-Chloroisopropyl) ether	34.7	4360
Chloroform (3)	0.19	15.7
2-Chlorophenol	0.1 (4)	
Chromium (III)	50 (5)	3433000
Chromium (VI)	50 (5)	
Copper	1000 (4)	
Cyanide (total)	200 (5)	
DDT and Metabolites		
4,4'-DDT (3)	0.0000024	0.0000024
4,4'-DDE (3)	0.0000024	0.0000024
4,4'-DDD (3)	0.0000024	0.0000024
Dichlorobenzenes		
1,2-Dichlorobenzene	400	2600
1,3-Dichlorobenzene	400	2600
1,4-Dichlorobenzene	75 (5)	2600
Dichlorobenzidenes		
3,3'-Dichlorobenzidine (3)	0.01	0.02
Dichloroethylenes		
1,1-Dichloroethylene (3)	0.033	1.85
2,4-Dichlorophenol	0.3 (5)	
Dichloropropanes/Dichloropropenes		
1,3-Dichloropropylene	87	14100
Dieldrin (3)	0.000071	0.000076
2,4-Dimethylphenol	400 (4)	
2,4-Dinitrotoluene (3)	0.11	9.1
1,2-Diphenylhydrazine (3)	0.042	0.56
Dioxin (2,3,7,8-TCDD) (3)	1.3×10^{-8}	1.4×10^{-8}
Endosulfan		
alpha-Endosulfan	74	159
beta-Endosulfan	74	159
Endosulfan sulfate	74	159
Endrin	0.2 (5)	

Table 22 (cont.): Numeric criteria for the protection of human health, Utah

Pollutant	Maximum Concentration (µg/l) Class 1C (1)	Class 3 (2)
Endrin aldehyde	0.2 (5)	
Ethylbenzene	1400	3260
Fluoroanthene	42	54
Halomethanes		
Methylene chloride (3)	0.19	15.7
Methyl chloride (3)	0.19	15.7
Methyl bromide (3)	0.19	15.7
Bromoform (3)	0.19	15.7
Dichlorobromomethane (3)	0.19	15 7
Chlorodibromomethane (3)	0.19	15.7
Heptachlor (3)	0.00028	0.00029
Heptachlor epoxide (3)	0.00028	0.00029
Hexachlorobutadiene (3)	0.45	50
Hexachlorocyclohexane		
Hexachlorocyclohexane-alpha (3)	0.0092	0.031
Hexachlorocyclohexane-beta (3)	0.016	0.055
Hexachlorocyclohexane-gamma (3)	0.019	0.063
Hexachlorocyclopentadiene	1.0 (5)	
Isophorone	5200	520000
Lead		50 (5)
Mercury	0.144	0.146
Nickel		13.4100
Nitrobenzene	30 (5)	
Nitrophenols		
4,6-Dinitro-o-cresol	13.4	765
2,4-Dinitrophenol	70	14300
Nitrosamines		
N-Nitrosodimethylamine (3)	0.0014	16
N-Nitrosodiphenylamine (3)	4.9	16.1
Pentachlorophenol	30 (5)	
Phenol	300 (5)	
Phthalate Esters		
Dimethyl phthalate	313000	2900000
Diethyl phthalate	350000	1800000
Di-n-butyl phthalate	34000	154000
Bis (2-ethylhexyl) phthalate (3)	15000	50000
Polychlorinated Biphenyls		
PCB 1242 (3)	0.000079	0.000079
PCB 1254 (3)	0.000079	0.000079
PCB 1221 (3)	0.000079	0 000079
PCB 1232 (3)	0.000079	0.000079
PCB 1248 (3)	0.000079	0.000079
PCB 1260 (3)	0.000079	0.000079
PCB 1016 (3)	0.000079	0.000079
Polynuclear Aromatic Hydrocarbons		
Benzo(a)anthracene (3)	0.0028	0.0311
Benzo(a)pyrene (3)	0.0028	0.0311
Benzo(b)fluoranthene (3)	0.0028	0.0311
Benzo(k)fluoranthene (3)	0.0028	0.0311
Chrysene (3)	0.0028	0.0311
Acenaphthylene (3)	0.0028	0.0311
Anthracene (3)	0.0028	0.0311
Benzo(g,h,i)perylene (3)	0.0028	0.0311
Fluorene (3)	0.0028	0.0311
Phenanthrene (3)	0.0028	0.0311
Dibenzo(a,h)anthracene (3)	0.0028	0.0311
Indeno(1,2,3-cd)pyrene (3)	0.0028	0.0311
Pyrene (3)	0.0028	0.0311

Table 22 (cont.): Numeric criteria for the protection of human health, Utah

Pollutant	Maximum Concentration ($\mu g/l$) Class 1C (1)	Class 3 (2)
Selenium	10 (5)	
Silver		50 (5)
Tetrachloroethylene	0.80	8.85
Thallium	13	48
Toluene	14300	424000
Toxaphene (3)	0.00071	0.00073
Trichloroethylene (3)	2.7	80.7
Vinylchloride (3)	2.0 (5)	525
Zinc		5000 (4)
Asbestos (3)	30000 (6)	30000 (6)

(1) Human health criteria will be applied to all class 1C waterbodies to protect for the consumption of water and aquatic organisms.

(2) Human health criteria will be apllied to all class 3 waterbodies (i.e 3A, 3B, 3C, 3D) to protect for the consumption of aquatic organisms only.

(3) Carcinogenic compound. Human health criteria have been calculated using a 10^{-6} incremental risk factor.

(4) Criterion based on organoleptic data to control undesirable taste and odor quality of ambient waters.

(5) Criteria based on drinking water maximum contaminant levels (MCL).

(6) Concentration in fibers/L.

Taken from Utah Department of Environmental Quality 1992

primary productivity of the rivers below (Petts 1984, Ward and Stanford 1987). Conversely, release waters may be nutrient-enriched as a result of phytoplankton decomposition (Yahnke, personal communication). The quality of water leaving a dam is primarily a function of release depth; reservoirs that are deep and stratified with long water retention times normally result in the greatest variations in water quality between upstream and downstream river reaches (Ward and Stanford 1987). Furthermore, the regulated flow regimes of reservoirs alter the supply of organic and inorganic particles downstream. Sediment and detritus tend to settle out in reservoir basins, increasing water clarity downstream (Ward and Stanford 1987).

The concentrations of dissolved gases in release water can also be of concern. In some reservoirs, anaerobic conditions develop in the lower depths (Joseph and Sinning 1977). If this water is then released, the capacity of the stream below to assimilate residual organic wastes is impaired and fisheries can be adversely affected (Upper Colorado Region State-Federal Inter-Agency Group 1971). In the lower depths of Navajo Reservoir, dissolved oxygen values of 5.0 mg/l have been noted (Melancon et al. 1979). New Mexico's standards require dissolved oxygen to be above 5.0 mg/l in the San Juan River.

Gas supersaturation can also occur in the tailwaters of large dams When water is spilled over high dams, it traps air and plunges it to depths where high pressures enhance supersolubility. So-called "gas-bubble disease" may result, causing fish kills immediately downstream of dams (Holden 1979). Aeration of the water tends to normalize the water within a short distance of the dam, with supersaturation normally only affecting the tailwaters. In some cases, deflectors have been used in spillways to prevent supersaturation. At least one fish kill of stocked trout has occurred below Navajo Dam as a result of gas supersaturation (Holden 1979).

When a reservoir reduces stream discharge, there is a resulting reduction in water velocity. This in turn changes water temperature as well as water's sediment-transport capacity and erosion potential. Eventually, streambed characteristics will be altered and stream communities will be affected (Gosz 1980). A reduction in flow also has the effect of decreasing the amount of dilution water available downstream, thereby increasing the surface water concentration of contaminants. Furthermore, a reduction in flow rate below a reservoir can inhibit the ability of aquatic organisms to obtain dissolved oxygen. Flow constantly renews materials in solution near the surface of aquatic organisms; at a low flow rate, the concentration of dissolved oxygen molecules must be relatively high in order for organisms to obtain a sufficient quantity. Especially in warm weather, higher flows are necessary to supply adequate oxygen (Gosz 1980)

Perhaps the single biggest concern about the effect of reservoirs on water quality is the changes in temperature that they cause. In large, stratified, deep-release reservoirs, also called hypolimnial-release reservoirs, there is a marked decrease in annual and diel temperature ranges immediately downstream, producing winter warm and summer cool conditions (Petts 1984, Ward and Stanford 1987). The temperature effect may be delayed at first, with the tailwaters becoming colder as a reservoir fills and intakes for the tailwaters become deeper (Holden 1980). All of the major dams in the Upper Colorado River basin are high dams, creating large reservoirs and releasing cold downstream summer flows (Holden 1979).

Vanicek et al. (1970) conducted a study of Green River fishes in Utah and Colorado following closure of Flaming Gorge Dam in 1962 In the two years following the dam closure, no reproduction of any native fish species was observed in the 65-mile reach of the Green River above its confluence with the Yampa River. A comparison of pre- and post-impoundment water chemistry data for bicarbonates, TDS, specific conductance, and pH did not show any permanent changes in these parameters after dam completion The Green River immediately below the dam at Greendale was almost entirely sediment-free, but the silt-load increased progressively downstream and the researchers did not attribute the loss of fish reproduction to the decrease in sediment load. They found instead that the primary factor responsible for the shift in fish fauna from natives to exotics was most likely the change in water temperature caused by the dam. Since impoundment, water temperatures at least as far as seven miles downstream had not reached the mid-60 degree Fahrenheit range in which native fish were observed to spawn below the Yampa River (Vanicek et al. 1970).

Holden and Stalnaker (1975) observed a similar decrease in native fish below Glen Canyon Dam in Marble Canyon and in most of the Grand Canyon due to reduced water temperatures. From 1969-1971, they also found a loss of reproduction within Colorado squawfish populations in the Green River at Dinosaur National Monument; from 1964-1966, prior to the closure of Flaming Gorge Dam, Vanicek et al. (1970) showed abundant reproduction in the same waters (Joseph et al. 1977). Analyses of U.S. Geological Survey (USGS) records showed that dam operation has not reduced temperatures in most of the Colorado and Green River reaches that are still inhabited by Colorado squawfish (Kaeding and Osmundson 1988). Marsh (1985) reported that big river fishes persist in the Upper Colorado River basin only in areas other than those impacted by mainstream reservoirs or downstream reaches modified by hypolimnetic water releases.

A number of studies have documented the temperature preferences and tolerances of San Juan River rare and endangered fish species at various life history stages. Temperature preference refers to the tendency of a fish, when presented with a suitable range of temperatures in a restricted space, to congregate or spend most of its time in a relatively narrow range of temperatures (Black and Bulkley 1985). Adult Colorado squawfish appear to have the broadest thermal tolerance; they are currently found near Yuma, Arizona, where summer temperatures can reach 35°C and winter temperatures may be below 10°C. In their range within the Upper Colorado River basin, water temperatures fall as low as 0°C, while within the Lower Colorado River basin temperatures often exceed 35°C (Recovery Implementation Task Group 1987, Colorado River Fishes Recovery Team 1991). It is important to note, however, than main channel temperatures may not accurately represent actual temperature preferences because fish often use habitats outside the main channel, where water temperatures may be highly affected by ambient air temperatures and solar radiation (Colorado River Fishes Recovery Team 1991)

The temperature preference for adult Colorado squawfish, determined at the Willow Beach National Fish Hatchery, Arizona, was found to be 25.4°C, with maximum growth at 20°C (Colorado River Fishes Recovery Team 1991). Adult razorback sucker have a preference of 23-25°C (Black and Bulkley 1985).

Colorado squawfish spawning occurs from July-August and coincides with decreasing flows and rising water temperatures, with peak spawning occurring in late July (Haynes et al 1985). Tyus (1990), studying Colorado squawfish in the Upper Green River basin, found that spawning migrations were initiated at 14-20°C, with spawning occurring at 15-27.5°C (mean 22°). Tyus and Karp (1989) studied the Yampa River from 1981-88 and found that Colorado squawfish migrations occurred at a mean temperature of 14°C and spawning occurred at a mean temperature of 21°C Spawning of roundtail chub appears to occur at 18.3°C, but no field observations of spawning were made (Meneely et al. 1979).

Marsh (1985) studied the effect of incubation temperature on the survival of embryos of native fishes, including Colorado squawfish and razorback sucker. He found that total mortality for razorback sucker and Colorado squawfish embryos occurred in 12-96 hours at 5, 10, and 30° C and for squawfish in 48-60 hours at 15° C. Survival and percentage hatch were highest at 20° C for all species; hatched protolarvae were 0.2-1.3 mm longer in total length when reared at 20° than at 15 or 25°; and spinal and other anomalies were more frequent at 15 and 25° than at 20° C. Marsh (1985) also found that development rates were similar for all species studied, and concluded that the optimal temperature for hatching and development was probably near 20° C

Kaeding and Osmundson (1988) suggest that temperatures in the Upper Colorado River basin, where Colorado squawfish are restricted and declining, are sub-optimal for YOY and subadult growth. In the cold waters the fish experience lower growth rates, making them more susceptible to mortality and lengthening the time to sexual maturity. Black and Bulkley (1985) found the acute temperature preferences for yearling Colorado squawfish to be 21.9, 27.6, and 23.7°C for 14, 20, and 26°-acclimated fish, respectively. The final preference was determined to be 25°C YOY Colorado squawfish collected from the San Juan River from 1987-1989 were found in water temperatures of 18-28°C, and roundtail chub YOY were collected at temperatures of 13-25°C (Platania 1990). Bulkley et al. (1981) found subadult razorback sucker preferred temperatures of 23-29°C, with some fish dying at temperatures above 34°C and reduced activity levels at or below 14°C (Wick et al. 1982).

Water temperature data for the San Juan River basin have been collected regularly at USGS gaging stations since they were established. Temperature data for 1992 can be found in the USGS water resources data (Appendices 4d-f) (Cruz et al. 1993, ReMillard et al. 1993, Ugland et al. 1993). Although the temperature changes resulting from hypolimnial reservoir releases are attenuated within a short distance, reservoirs may change temperature regimes for greater distances by changing downstream flows.

Within the San Juan River basin there are currently two major reservoirs, Navajo Reservoir and Lake Powell. Navajo Reservoir, at the upper end of the San Juan River, in effect serves as a potential contaminants source for the basin by redistributing and possibly concentrating contaminants originating upstream; Lake Powell, at the terminus of the river, acts primarily as a contaminants sink.

Navajo Reservoir is located in San Juan and Rio Arriba counties in New Mexico, and in Archuleta County in Colorado (New Mexico Department of the Environment 1990). Water storage began in the reservoir in 1962, and operation began in 1963 (Goetz et al 1987, New Mexico Department of the Environment 1990). Normal reservoir capacity is 1,708,600 acre-feet (about 2.1 billion m^3) (Liebermann et al. 1989). The reservoir is fed by the San Juan River, Frances Creek, La Jara Creek, the Piedra River, Sambrito Creek, the Los Pinos River, Spring Creek, and a number of canyons (New Mexico Department of the Environment 1990). It is the third largest reservoir in the Upper Colorado River basin after Lake Powell and Flaming Gorge, and its dam is hypolimnial-release (Bureau of Reclamation 1976, Liebermann et al. 1989, New Mexico Department of the Environment 1990). In 1992 the reservoir did not fully support its cold and warmwater fisheries uses due to mercury contamination of fish; contamination was determined based on standards for human consumption of fish, rather than for fish health (New Mexico Water Quality Control Commission 1992)

The most recent water quality data available for the reservoir is from 1989 (Appendices 8a-d) (New Mexico Department of the Environment 1990) In 1989, despite temperature exceedances, the reservoir was fully supporting all of its designated uses (as listed in Table 5) (New Mexico Department of the Environment 1990).

There have been two significant attempts to analyze the effects of Navajo Reservoir on downstream water quality. Liebermann et al (1989) analyzed trends in streamflow and dissolved solids at USGS gaging stations. They found that, following the filling of Navajo Reservoir, streamflow in the San Juan River near Archuleta became almost constant and seasonal variability in dissolved solids concentration decreased. Goetz (1981) also analyzed historic water quality records and determined that daily streamflow and sediment load for the San Juan River at Shiprock decreased after 1963, in part due to the effects of Navajo Reservoir as a sediment-trap facility. She noted that the mean sediment concentrations at Shiprock for the pre- and post-1963 periods were nearly equal, suggesting that the decrease in streamflow caused by the filling of the reservoir resulted in the decreased sediment load.

Lake Powell, a hydroelectric and storage reservoir, began filling in 1963 behind Glen Canyon Dam on the Colorado River close to the Utah-Arizona border (Bussey et al. 1976). The reservoir covers 255 mi^2, primarily in southeastern Utah (Waddell and Wiens 1992). The San Juan and Colorado rivers constitute the two major tributaries to the lake. The tributaries contribute an estimated 60 million metric tons of sediment and 7.8 million metric tons of salt to the reservoir annually (Potter and Drake 1989, Waddell and Wiens 1992). The reservoir also retains a high portion of the trace elements that enter it; according to a study by Kidd and Potter (1978), dissolved concentrations of six trace elements entering Lake Powell were significantly higher than concentrations in water leaving.

The San Juan arm of Lake Powell receives nearly all suspended water quality constituents and most dissolved materials carried by the San Juan River (Platania et al. 1991). Both Colorado squawfish and razorback sucker have been verified in the San Juan arm (Roy and Hamilton 1992). Bank storage water quality in the San Juan arm is unknown but may serve as a significant source of trace elements draining into the lake when reservoir levels decrease (U S. Fish and Wildlife Service and U.S. National Park Service 1991). Sediment buildup in the San Juan arm occurs but has not been as large as in the Colorado arm because the lake rapidly widens at the San Juan River confluence (U.S. Fish and Wildlife Service and U.S. National Park Service 1991).

Several contaminant studies have been conducted on Lake Powell water quality and biota, although there have been no systematic contaminants studies for the entire lake (Waddell and Wiens 1992). The Lake Powell Research Project conducted studies of Lake Powell in the 1970s in order to establish baseline concentrations prior to the impact of large-scale heavy metal pollution on the lake. In one study, Bussey et al. (1976) examined the concentrations of ten metals in the flesh of Lake Powell fish. The results for eight of the 10 elements were summarized together (Table 23). The authors did not compile summary information for arsenic or selenium; however, they did note mean selenium concentrations in tissue of 0.50-179 mg/kg and mean arsenic concentrations in tissue of 0.03-10.80 mg/kg The fish were collected from two locations at the extreme lower end of Lake Powell.

Kidd and Potter (1978), also as part of the Lake Powell Research Project, collected sediment, soil, plankton, vegetation, and water samples from 15 sites on Lake Powell and its tributaries. Among these sites was one at Mexican Hat, Utah, and one at Lake Powell below the confluence of the San Juan River. The annual mean and range of cation concentrations in the surface water were compiled (Table 24), as were the annual mean and range of cations in bottom waters (Table 25). Kidd and Potter (1978) noted that the Navajo Power Plant was situated at the south end of Lake Powell and could potentially contribute various trace elements to the lake through fallout. They concluded that the only element that could increase in the lake as a result of fallout was selenium and that the amount added was insignificant in comparison to ambient water levels at the time.

The National Contaminant Biomonitoring Program (NCBP) has been documenting national trends of contaminants in fish and wildlife since 1967 (Lowe et al. 1985, Schmitt and Brumbaugh 1990). One of the program's sampling sites is at Lake Powell in Arizona. For each sampling period, common carp and largemouth bass (*Micropterus salmoides*) have been collected at Lake Powell to make three whole-body composite fish samples. The national geometric means are compared to the Lake Powell samples for the periods 1978-79, 1980-81, and 1984 (Table 26).

In the spring of 1991 the FWS began conducting a reconnaissance study of trace elements in water, sediment, and biota in Lake Powell (Waddell and Wiens 1992). The sampling sites include Piute Farms (Zahn Bay) and Cha Canyon (Slump Dam) in the San Juan arm of Lake Powell (Figure 10) (U.S. Fish and Wildlife Service and U.S. National Park Service 1991, Waddell and Wiens 1992). Samples were collected in the summer of 1991, November 1991, and July 1992. A total of 175 fish of 6 species at 16 sites and 22 sediment samples from 11 sites have been taken; additionally, 44 bile samples from two fish species at 15 sites have been taken for petroleum hydrocarbon exposure analysis. The results from 71 of the fish samples were available (Table 27) (Waddell and Wiens 1992). Preliminary analysis of the data suggests elevated levels of selenium, mercury, arsenic, and cadmium in the fish samples as compared to NCBP geometric mean data (Waddell and Wiens 1992).

4.5 SEDIMENT

The semi-arid watersheds of the San Juan River basin produce some of the highest sediment yields in the western United States, making sediment a major component of basin waters and potentially a concern for the health of native fishes (Wells and Rose 1981). Longitudinal studies have shown that total suspended solids loads and concentrations have varied over time in the San Juan River basin, but there is no consensus as to the effects that these changes have had on native fish populations (Wydoski 1980) Colorado squawfish, razorback sucker, and other native fishes evolved in environments that were generally turbid but also fluctuated widely; it has therefore been hypothesized that these fish are adapted to extremes and may benefit from high TSS concentrations (Holden 1979, Colorado River Fishes Recovery Plan 1991,

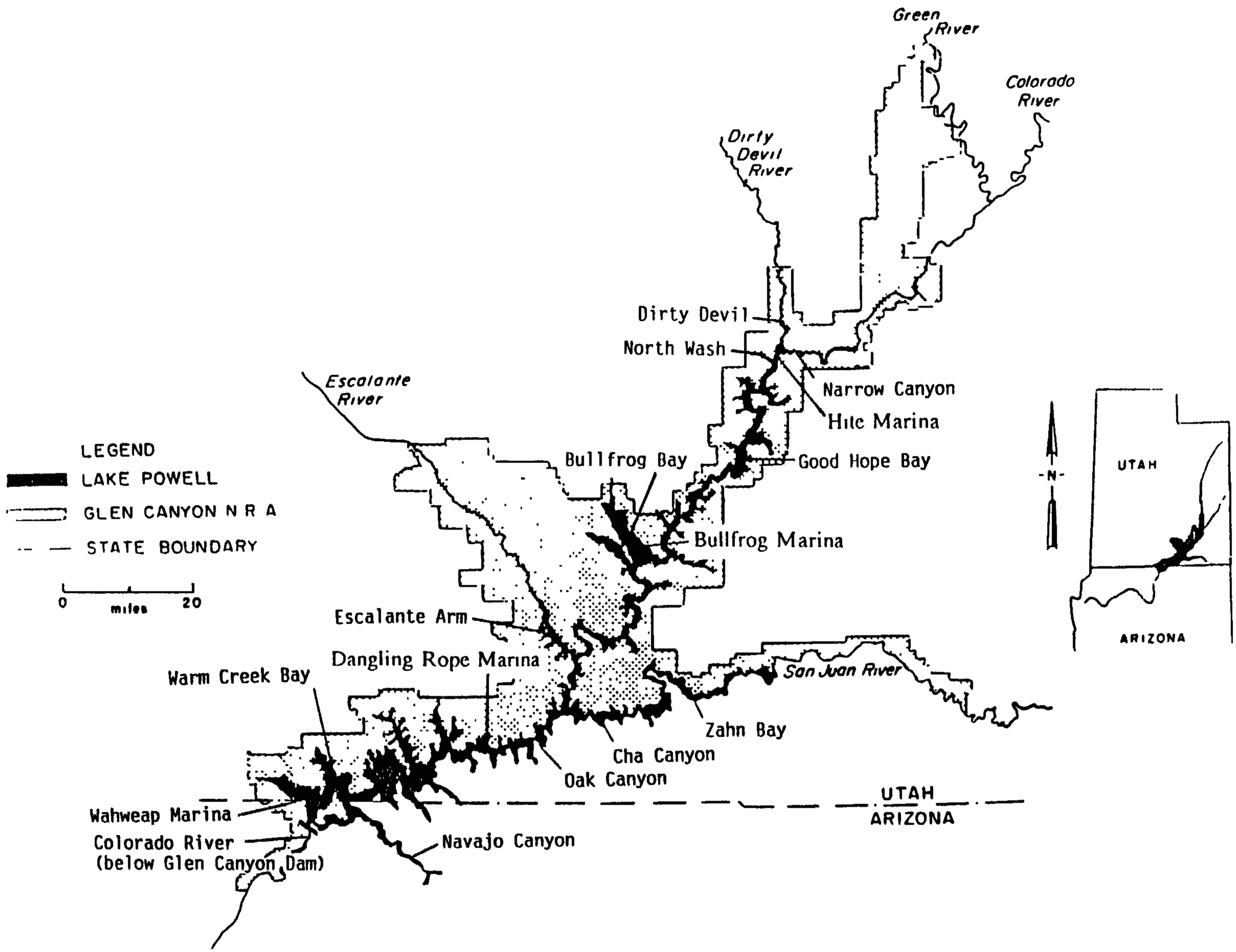

Figure 10. Lake Powell sample sites, U.S. Fish and Wildlife Service study, 1991-1992.
(Taken from Waddell and Wiens 1992)

Table 23: Mean concentrations of eight metals in the flesh of selected Lake Powell fishes, 1973 (all concentrations in dry weight)

Fish	No. tested	Calcium mg/g	Cadmium mg/kg	Chromium mg/kg	Copper mg/kg	Iron mg/g	Lead mg/kg	Magnesium mg/g	Zinc mg/g
Bass	3	0.697	0.008	0.429	1.339	0.012	0.210	1.576	0.029
Walleye	6	0.629	0.014	0.255	1.231	0.011	0.097	1.376	0.021
Black crappie	4	1.167	0.008	0.223	3.400	0.026	0.288	1.459	0.024
Channel catfish	4	0.475	0.011	0.111	1.822	0.020	0.121	1.190	0.039
Bluegill	3	0.858	0.002	0.384	2.623	0.016	0.312	1.414	0.036

Modified from Bussey *et al.* 1976

Table 24: Annual mean and range of selected elements in surface waters of Lake Powell and major tributary sites, 1974-1975

Site	Cd µg/l	Cr µg/l	Pb µg/l	Zn µg/l	Fe mg/l	Ca mg/l	As µg/l	Se µg/l	Mg mg/l	Cu µg/l
1	0.4	0.5	2	17	0.02	62	0.7	5	23	2
	0-0.9	0-0.9	0-9	4-49	0.004-0.05	53-68	0-1	2-8	20-26	0-4
2	0.2	0.9	0.6	9	0.02	62	1	2	22	2
	0-0.9	0-3	0.1-1	0-25	0.02-0.03	55-68	0-2	1-3	20-24	0-5
3	0.3	0.2	2	13	0.04	60	9	3	23	1
	0-0.8	0-0.5	0.5-9	2-47	0-0.08	46-68	5-12	0-7	20-25	0.3-3
5	0.2	0.04	0.7	13	0.03	58	4	16	21	1
	0.1-0.5	0-0.2	0-2	2-32	0.02-0.014	48-63	0-8	5-36	18-24	0-4
6*	0.6	0.9	3	17	0.03	59	3	2	19	3
	0.2-2	0-4	0.8-10	2-37	0.005-0.08	47-74	0 7-8	0.1-4	16-22	0-9
7	0.9	0.1	1	12	0 03	55	4	2	19	3
	0.1-2	0-0.4	0.2-3	1-27	0-0.04	48-63	2-6	0 2-3	16-24	0-6
8	0.6	0.5	2	8	0.06	54	3	0 9	19	2
	0-2	0-2	0.6-5	0-19	0.004-0.2	46-63	0-5	0.5-2	14-23	0-5
9	1	0.4	3	10	0.2	60	0.9	6	22	0.8
	0.1-5	0-2	0.4-9	2-21	0.02-0.6	43-76	0.2-1	0-13	13-29	0-3
Dirty	0.3	0.2	2	11	0.1	64	10	5	23	5
Devil	0-1	0-0.6	0.8-4	0-33	0.001-0.2	45-80	7-15	3-8	14-31	0 1-14
Colo. R.	0.9	9	5	31	4	91	7	4	28	19
at Moab	0-2	0-13	2-8	0-91	1-9	52-138	2-15	3-6	13-45	6-54
Colo. R. at	0.9	5	7	70	2	65	2	1	17	14
Gr. Junction	0.1-3	0-20	0-27	2-178	0.2-3	36-89	0.5-3	0.5-2	7-26	2-44
San Juan R.	1	12	9	74	7	9	3	5	26	30
at Mex. Hat	0.1-3	0-51	3-23	2-223	0.5-24	42-129	0-4	0-9	8-49	4-92
Gunnison	0.8	5	8	35	2	86	3	5	28	18
River	0-3	0-14	0-16	2-99	0.5-5	55-129	1-5	1-9	19-39	4-52
Green	2	12	5	320	7	76	1	6	30	23
River	0-8	0.4-45	0-10	0-1971	0.2-29	42-133	0 2-2	1-14	13-38	6-77
Dolores	2	3	8	67	3	99	4	4	40	17
River	0-4	0-10	0.6-18	5-156	0.5-9	37-137	0-9	1-6	8-68	4-54
Criteria**	10	50	50	500	30 (filterable)	-	50	10	-	1000

* Site 6: At Lake Powell below confluence of the San Juan River

** *Federal Water Pollution Control Administration* (FWPCA) water criteria

Taken from Kidd and Potter 1978

Table 25: Annual mean and range of selected elements in bottom waters, Lake Powell, 1974-1975

Site	Cd µg/l	Cr µg/l	Pb µg/l	Zn µg/l	Fe mg/l	Ca mg/l	As µg/l	Se µg/l	Mg mg/l	Cu µg/l
1	0.3	0.2	1	12	33	61	3	0.5	23	3
	0-0.7	0-0.7	0.4-3	1-27	16-50	52-68	0.8-4	0-0.9	20-25	0-5
2	0.6	0.2	4	15	50	72	2	5	26	3
	0.01-2	0-0.6	0-19	2-27	20-90	65-81	0-5	3-7	23-29	0.3-6
3	0.9	6	9	15	1252	76	2	1	28	6
	0-2	0-36	0-49	2-47	21-7322	55-89	0-4	0.1-2	24-32	0.1-14
5	1	0.2	3	16	73	71	4	7	26	3
	0-5	0-1	0.8-13	2-25	20-194	61-81	3-4	2-11	23-32	0-6
6*	0.9	5	5	15	1409	71	2	4	27	8
	0.3-2	0-31	2-15	2-42	20-5257	56-82	0-4	3-6	24-29	0-16
7	1	1	1	12	86	71	0.5	7	26	4
	0.1-3	0-1	0.4-6	2-22	31-116	65-79	0-2	4-12	24-29	0-16
8	1	9	4	17	2941	74	8	1	27	8
	0.2-3	0-44	0-14	4-33	16-15,022	62-92	2-20	0.9-2	18-32	0.1-25
9	0.7	6	4	13	2094	71	2	2	28	9
	0.1-1	0-35	0.8-10	0-28	110-10,891	56-78	0.4-6	0-7	18-30	0-36

* Site 6: At Lake Powell below the confluence of the San Juan River

Modified from Kidd and Potter 1978

Table 26: NCBP geometric mean concentrations, and Lake Powell concentrations

All concentrations are in µg/g wet weight

	1978-79		1980-81		1984	
Element	Nat'l	L. Powell	Nat'l	L. Powell	Nat'l	L. Powell
Arsenic	0.16	0.21 (cc) 0.14 (cc) 0.19 (lm)	0.15	0.16 (cc) 0.13 (cc) 0.72 (lm)	0.14	0.09 (cc) 0.10 (cc) 0.21 (lm)
Cadmium	0.04	0.37 (cc) 0.32 (cc) 0.02 (lm)	0.03	0.18 (cc) 0.20 (cc) 0.01 (lm)	0.03	0.18 (cc) 0.17 (cc) 0.00 (lm)
Copper	0.82	1.8 (cc) 1.4 (cc) 0.6 (lm)	0.65	1.2 (cc) 1.0 (cc) 0.4 (lm)	0.65	0.95 (cc) 1.14 (cc) 0.67 (lm)
Mercury	0.12	0.09 (cc) 0.14 (cc) 0.08 (lm)	0.12	0.12 (cc) 0.10 (cc) 0.11 (lm)	0.10	0.08 (cc) 0.09 (cc) 0.18 (lm)
Lead	0.19	0.43 (cc) 0.43 (cc) 0.25 (lm)	0.17	0.19 (cc) 0.15 (cc) 0.10 (lm)	0.11	0.28 (cc) 0.43 (cc) 0.08 (lm)
Selenium	0.48	2.99 (cc) 2.77 (cc) 2.94 (lm)	0.46	1.12 (cc) 0.93 (cc) 0.67 (lm)	0.42	1.61 (cc) 1.78 (cc) 1.37 (lm)
Zinc	23.8	101.7 (cc) 92.2 (cc) 22.9 (lm)	21.4	67.3 (cc) 60.2 (cc) 13.5 (lm)	21.7	66.68 (cc) 64.99 (cc) 13.80 (lm)

(cc) = common carp

(lm) = largemouth bass

Taken from Lowe et al 1985, Schmitt and Brumbaugh 1990

Table 27: Trace element concentrations (ug/g dry weight) in fish muscle viscera, and whole-body samples of selected speces from Lake Powell, Utah, during the summer of 1991

Sample Site	Species	Tissue	% Moist	Al	As	Ba	Be	B	Cd	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Mo	Ni	Se	Sr	V	Zn
Lee's Ferry	Rainbow trout	Whole-body	69.4	15	1.6	2.4	0.01	<2	0.03	0.6	7.1	70	<0.1	710	3.6	0.14	<1	0.5	4.6	16.8	<0.3	50.0
Wahweap Marina	Channel catfish	Muscle	77.7	9	0.2	0.2	0.01	<2	0.03	0.2	2.4	29	<0.1	1070	0.8	0.34	<1	<0.2	4.3	2.4	<0.3	24.0
		Viscera	64.9	140	0.4	7.5	0.01	<2	0.06	0.6	3.9	179	0.6	1180	15.0	0.10	<1	0.5	3.7	98.4	1.3	96.6
Wahweap Marina	Common carp	Whole-body	74.0	25	0.2	11.3	0.01	<2	0.69	1.5	4.3	141	1.0	1310	6.5	0.29	<1	0.9	11.0	137.0	0.5	316.0
Warm Creek	Black crappie	Whole-body	76.7	15	1.1	7.1	0.01	<2	0.06	0.9	0.8	55	<0.1	1970	6.8	0.19	<1	0.4	7.1	309.0	<0.3	89.3
Warm Creek	Bluegill	Whole-body	76.0	64	0.5	10.9	0.01	<2	0.05	2.3	4.0	128	<0.1	1190	7.9	0.06	<1	1.3	13.0	155.0	<0.3	60.6
Warm Creek	Channel catfish	Muscle	79.5	342	0.2	10.2	0.01	<2	0.13	2.9	10.0	341	<0.1	1350	8.8	0.32	<1	1.6	4.6	109.0	1.5	81.8
		Viscera	74.4	5	0.4	0.3	0.01	<2	0.04	0.5	1.9	34	0.4	971	0.7	0.13	<1	0.3	5.1	2.5	<0.3	15.0
Warm Creek	Common carp	Whole-body	76.8	32	0.3	7.2	0.01	<2	1.10	0.5	5.0	173	0.8	1320	5.4	0.35	<1	0.3	11.0	136.0	0.6	283.0
Warm Creek	Smallmouth bass	Muscle	77.8	6	1.1	0.2	0.01	<2	0.03	<0.1	0.9	15	<0.1	1360	0.4	0.75	<1	<0.2	9.7	3.4	<0.3	19.0
		Viscera	68.1	38	1.4	7.5	0.01	<2	0.04	1.0	6.5	90	<0.1	1540	4.6	0.26	<1	0.8	6.9	179.0	<0.3	64.8
Warm Creek	Striped bass	Muscle	72.2	8	1.4	0.7	0.01	<2	0.03	0.2	1.7	42	<0.1	1100	0.7	0.47	<1	0.2	8.8	4.2	<0.3	17.0
		Viscera	63.4	67	1.8	10.7	0.01	<2	0.08	2.0	9.5	153	<0.1	1110	5.4	0.18	<1	1.1	6.5	125.0	<0.3	72.5
Warm Creek	Threadfin shad	Whole-body	74.0	280	1.7	4.5	0.01	<2	0.11	0.8	3.8	268	0.1	1330	14.0	0.22	<1	0.6	7.8	48.3	0.6	82.8
Navajo Canyon	Channel catfish	Muscle	79.5	42	0.2	8.1	0.01	<2	0.68	0.3	4.3	159	<0.1	1410	5.5	1.00	<1	0.3	5.5	151.0	0.6	243.0
		Viscera	72.5	3	0.1	0.1	0.01	<2	0.03	0.4	1.5	17	0.2	996	0.8	0.29	<1	0.4	6.3	1.0	<0.3	15.0
Navajo Canyon	Common carp	Whole-body	74.5	110	0.3	9.8	0.01	<2	0.04	1.2	1.4	90	0.5	1630	7.0	0.54	<1	0.4	12.0	163.0	0.7	109.0
Navajo Canyon	Green sunfish	Whole-body	77.1	319	0.6	75.8	0.01	<2	0.06	2.8	2.0	268	0.5	1180	10.0	0.30	<1	0.5	8.5	80.1	1.1	83.4
Navajo Canyon	Smallmouth bass	Muscle	76.1	5	1.3	0.1	0.01	<2	0.03	0.2	1.1	16	<0.1	1010	0.7	0.70	<1	0.3	9.5	1.1	<0.3	21.0
		Viscera	70.3	100	1.4	9.6	0.01	<2	0.13	5.5	2.2	101	<0.1	1410	7.2	0.26	<1	2.4	7.4	177.0	<0.3	85.6
Navajo Canyon	Striped bass	Muscle	70.4	9	1.5	0.1	0.01	<2	0.03	0.1	1.4	15	<0.1	1190	0.6	0.50	<1	<0.2	8.6	1.5	<0.3	17.0
		Viscera	60.3	3	2.0	2.2	0.01	<2	0.04	0.5	2.1	53	0.4	1030	2.3	0.15	<1	0.3	6.4	111.0	<0.3	49.1
Navajo Canyon	Threadfin shad	Whole-body	77.4	658	2.0	11.3	0.02	<2	0.10	2.1	4.1	365	0.4	1610	50.5	0.41	<1	1.2	5.8	61.3	1.1	96.7
Bullfrog Bay	Bluegill	Whole-body	71.3	21	<0.2	6.5	0.01	<2	0.02	1.1	5.0	37	<0.4	1280	4.7	0.07	<1	0.7	6.8	158.0	0.5	82.4
Bullfrog Bay	Channel catfish	Whole-body	80.3	130	0.4	4.3	0.01	<2	0.20	0.6	<2	188	<0.4	1390	6.6	0.54	<1	0.5	4.8	107.0	1.8	89.4
Bullfrog Bay	Common carp	Whole-body	71.4	200	0.3	8.0	0.01	<2	0.57	0.7	5.0	239	0.5	1330	6.5	0.33	<1	0.4	7.6	112.0	0.8	223.0
Bullfrog Bay	Largemouth bass	Muscle	79.0	<3	0.5	0.1	0.01	<2	0.02	0.7	<2	24	<0.4	1270	<0.2	0.65	<1	0.6	11.0	1.1	1.0	21.0
		Viscera	68.5	13	0.5	3.2	0.01	<2	0.02	0.8	<2	48	<0.4	1330	1.4	0.26	<1	0.9	6.5	113.0	2.1	51.6
Bullfrog Bay	Striped bass	Muscle	78.3	<3	0.4	0.2	0.01	<2	0.02	0.2	5.0	29	<0.4	1270	0.3	1.20	<1	<0.1	11.0	2.0	<0.3	18.0
		Viscera	73.1	19	0.8	6.7	0.01	<2	0.13	0.5	3.0	96	<0.5	1250	2.9	0.58	<1	0.3	10.0	79.2	<0.3	69.8
Bullfrog Bay	Threadfin shad	Whole-body	76.5	608	1.1	19.2	0.02	<2	0.17	1.7	4.0	326	1.0	1290	17.0	0.10	<1	2.1	6.5	79.3	5.4	78.8
Good Hope Bay	Channel catfish	Whole-body	81.5	120	0.5	13.6	0.01	<2	0.23	0.8	6.0	194	<0.4	4650	4.9	0.51	<1	0.3	3.6	80.2	0.6	100.0
Good Hope Bay	Common carp	Whole-body	70.1	296	0.8	9.8	0.01	<2	0.54	1.1		242	0.6	1730	12.0	0.44	<1	0.7	4.4	136.0	0.8	218.0
Good Hope Bay	Smallmouth bass	Muscle	75.9	<3	1.9	0.1	0.01	<2	0.02	0.6	5.0	12	<0.4	1170	<0.2	0.25	<1	0.2	5.6	2.7	<0.3	20.0
		Viscera	68.3	96	1.4	6.2	0.29	29	0.02	1.0	3.0	105	<0.4	1090	2.5	0.09	<1	0.5	4.2	109.0	0.5	57.1
Good Hope Bay	Striped bass	Muscle	75.6	<3	1.6	<0.1	0.01	<2	0.02	0.3	<2	17	<0.4	1130	<0.2	0.23	<1	0.2	5.3	0.3	0.3	16.0
		Viscera	65.3	54	2.4	6.0	0.01	<2	0.02	0.4	3.0	68	<0.4	1260	4.6	0.08	<1	0.3	3.3	78.4	0.3	54.6
Good Hope Bay	Threadfin shad	Whole-body	81.6	8000	3.7	46.0	0.28	6	0.29	7.0	18.0	3660	3.1	1320	100.0	0.06	<1	4.0	3.8	160.0	9.4	132.0

Table 27 (cont.): Trace element concentrations (ug/g dry weight) in fish muscle viscera, and whole-body samples of selected speces from Lake Powell, Utah, during the summer of 1991

Sample Site	Species	Tissue	% Moist	Al	As	Ba	Be	B	Cd	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Mo	Ni	Se	Sr	V	Zn
North Wash	Largemouth bass	Muscle	79.4	<3	1.0	<0.1	0 01	<2	0.02	0.8	7.8	13	<0.5	1330	<0.2	0.57	<1	0.3	9 0	1.0	<0 3	21.0
		Viscera	77.9	28	1.2	1.8	0.01	<2	0.02	0 9	3 0	88	<0.4	890	5.0	0.35	<1	0.6	6.4	73.1	0 4	67.6
Narrow Canyon	Channel catfish	Whole-body	77 4	120	0 4	3.7	0.01	<2	0 13	1.3	<2	146	0.5	4240	3.9	0.45	<1	0.8	3.7	97.8	1.0	76.1
Narrow Canyon	Common carp	Whole-body	71.2	150	0.8	8 3	0.01	<2	0.39	0 8	4 0	177	0 8	1220	6.8	0.36	<1	0.7	4.8	149.0	1.9	327.0
Narrow Canyon	Fl'mouth sucker	Whole-body	79.3	160	<0 2	6.8	0 01	<2	0 26	0.9	3 0	164	3.1	1380	15.0	1 02	<1	0 6	5.7	96.6	1.4	79.5
Narrow Canyon	Striped bass	Muscle	79.2	12	1.0	0 4	0.01	<2	0 02	0.4	<2	28	<0.4	1200	0.3	1.30	<1	0 2	7.4	3.5	<0.3	19.0
		Viscera	75.8	210	1.5	9.1	0.01	<2	0 08	1 2	<2	206	<0.4	1200	5.9	0 76	<1	0.6	7.1	114.0	1.0	71 5
Dirty Devil Canyon	Bluegill	Whole-body	77 4	497	1 4	7 8	0 02	<2	0.10	1.7	<2	274	<0 5	1410	34.3	0.14	<1	1 4	5 4	147.0	3.3	81.2
Dirty Devil Canyon	Channel catfish	Whole-body	78 7	300	0.5	3 7	0 01	<2	0.37	1 1	4.0	210	<0 4	1670	15.0	0 36	<1	0.8	3.5	70.8	1 1	77.7
Dirty Devil Canyon	Common carp	Whole-body	69 6	130	0.9	6 5	0 01	<2	0 84	0 4	4.0	146	0.6	1860	5.7	0.57	<1	0.2	4 0	154.0	0.7	230 0
Oak Canyon	Channel catfish	Whole-body	78 7	13	0 2	4.0	0 01	<2	0 07	1 7	<2	133	<0.4	1220	3 1	0.28	<1	0.9	3 9	87 8	0 7	84.4
Oak Canyon	Largemouth bass	Muscle	79 5	9	0 4	<0 1	0.01	<2	0 02	0 3	<2	20	<0 4	1200	<0 2	0 72	<1	0 4	10.0	1.7	0.4	18.0
		Viscera	72.1	12	0 4	3 8	0.01	<2	0 02	0 6	3 0	62	<0.4	1170	2 1	0 31	<1	0 3	6.9	114.0	<0.3	58 3
Oak Canyon	Threadfin shad	Whole-body	73 5	4040	2 5	99 1	0 18	4	0 20	6 5	9 5	2230	2 2	5940	60.6	0.09	<1	3 5	4.8	119.0	5.8	73.6
Cha Canyon	Bluegill	Whole-body	73 8	3	0 5	2 6	0 01	<2	0 03	1 1	1 0	51	<0 1	706	2.9	0.26	<1	0 6	5.9	61.6	<0 3	39 6
Cha Canyon	Channel catfish	Whole-body	78 0	280	0 4	15 4	0 01	<2	0 97	2 2	5 4	330	0 5	1630	11 0	0 54	<1	1 2	5.4	188.0	1 3	223 0
Cha Canyon	Common carp	Whole-body	73 1	52	0 4	5 5	0 01	<2	0 03	0 4	1 8	73	0 6	1300	3 9	0 41	<1	0.4	7.1	160 0	0.4	67.8
Cha Canyon	Largemouth bass	Muscle	79 9	3	0 9	0 1	0 01	<2	0 04	0.2	0 9	14	<0.1	1020	0 7	1.00	<1	0 3	9.0	0.8	<0 3	22.0
		Viscera	75 5	110	0 8	7 2	0 01	<2	0 08	1.2	3 2	125	<0 1	608	3 2	0 47	<1	0.7	6.8	49 0	0.4	56.2
Cha Canyon	Striped bass	Muscle	78 8	4	1 0	0.1	0 01	<2	0 04	0 1	1 1	12	0 2	1130	0 4	4.20	<1	0 3	5 4	2 0	<0.3	19.0
		Viscera	76 6	9	0 8	2.1	0 01	<2	0.04	0.5	1.8	65	0 2	1010	1 8	1 49	<1	0 4	6 5	105.0	<0.3	61 9
Escalante Canyon	Bluegill	Whole-body	75 4	34	0 4	5 5	0 01	3	0 09	0 7	<2	76	<0 4	1370	6.3	0 16	<1	0 7	6 8	171 0	0 6	83 4
Escalante Canyon	Common carp	Whole-body	76 6	59	<0 2	15 4	0 01	<2	1 20	1 4	6 0	189	1 0	1240	13 0	0 69	<1	0.8	8 4	209 0	0.9	328 0
Escalante Canyon	Largemouth bass	Muscle	79 7	<3	0 7	<0 1	0 01	<2	0 02	0 8	4 0	16	<0 4	1270	<0 2	0 54	<1	0 4	9 8	2 2	<0.3	20 0
		Viscera	73 2	17	1 0	2 9	0 01	<2	0 03	0 6	<2	52	<0 4	1190	1 9	0 24	<1	0 4	6 6	116 0	<0 3	55.6
Escalante Canyon	Threadfin shad	Whole-body	79 8	6890	2 5	73 7	0 24	8	0 11	7.4	9 0	3360	3 4	1430	94 1	0 19	<1	3 9	8 9	115 0	10 0	87 8
Zahn Canyon	Channel catfish	Whole-body	76 8	180	0 3	11 2	0 01	<2	0 07	1 4	5 1	197	0 4	1430	11 0	0.82	<1	0 4	3 2	163 0	0 7	91 7
Zahn Canyon	Common carp	Whole-body	73 8	170	0 7	9 6	0 01	<2	0 67	0 5	4 3	172	0 7	1360	9 2	0 65	<1	0 4	4 4	180.0	0 7	238.0
Zahn Canyon	Smallmouth bass	Whole-body	77 7	57	1 2	5 2	0 01	<2	0 05	0 6	6 0	112	0 7	1430	5 0	0 49	<1	0 4	4 2	127 0	<0 3	64.3
Zahn Canyon	Striped bass	Muscle	75 3	3	1 6	0 1	0.01	<2	0 03	0 8	1 2	19	<0 1	935	0 7	2 20	<1	0.5	7 6	0.8	<0.3	15 0
		Viscera	68 6	10	1 2	3 9	0 01	<2	0 03	0 4	1 5	54	0 1	695	4.2	0 66	<1	0 3	6.2	72 1	<0.3	42 6

Taken from Waddell and Wiens 1992

Valdez et al. 1992). Osmundson and Kaeding (1989) suggest that, in the Colorado River, increased water clarity may put native fishes, especially juveniles, at a disadvantage to exotic sight-feeding predators. They also note that Colorado squawfish are more likely to use shallow-water habitats when turbidity is high and move into deeper waters during periods of high clarity (Osmundson and Kaeding 1989).

Very little evidence exists regarding the effects of sediment, suspended or settleable, on fish populations in general, let alone on San Juan basin fish. According to the European Inland Fisheries Advisory Commission (1969), high TSS may affect fish and fish food populations in four ways: 1) reduced growth rate and resistance to diseases, 2) impeded development of fish eggs and larvae, 3) altered movements and migrations, and 4) reduced food abundance (Valdez et al. 1992). Although this assessment assumes that the fish species in question are not adapted to high TSS environments, it is nevertheless pertinent to San Juan basin native fish to the extent that changes in TSS may indeed affect their growth rates, egg and larvae development, movements and migrations, and food abundance.

Because larval and juvenile fish are highly vulnerable to environmental stress, there has been an emphasis on determining the effects of TSS on fish reproduction. Muncy et al. (1979) compiled a fairly substantial review of the effects of suspended and settleable solids on the reproduction and early life-history of warmwater fishes. A summary of the most significant findings:

·As of 1979, no substantial empirical evidence existed for the sensitivity of warmwater fish eggs and larvae to suspended sediment.

·Only limited evidence exists linking TSS to effects on gonad development (but according to Muncy this evidence has been inadequately investigated).

·As sediment loads increase, those species whose reproductive activities are carried on outside the times of highest turbidity will be most successful.

·Species that protect developing eggs from siltation, behaviorally or otherwise, will be at an advantage if sediment loads increase.

·Reproductive failure may result from direct loss of spawning habitat through siltation of clean bottoms and vegetation loss.

·Fishes with complex patterns of reproductive behavior are vulnerable to interference by suspended solids, especially if there is a strong visual component to the spawning behavior.

·Death to embryos by smothering may occur when sediment deposition is sufficient for complete burial of eggs, interfering with gas exchange across membranes.

·Laboratory bioassays indicate that larval stages of selected species are less tolerant of suspended solids than are eggs or adults.

·Larvae and juveniles employing tactile senses for food detection are more suited for existence under low levels of illumination and possibly derive benefits from the concealing properties of suspended solids.

·There is evidence that larvae and juveniles of several species are able to successfully circumvent the adverse effects of sustained high levels of suspended solids through functional and behavioral adaptations conducive to survival in highly turbid habitats.

The majority of these findings are fairly intuitive, and, as none of them is quantitative, they give little guidance for policymakers attempting to protect fish. Unfortunately, there is apparently no better information, especially for San Juan basin native fishes.

Although no substantive information exists concerning the effects of sediment on fishes of the San Juan basin, there is a relative wealth of sediment load and concentration data for the basin, and these data have allowed for analyses of historic trends. Records and accounts show that rivers in the Upper Colorado River basin experienced dramatic sediment load increases in the early 1900s (Joseph et al. 1977). More specifically, accounts indicate that from 1880-1920, many arroyos in the San Juan basin, particularly in New Mexico, incised and contributed large volumes of sediment to main channels. The formation of these large arroyos is believed to have been caused either by the climate or land use practices. Since 1920, many arroyos have been evolving through the process of channel deepening, followed by channel widening, then floodplain formation, and finally the establishment of vegetation (Figure 11). This progression of channel changes proceeds upstream through a watershed and eventually leads to channel aggradation and reduced sediment yields. There is an initial period of high erosion and sediment yields that decrease through time, with downstream reaches aggrading while upstream reaches are still in the process of eroding (Gellis 1992).

A number of studies have reported decreasing trends in sediment load and concentration over time in the San Juan basin. Sediment data beginning in the early 1900s suggest that sediment load, at least in the San Juan River, decreased prior to the closing of Navajo Reservoir (Joseph et al. 1977). Gellis (1992) analyzed the annual suspended sediment concentrations of the Animas River at the Farmington gaging station (USGS #09364500). This station drains an area of 1,390 mi^2. Records of sediment load and runoff for the Farmington station from 1950-1990 indicated a decrease in annual suspended sediment loads relative to annual runoff (Figure 12a), and an analysis of annual suspended sediment concentrations for the same period showed a decreasing trend whose significance has been supported by a Spearman's rank correlation test (Figure 12b). There are no reservoirs upstream of the Farmington station to alter sediment load, suggesting other causes for the decrease. That five other stations in New Mexico, all outside the San Juan basin, each showed similar downward trends in sediment concentration suggests a common cause, whether climatic or anthropogenic (Gellis 1992). Goetz and Abeyta (1987) suggested that the decrease in sediment concentration at Farmington may be due in part to efforts to decrease erosion from farmed lands as well as from a change in land use from farms to resort properties.

Navajo Reservoir has affected sediment load downstream in the San Juan River, although no quantitative analyses of its effect have been conducted. The sediment trap efficiency of reservoirs such as Navajo commonly exceeds 95% (Thompson 1982). This effect may be tempered, however, if the transport capacity of reduced flows below a dam are increased as a result of deposition within the reservoir of the original bed load (Joseph et al. 1977).

It is difficult to identify the effects of Navajo Dam on sediment load within the San Juan River because a number of other land and water use changes occurred at approximately the same time as the closing of the reservoir in 1963. The mean sediment load at the USGS Shiprock gaging station (USGS #09368000) decreased from 26,621,232 to 21,182,582 kg/day from before 1963 to the period 1963-1979. The streamflow mean also decreased, from 64.8 to 52.1 m^3/second for the same periods. The mean sediment concentration for the two periods was nearly equal, indicating that the decrease in streamflow caused by the reservoir led to a subsequent decrease in sediment load (Goetz 1981).

Thompson and Mundorff (1982) analyzed suspended sediment records from the USGS gaging station on the San Juan River at Bluff, Utah (USGS #09379500) (Figures 13a and 13b). According to historic data, Navajo Reservoir, which is 180 miles upstream of Bluff, has apparently had no significant effect on the relationship between stream discharge and suspended sediment load at Bluff. This is to be expected, because Navajo Dam impounds runoff from less than 14% of the drainage area upstream from Bluff. Furthermore, much of the area draining to the reservoir is underlain by crystalline rock and is well vegetated, resulting in a much lower sediment yield per unit area than is found in downstream portions of the basin (Thompson and Mundorff 1982). In contrast, the lower San Juan basin's sedimentary deposits contribute a disproportionate amount of suspended sediment to the San Juan River. Naturally occurring sediment loads, a large portion of which are caused by erosion of dry washes during summer storms, are supplemented by irrigation return flows (Joseph et al. 1977, Bureau of Land Management 1984).

Suspended sediment contributions throughout the San Juan basin are not uniform (Table 28) (Thompson and Mundorff 1982). Canyon Largo, the Chaco River, and Chinle Wash all contribute large sediment loads (Melancon et al. 1979). The 10,100 mi^2 drainage area downstream from the USGS Shiprock gaging station has historically yielded more sediment than the 12,600 mi^2 area upstream from Shiprock. Of the sediment discharge at Shiprock, about 9% originates from the Animas River, which contributes 43% of the water discharge. Furthermore, the annual suspended sediment load at Bluff includes a disproportionately large amount of sediment from the 8,400 mi^2 area downstream from the

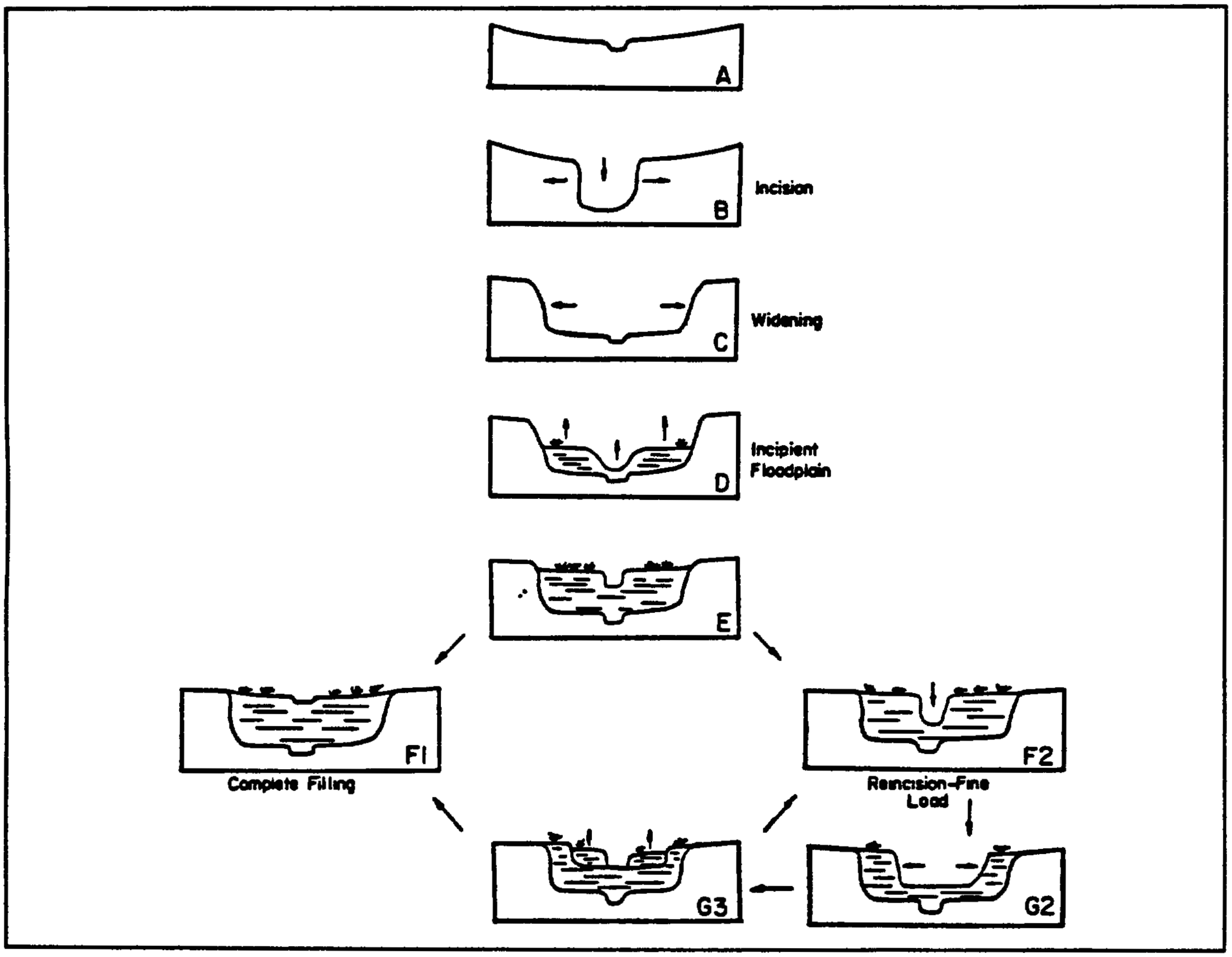

Figure 11. Stages of arroyo evolution. (Taken from Gellis 1992)

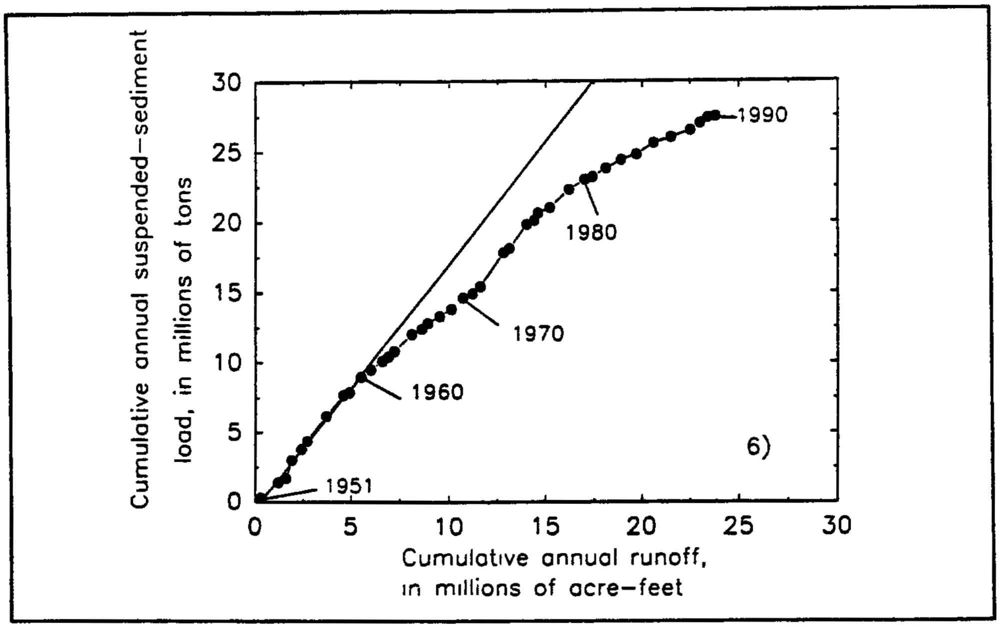

Figure 12a. Relation between annual suspended sediment load and annual runoff for Animas River at Farmington, New Mexico. (Taken from Gellis 1992)

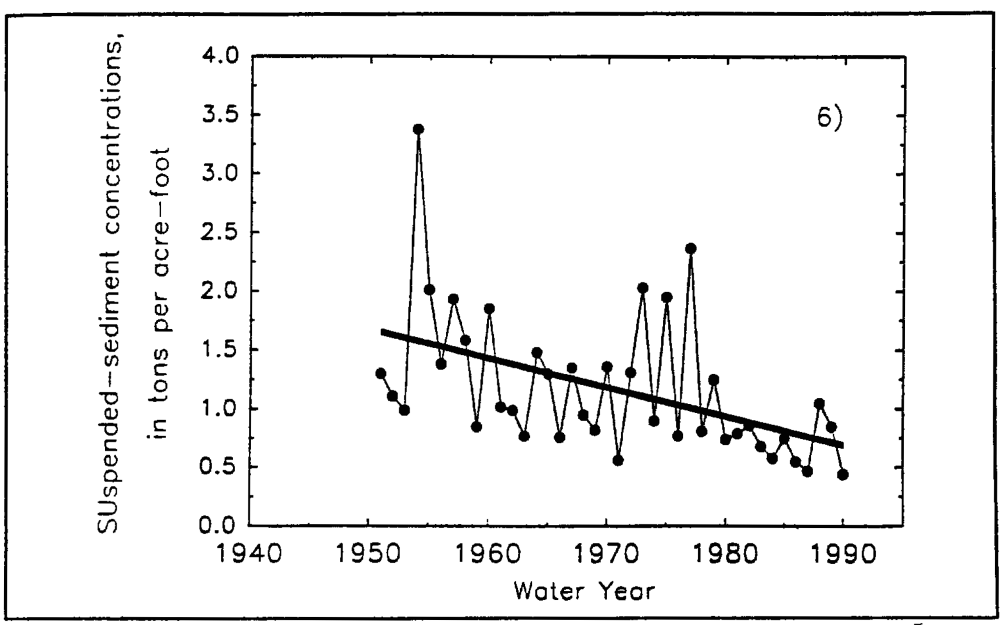

Figure 12b. Annual suspended sediment concentrations through time for the Animas River at Farmington, New Mexico. (Taken from Gellis 1992)

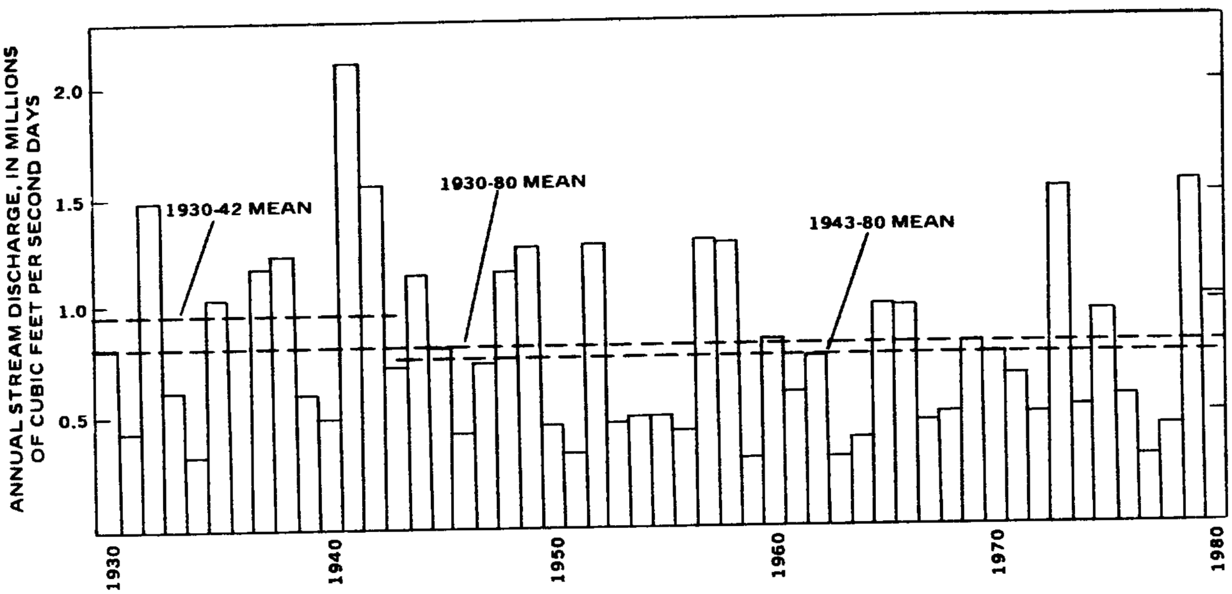

Figure 13a. Annual stream discharge, San Juan River near Bluff, Utah, water years 1930-1980.
(Taken from Thompson and Mundorff 1982)

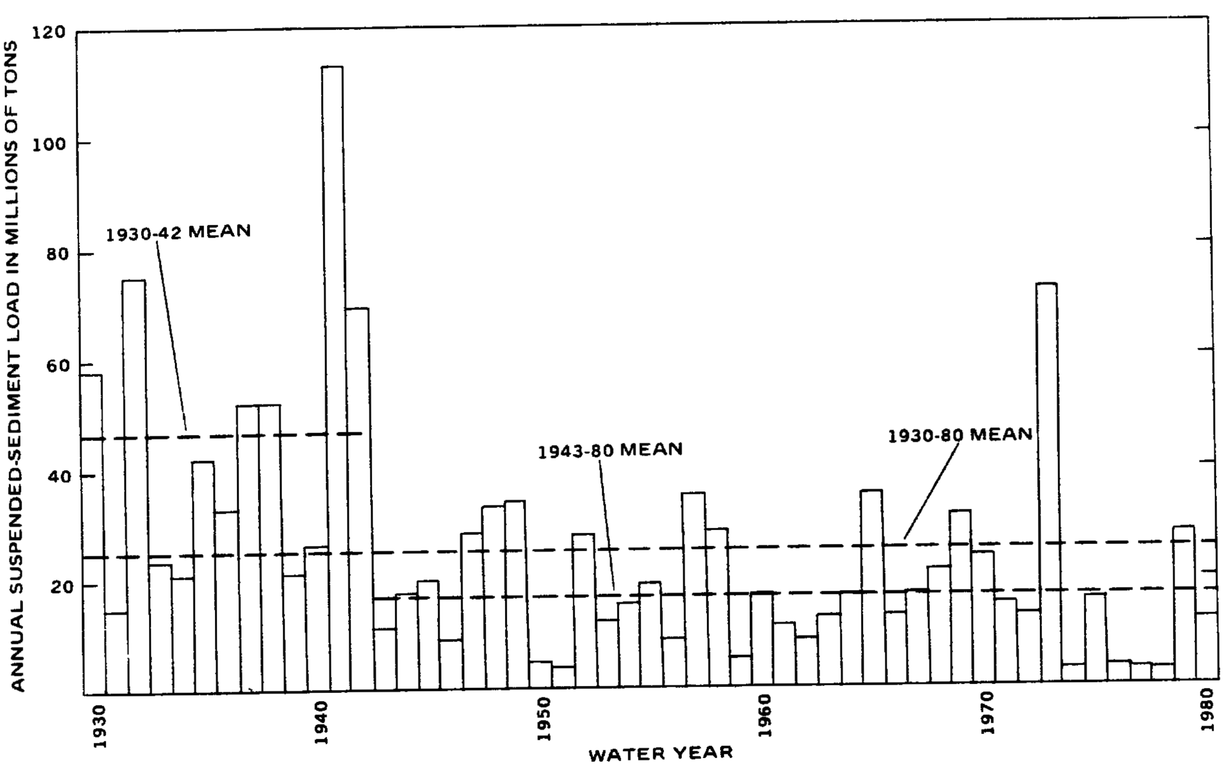

Figure 13b. Annual suspended sediment load, San Juan River near Bluff, Utah, water years 1930-1980. (Taken from Thompson and Mundorff 1982)

Table 28: Relative contributions of stream and suspended sediment discharges in the San Juan River from various parts of the ba

Water Year	Animas River at Farmington, NM (station 09364500) — Percentage of discharge of San Juan River at Shiprock: Streamflow	Sus sed	San Juan River at Shiprock, NM (station 09368000) — Percentage of discharge of San Juan River at Shiprock: Streamflow	Sus sed	Cottonwood Wash near Blanding, UT (station 09378700) — Percentage of discharge of San Juan River at Shiprock: Streamflow	Sus sed
1952	38	8	98	40	--	--
1953	43	17	92	18	--	--
1954	40	3	96	74	--	--
1955	43	3	97	62	--	--
1956	42	7	100	59	--	--
					--	--
1957	39	4	96	63	--	--
1958	38	9	94	59	--	--
1959	45	10	101	46	--	--
1960	36	8	100	84	--	--
1961	41	7	99	64	--	--
					--	--
1962	40	15	95	44	--	--
1963	74	7	81	34	--	--
1964	44	5	88	58	--	--
1965	44	13	95	24	--	--
1966	31	10	89	30	--	--
					--	--
1967	39	3	88	87	--	--
1968	61	8	88	31	1 (1)	10 (1)
1969	40	4	93	42	0.5	1
1970	45	9	89	37	0.2	1
1971	40	6	91	31	0.1	0.5
					--	--
1972	38	6	104	28	--	--
1973	47	18	82	18	--	--
1974	30	20	96	41	--	--
1975	50	17	91	64	--	--
1976	40	15	91	58	--	--
					--	--
1977	35	7	81	156	--	--
1978	68	8	92	183	--	--
1979	39	10	88	45	--	--
1980	45	13	88	40	--	--

(1) March-September 1968

Note: The drainage area of the Animas River at Farmington is 1,360 square miles or about 11 percent of the drainage area upstream from San Juan River at Shiprock.

The drainage area of the San Juan River at Shiprock is 12,600 square miles or about 55 percent of the drainage area upstream from San Juan River near Bluff, which has a drainage area of 23,000 square miles

The drainage area of Cottonwood Wash near Blanding is 205 square miles or about 1 percent of the drainage area upstream from San Juan River near Bluff.

Taken from Thompson and Mundorff 1982

confluence of the San Juan and Animas rivers and upstream from Shiprock; this area includes the Chaco River drainage (Thompson and Mundorff 1982).

During storm runoff events, the numerous tributaries to the San Juan River carry high sediment loads and are consequently high in turbidity (New Mexico Department of the Environment 1992). Stormflows in these tributaries often have sediment concentrations that exceed 10,000 mg/l (Stone et al. 1983). These tributaries may substantially increase sediment concentrations in the San Juan River, although the effect on annual sediment load in the river is minimal (Thompson and Mundorff 1982).

During its 1991 intensive water quality stream survey of the San Juan River from Bloomfield to Shiprock, the New Mexico Department of the Environment recorded the results of a runoff event that produced heavy runoff within Canyon Largo, an arroyo that enters the San Juan River near Blanco (New Mexico Department of the Environment 1991). Canyon Largo drains 1700 mi^2 and is one of the more significant sources of salinity in the San Juan River (New Mexico Department of the Environment 1992). Before the event, suspended solids as well as nutrients and dissolved constituents were low to moderate in concentration, increasing gradually downstream. During the event non-filterable residue in the river rose 80-fold with dramatic increases in all sediment-associated constituents (Appendices 9a-b) (New Mexico Department of the Environment 1991). According to the New Mexico Department of the Environment (1992), segment 2-401 of the San Juan River, which begins at Blanco and ends downstream at the New Mexico-Utah border, is severely stressed by recurring sediment loading events.

Suspended sediments may transport chemical constituents in three important ways. Chemical constituents may be part of the mineral assemblage of the suspended sediment, they may be adsorbed on the sediment, or they may form an oxide coating on the surfaces of sediment particles. The total recoverable concentration of a chemical constituent includes the dissolved concentration plus the concentration recovered from suspended sediments (Roybal et al. 1983). The adsorption of trace elements on sediments causes the total concentration of trace elements to exceed the dissolved concentration, and in fact a greater proportion of the total concentration is associated with sediments than is dissolved in water (Roybal et al. 1983, Bureau of Land Management 1984). The majority of sediment in the San Juan basin is in the form of clay and silt, or particles of 0.0625 mm or less in diameter. These materials are slow to settle and are likely to adsorb trace elements (Bureau of Land Management 1984).

4.6 SALINITY

Total dissolved solids (TDS), also referred to as salinity or filterable residue, consist of organic salts, small amounts of organic matter, and dissolved materials. Principal inorganic anions include carbonates, chlorides, sulfates, and nitrates; principal cations include sodium, potassium, calcium, and magnesium (U.S. Environmental Protection Agency 1986) The USGS classifies waters according to their salinity. Water with a TDS concentration of 0-1,000 mg/l is considered fresh; 1,000-3,000 is slightly saline; 3,000-10,000 is moderately saline; 10,000-35,000 is very saline; and greater than 35,000 is classified as briny (Spangler 1992).

It has been reported that salinity is a major water quality problem in the Colorado River basin, but that it is not possible to show deleterious effects of salinity on aquatic organisms for the 100-1000 mg/l range of TDS usually found in the Colorado River because too many other variables are involved (Gosz 1980). The U.S. Environmental Protection Agency (1986) reports that water systems with TDS concentrations exceeding 15,000 mg/l are unsuitable for most freshwater fish. TDS concentrations within the San Juan basin are well below this level, although reproduction and growth may be affected during unusually high salinity periods by placing additional stress on fish (Melancon et al. 1979).

The one study conducted on the tolerances or preferences of San Juan basin native fishes to TDS provides potentially important quantitative findings regarding Colorado squawfish. Pimentel and Bulkley (1983) studied TDS concentrations preferred or avoided by juvenile Colorado squawfish as well as humpback chub (*Gila cypha*) and bonytail (*Gila elegans*). Juveniles were selected for the study because preliminary tests indicated that larger fish were less sensitive to high TDS concentrations than were smaller fish. The fish were hatchery-raised and the experiments were performed with a salinity gradient device. Of the three species tested, Colorado squawfish had the lowest preferred TDS concentration (560-1,150 mg/l) as well as the lowest avoided concentration (more than 4,400 mg/l) (Table 29). Preferred values for Colorado squawfish were somewhat higher than those normally found in the San Juan River, with the possible exception of the most downstream portion of the river. From October 1990 to September 1991, TDS concentrations at Bluff ranged from 215-696 mg/l, with a mean of 485 mg/l (Cruz et al. 1993, ReMillard et al. 1993, Ugland et al. 1993) Unfortunately, similar preference data do not exist for razorback sucker or other San Juan basin native fish species.

The San Juan River basin annually contributes approximately 1 million tons of salt to the Colorado River, or less than 19% of the total salinity of the Upper Colorado River basin (Joseph et al. 1977, Bureau of Reclamation 1989, Bureau of Reclamation 1993). Most of the salt that is naturally contributed by surface runoff and groundwater discharge is from the Nacimiento Formation and the Mancos Shale, two sparsely vegetated sedimentary formations that cover much of the basin (Figure 14) (Liebermann et al. 1989, Colorado River Basin Salinity Control Forum 1990). Mancos Shale is exposed to the river's alluvium from the Hogback, nearly 30 miles east of Shiprock, to just upstream of the confluence of the Mancos and San Juan rivers near the Four Corners area. The Mancos River cuts across the Mancos Shale for about 25 miles before it meets the San Juan River (Bureau of Reclamation 1989). Soils derived from the Mancos Shale and Nacimiento Formation experience continuous salt pickup rather than ultimately reaching a salt balance (Upper Colorado Region State-Federal Inter-Agency Group 1971). The Mancos Shale is also a major source of saline springs and groundwater, which eventually drain into the surface waters (Bureau of Reclamation 1989).

With the exception of high mountain areas where many of the tributaries head, the San Juan basin surface water is high in dissolved solids, with sodium, calcium, bicarbonate, and sulfates as the predominant ions. Ephemeral streams experience some of the highest TDS concentrations as a result of the flushing of soluble materials that accumulate from the weathering of soils and rocks and from the decomposition of plants and animal wastes. As with sediment, TDS loads are highest in these ephemeral streams directly following storms, and runoff early in the storm season is of poorer quality than runoff produced later (Joseph et al. 1979, San Juan Basin Regional Uranium Study 1980). Within the basin, the specific conductance of non-stormflows in the lower reaches of tributaries generally exceeds 2,500 μmhos. The specific conductance of stormflows is variable, with the highest conductance of as much as 7,000 μmhos occurring early in a stormflow (Stone et al. 1983). (Specific conductance is a measure of the ability of a water to conduct an electrical current and is related to salinity (Roybal et al. 1983). *See* glossary for further information.)

The concentration and composition of dissolved solids in surface water vary with the flow. As flow decreases, ion concentrations increase and chemical composition shifts as groundwater discharge contributes a larger portion of the dissolved solids. During high flows, calcium bicarbonate predominates, with a shift to calcium sulfate during medium and low flows. Local geology also influences chemical composition (Figure 15) (Melancon et al. 1979). Data from USGS records have been compiled to produce a generalized picture of San Juan basin surface water chemical composition (Figure 16) (Iorns et al. 1965).

As with sediment, TDS contributions are not equal throughout the basin because of variations in geology and land-use (Figure 17) (Iorns et al. 1965). Dissolved solids concentrations differ within the basin waters (Figure 18), with TDS contributions to the San Juan River subsequently varying by tributary (Figure 19) (Iorns et al. 1965, Melancon et al. 1979). Unfortunately, these data are somewhat outdated, and it is important to understand that waters in areas of recent irrigation, mining, industrial, or oil and gas activities could be more saline today.

The U.S. Environmental Protection Agency (1971) has estimated that salinity in the Upper Colorado River basin results from two-thirds natural causes and one-third anthropogenic causes, with nonpoint sources comprising 84% of salinity and point sources comprising 16% (Wydoski 1980). Iorns et al. (1965) estimated that for the water years 1914-1957, human activities increased the TDS concentration in the San Juan River near Bluff by 133 mg/l, or one-third of the total 361 mg/l. In the San

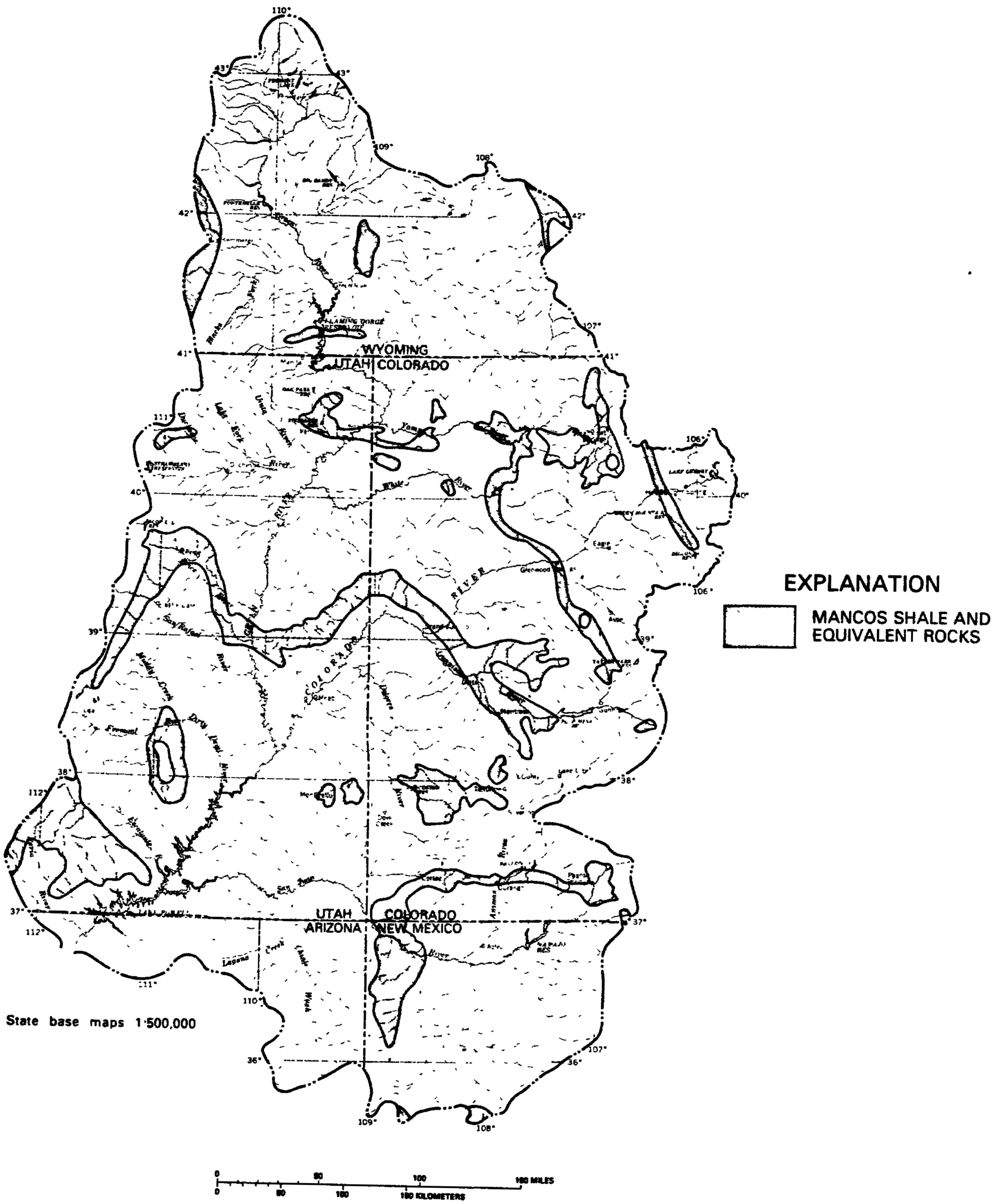

Figure 14. Major exposures of Mancos Shale and equivalent rocks in the Upper Colorado River basin. (Taken from Liebermann et al 1989)

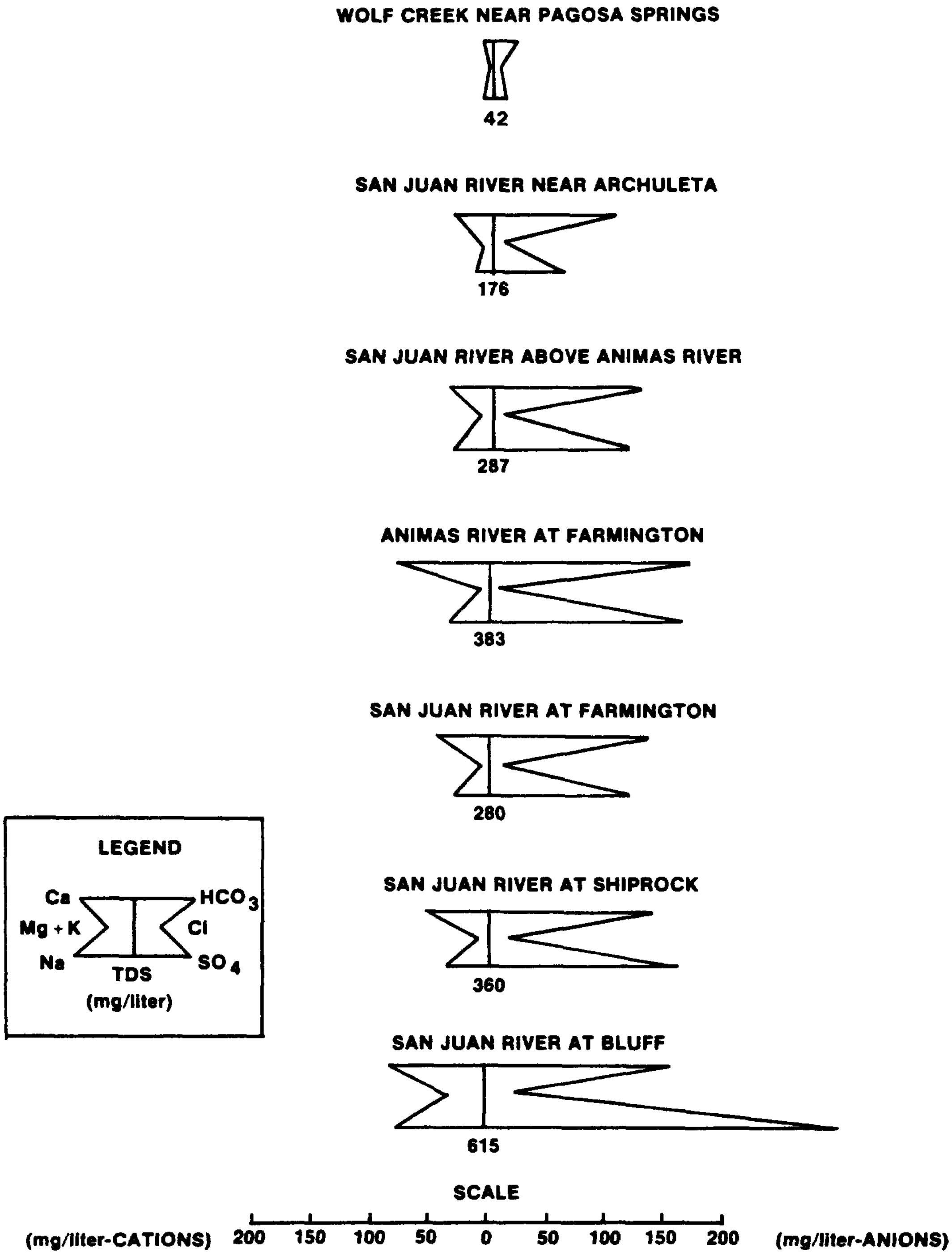

Figure 15. Distribution of major cations and anions at selected stations in the San Juan River basin, 1975. (Taken from Melancon et al 1979)

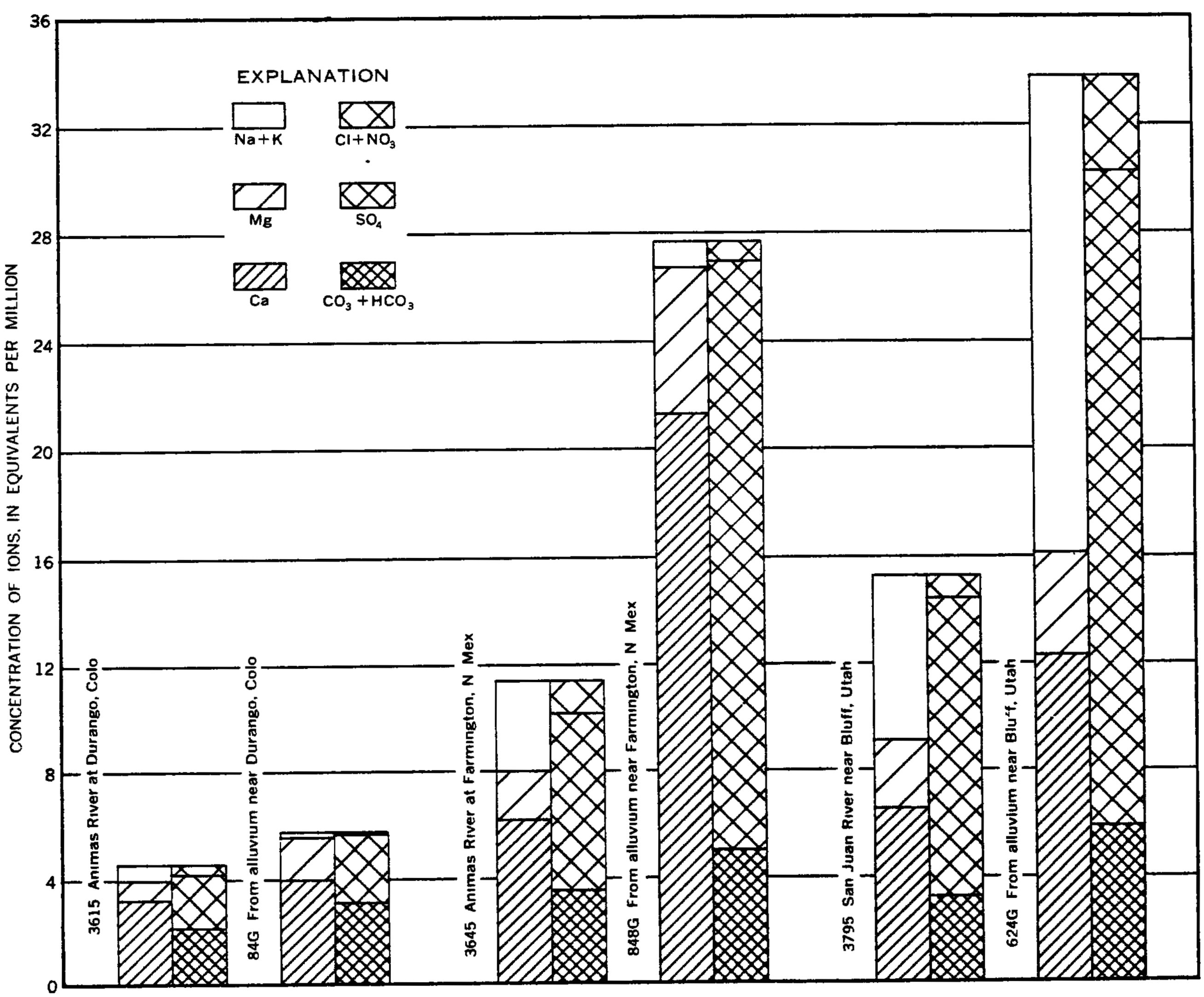

Figure 16. Analyses of water from selected streams in the San Juan River basin and from alluvium nearby. (Taken from Iorns et al 1965)

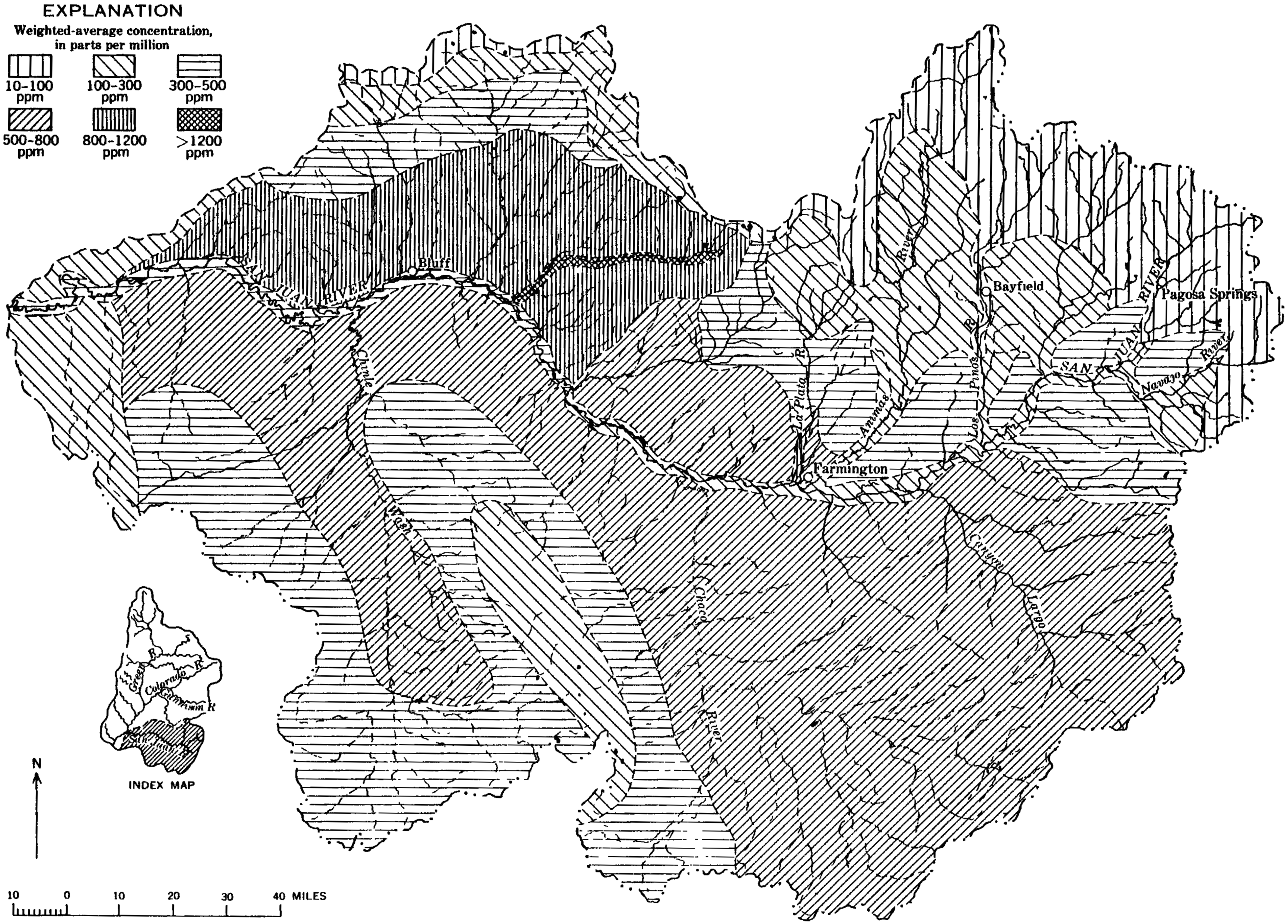

Figure 17. Approximate weighted-average concentration of dissolved solids of streams in the San Juan River basin. (Taken from Iorns et al. 1965)

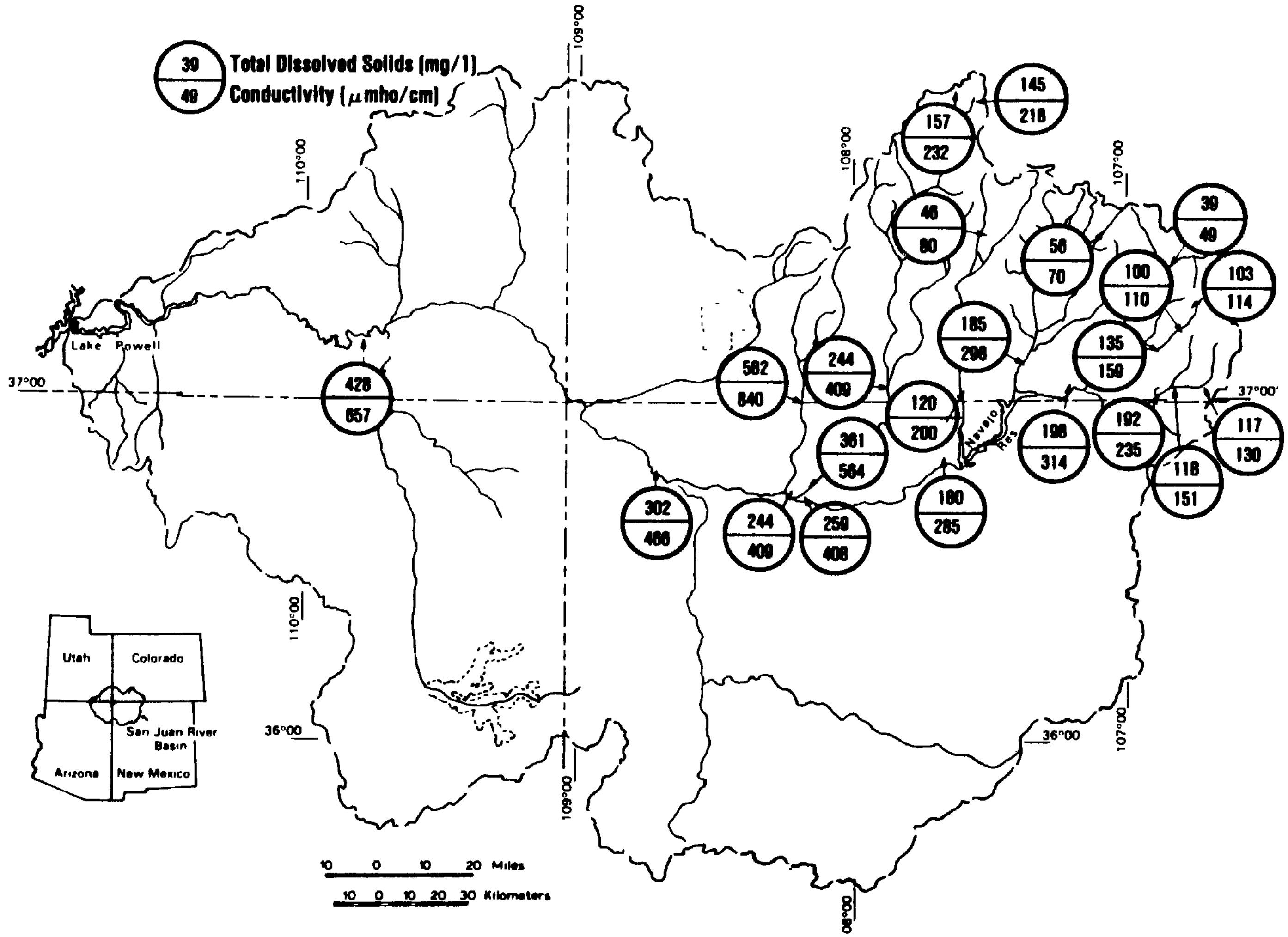

Figure 18. Mean total dissolved solids and conductivity, 1973, at USGS sampling stations.
(Taken from Melancon et al. 1979)

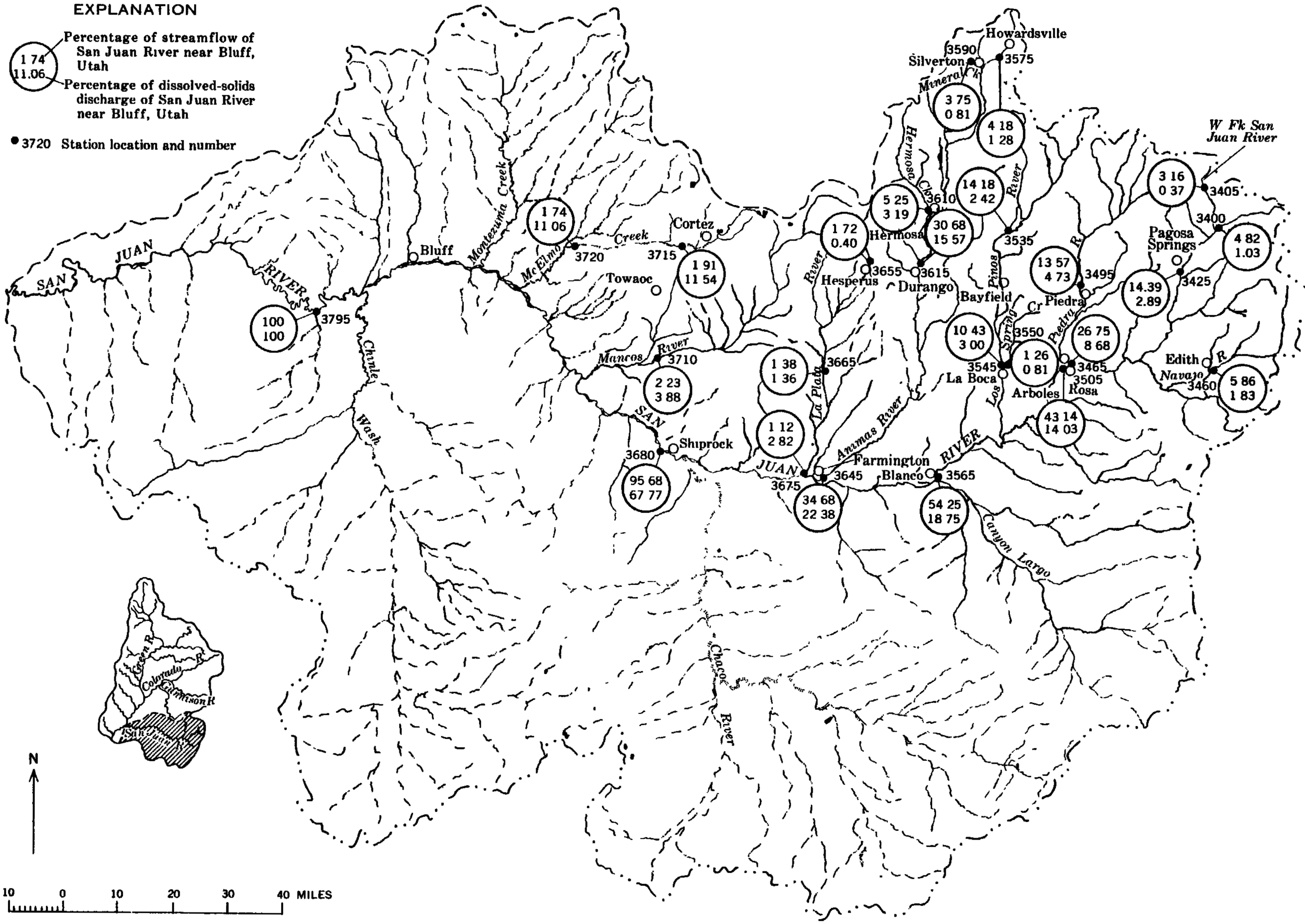

Figure 19. Approximate dissolved-solids discharge and streamflow expressed as percentages of the dissolved-solids discharge and streamflow of the San Juan River near Bluff, Utah. (Taken from Iorns et al. 1965)

Table 29: TDS *concentrations* preferred and avoided by three Colorado River fishes

Species	TDS preferred * (mg/l)	TDS avoided ** (mg/l)	Temp. of gradient (C)
Colorado squawfish	560-1,150	4,400	14-16
Humpback chub	1,000-2,500	5,100	12
Bonytail	4,100-4,700	560; 6,600	16-18

Concentrations of TDS measured as conductivity after 24 hours and converted to mg/liter TDS by the equation mg/liter = (µmhos conductivity - 618)/0.68. Preferred TDS concentration given as the range of concentrations over the three replicates for the pooled modal compartment.

* Mode of the pooled-treatment distribution
** Concentration avoided by 95% of the fish

Taken from Pimentel and Bulkley 1983

Juan basin, major non-point and point sources of salinity to surface waters include mine drainage, mineral springs, municipal and industrial effluents, irrigation, and runoff. The latter two sources are by far the largest contributors (Table 30). From 1965-66, runoff contributed over 69% of the TDS load, and irrigation contributed over 24% (Melancon et al. 1979). Considering that the major irrigation projects within the basin have been developed since 1966, it is likely that the percentage of TDS load derived from irrigation is much greater today.

All of the major tributaries that have high salinity are downstream from extensive areas of irrigation (Liebermann et al. 1989). An average of two-thirds agricultural delivery water is lost by evaporation from water and land surfaces and by transpiration of plants, thereby concentrating salts in the remaining water that is returned to ground or surface waters The TDS concentrations in irrigation return water is further increased by the leaching of salt by water percolating into the ground (Upper Colorado Region State-Federal Inter-Agency Group 1971). Newly irrigated land produces the highest dissolved solids loads, picking up an average of 2 tons per acre (Joseph et al 1977). An example of the effects of irrigation can be found at a sampling site on McElmo Creek near the CO-UT border (site 67 in Tables 31 and 32), which is downstream from about 33,000 acres of irrigated land. The chemical composition of water at this site is similar to that near Cortez on the Mancos River (site 66), but the mean annual flow-weighted TDS concentration and load are much greater, averaging 2,210 mg/l and 110,000 tons, respectively. Most of the streamflow passing the McElmo Creek site is from irrigation return flows (U.S. Department of the Interior 1987, Liebermann et al. 1989). In total, the McElmo Creek basin contributes an average of 119,000 tons of salt a year to the San Juan River (U S Department of the Interior 1987).

Mine and mill tailings, oil and gas wells, and open cuts and fills created during road construction do not contribute a large percentage of the total TDS load but produce highly concentrated point source inputs (Upper Colorado Region State-Federal Inter-Agency Group 1971) For example, TDS concentrations in Cement Creek, a tributary to the upper Animas River, were over 1,000 mg/l from 1965-1966 due to salt contributions from an active mine at Gladstone as well as from abandoned mines. At Shiprock during the same period, 9,980 kg/day of dissolved solids were added to the San Juan River from tailing ponds at the Vanadium Corporation of America's uranium mill, and an additional 4,535 kg/day were contributed from flowing oil-test holes in the Four Corners area (Melancon et al. 1979).

The Federal Water Pollution Control Act Amendments of October 1972 (Public Law 92-500), as amended by the Clean Water Act of 1977 (Public Law 95-217) and the Colorado River Basin Salinity Control Act of June 24, 1974 (Public Law 93-320, as amended by Public Law 98-569 on October 30, 1984) have together mandated a federal government effort to locate significant sources of salt loading in the Colorado River Basin (Thorn 1993). Consequently, a number of salinity investigations have been undertaken within the San Juan basin. Most recently, the USGS and the BR jointly sampled the San Juan and Chaco rivers in San Juan County, New Mexico, as well as groundwater in an attempt to determine the potential salinity contributions from deep formation waters and oil-field brines (Figure 20) (Thorn 1993). This study included analyses of major ions, trace elements, and stable isotopes of sulfur, but contained no data interpretation (Appendices 11a-d) (Thorn 1993). Presumably, an analysis will be conducted in the future in order to identify salinity sources.

In 1985 the BR's San Juan River Unit, which is part of the Colorado River Water Quality Improvement Program, began to investigate the San Juan basin to locate significant salt sources (Bureau of Reclamation 1993). Investigators found that significant salt loading occurred in the San Juan River between Shiprock and the Four Corners area. At Bluff, the average annual flow of 2,047,000 acre-feet (about 2.5 billion m^3) contains approximately 1,165,000 tons of salt Most of this water originates in the San Juan Mountains, while most of the TDS load comes from areas downstream from the mountains. In fact, almost 90% of the water comes from less than 20% of the total basin area (Iorns et al. 1965) About 18% of the dissolved solids at Bluff are added downstream of Shiprock, although only 7% of the water is added in this reach (Bureau of Reclamation 1989) Most of the loading is from surface runoff and

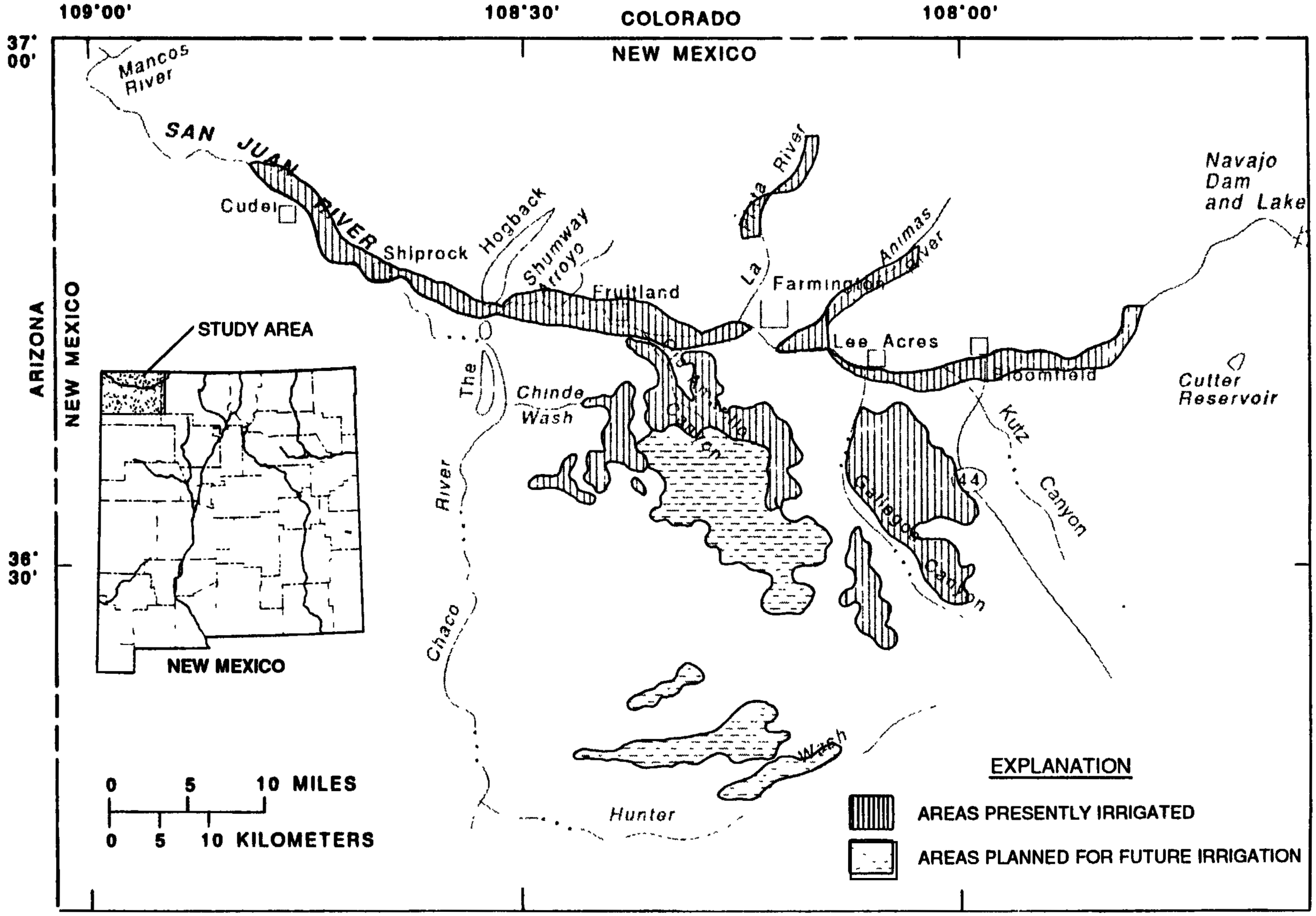

Figure 20. Location of 1993 USGS study area and approximate location of irrigation projects. (Taken from Blanchard et al. 1993)

Table 30: Sources of dissolved solids in the San Juan basin

Source	Loadings kg/day x 1000 (tons/day)	Percent Total Load
Mine drainage	13.608 (15)	1.0
Irrigation	328.400 (362)	24.2
Mineral springs	22.679 (25)	1.7
Runoff	940.746 (1037)	69.3
Municipal effluents	9.071 (10)	0.7
Industrial effluents	41.730 (46)	3.1
Total	1356.234 (1495)	100.0

Taken from Melancon et al. 1979, after U.S. Environmental Protection Agency 1971

Table 31: Streamflow gaging stations for which dissolved solids were estimated by Liebermann et al. 1989

Site No.	USGS Station No.	Station name	Latitude (°-min-sec)	Longitude (°-min-sec)	Elevation (feet)	Drainage area (sq. miles)	Period of record (complete water years)
58	09333500	Dirty Devil River above Poison Spring Wash, near Hanksville, Utah	38-05-50	110-24-27	3850	4159	1969-76
59	09335000	Colorado River at Hite, Utah	37-48-30	110-26-55	3440	72,340	1951-56
60	09352900	Vallecito Creek near Bayfield, Colo.	37-28-39	107-32-35	7906	72	1963-83
61	09355500	San Juan River near Archuleta, N. Mex.	36-48-05	107-41-51	5655	3260	1956-83
62	09364500	Animas River at Farmington, N. Mex.	36-43-17	108-12-05	5280	1360	1955-83
63	09365000	San Juan River at Farmington, N. Mex.	36-43-22	108-13-30	5230	7240	1962-82
64	09367950	Chaco River near Waterflow, N. Mex.	36-43-28	108-35-27	4980	4350	1977-83
65	09368000	San Juan River at Shiprock, N. Mex.	36-47-32	108-43-54	4849	12,900	1958-83
66	09370800	Mancos River near Cortez, Colo.	37-06-27	108-27-43	5685	302	1977-82
67	09372000	McElmo Creek near Colorado-Utah State line	37-19-27	109-00-54	4890	346	1978-81
68	09379500	San Juan River near Bluff, Utah	37-08-49	109-51-51	4048	23,000	1930-83
69	09380000	Colorado River at Lees Ferry, Ariz.	36-51-53	111-35-15	3106	107,540	1942-83
70	09382000	Paria River at Lees Ferry, Ariz.	36-52-20	111-35-38	3123	1410	1948-50

Taken from Liebermann et al. 1989

Table 32: Mean annual values of runoff, streamflow, dissolved-solids concentrations and loads, and major constituent loads, San Juan region

[Periods of record for some sites are divided into preintervention and postintervention periods; asterisks indicate mainstem sites]

Site (Table 28)	Period of record (water years) (1)	Runoff (inches)	Streamflow (acre-feet)	Streamflow (cubic feet/sec)	Dissolved solids: Flow-weighted conc (mg/l)	Dissolved solids: Load (tons)	Major-constituent loads (tons): Calcium	Magnesium	Sodium plus potassium	Carbonate equivalent (2)	Chloride	Sulfate
58	1969-76	0.26	57,000	78	1,110	85,000	13,500	3,000	10,100	6,800	8,300	43,700
59	1951-56	2.17	8,380,000	11,600	580	6,616,000	887,000	321,000	950,000	1,020,000	659,000	2,780,000
60	1963-83	26.8	103,000	142	34	4,800	1,200	300	200	1,900	100	1,100
61*	1956-61	5.45	947,000	1,310	163	210,000	39,700	8,520	25,000	68,000	5,000	63,800
61*	1964-83	4.80	835,000	1,150	166	188,000	37,600	7,200	20,600	58,600	3,400	61,100
62	1955-83	8 06	585,000	807	263	209,000	46,800	6,500	17,100	49,000	9,000	80,800
63*	1962-82	3.43	1,327,000	1,830	256	462,000	89,900	12,800	52,300	107,000	11,900	188,000
64	1977-83	0.13	31,000	42	801	33,000	3,600	900	6,200	2,800	2,200	17,800
65*	1958-61	2.09	1,440,000	1,990	324	634,000	110,000	17,300	82,400	123,000	25,100	276,000
65*	1964-83	2.00	1,379,000	1,900	324	607,000	107,000	19,100	76,000	121,000	18,300	274,000
66	1977-82	2.79	45,000	62	666	41,000	5,700	2,800	3,500	4,000	500	24,300
67	1978-81	1.99	37,000	51	2,210	110,000	13,700	8,400	9,300	7,400	2,300	69,100
68*	1930-61	1.39	1,710,000	2,360	413	961,000	165,000	36,000	115,000	180,000	27,000	438,000
68*	1964-83	1.26	1,545,000	2,130	467	981,000	149,000	40,800	120,000	173,000	33,600	465,000
69*	1942-62	2 01	11,520,000	15,900	539	8,443,000	1,220,000	381,000	1,170,000	1,430,000	752,000	3,490,000
69*	1966-80	1 53	8,754,000	12,100	564	6,714,000	885,000	311,000	983,000	954,000	640,000	2,940,000
69*	1981-83	1.98	11,360,000	15,700	520	8,039,000	1,040,000	382,000	1,190,000	1,200,000	765,000	3,460,000
70	1948-50	0.23	17,000	24	1,340	32,000	3,700	1,500	4,200	2,600	600	19,100

(1) All mean values are based only on those water years having estimates of the major constituents

(2) Carbonate equivalent is computed from alkalinity; bicarbonate is the primary dissolved form.

Taken from Liebermann et al. 1989

groundwater discharge, although irrigation projects, coal-fired powerplants, surface mining activities, gas and oil fields, and refineries are also contributors (Bureau of Reclamation 1989, Colorado River Salinity Control Forum 1990).

Significant salt loading also occurs between Archuleta and Shiprock, where the San Juan River experiences TDS increases of about 3.8 mg/mile, most of which results from irrigation return flows and groundwater inputs (Bureau of Reclamation 1976). Known salt inputs within this segment include approximately 18,500 tons of salt/year from Hammond Project onfarm sources, 17,000 tons/year from Canyon Largo, and 4,000 tons/year from Gallegos Canyon (Bureau of Reclamation 1993). Below Farmington, the San Juan River accumulates over 500,000 tons of salt a year (U S. Department of the Interior 1987).

The Hammond Project, NIIP, and Hogback Irrigation Project are the main irrigation sources of salt in the San Juan basin. An evaluation of historic water data shows that these projects contribute over 18,500 tons of salt annually (Bureau of Reclamation 1989). Prior to 1989, the areas irrigated by the NIIP began discharging water of TDS concentrations exceeding 3,000 mg/l; most of these saline discharges were from Gallegos and Ojo Amarillo washes. The Hogback project also contributes heavy TDS loads, but the specific input mechanisms are as yet unknown. Groundwater accruing to the San Juan River alluvium in the Hogback Project area has TDS concentrations above 15,000 mg/l (Bureau of Reclamation 1989)

The Colorado Salinity Control Forum (1990) concluded that, of the three irrigation projects implicated in major salt loading, salinity control on the Hammond Project would be cost-effective. The Hammond Project Portion of the San Juan River Unit was consequently established. The Hammond Project was originally designed as an earth-lined system, operation of which resulted in salt pickup within the San Juan River due both to deep percolation of irrigation water through underlying shales high in salt content and to excessive canal seepage losses (Bureau of Reclamation 1993). Hydrosalinity studies of the Hammond Project estimate that canal and lateral losses alone were contributing 31,650 tons of salt per year to the San Juan River (Bureau of Reclamation 1993). The BR has recommended that all unlined sections of the Hammond Project irrigation system be lined, resulting in an estimated salt reduction of 27,700 tons/year (Colorado River Basin Salinity Control Forum 1990). Furthermore, the BR has estimated that implementation of the canal-lining project would save 4,900 acre-feet (about 6 million m^3) of water currently lost via canal seepage. The BR conducted a biological assessment of the proposed project and has determined that it would not affect any of the federally listed or candidate species.

The Bloomfield Refining Company, a small oil refinery located directly adjacent to the Hammond Project, has committed to minimizing any discharges from the facility that might aggravate salt loading in the area The refinery has adopted a zero-discharge policy and a program to eliminate salt leaching as a result of indirect discharges to groundwater. Two 5-acre, double lined evaporation ponds have been installed on the property, and in the future the refinery plans both to eliminate the use of spray irrigation and to double-line or eliminate two existing evaporation ponds on the site (Roderick 1991).

Liebermann et al (1989) examined TDS and flow records for 30 sampling sites in the Upper Colorado River basin to determine if any historic trends existed. The authors found that most trends were related to changes in land use, salinity-control projects, the development of reservoirs, and transmountain exports. Because most transmountain exports occur in the upper portion of the basin where salinity is generally less than 100 mg/l, water is removed that otherwise would serve to dilute the more saline waters of the lower portion of the basin (Joseph et al 1977).

Liebermann et al. (1989) found the following dissolved solids trends at sampling stations within the San Juan basin (Table 32):

·San Juan River near Archuleta (site 61): The period of record was divided into a preintervention period (1956-61) and a postintervention period (1964-83), based on the initial filling of Navajo Reservoir. Seasonal variability in TDS concentration greatly decreased since the initial reservoir filling, but mean annual TDS concentration did not change between the two periods. No annual step trends were statistically significant. Annual monotonic trend-analyses of the postintervention period indicated a marginally significant decrease in median annual dissolved solids concentration of 1 1 mg/l per year From 1964 to

1983, the mean annual flow-weighted TDS concentration averaged 166 mg/l. There was no evidence of leaching or mineral precipitation in Navajo Reservoir.

·Animas River at Farmington (site 62)· No statistically significant annual trends in dissolved solids were detected during 1955-83, although monthly concentrations of dissolved sodium and chloride decreased significantly, mainly during the low-flow season

·San Juan River at Farmington (site 63): No statistically significant annual trends in dissolved solids were detected during 1962-82.

·Chaco River near Waterflow (site 64): Site 64 is about five miles downstream from the Four Corners Powerplant, which began operating in 1967. Wastewater from the plant drains from several holding ponds into the Chaco River, creating a perennial stream downstream from the powerplant. The remainder of the flow of the river is almost entirely from seasonal rainstorms. Mean annual flow-weighted dissolved solids concentration averaged 801 mg/l, and the mean TDS load was 33,000 tons per year.

·San Juan River at Shiprock (site 65)· The period of record for site 65 was also divided into pre- (1958-61) and postintervention periods (1964-83) based on the initial filling of Navajo Reservoir. The preintervention period was too short for an evaluation of trends. Annual monotonic-trend analyses for the postintervention period indicated marginally significant decreases in median annual flow-adjusted concentration of 2.7 mg/l per year.

·Mancos River near Cortez (site 66). Site 66 is downstream from about 12,000 acres of irrigated land underlain by Mancos Shale. Navajo Wash drains additional irrigation areas and discharges into the Mancos River downstream from site 66; the Mancos River thus contributes far more TDS than reported for this site. The TDS concentration during base flow averaged about 1,800 mg/l, but the large snowmelt runoff volume lowered the average flow-weighted dissolved-solids concentration to 666 mg/l. No trends were apparently evaluated for this site.

·McElmo Creek near Colorado-Utah State line (site 67) Site 67 is downstream from about 33,000 acres of irrigated agriculture, with a mean annual flow-weighted dissolved solids concentration of 2,210 mg/l and an annual load of 110,000 tons. Most of the streamflow is composed of irrigation return flows. No trends were apparently evaluated for this site.

·San Juan River near Bluff (site 68)· The period of record was also divided into pre- (1930-61) and postintervention periods (1964-83), based on the initial filling of Navajo Reservoir. Annual step-trend analyses indicated a marginally significant increase in annual dissolved-solids concentration of 47 mg/l, which represented an 11% change from the preintervention median concentration. Annual monotonic-trend analysis indicated a significant decrease in median annual flow-adjusted concentration of 1.5 mg/l per year, a 10% change from the preintervention median concentration During the postintervention period, trends indicated a marginally significant decrease in median annual TDS concentration of 7.1 mg/l per year and a significant decrease in median annual flow-adjusted concentration of 3 7 mg/l per year A second step-trend analysis, using 1968-83 as the postintervention period, indicated no significant annual trends From 1963 to 1968, releases from Navajo Reservoir were small and downstream TDS contributions were not diluted as much as after 1968 when the reservoir was mostly full and releases were larger.

Nordlund and Liebermann (1990), using the same data set as Liebermann et al. (1989), made extensive historical estimates of dissolved solids for the same gaging stations in the Upper Colorado River basin which have been included to provide further detail (Appendices 12a-b)

4.7 GROUNDWATER

Groundwater in the San Juan River basin is naturally high in dissolved solids, although land use practices may increase dissolved solids concentrations (Melancon et al 1979). Groundwater quality is pertinent to the issue of San Juan basin native fishes because it generally discharges into tributaries to the San Juan River or to the mainstem river itself. The volume of groundwater flow contributions to surface water streamflow are presumed to be small (Stone et al 1983), but groundwater can nonetheless affect surface water quality, especially in the case of dissolved solids

Within the San Juan basin, wells may yield water whose quality is considered too poor for domestic or livestock use (Blanchard et al. 1993). New Mexico groundwater standards (Table 33) have not been promulgated for the protection of aquatic life and are less stringent, generally by three orders of magnitude, than surface water quality standards (New Mexico Water Quality Control Commission 1991).

Wilson (1981) compiled a review of groundwater pollution problems in New Mexico that is applicable to the San Juan basin (Table 34). Major sources of groundwater pollution in New Mexico include dumping-induced saline intrusion, mill wastewater, septic tank effluent, and brine disposal. Leaks, spills, municipal wastewater, animal confinement facilities, mine drainage, and industrial wastewater can be locally important sources of groundwater pollution. Natural recharge of aquifers is limited, so induced recharge serves as a major pollutant pathway. Artificial recharge can be caused by seepage from pits, ponds, lagoons, irrigated fields, or arroyos. Injection wells, poorly constructed wells, leaks and spills, and overpumping of artesian wells can also serve as recharge sources (Wilson 1981).

Northwestern New Mexico is an area where abundant pollutant sources, vulnerable aquifers, and viable pollutant pathways exist together (Figure 21) (Wilson 1981). Within the San Juan basin are extensive coal, uranium, oil, and gas developments, as well as animal containment systems, electrical powerplants, and potential wastewater discharge into groundwater

Irrigation is the largest groundwater pollution source in New Mexico. Nonetheless, because irrigation is deemed a beneficial use and salinity impacts are considered inevitable, New Mexico regulations do not consider salinity inputs from irrigation to be pollution (Wilson 1981). In the San Juan basin, irrigation return water that is not returned to rivers and streams by overland flow, seepage, or subsurface tiles is incorporated into the groundwater system (Blanchard et al. 1993). When irrigation drainage water flows through valley-fill deposits in the subsurface, the specific conductance of the water increases from less than 500 μmhos, when applied to the land, to 2,000 μmhos or more by the time it reaches the river (Stone et al. 1983).

Groundwater pollution sources in New Mexico that involve highly toxic or very saline fluids include saline intrusion, mill wastes, brine disposal, and septic tanks. Minor sources include leachate (in situ) from mining, sewer leaks, sludge disposal, solid waste disposal, air pollution, urban runoff, seepage from stockpiles, nuclear waste storage and disposal, highway deicing, range management, silviculture, and mine development and abandonment. Within the San Juan basin, mining and related activities, industrial discharges, and saline intrusion are the most significant groundwater pollution sources. Aquifers within the New Mexico portion of the San Juan basin generally have low to moderate vulnerability, except in the geologic San Juan valley where aquifer vulnerability is high (Figure 22) (Wilson 1981).

Abandoned or poorly constructed wells provide a mechanism for bypassing the protection of the vadose zone, or zone of aeration. In New Mexico a large number of groundwater contamination episodes have occurred as a result of faulty well casings or drill holes that were not adequately plugged (Wilson 1981).

Groundwater contamination with petroleum products is of special concern in the San Juan basin Petroleum products may eventually recharge surface water through springs or influent seepage. From 1972-1984, 34 contamination incidents with petroleum products were reported in San Juan County, New Mexico, with two of these incidents resulting in documented groundwater contamination (Jercinovic 1985).

The USGS is currently conducting a study in the Aneth, Utah, area of potential groundwater contamination by oil-field brines, which are injected for secondary recovery of oil. The USGS study was initiated in response to work done by Avery (1986), which found that water from some wells near Aneth that tap the Navajo Sandstone had larger than expected salinity concentrations. Further sampling was conducted in 1989, 1990, and 1991, which indicated that the saline wells are in and adjacent to the southeastern part of the Greater Aneth Oil Field and in and just to the northwest of the South Ismay-Flodine Park field. Three wells in the area have reportedly undergone salinity increases of more than 50% (U.S. Geological Survey and Utah Division of Oil, Gas, and Mining 1993). Following the Avery (1986) study, Kimball (1992) sampled well water from the Montezuma Canyon area, north of Aneth. Moving north to south, wells became more saline, these increases were ascribed to injection of oil-production water rather than to natural sources (U.S. Geological Survey and Utah Division of Oil, Gas, and Mining 1993).

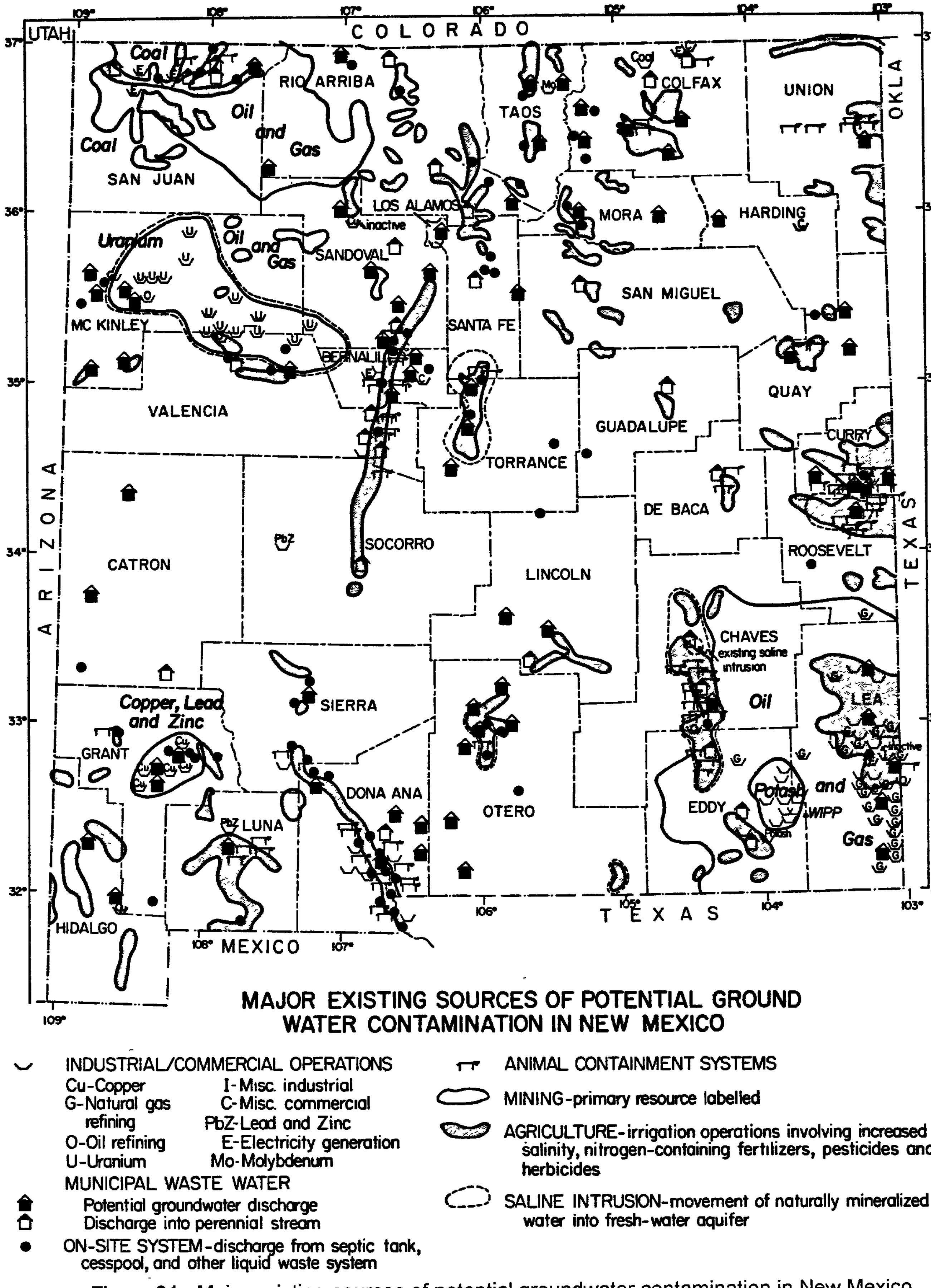

Figure 21. Major existing sources of potential groundwater contamination in New Mexico.
(Taken from Wilson 1981)

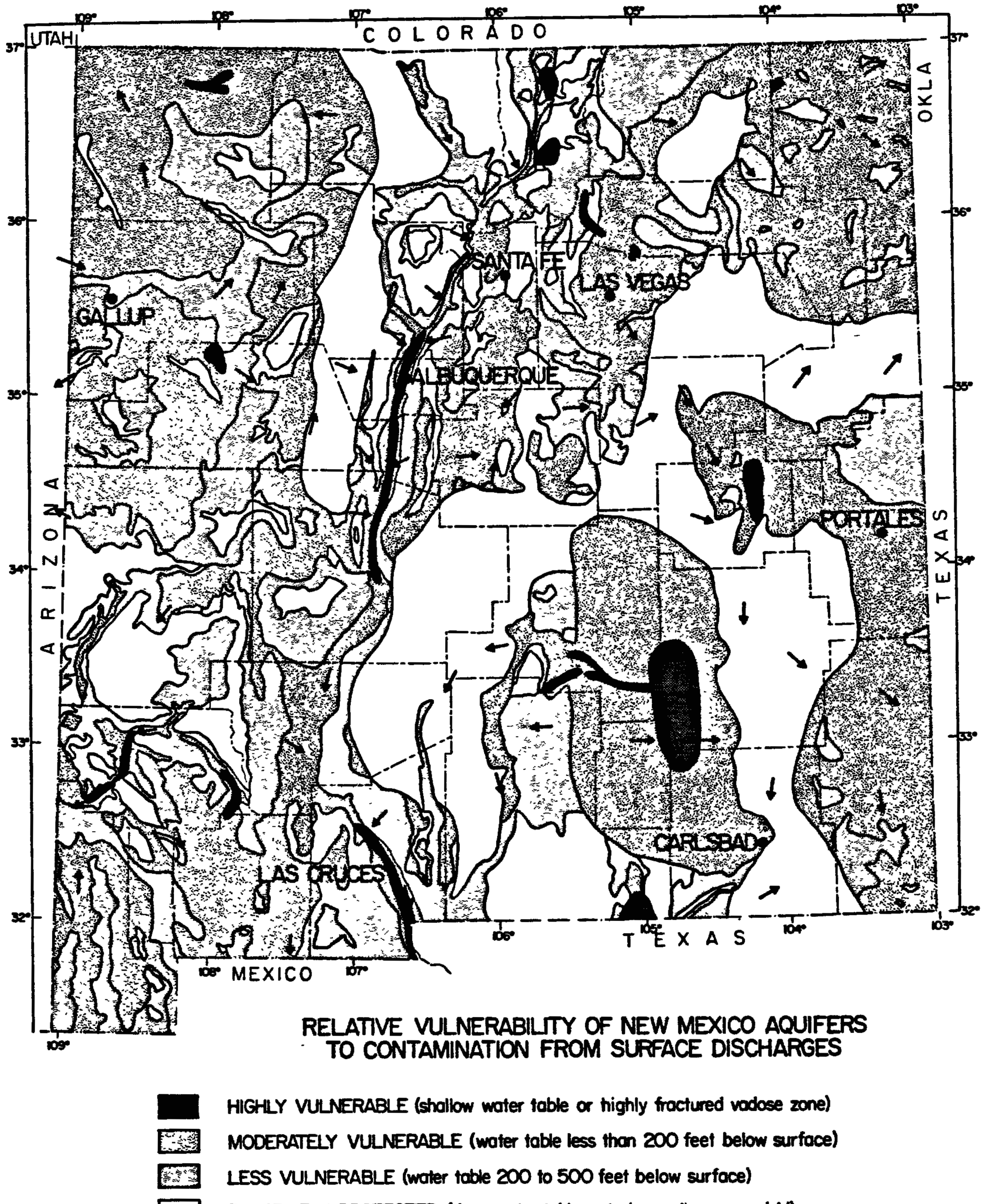

Figure 22. Relative vulnerability of New Mexico aquifers to contamination from surface discharges. (Taken from Wilson 1981)

Table 33: Groundwater pollution problems in New Mexico

A. Human Health Standards - Groundwater shall meet the standards of Section A and B unless otherwise provided.

Arsenic	0.1 mg/l
Barium	1.0 mg/l
Cadmium	0.01 mg/l
Chromium	0.05 mg/l
Cyanide	0.2 mg/l
Fluoride	1.6 mg/l
Lead	0.05 mg/l
Total mercury	0.002 mg/l
Nitrate (as N)	10.0 mg/l
Selenium	0.05 mg/l
Silver	0.05 mg/l
Uranium	5.0 mg/l
Radioactivity: combined Radium-226 and Radium-228	30.0 pCi/l
Benzene	0.01 mg/l
Polychlorinated biphenyls (PCBs)	0.001 mg/l
Toluene	0.75 mg/l
Carbon tetrachloride	0.01 mg/l
1,2-dichloroethane (EDC)	0.01 mg/l
1,1-dichloroethylene (1,1-DCE)	0.005 mg/l
1,1,2,2-tetrachloroethylene (PCE)	0.02 mg/l
1,1,2-trichloroethylene (TCE)	0.1 mg/l
Ethylbenzene	0.75 mg/l
Total xylenes	0.62 mg/l
Methylene chloride	0.1 mg/l
Chloroform	0.1 mg/l
1,1-dichloroethane	0.025 mg/l
Ethylene dibromide (EDB)	0 0001 mg/l
1,1,1-trichloroethane	0.06 mg/l
1,1,2-trichloroethane	0.01 mg/l
1,1,2,2-tetrachloroethane	0.01 mg/l
Vinyl chloride	0.001 mg/l
PAHs: total Naphthalene plus Monomethylnaphthalenes	0.03 mg/l
Benzo(a)pyrene	0.0007 mg/l

B. Other standards for domestic water supply

Chloride	250. mg/l
Copper	1.0 mg/l
Iron	1.0 mg/l
Manganese	0.2 mg/l
Phenols	0.005 mg/l
Sulfate	600. mg/l
Total Dissolved Solids (TDS)	1000. mg/l
Zinc	10.0 mg/l
pH	between 6 and 9

C. Standards for Irrigation Use - Groundwater shall meet the standards of subsections A, B, and C unless otherwise provided.

Aluminum	5.0 mg/l
Boron	0.75 mg/l
Cobalt	0.05 mg/l
Molybdenum	1.0 mg/l
Nickel	0.2 mg/l

Taken from Wilson 1981

Table 34: Groundwater pollution problems in New Mexico

Pollutant source	Typical pathway
Irrigation	Salinity, nutrients, and pesticides in return flows
Saline intrusion	Overpumping of fresh water which is adjoined or overlain by saline water
Septic tanks and cesspools	Nutrients and pathogens in discharges, especially where systems are poorly constructed
Oil field brines	Disposal of brines by ponds or through leaky injection wells
Leaks and spills	Accidental releases of hydrocarbons or chemicals from pipelines, tanks, and vehicle accidents
Municipal wastewater	Nutrients and pathogens in discharges to arroyos and fields and in pond seepage
Industrial wastewater	Salinity and chemicals in seepage from cooling ponds, refinery wastewater ponds, and industrial septic tanks
Animal confinement facilities	Nutrients and organics in dairy washwater and seepage from feedlots
Mine drainage	Radionuclides and chemicals drawn in by mine pumping and/or in seepage when drain water is discharged to arroyos
Mill wastes	Chemicals and radionuclides in seepage from decant ponds

Taken from Wilson 1981

The current USGS study area covers about 800 mi^2 in the southeast corner of San Juan County, Utah (Figure 23) (Spangler 1992). The area is crossed by the San Juan River and McElmo Creek, as well as by Montezuma Creek and several other smaller intermittent streams (Spangler 1992). There is evidence that the San Juan River is the discharge line for all consolidated rock aquifers, underlying aquifers, and unconfined or semiconfined aquifers in the study area. Discharge from aquifers occurs as springs, evapotranspiration, and seepage along the San Juan River (U.S. Geological Survey and Utah Division of Oil, Gas, and Mining 1993). Preliminary analysis of data collected in 1992 and 1993 suggests that non-oil-field brine may be the source of salinization (U.S. Geological Survey 1993b).

Since 1988 the USGS has been analyzing well water for major anions and cations; selected trace elements; and oxygen, sulfur, hydrogen, and strontium isotopes. In 1989, 18 water samples from wells in the Navajo aquifer and two production water samples were collected. In the summer of 1990 seven additional water samples were collected from wells that previously had large TDS concentrations. During the summer of 1991, 12 wells were sampled, some for the first time. Results indicated that the dissolved solids concentration in water from one well had increased substantially from 1989 to 1991. In 1992, 20 wells in the Navajo, Entrada, and alluvial aquifers were sampled (U S Geological Survey and Utah Division of Oil, Gas, and Mining 1993)

Well record data for the Morrison, Bluff, Entrada, and Navajo aquifers, and chemical data for wells producing water primarily from the Navajo aquifer, were reported by Spangler (1992). Dissolved solids concentrations in well water in the Navajo aquifer ranged from 150 mg/l to 17,800 mg/l, with some of the highest concentrations occurring in the vicinity of the Aneth and South Ismay-Flodine Park Fields. However, water from most of the wells in the Navajo aquifer to the north, west, and south of the Greater Aneth Oil Field contained dissolved solids concentrations less than 1,000 mg/l Data showed that water from several wells in the Aneth area have undergone anomalous changes in dissolved solids concentration in relatively short periods of time; these changes have included both increases and decreases (Spangler 1992). The data from Spangler (1992), collected from 1989 to 1991, has been included along with accompanying well locations (Appendices 13a-e).

From 1973 to 1976, Hutchinson and Brogden (1976) conducted surface and groundwater sampling on the Southern Ute Indian Reservation of southwestern Colorado. Samples were analyzed for major cations and anions, and for selenium and arsenic (Appendix 14a).

In response to the projected increases in coal surface mining of the Fruitland Formation, Myers and Villanueva (1986) conducted groundwater sampling in those areas that would be affected in order to establish baseline conditions. The locations of the observation wells and the accompanying data have been included as appendices (Appendices 15a-d)

A final groundwater study conducted for the San Juan basin is a USGS investigation of methane contamination in the Animas River Valley of Colorado and New Mexico (U S. Geological Survey 1993a). Water quality data were collected during August 1990-May 1991 for 71 wells and one spring in Colorado and 132 wells and one spring in New Mexico (Figure 24). Data consist of water and gas well records; water quality data, including methane concentrations, from wells and springs in the Animas River valley; concentrations of methane in soil gas near water wells and springs and adjacent to gas-well casings within about one-half mile of the Animas River valley, and molecular composition and methane-isotope data for gas samples collected from ground-water headspace, soil, and gas-well production casings (U S Geological Survey 1993a) The preliminary data were released in an interim report, but no analysis of the data was included (Appendices 16a-d).

4.8 PESTICIDES AND PCBs

Both surface and subsurface irrigation return flow can transport pesticide and polychlorinated biphenyl (PCB) residues (New Mexico Water Quality Control Commission, 1976). Pesticides other than chlorohydrocarbon compounds (more commonly known as organochlorine compounds) can be relatively water soluble, and although they may be short-lived they can harm aquatic life at elevated concentrations.

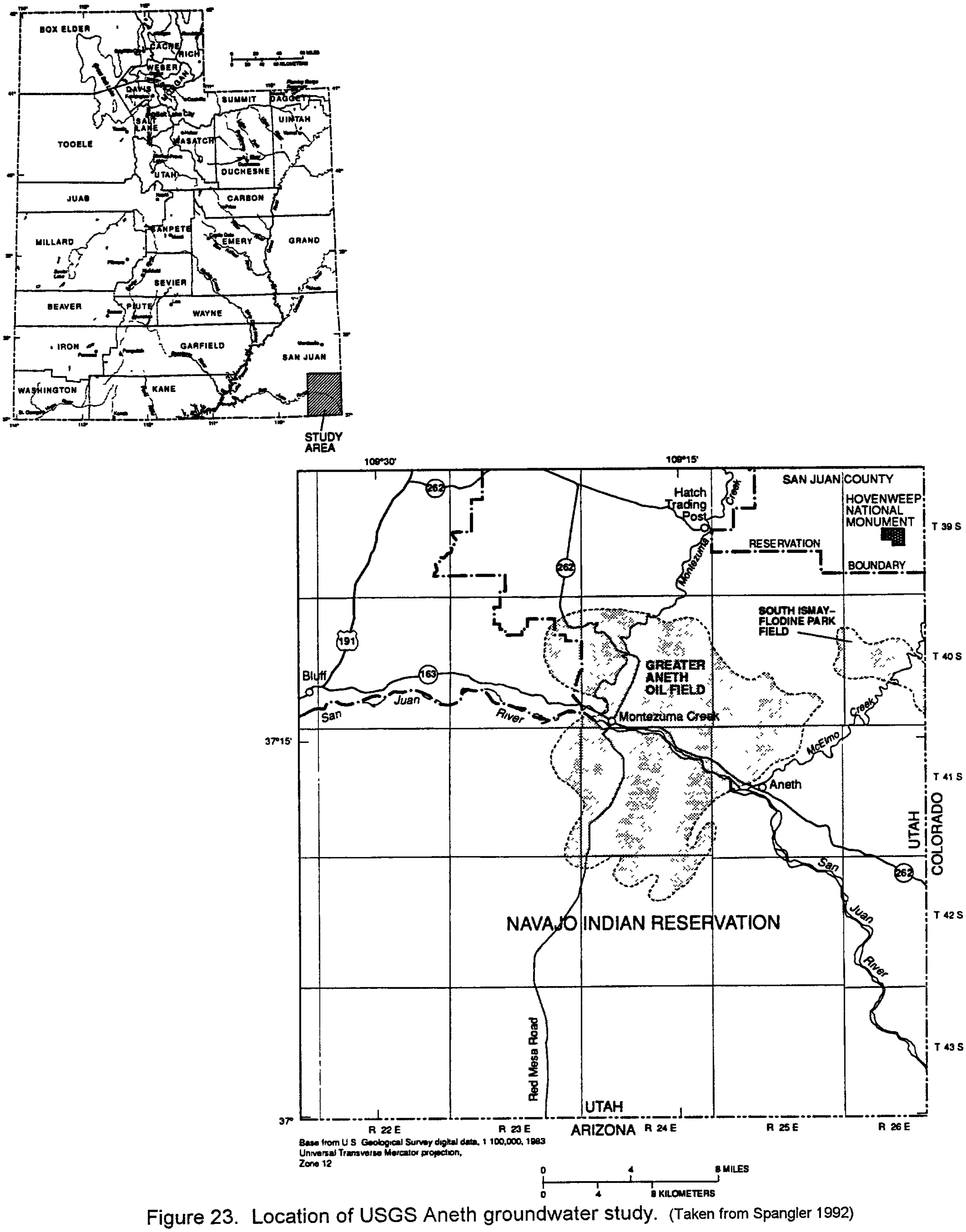

Figure 23. Location of USGS Aneth groundwater study. (Taken from Spangler 1992)

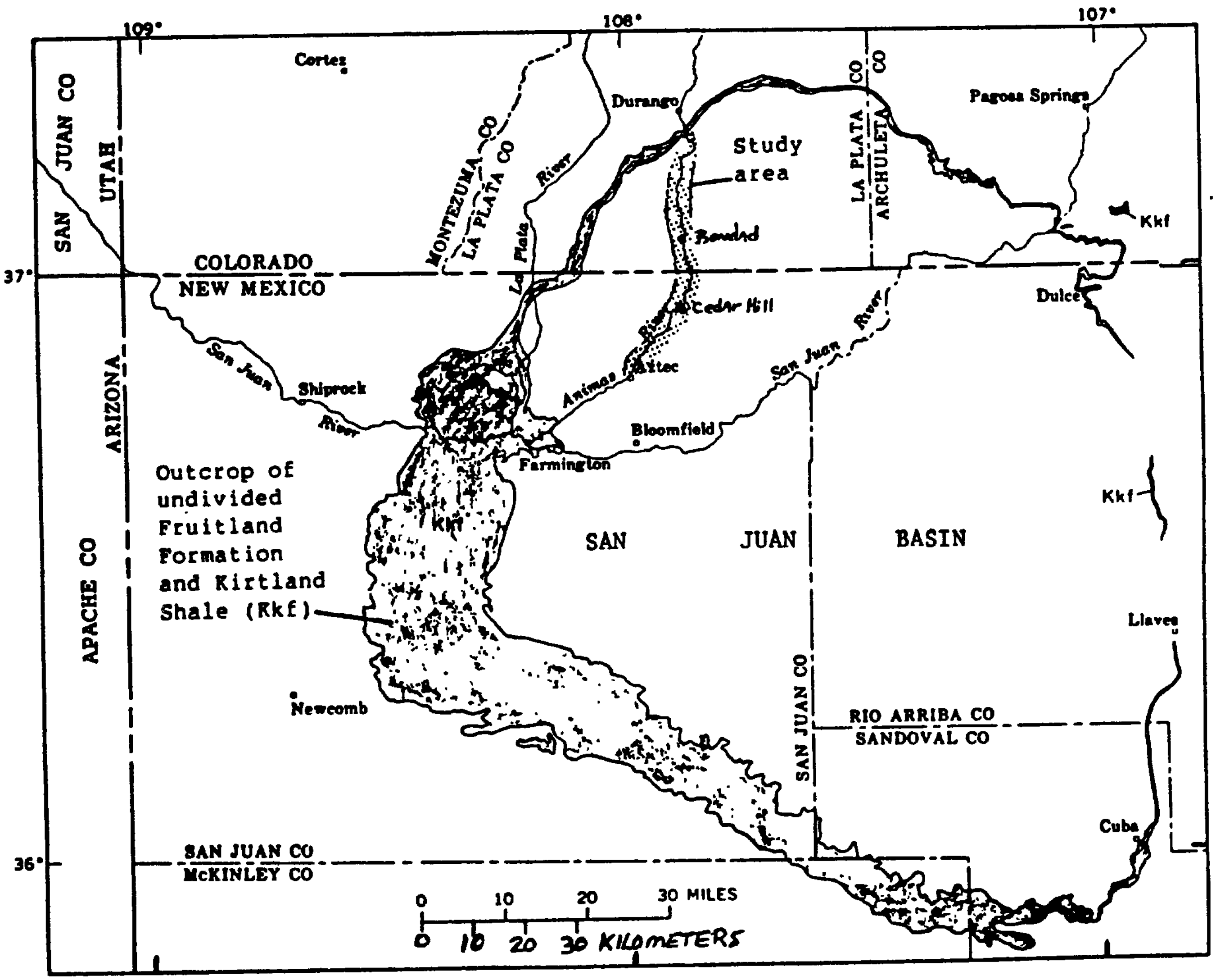

Figure 24. Location of USGS Animas River Valley groundwater study. (Taken from USGS 1993a)

Chlorohydrocarbon compounds, used extensively before the mid-1970s, are only slightly soluble in water but are highly soluble in lipids and thus are very persistent in biological tissues (National Fisheries Contaminant Research Center et al. 1991). Fish that inhabit areas receiving drain water may still be exposed to chlorohydrocarbon pesticides that have remained in fields since their use was terminated (National Fisheries Contaminant Research Center et al. 1991). The tendency of chlorohydrocarbon compounds to accumulate in the tissue of fish where they can persist for long periods of time is of particular concern for long-lived fish such as the Colorado squawfish and razorback sucker (U.S. Fish and Wildlife Service 1991b).

The most extensive study of chlorohydrocarbon compounds was conducted by O'Brien (1987) within the New Mexico portion of the San Juan basin (Figure 25) The study, which also analyzed for trace element contamination, selected four sites on the San Juan River and two sites on the Animas for fish as well as bird collections. The sites were chosen with regard to the most probable contaminant sources. irrigation return flows, mine tailings, and emissions and effluent from the two coal-fired powerplants near Shiprock. A total of 53 fish plus three composite samples of speckled dace (*Rhinichthys osculus*) were collected from six sites.[1] The fish samples included 16 flannelmouth sucker from 4 sites, 27 bluehead sucker from 5 sites, and 3 rainbow trout, 2 brown trout (*Salmo trutta*), and 5 common carp each from 1 site (Table 35). Each composite sample of speckled dace contained 50 fish and weighed 255-312 grams (O'Brien 1987).

Tissue samples from the fish were analyzed for 17 chlorohydrocarbon compounds (Table 36). Residue levels for all compounds except PCBs were below the detection limit or at very low values compared to NCBP data (Table 37). Within the San Juan River proper, the geometric mean was lower for all organochlorines than the NCBP geometric mean (Schmitt et al. 1985). In San Juan River fish, only PCBs were detected in individual samples at levels higher than the national mean. The highest PCB level in any fish sample, 1.3 ppm (mg/kg wet weight), came from a flannelmouth sucker at the Animas River station. The PCB levels found in this study were well below those levels reported in other studies as causing mortality in fry, increasing thyroid activity, causing gill lesions, or causing degenerative liver changes (O'Brien 1987).

Prior to O'Brien's investigations, very little was known regarding chlorohydrocarbon compounds in the San Juan basin. In preparation for the Environmental Impact Statement for proposed modifications to the Four Corners Powerplant and Navajo Mine (Bureau of Reclamation 1976), limited surface water monitoring occurred at stations on the Animas River at Cedar Hill, New Mexico, and on the San Juan River at Shiprock. Hexachloride, DDD, DDE, DDT, Dieldrin, Endrin, and Heptachlor were detected at the stations, but the data were not considered adequate to provide an evaluation of the contamination and were therefore not published in the EIS (Bureau of Reclamation 1976).

Subsequent to O'Brien (1987), there has been a limited amount of additional information gathered concerning chlorohydrocarbon compounds in the basin. Blanchard et al. (1993), in their investigations of the same general study area as that covered by O'Brien (1987), analyzed bottom sediment for 17 chlorohydrocarbon compounds and flannelmouth sucker for 22 compounds (Tables 38 and 39). They found DDE concentrations greater than laboratory reporting levels in eight of 10 bottom sediment samples, and in five of six fish samples total PCBs were above the laboratory detection level.

For the bottom sediment samples, concentrations of chlorohydrocarbon compounds at or greater than the laboratory reporting levels included DDE at Gallegos Canyon drainage middle pond, Ojo Amarillo Canyon, and the East Hammond Project west drain and adjacent wetlands, DDD and DDE at the West Hammond Project pond; DDD, DDE, and chlordane at the Fruitland Project site, the Hogback marsh, and the Hogback Project west drain; and DDT, DDD, DDE, and chlordane at the Hogback Project east drain Maximum concentrations for these compounds were DDT, 0.1 μg/kg; DDD, 0 2 μg/kg; DDE, 0.4 μg/kg; and chlordane, 2.0 μg/kg (Blanchard et al. 1993).

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[1]O'Brien (1987) states that longnose dace (*Rhinichthys cataractae*) was sampled. However, this species of fish does not occur in the San Juan basin. This review therefore assumes that the correct species was the speckled dace.

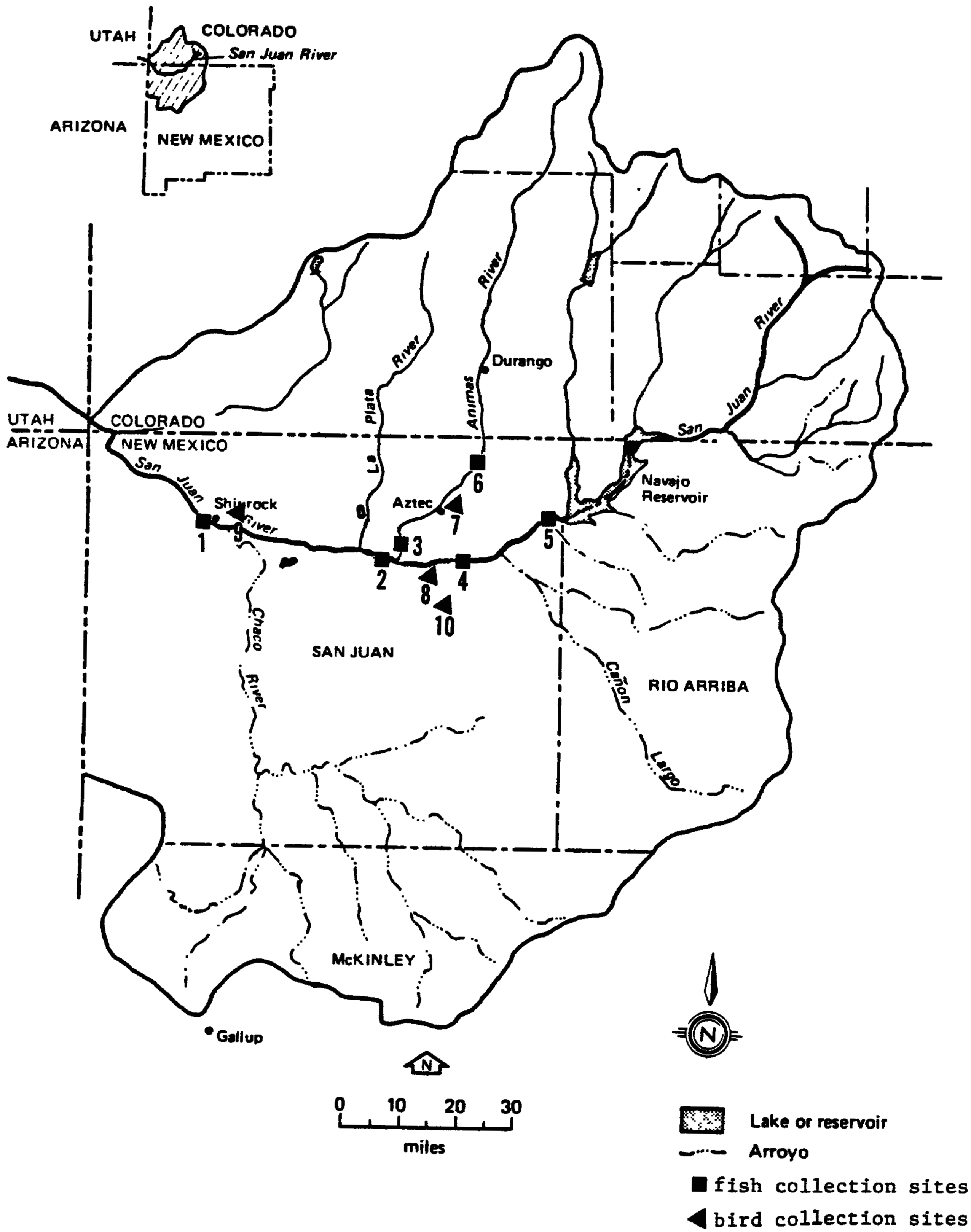


Figure 25. O'Brien (1987) study area and collection sites. (Taken from O'Brien 1987)

Table 35: Fish sampling locations and species, O'Brien study, 1984

Station No.	Location	Species	No. in Sample
1	Shiprock	Flannelmouth sucker *Catostomus latipinnis*	5
1	Shiprock	Bluehead sucker *Catostomus discobolus*	4
1	Shiprock	Bluehead sucker	3
2	Farmington	Longnose dace* *Rhinichthys cataractae*	50
2	Farmington	Bluehead sucker	5
2	Farmington	Longnose dace	50
3	Animas River confluence	Flannelmouth sucker	5
3	Animas River confluence	Bluehead sucker	5
4	Bloomfield	Longnose dace	50
4	Bloomfield	Flannelmouth sucker	3
4	Bloomfield	Bluehead sucker	5
5	Archuleta	Carp *Cyprinus carpio*	5
5	Archuleta	Trout (rainbow & brown) *Salmo gairdneri, salmo trutta*	5
6	Animas North of Aztec	Bluehead sucker	5
6	Animas North of Aztec	Flannelmouth sucker	3

*This species is presumed to actually have been speckled dace (Rhinichthys osculus) because longnose dace does not occur in the San Juan basin

Taken from O'Brien 1987

Table 36: *Organochlorines scanned by O'Brien (1987)*

Aldrin	Cis-Chlordane (ALPHA)
Dieldrin	Trans-Chlordane (GAMMA)
Endrin	Heptachlor
Lindane	Heptachlor Epoxide
(BAH-ALPHA & GAMMA)	Cis-Nonachlor (BETA)
Mirex	Trans-Nonachlor
Toxaphene	DDE
HCB	DDT
PCB	DDD

Taken from O'Brien 1987

Table 37: Organochlorine residule analysis for fish tissue from the San Juan and Animas Rivers (units are mg/kg wet weight or ppm)

		Organochlorine compound (Geometric mean wet weight 1980-81 National Pesticide Monitoring Program, Schmitt et al. 1985)								
Station No.	Species	Aldrin (NA)	Dieldrin (0.04)*	Endrin (0.01)	Lindane-Gamma-BHC (0.01)	Mirex (0.01)	Toxaphene (0.27)	HCB (0.01)	PCB (0.53)	CIS-Chlorodane (0.03)
1	Flannelmouth sucker	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	0.25	<0.01
1	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	<0.10	<0.01
1	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	0.23	<0.01
2	Longnose dace***	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	<0.10	<0.01
2	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	<0.10	<0.01
3	Longnose dace***	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	0.12	<0.01
3 Assay A	Flannelmouth sucker	0.02	0.06	<0.01	<0.01	<0.01	<1	<0.01	0.94	0.05
3 Assay B	Flannelmouth sucker	0.02	0 06	<0 01	<0.01	<0.01	<1	<0.01	0.87	0.05
3	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	0.18	<0.01
4	Longnose dace***	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	<0.10	<0.01
4	Flannelmouth sucker	<0 01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	0.28	<0.01
4	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	<0.10	<0 01
5	Carp	<0.01	<0.01	<0 01	<0 01	<0.01	<1	<0.01	<0.10	<0.01
5	Trout	<0.01	<0.01	<0.01	<0.01	<0.01	<1	<0.01	0.1	<0.01
6	Bluehead sucker	0.05	<0.01	<0.01	<0.01	0.03	<1	<0.01	0.97	0.09
6	Flannelmouth sucker	<0.01	0 04	<0.01	<0.01	0.04	<1	<0.01	1.3	0.06
	Geometric mean	<0.01	0 015	0 01	0 01	0.01	<1	<0.01	0.22	0.015

Table 37 (CONT): Organochlorine residule analysis for fish tissue from the San Juan and Animas Rivers (units are mg/kg wet weight or ppm)

		Organochlorine compound (Geometric mean wet weight 1980-81 National Pesticide Monitoring Program, Schmitt et al. 1985)								
Station No.	Species	Trans Chlorodane (0.02)	Heptachlor (0.01)**	Heptachlor-Epoxide (NA)	CIS-Nonachlor (0.02)	Trans-Nonachlor (0.04)	DDE (0.2)	DDE (0.07)	DDT (0.29)	Lindame Alpha-BHG (0.01)
1	Flannelmouth sucker	<0.01	<0.01	<0.01	<0.01	0.01	0.05	---	---	0.07
1	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	---	---	0.01
1	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	0.01	0.06	---	---	---
2	Longnose dace***	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	---	---	0.01
2	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	---	---	0.01
3	Longnose dace***	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	---	---	---
3 Assay A	Flannelmouth sucker	<0.01	<0.01	<0.01	<0.01	<0.01	0.10	0.01	0.02	0.01
3 Assay B	Flannelmouth sucker	<0.01	<0.01	<0.01	<0.01	<0.01	0.10	<0.01	0.02	0.01
3	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	0.01	0.04	---	---	0.02
4	Longnose dace***	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	---	---	0.01
4	Flannelmouth sucker	<0.01	<0.01	<0.01	<0.01	0.01	0.10	0.02	---	0.02
4	Bluehead sucker	<0.01	<0.01	0.01	<0.01	<0.01	0.03	---	---	0.01
5	Carp	<0.01	<0.01	<0.01	<0.01	<0.01	0.015	---	---	---
5	Trout	<0.01	<0.01	<0.01	<0.01	<0.01	---	---	---	---
6	Bluehead sucker	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	---	---	0.04
6	Flannelmouth sucker	<0.01	<0.01	<0.01	<0.01	<0.01	0.14	0.02	0.04	---
	Geometric mean	0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.02	0.015

* Includes traces of aldrin, Schmitt et al 1985

** Includes heptachlor epoxide, Schmitt et al. 1985

*** O'Brien states that longnose dace were sampled. However, this species of fish does not occur in the San Juan basin This review therefore assumes that the correct species was the speckled dace

Taken from O'Brien 1987

Table 38. Concentrations of pesticides in water and bottom-sediment samples, 1990

Site number*	Date	Time	Alachlor, total recoverable (µg/l) (77825)	Ametryne, total (µg/l) (82184)	Altrazine, total (µg/l) (39630)	Cyanazine, total (µg/l) (81757)	Metolachlor, water, whole, tot rec (µg/l) (82612)	Metribuzin, water, whole, tot rec (µg/l) (82611)	Prometone, total (µg/l) (39056)	Prometryne, total (µg/l) (39057)	Propazine, total (µg/l) (39024)	Simazine, total (µg/l) (39054)	Simetryne, total (µg/l) (39054)	Trifluralin, tot rec (µg/l) (39030)
			Triazine herbicides in water											
I-1	19-Jun-90	1600	<0 10	<0 10	4.9	2 3	<0 1	<0 1	<0.1	<0 1	<0 10	<0 10	<0.1	<0.10
I-2	17-May-90	1000	<0.10	<0 10	1 0	0 10	<0.1	<0.1	<0.1	<0 1	<0 10	<0 10	<0 1	<0.10
I-3	17-May-90	1100	<0.10	<0 10	1.0	0.10	<0 1	<0 1	<0.1	<0.1	<0.10	<0.10	<0.1	<0.10
I-4	19-Jun-90	1330	<0 10	<0 10	0.10	<0 10	<0 1	<0.1	<0.1	<0 1	<0.10	<0.10	<0.1	<0 10
I-6	20-Jun-90	0900	<0 10	<0 10	0 10	<0 10	<0 1	<0 1	<0.1	<0 1	<0.10	<0.10	<0.1	<0.10
I-8	20-Jun-90	0910	<0 10	<0 10	0.10	<0 10	<0.1	<0 1	<0.1	<0 1	<0 10	<0 10	<0 1	<0.10
I-10	19-Jun-90	1200	<0.10	<0.10	0 10	<0 10	<0 1	<0.1	<0 1	<0 1	<0.10	<0 10	<0 1	<0 10
I-13	19-Jun-90	0930	<0 10	<0 10	<0 10	<0 10	<0.1	<0.1	<0 1	<0 1	<0.10	<0 10	<0 1	<0.10

Site number*	Date	Time	2,4-D, total (µg/l) (39730)	2,4-DP, total (µg/l) (82183)	2,4,5-T, total (µg/l) (39740)	Dicamba (Mediben) (Banvel D) total (µg/l) (82052)	Picloram (Tordon) (Amdon), total (µg/l) (39720)	Silvex, total (µg/l) (39720)
			Chlorophenoxy acid herbicides in water					
I-1	19-Jun-90	1600	0 02	<0 01	<0 01	0 12	<0 01	<0.01
I-2	17-May-90	1000	<0.01	<0 01	<0 01	<0 01	<0 01	<0 01
I-3	17-May-90	1100	<0 01	<0 01	<0 01	<0 01	<0 01	<0 01
I-4	19-Jun-90	1330	0 03	<0 01	<0 01	<0 01	<0 01	<0 01
I-6	20-Jun-90	0900	0 02	<0 01	<0 01	<0 01	<0 01	<0 01
I-8	20-Jun-90	0910	<0 10	<0 10	<0 10	<0 10	<0 10	<0 10
I-10	19-Jun-90	1200	<0 10	<0 10	<0 10	<0 10	<0 10	<0 10
I-13	19-Jun-90	0930	<0 10	<0 10	<0 10	<0 10	<0.10	<0 10

* Site number, see table 50

Table 38 (CONT)· Concentrations of pesticides in water and bottom-sediment samples, 1990

Site number*	Date	Time	Carbaryl, (Sevin) (µg/l) (39750)	Methomyl (µg/l) (39051)	Propham (µg/l) (39052)	Aldicarb (µg/l)	Aldicarb sulfone (µg/l)	Carbofuran, total (µg/l)	3-hydroxy-carbofuran, total (µg/l)	1-naphthol, total (µg/l)	Oxamyl, total (µg/l)
			Carbamate insecticides in water								
I-1	6-Aug-90	0800	<0.50	<0.5	<0 5	<0.5	<0 5	<0.5	<0.5	<0.5	<0.5
	6-Aug-90	0805	<0.50	<0.5	<0.5	<0.5	<0.5	<0 5	<0.5	<0.5	<0.5
I-2	4-Aug-90	1700	<0.50	<0 5	<0.5	<0 5	<0 5	<0.5	<0.5	<0.5	<0 5
I-3	22-Aug-90	0900	<0 50	<0.5	<0 5	<0.5	<0 5	<0 5	<0 5	<0 5	<0 5
I-4	6-Aug-90	0900	<0.50	<0.5	<0.5	<0.5	<0.5	<0 5	<0 5	<0 5	<0.5
I-7	5-Aug-90	1000	<0 50	<0.5	<0 5	<0 5	<0 5	<0.5	<0.5	<0 5	<0.5
I-12	21-Aug-90	1300	<0.50	<0 5	<0 5	<0 5	<0.5	<0.5	<0 5	<0.5	<0.5
I-13	5-Aug-90	1200	<0 50	<0.5	<0.5	<0 5	<0 5	<0 5	<0 5	<0 5	<0.5

Site number*	Date	Time	Chloropy-rifos, total (µg/l) (38932)	Def, total (µg/l) (39040)	Disyston, total (µg/l) (39011)	Diazinon, total (µg/l) (39570)	Fonofos (Dyfonate), total (µg/l) (82614)	Ethion, total (µg/l) (39398)	Malathion, total (µg/l) (39530)	Methyl parathion, total (µg/l) (39600)	Methyl trithion, total (µg/l) (39790)	Parathion, total (µg/l) (39540)	Phorate, total (µg/l) (39023)	Ethyl trithion, total (µg/l) (39786)
			Organophosphate compound insecticides in water											
I-1	6-Aug-90	0800	---	<0 01	<0.01	<0 01	<0 01	---	<0.01	<0 01	<0 01	<0 01	<0 01	<0 01
	6-Aug-90	0805	---	<0 01	<0 01	<0 01	<0 01	---	<0 01	<0 01	<0.01	<0 01	<0.01	<0 01
I-2	4-Aug-90	1700	---	<0 01	<0 01	<0 01	<0 01	---	<0.01	<0.01	<0 01	<0 01	<0.01	<0 01
I-3	22-Aug-90	0900	<0 01	<0 01	<0 01	<0 01	<0 01	0 0	<0 01	<0 01	<0 01	<0 01	<0 01	<0 01
I-4	6-Aug-90	0900	---	<0.01	<0 01	<0 01	<0 01	---	<0.01	<0 01	<0.01	<0 01	<0 01	<0 01
I-7	5-Aug-90	1000	---	<0 01	<0 01	<0 01	<0 01	---	<0 01	<0.01	<0 01	<0 10	<0.01	<0.01
I-12	21-Aug-90	1300	<0 01	<0.01	<0.01	<0 01	<0 01	0 0	<0 01	0 14	<0 01	0 61	<0.01	<0 01
I-13	5-Aug-90	1200	<0 01	<0.01	<0 01	<0 01	<0 01	0 0	<0.01	<0.01	<0 01	<0 10	<0 01	<0 01

* Site number see table 50

Table 38 (CONT). Concentrations of pesticides in water and bottom-sediment samples, 1990

Site number*	Date	Time	Aldrin, total (µg/kg) (39333)	Chlordane, total (µg/kg) (39351)	DDD, total (µg/kg) (39363)	DDE, total (µg/kg) (39368)	DDT, total (µg/kg) (39373)	Dieldrin, total (µg/kg) (39383)	Endosulfan, total (µg/kg) (39389)	Endrin, total (µg/kg) (39393)	Heptachlor, total (µg/kg) (39413)
			Organochlorine compound pesticides in bottom sediment								
I-1	3-Dec-90	1000	<0.1	<0 1	<0 1	<0.1	<0 1	<0.1	<0 1	<0.1	<0 1
I-2	7-Nov-90	1600	<0.1	<0 1	<0 1	0.4	<0.1	<0 1	<0.1	<0 1	<0.1
I-7	8-Nov-90	1000	<0.1	<0 1	<0.1	0 1	<0 1	<0 1	<0.1	<0 1	<0.1
I-7	8-Nov-90	1000	<0.1	<0 1	<0 1	<0 1	<0.1	<0.1	<0 1	<0.1	<0.1
I-17	7-Nov-90	1000	<0 1	<0 1	<0.1	0 1	<0 1	<0 1	<0 1	<0.1	<0.1
I-20	7-Nov-90	1300	<0.1	<0 1	0.2	0 1	<0.1	<0 1	<0.1	<0 1	<0.1
I-21	6-Nov-90	0900	<0 1	1 0	0 1	0.3	<0.1	<0.1	<0.1	<0 1	<0 1
I-22	6-Nov-90	1600	<0.1	1 0	0.1	0 2	0 1	<0 1	<0.1	<0 1	<0.1
I-23	6-Nov-90	1400	<0 1	1.0	0 2	0 3	<0 1	<0 1	<0 1	<0.1	<0 1
I-24	2-Dec-90	1030	<0 1	2 0	0.1	0.4	<0 1	<0 1	<0 1	<0 1	<0.1

Site number*	Date	Time	Heptachlor epoxide, total (µg/kg) (39423)	Lindane, total (µg/kg) (39343)	Methoxy-chlor total (µg/kg) (39481)	Mirex, total (µg/kg) (39758)	PCB, total (µg/kg) (39519)	PCN, total (µg/kg) (39251)	Perthane, (µg/kg) (81886)	Toxaphene, total (µg/kg) (39403)
			Organochlorine compound pesticides in bottom sediment							
I-1	3-Dec-90	1000	<0 1	<0 1	<1.0	<0 1	<1	<1 0	<1 00	<10
I-2	7-Nov-90	1600	<0.1	<0 1	<1 0	<0.1	<1	<1 0	<1 00	<10
I-7	8-Nov-90	1000	<0 1	<0 1	<0 1	<0.1	<1	<1 0	<1 00	<10
I-7	8-Nov-90	1000	<0 1	<0 1	<0.1	<0.1	<1	<1 0	<1 00	<10
I-17	7-Nov-90	1000	<0 1	<0 1	<0 1	<0 1	<1	<1 0	<1.00	<10
I-20	7-Nov-90	1300	<0 1	<0 1	<0.1	<0 1	<1	<1 0	<1.00	<10
I-21	6-Nov-90	0900	<0.1	<0 1	<0 1	<0 1	<1	<1 0	<1.00	<10
I-22	6-Nov-90	1600	<0 1	<0 1	<0 1	<0 1	<1	<1 0	<1 00	<10
I-23	6-Nov-90	1400	<0 1	<0 1	<0 1	<0 1	<1	<1 0	<1 00	<10
I-24	2-Dec-90	1030	<0 1	<0 1	<1.0	<0 1	<1	<1 0	<1 00	<10

* Site number: see table 50

Taken from Blanchard et al 1993

Table 39: Concentrations of organochlorine compounds in composite whole-body flannelmouth sucker samples, 1990 (units are µg/g wet weight)

River Reach*	Weight (grams)	Number	Percent moisture	Lipid (percent)	HCB	a-BHC	r-BHC	s-BHC	Oxychlor-dane	Hepta-chlor epoxide	r-Chlor-dane	t-Nona-chlor	Toxa-phene	PCBs total	o,p'-DDE
A	3,220	5	68.0	13.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C	5,273	5	71.0	10.7	ND	ND	ND	ND	ND	ND	0.01	0.02	ND	0.16	ND
D	4,691	5	66.5	15.1	ND	ND	ND	ND	ND	ND	0.01	0.02	ND	0.21	ND
E	3,261	5	70.0	12.1	ND	ND	ND	ND	ND	ND	0.01	0.02	ND	0.20	ND
F	3,218	5	65.5	16.5	ND	ND	ND	ND	ND	ND	0.01	0.01	ND	0.17	ND
G	3,444	5	66.5	14.2	ND	ND	ND	ND	ND	ND	0.01	0.01	ND	0.14	ND

River Reach*	a-Chlor-dane	p,p'-DDE	Dieldrin	o,p'-DDD	Endrin	Cis-Non-achlor	o,p'-DDT	p,p'-DDD	p,p'-DDT	Mirex
A	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND
C	0.02	0.08	ND	ND	ND	ND	ND	0.02	0.02	ND
D	0.03	0.06	ND	ND	ND	ND	ND	0.02	0.02	ND
E	0.02	0.07	ND	ND	ND	ND	ND	0.02	0.02	ND
F	0.02	0.04	ND	ND	ND	ND	ND	0 02	0.01	ND
G	0.02	0.03	ND	ND	ND	ND	ND	0.01	0.01	ND

* River reach, see Table 51

Taken from Blanchard et al. 1993

Of the 132 total analyses conducted on the sucker samples, concentrations of compounds in 96 of the analyses were below the laboratory reporting level of 0.01 μg/g wet weight, and no concentration of any compound was greater than the NCBP (1984) geometric mean (Schmitt et al. 1990, Blanchard et al. 1993). In 1991, the annual New Mexico Department of the Environment water quality stream survey included analyses of 56 water samples for 23 chlorohydrocarbon pesticides and five PCBs The samples were collected from the Animas River at Farmington and the San Juan River below Shiprock (New Mexico Department of the Environment 1992). Sample concentrations were below detection limits for all compounds (Appendix 10).

Most of the long-lasting chlorohydrocarbon pesticides were discontinued by the late 1970s; however, many other varieties of pesticides (e.g. carbamates, organophosphates, etc) are widely used on agricultural lands within the San Juan basin. The Colorado Water Quality Control Division (1992) has compiled statistics for pesticide use per county, presumably for 1992. In Archuleta County, 600 acres received pesticide applications; in Dolores County, 28,400 acres; in La Plata County, 10,900 acres; and in Montezuma County, 17,300 acres. USGS water quality data from the Shiprock station on the San Juan River indicate that 2,4-D has historically been present in concentrations greater than the laboratory reporting level of 0.01 μg/l (Blanchard et al 1993). On NIIP lands, pesticides that are used include triazine herbicides, organophosphate compounds, carbamate insecticides, and chlorophenoxy acid herbicides (O'Brien 1991).

Blanchard et al. (1993) collected water samples from seven sites on the NIIP and analyzed them for 12 triazine herbicides and six chlorophenoxy acid herbicides. Those present at concentrations at or above laboratory reporting levels were: cyanazine at three sites in the Gallegos Canyon area; 2,4-D at one site in the Gallegos Canyon area and at two sites in the Ojo Amarillo Canyon area; and dicamba at one site in the Gallegos Canyon area. Water samples from the seven NIIP sites were also analyzed for 22 insecticides. At the block 3 Northwest pond (site I-12), methyl parathion and parathion were above laboratory reporting levels; none of the insecticides was at detectable levels at any other sample site (Blanchard et al. 1993).

4.9 TRACE ELEMENTS

Within the San Juan River basin certain trace elements consistently exceed standards and national averages and are therefore of greater concern than are pesticides or PCBs. Mercury and selenium are most often identified as potentially significant contaminants in the basin; because of the large quantity of information, each element is accorded its own section in this review. This section will focus on one study, O'Brien (1987), which is the best available investigation of trace element contamination of San Juan basin fish.

Although O'Brien (1987) is the most thorough fish contamination study for the basin, it must be noted that the study area is restricted to New Mexico. A total of fifteen composite samples were analyzed, and the resulting data were compared to NCBP geometric mean values and residue levels reported in the literature (Table 40) (O'Brien 1987). Comparison of the data suggested that fish in the San Juan area are probably not at risk from cadmium, nickel, mercury, arsenic, or zinc (Eisler 1985, O'Brien 1987). A discussion of elements that may be of concern follows.

Eisler (1986) noted that normal levels of chromium in fish range from 0.1-1.9 ppm; the geometric mean for chromium in the San Juan basin samples exceeded Eisler's recommended level of 0 20 ppm, and a maximum chromium level of 0.83 was found in a bluehead sucker from the Animas River. The sources of chromium in the basin could include metal extraction and production, coal combustion, cooling towers associated with powerplants, and atmospheric emissions O'Brien (1987) suggested that the chromium levels in San Juan basin fish, while somewhat elevated, are not cause for concern.

The geometric mean of 1.24 ppm for copper in the San Juan basin samples exceeded the NCBP 85th percentile concentration of 0 90 ppm (Lowe al. 1985) The 85th percentile is an arbitrarily chosen level that researchers often use for data comparison; levels exceeding the 85th percentile are generally

Table 40: Heavy metal analysis for fish from the San Juan and Animas rivers (units are mg/kg wet weight or ppm)

		Heavy metal (85 percentile of geometric mean of all NCBP Stations)											
Station	Species	Cd (0.06)*	Cr (0.20)**	Cu (0.90)*	Mn	Ni (0.76)***	Pb (0.17)*	Sn	Hg (0.18)*	As (0.22)*	Mg	Zn (46.26)*	Se (0.71)*
1	Flannelmouth sucker	0.02	0.54	1.1	14.0	0.3	0.45	2.1	0.073	0.16	400	21	0.72
1	Bluehead sucker	0.037	0.37	1.2	21.0	0.33	0.58	1.5	0.04	0.37	460	20	0.43
1	Bluehead sucker	0.02	0 2	0.97	8.1	0.2	0.32	1.9	0.088	0.1	350	19	0.65
2	Longnose dace#	0.045	0.5	1.1	20	0.36	0.48	1	0.069	0.18	420	27	0.87
2	Bluehead sucker	0.03	0.51	1.2	16	0.36	0.42	1	0.05	0.31	360	17	0.46
3	Longnose dace#	0.15	0.46	1.4	20	1.2	0.74	0.6	0.093	0.18	410	41	1.4
3	Flannelmouth sucker	0.076	0.52	1.3	24	0 34	1.0	2.3	0.096	0.17	360	21	0.48
3	Bluehead sucker	0.078	0.83	1.7	50	0.62	1.5	2	0.068	0.42	430	20	0.24
4	Longnose dace#	0 02	0.3	1.1	4 9	0.42	0.05	0.5	0.14	0.07	320	38	2.3
4	Flannelmouth sucker	0.02	0 3	1.1	8.8	0.1	0.18	1	0.21	0.18	310	17	0.62
4	Bluehead sucker	0.02	0.64	0.95	19	0.32	0.47	1.5	0.062	0.33	410	18	0.53
5	Carp	0.01	0.2	1.1	3.1	0.1	0 05	2.8	0.073	0.05	340	59	0.74
5	Trout	0.01	0.3	1.2	5.8	0.1	0.14	1.0	0.068	0 05	320	21	1.5
6	Bluehead sucker	0.12	0.51	1.5	26	0.53	1.3	1.0	0.05	0.24	340	21	0.32
6	Flannelmouth sucker	0.12	0.31	1 4	16	0.2	1.1	1.5	0 13	0.09	330	23	0.45
	Geometric mean	0.035	0 4	1.24	13 7	0.29	0.39	1 3	0.08	0.15	368	23.7	0.57

* Lowe et al. 1985

** Eisler, R.1986 Chromium level reported in animal tissue for protection of resources

*** Ohlendorf et al. 1986 (1.9 ppm dry weight converted to wet weight assuming 30 percent moisture)

O'Brien states that longnose dace were sampled However, this species of fish does not occur in the San Juan basin. This review therefore assumes that the correct species was the speckled dace

Taken from O'Brien 1987

considered elevated, although the level has no physiological significance. The copper residue levels in bluehead sucker, which ranged from 0.95-1.7 ppm, were all above the NCBP 85th percentile. The U.S. Environmental Protection Agency (1986) has stated that normal copper levels in domestic animals range from 0.42-11 ppm. O'Brien (1987) concluded that the maximum value of 1.7 ppm of copper in a bluehead sucker sample in the San Juan study indicates that copper is probably not a concern for aquatic resources in the basin.

The geometric mean of 0.39 ppm for lead in whole-body composites of San Juan basin fish exceeded the NCBP geometric mean of 0.17 ppm (Lowe et al. 1985). Walsh et al. (1977) have stated that whole-body lead residues exceeding 0.5 ppm may be harmful to aquatic life. Six of the 15 San Juan composite samples had lead residue levels exceeding 0.5 ppm. In light of these data, O'Brien (1987) concluded that lead may be an element of concern for San Juan basin fish.

The geometric mean for selenium in San Juan basin fish was 0.57 ppm, which was lower than the NCBP geometric mean of 0.71 ppm (Lowe et al. 1985). However, a maximum level of 2.3 ppm was recorded for a speckled dace sample, which is nearly as high as the NCBP maximum level of 2.47 ppm. Furthermore, 6 of the 15 composite San Juan basin samples had selenium levels above the NCBP 85th percentile concentration, and 10 samples were above the NCBP geometric mean (Lowe et al. 1985, O'Brien 1987). Lemly (1985) reported that trout in Belews Lake, North Carolina, experienced reproductive failure when selenium tissue levels exceeded 2.42 ppm wet weight.

Because the highest selenium concentrations in the San Juan basin fish were in speckled dace and trout, as compared to common carp and sucker, there is an indication that selenium is bioconcentrating through the food chain. Moreover, the highest selenium levels seemed to occur in the upper portion of the San Juan River (O'Brien 1987). This trend was not statistically tested, although it suggests that mining and/or irrigation return flows may be significant selenium sources in the basin.

Selenium in fish, food items, soils, sediment, and surface water have been found at levels of concern in other studies, particularly those focusing on the Animas-La Plata Project, NIIP, and the other DOI-sponsored irrigation projects within the San Juan basin. As these studies are quite substantial, they will be discussed separately in this review under the IRRIGATION section (4.10).

4.9.1 MERCURY

Although O'Brien (1987) did not identify mercury as an element of concern in San Juan River basin fish, other basin studies have shown it to be a potentially significant contaminant, particularly in certain reservoirs. In 1970, mercury concentrations in fish in Navajo Reservoir were apparently among the highest in the Southwest, with brown trout reportedly containing 1.4 μg/g mercury and chubs containing 8.9 μg/g (Melancon et al. 1979); it is not clear if these were whole-body measurements or whether they were wet or dry weight. In 1977 the EPA analyzed fish flesh from the San Juan arm of Lake Powell and found mercury concentrations of 6.0 μg/g in a common carp, 0.415 μg/g in a crappie, 0.34 μg/g in a cutthroat trout, and 0.26 μg/g in a dace (Melancon et al. 1979).

In 1971 mercury concentrations in surface water samples from the San Juan, Navajo, Piedra, Los Pinos, La Plata, and Mancos rivers exceeded the EPA standard for aquatic life, which at the time was set at 0.05 μg/l in order to ensure safe levels in edible portions of fish. The highest concentrations were found in the La Plata and Mancos rivers (Melancon et al. 1979). In 1977 the mean mercury concentration for sediment in the basin was 0.064 μg/g (ppm). One sediment sample from Navajo Reservoir contained 40 μg/g mercury, and one sample from McElmo Creek contained 80 μg/g. Neither of these unusually high concentrations was included in calculation of the basin mean, as both samples were apparently abnormal, containing visible amounts of oil and tar (Melancon et al. 1979).

From 1988 to 1991, the CDOW and the FWS sampled fish in a number of reservoirs and river reaches within the Colorado portion of the San Juan basin (Table 41) (Colorado Division of Wildlife 1991). Mercury concentrations in whole-body fish samples from this study may be compared to the NCBP data from 1984-1985. For those years, the NCBP geometric mean for mercury was 0.10 μg/g wet weight,

Table 41: Mercury levels in fish taken from southwest Colorado waters (updated 11/05/91)

river reach/ water body	species	length or weight	ppm mercury (wet weight)	no in sample	sample type	origin/date of analysis
McPhee Reservoir, Montezuma County	kokanee salmon	12-18"	0 10	9	carcass	CDOW/1-91
		12-18"	0 08	4	carcass	USFWS/3-91
	rainbow trout	6-12"	0 11	7	fillet	CDOW/9-89
		12-18"	0 23	6	fillet	CDOW/9-89
		14"	0 185	3	fillet	USFWS/11-90
		14"	0 30	1	fillet	USFWS/11-90
	yellow perch	0-6"	0 15	9	fillet	CDOW/9-89
		6-12"	0 27	9	fillet	CDOW/9-89
	smallmouth bass	0-6"	0.28	5	fillet	CDOW/9-89
		6-12"	0 29	5	fillet	CDOW/9-89
	black crappie	6-12"	0 527	9	fillet	CDOW/1-91
	largemouth bass	12-18"	0 73	7	fillet	CDOW/9-89
		12"	0 60	1	fillet	USFWS/3-91
Narraguinnep Reservoir, Montezuma County	yellow perch	0-6"	0 11	5	fillet	CDOW/9-89
		6-12"	0.33	9	fillet	CDOW/9-89
	channel catfish	18-24"	0.43	9	fillet	CDOW/9-89
	northern pike	12-18"	0 21	4	fillet	CDOW/9-89
		18-24"	0 67	4	fillet	CDOW/9-89
		24-30"	0.61	1	fillet	CDOW/9-89
		30-36"	1 0	1	fillet	CDOW/9-89
	walleye	12-18"	0 62	9	fillet	CDOW/9-89
		18-24"	1 2	10	fillet	CDOW/9-89
Totten Reservoir, Montezuma County	channel catfish	24"	0 05	1	whole fish	USFWS/4-90
	bluegill	5"	0.13	4	whole fish	USFWS/4-90
	black crappie	9"	0.17	1	whole fish	USFWS/4-90
	yellow perch	8"	0.08	2	fillet	USFWS/11-90
		13"	0 20	2	whole fish	USFWS/4-90
	northern pike	22"	0 24	1	whole fish	USFWS/11-90
		29"	0.25	1	whole fish	USFWS/4-90
		31"	0 40	1	fillet	USFWS/11-90
		39"	0 35	1	fillet	USFWS/4-90
	walleye	21"	0 55	2	whole fish	USFWS/11-90
		22"	0 39	2	whole fish	USFWS/4-90
		23"	0 72	1	fillet	USFWS/4-90
		24"	0 62	1	fillet	USFWS/11-90
Summit Reservoir, Montezuma County	black crappie	6-12"	0 333	3	fillet	CDOW/6-91
		8"	0.25	1	whole fish	USFWS/4-90
	smallmouth bass	10"	0.25	3	whole fish	USFWS/4-90
		10"	0 33	2	fillet	USFWS/4-90
		15"	0 48	2	fillet	USFWS/11-90
		15"	0 69	2	fillet	USFWS/11-90
	white sucker	14"/530 gm	0 05	1	whole fish	USFWS/4-90
Navajo Reservoir/ Piedra and San Juan arms/Colorado, Archuleta County	smallmouth bass	13"/434 gm	0 29	1	edible portion	USFWS/3-91
		13"/446 gm	0.42	1	edible portion	USFWS/3-91
		14"/572 gm	0.35	1	edible portion	USFWS/3-91
		14"/551 gm	0 27	1	edible portion	USFWS/3-91
		14"/623 gm	0 50	1	edible portion	USFWS/3-91
		15"/895 gm	0.48	1	edible portion	USFWS/3-91
	white crappie	6-12"	0 26	9	fillet	CDOW/6-91
	channel catfish	12-18"	0.23	4	fillet	CDOW/6-91
		13"/323 gm	0.20	1	edible portion	USFWS/3-91
		13"/346 gm	0 15	1	edible portion	USFWS/3-91
		14"/384 gm	0 26	1	edible portion	USFWS/3-91
		14"/370 gm	0 12	1	edible portion	USFWS/3-91
		14"/450 gm	0 356	1	edible portion	USFWS/3-91
		17"/614 gm	0 14	1	edible portion	USFWS/3-91
		17"	0 158	3	whole fish	USFWS/6-89
		18-24"	0 36	4	fillet	CDOW/6-91

Table 41 (CONT): Mercury levels in fish taken from southwest Colorado waters (updated 11/05/91)

river reach/ water body	species	length or weight	ppm mercury (wet weight)	no in sample	sample type	origin/date of analysis
Navajo Reservoir/ Piedra and San Juan arms/Colorado, Archuleta County (CONT)	northern pike	12-18"	0.19	4	fillet	CDOW/6-91
		24-30"	0 360	1	fillet	CDOW/3-91
		24"	0 146	3	whole fish	USFWS/11-88
		35"	0 40	1	edible portion	USFWS/3-91
		39"	0 59	1	edible portion	USFWS/3-91
		42"	0.73	1	edible portion	USFWS/3-91
	bullhead	9"	0.158	6	whole fish	USFWS/11-88
		9"	0 161	4	whole fish	USFWS/3-89
		9"	0 197	4	whole fish	USFWS/6-89
	sucker	18"	0 193	3	whole fish	USFWS/11-88
	common carp	17"	0.25	3	whole fish	USFWS/6-89
		18"	0 192	3	whole fish	USFWS/11-88
		19"	0.289	2	whole fish	USFWS/3-89
Vallecito Reservoir, La Plata County	kokanee salmon	11"	0.22	1	fillet	CDOW/6-91
	rainbow trout	12-18"	0.096	2	fillet	CDOW/6-91
	brown trout	6-12"	0 047	2	fillet	CDOW/6-91
		12-18"	0 10	2	fillet	CDOW/6-91
	walleye	16"	0 29	2	fillet	USFWS/11-90
		19"	0 40	1	fillet	USFWS/3-91
	northern pike	12-18"	0.26	2	fillet	CDOW/6-91
		12-18"	0.18	2	fillet	CDOW/6-91
		18-24"	0 26	2	fillet	CDOW/6-91
		18-24"	0.21	1	fillet	CDOW/6-91
		24-30"	0 26	4	fillet	CDOW/6-91
		26"	0 34	1	fillet	USFWS/4-90
		30-36"	0 342	1	fillet	CDOW/6-91
		32"	0 29	1	fillet	USFWS/3-91
		36-42"	0 598	1	fillet	CDOW/6-91
	white sucker	6-12"	0 13	1	fillet	CDOW/6-91
		12-18"	0 19	9	fillet	CDOW/6-91
		18-24"	0 447	2	fillet	CDOW/6-91
Puett Reservoir, Montezuma County	walleye	26"	0 63	2	fillet	USFWS/3-91
Dolores River, 1/8 mi above Barlow Creek confluence , Dolores County	brown trout	13"/426 gm	0 044	1	whole fish	USBR/12-89
Dolores River, 2.5 mi above Rico, Dolores County	brown trout	19"/1277 gm	0 127	1	whole fish	USBR/12-89
		8-9"	0.020	5	whole fish	USBR/12-89
Dolores River @ Hwy 145 bridge, Rico, Dolores County	brown trout	8-9"	0 021	4	whole fish	USBR/12-89
Dolores River @ Rico cemetery, Dolores County	brown trout	10"	0.033	1	whole fish	USBR/12-89
Dolores River @ Montelores bridge, Montezuma-Dolores Counties	brown trout	14-16"	0 083	3	whole fish	USBR/12-89
Hartman Draw, near Lebanon, Montezuma County	bluehead sucker	10"	0 08	1	whole fish	USFWS/11-90
Lower Hartman Draw, Montezuma County	flannelmouth sucker	18"	0 15	2	whole fish	USFWS/11-90

Table 41 (CONT): Mercury levels in fish taken from southwest Colorado waters (updated 11/05/91)

river reach/ water body	species	length or weight	ppm mercury (wet weight)	no in sample	sample type	origin/date of analysis
McElmo Creek near Cortez, Montezuma County	flannelmouth sucker	17"	0 12	2	whole fish	USFWS/11-90
McElmo Creek above Yellowjacket, Montezuma County	common carp	19"	0.08	2	whole fish	USFWS/11-90
	flannelmouth sucker	17"	0 165	1	whole fish	USFWS/11-90
McElmo Creek below Yellowjacket, Montezuma County	common carp	20"	0.12	2	whole fish	USFWS/11-90
	flannelmouth sucker	18"	0.09	2	whole fish	USFWS/11-90
Mancos River, above Navajo Wash, Montezuma County	common carp	18"	0 14	2	whole fish	USFWS/11-90
	flannelmouth sucker	15"	0 05	1	whole fish	USFWS/11-90
Alkali Creek, northwest of Cortez, Montezuma County	flannelmouth sucker	19"	0 17	2	whole fish	USFWS/11-90
Yellowjacket Canyon, Montezuma County	bluehead sucker	9"	0 129	1	whole fish	USFWS/11-90
Dawson Draw, Montezuma County	bluehead sucker	3"	0.03	2	whole fish	USFWS/11-90

Taken from Colorado Division of Wildlife 1991 the maximum concentration was 0.37, and the 85th percentile concentration was 0.17 (Schmitt and Brumbaugh 1990).

Reservoirs from which fish samples were collected for the CDOW survey were McPhee, Narraguinnep, Totten, Puett, and Summit reservoirs, all in Montezuma County, as well as Navajo Reservoir in Archuleta County and Vallecito Reservoir in La Plata County. No whole-body fish samples were taken from McPhee, Narraguinnep, Vallecito, or Puett reservoirs, although fillets had mercury concentrations as high as 0.598 $\mu g/g$ for northern pike in Vallecito, 0.63 for walleye in Puett, 0.73 for largemouth bass in McPhee, and 1.2 for walleye in Narraguinnep. From Totten Reservoir, eight whole fish samples were analyzed. Of these, seven had mercury levels above the NCBP geometric mean, five were above the 85th percentile, and two were above the NCBP maximum concentration. Three whole-body samples were taken from Summit Reservoir, two of which were above the 85th percentile but below the maximum NCBP concentration (Schmitt and Brumbaugh 1990, Colorado Division of Wildlife 1991). Nine whole-body samples were taken from the Piedra and San Juan arms of Navajo Reservoir, all of which had mercury concentrations above the NCBP geometric mean and five of which had concentrations above the 85th percentile but below the maximum value.

The same study took additional whole-body fish samples from rivers and streams in Colorado. Lower Hartman Draw, McElmo Creek, the Mancos River, Alkali Creek, and Yellowjacket Canyon, all in Montezuma County, each produced fish samples with mercury levels above the NCBP geometric mean, although no fish had concentrations above the 85th percentile. Fish were also sampled from the Dolores River, from which water is diverted to the San Juan basin for the Dolores Project (to be discussed further in section 4.10.3 of this review). Of six fish samples from the Dolores River, one had a mercury level greater than the NCBP geometric mean but below the 85th percentile concentration (Schmitt and Brumbaugh 1990, Colorado Division of Wildlife 1991).

According to Standiford et al. (1973), mercury-bearing sedimentary rock is probably the main source of the metal in the waters. The two coal-fired powerplants in New Mexico may also add mercury to the system (Melancon et al. 1979). In 1976, the Bureau of Reclamation estimated that approximately 562 kg/year of mercury were present in emissions from the Four Corners Powerplant (U.S. Bureau of Reclamation 1976), of which approximately 55 g were deposited per year in Navajo Reservoir and 580 g were deposited into the remainder of the San Juan basin (Melancon et al. 1979).

Mercury-containing manometers used to measure pressure at natural gas wells may also be sources of contamination in the basin. When elemental mercury leaked from manometers is inundated by slow moving, acidic, sediment-filled floodwaters that are low in oxygen, methyl mercury can be formed (Fulton 1993). Within the San Juan basin, the BLM has required parties with BLM-supervised oil and gas leases or gas pipeline right of ways to determine the number of mercury manometers in use and to estimate the extent of mercury contamination at each site (Lockwood 1990). On BLM lands in New Mexico, Williams Field Service, Gas Company of New Mexico, and El Paso Natural Gas have undertaken cleanup efforts of leaking manometers at their well sites (Kelley, personal communication). The extent of mercury contamination of soils within the basin by mercury manometers has apparently not been determined.

4.9.2 SELENIUM

Selenium is one of 65 priority pollutants listed by the EPA. It is a non-metallic trace element and a micronutrient required by animals in small amounts (Hunn et al. 1987). The two major anthropogenic causes of selenium mobilization and introduction into aquatic systems are the procurement, processing, and combustion of fossil fuels and the associated storage of produced ash in settling basins; and the irrigation of seleniferous soil to produce selenium-laden return flows (Hunn et al. 1987, Lemly and Smith 1987, Lemly in press).

Soil concentrations of selenium rarely exceed 2 $\mu g/g$ dry weight except when soil is derived from the weathering of sedimentary rock (Lemly and Smith 1987). Underlying much of the San Juan basin are Cretaceous and Tertiary age sedimentary formations that can potentially yield large amounts of selenium to soils and subsequently to sediment and water (Blanchard et al. 1993). The National Irrigation Water Quality Program of the DOI has identified the DOI-sponsored irrigation projects along the main stem of the San Juan River in New Mexico as contributing significant selenium loads to the river (Roy and Hamilton 1992).

Within the San Juan basin are also two large-scale coal-fired powerplants, the San Juan and Four Corners plants, both located in New Mexico near Shiprock. Selenium is an important trace element in coal as well as in coal conversion materials and their waste products, and it can be leached directly from coal mining, preparation, and storage sites (Lemly in press). Selenium in coal may be more than 65 times greater than concentrations in the surrounding soil. After coal is burned, fly-ash and bottom ash remain in which selenium is even more concentrated, up to as much as 1,250 times the concentration in coal (Lemly 1985). This ash is disposed of in wet-slurry or dry-ash basins, and from these basins selenium can be leached during overflow events (Lemly in press). Lemly (1985) has compiled a list of the concentrations of selenium in various raw materials used in the power industry and in the wastes produced (Table 42). It must be noted that coal's selenium concentration is related to its sulfur content, and that Western coal has significantly lower sulfur levels than does coal from the East, where most coal-selenium studies have been conducted (Yahnke, personal communication).

Selenium standards for water bodies within the San Juan basin are found under the STANDARDS section of this review (4.3); additionally, selenium standards for the San Juan River proper are summarized (Table 43). Data collected by the USGS within the basin show that these standards have been exceeded on numerous occasions. From 1970-1989, samples collected in New Mexico from 16 of 24 surface water quality stations and from 7 of 35 miscellaneous surface water sites had selenium concentrations exceeding New Mexico's chronic standard of 5 μg/l (Blanchard et al. 1993).

Within the basin, irrigation return flows drain into backwaters that are often rich in primary production. It is in these backwaters that inorganic selenium may become concentrated into primary consumers in the organic form and subsequently transferred up the food chain. This process could help to explain why waterborne selenium concentrations in the San Juan basin may be low (less than 35 μg/l) but fish and bird tissue concentrations are elevated (O'Brien 1987, National Fisheries Contaminant Research Center et al. 1991). Another explanation may be the existence of ultra-trace amounts (less than 1 μg/l) of organoselenium compounds that may bioaccumulate and produce much higher tissue residues than do inorganic selenate or selenite (Besser et al 1989, Besser et al. 1992, Lemly in press).

When dissolved selenium enters an aquatic system, it will either be absorbed or ingested by organisms, it will bind or complex with particulate matter, or it will remain free in solution. Over time, most selenium will either be taken up by organisms or will bind to particulate matter. Of that which becomes bound, most accumulates in the top layer of sediment and detritus. Ninety-percent of all selenium in an aquatic system may be sequestered in the upper few centimeters of sediment and overlying detritus. Immobilization processes are most efficient in slow-moving or still-water habitats and wetlands. In most aquatic systems, though, there exist mechanisms that can remobilize such selenium into food chains (Lemly and Smith 1987).

The following explanation of selenium mobilization processes is excerpted directly from Lemly and Smith (1987):

> Selenium is made available for biological uptake by four oxidation processes. The first is the oxidation and methylation of inorganic and organic selenium by plant roots and microorganisms. (Oxidation refers to the conversion of inorganic or organic selenium in the reduced organic, elemental, or selenite forms to the selenite or selenate forms; methylation is the conversion of inorganic or organic selenium to an organic form containing one or more methyl groups, which usually results in a volatile form.) The second process is the biological mixing and associated oxidation of sediments that results from the burrowing of benthic invertebrates and feeding activities of fish and wildlife. The third process is represented by physical perturbation and chemical

Table 42: Concentrations of selenium present in raw materials used by the power industry, and in various wastes produced during processing and utilization

Material or waste	Selenium concentration
Earth's crust	0.2 μg/g*
Surface water	0.2 μg/l*
Coal	0.4-24 μg/g**
Coal cleaning process water	15-63 μg/l
Coal cleaning solid waste	2.3-31 μg/g**
Coal cleaning solid waste leachate	2-570 μg/l
Coal burner ash (bottom ash)	7.7 μg/g**
Precipitator ash (fly ash)	0.2-500 μg/g**
Scrubber ash (fly ash)	73-440 μg/g**
FGD process water	1-2700 μg/l
FGD sludge	0.2-19 μg/g***
Boiler cleaning water	5-151 μg/l
Coal ash slurry	50-1500 μg/l
Ash settling ponds	87-2700 μg/l
Ash pond effluents	2-260 μg/l
Ash pond sediments	1.6-17 μg/g***
Fly ash leachate	40-610 μg/l
Ash disposal pit leachate	40 μg/l
Coal storage pile leachate	1-30 μg/l
Coal gasification process water	5-460 μg/l
Coal gasification solid wastes	0.7-17.5 μg/g***
Gasification solid waste leachate	0.8-100 μg/l
Coal liquifaction process water	100-900 μg/l
Coal liquifaction solid wastes	2.1-22 μg/g***
Oil shale	1.3-5.2 μg/g**
Crude shale oils	92-540 μg/l
Shale oil retort water	3-100 μg/l
Retort solid waste leachate	10-30 μg/l
Crude oil	500-2200 μg/l
Refined oils	5-258 μg/l
Oil burner ash (fly ash)	3-10 μg/g**

*Representative values

**Expressed on a dry weight basis

***Expressed on a wet weight basis

Modified from Lemly 1985

Table 43: Surface water selenium standards for the San Juan River in NM, CO, and UT, and EPA criteria

	New Mexico*	Colorado (1)**	Colorado (2)**	Utah***	EPA****
Acute (µg/l)	20.0 (diss)	10.0 (tot)		20 0 (diss)	20 (diss)
Chronic (µg/l)	5.0 (diss)		20 0 (tot)	5 0 (diss)	5 (diss)

(1) Mainstem of San Juan River from the boundary of the Weminuche Wilderness Area (West Fork) and the source (East Fork) to the confluence with Fourmile Creek

(2) Mainstem of the San Juan River from the confluence with Fourmile Creek to Navajo Reservoir

* Acute criteria apply to any single grab sample Acute criteria shall not be exceeded
Chronic criteria apply to the arithmetic mean of 4 samples collected on each of 4 consecutive days
Chronic criteria shall not be exceeded more than once every 3 years

** Both acute and chronic numbers adopted as stream standards are levels not to be exceeded more than once every three years on average

*** Acute: 1-hour average. Chronic: 4-day average Where criteria are listed as 4-day average and 1-hour average concentrations, these concentrations should not be exceed more often than once every 3 years on the average

**** The acute concentration should not be exceeded at any time. The chronic concentration is a 24-hour average

Modified from Office of the Federal Register 1993, New Mexico Water Quality Control Commission 1991, Utah Department of Environmental Quality 1992, Colorado Water Quality Control Commission 1993b

> oxidation associated with water circulation and mixing (current, wind, stratification, precipitation, and upwelling). Finally, sediments may be oxidized by plant photosynthesis.
>
> Two additional pathways provide for direct movement of selenium from sediments into food chains, even when surface water does not contain the element. Those pathways are uptake of selenium by rooted plants and uptake by bottom-dwelling invertebrates and detrital-feeding fish and wildlife. These two pathways may be the most important in the long-term cycling of potentially toxic concentrations of selenium. Thus, rooted plants and the detrital food pathway can continue to be highly contaminated and expose fish and wildlife through dietary routes even though concentrations of selenium in water are low (Lemly and Smith 1987).

A further explanation of selenium's forms in aquatic systems is taken from Keller-Bliesner Engineering and Ecosystems Research Institute (1991) (Table 44).

Lemly and Smith (1987) note that fast-flowing waters have a smaller capacity for selenium retention than do standing or slow-moving waters that have low-flushing rates, because in fast-flowing waters there is less opportunity for a contaminated surface layer of sediment to develop and there tend to be few rooted plants. In slow-moving or standing waters, biological activity tends to be high, and sediments build up a selenium load that can be continually mobilized through detrital and planktonic food. In either habitat, as long as selenium persists in sediments there remains the risk that it will be mobilized through the detrital food pathways and thereby be made available to fish.

Because Colorado squawfish and razorback sucker use backwaters as nursery and feeding habitats, they are exposed to potentially high selenium concentrations. Toxicity tests, however, suggest that these fish would generally not be at risk from waterborne selenium concentrations found in the San Juan basin. The 96-hour LC_{50} for young squawfish and razorback sucker was found to be about 15,000 μg/l for selenite and 50,000 μg/l for selenate (Kemp et al. 1973, National Fisheries Contaminant Research Center et al. 1991). Furthermore, toxicity tests showed that Colorado squawfish are more tolerant of various toxicants, including selenium, than are fathead minnows or goldfish and that EPA surface water standards should therefore protect squawfish (National Fisheries Contaminant Research Center et al. 1991). In general, cyprinids are less tolerant of selenium than are salmonids, and centrarchids are apparently the least tolerant group of freshwater fishes that have been tested (Lemly 1985, Bertram and Brooks 1986, National Fisheries Contaminant Research Center et al. 1991).

Only limited information exists concerning actual selenium levels in San Juan basin endangered fish. Data collected by Hamilton and Waddell (in press) on razorback sucker in the Green River may be relevant to San Juan basin razorback sucker. A sample of razorback sucker eggs taken in 1988 from the Green River had selenium concentrations of 4.9 μg/g dry weight, and a subsequent sample from 1991 had a concentration of 28 μg/g. More recently, eggs from razorback sucker in the Green River were found to contain 3.7-10.6 μg/g selenium dry weight, and milt from male fish in the same area had concentrations of less than 1.1-6.7 μg/g. The selenium concentration from the 1991 egg sample was greater than the concentration of 16 μg/g in viscera that Lemly and Smith (1987) have reported to be associated with reproductive problems in fish. The eggs sampled in 1988 and those from the most recent sampling effort each had concentrations of selenium that are above normal concentrations in control and reference fish, but which are below concentrations reported to cause reproductive problems. However, streamside spawning of three pairs of fish from whom eggs and milt were sampled produced no hatching of fertilized eggs, suggesting that selenium levels may have been high enough to cause reproductive impairment (Hamilton and Waddell in press).

The razorback sucker from whom eggs and milt were sampled were apparently healthy and exhibiting reproductive behavior. It is possible, though, that fish whose reproduction is impaired by selenium may still engage in apparently normal reproductive behavior. In fact, in at least one study fathead

Table 44: Common forms of selenium compounds and their characteristics

Valence State	Common Forms	Inorganic or Organic	Solubility in Water	Toxicity*	Remarks
Se^{+6}	Selenate ion (SeO_4^{-2})	Inorganic	Highly soluble	Moderately toxic	Most common form in alkaline soils and waters. Readily taken up by plants.
Se^{+4}	Selenate ion (SeO_3^{-2})	Inorganic	Moderately soluble	Moderately to highly toxic	Common waterborne form. Readily reduced to elemental selenium and precipitates with iron and aluminum.
Se^{0}	Elemental selenium (Se^{0})	Inorganic	Insoluble	Nontoxic	Metalloid mineral. Poorly taken up by organisms.
Se^{-2}	Selenomethionine ($C_5H^{11}NO_2Se$)	Organic	Highly soluble	Moderately to highly toxic	Amino acid. May be dominant form in plant tissues.
Se^{-2}	Selenocysteine ($C_3H_7NO_2Se$)	Organic	Highly soluble	Unknown	Animo acid. May be dominant form in animal tissues.
Se^{-2}	Selenocystine ($C_6H_{12}N_2O_4Se_2$)	Organic	Highly soluble	Slightly toxic	Amino acid.
Se^{-2}	Dimethyl selenide ($(CH_3)_2Se$)	Organic	Relatively insoluble	Nontoxic	Volatile, rapidly changes form. Common form excreted through exhalation.
Se^{-2}	Dimethyl diselenide ($(CH_3)_2Se_2$)	Organic	Relatively insoluble	Unknown	Volatile, rapidly changes form. Common form released by plants.
Se^{-2}	Hydrogen selenide (H_2Se)	Inorganic	Relatively insoluble	Highly toxic	Occurs in industrial settings. Volatile, rapidly decomposes to elemental selenium and water in presence of oxygen.
Se^{-2}	Trimethyl selenonium ($(CH_3)_3Se)^{+1}$	Organic	Soluble	Nontoxic	Excreted with urine.
Se^{-2}	Metal selenides	Inorganic	Insoluble	Nontoxic	Excreted with feces.

* Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments.

Modified from Keller-Bliesner Engineering and Ecosystems Research Institute 1991, after San Joaquin Valley Drainage Program 1990 minnow failed to behaviorally avoid concentrations of selenium that would cause death in 24 hours (Watenpaugh and Beitinger 1985, Hamilton and Waddell in press). Further studies are necessary to determine the selenium levels in razorback sucker eggs and milt above which viable offspring are not produced. Future data obtained for razorback sucker in the Green River may be relevant to San Juan River razorback sucker, as the chemical composition of the two rivers is considered similar (Waddell, personal communication).

There are currently no toxicity data for selenium residues in Colorado squawfish or razorback sucker. From numerous studies conducted on selenium toxicity in other species (Table 45), Lemly and Smith (1987) compiled a table of selenium levels that are of concern for fish and wildlife (Table 46). Lemly (in press) suggested that total waterborne selenium concentrations greater than or equal to 2 μg/l should be considered hazardous to the health and long-term survival of fish and wildlife populations because of selenium's capacity for bioaccumulation. Other recommendations have been higher; Hunn et al. (1987) have suggested that 12 μg/l may represent the no-effect level of inorganic selenium for fish. Lemly (1985) noted that maximum permissible selenium levels in rivers need not be as high as in reservoirs and lakes, because of the different selenium cycling dynamics.

Wide ranges of selenium levels have been reported from field studies. The highest residues ever reported in any fish were from *Gambusia* at Kesterson National Wildlife Refuge, where levels ranged from 90-430 mg/kg dry weight, with an average concentration of 167 mg/kg (O'Brien 1987, Keller-Bliesner Engineering and Ecosystems Research Institute 1991). Far lower levels, though, may result in reproductive impairment or other physiological problems (Table 47) (Lemly 1985). In North Carolina, a coal-fired powerplant cooling reservoir, Belews Lake, had mean waterborne selenium concentrations of only 10 μg/l, with a range of 3-22 μg/l. Within two years of the powerplant's operation, the entire fish community in the lake was effectively eliminated, with only *Gambusia* remaining. Tissue selenium concentrations in the Belews Lake fish ranged from 2.1-77.1 μg/g wet weight (Lemly 1985). Reproductive failure rather than direct mortality was the cause of the population collapse, illustrating that complete reproductive failure can occur with little or no tissue pathology or mortality among adults (Lemly and Smith 1987). Similarly, the largemouth bass population in Hyco Reservoir, another North Carolina powerplant cooling reservoir, suffered severe declines; selenium carcass concentrations averaged 4 μg/g wet weight, and ovary concentrations averaged 7.4 μg/g (Baumann and Gillespie 1986).

Extensive bioaccumulation of selenium may result because it is an essential micronutrient and is chemically similar to sulphur. Bioaccumulation of selenium from 100 to more than 30,000 times can occur in habitats where waterborne selenium concentrations range from 2-16 μg/l (Table 48) (Lemly 1985, Lemly and Smith 1987, Lemly in press). Studies indicate that algae and zooplankton bioaccumulate selenium more readily than do fish (Besser et al. 1989, National Fisheries Contaminant Research Center et al. 1991). Zooplankton, benthic invertebrates, and certain forage fishes can accumulate up to 30 μg/g dry weight selenium with no apparent effects on their survival or reproduction. Fish, on the other hand, experience toxic effects from ingesting food items of 3 μg/g selenium or more (Lemly and Smith 1987, Lemly in press).

Biomagnification of selenium, the occurrence of progressively higher concentrations in successive trophic levels, has not been definitively shown in laboratory studies but has been observed in some field investigations where selenium levels have risen from 2-6 times through the food chain between producers and lower consumers (Lemly in press). The majority of investigations of selenium in fish have concluded that dietary rather than waterborne exposure is the primary route of uptake (National Fisheries Contaminant Research Center et al. 1991, Lemly in press).

Lemly and Smith (1987) suggested that whole body concentrations of 12 μg/g dry weight or more in fish tissue and 5 μg/g dry weight in food items may cause reproductive failure. The lowest tissue concentration of selenium known to cause reproductive impairment in fish is about 3 μg/g wet weight, with higher concentrations in fish having been documented with no pathological effect (Bureau of Reclamation 1992). Lemly (in press) suggests that fish health and reproduction may be impaired above a whole body selenium concentration of 4 μg/g dry weight, a skeletal muscle concentration of 8 μg/g, a liver

Table 45: Concentrations of selenium known to be hazardous to fish and wildlife

Source	Concentration ug/l (water) or ug/g dry weight (diet). Mean shown in parentheses	Exposure setting, duration, and test conditions	Species and life stage	Toxic effect	Tissue residue (ug/g or ppm)
Water[a]	1,100	Laboratory, 48 days, flow-through. Hardness = 330 mg/l	Fathead minnow, *Pimephales promelas*, larvae	50% mortality	---
Water[a]	400	Laboratory, 48 days, flow-through. Hardness = 330 mg/l	Bluegill, *Lepomis macrochirus*, larvae	50% mortality	---
Water[a]	500	Laboratory, 48 days, flow-through. Hardness = 330 mg/l	Rainbow trout, *Salmo gairdneri*, larvae	50% mortality	---
Water[a]	160	Laboratory, 48 days, flow-through. Hardness = 330 mg/l	Coho salmon, *Oncorhynchus kisutch*, larvae	50% mortality	---
Water[a]	30-170 (80)	Laboratory, 60 days, flow-through. Harness = 28 mg/l, temperature = 11°C	Rainbow trout, eggs	Significant number of deformities	---
Water[a]	30-170 (80)	Laboratory, 12 months, flow-through. Hardness = 28 mg/l, temperature = 11°C	Rainbow trout, eggs	Significant mortality	---
Water[a]	47	Laboratory, 90 days, flow-through. Hardness = 272 mg/l, temperature = 12°C	Rainbow trout, sac fry	Significant mortality	Whole body = 1.07 wet weight (survivors)
Water[a]	28	Laboratory, post-fertilization through hatching, flow-through. Hardness = 135 mg/l, temperature = 0°C	Rainbow trout, eyed eggs	Significantly reduced hatching	---
Water[a]	17	Laboratory, 30 days, flow-through. Hardness = 371 mg/l, temperature = 12°C, sulfate = 200 mg/l	Chinook salmon, *Oncorhynchus tshawytscha*, fry	Significant mortality	---
Water[b]	90	Laboratory, post-fertilization through 60 days posthatch, flow-through. Temperature = 20-26°C, salinity = 3.5-5.5‰	Striped bass, *Morone saxatilis*, eggs 24 h postfertilization	Significant number of deformities	---
Diet[a]	8.9	Laboratory, 42 weeks, flow-through. Hardness = 28 mg/l, temperature = 11°C	Rainbow trout, juveniles	Significant mortality	---
Diet[c]	13	Laboratory, 6 weeks, flow-through, 3% body weight per day feeding. Hardness = 74 mg/l, temperature = 10°C	Chinook salmon, parr	Reduced smolting success	Whole body = 2.9 wet weight, 13.4 dry weight (survivors)
Diet[c]	54[g]	Laboratory, 44 days, flow-through, satiation feeding. Temperature = 21°C	Bluegill, juveniles	75% mortality	Skeletal muscle = 5-7 wet weight, liver = 8-86 wet weight

Table 45 (CONT): Concentrations of selenium known to be hazardous to fish and wildlife

Source	Concentration ug/l (water) or ug/g dry weight (diet). Mean shown in parentheses	Exposure setting, duration, and test conditions	Species and life stage	Toxic effect	Tissue residue (ug/g or ppm)
Diet[c]	45	Laboratory, 7 days, flow-through, satiation feeding. Hardness = 18 mg/l, sulfate = 5.7 mg/l, temperature = 25°C	Bluegill, juveniles	100% mortality	Whole body = 21-32 dry weight
Diet[c]	25-70	Laboratory, 61 days, flow-through, satiation feeding. Hardness = 19 mg/l, sulfate = 5.4 mg/l, temperature = 25°C	Bluegill, juveniles	100% mortality	Whole body = 44-53 dry weight
Water[d] and diet[c]	8.9-12 (10) 21-73	Field (reservoir), 14 days. Alkalinity = 26 mg/l, temperature = 26°C	Bluegill, juveniles	100% mortality	Muscle = 13.1-17.5 dry weight; viscera = 27.5-37.5 dry weight
Water[d] and diet[c]	5-22 (10) 15-70	Field (reservoir), 2 years. Alkalinity = 20-38 mg/l, sulfate = 5.5-17.1 mg/l	All life stages of centrarchids, percichthyids, ictalurids, cyprinids, percids, clupeids, catostomids	Mortality and deformity of fry, juveniles, and adults; total reproductive failure	Skeletal muscle = 3.2-22.3 wet weight; viscera (minus gonad) = 13-52.4 wet weight; ovary = 5.2-41.7 wet weight; testis = 15-22.8 wet weight (survivors)
Water[e] and diet[c]	8-12 (10) 25-45	Field (reservoir), 2 years. Alkalinity = 20 mg/l avg, sulfate = 27 mg/l avg	Bluegill, adults exposed in the field and spawned in the laboratory	Mortality and deformity of larvae; total reproductive failure	Carcass (minus gonad) = 5.9-7.8 wet weight; ovary = 6.9-7 2 wet weight (38-54 dry weight); testis = 4.3 wet weight
Diet[f]	10[h]	Reproductive study	Mallard, *Anas platyrhynchos*, adults received treated diets	Productivity and duckling survival reduced	Concentrations in eggs ranged from 2.9 to 5 6 (wet weight) and wet weight concentration ranges in adult male and female livers were 6.1 to 12.0 and 2.6 to 6.2, respectively (use 71% moisture for conversion to dry weight)

Table 45 (CONT): Concentrations of selenium known to be hazardous to fish and wildlife

[a] In the form of selenite
[b] In the form of selenate
[c] Selenium source was food organisms from selenium-contaminated habitats
[d] Measured as total recoverable selenium in filtered (0.45 μm) samples
[e] In the form of selenite (57%), selenate (34%), and selenide (9%)
[f] In the form of selenomethionine
[g] Converted from 13.6 ug/g wet weight, assuming 75% moisture. Formula for converting wet weight to dry weight:

$$\text{dry weight concentration} = \frac{\text{wet weight concentration}}{1 - \%\text{ moisture sample}}$$

[h] Fresh weight, diet contained about 10% moisture

Modified from Lemly and Smith 1987

Table 46: Selenium levels of concern for fish and wildlife

Source or tissue residue	Concentration µg/l (water) or µg/g dry weight	Affected group	Suspected toxic effect
Water	> 2-5	Fish and waterfowl	Reproductive failure or mortality due to food-chain bioconcentration
Sediment	≥4	Fish and waterfowl	As above
Food	≥5	Fish	As above
Whole body residue	≥12	Fish	Reproductive failure
Visceral residue[a]	≥16	Fish	Reproductive failure
Skeletal muscle residue	≥8	Fish	Reproductive failure

[a]Approximate conversion factors for fish:
Whole body to muscle = whole body x 0.6
Viscera (liver or female gonad) to muscle = viscera x 0.25
Viscera to whole body = viscera x 0.33
[b]Converted from a mean wet-weight concentration of 4.6 µg/g based on a 71% moisture content.
Note: The 85th percentile whole-body concentration of selenium in fish tissues measured by the National Contaminant Biomonitoring Program was 0.82, 0.70, and 0.71 µg/g wet weight for 1976-77, 1978-79, and 1980-81, respectively.

Modified from Lemly and Smith 1987

Table 47: Effects of selenium on aquatic communities under natural conditions in the field

Source of Selenium[a]	Abiotic levels of selenium (mean)		Duration of Exposure	Concentration of selenium accumulated in biota					Toxic effects
	Water[b]	Sediment[c]		Benthos[d]	Plankton[e]	Fishes	Plants[f]	Birds[g]	
1	3.0-22 3 (10)	1.0-7.5 (3 6)	8 years	1 1-22 1	3.5-20 0	2.1-77.1	---	---	Massive reproductive failure among fishes; 17 of 20 species eliminated within 2 years, 2 persisted as sterile adults,[h] 1 was unaffected.[i] Biota other than fishes not affected Impact on fishes attributed to dietary and reproductive toxicity, and associated pathology.
1	1 0-30 0 (10)	0 7-10 0 (1.2)	3 years	0.7-52.0	0.4-18.0	1 6-270 0	0 07-9 2	---	Severely decreased reproduction and survival of gam fishes during first year; complete elimination of one species.[j] Teratogenic effects on larval fishes. Biota other than fishes not affected. Dietary and reproductive toxicity implicated as causes for fishery decline.
1	1.0-34.0	0.2-17 1	2 years	0.5-14.0	0.3-16.1	1 3-16 0	0 2	---	Progressive mortality of fishes after 2 months; most severe reductions were carnivores and planktivores. Dead fishes exhibited symptoms of selenium poisoning Reproductive sucess of all species was reduced significantly; pathological correlates of selenium exposure identified.
2	8 0-360 (101)	1 9-4 9 (2 2)	<2 years	4 8-72.3	13.6-26 7	25.7-66 5[k]	9 7-26 6	4.7-22.5	Reproductive failure of waterfowl and marsh birds Teratogenic effects on embryos and young, mortality of adult birds Four species of fish eliminated[l]
3	96-160	---	<1 year	3 5-5.0	---	0 5-8.0	15 0-20.0	---	Progressive mortality of stocked game fishes. Effects attributed to dietary toxicity.
4	100	---	56 days	---	---	---	---	---	Biomass and numbers of zooplankton reduced by 66-99%, role of selenium toxicity questioned.

[a] Sources of selenium (1) ash basin effluent from a coal-fired powerplant, (2) irrigation drainage water from natural high-selenium soils, (3) natural high-selenium soils, (4) experimental addition of selenium (as selenite)
[b] μg Se/liter (ppb)
[c] μg Se/g (ppm), wet weight (70-80% moisture)
[d] Aquatic insects, annelids, crustaceans, molluscs
[e] Zooplankton and phytoplankton
[f] Rooted macrophytes
[g] Migratory waterfowl and marsh birds
[h] Black bullheads (*Ictalurus melas*) and carp (*Cyprinus carpio*)
[i] Mosquitofish (*Gambusia affinis*) were unaffected
[j] Largemouth bass (*Micropterus salmoides*) were eliminated
[k] Mosquitofish
[l] Largemouth bass, carp, catfish (*Ictalurus* spp) and striped bass (*Morone saxatilis*)

Modified from Lemly 1985

Table 48: Bioconcentration factors of selenium in freshwater organisms following exposure to combined waterborne and dietary sources under natural conditions in the field

Organism	Bioconcentration factor*
Fishes	
Carnivores	590-35,675
Planktivores	445-27,000
Omnivores	364-23,000
Benthos	
Insects	371-5200
Annelids	770-1320
Crustaceans	420-1975
Molluscs	600-2550
Plankton	
Zooplankton	176-2080
Phytoplankton	237-1320
Periphyton**	158-1070
Plants***	166-24,400
Birds****	
Waterfowl	190-3750
Marsh birds	300-3850

*Concentration present in tissues (μg/g wet weight) divided by the mean waterborne concentration (μg/l). Largest numbers for fishes represent maximum bioconcentration observed in visceral tissues (spleen, heart, kidney, hepatopancreas, gonad); smallest numbers for fishes represent low bioconcentration factors for skeletal muscle.

**Attached diatoms and filamentous algae.

***Rooted macrophytes; roots, stems, leaves, seeds.

****Migratory species

Modified from Lemly 1985

concentration of 12 μg/g, and ovary and egg concentrations of 10 μg/g. In comparison, fish from control test groups or where habitats have low waterborne selenium levels usually have tissue concentrations of about 1-8 μg/g (Lemly 1985, Gillespie and Baumann 1986, Hermanutz et al. 1992, Lemly in press). Lemly (in press) stresses that "this extremely narrow margin between 'normal' and toxic levels in tissues, along with the propensity of selenium to bioaccumulate in aquatic food-chains, underscores the biological importance of even slight increases in environmental selenium." This may be of fundamental importance to future San Juan basin development.

Studies of selenium residues in fish have generally shown that gonads bioaccumulate selenium and that ovarian tissue has a greater bioaccumulation capacity than does testicular tissue (Table 49) (Baumann and Gillespie 1986, Hamilton and Waddell in press, Lemly in press). Gonads in control or reference fish have uniformly low selenium concentrations of 0.5-0.77 μg/g wet weight in both males and females (Hamilton and Waddell in press). Baumann and Gillespie (1986), in their study of North Carolina reservoirs, found that selenium concentrations were always higher in ovaries than in carcasses and that, unlike testes, they experienced no relative decline in concentration as carcass selenium levels increased.

When selenium concentrates in ovaries, it can then be transferred to the eggs during oogenesis (Baumann and Gillespie 1986, Schultz and Hermanutz 1990, National Fisheries Contaminant Research Center et al. 1991). It is not known with any precision what levels of selenium cause adverse effects in eggs. Normal background concentrations in eggs are 0.5-0.7 μg/g wet weight, while concentrations in ovaries of 4.4 μg/g wet weight in bluegill (*Lepomis macrochirus*) and 5.89 μg/g wet weight in fathead minnow have reportedly caused adverse effects in larvae. The effect level for eggs is most likely somewhere between these two sets of values (Schultz and Hermanutz 1990, Hermanutz et al. 1992, Hamilton and Waddell in press). Lemly (in press) suggests that the best way to evaluate the potential reproductive impacts of selenium to adult fish is to measure selenium concentrations in gravid ovaries and eggs, because it is a measure of the most sensitive biological endpoint and it takes into account both dietary and waterborne selenium exposure.

The effects of selenium exposure on fish reproductive success can be manifested at several developmental stages. Sorensen et al. (1984) reported that in green sunfish (*Lepomis cyanellus*) selenium exposure resulted in swollen, necrotic, and ruptured egg follicles. In another study, largemouth bass and bluegill adults were exposed to high selenium levels prior to spawning and produced larvae with a high incidence of mortality and deformities in bone structure (Baumann and Gillespie 1986, National Fisheries Contaminant Research Center et al. 1991). Schultz and Hermanutz (1990) exposed adult fathead minnows to 10 μg/l waterborne selenite in streams for a year and found a 23-25% incidence of edema and lordosis in larvae. Adult fathead minnows exposed to 20 mg/l selenate for 24 hours produced larvae of which nearly all exhibited edema and 100% of which died within seven days of hatching (Pyron and Beitinger 1989, National Fisheries Contaminant Research Center et al. 1991).

The investigations conducted to date provide solid background data for studies that must now be conducted specifically for the San Juan basin and its native fish. Future studies in the basin must determine threshold selenium concentrations for fish species of concern, threshold levels in the ecosystem and their relationship to fish tissue levels, and the mass balance of selenium in the water (Anonymous 1991). In 1991, the FWS's National Fisheries Contaminant Research Center field station in Yankton, South Dakota, and the New Mexico Ecological Services Office proposed a study that would investigate selenium in San Juan basin irrigation flows and its effects on the reproduction and early life stages of the basin's endangered fish. The study would be divided into four tasks: aquatic monitoring, a toxicological assessment of waterborne selenium on endangered fishes, a toxicological assessment of dietary selenium on endangered fishes, and a field validation of laboratory studies with early life stages of the endangered fishes. As originally proposed, the aquatic monitoring portion of the study was to begin in May 1992 and terminate in October 1992, with the toxicological assessment set to begin in October 1992 and to terminate in August 1995 (National Fisheries Contaminant Research Center et al. 1991). However, the study has not been funded to date.

Table 49: Selenium concentrations in gonads of fish (wet weight)

Species*	Selenium (μg/g)	Exposure**
Female		
Fathead minnow	5.89	10 μg/l - 1 year
	0.77	Control
	2 18***	30 μg/g - 100+ days
	1 21***	Control
Black bullhead	20 7-41 7	approx 10 μg/l - >1 year Belews Lake, NC
Warmouth	13.7-34 6	approx 10 μg/l - >1 year Belews Lake, NC
Bluegill	4.4	10 μg/l - 258 days
	0.5	Control
	6.96	9-12 μg/l - >1 year Hyco Reservoir, NC
	0.66	Reference Lake - Roxboro City Lake, NC
	10 0-11 9	9-12 μg/l - >1 year Hyco Reservoir, NC
	0.7	Reference Lake - Roxboro City Lake, NC
	5 3	approx 10 μg/l - >1 year
Redear sunfish	4 33	>10 μg/l - >1 year Martin Lake, TX (2 5 mg/l in ash pond water)
	28 2	approx 10 μg/l - >1 year Belews Lake, NC
Largemouth bass	7.4	9-12 μg/l - >1 year Hyco Reservoir, NC
Male		
Fathead minnow	1.56***	30 μg/g - 100+ days
	0.77***	Control
Bluegill	3 0	10 μg/l - 258 days
	0 6	Control
	4 37	9-12 μg/l - >1 year Hyco Reservoir, NC
	0 50	Reference Lake - Roxboro City Lake, NC
	4.9-6 6	9-12 μg/l - >1 year Hyco Reservoir, NC
	0.5	Reference Lake - Roxboro City Lake, NC
	15.2	approx 10 μg/l - >1 year Belews Lake, NC
Redear sunfish	22.8	approx 10 μg/l - >1 year Belews Lake, NC
Largemouth bass	3.2	9-12 μg/l - >1 year Hyco Reservoir, NC

*Fathead minnow (Pimephales promelas), black bullhead (Ameiurus melas), warmouth (Lepomis gulosus), bluegill (Lepomis macrochirus), redear sunfish (Lepomis microlophus); largemouth bass (Micropterus salmoides)

**Exposure: μg/l = waterborne exposure; μg/g = dietary exposure

***Wet weight value based on 80% moisture

Taken from Hamilton and Waddell (in press)

4.10 IRRIGATION

Irrigation, by nature of its return flows, has a high potential to contaminate both ground and surface water with trace elements such as selenium as well as organics, pesticides, and other constituents. The DOI-sponsored irrigation projects and several private accquias discharge surface and subsurface irrigation return flows to backwater habitats along the San Juan River and its tributaries (National Fisheries Contaminant Research Center et al. 1991). The following sections will discuss each of the large-scale projects in the basin in turn.

4.10.1 SAN JUAN DOI RECONNAISSANCE INVESTIGATION

The most extensive study to date of contaminants in the New Mexico portion of the San Juan basin is the DOI's National Irrigation Water-Quality Program (NIWQP) reconnaissance investigation of water quality, bottom sediment, and biota in the area affected by the five DOI-sponsored irrigation projects on the San Juan River. All material in this section has been taken from Blanchard et al. (1993) unless otherwise stated.

The reconnaissance investigation of the San Juan area is one of several sponsored by the DOI in the western United States. Like the others, the San Juan investigation was conducted by interbureau teams composed of team leaders from the USGS and supporting scientists from the USGS, FWS, BR, and Bureau of Indian Affairs (BIA). The study was initiated because of concerns of a trace element loading problem in the San Juan River resulting from irrigation return flows.

The study area includes approximately 90 miles of the San Juan River valley, extending from Navajo Dam to the mouth of the Mancos River. Additionally, the study includes the upland area south of the San Juan River valley, bounded on the west by the Chaco River, on the south by Hunter Wash, and on the east by New Mexico State Highway 44 (Figure 7). The San Juan River area has a consolidated rock surface geology that includes sedimentary strata of Cretaceous to Tertiary age The strata typically consist of sequences of interbedded sandstone, mudstone, shale units, and occasional coal deposits In addition to the land irrigated by the Hammond Irrigation Project, Hogback Irrigation Project, Cudei Irrigation Project, Fruitland Irrigation Project, and Navajo Indian Irrigation Project, about 7,000 acres are irrigated within the study area.

The NIIP was authorized in 1962. Construction of the delivery canal from Navajo Reservoir began in 1964 and the first irrigation water was delivered to Block 1 in the spring of 1976 (New Mexico State Engineer Office 1991). The project is divided into 11 blocks, each of which contains about 8,000-12,000 acres of cropland. By 1991 development of the first six blocks was complete, with a total irrigated area of 54,494 acres (New Mexico State Engineer Office 1991). Irrigation of the first six blocks began between 1976-1982. The canal structures for Block 7 and a portion of Block 8 were completed by 1991, and the third and fourth phases of construction were scheduled to begin in late fiscal year 1990 (New Mexico State Engineer Office 1991). When all 11 blocks are fully developed, about 110,000 acres will be irrigated.

The Hammond Project is located south of and adjacent to the San Juan River, from about two miles southwest of Blanco to about two miles southeast of Farmington. The project was built by the BR and is owned and operated by the Hammond Conservancy District. The project irrigates about 3,900 acres. Irrigation began in 1962, at which time about 700 acres within the project area were already being irrigated.

The Fruitland Project is located south of and adjacent to the San Juan River, from about two miles west of Farmington to about two miles west of the Hogback The project irrigates about 3,300 acres. Irrigation began in 1910. and development of the project as it is today was completed in the early 1940s.

The Hogback Project is located north of and adjacent to the San Juan River, from the Hogback to about 10 miles northwest of Shiprock. Irrigation began in 1904 and most of the original project was completed by 1940. In 1952 a pumping plant and two main laterals were added. The project irrigates about 7,000 acres.

The Cudei Project is located south of and adjacent to the San Juan River, from about five miles northwest of Shiprock to about two miles northwest of Cudei. Irrigation of the project area began in 1910. The project irrigates about 540 acres.

The NIIP water distribution system consists of a reservoir and a network of main canals, laterals, and pumping stations. Irrigation water for the NIIP is diverted from Navajo Reservoir and is stored eight miles away in Cutter Reservoir. When the NIIP is complete it will include about 110 miles of open canals and the delivery system will be able to handle as much as 1,800 ft^3/sec. The drainage system on the NIIP is composed of about 200 miles of channels which collect storm runoff, overland irrigation return flow, and groundwater seepage from irrigated land. There are 10-15 ponds on the NIIP Gallegos Canyon and Ojo Amarillo Canyon washes are also located on the NIIP and supply a perennial flow to the San Juan River.

The water distribution systems on the Hammond, Fruitland, Hogback, and Cudei projects consist of a diversion, a main canal, and a series of field laterals The Hammond and Hogback Projects also include pumping plants and a main lateral. Several ponds are on the Hammond Project lands, and wetlands connect much of the project area to the San Juan River Wetlands also connect parts of the Fruitland and Hogback Projects to the river

Sampling sites for the DOI reconnaissance investigation were chosen on the irrigation projects as well as on the San Juan River. Irrigation project sampling sites ("I" sites) included selected ponds, marshes, and wetlands that were known to support wildlife, and selected irrigation drains and canals that flow from the projects into the San Juan River (Figure 26 and Table 50). "R" sites are those on the San Juan River (Figure 27 and Table 51). Site R-1 is upstream from the irrigation projects in the study area and serves as a background reference site, and Site R-11 is downstream from all five projects. Sites R-2 through R-10 are located at diversions of river water to the projects, at the municipal-supply diversion at Shiprock, and at or near tributary mouths.

Surface water samples were analyzed for physical properties, major ions, and trace elements; these samples were collected prior to, during, and after the 1990 irrigation season (Table 52). Water samples analyzed for triazine and chlorophenoxy acid herbicide compounds were collected in May and June 1990, and those analyzed for organophosphate and carbamate insecticide compounds were collected in August 1990. Bottom sediment samples were collected after the 1990 irrigation season. The laboratory reporting levels for selected constituents measured in the water and bottom sediment samples were apparently low enough to detect criteria exceedances, with the exception of the standard for mercury (Table 53). Bird samples were collected in the late spring and early summer of 1990. Aquatic plant, invertebrate, amphibian, and fish samples in wetland habitats were collected in summer 1990 during peak metabolic activity. The San Juan River fish samples were collected in the spring, prior to the 1990 irrigation season, and in the fall after the irrigation season. Analyses for inorganic and organic contaminants were conducted on the fish samples, although analyses for both types of contaminants were not performed on every species in every river reach (Table 54).

The surface water sample data were compared to National Baseline Values for U.S. rivers, which were calculated from databases of the National Stream-Quality Accounting Network (NASQAN) and the National Water-Quality Surveillance System (NWQSS) The median and maximum values found at the river and irrigation sites in the San Juan investigation were compared to the 25th, 50th, and 75th percentiles of these National Baseline Values for eight trace elements (Table 55).

For the "R" sites, the median concentration of each trace element except arsenic was less than or equal to the 25th percentile baseline concentration. For the "I" sites, the median concentration of each trace element except arsenic and selenium was less than the 25th percentile baseline concentration. In each case, the median arsenic concentration was equal to the 50th percentile baseline concentration. The median selenium concentration of 2 μg/l from the irrigation sites was greater than the 75th percentile baseline concentration of less than 1 μg/l.

In samples collected from the San Juan River and tributary mouths, the maximum concentration of each trace element except mercury was less than or equal to the New Mexico chronic standard for

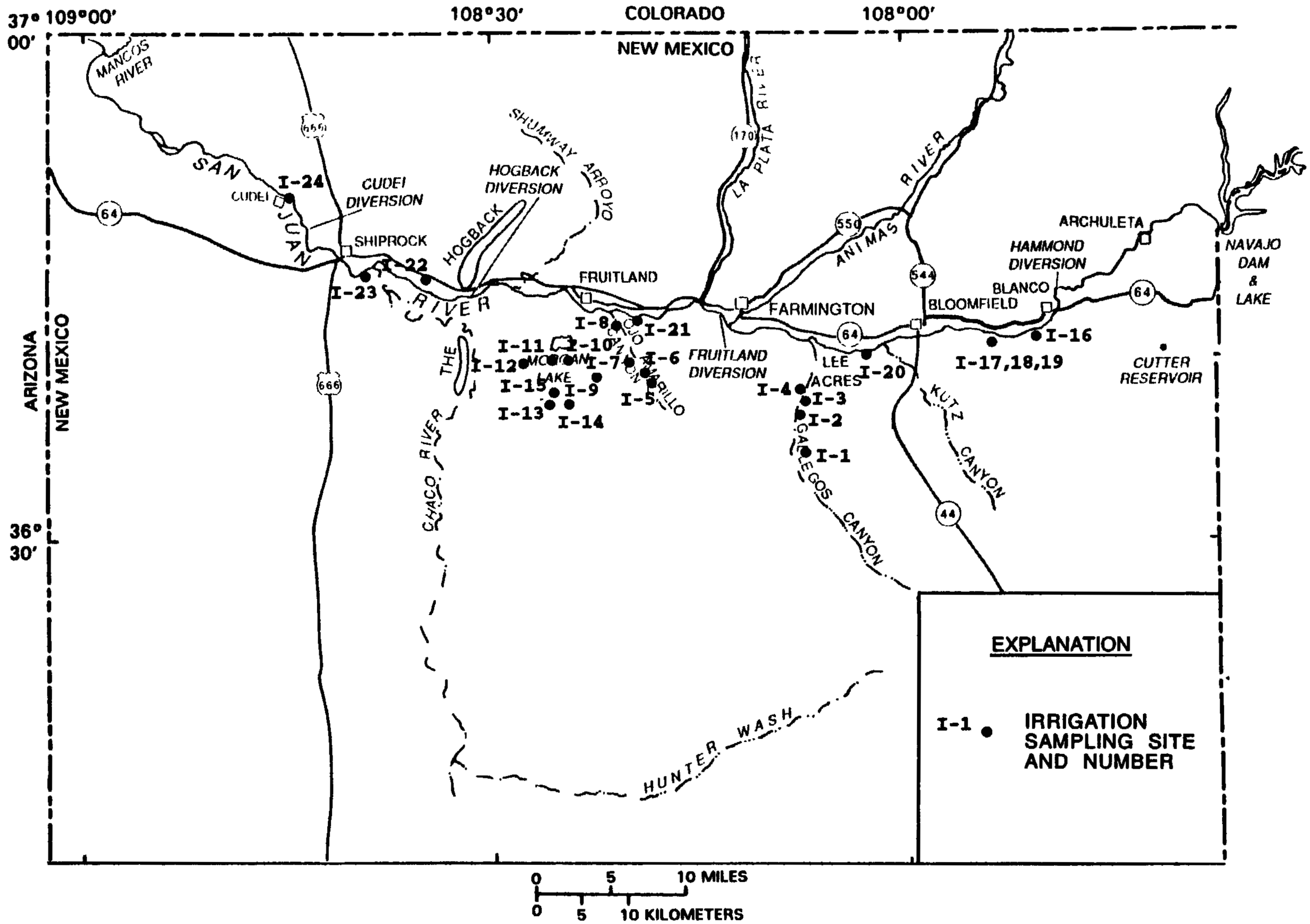


Figure 26. Water quality, bottom sediment, and biota sampling sites on or adjacent to DOI-sponsored irrigation projects, San Juan DOI reconnaissance investigation. (Taken from Blanchard et al. 1993)

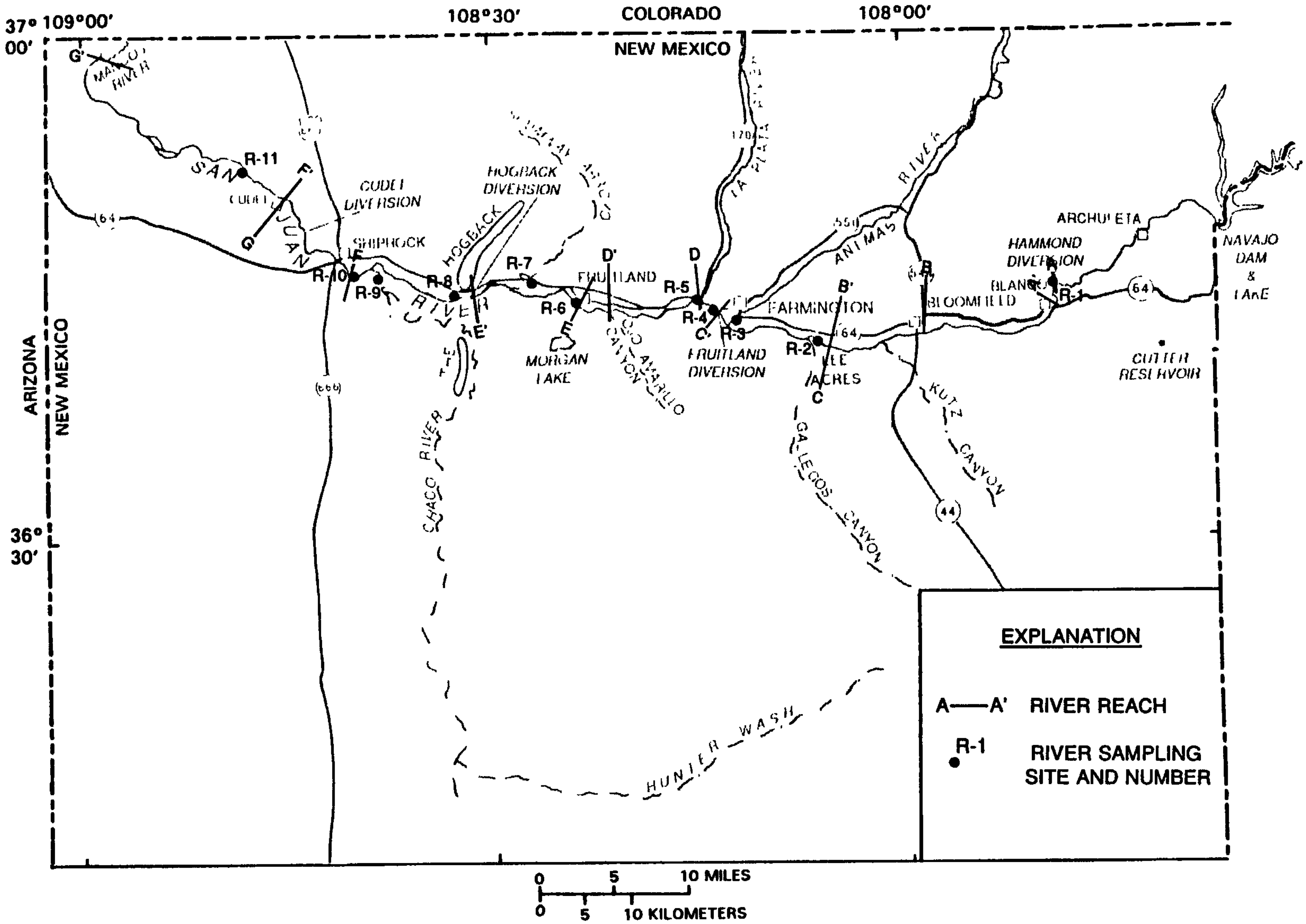


Figure 27. Water quality and bottom sediment sampling sites and fish sampling reaches of the San Juan River and at the mouths of tributary streams, San Juan DOI reconnaissance investigation. (Taken from Blanchard et al. 1993)

Table 50: Sampling ("I") sites on or adjacent to irrigation projects

NAVAJO INDIAN IRRIGATION PROJECT

Gallegos Canyon drainage

I-1 Gallegos Canyon drainage south pond
I-2 Gallegos Canyon drainage middle pond
I-3 Gallegos Canyon drainage north pond
I-4 Gallegos Canyon 2 miles north of Navajo Highway 3003

Ojo Amarillo Canyon drainage

I-5 Ojo Amarillo Canyon three-fourths mile north of Navajo Highway 3003
I-6 Ojo Amarillo Canyon drainage ponds (1 mile north of Navajo Highway 3003)
 I-6A Upstream drainage pond
 I-6B Downstream drainage pond
I-7 Ojo Amarillo Canyon 2 ¼ miles north of Navajo Highway 3003
I-8 Ojo Amarillo Canyon 4 miles north of Navajo Highway 3003

Ponds in enclosed drainages

I-9 Hidden Pond
I-10 Avocet Pond
I-11 West Avocet Pond
I-12 Northwest Pond-block 3

Chinde Wash drainage

I-13 Chinde Wash drainage southwest pond
I-14 Chinde Wash drainage southeast pond
I-15 Chinde Wash at Navajo Highway 5005

HAMMOND PROJECT

East Hammond Project

I-16 East Hammond Project east drain and wetland (about 8 miles east of New Mexico Highway 44
I-17 East Hammond Project west drain and wetland (about 3 ½ miles east of New Mexico Highway 44
I-18 East Hammond Project pond one-tenth mile north of West Drain (Red Pond)
I-19 East Hammond Project pond four-tenths mile northwest of West Drain (adjacent to oil production facility)

West Hammond Project

I-20 West Hammond Project pond (about 2 ½ miles west of New Mexico Highway 44)

FRUITLAND PROJECT

I-21 Fruitland Project site

HOGBACK PROJECT

I-22 Hogback Project east drain (about 2 ¾ miles west of the Hogback)
I-22B West tributary to Hogback Project east drain
I-23 Hogback marsh (about 1 ½ miles southeast of Shiprock)
I-24 Hogback Project west drain (about 3 miles northwest of Shiprock)

Taken from Blanchard et al. 1993

Table 51: San Juan reaches from which fish samples were collected, and water and bottom sediment sampling ("R") sites within each river reach

Reach A		Hammond Diversion to Blanco
	R-1	San Juan River at Hammond Project Diversion (reference site; upstream from Department of Interior-sponsored irrigation)
Reach B		Bloomfield to Lee Acres
Reach C		Lee Acres to Farmington
	R-2	San Juan River 1 mile upstream from mouth of Gallegos Canyon
	R-3	Animas River at mouth
	R-4	Fruitland Project Diversion[1]
Reach D		La Plata River to Ojo Amarillo Canyon
	R-5	La Plata River at mouth
Reach E		Fruitland to Hogback
	R-6	San Juan River one-half mile downstream from Fruitland Bridge
	R-7	Shumway Arroyo
	R-8	Hogback Project Diversion[1]
	R-9	Chaco River one-half mile upstream from mouth[1]
	R-10	San Juan River at Shiprock Municipal Diversion[1]
Reach F		Shiprock to Cudei
Reach G		Cudei to Mancos River
	R-11	San Juan River 3 miles downstream from Cudei (downstream from Department of Interior-sponsored irrigation)

[1]Water and bottom-sediment sampling site is outside of river reaches from which fish samples were collected.

Taken from Blanchard et al. 1993

Table 52: Number of samples and types of analyses for media at sampling sites on irrigation projects, the San Juan River, and tributaries

Site*	Water I**	Water O**	Bottom sediment I	Bottom sediment O	Aquatic plants I	Inverte-brates I	Amphib-ians I	Fish A#	Fish B#
Irrigation project sites									
I-1	3	2	1	1	1	1	1	0	0
I-2	3	2	1	1	1	1	1	0	0
I-3	3	1	1	0	1	1	1	0	0
I-4	3	2	1	0	0	0	0	0	0
I-5	0	0	0	0	0	0	0	0	0
I-6A	0	0	1	0	1	1	1	0	0
I-6B	3	1	0	0					
I-7	1	1	1	1	1	1	1	0	0
I-8	2	1	0	0	0	0	0	0	0
I-9	0	0	0	0	0	0	0	0	0
I-10	3	1	0	0	1	1	0	0	0
I-11	1	0	0	0	1	0	1	0	0
I-12	1	1	0	0	1	1	1	0	0
I-13	3	2	0	0	1	1	1	0	0
I-14	1	0	0	0	0	0	0	0	0
I-15	1	0	0	0	0	0	0	0	0
I-16	0	0	0	0	1	1	0	2	0
I-17	3	0	1	1	0	0	0	0	0
I-18	1	0	0	0	1	0	0	0	0
I-20	3	0	1	1	1	1	0	2	0
I-21	3	0	1	1	1	1	1	2	1
I-22	4	0	1	1	1	2	0	2	2
I-22B	1	0	0	0	0	0	0	0	0
I-23	3	0	1	1	1	1	0	1	2
I-24	3	0	1	1	0	0	0	0	0
San Juan River and tributary sites									
R-1	3	0	1	0	0	0	0	0	0
R-2	3	0	1	0	0	0	0	0	0
R-3	3	0	0	0	0	0	0	0	0
R-4	2	0	0	0	0	0	0	0	0
R-5	3	0	1	0	0	0	0	0	0
R-6	3	0	1	0	0	0	0	0	0
R-7	2	0	0	0	0	0	0	0	0
R-8	2	0	0	0	0	0	0	0	0
R-9	3	0	1	0	0	0	0	0	0
R-10	3	0	0	0	0	0	0	0	0
R-11	3	0	1	0	0	0	0	0	0

* Site, see tables 50 and 51 for name and location

** I, analysis for inorganic constituents; O, analysis or organic pesticides

\# A, killifish, mosquitofish, fathead minnow; B, common carp, flannelmouth sucker

Taken from Blanchard et al. 1993

Table 53: Laboratory reporting levels for selected constituents in water and bottom sediment

Constituent	Analytical reporting limit Water (µg/l)	Bottom sediment (µg/g)	Bottom sediment (µg/kg)
Inorganic constituents			
Arsenic	1	0.1	
Boron	10	0.4	
Cadmium	1.0	2	
Chromium	1	1.0	
Copper	1	1.0	
Lead	1	4.0	
Mercury	0.1	0.02	
Molybdenum	1	2	
Selenium	1	0.1	
Strontium		2.0	
Uranium	1.0	100	
Vanadium	1	2.0	
Zinc	10	2.0	
Organic constituents			
Triazine herbicides	0.1		
Chlrophenoxy acid herbicides	0.1		
Carbamate insecticides	0.05		
Organophosphate insecticides	0.01		
Organochlorine insecticides			
Toxaphene			10
Chlordane			1
PCBs			1
PCNs			1
Perthane			1
All other compounds			0.1

Modified from Blanchard et al. 1993

Table 54: Types of analyses conducted on fish samples from reaches of the San Juan River

River reach	Common carp S	Common carp F	Flannelmouth sucker S	Flannelmouth sucker F	Brown trout S	Brown trout F	Channel catfish S	Channel catfish F
A: Hammond Diversion to Blanco	I	I	I/O	I	I	I		
B: Bloomfield to Lee Acres		I		I				
C: Lee Acres to Farmington	I	I	I/O	I	I			
D: La Plata River to Ojo Amarillo Canyon	I	I	I/O	I				
E: Fruitland to Hogback	I	I	I/O	I			I	I
F: Shiprock to Cudei	I	I	I/O	I			I	I
G: Cudei to Mancos River	I	I	I/O	I			I	I

S, spring sampling period; F, fall sampling period
I, analysis for inorganic constituents; O, analysis for organochlorine pesticides

Taken from Blanchard et al. 1993

Table 55: Comparison of baseline concentrations of selected constituents in samples collected from rivers of the United States with concentrations in 28 samples from the San Juan River, diversions, and tributaries, and in 48 samples from irrigation project sites

Trace element	Concentration (µg/l) Baseline percentiles* 25	50	75	San Juan River diversions, and tributaries Median	Maximum	Irrigation project site Median	Maximum
Arsenic	<1	1	3	1	1	1	48
Cadmium	<2	<2	<2	<1	1	<1	2
Chromium	9	10	10	<1	3	<1	2
Lead	3	4	6	<1	1	<1	12
Mercury	0.2	0.2	0.2	<0.1	0.2	<0.1	0.2
Nitrate	0.2	0.41	0.89	0.2	6.3	0.2	19
Selenium	<1	<1	<1	<1	4	2	67
Zinc	12	15	21	7	13	<10	20

* Baseline percentiles determined from data in National Stream-Quality Accounting Network and National Water-Quality Serveillance System databases

Taken from Blanchard et al. 1993

fisheries protection. The mercury standard is 0 012 μg/l, but the laboratory detection level was 0.1 μg/l. Therefore, it is not known how many samples had concentrations that were actually above the standard but below 0.1 μg/l.

Selenium concentrations in the San Juan River and at the tributary mouths were less than 1 μg/l except at the Shiprock Municipal Diversion (site R-10) and on the San Juan River near Cudei (site R-11); concentrations at these two sites were 1 and 2 μg/l, respectively. The observed increase in selenium could be due to natural processes acting on the Mancos Shale that is at the surface of most of the study area west of the Hogback, to irrigation from the east Hogback Project, or to a combination of the two

Water samples from the irrigation sites generally had larger trace element concentrations than the "R" sites, with the exception of mercury and chromium. Concentrations of cadmium were greater than the New Mexico fisheries standard of 1 1 μg/l at two irrigation sites, and at one site the New Mexico lead standard of 3.2 μg/l was exceeded Each exceedance occurred for only one of three samples collected at each site, suggesting that the standards for cadmium and lead were not being chronically exceeded.

Selenium concentrations exceeding the New Mexico fisheries standard of 5 μg/l were found on the NIIP, Hammond Project, and Hogback Project sites The selenium values that exceeded 5 μg/l were divided into outlying and far-outlying categories (Figure 28). All far-outlying values occurred in three locations· Gallegos Canyon drainage on the NIIP (sites I-2 and I-4), Ojo Amarillo Canyon on the NIIP (sites I-7 and I-8), and the Hogback Project east drain (site I-22A) The median selenium concentration at each location was. site I-2, 25 μg/l, site I-4, 12 μg/l; sites I-7/I-8, 42 μg/l; and site I-22, 12 μg/l.

Selenium concentrations from water samples from the West Hammond Project pond (site I-20) and the Gallegos Canyon drainage south pond (site I-1) also exceeded the New Mexico fisheries standard, with values of 6 and 7 μg/l, respectively. However, the median selenium concentration at each site was 3 μg/l, suggesting that the standard was not being chronically exceeded.

The data indicate that in specific geographical areas or at specific locations on irrigation projects, selenium levels do exceed New Mexico's chronic standard for the protection of fisheries. Although none of these problem areas has been designated as a fishery, there is the potential for aquatic life at these sites to be adversely affected by the present selenium levels Fish from the San Juan River do not have easy access to Ojo Amarillo Canyon or the Hogback drain, but could potentially be exposed to the high selenium levels where the irrigation return flows enter the river's backwaters (National Fisheries Contaminant Research Center et al 1991).

In summer 1990 water samples from 22 sites were screened for acute toxicity using the Microtox photobacteria bioassay test system Of the 149 tests performed, 22 water samples from seven sites induced toxic responses in the bacteria These results were used to choose eight sites for comparative 48-hour acute toxicity tests using *Daphnia magna* and captively-reared Colorado squawfish larvae from the Dexter National Fish Hatchery None of the subsequent tests indicated that the samples were acutely toxic to either the *Daphnia magna* or the larvae. The maximum concentration of selenium at the bioassay test sites was 42 μg/l at Ojo Amarillo Canyon and at all sample sites was 67 μg/l, but the 96-hour LC_{50} for Colorado squawfish was determined to be 50,000 μg/l Selenium concentrations are not at acutely toxic levels in the San Juan River area but may be chronically toxic.

Eighteen samples of bottom sediments were analyzed for trace elements. The results were compared to three sets of soils data soils of the U.S west of the 97th parallel (Shacklette and Boerngen 1984), soil samples collected in the San Juan basin, New Mexico (Severson and Gough 1981), and soil samples collected as part of 19 studies of the NIWQP (Table 56) Selenium was not included in the San Juan basin soils data and therefore was considered separately. Of the 198 total analyses performed, 22 had trace element concentrations exceeding the upper-expected value concentration in soils in the San Juan River basin (Severson and Gough 1981). The 22 samples included 9 elevated strontium samples, 5 lead, 4 chromium, 2 copper, and 2 zinc samples

Lacking San Juan basin soils data, the selenium concentrations in the bottom sediment samples were compared to concentrations in soils of the western U.S. (Shacklette and Boerngen 1984). A total of eight samples was collected from the San Juan River and its tributaries, with a maximum selenium

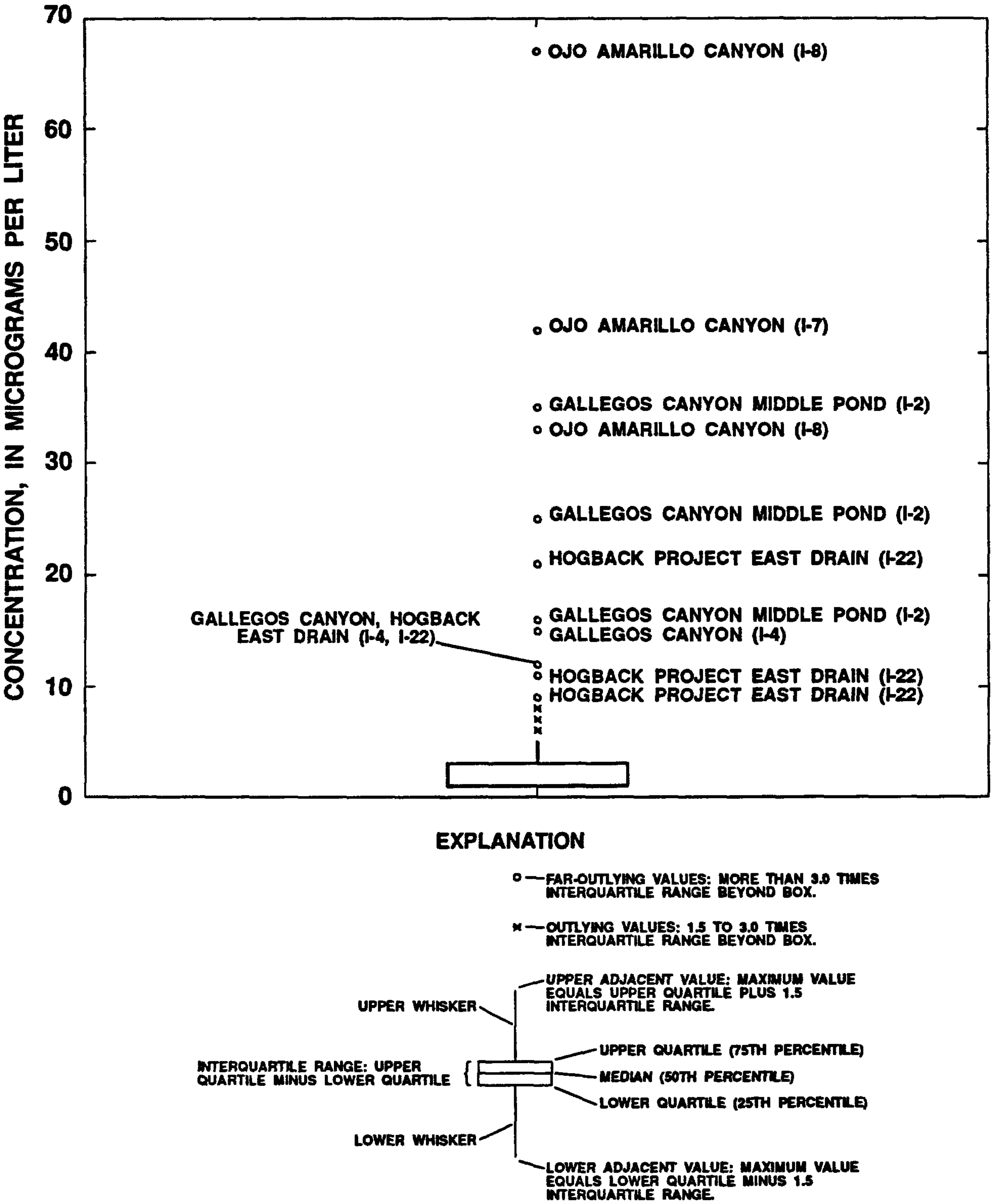


Figure 28. Concentrations of dissolved selenium in water samples from irrigation project sites, San Juan DOI reconnaissance investigation (Taken from Blanchard et al 1993)

Table 56: Concentrations of selected trace elements in soils of the western United States, in soils from the San Juan Basin, in bottom sediment from 19 National Irrigation Water-Quality Program (NIWQP) study areas, and in bottom sediment from the San Juan River area

[Concentrations are in microgram per gram (μg/g); San Juan River area bottom sediment consists of a size fraction less than 0.062 millimeter]

	Concentration in Western U.S. soils		Cocentration in San Juan Basin soils		Concentration range in bottom sediment from 19 NIWQP study areas		Concentration in bottom sediment from the San Juan River area	
							<0.062 mm	
Trace elements	Expected 95 percent range	Geometric mean	Expected 95 percent range	Geometric mean	<0.062 mm	<2.0 mm	Range	Median
Arsenic	1.2-22	5.5	2.3-13	5.4	0.6-59	0.6-120	2.1-5.1	3.6
Cadmium	---	---	---	---	---	---	<2-<2	<2
Chromium	8.5-200	41	7.9-41	18	1.0-300	20-330	24-53	31
Copper	4.9-90	21	2.3-33	8.8	3.0-180	5.0-520	13-36	21.5
Lead	5.2-55	17	6.5-22	12.5	<4.0-250	<4.0-500	15-44	19
Mercury	0.0085-0.25	0.046	0.01-0.07	0.02	<0.02-20	<0.02-18	0.02-0.04	0.02
Molybdenum	0.18-4.0	0.85	0.4-3.5	1.3	<2.0-54	<2.0-73	<2-3	<2
Nickel	3.4-66	15	3.1-24	8.5	<2.0-160	8.0-170	10-20	12
Selenium	0.039-1.4	0.23	---	---	0.1-120	0.1-85	0.1-37	0.65
Strontium	43-930	200	85-410	180	69-1,400	59-110,600	160-1,500	365
Uranium	1.2-5.3	2.5	1.4-5.3	2.6	---	---	3.56-16.7	5.95
Vanadium	18-270	70	18-110	42.5	5.0-220	20-310	42-110	66
Zinc	17-180	55	13-100	38	10-860	23-1,600	41-150	65.5

Taken from Blanchard et al. 1993

concentration of 0.4 μg/g. This value is less than the upper expected value of 1.4 μg/g in soils, and the median concentration of 0.25 μg/g from the San Juan River samples is similar to the geometric mean of 0.23 μg/g for western U.S. soils.

Twelve additional bottom sediment samples were collected from the irrigation projects and tested for selenium. The maximum selenium concentration was 37 μg/g in a sample from the Gallegos Canyon drainage middle pond (site I-2). Eight of these 12 samples had selenium concentrations greater than 1.4 μg/g. The Hogback Project east drain (site I-22), the Hogback Project west drain (site I-24), Ojo Amarillo Canyon (site I-7), and the Hogback marsh (site I-23) had selenium concentrations of 6.0, 5.5, 5.0, and 4.5 μg/g, respectively.

Fifteen plant samples, 15 invertebrate samples, 9 amphibian samples, and 14 fish samples were collected from pond and wetland areas and analyzed for 18 trace elements (Tables 57 and 58). Lemly and Smith's (1987) determination that food items with selenium concentrations of 5 μg/g dry weight or greater may result in reproductive failure or mortality in fish was used to evaluate the results. Samples from all media had selenium concentrations greater than 5 μg/g dry weight, and invertebrates, amphibians, and smaller fish (mosquitofish, killifish, and fathead minnow) each had maximum concentrations exceeding the 5 μg/g criterion by 6-10 times.

Lemly and Smith's (1987) criterion that whole-body selenium concentrations greater than 12 μg/g may cause reproductive failure in fish was exceeded for both smaller fish and the group of larger fish, composed of common carp and flannelmouth sucker. Furthermore, at the Hogback Project east drain, 15% of the western mosquitofish collected were observed to have scoliosis; selenium concentrations in small fish from this site were as high as 41.7 μg/g dry weight. Sites in which selenium concentrations exceeded either the food-item or whole-body criteria for fish or the food-item criterion for birds of 4-8 μg/g dry weight are identified (Table 59).

A generally accepted safe maximum lead concentration in food items is 0.3 μg/g wet weight, or approximately 1 μg/g dry weight (Irwin 1988). In the San Juan investigation, 11 of 15 plant samples, 6 of 15 invertebrate samples, 1 of 9 amphibian samples, and 4 of 14 fish samples had lead concentrations greater than 1 μg/g dry weight. The median lead concentration for each group was: plants, 1.37 μg/g, invertebrates, 0.884 μg/g; amphibians, 0.296 μg/g, and fish, 0.440 μg/g dry weight. Plant samples from Avocet Pond and the Chinde Wash drainage southwest pond (sites I-10 and I-13), invertebrate samples from the Chinde Wash drainage south pond, the East Hammond Project east drain and wetland, and the Fruitland Project site (site I-13, I-16, and I-21); and a tadpole from the Fruitland project site (site I-21) each had lead concentrations greater than 3 μg/g dry weight.

Eisler (1985) recommended a safe maximum concentration of mercury in food items as 0.1 μg/g dry weight. In the San Juan investigation, 7 of 15 invertebrate samples, 2 of 9 amphibian samples, and 3 of 14 fish samples collected from wetlands had mercury concentrations larger than 0.1 μg/g dry weight. Invertebrate samples from the NIIP Block 3 northwest pond, the Chinde Wash drainage southwest pond, and the Hogback marsh (sites I-12, I-13, and I-23); the amphibian sample from the Chinde Wash southwest pond (site I-13); and fish samples from the Hogback marsh (site I-23) all had mercury concentrations greater than 0.2 μg/g dry weight. Median concentrations for all media were less than the laboratory detection level of 0.05 μg/g.

Composite fish samples, generally consisting of five individuals from a single species, were collected from six reaches of the San Juan River in the spring of 1990 and from seven reaches in the fall of 1990 (Table 60). NCBP data from 1981 to 1984, both nationwide and for the western U.S., were used for comparison (Schmitt and Brumbaugh 1990). From the comparison, the investigators concluded that concentrations of selenium in San Juan River flannelmouth sucker were elevated, with all 13 samples containing concentrations larger than the nationwide NCBP 85th percentile (Figure 29). The data indicated that neither common carp nor flannelmouth sucker had been exposed to significantly increased selenium concentrations during the irrigation season.

The highest selenium concentrations in common carp and flannelmouth sucker were found upstream from the DOI-sponsored irrigation projects (reach A) and along the Hammond Irrigation Project

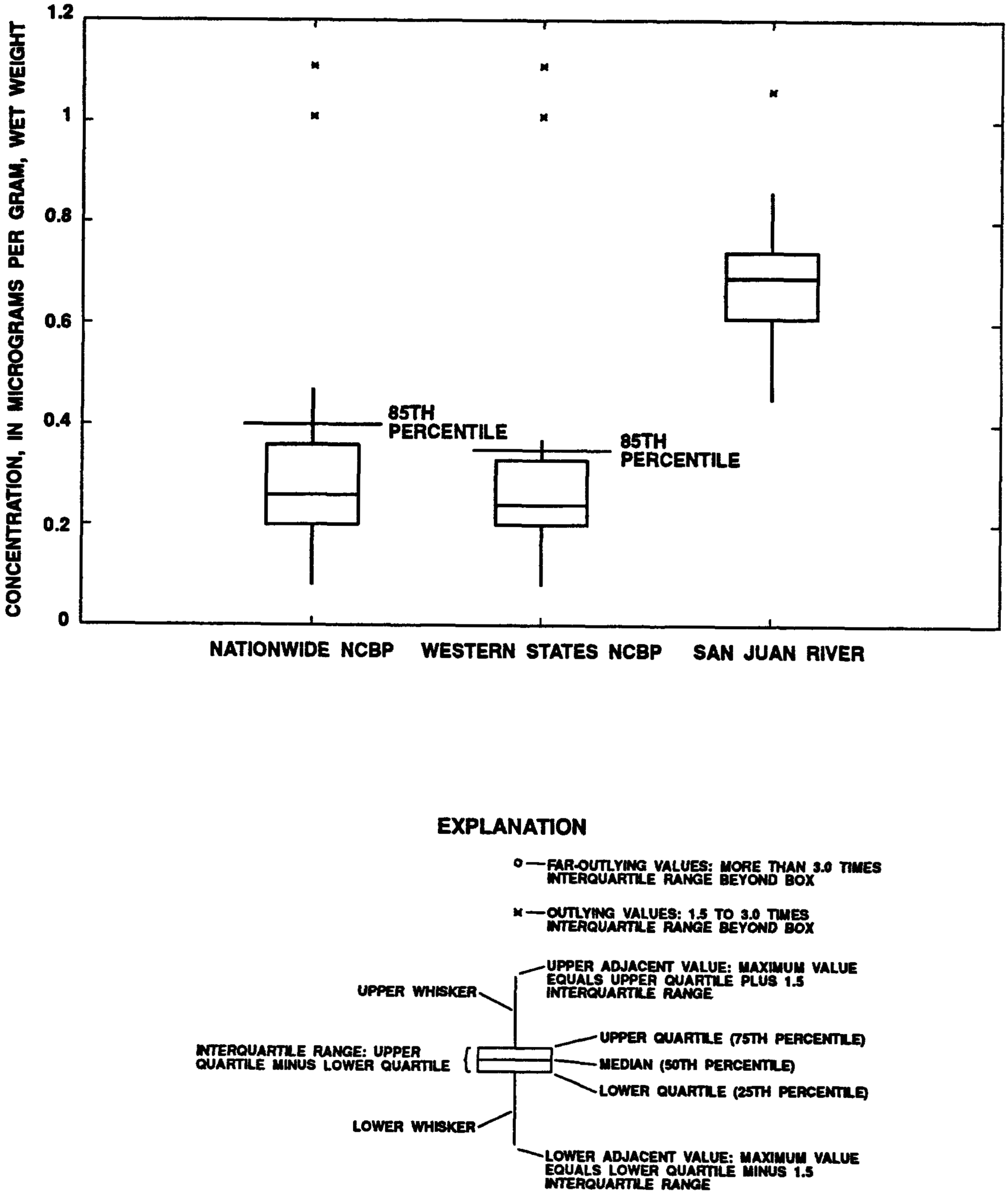


Figure 29. Comparison of selenium concentrations in all species of suckers collected for the NCBP in 1984, and in flannelmouth suckers from the San Juan River in 1990, San Juan DOI reconnaissance investigation. (Taken from Blanchard et al. 1993)

Table 57: Ranges of whole-body concentrations of selected trace elements in biota from pond and wetland sites

Trace element	15 plant samples			15 invertebrate samples			14 fish samples		
	No.*	Minimum	Maximum	No.*	Minimum	Maximum	No.*	Minimum	Maximum
Antimony	1	<5.00	6.62	0		<5.00	0		<5.00
Arsenic	14	<0.35	13.2	14	<0.3	4.77	3	<0.3	0.813
Barium	15	10.8	932	15	2.54	931	14	1.21	24.6
Beryllium	1	<0.100	0.238	0		<0.100	0		<0.100
Boron	15	5.00	208	14	<1.50	8.56	8	<1.50	3.69
Cadmium	5	<0.100	0.362	9	<0.100	0.735	0		<0.100
Chromium	15	0.618	2.92	9	0.500	2.28	14	0 756	181
Cobalt	14	<0.500	3.75	7	<0.500	3.99	1	<0.500	0.881
Copper	15	0.774	81.4	15	6.50	139	13	<0.500	17.8
Lead	13	<0.35	6.03	15	0.206	25.4	11	<0.2	1.62
Mercury	0		<0.05	7	<0.05	0.628	4	<0.05	0.397
Molybdenum	5	<0 500	2.63	2	<0.500	0.646	0		<0.500
Nickel	13	<0.500	3.59	7	<0.500	2.61	2	<0.500	1.30
Selenium	11	<0.5	9.90	15	0.359	32.30	13	<0.3	41.7
Strontium	15	45.0	2,700	15	16.0	457	14	71.7	341
Tin	4	<5.00	7.22	0		<6.00	0		<0.600
Vanadium	14	<0.500	9.76	8	<0.500	9 39	5	<0.500	3.13
Zinc	15	3.67	74.4	15	9.22	353	14	25.0	182

* No. = number of samples having concentrations larger than respective laboratory reporting level

Taken from Blanchard et al. 1993

Table 58: Selenium ranges and medians for pond and wetland community media

Medium	Concentration (μg/g dry weight)		
	Minimum	Maximum	Median
Plants	0.5	9.90	1.16
Invertebrates	0.359	32.3	3.12
Amphibians	2.40	51.3	4.22
Fish (1)	<0.3	41.7	3.77
Fish (2)	2.00	35.1	2.32

(1) Mosquitofish, killifish, and fathead minnow
(2) Common carp and flannelmouth sucker

Taken from Blanchard et al. 1993

Table 59: Pond and wetland sites in which the concentrations of selenium in biota exceeded food-item criteria*

[Selenium concentration in micrograms per gram (µg/g) dry weight]

Site number	Site name	Selenium Concentration
	Plants (15 samples)	
I-2	Gallegos Canyon drainage middle pond	9.90
I-22	Hogback Project east drain	5.10
	Invertebrates (15 samples)	
I-2	Gallegos Canyon drainage middle pond	32.3
I-22	Hogback Project east drain	17.4
I-22	Hogback Project east drain	11.1
I-6	Ojo Amarillo Canyon drainage ponds	10.2
I-20	West Hammond Project pond	9.62
I-3	Gallegos Canyon drainage north pond	8.75
I-1	Gallegos Canyon drainage south pond	4.42
	Amphibians (8 samples)	
I-2	Gallegos Canyon drainage middle pond	51.3
I-3	Gallegos Canyon drainage north pond	23.5
I-6	Ojo Amarillo Canyon drainage ponds	14.7
I-1	Gallegos Canyon drainage south pond	5.24
I-6	Ojo Amarillo Canyon drainage ponds	4.22
	Fish: mosquitofish, killifish, and fathead minnow (9 samples)	
I-22	Hogback Project east drain	41.7
I-22	Hogback Project east drain	27.2
I-20	West Hammond Project pond	15.5
I-20	West Hammond Project pond	13.6
	Fish: common carp and flannelmouth sucker (5 samples)	
I-22	Hogback Project east drain	35.1
I-22	Hogback Project east drain	28.5

* Criteria: 4 to 8 µg/g as a waterfowl food item
5 µg/g as a fish food item

Taken from Blanchard et al. 1993

Table 60: Comparison of concentrations of trace elements in fish samples collected for the National Contaminant Biomonitoring Program (NCBP) with samples collected from the San Juan River in 1990

[Concentrations are in micograms per gram (ug/g) wet weight]

Trace element	NCBP (1990) 85th percentile concentration		San Juan River Concentration			San Juan River Number of samples with concentration larger than the NCBP 85th percentile*	
	Nationwide	Western	Minimum	Maximum	Median	Nationwide	Western
Common Carp							
Arsenic	0.15	0.14	0.07	0.10	0.09	0	0
Cadmium	0.14	0.14	0.02	0.17	0.09	2	2
Copper	1.12	1 02	0.79	1 87	1.32	11	12
Lead	0.30	0.25	<.06	1.69	0 19	4	4
Mercury	0.11	0.10	0.06	0 19	0.08	3	3
Selenium	1.25	1.70	0.61	1.56	0.84	2	0
Zinc	73.7	68.8	15.1	90.3	66 4	3	4
Sucker species							
Arsenic	0.17	0.20	<0.09	0.19	0.10	1	0
Cadmium	0.05	0.04	<0.03	0.45	0.05	0	2
Copper	1.01	0.99	0.58	1.47	0.79	2	3
Lead	0.22	0.20	<0.06	0.90	0.20	4	5
Mercury	0.18	0.13	0.05	0.32	0 13	4	6
Selenium	0.40	0.35	0.45	1.06	0.69	13	13
Zinc	20.8	21.5	12.4	42 1	15.8	2	2

* The total number of samples collected was 13 for both common carp and sucker species

Taken from Blanchard et al. 1993

from Bloomfield to just downstream of Lee Acres (reach B). The lowest selenium concentrations in fish were found in the San Juan River from the La Plata River confluence to the Hogback (reaches D and E). The NIIP and the Fruitland Project are adjacent to reaches D and E on the south side of the San Juan River, and non-DOI-sponsored irrigation projects are adjacent to the reaches on the north.

The FWS (National Fisheries Contaminant Research Center et al 1991) has compared biological effect concentrations of selenium in fish to concentrations found in the San Juan reconnaissance investigation in order to determine margins of safety for fish in the study area. A margin of safety is calculated by dividing the biological effects concentration by the expected environmental concentrations; a margin of safety greater than 5000 indicates low hazard, a margin from 100-1000 indicates a moderate hazard, and a margin less than 100 indicates a high hazard. For Ojo Amarillo Canyon, the FWS calculated a margin of 224 for selenite and 764 for selenate, suggesting that fish in this region are at a moderate hazard from selenium contamination

The data from the San Juan investigation also indicate that copper, lead, and mercury were elevated in the fish. The median copper concentration in San Juan River carp was greater than the NCBP 85th percentile concentration for both the national and western data sets (Figure 30). Concentrations of lead in flannelmouth sucker from the San Juan River were elevated, with the median concentration of lead in the San Juan fish about the same as the NCBP 85th percentile concentration for both the national and western data sets (Figure 31) Mercury concentrations in San Juan River flannelmouth sucker were also elevated, with the median concentration for the San Juan fish about equal to the 85th percentile concentration of the NCBP western data set (Figure 32).

An evaluation of external health was conducted on all fish sampled during the spring and fall collections, except common carp. Twenty-eight percent of all flannelmouth sucker and 35% of all channel catfish had external lesions, with the highest incidence rate for both species between Shiprock and Cudei (reach F). However, the selenium concentrations in water and bottom sediment in this reach of the river were low, suggesting that the incidence rate of lesions was not related to selenium concentrations.

The reconnaissance investigation also included a sampling effort for determination of pesticide and organochlorine contamination A summary of the results is given in this review in section 4.6, PESTICIDES and PCBs.

Hydrocarbon analyses were performed on water samples from all three ponds in the Gallegos Canyon drainage (sites I-1, I-2, and I-3), from the East Hammond Project pond one-tenth of a mile north of the west drain (site I-18), and from a wetland near the Gallegos Canyon drainage south pond (site I-1) that receives runoff from the area surrounding an oil production well These sites were chosen because of their proximity to oil and gas production activities. After initial gas chromatographic/flame ionization detection scans, sites I-1 and I-18 were chosen for further analyses by gas chromatography/mass spectrometry. The analyses tested for 34 hydrocarbons, none of which was present in concentrations at or larger than the respective laboratory reporting levels.

The most significant finding of the San Juan reconnaissance investigation is that the DOI-sponsored irrigation projects are contributing significant selenium loads to the San Juan River. Roy and Hamilton (1991) suggest that the San Juan River is at or near its "assimilation capacity" for selenium and that further inputs, such as from the Animas-La Plata Project or development of Blocks 7 and 8 of the NIIP, could adversely affect the river's aquatic organisms (Roy and Hamilton 1992).

4.10.2 NAVAJO INDIAN IRRIGATION PROJECT

Although the NIIP and its effects on basin water quality have been investigated by the San Juan NIWQP Reconnaissance Investigation, there have been additional, more detailed studies of NIIP water quality and its potential for harming San Juan basin native fishes. Because the NIIP is by far the largest of the DOI-sponsored irrigation projects, an extra section is devoted to a discussion of its potential to contaminate the San Juan River.

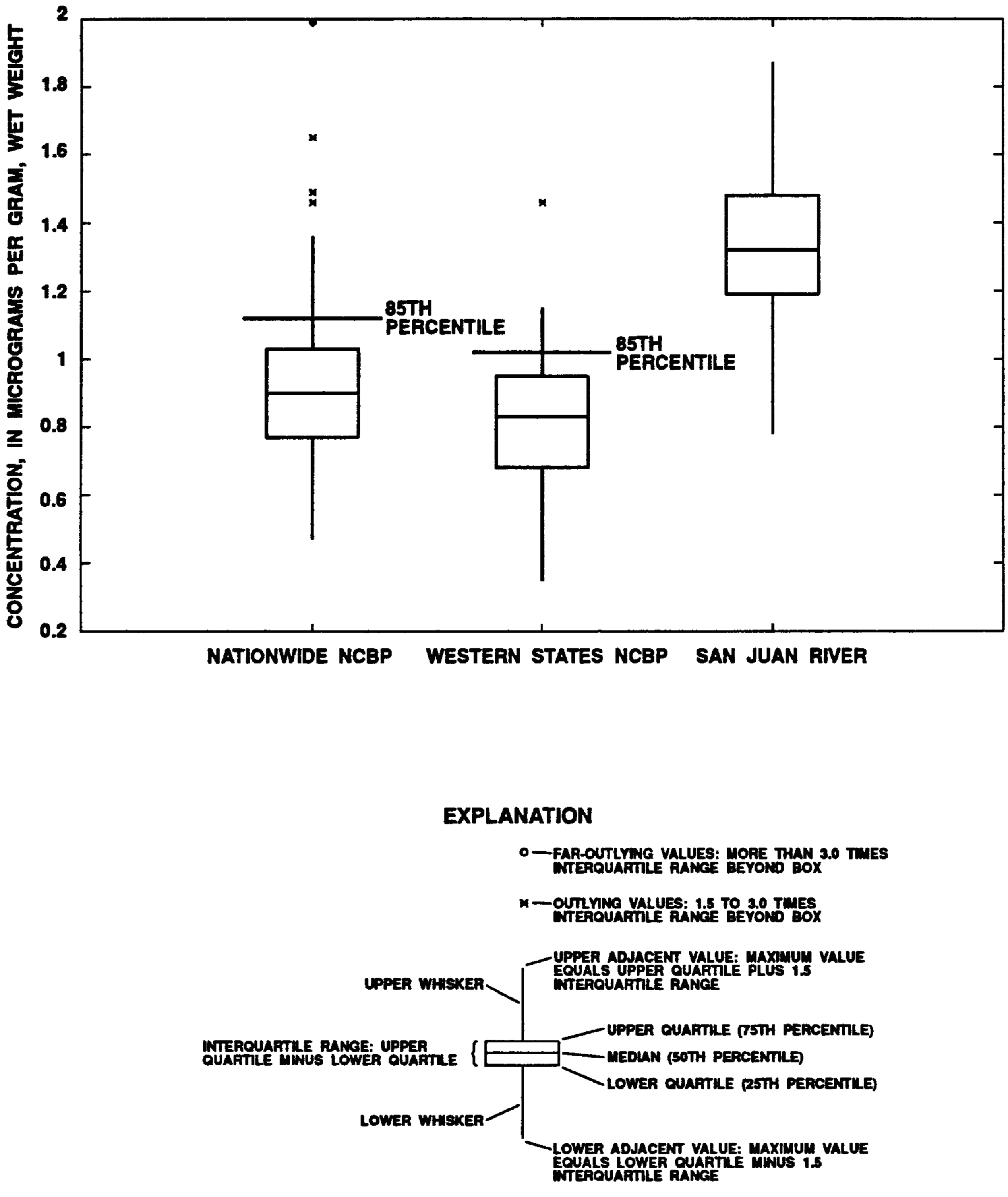
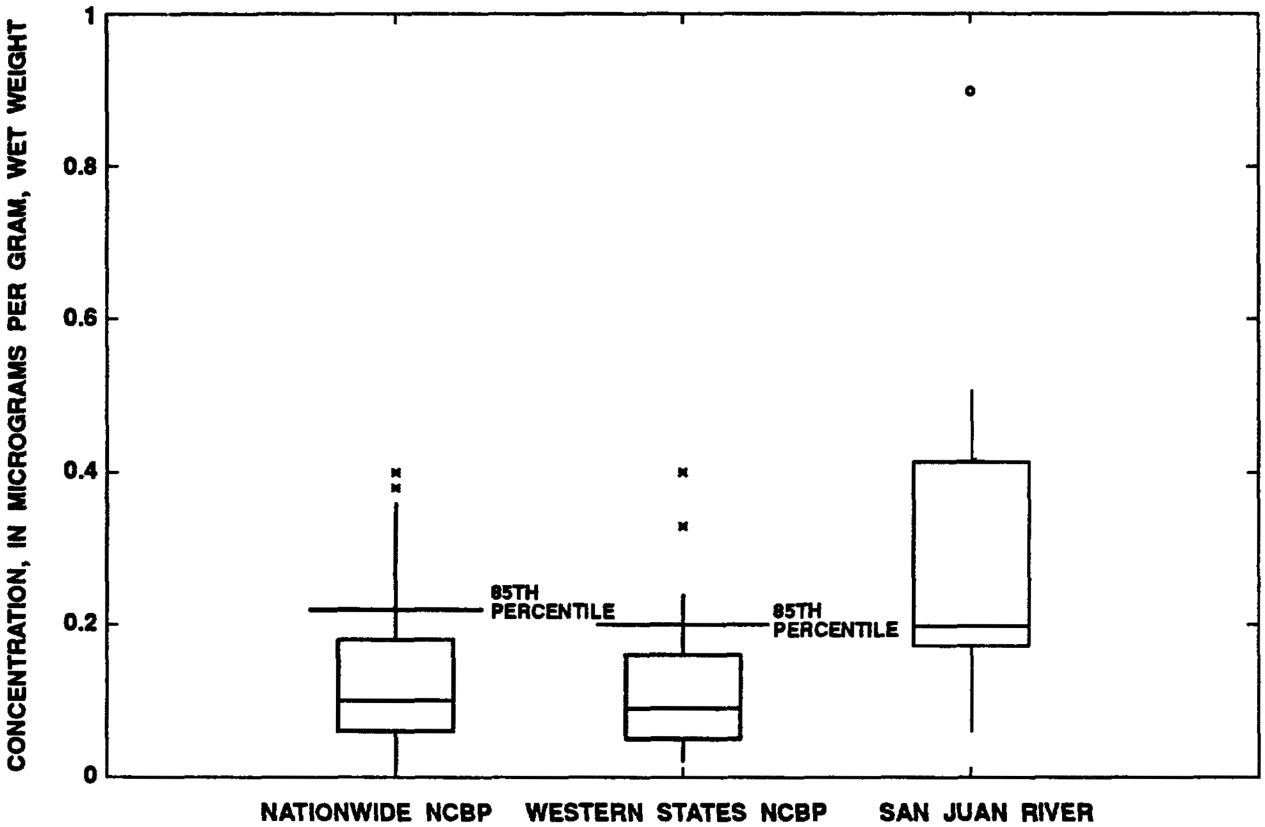


Figure 30. Comparison of copper concentrations in carp collected for the NCBP in 1984 and from the San Juan River in 1990, San Juan DOI reconnaissance investigation.
(Taken from Blanchard et al 1993)



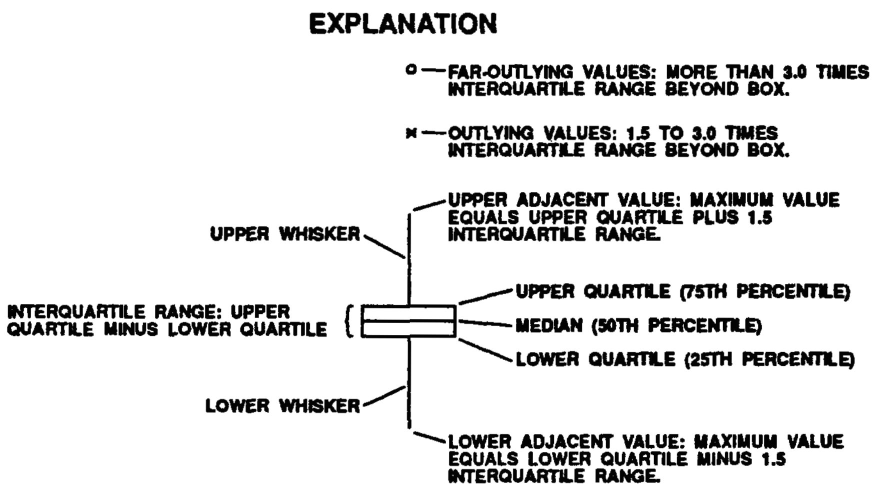


Figure 31. Comparison of lead concentrations in all species of suckers collected for the NCBP in 1984, and in flannelmouth suckers from the San Juan River in 1990, San Juan DOI reconnaissance investigation. (Taken from Blanchard et al 1993)

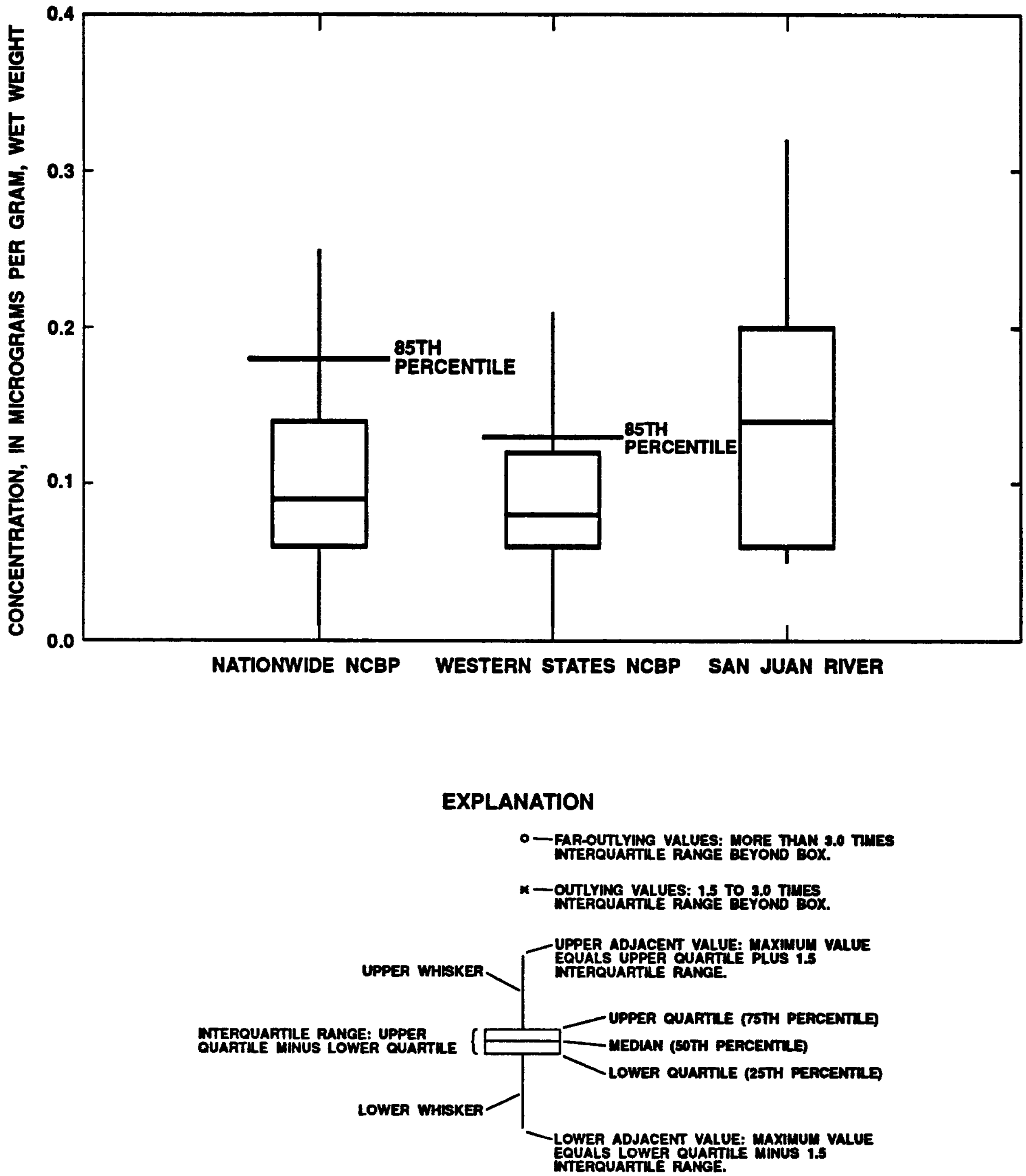


Figure 32. Comparison of mercury concentrations in all species of suckers collected for the NCBP in 1984, and from flannelmouth suckers from the San Juan River in 1990, San Juan DOI reconnaissance investigation. (Taken from Blanchard et al 1993)

The NIIP obtains its irrigation water from Navajo Reservoir. In 1984 the project diverted about 120,000 acre-feet (148 million m^3) of water from the reservoir, which is about half as much water as would be depleted at full development (Liebermann et al. 1989). The courts have authorized the project to divert a maximum of 508,000 acre-feet (about 626.6 million m^3) a year from the reservoir, or about one-half of the annual inflow to Navajo Reservoir (Melancon et al. 1979). Bureau of Reclamation estimates from 1975 predicted that at full development the NIIP would create 104,000 acre-feet (about 128 3 million m^3) a year of return flows, with up to 25,600 acre-feet (about 31 6 m^3) a year of this flow draining into Chaco Wash through the old mining areas of Burnham (Melancon et al. 1979). The U.S Bureau of Indian Affairs (1976) estimated that during the irrigation season of a drought year the San Juan River could potentially become dry below Shiprock for many miles, although fisheries immediately below the dam would be maintained (Melancon et al. 1979)

At full development of the NIIP, a 23-megawatt powerplant is planned for installation at Navajo Dam in order to provide power for the irrigation pumps. It is expected that during the irrigation season operation of this powerplant would result in fluctuations in the water level of the San Juan River by about one-half foot each day (U.S. Bureau of Reclamation 1976). The projected change in TDS as a result of the powerplant is small and not expected to adversely affect the river's native fish. The month of August, when flows would be lowest and salinity would be highest, would be the most critical time for fish between Farmington and Lake Powell (U.S. Bureau of Reclamation 1976).

The irrigation returns from the NIIP flow into surface channels or infiltrate to the subsurface flow, with the infiltrated water eventually discharging to basin streams. Depth to the water table is more than 200 feet in most places, there is a large storage capacity in the unsaturated zone, and there are relatively low permeabilities; because of these factors, the effects of the infiltration on streams might not be evident for many years (Stone et al. 1983). The BIA began monitoring groundwater quality from observation wells on the NIIP in 1985. Among the BIA's findings have been selenium concentrations as high as 180 μg/l (Blanchard et al 1993)

In 1992 the BIA began sampling water quality on the NIIP as well as on the San Juan River and its tributaries (Appendices 17a-c) (U S. Bureau of Indian Affairs 1993) It is important to note that at most sites dissolved (filtered) and total (unfiltered) measurements were each taken for a given constituent. It should also be emphasized that the laboratory detection level for mercury was 0.02 μg/l, which is greater than the New Mexico and Utah fisheries standard of 0.012 μg/l and the Colorado fisheries standard of 0.010 μg/l. The highest selenium concentration recorded by the BIA from an NIIP site was 38 2 μg/l in a filtered sample from Ojo Amarillo Wash collected in January 1993. This site produced a number of the higher selenium levels reported, although every site on the NIIP had selenium concentrations exceeding 5 μg/l on at least one occasion. The river and stream collections produced a maximum selenium value of 45.7 μg/l in an unfiltered sample taken in July 1992 on the San Juan River at Bluff, Utah

The most extensive water quality study that has been conducted to date on the NIIP is the Biological Assessment for development of Blocks 1-8 (Keller-Bliesner Engineering and Ecosystems Research Institute 1991). Blocks 1-6 have already been developed and comprise 54,500 acres; the Biological Assessment deals with the proposed construction of Blocks 7 and 8, which would bring an additional 23,300 acres into development (U.S Fish and Wildlife Service 1991b). The water quality analysis section of the Biological Assessment focuses principally on potential selenium loading from the NIIP Blocks 1-8 and concludes that the impact of the NIIP on San Juan River selenium levels would be negligible. What follows is a summary of the results presented in the Water Quality Analysis Section of the Biological Assessment (Keller-Bliesner Engineering and Ecosystems Research Institute 1991).

Sampling sites for the Biological Assessment were chosen after reviewing the preliminary results of the San Juan DOI Reconnaissance Investigation and identifying areas that warranted further examination. The sampling program was begun in April 1991 Water, sediment, and biota (plants and/or macroinvertebrates) were sampled from ponds, major seeps, and surface water at several locations along Gallegos and Ojo Amarillo Canyons. Alluvial groundwater samples were also taken at several locations on the NIIP. Additionally, water, bed sediment, and macro-invertebrate samples were collected on the San

Juan River at 14 stations between Archuleta and Shiprock Sample sites were located on both sides of the river, with the south side points serving as indicators of NIIP effects on the river.

During the summer of 1991, soil sampling was conducted adjacent to observation wells in order to determine the source of groundwater selenium (Appendices 18a and 18b) The soil studies, coupled with the observation well data, indicated that selenium concentrations in groundwater on the NIIP were a reflection of the extractable selenium in the local soil. During the early part of 1991, the average observation well selenium concentration was 24 μg/l.

Beginning in April 1991 water from seeps and springs in Horn, Ojo Amarillo, and Gallegos Canyons was sampled on a monthly basis. The concentrations of selenium in sediments and periphyton at the sites, as well as the concentrations of selenium and arsenic in water, are listed as appendices (Appendices 18c and 18d). The average perched groundwater selenium concentration was about 20 μg/l. The data indicated that in Ojo Amarillo Canyon selenium was not adhering to the bed sediments below the seeps, while in Gallegos Canyon selenium was adhering to sediments with lower uptake by vegetation.

The ponds on the NIIP are utilized as drainage control features and stock watering areas. Water from ponds was sampled beginning in April 1991, and a portion was later resampled (Appendix 18e). Data indicate that dissolved selenium concentrations are variable in the ponds and are dependent upon the amount of surface flow. For this reason, pond selenium concentrations can evidently be controlled by dilution. In certain ponds, selenium concentrations in all ecosystem compartments were elevated, and data indicate that bioaccumulation of selenium is also occurring in several ponds.

Beginning in April 1991 water from Chaco Wash, Chinde Wash, Ojo Amarillo Canyon, and Gallegos Canyon was sampled. In the drainages upstream and downstream from the NIIP there were low or undetectable selenium concentrations Water in Ojo Amarillo and Gallegos Canyons, the main washes draining the project, had significant selenium levels (Appendix 18f) The percent of drainage pond observations that exceeded suggested selenium criteria are listed. broken down by ecosystem compartment (Table 61).

Bed sediment sampling indicated that selenium concentrations were low in all locations except at one site in Ojo Amarillo Canyon The average sediment selenium concentration in Gallegos Canyon was 0.23 mg/kg, with 66% of all samples below the detection limit. These findings suggest that sediment transport into the San Juan River, which would potentially increase with further development of the NIIP, would not significantly affect selenium levels in the river

The selenium concentrations found in water, sediments, periphyton, macroinvertebrates, and fish collected from the San Juan River in this study are listed as an appendix (Appendix 18g). Analysis of the macroinvertebrate selenium concentrations suggests that the NIIP is not contributing selenium-rich water to the San Juan River through Gallegos or Ojo Amarillo Canyons The highest selenium concentrations found in fish were from upstream of the NIIP, which coincides with the decrease in waterborne selenium concentrations from Archuleta to the Hogback (Figure 33). The highest selenium concentrations in fish were 3.5 mg/kg in a whole body flannelmouth sucker sample and 4 5 mg/kg in a whole body bluehead sucker sample, both of which were collected about five miles downstream of Archuleta Selenium concentrations in aquatic vegetation, macroinvertebrates, and fish collected from different points along the San Juan River are shown in graph form (Figures 34, 35, and 36). Data from the various ecosystem compartments suggest that biomagnification is occurring in all groups except for fish, which had lower selenium concentrations than did macroinvertebrates

Selenium concentrations in all ecosystem compartments were higher at San Juan River sampling sites upstream of the NIIP than at those adjacent to and below the project area The percentage of San Juan River observations that exceeded suggested selenium criteria are broken down by ecosystem compartment (Table 62). Because elevated selenium levels in the plant and invertebrate categories were at sites either upstream of the NIIP or on the north side of the river, the investigators concluded that the effect of the NIIP on selenium levels in the river was, at the time of the study, negligible.

PAHs are also potential contaminants of concern on the NIIP Because PAHs are relatively insoluble in water and thus not very mobile unless sorbed to waterborne sediments (*see* section 4.12 1 for

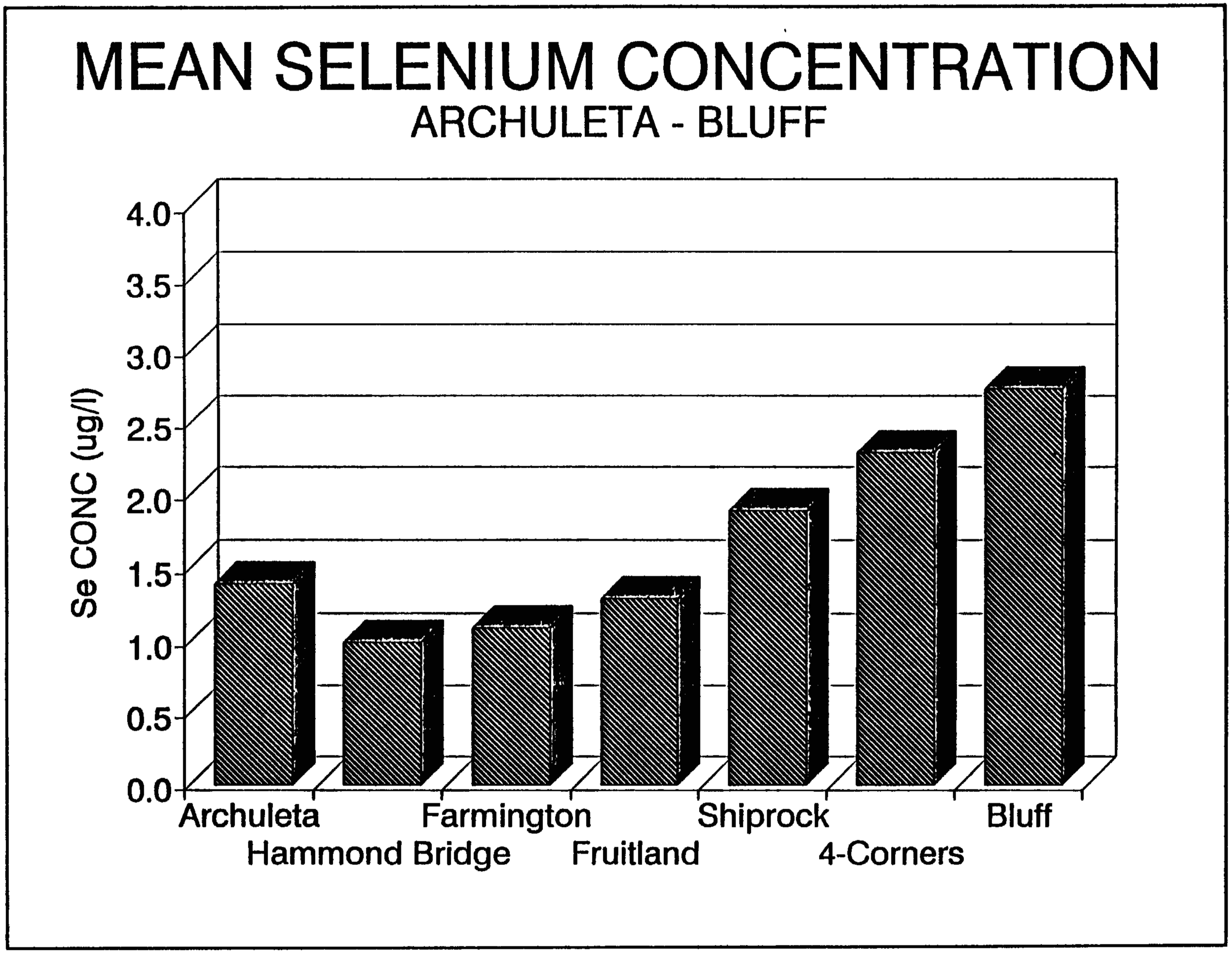


Figure 33. Mean selenium concentration in the San Juan River from Archuleta, New Mexico to Bluff, Utah, 1958-1988. (Taken from Keller-Bliesner Engineering and Ecosystems Research Institute 1991)

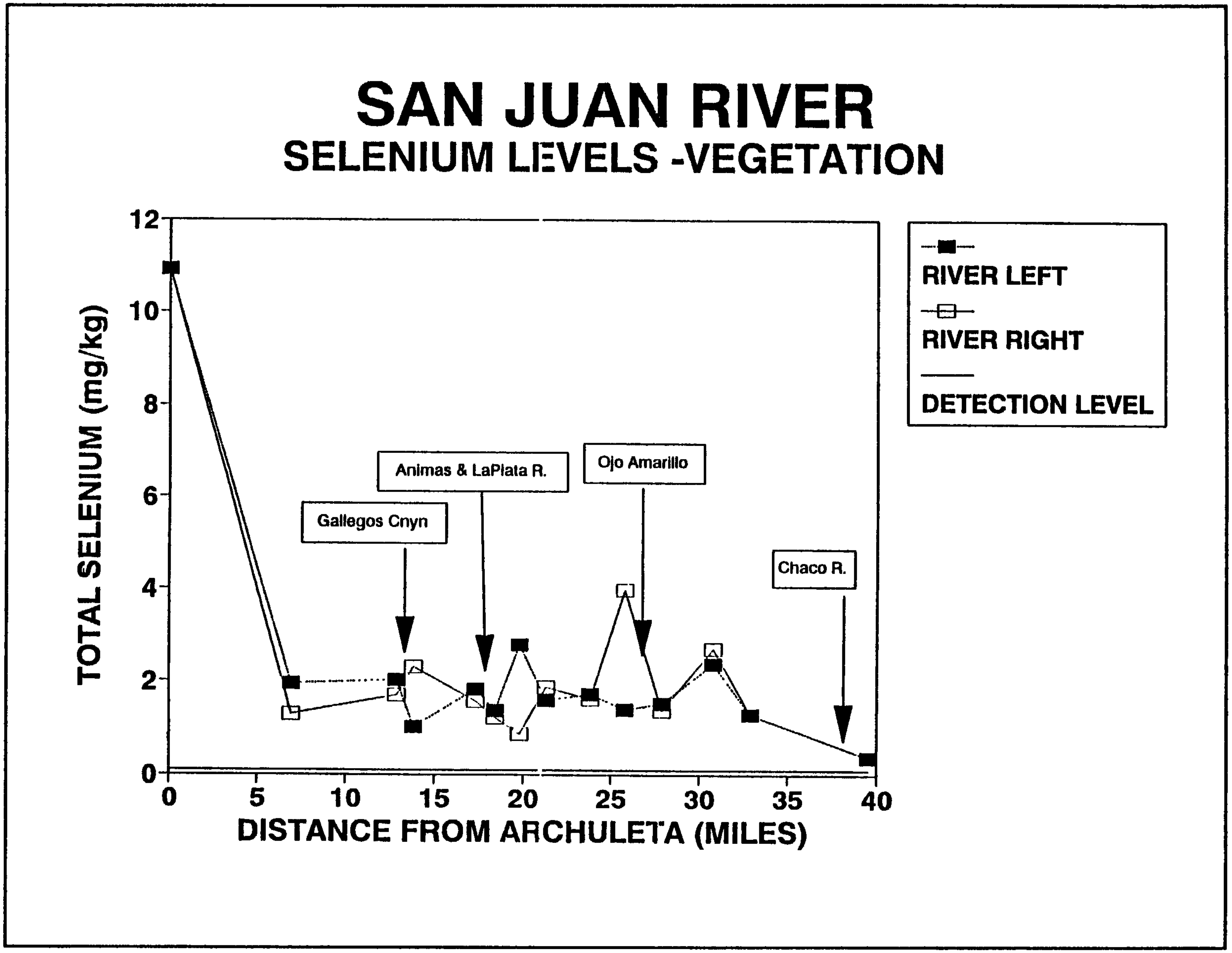


Figure 34. Selenium concentrations in aquatic vegetation at various locations on the San Juan River, as measured for the NIIP Biological Assessment. (Taken from Keller-Bliesner Engineering and Ecocystems Research Institute 1991)

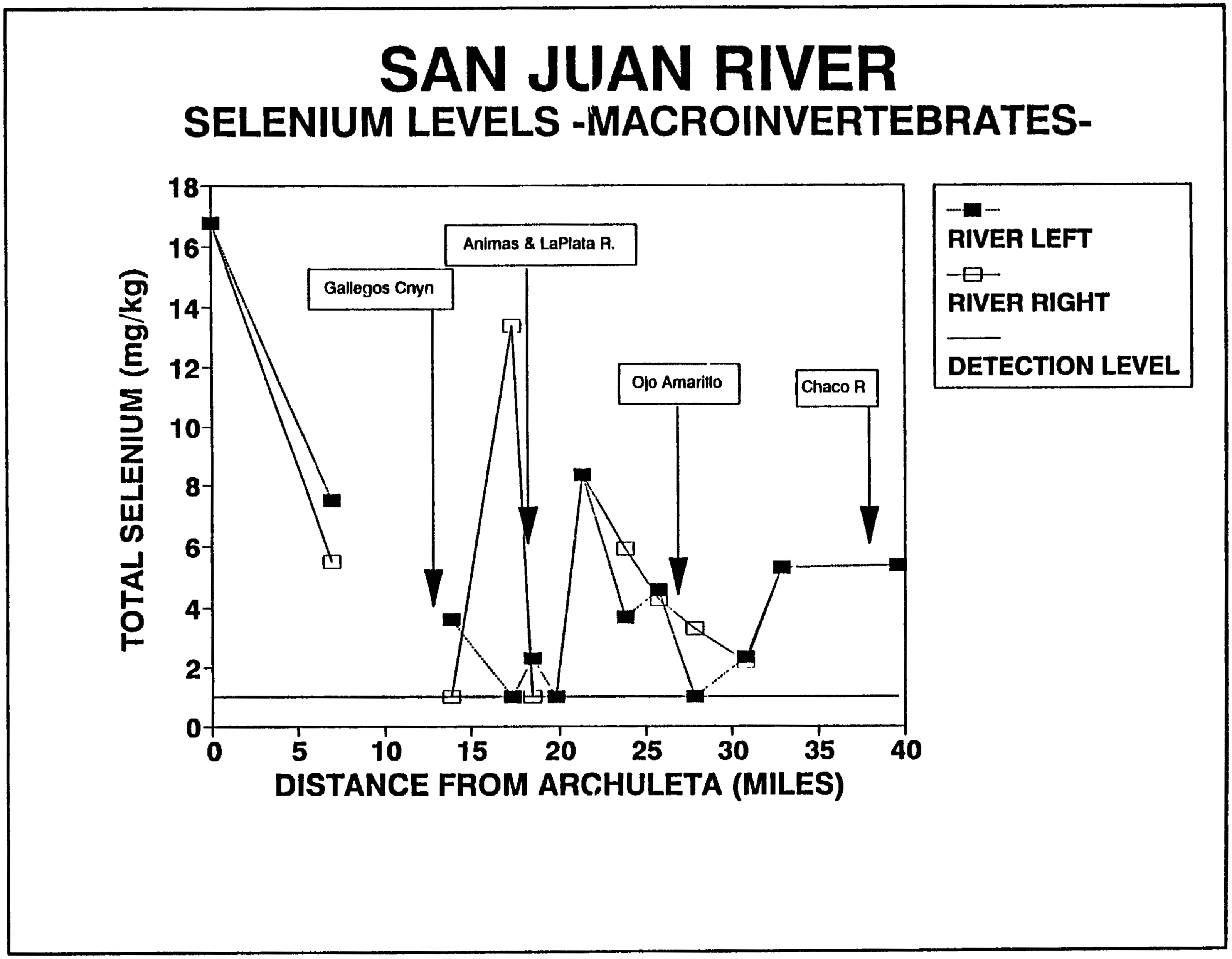


Figure 35. Selenium concentrations in macroinvertebrates at various locations on the San Juan River, as measured for the NIIP Biological Assessment. (Taken from Keller-Bliesner Engineering and Ecosystems Research Institute 1991)

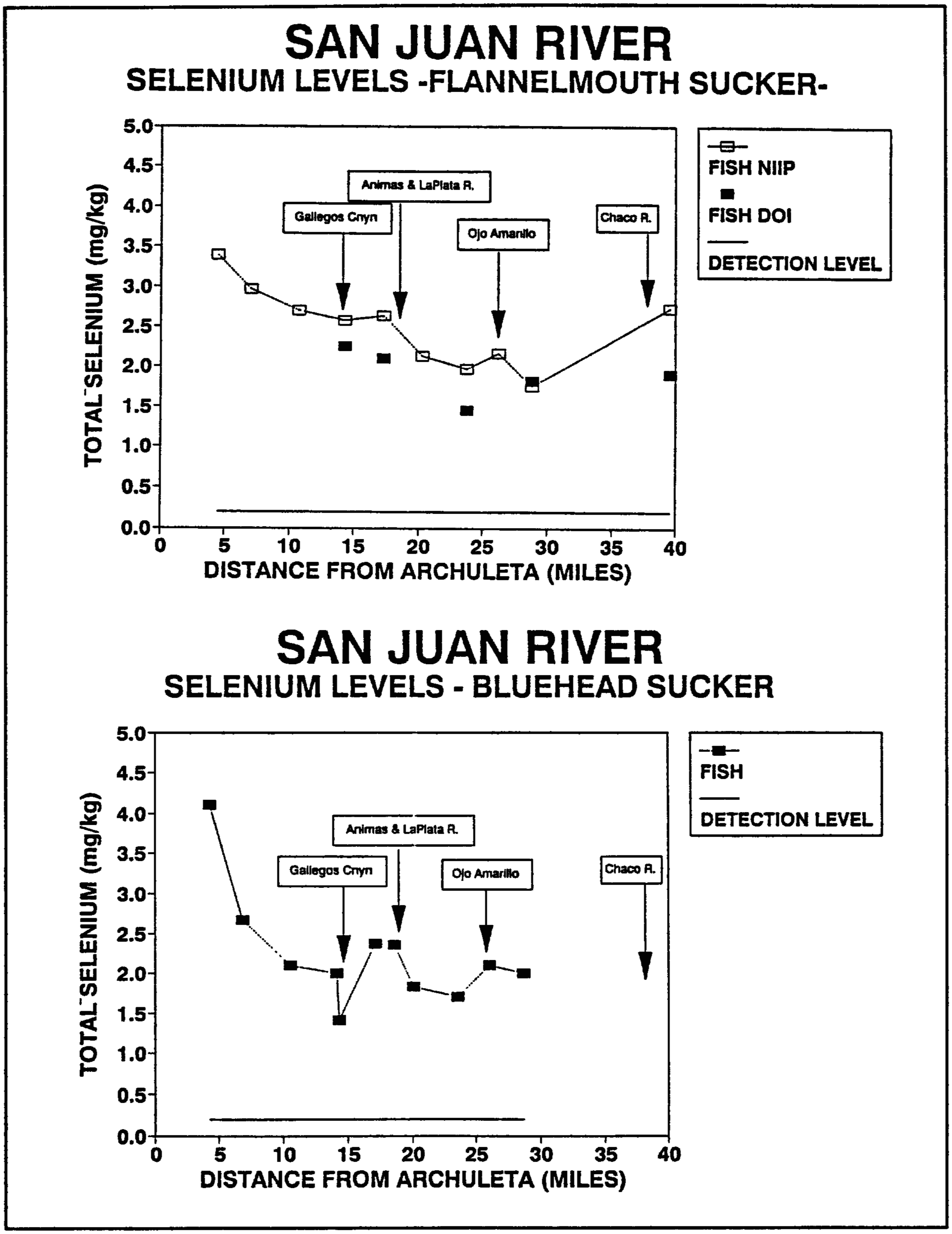


Figure 36. Selenium concentrations in fish at various locations on the San Juan River, as measured for the NIIP Biological Assessment. (Taken from Keller-Bliesner Engineering and Ecosystems Research Institute 1991)

Table 61: Percent of observations exceeding suggested criteria within various ecosystem components for the on-site locations

Location	Compartment					
	Water	Sediments	Plants	Invertebrates	Fish*	Birds
Ponds	40%	20%	11%	38%	38%	16%
Drainages	50%	6%	9%			

* Amphibians

Taken from Keller-Bliesner Engineering and Ecosystems Research Institute 1991

Table 62: Percent of observations exceeding suggested criteria within various ecosystem components for the San Juan River samples

	Compartment					
San Juan River	Water	Sediments	Plants	Invertebrates	Fish	Birds
Above NIIP	0%	0%	11%	30%	0%	
Adjacent	0%	0%	0%	25%	0%	
Below NIIP	0%	0%	0%	0%	0%	

Taken from Keller-Bliesner Engineering and Ecosystems Research Institute 1991 further background information), the investigators determined that the only potential sources of PAHs on the NIIP were oil wells within the main drainage channels. An oil well was identified within Gallegos Canyon where seepage water was running through the containment pad around the storage tank; this location was determined to represent the worst case scenario for the transport of PAHs into the San Juan River. Neither two Gallegos Wash samples nor an effluent sample from an oil well at the facility indicated the presence of PAHs. The detection level for the analyses was 2 μg/l. The investigators concluded that organics on and adjacent to the NIIP were not elevated relative to other samples collected in the basin. They also noted that although numerous oil wells existed within the NIIP, they were not in the vicinity of major drainage channels and therefore would not be likely to contaminate the San Juan River.

In conducting the Biological Assessment, the investigators noted preliminary chlorohydrocarbon compound analyses from the San Juan DOI Reconnaissance Investigation The Reconnaissance Investigation found measurable quantities of six pesticide residues, with the highest concentrations for total PCBs at the station below the confluence of the San Juan and La Plata rivers. Because most of the pesticides scanned for were at or below detection levels, and those above detection levels were apparently common for all areas sampled, Keller-Bliesner Engineering and Ecosystems Research Institute (1991) concluded that chlorohydrocarbon compounds were not of concern on the NIIP

Judging that PAHs and pesticides on the NIIP did not pose a significant hazard to water quality, the investigators focused their final analysis on selenium They determined that the source of selenium on the NIIP was underlying soils from which dissolved selenium was leached. On the NIIP site itself, selenium levels were high enough in certain ponds and wetland areas to present a hazard to wildlife. The areas with the highest potential for harm to wildlife were primarily related to Blocks 1-3, with less significant selenium contributed from Blocks 4 and 5. Because no surface discharges are related to Block 6, it would therefore not affect selenium levels on the NIIP. According to the NIIP investigators, Blocks 7 and 8 are further from areas of surface discharge and would most likely not affect these areas. Those areas exhibiting elevated selenium levels are directly affected by subsurface discharge of irrigation return flow; where this flow is diluted with surface runoff, selenium concentrations are lower.

Keller-Bliesner Engineering and Ecosystems Research Institute (1991) calculated the selenium contribution of the NIIP to the San Juan River for Blocks 1-6. Surface return flow from the NIIP was assumed to contain 20 μg/l of selenium for a flow of about 6.0 ft^3/sec. Runoff from the project's drainages was projected to add 236 lb of selenium annually, which would increase the concentration of selenium in the river at Bluff by 3.1%. Development of Blocks 7 and 8 would add another 165 lb selenium per year, or about 1.7% of the load at Bluff. The investigators concluded that these contributions would be so small as to be undetectable.

As opposed to contributions via irrigation return flows, the investigators considered the selenium contribution from deep percolation through the aquifer system to be measurable. Assuming that the selenium supply in NIIP soils would decrease with time and that it would take about 50 years for the full amount of deep percolation to return to the river, they calculated that no selenium increase from groundwater would be detectable in the river in fewer than 100 years.

Finally, the investigators calculated the maximum impact of NIIP development on the San Juan River (Figure 37). They determined that the impact would be greatest during March, when the selenium concentration in the river at Bluff would be 5 0 μg/l. The average annual impact of the NIIP would be 0.65 μg/l, which would result in an average annual selenium value at Bluff of 3 4 μg/l

Contrary to the conclusions of the Biological Assessment for the NIIP, the FWS stated in a Biological Opinion issued on October 25, 1991 that construction and operation of Blocks 1-8 of the NIIP would jeopardize the continued existence of the Colorado squawfish, in part by increasing concentrations of contaminants in the squawfish's habitat. The Biological Assessment concluded that increased selenium concentrations within the San Juan River from development of Blocks 1-8 would be small and predicted that with development of Blocks 1-8 the whole-body selenium concentration in squawfish would be approximately 3.87 μg/g dry weight. As there are no data on the toxic effect concentrations of selenium

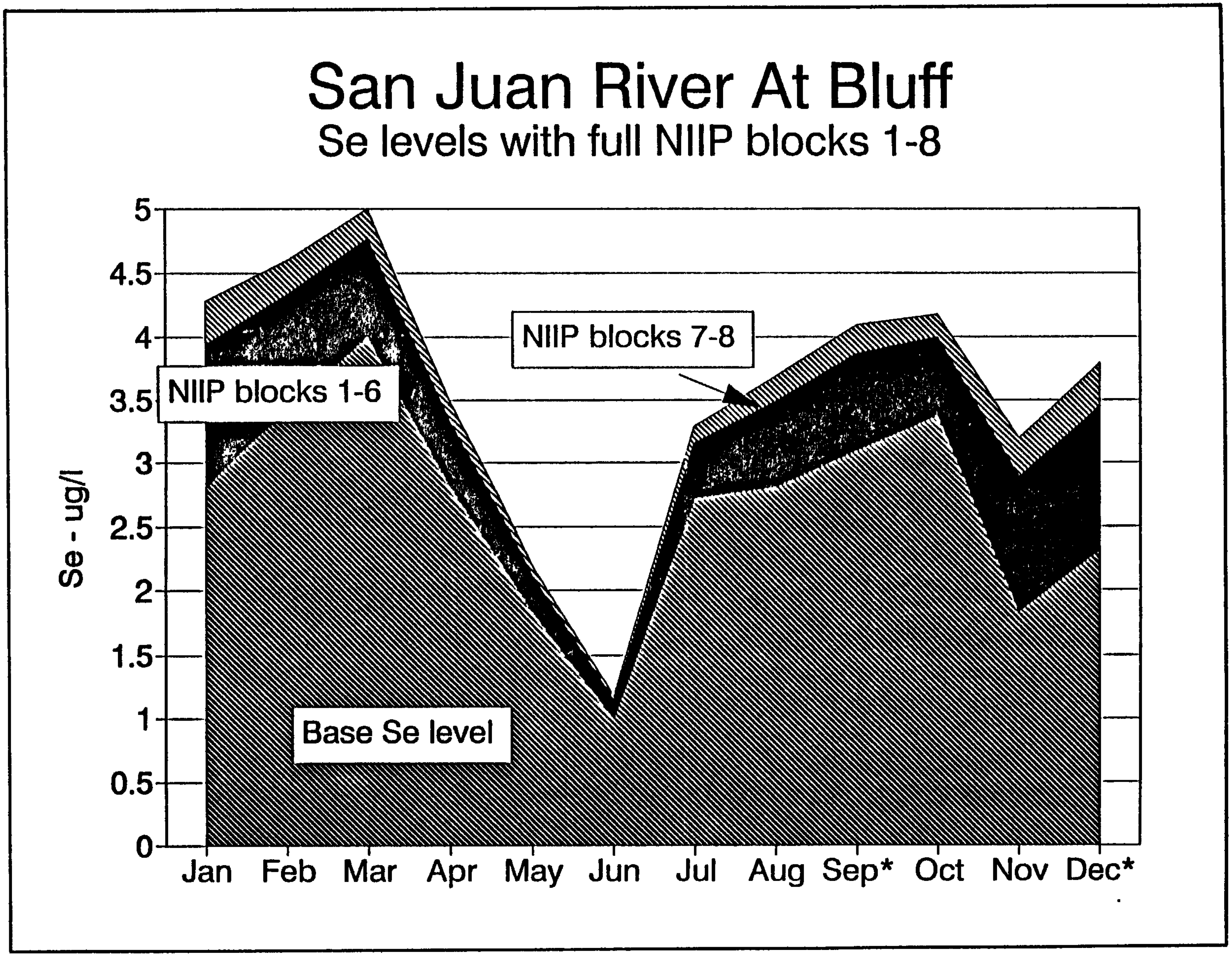


Figure 37. Projected maximum monthly selenium levels for full development of Blocks 1-8 of the NIIP, as determined for the NIIP Biological Assessment. (Taken from Keller-Bliesner Engineering and Ecosystems Research Institute 1991)

in squawfish, it was the opinion of the FWS that any increase in selenium concentrations would be likely to jeopardize the squawfish and was therefore unacceptable (U.S. Fish and Wildlife Service 1991b; Fowler-Propst, personal communication).

As part of a reasonable and prudent alternative, the FWS suggested a sampling effort to obtain more detailed information concerning selenium inputs to the river and wetlands from the NIIP. This alternative includes sampling whole fish at 11 locations on the San Juan River, with three fish sampled from each reach for total selenium. The fish to be sampled would include only adult bluehead or flannelmouth sucker, and the detection level would be 0.1 mg/kg (ppm) (U.S. Fish and Wildlife Service 1991b). Keller-Bliesner Engineering and Ecosystems Research Institute are currently conducting such a sampling effort.

The alternative also includes the monitoring of ponds on the NIIP that need remediation. Parameters to be analyzed include total selenium, dissolved selenium, and discharge from the ponds. During the dilution period from March to October, if selenium levels exceed 5 μg/l, then dilution water should be adjusted in order for the pond water to meet the standard. The detection level for this monitoring would be no less than 2 μg/l. Tiger salamander larvae (*Ambystoma tigrinum*) should be collected in March and October from the ponds, with four specimens collected in each month and whole body selenium concentrations determined. Detection levels would be no less than 0 1 mg/kg (ppm) (U.S. Fish and Wildlife Service 1991b).

As part of the alternative. Ojo Amarillo Canyon and Gallegos Canyon would also be sampled monthly for surface flows at their confluence with the San Juan River The parameters to be measured would include flow, total selenium, and dissolved selenium, with a detection level not less than 2 μg/l. From March to October, selenium concentrations in the drainages should not exceed 5 μg/l (U.S. Fish and Wildlife Service 1991b).

4.10.3 DOLORES PROJECT

The Dolores Project is a DOI-sponsored irrigation project located in southwest Colorado in Montezuma and Dolores counties. Construction of the project began in 1977 and was 64% complete as of 1989. The project, when finished, will import water from the Dolores River basin into the San Juan basin for irrigation of three areas. The Montezuma Valley area is centered around Cortez, Colorado, and has historically been irrigated by non-project water supplied by the Montezuma Valley Irrigation Company (MVIC); the Dolores Project will supplement this water and will service 26,300 acres of land. The Dove Creek area is located between Yellowjacket Canyon and Dove Creek; the project will irrigate 27,920 acres in this area, none of which has been irrigated before. The Towoac area is located on the southwest flanks of Sleeping Ute Mountain on the Ute Mountain Ute Reservation and has not been previously irrigated either; 7,500 acres in the area will be irrigated by the Dolores Project In total, the Dolores Project will provide an average of 90,900 acre-feet (about 112 million m^3) of water a year from the Dolores River for irrigation and 8,700 acre-feet (about 10.7 million m^3) for municipal and industrial uses (Butler et al. 1991).

Although the San Juan River is not adjacent to any of the lands to be irrigated, it would eventually receive all of the irrigation return flows from the project Additionally, all aquifers in the project area eventually discharge to the San Juan River or its tributaries (Butler et al. 1991).

As part of the NIWQP, the DOI has initiated a reconnaissance investigation of the Dolores Project area. The results of the reconnaissance investigation are in review and have not yet been published; they should be available in 1994 (Butler personal communication). The reconnaissance investigation was prompted by a desk evaluation that contains valuable background information concerning the project area. A summary of this information follows and is from Butler et al (1991) unless otherwise stated.

The review area for the DOI investigation is larger than the irrigated lands of the Dolores Project alone. The review area includes the McElmo Creek and Mancos River basins, the canyons north and west of the McElmo Creek basin which drain into the San Juan River in Utah via Montezuma Creek, the Dolores

River, and McPhee Reservoir. Though not themselves in the project area, the Dolores River and McPhee reservoir are included because they are the sources of water for the project.

The DOI desk evaluation also includes lands currently irrigated by the Ute Mountain Ute Irrigation Project. This project was not large enough to warrant a separate investigation and was therefore grouped with the Dolores Project, although the two are unrelated The Ute Mountain Ute Irrigation Project is located north of the Mancos River and west of Highway 666, and the review area includes the Mancos River basin downstream of Mesa Verde National Park to its confluence with the San Juan River (Butler et al. 1991).

Of the three sections of land to be irrigated by the Dolores Project, the Montezuma Valley and Towoac areas are each underlain at least in part by Mancos Shale. In addition to selenium and other trace elements associated with the shale, the review area contains major uranium ore deposits; development of these deposits could serve as future contaminant sources.

Within the Dolores Project review area the main economic activity is agriculture and related services. The MVIC currently provides water for the irrigation of about 37,500 acres within Montezuma Valley. About 4,600 acres of non-project land is also irrigated in the upper McElmo Creek basin by the Summit Irrigation District. Between 1987 and 1991, about 8,000 acres in the Yellowjacket and Cahone areas of the Montezuma Valley were brought into irrigation as part of the Dolores Project. The only other land presently irrigated in the review area is a very small area on Ute Mountain Ute land, the majority of the reservation is used for grazing of cattle and sheep.

The only urban center in the review area is Cortez, which in 1990 had a population of 7,284 (U.S. Department of Commerce 1992). The sewage plant at Cortez discharges effluent into McElmo Creek. With the exception of the plant, neither municipal nor industrial effluents are considered to pose significant contaminant hazards to surface water quality. Oil and gas development have historically been important activities in the review area, but the contamination hazards posed by them to surface water quality are unknown.

Metals mining has been extensive in the upper Dolores River basin and could contribute heavy metals to irrigation water. In the 1960s, heavy metal contamination of the Dolores River was discovered at Rico, Colorado, from tailings ponds maintained by the Rico Argentine Mining Company At the time, the company was operating a sulfuric acid plant. Biota sampling efforts determined that almost no aquatic life was present immediately below Rico. Heavy metals pollution has also been cited recently as a fishery limiting factor in the Dolores River below Rico. The CDOW conducted electrofishing surveys of that section in August 1992, November 1984, October 1983, and September 1982. The 1992 survey found no evidence of natural reproduction in trout in the reach, although mottled sculpins were self-sustaining (Japhet, personal communication). Additionally, high concentrations of mercury found in Narraguinnep Reservoir fish are suspected to be the result of high Dolores River mercury levels but have not yet been traced.

Recreation is becoming increasingly important within and adjacent to the review area. Major recreational attractions are found throughout the San Juan basin (Figure 38) (U S. Bureau of Reclamation 1980). Several large year-round resorts are currently being proposed in Colorado in the upper reach of the San Juan River and above Electra Lake in the Animas Basin (Colorado Water Quality Control Division 1992). In 1987 Mesa Verde National Park had 772,183 visitors, and McPhee Reservoir is becoming popular for fishing and boating. As the numbers of visitors increase so do the sewage loads that must be stored and treated. Furthermore, motorized boats are a potential source of PAHs, as they exhaust their combustion products directly into the surface water (Olson 1992).

Irrigation return flows from those areas currently irrigated are poor in quality. Irrigation return flow volume from the MVIC area is approximately 36,800 acre-feet/year (45.4 million m^3/year) If the MVIC diverted its full allocation of water and additionally received 13,700 acre-feet (16.9 million m^3) of water through the Dolores Project, irrigation return flow from the Montezuma Valley area would be about 50,500 acre-feet/year (62 3 million m^3/year) Most of these return flows drain to McElmo Creek, in 1989 the salt load pickup from the McElmo Creek basin was estimated to be 117,900 tons a year Navajo Wash,

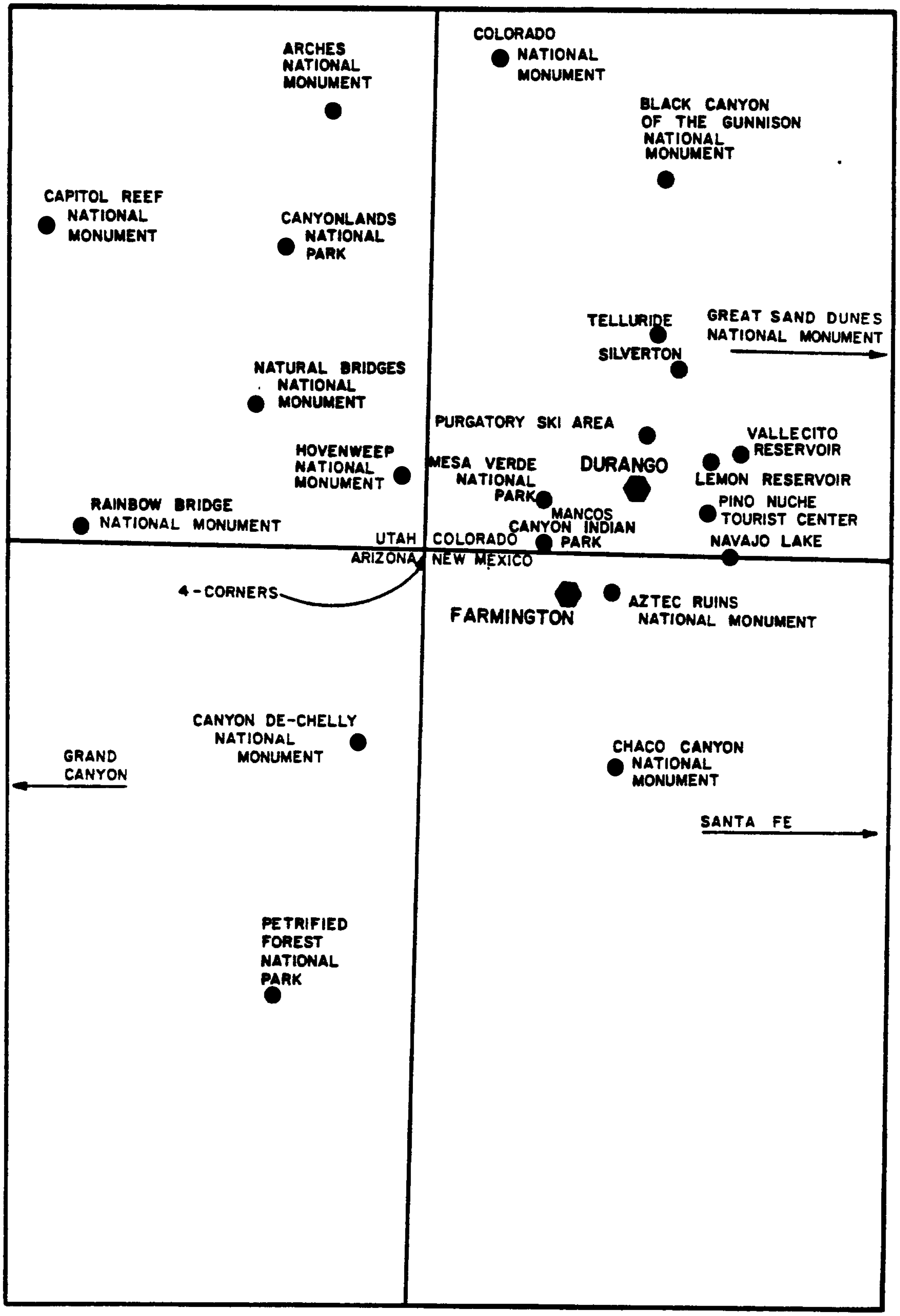


Figure 38. Recreational attractions in the San Juan basin. (Taken from U S Bureau of Reclamation 1980)

which receives return flows from the extreme southern portion of the MVIC area, has also had high TDS concentrations.

The estimated volume of return flow from the Dove Creek area is about 10,920 acre-feet (13.5 million m^3). Most of the runoff should return to the San Juan River via deep percolation rather than surface drainage. Salt loading from the Dove Creek area is predicted to be small, with return flows having 36% less salt load than the water that will be applied to the land. The TDS concentration is expected to be 360 mg/l in return flows from the area, with salts precipitated in the soil.

The predicted quality of return flows from the Towoac area will be far worse than that from the Dove Creek area. The estimated volume of return flows is about 4,930 acre-feet (6.1 million m^3) a year, with a salt load of 30,000 tons per year to enter the San Juan River for the first six years of irrigation and an average of 12,600 tons per year for the following 100 years. The TDS concentration is predicted to increase from 127 mg/l in applied water to 2,470 mg/l in return flows from the Towoac area. Because of its propensity for salt pickup, most of the eastern section of the Towoac area between Aztec and Navajo washes will likely be removed from the Dolores Project and replaced with 2,000 acres of land in the Marble Wash area.

Ute Mountain Ute Irrigation Project was originally designed to irrigate 563 acres but has never irrigated more than 290 acres at one time. In 1988 the project irrigated 205 acres. Surface runoff from the project has not been measured, but the small volume of water supplied to the project results in little if any runoff during a large part of the irrigation season. Because Mancos Shale underlies much of the area, irrigation return flows are expected to be of poor quality.

Most pesticides used in the Montezuma Valley are herbicides, including Tordon® (picloram), Banvel® (dicamba), 2,4-D, and Roundup®. Pesticide usage is expected to increase four-fold with the completion of the Dolores Project, although pesticide levels in return flows are predicted to remain similar to current levels. No pesticide residue analyses have been performed on biota collected from the review area.

In 1988 the BR collected biota samples from the Dolores Project area and analyzed them for selected trace elements. The data indicated that biota in the project area were at a potential risk from selenium and mercury exposure (Tables 63 and 64).

Most of the water quality data that exists for the review area was collected at USGS gaging stations. Data from 1991 and 1992 for these stations can be found in the appendices (Appendices 4a-f), with the exception of Dolores River basin data Dolores River water quality data from USGS stations from 1969-1975 have been summarized separately (Table 65)

Valdez et al. (1992) recently conducted a habitat suitability study for native fish in the Dolores River. As part of the study, water quality data were collected, although selenium was apparently not measured (Table 66). Based on the 1990-91 samples, copper and iron appear to be the only trace elements of concern for fish health. Total copper levels ranged from less than 0.01 to 0.32 mg/l. At a hardness of 50 mg/l, copper concentrations of 0 016 mg/l have been found to be acutely toxic to *Ptychocheilus* spp. The Dolores River has a high water hardness, which may temper copper's toxicity. During spates, though, water hardness generally decreases. The EPA criterion for iron is 1 0 mg/l for the protection of freshwater aquatic life. Twenty-five of 28 water samples taken from the Dolores in 1990-91 exceeded this value. The effect of these elevated levels on San Juan basin water quality as a result of the Dolores Project is unknown.

4.10.4 MANCOS PROJECT

The Mancos Project diverts water from the West Mancos River to Jackson Gulch Reservoir, where water is stored for irrigation of lands in Weber Canyon and in the Mancos River valley to the west of Mesa Verde National Park. The service area is about 13,746 acres. In 1981, a total of 11,683 acres was irrigated. The entire area is underlain by Mancos Shale Nevertheless, preliminary screenings by the DOI Irrigation Drainage Program did not indicate major water quality problems stemming from the project. It

Table 63: Trace element data for fish samples collected by USBR in Dolores Project area in December, 1988

[Concentrations in parts per million, dry weight]

Location	Sample matrix	No. of samples	Range of Concentrations			
			Cadmium	Lead	Mercury	Selenium
McPhee Reservoir	whole body	3	0.04-0.08	0.07-0.21	0.44-1.53	2.4-2.5
	fillet	2	<0.01-0.04	0.07-0.33	1.50-2.70	1.8-2.2
Narraguinnep Reservoir	fillet	3	<0.01-0.01	<0.07-<0.07	4.80-6.40	2.8-3.0
	whole body	1	<0.01	0.10	1.90	2.6
	liver	1	0.13	0.10	2.80	6.6
	kidney	1	0.67	0.10	5.10	8.0
	skin	1	0.10	0.68	0.89	2.1
Dolores River	fillet	1	0.02	<0.07	0.31	3.0
	whole body	2	0.19-0.37	0.10-0.20	0.16-0.26	7.1-8.9

Taken from Butler et al. 1991

Table 64: Trace element data for biota samples collected in Dolores Project area in May and June, 1988

[Concentrations in parts per million, dry weight; WB, whole body; analyses by USFWS]

		No. of	Range of Concentrations				
Location	Sample matrix	samples	Arsenic	Mercury	Selenium	Aluminum	Barium
McPhee Reservoir	Fish, WB	3	<0.10-0.49	0.93-1.50	1.50-2.10	33-130	4.80-9.57
Dolores River	Fish, WB	3	<0.10-0.36	0.27-0.31	3.00-6.10	75-997	5.61-16.4
Narraguinnep Reservoir	Fish, WB	3	<0.10-0.20	0.69-2.60	1.40-2.10	29-1040	3.40-16.0
Totten Reservoir	Fish, WB	3	<0.10-0.40	0.09-0.46	1.40-2.00	67-298	1.70-6.58
Dawson Draw	Fish, WB	7	<0.10-0.20	0.18-0.50	1.10-4.60	160-710	6.11-22.6
	Canada goose liver	3	<0.20-0.20	0.05-0.09	2.90-3.20	3-5	<0.05-0.09
	Mallard liver	3	<0.20-0.20	0.37-1.70	11.0-14.6	4-8	0.10-0.38
	Aq invertebrate	5	1.3-2.4	0.05-0.13	0.93-1.80	784-7,800	59-141
	Algae	4	3.3-5.5	0.02-0.05	0.57-3.40	11,800-23,800	132-271

		No. of	Range of Concentrations				
Location	Sample matrix	samples	Beryllium	Boron	Cadmium	Chromium	Copper
McPhee Reservoir	Fish, WB	3	<0.05-<0.05	<3.0-<3.0	0.04-0.07	2.00-5.40	0.50-3.00
Dolores River	Fish, WB	3	<0.05-<0.05	<3.0-<3.0	0.08-0.40	1.00-6.00	3.60-7.90
Narraguinnep Reservoir	Fish, WB	3	<0.05-<0.05	<3.0-<3.0	0.04-0.15	2.00-5.20	0.90-28.0
Totten Reservoir	Fish, WB	3	<0.05-<0.05	<3.0-<3.0	0.03-0.04	1.00-2.00	1.10-64.6
Dawson Draw	Fish, WB	7	<0.05-<0.05	<3.0-<3.0	0.03-0.38	<1.00-4.40	2.10-5.30
	Canada goose liver	3	<0.05-<0.05	<3.0-<3.0	0.05-0.08	<1.00-1.00	52.7-65.0
	Mallard liver	3	<0.05-<0.05	<3.0-<3.0	0.41-0.95	<1.00-<1.00	67.0-110
	Aq invertebrate	5	<0.05-0.32	<3.0-<3.0	0.08-0.31	3.00-8.00	14.0-95.7
	Algae	4	0.45-0.92	5.0-65	0.15-1.00	10.0-18.0	5.80-16.0

Table 64 (Cont.): Trace element data for biota samples collected in Dolores Project area in May and June, 1988

[Concentrations in parts per million, dry weight; WB, whole body; analyses by USFWS]

Location	Sample matrix	No. of samples	Range of Concentrations				
			Iron	Lead	Magnesium	Manganese	Molybdenum
McPhee Reservoir	Fish, WB	3	102-180	<0.10-0.10	1180-1380	9.9-44.4	<0.50-0.50
Dolores River	Fish, WB	3	101-622	0.10-0.69	933-1300	24.6-35.2	<0.50-<0.50
Narraguinnep Reservoir	Fish, WB	3	79.6-672	<0.10-0.52	1140-1490	3.1-32.3	<0.50-2.00
Totten Reservoir	Fish, WB	3	120-407	<0.10-0.60	758-1810	3.1-13.0	<0.50-0.90
Dawson Draw	Fish, WB	7	160-507	0.20-0.64	1060-1330	23.4-72.4	<0.50-0.60
	Canada goose liver	3	523-1,670	<0.10-0.20	761-819	11.0-18.0	0.90-1.00
	Mallard liver	3	3,070-5,300	0 30-0.56	699-760	17.0-25.7	3.20-7.40
	Aq invertebrate	5	610-5,970	0.57-4.50	1820-2180	229-1880	<0.50-2.00
	Algae	4	11,300-13,100	3.80-12.0	4720-6740	1050-5840	<1.00-2.00

Location	Sample matrix	No. of samples	Range of Concentrations			
			Nickel	Strontium	Vanadium	Zinc
McPhee Reservoir	Fish, WB	3	2.0-3.0	29 2-91.9	<1-<1	47-107
Dolores River	Fish, WB	3	2.0-3.0	30.2-72.6	<1-1	44-109
Narraguinnep Reservoir	Fish, WB	3	2.0-3.0	44.3-97.4	<1-2	41-68
Totten Reservoir	Fish, WB	3	<2.0-2.0	32.3-109	<1-1	55-200
Dawson Draw	Fish, WB	7	2.0-3.0	64 2-83.3	<1-1	31-140
	Canada goose liver	3	<2.0-2.0	0.20-0.57	<1-<1	155-190
	Mallard liver	3	<2.0-2.0	0 40-0.62	<1-<1	109-155
	Aq invertebrate	5	2.0-7.5	45.4-639	1-10	60-96
	Algae	4	6.0-14	90.1-1010	18-28	46-67

Taken from Butler et al. 1991

Table 65: Summary of trace-element and toxic-element concentrations in the Dolores River at Dolores, 1969-75

Constituent	Units	No. of samples	Mean	Maximum	Minimum
Ammonia	mg/l	29	0.046	0.33	0.00
Nitrate	mg/l	29	0.101	0.50	0.00
Cyanide	mg/l	23	0.00	0.00	0.00
Fluoride	mg/l	25	0.26	0.70	0.00
Arsenic	μg/l	25	0.16	4.0	0.0
Boron	μg/l	28	35	180	0
Cadmium	μg/l	24	0.0	0.0	0.0
Chromium	μg/l	25	0.0	0.0	0.0
Copper	μg/l	25	0.0	0.0	0.0
Iron	μg/l	26	152	330	50
Lead	μg/l	25	4.4	67	0.0
Manganese	μg/l	24	2.1	50	0.0
Mercury	μg/l	4	0.125	0.50	0.00
Molybdenum	μg/l	9	0.0	0.0	0.0
Selenium	μg/l	25	0.08	2.0	0.0
Silver	μg/l	7	0.00	0.0	0.0
Zinc	μg/l	26	13.1	140	0.0
Dissolved alpha	pci/l	4	20.7	44.1	8.9
Dissolved beta	pci/l	2	5.6	11.0	0.28

Taken from Butler et al. 1991

Table 66: Water quality data for the Dolores River, 1990 and 1991

Parameter	BIO/WEST 1990	BIO/WEST 1991
Alkalinity as $CaCO_3$ (T), mg/l	92.1-165.5	165-3424
Alkalinity as $CaCO_3$ (Diss), mg/l		62.7-146
Hardness as $CaCO_3$ (Diss), mg/l		139-534
pH Units	7.67-8.45	7.53-8.41
TDS, mg/l	226-6320	2.030-1318
Ammonia as NH_3-N, mg/l	0.10-0.963	<.2-0.61
Nitrate as NO_3-N, mg/l	0.03-1.26	<0.1-1.26
Phosphate as PO_4-P (Ortho), mg/l	<.01-0.044	<.01-0.044
Phosphate as PO_4-P (Total), mg/l	0.01-3.19	0.022-11.5
Sulfate as SO_4, mg/l		100-424
Oil and Grease, mg/l	<.5	< 5-1.8
TSS, mg/l	14-9050	2.080-18600
Aluminum as Al (T), mg/l		6.2-57
Cadmium as Cd (T), mg/l		<.01-0.015
Copper as Cu (T), mg/l	<.01-0.282	<.01-0.320
Iron as Fe (T), mg/l	0.2-32.8	1.8-267
Lead as Pb (T), mg/l	<.01-0.098	<.01-0.36
Silver as Ag (T), mg/l		<.01
Zinc as Zn (T), mg/l	0.02-1.2	0.015-1.2
Aluminum as Al (D), mg/l		<.1
Cadmium as Cd (D), mg/l		<.01
Copper as Cu (D), mg/l	<.01	<.01-0.032

Taken from Valdez et al. 1992

is possible that because the area receives more rainfall than other areas underlain by Mancos Shale, natural leaching has removed a portion of the salts and trace elements (Butler et al 1991).

4.10.5 SOUTHERN UTE INDIAN RESERVATION

Limited water quality sampling on the Southern Ute Indian Reservation in southwestern Colorado has suggested that selenium and other trace elements might be at levels of concern. Hutchinson and Brogden (1976) measured ground and surface water on the reservation and found elevated selenium levels, particularly in groundwater; one groundwater sample had a reported selenium concentration of 3100 μg/l (Appendices 14a-b). The maximum concentration of dissolved selenium in surface water was 30 μg/l. High selenium concentrations in plants and water have reportedly caused the poisoning of humans and livestock on the reservation. Hutchinson and Brogden (1976) also found that water samples from the reservation had arsenic, chloride, TDS, fluoride, iron, magnesium, manganese, nitrogen, and sulfate concentrations exceeding water quality standards.

In April 1993, a monthly water quality sampling program was begun by the Southern Ute Tribe; prior to April 1993, erratic sampling was conducted Samples have been analyzed for metals as well as for basic chemical parameters (Appendix 19) (Southern Ute Indian Tribe 1993). As of August 1993 the only point source polluter on the reservation was a gas well that was being dewatered. Groundwater studies that would be similar in scope to the surface water studies are planned for the near future (Crist, personal communication 1993)

A DOI NIWQP reconnaissance investigation has been conducted in the Pine River Project Area on the Southern Ute Reservation. The report was released in late 1993 but was not available for inclusion in this review.

4.10.6 ANIMAS-LA PLATA PROJECT

The Animas-La Plata Project is a proposed BR multiple-use water resource development that would be located in La Plata and Montezuma counties in Colorado and San Juan County in New Mexico. The project would divert flows of the Animas and La Plata rivers for irrigation, municipal, and industrial uses. It would also partially satisfy water rights claims of the Colorado Ute Indians (Melancon et al. 1979, U.S. Bureau of Reclamation 1992a). Approximately 80% of project lands would be within the La Plata River basin, with 17,650 acres in the basin receiving supplemental irrigation and 37,830 acres receiving full service irrigation. Additionally, approximately 11,600 acres would receive full-service irrigation within the Mancos River basin. All irrigation return flows would eventually discharge to the San Juan River (U.S. Bureau of Reclamation 1992c).

The project was authorized in 1968 by the Colorado River Basin Project Act as part of the CRSP, but it has not yet been developed due to a series of suspensions On October 25, 1991, a final Biological Opinion for the Animas-La Plata Project was issued by Region 6 of the FWS to the Bureau of Reclamation. That opinion found that the project as proposed was likely to jeopardize the continued existence of the Colorado squawfish by reducing the likelihood of both the survival and recovery of the species in the wild. In an appended Conference Opinion, the FWS also found jeopardy by the project on the razorback sucker, which at the time was a candidate species for the Federal endangered species list (Fowler-Propst, personal communication).

The FWS proposed a reasonable and prudent alternative to the project as proposed. That alternative, in the opinion of the FWS, would avoid the likelihood of jeopardy to the Colorado squawfish. With the opinion, only those project features which result in a net annual depletion not exceeding 57,100 acre-feet will be constructed and operated (Yahnke, personal communication)

A Memorandum of Understanding to implement the reasonable and prudent alternative was executed on October 24, 1991. The San Juan River Basin Recovery Implementation Program (Implementation Program) was established by a Cooperative Agreement signed in October 1992 by the

Department of the Interior, the states of New Mexico and Colorado, and the Ute Mountain Ute Indian Tribe, the Southern Ute Indian Tribe, and the Jicarilla Apache Indian Tribe (Fowler-Propst, personal communication).

The purpose of the Implementation Program is to protect and recover endangered fishes in the San Juan River basin while water development proceeds in compliance with all applicable federal and state laws. The seven year research program required by the Animas-La Plata Biological Opinion was incorporated into and now forms the core of the biological and hydrological investigations of the Implementation Program (Fowler-Propst, personal communication).

Since 1968 a number of BR documents have addressed the potential water quality effects of the Animas-La Plata Project and the subsequent impact to aquatic biota The BR completed a Draft Supplement (U S. Bureau of Reclamation 1992a) to the Final Environmental Statement (FES) (U.S. Bureau of Reclamation 1980) in 1992. It should be noted that the Draft Supplement is subject to significant change. The BR has undertaken a major water quality analysis since 1992 that will result in a more complete and accurate description of the impacts of the project

The Supplement describes changes in project effects as a result of design refinements, new information, and additional compliance requirements. The 1980 FES predicted that the Animas, La Plata, Mancos, and San Juan rivers would each experience increases in salinity and trace element loads as a result of the project, a prediction that the Draft Supplement supports. Additionally, irrigation return flows are expected to increase groundwater salinity in the project area (U S Bureau of Reclamation 1992a).

As a result of flow reductions below the proposed Durango Pumping Plant, the native fish populations of the Animas River were predicted by the FES to decline by 10%; this estimate is supported by the Draft Supplement. Since 1980 the BR has determined that a native fishery may exist in the La Plata River and has committed to conducting a study to determine the fishery's extent and composition.

Finally, in 1986 Congress amended existing land certification legislation to require soil investigations on all federal lands where toxic or hazardous irrigation return flows might result. A soils investigation conducted prior to 1992 determined that soils in the project area did not contain toxic levels of trace elements and therefore would not result in toxic return flows (U S. Bureau of Reclamation 1992a).

The potential impacts from the Animas-La Plata Project on San Juan basin water quality are complex because they stem from a number of sources and involve four rivers and two reservoirs. The following discussion combines information from a number of BR documents concerning the impacts (Table 67) (U.S. Bureau of Reclamation 1992a).

As part of the Draft Supplement, soil samples from the project area were analyzed for soluble and total concentrations of 38 trace elements The soluble concentration, or saturation extract, is an approximation of the actual field concentrations that would contribute to irrigation return flows; total concentration indicates the soil's long-term potential for contributing trace elements The total concentrations for all elements tested, with the exception of lithium, were within the common range found in soils of the western U.S. (Table 68) (U.S. Bureau of Reclamation 1992a, U.S. Bureau of Reclamation 1992c). The mean total selenium concentration in the soil samples was 0.20 ppm; the mean concentration for western soils is 0.23 ppm (U S. Bureau of Reclamation 1992a). Mancos Shale occurs to the west of the project area within the Mancos River drainage but is not present within the project area. A narrow strip of Mancos Shale is exposed above the project area, but water samples from the La Plata River and Cherry Creek do not indicate selenium contributions to the project area (U.S. Bureau of Reclamation 1992c).

In contrast to the total concentration analyses, soil saturation analyses suggested that water soluble concentrations of mercury, silver, copper, and selenium were a potential source of water quality problems from the project. Weighted averages of soluble concentrations of the elements within the soil profile indicated that selenium was of the greatest concern (U.S. Bureau of Reclamation 1992a).

The Draft Supplement considered soils to be potential sources of toxic irrigation return flows if soluble selenium concentrations exceeded 15 $\mu g/l$ and total concentrations exceeded 0.3 ppm. Five of 113 soil samples analyzed exceeded these criteria These five samples were from three separate areas (U.S. Bureau of Reclamation 1992a). Most samples with values greater than 15 $\mu g/l$ soluble selenium had low

Table 67: Summary of impacts and comparison of resource/issues described in 1980 FES and 1992 plan, Animas-La Plata Project

Impact/resource	1980 FES	1992 plan	Difference
WATER QUALITY			
Groundwater			
Irrigation return flow	Increased salinity, trace elements - no change	Same	None
Durango Pumping Plant	Not addressed	Monitoring, no effect	None
Streams and Rivers			
Animas	Slight increases in salinity, trace elements	Same	None
La Plata	Slight increases in salinity, trace elements	Same	None
Mancos	Slight increases in salinity, trace elements	Same	None
San Juan	Slight increases in salinity, trace elements	Same	None
Colorado	Salinity at Imperial increased by 17.9 mg/l	Same	None
Reservoirs			
Ridges Basin	Mesotrophic, accumulate metals	Same	None
Southern Ute	Eutrophic, accumulate metals and pesticides	Same	None
SOILS			
Toxic characteristics	Not investigated	Nontoxic	None
ANIMAS RIVER TROUT FISHERY			
Trout biomass/acre (lbs)			
Durango to Purple Cliffs	6.5 to 9.8	65-90	+58 to 80
Purple Cliffs to Bondad	8 5	17	+8 5
Predicted impact trout	None	Reduction in trout biomass	Reduction in biomass
Mitigation	None	Stocking program in Animas River from Purple Cliffs to Bondad, CO	Stocking program in Animas River

Table 67 (Cont): Summary of impacts and comparison of resource/issues described in 1980 FES and 1992 plan, Animas-La Plata Project

Impact/resource	1980 FES	1992 plan	Difference
NATIVE FISHERY			
Animas River	10 percent population reduction	10 percent population reduction	None
La Plata River	Native fishery was not identified	Native fishery may be present	Native fishery may be present
Impact	Undefined	Anticipated reduction in total population	Anticipated reduction in total population
Mitigation	Undefined	Reclamation will conduct a study to determine extent and composition of native fishery, if one is present	
THREATENED AND ENDANGERED SPECIES			
Colorado squawfish			
Status	Endangered	Endangered	None
Biological opinion	No jeopardy	Jeopardy with reasonable and prudent alternative	Jeapardy with reasonable and prudent alternative
Razorback sucker			
Status	Not listed	Endangered	Change in status
Biological opinion	N/A	Jeopardy with reasonable and prudent alternative	Jeopardy with reasonable and prudent alternative

Taken from U S. Bureau of Reclamation 1992a

Table 68: Comparison of element concentrations in baseline data for western states and the Animas-La Plata Project

Element	Western States			Animas-La Plata Project		
Unit of	Geometric		Baseline*	Geometric		Observed
Measure	Mean	Deviation		Mean	Deviation	Range
Al, %	5.8	2	1.5-23	5.0	1.17	3.0-6.6
As, ppm	5.5	1.98	1.2-22	5.8	1.25	1.9-9.6
B, ppm	23	1.99	5.8-91	Not Analyzed		
Ba, ppm	580	1.72	200-1700	569	1.30	210-990
Be, ppm	0.68	2.3	0.13-3.6	1.08	1.38	0.5-2.0
Ca, %	1.8	3.05	0.19-17	2.0	2.45	0.32-16
Ce, ppm	65	1.71	22-190	54	1.15	32-69
Co, ppm	7.1	1.97	1.8-28	8.3	1.19	4-13
Cr, ppm	41	2.19	8.5-200	36	1.31	19-91
Cu, ppm	21	2.07	4.9-90	17	1.45	7-67
Fe, %	2.1	1.95	0.55-8.0	2.0	1.21	0.9-3.8
Ga, ppm	16	1.68	5.7-45	11	1.20	7-16
Hg, ppm	0.046	2.33	0.0085-0.25	Not Calculated		<0.01-0.04
K, %	1.8	0.71	0.38-3.2	1.7	1.18	0.9-2.5
La, ppm	30	1.89	8.4-110	30	1.14	18-41
Li, ppm	22	1.58	8.8-55	27	1.28	16-76
Mg, %	0.74	2.21	0.15-3.6	0.72	1.34	0.31-1.5
Mn, ppm	380	1.98	97-1500	300	1.53	68-870
Mo, ppm	0.85	2.17	0.18-4.0	All values reported as <2.0		
Na, %	0.97	1.95	0.26-3.7	0.68	1.42	0.21-1.5
Nd, ppm	36	1.76	12-110	25.5	1.16	17-35
Ni, ppm	15	2.1	3.4-66	14.2	1.25	7-28
P, %	0.032	2.33	0.0059-0.17	0.045	1.40	0.02-0.09
Pb, ppm	17	1.8	5.2-55	16	1.24	8-22
Sc, ppm	8.2	1.74	2.7-25	6.3	1.23	4-10
Se, ppm	0.23	2.43	0.039-1.4	0.20	1.98	<0.01-1.1
Sr, ppm	200	2.16	43-930	183	1.71	74-520
Ti, %	0.22	1.78	0.069-0.70	0.24	1.21	0.14-0.32
Th, ppm	9.1	1.49	4.1-20	8.5	1.22	5-12
U, ppm	2.5	1.45	1.2-5.3	All values reported as <100		
V, ppm	70	1.95	18-270	58.7	1.21	41-110
Y, ppm	22	1.66	8.0-60	16.6	1.20	9-24
Yb, ppm	2.6	1.63	0.98-6.9	1.7	1.35	1-2
Zn, ppm	55	1.79	17-180	51	1.22	29-92

* Values chosen to represent an expected 95% range (Shacklette & Boerngen 1984). From a suite of randomly selected soils, 95% are expected to occur within +/- two standard deviations. Values in this range are defined as common.

Taken from U.S. Bureau of Reclamation 1992c concentrations of total selenium, indicating that sustained yields of soluble selenium would not occur (U.S. Bureau of Reclamation 1992c).

The Draft Supplement noted that project irrigation would leach some trace elements from the soil and subsequently increase their concentrations in groundwater. The eventual effect of these groundwater concentrations on surface water quality is not discussed in further detail within the Supplement (U.S. Bureau of Reclamation 1992a).

In order to determine baseline levels of trace elements associated with present irrigation return flows in the project area, small drainages, shallow wells, and agricultural drains were sampled (Table 69). The results indicated that selenium, silver, and mercury occasionally exceeded water quality standards. In order to further investigate potential selenium problems, additional irrigation drainage toxicity studies are planned for full-service irrigation lands (U.S. Bureau of Reclamation 1992a).

The Draft Supplement has predicted that the concentrations of trace elements in return flows would not increase adverse impacts to the environment beyond current conditions. According to the Supplement, irrigation return flows are expected by the BR to be similar in composition to return flows on lands that are currently irrigated in the project area. Certain lands that are currently irrigated with La Plata River water would be irrigated instead by Ridges Basin Reservoir water, which is expected to be of good quality. Dryland soils that would be irrigated would gradually decrease in salinity and trace element concentrations until an equilibrium was reached with the applied water. Areas identified as likely to cause toxic irrigation return flows would be removed from the project and additional land would be found to replace it (U.S. Bureau of Reclamation 1992a).

Sampling of the La Plata River in 1992 by the BR indicated that zinc, cadmium, copper, manganese, selenium, and mercury were present at measurable levels. In New Mexico, mercury levels in the river range from less than 0.2 μg/l to 0.25 μg/l; the detection limit of 0 2 is higher than both the New Mexico standard of 0.012 μg/l and the Colorado standard of 0.010 μg/l (U.S. Bureau of Reclamation 1992a). Soil mercury concentrations are low, suggesting that the waterborne mercury must be from another source such as deeper groundwater brought up by abandoned gas wells. Because mercury soil levels are not high, irrigation return flows should not increase the river's mercury load (U.S. Bureau of Reclamation 1992b).

In at least one stretch of the river selenium concentrations reach levels greater than 5 μg/l when river flow is composed primarily of irrigation returns However, fish samples from shallow pools where waterborne selenium concentrations were 5-11 μg/l did not have selenium tissue levels greater than 3 ppm wet weight. According to the BR, these fish samples represent long-term biomagnification potential from existing irrigation return flows, and these current baseflow water quality conditions are not expected to change with project development (U.S. Bureau of Reclamation 1992a) No significant flow sources (greater than 0.1 ft^3/sec) of selenium have been found in the La Plata River basin (U.S Bureau of Reclamation 1992c).

The flow of the La Plata River would, under project development, continue to be composed of irrigation returns during the irrigation season and the river would be the main recipient of irrigation return flows from the project. Although selenium and mercury concentrations are not expected to increase in the river, base flows would increase and loading of the elements would therefore also increase. The project is expected to increase annual flow-weighted salinity of the La Plata River from 845 to 2,530 mg/l (U S. Bureau of Reclamation 1992b).

In February 1992, the FWS collected fish samples from the La Plata River basin in Colorado and New Mexico. In total, there were eight collection sites on the La Plata, one on Cherry Creek and two on Long Hollow Creek. The results of the sampling effort have been compiled (Table 70); wherever there is a blank field the result was less than the NCBP 85th percentile concentration and indicates, according to the BR, no contamination. The metal in the samples that most frequently exceeded the 85th percentile concentration was copper, with 15 of 30 samples from the La Plata River exhibiting levels greater than or equal to the baseline. Copper was present in high concentrations in soils and soil extracts but was generally below detection levels in the river. In nine of the 30 samples cadmium also exceeded the NCBP

Table 69: Animas-La Plata Project, trace element samples collected during March 1992

Area	Site No.	Site-Type	E.C. (uS/cm)	Contaminants of concern (µg/L) Cu	Hg	Se	Ag	Zn	Mn	Other
Valley lands	83	Deep well	2230	9	<0.20	7	<0.2	40	<50	
Valley lands	90	Deep well	1765	15	<0.20	7	0.4	<10	<50	
Valley lands	115	Drain	1440	<5	<0.20	4	<0.2	15	<50	
Valley lands	111	Allen Arroyo	3380	<5	0.35	10	0.4	<10	333	
Valley lands	102	Drain ditch	1836	<5	<0.20	5	<0.2	<10	<50	
Valley lands	82	Well	1506	<5	<0.20	<2	<0.2	50	<50	
Valley lands	81	Well	1534	13	<0.20	<2	<0.2	10	490	
2nd terrace	98	Deep well	3230	27	<0.20	<2	0.2	170	160	
2nd terrace	110	Allen Arroyo	2410	<5	0.25	<2	0.2	<10	88	
2nd terrace	97	Well		15	<0.20	3	0.2	950	<50	
2nd terrace	92	Well	2560	<5	<0.20	<2	0.3	80	210	
2nd terrace	99	Well	4320	12	<0.20	<2	0 4	60	33,800	Fe=148,000
Dry Side	96	Cherry Creek	1030	5	<0.20	<2	<0 2	<10	<50	
Dry Side	141	Deep well	643	<5	0.20	2	<0.1	34	230	
Dry Side	89	Deep well	1250	<5	<0.20	<2	<0.2	<10	230	
Dry Side	100	Dug well	274	<5	<0.20	<2	<0.2	<10	50	
Dry Side	140	San Juan Arroyo	6100	<5	0.30	10.5	0.3	29	190	
Dry Side	137	San Juan Arroyo	7280	<5	0.30	5	2.1	<10	110	
Dry Side	142	Seeps	888	<5	0.30	<2	<0.1	20	210	
Eastside terrace	91	Well	2270	<5	<0.20	<2	<0.2	480	<50	
Red Mesa	86	Deep well	2910	76	<0.20	4	0.65	45	290	
Red Mesa	84	Deep well	565	<5	<0.20	<2	<0.2	1170	<50	Fe=1370
Red Mesa	80	Deep well	548	458	<0.20	<2	<0.2	230	<50	
Red Mesa	88	Dug well	740	<5	<0.20	4	<0.2	30	<50	
Red Mesa	85	Marvel Spring	438	<5	<0.20	2	<0.2	<10	<50	
Red Mesa	120	Seep	3020	8	0 35	<2	0.6	<10	995	
Red Mesa	119	Seep	467	10	<0.20	<2	<0 2	<10	<50	
River - source water	132	Animas River	350	<5	<0 20	8	<0.1	<10	190	Pb=17
River - source water	133	Animas River	344	6	0.25	11	0.1	50	170	Pb=17
River - source water	134	Animas River	331	5	<0 20	9	<0.1	50	140	Pb=16
River - source water	135	Animas River	341	5	<0.20	6	0 1	54	60	Pb=10
River - source water	136	Animas River	303	6	<0.20	6	<0.1	30	110	Pb=14
River - Red Mesa + Dry Side	124	Cherry Creek	796	<5	<0 20	5	<0 2	<10	92	
River - above project	126	La Plata River	135	<5	<0.20	<2	<0.2	<10	<50	
River - Red Mesa + Dry Side	125	La Plata River	160	<5	<0.20	5	<0 2	<10	<50	
River - Red Mesa + Dry Side	123	La Plata River	371	<5	<0.20	<2	<0.2	<10	<50	
River - Red Mesa + Dry Side	95	La Plata River	803	<5	<0.20	<2	<0.2	<10	<50	
River - Red Mesa + Dry Side	118	La Plata River	853	10	<0.20	<2	<0 2	19	236	Cd=0.4
River - Red Mesa + Dry Side	116	La Plata River	886	<5	0.25	5	<0 2	11	184	Cd=0.3
Valley - River	101	La Plata River	1326	6	<0.20	5	<0 2	<13	90	
Valley - River	114	La Plata River	969	<5	<0.20	5	<0 2	13	159	
Valley - River	113	La Plata River	1140	<5	0.20	<2	<0.2	10	139	Cd=0.35
Valley - River	112	La Plata River	1109	<5	0.20	5	<0.2	11	186	
Valley - River	109	La Plata River	1182	<5	0.20	<2	<0.2	10	193	Cr=12; Pb=6
River - Red Mesa	122	Long Hollow	922	<5	<0.20	10	<0.2	<10	<50	Cr=6; Ni=7
River - Red Mesa	121	Long Hollow	804	<5	<0.20	<2	0.2	11	187	As=15; Cr=8
River - Red Mesa	117	Long Hollow	893	<5	<0.20	<2	<0.2	20	161	As=12

Taken from U.S. Bureau of Reclamation 1992b

Table 70: Animas-La Plata Project, fish toxicant data ($\mu g/g$ wet weight)

Species	Site*	As	Cd	Cu	Hg	Pb	Se	Zn
Brook trout	1			1.50				
Rainbow trout	1		0.062	3.10				35.9
Mottled sculpin	1			2.10		0.250		
Brown trout	2			3.90		0.360		
Brook trout	2			1.70				
Mottled sculpin	2							
Bluehead sucker	3		0.110	1.00		0.260	0.90	
Brook trout	4			1.70				
Bluehead sucker	4	0.470		3.20		0.340		
Speckled dace	4			2.10			0.97	46.8
Flannelmouth sucker	5						0.83	
Bluehead sucker	5			1.00				
Speckled dace	5						2.20	44.1
Fathead minnow	6		0.079	1.90			0.92	
Speckled dace	6		0.089				1.80	
Fathead minnow	7							
Speckled dace	8						1.90	
Flannelmouth sucker	8						0.78	
Fathead minnow	8						0.97	
Brown trout	8			4.60	0.250		1.50	
Brown trout (fillet)	8				0.250		0.73	
Brown trout (liver/kidney)	8		0.230	364.00	0.390		46.00	
Flannelmouth sucker	9					0.340	0.91	
Bluehead sucker	9						0.69	
Speckled dace	9						1.80	37.6
Speckled dace	10		0.140	1.00			1.30	49.5
Bluehead sucker	10	0.300	0.150					
Speckled dace	11		0.050				2.70	43.6
Bluehead sucker	11						2.20	
Fathead minnow	11		0.053	1.00			2.50	34.6
Baseline* - 1984		0.270	0.050	1.00	0.170	0.220	0.73	34.2

* See list below for site locations

** Baseline is taken from the National Contaminant Biomonitoring Program, described as the 85th percentile concentration in Schmitt and Brumbaugh (1990)

Animas-La Plata Fish Collection Sites

Site	Stream	Location
1	La Plata River	At Mayday
2	La Plata River	In Hesperus below Bigstick Diversion
3	Cherry Creek	At Lamour Ranch
4	La Plata River	1 mile downstream from Mormon Reservoir
5	La Plata River	1/4 mile upstream from State Line
6	La Plata River	1.5 miles south of La Plata, New Mexico
7	La Plata River	1 mile south of Jackson Lake on New Mexico State land
8	La Plata River	1/4 mile downstream from mouth of Long Hollow Creek
9	Long Hollow Creek	1/4 mile upstream from mouth
10	La Plata River	Below confluence with Cherry Creek
11	Long Hollow Creek	3 miles upstream from mouth

Taken from U.S. Bureau of Reclamation 1992b baseline concentration, and three samples taken from two fish on the La Plata River, immediately downstream from the mouth of Long Hollow Creek, had mercury concentrations greater than the NCBP baseline concentration (U.S. Bureau of Reclamation 1992b)

The main source of concern for the Animas River is the proposed Durango Pumping Plant, which is on the site of a Uranium Mill Tailings Remedial Action (UMTRA) Project. The UMTRA Project has been involved in stripping uranium mill tailings from the site of an inactive mill just south of Durango. In the early 1960s high levels of radioactivity were reported downstream of Durango, but after the mill closed in 1963 radioactivity in the river decreased almost immediately (U.S Bureau of Reclamation 1980). Removal of the tailings piles at the mill site has apparently had no further effect on river radioactivity levels (Appendix 20a) (U.S. Bureau of Reclamation 1992b).

Because the proposed Durango Pumping Plant is at the site of the mill tailings, the Department of Energy (DOE) and the BR have conducted groundwater sampling at the UMTRA site. From 1982-1991, the DOE sampled groundwater at two wells at the site (Appendix 20b), and from 1990-1992 the BR sampled nine additional wells at the site (Appendices 20c-d). Groundwater modeling studies suggest that water generated during construction of the pumping plant would not contain hazardous levels of radioactivity (U.S. Bureau of Reclamation 1992b).

Groundwater at the pumping plant site has been found to contain potentially toxic concentrations of cadmium, copper, zinc, iron, and manganese Under a worse case projection, several of these elements could exceed water quality standards, but if the groundwater were discharged to the river there would be no measurable change in the surface water quality. The parameter exceeding its standard by the largest amount in the groundwater is sulfate, but no adverse impacts to Animas River water quality are expected because the groundwater would be treated to specified permit requirements (U.S. Bureau of Reclamation 1992b).

The U.S. Bureau of Reclamation (1992b) has predicted that any increases in contaminants concentrations in the San Juan River would be a result of water depletions, but that the dilution factor of the San Juan River would render contaminants in Mancos and La Plata river inflows negligible. During low-flow conditions, when the San Juan River has its greatest trace element concentrations, the Animas-La Plata Project should cause selenium increases in the river of less than 1 μg/l, with river concentrations not exceeding 5 μg/l (U.S. Bureau of Reclamation 1992b). In general, the BR expects project irrigation return flows to be very similar to existing return flows in quality because most landforms to be irrigated are largely being irrigated now. Because the La Plata River is currently composed of return flows for much of the year, the BR expects this baseflow quality to represent project conditions However, the quantity of return flows will be larger, resulting in higher loading from these streams to the San Juan River (Yahnke, personal communication).

Two impoundments, Ridges Basin and Southern Ute reservoirs, would be constructed as part of the Animas-La Plata Project Water quality in the reservoirs is difficult to predict Soil samples collected from the Ridges Basin site contained soluble selenium concentrations of about 10 μg/l, soil samples from the Southern Ute site did not indicate soluble selenium Selenium concentrations are expected to range from less than 1 μg/l to 3 μg/l in both reservoirs, assuming that the selenium would become immobilized in insoluble mineral forms in the reservoir sediment Fish tissue samples from Ridgway Reservoir, which is 80 miles northwest of the proposed Ridges Basin Dam site, were generally below 0.2 ppm; the Ridges Basin Dam site was judged by the BR to be similar enough to Ridgway Reservoir that mercury levels in the two would probably be equivalent. Mercury levels in Southern Ute Reservoir were predicted to be potentially high because of the abundance of organic nutrients The BR has concluded that mercury levels will not cause any adverse effects to fish in either of the reservoirs (U.S. Bureau of Reclamation 1992a).

In response to comments received from the FWS and EPA, the BR has initiated a major environmental data collection program to address concerns raised regarding potential ecological impacts associated with the Animas-La Plata Project. As part of its additional research, the BR has recently collected fish and sediment samples from the project area. Fish samples, largely whole body, were collected from the Animas River and several of its tributaries in April, May, June, and July 1992. The preliminary results of trace element analysis conducted on the samples are listed within the appendices (Appendices 21a-b) (U.S. Bureau of Reclamation 1993a). Bottom sediment samples were also collected from the project area in March, July, August, and December 1992 (Appendices 22a-b) (U.S. Bureau of Reclamation 1993c).

4.11 GRAZING AND LOGGING

Although irrigation has received far more attention as a contaminants source, grazing is the predominant land use activity in the San Juan River basin. Only 1.6% of available land in the basin, or about 65,000 km^2, is irrigated, whereas over 75% of the basin is used for grazing. Grazed lands include both rangeland and timberland; commercial timberlands, which make up the next largest use of basin land, are not grazed (Melancon 1979). In general, grazing occurs at lower elevation lands, and lands at higher elevations are used for timber production (Stone et al. 1983).

Grazing can induce erosion, which in turn leads to increased sediment loads in surface waters (Joseph and Sinning 1987). Lusby (1970) conducted a study of the hydrologic effects of grazing on a study area near Grand Junction, Colorado, that was underlain entirely by Mancos Shale. After the initial two years of study, ungrazed watersheds in the study area averaged 30% less runoff and 45% less sediment than grazed watersheds.

Grazing can also lead to increased fecal coliform levels in surface water (Joseph and Sinning 1987). Two exceedances of fecal coliform standards in 1991 at Shiprock were a likely result of cattle grazing in the Navajo Nation (New Mexico Department of the Environment 1991).

Logging generally increases temperature and turbidity in affected streams. During periods of clear cutting, spawning areas may be silted in completely by high sediment loads. In the San Juan basin, almost all logging occurs where streams are naturally clear and cold (Joseph and Sinning 1977).

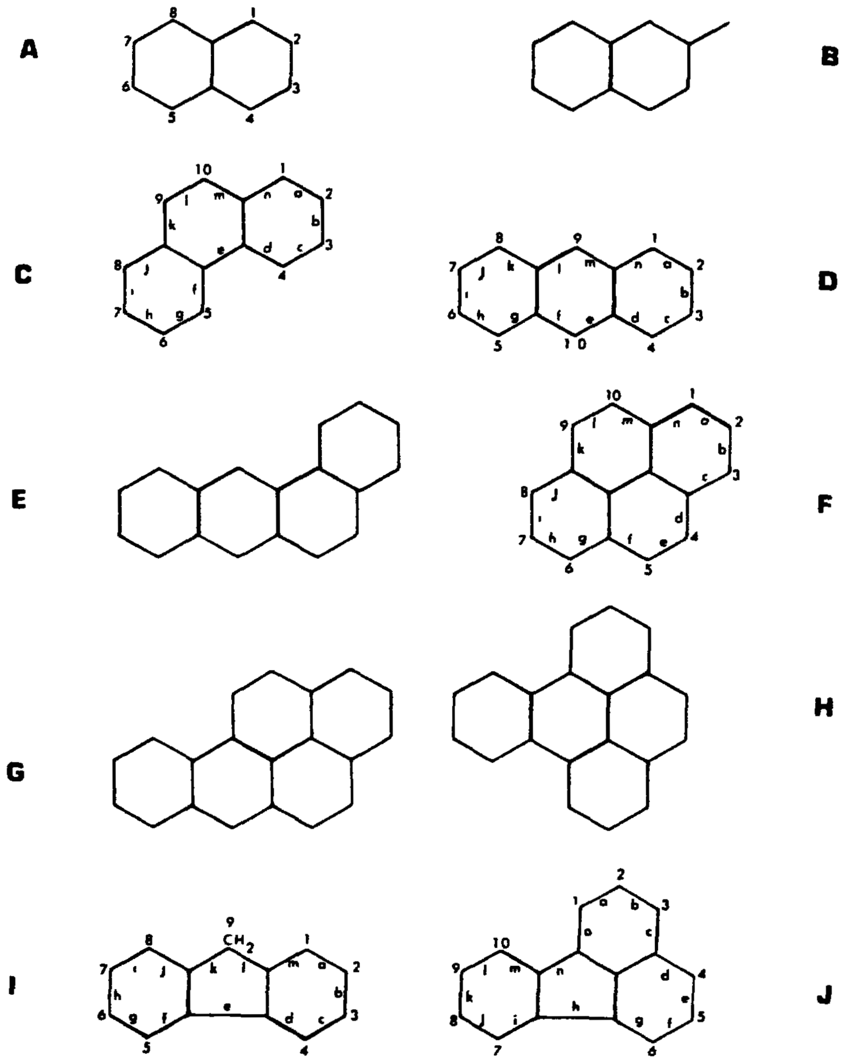
Forest lands in the northeast section of the San Juan basin were over-logged and over-grazed in the early 20th century, and the resulting erosion has persisted through today (New Mexico Water Quality Control Commission 1976). Navajo Forest Products Industries has been logging the western part of the basin along Lukachukai Mountain Range; as of 1976, the Northern Arizona Council of Governments had planned to contract with the Navajo Tribe to study forest and agricultural runoff in the basin (New Mexico Water Quality Control Commission 1976). No other studies of grazing or timber have apparently been conducted or planned.

4.12 MINERAL EXTRACTION, PROCESSING, AND USE

By virtue of its geology, the San Juan basin contains major deposits of oil, natural gas, coal, uranium, and non-fuel metals. Income from mineral production in the basin is far greater than that from agriculture, which dominated the economy until around 1945 (Goetz and Abeyta 1987). The extraction, processing, and use of minerals are potentially significant sources of surface water pollution in the basin. Among the major pollution problems, coal mining and combustion are sources of selenium, uranium mining and milling produce radionuclides, non-fuel metals mining leads to heavy metal pollution; and natural gas, oil, and coal are all sources of PAHs. Each mineral resource will be discussed in turn, but background information on PAHs will be provided first.

4.12.1 POLYCYCLIC AROMATIC HYDROCARBONS

Polycyclic aromatic hydrocarbons (PAHs), also referred to as polynuclear aromatic hydrocarbons (PNAs), are a large group of natural and anthropogenic hydrocarbon compounds arranged in two or more fused benzene rings (Niimi and Palazzo 1986, Blanchard 1991, Menzie et al. 1992). As examples, ring structures of representative PAHs are shown (Figure 39) (Neff 1979). High incidences of



A, naphthalene; B, 2-methylnaphthalene; C, phenanthrene; D, anthracene; E, benz[a]anthracene; F, pyrene; G, benzo[a]pyrene; H, benzo[e]pyrene; I, fluorene; J, fluoranthene.

Figure 39. Ring structures of representative polycyclic aromatic hydrocarbons.
(Modified from Neff 1979)

diseases and pathological anomalies have been observed in fish collected from areas with high PAH levels (Baumann et al. 1982, Niimi and Palazzo 1986). The EPA has identified 16 PAHs as high-priority pollutants (Table 71) (Menzie et al. 1992, Petty et al. 1992).

PAHs may be formed in three ways: high temperature pyrolysis of hydrocarbons, low to moderate temperature diagenesis of sedimentary organic material to form fossil fuels, and direct biosynthesis by microbes and plants (Harrison et al. 1975, Neff 1979, National Research Council of Canada 1983). Anthropogenic sources of PAHs include but are not limited to the combustion of fossil fuels, oil refinery operations, gas production from petroleum, waste incineration, coal gasification and liquification, petroleum cracking, and the production of coke, carbon black, coal tar pitch, and creosote (Neff 1979, Josephson 1981, McVeety and Hites 1988). The majority of environmental PAHs are emitted from fossil fuel combustion processes; the National Research Council of Canada (1983) has compiled a list of the PAH emissions from some such processes (Table 72). Within the San Juan basin the extensive oil, natural gas, and coal operations provide numerous sources for PAH pollution.

Both industrial and domestic wastewater may contain PAHs and as such represent significant point sources of surface water PAH contamination. PAH content normally increases in proportion to the industrial contribution to the wastewater, with industries such as oil refineries contributing some of the highest PAH loads. Domestic sewage, such as raw sewage and storm sewer runoff, may also contain PAHs (Neff 1979).

A number of transport mechanisms work to make PAHs ubiquitous in the terrestrial and aquatic environment (Niimi and Palazzo 1986). The most significant mode of transport is probably atmospheric. When PAHs are adsorbed onto airborne particulate matter such as soot or fly ash produced during the burning of fuels, they can be transported great distances by winds; the distance is a function of the aerosols' diameter. Runoff, conversely, has a short-range effect, transporting PAHs in surface water on the order of 100 km (McVeety and Hites 1988).

PAH compounds settle in soil where they may either be absorbed by microorganisms or plants or may be decomposed by bacteria. Soil contains natural background levels of PAH, which is likely a result of PAH production by plants and microorganisms For reference, the concentrations of several PAHs in various soils are listed (Table 73) (Archer et al. 1979).

In general, most of the environmental PAH load remains near to point sources, with PAH concentrations decreasing logarithmically with distance from the source (Neff 1979). The majority of environmental PAHs are localized in rivers, estuaries, and coastal marine waters, where PAHs are largely adsorbed to aquatic sediments with a small fraction remaining dissolved (Neff 1979, McVeety and Hites 1988). Reference concentrations of total PAHs in water are given (Table 74) (Archer et al. 1979).

Because of their high molecular weight and low polarity, PAHs are relatively insoluble in water (Table 75) (Harrison et al. 1975, National Research Council of Canada 1983) PAHs are normally found in water in association with sediment, either suspended or deposited (Archer et al 1979, National Research Council of Canada 1983). PAHs may adsorb to either inorganic or organic materials, but they are more often found in association with organic particles (National Research Council of Canada 1983). Adsorption to particulate matter, followed by sedimentation, is the primary mechanism by which high molecular-weight PAHs are removed from the water column. In the absence of large volumes of suspended sediment, low molecular-weight PAHs are apparently removed largely through volatilization It has been estimated that as much as 50% of benzo(a)pyrene (B(a)P) and other high molecular-weight PAHs that enter the water column are eventually incorporated into bottom sediment (Neff 1979).

PAHs in sediment are often found in concentrations 1000 or more times greater than in the water column. When incorporated into anoxic sediments, they may persist for very long, if not geologic, times (Neff 1979). Within aquatic ecosystems, PAH concentrations are generally highest in sediments, intermediate in aquatic biota, and lowest in the water column (Neff 1979, National Research Council of Canada 1983).

When adsorbed to inorganic rather than organic substances, PAHs are bound by weak forces and can be released through biological activity and dissolution. This re-mobilization is accelerated by

Table 71: EPA priority pollutant PAHs

Acenaphthene	Chrysene
Acenaphthalene	Dibenz(a,h)anthracene
Anthracene	Fluoranthene
Benz(a)anthracene	Fluorene
Benzo(b)fluoranthene	Indeno(1,2,3-c,d)pyrene
Benzo(g,h,i)perylene	Naphthalene
Benzo(k)fluoranthene	Phenanthrene
Benzo(a)pyrene	Pyrene

Taken from Petty et al. 1992

Table 72: Emission factors for benzo[a]pyrene and total PAHs. Units are μg/kg unless otherwise stated.

Source Type	Benzo[a]pyrene Typical	Benzo[a]pyrene Range	Total PAH Typical	Total PAH Range
Fuel Combustion (stationary sources)				
Utilities				
Pulverized coal-fired powerplants	1.6	1.1-2.7	19	0.5-32
Industrial				
Coal-fired boilers	0.9		41	
Oil-fired boilers	1.1		23	5.3-100
Commercial				
Oil-fired boilers	40		820	
Gas-fired intermediate boilers	10			490-1100
Residential				
Fuelwood				
Fireplace (green pine)			36,000	
Baffled woodstove (green pine)			37,000	
Non-baffled woodstove (green pine)			32,000	
Coal furnace	1500		60,000	1,000-1,200,000
Oil furnace				
30 kw	2.2	2.0-4.4	10,000	0.9-21.6
7.5 kw				900-21,600
Transportation				
Gasoline-powered cars				
No catalyst	1.7 μg/km	0.18-3.3 μg/km		
(cold start)	3.2 μg/km			
(hot start)	0.5 μg/km			
Catalyst	0.04 μg/km	0.02-0.07 μg/km		
Diesel-powered cars	1.7 μg/km			
(cold start)	2.4 μg/km			
(hot start)	1.1 μg/km			

Modified from National Research Council of Canada 1983

Table 73: Concentrations of PAHs in various soils

	All concentrations are in μg/kg		
Soil source	Benzo(a)pyrene	Chrysene	Benz(a)anthracene
Forest	<1300	not available	5-206
Nonindustrial	0-127	not available	not available
Towns and vicinities	0-939	not available	not available
Soil near traffic	<2000	not available	1500
Near oil refinery	200,000	not available	not available
Near airfield	785	not available	not available
Polluted by coal tar pitch	650,000	600,000	2,500,000

Taken from Archer et al. 1979, after Andelman and Suess 1970

Table 74: Carcinogenic PAH concentrations in water sources

Source	mg/cubic meter
Groundwater	0.001-0.1
Treated river and lake water	0.01-0.025
Surface water	0.025-0.100
Surface water, strongly contaminated	>0.100

Taken from Archer et al. 1979, after International Agency for Research on Cancer 1973

Table 75: Solubility of some PAHs in water (25 C)

Compound Name	Solubility* µg/l	Compound Name	Solubility* µg/l
Chrysene	1.8	2-Methylanthracene	21.3
	2		24.2
	6		28.8
	6	Phenanthrene	994
	1.9		1002
Naphthalene	approx 1.5		1070
Benz[a]anthracene	9.4		1151
	10		1180
	10		1290
	14		1600
	11.4		1782
Benzo[a]pyrene	0.2	1-Methylphenanthrene	269
	0.5	4,5-Dimethylphenanthrene	1100
	6.1	Fluoranthene	206
Benzo[e]pyrene	approx 4		236
Perylene	0.4		240
Dibenz[a,c]anthracene	approx 0.6		260
Anthracene	30		265
	41		265
	41.3	Pyrene	129
	44.3		132
	44.6		135
	73		171
	75		175
	75		
	57		

* Multiple values for a given compound represent variations between study results

Modified from National Research Council of Canada 1983 disruption of sediment layers by natural or anthropogenic activities, or when sediments are highly contaminated with PAHs (Neff 1979, National Research Council of Canada 1983). Upon re-mobilization, PAHs become available for uptake by aquatic biota.

PAHs can be permanently removed from the aquatic environment through volatilization from the water surface, photooxidation, chemical oxidation, microbial metabolism, and metabolism by higher metazoans (Neff 1979). Eiceman (1987), noting contamination of groundwater by PAHs at several locations within the U.S., suggests that PAHs are long-lived in aquatic systems and that normal mechanisms of removal may not work efficiently. In general, groundwater PAH concentrations are lower than surface water concentrations because groundwater is filtered as it flows through soil matrices, with PAHs adsorbing to organic soil particles (Menzie et al. 1992).

Aquatic organisms are probably able to accumulate PAHs from water, food, and sediment, but accumulation from water is considered to be by far the most efficient route (Neff 1979, Niimi and Palazzo 1986). Although accumulation of PAHs from sediment is possible in bottom-dwelling species such as bullheads, this route of uptake may be largely a result of PAH desorption from sediment particles into interstitial water (Neff 1979, Niimi and Palazzo 1986). Only in filter-feeding bivalves is uptake from food sources apparently significant (National Research Council of Canada 1983).

The method of PAH uptake varies according to an organism's complexity. Plants, invertebrates, and lower-level vertebrates probably acquire PAHs directly through the integument. In fish PAHs may be transferred from water to blood via the gills and subsequently from blood to tissues. PAHs may also be assimilated from ingested material through the gut (National Research Council of Canada 1983).

Because PAHs are strongly hydrophobic as well as lipophilic, they are readily accumulated in tissue through the process of water-lipid partitioning (Neff 1979, National Research Council of Canada 1983). In general, as PAHs increase in molecular weight they become less soluble in water and therefore tend to bioaccumulate to greater levels (National Research Council of Canada 1983).

Aquatic organisms can apparently release PAHs quickly. The method of release may be either passive or active, the latter involving the metabolic transformation of PAH to polar, water-soluble metabolites (Neff 1979). The highest rates of metabolism have been detected in fish (National Research Council of Canada 1983). Even those species that are unable to metabolize PAHs can generally release the compounds rapidly when no longer in a contaminated environment. Because PAHs are not readily absorbed from food, nor are they resistant to metabolism or excretion, the potential of biomagnification up the food chain is low (Neff 1979).

Once assimilated, PAHs or their metabolites may cause adverse effects in organisms. PAHs may bind to lipophilic sites in a cell and interfere with cellular processes, or the more hydrophilic, reactive, and electrophilic metabolites may bind covalently to cellular structures and cause long-term damage (Neff 1979, Josephson 1981, Geochemical and Environmental Research Group 1990). Because of their greater reactivity and solubility, metabolites may be more acutely toxic than their parent compounds (Neff 1979) Metabolism of PAHs within organisms by mixed-function oxidases (MFOs) can be rapid, resulting in only trace concentrations of a parent compound directly after high-level exposure to it (Geochemical and Environmental Research Group 1990).

PAHs and their metabolites may be acutely toxic, mutagenic, carcinogenic, or teratogenic (National Research Council of Canada 1983). Studies have indicated that compounds such as naphthalene, phenanthrene, and other lower-molecular weight compounds usually have acutely toxic effects, whereas heavier PAHs such as B(a)P are carcinogenic (National Research Council of Canada 1983, Blanchard 1991). Specifically, B(a)P has been shown to transform into a carcinogenic metabolite in a culture of human mammary epithelial cells (Josephson 1984). Because there is strong evidence of B(a)P's carcinogenicity and naphthalene's acute toxicity, these two compounds and their metabolites are the focus of most PAH studies (Niimi and Palazzo 1986) Exposure of an organism to environmental PAHs is determined by testing bile for both parent compounds and metabolites High Performance Liquid Chromatography (HPLC) with fluorescence detection is generally the method of detection used (Geochemical and Environmental Research Group 1990).

Studies suggest that only the most heavily-polluted environments cause significant sublethal responses in fish. Environmental concentrations of 1-50 ppb have elicited responses in sensitive organisms (Table 76); these concentrations are rarely found in the water column but are found in polluted sediments (Neff 1979). Tissue concentrations of PAHs and their metabolites are generally at the μg/g (ppm) level in heavily polluted environments and in the ng/g (ppb) range in relatively unpolluted areas (National Research Council of Canada 1983, Niimi and Palazzo 1986). The accepted normal range of naphthalene in fish bile is less than 10,000 ng/g; for phenanthrene the normal range is less than 3,000 ng/g. Normal B(a)P residues in bile range from 67-210 ng/g (Blanchard 1991). PAH levels can vary significantly within a fish, depending on such factors as when it last ate or if it had been recently moved from one location to another (Baumann 1990).

Although no studies have unequivocally linked PAH contamination to fish disease, high incidences of tumors and other abnormalities have been documented in areas of PAH contamination. For instance, in several areas of PAH pollution bullheads have had a high rate of deformed barbels. High incidences of eye cataracts and blindness have also been documented in fish species exposed to sediment contaminated with PAHs. In 1989, a histopathology workgroup under the Society for Environmental Toxicology and Chemistry recommended that open ulcers on the skin or lips of fish serve as a biomarker of PAH contamination. Researchers believe that such ulcers result when normally harmless fungi and bacteria are able to invade as a result of a chemically-caused immune system disfunction in a fish (Baumann 1990).

PAH studies of fish within the San Juan River basin have been limited. As discussed in the DISEASE section (4.1.2), bile from nine fish from the lower Animas River have been sampled by the CDOW and the BR for exposure to PAHs. Four of the fish had no external signs of disease; five had open sores or lesions. When tested, all five fish with lesions and two without showed evidence of exposure to PAHs (Japhet 1993). The samples were tested for naphthalene, phenanthrene, and B(a)P biliary metabolite equivalents (Table 77) (McDonald 1992).

According to Susanne McDonald of the Geochemical Environmental Research Group (GERG), all samples except J6124 and J6125 showed evidence of PAH exposure on the basis of the summed metabolite equivalents for the three PAHs. Samples J6128 and J6129 exhibited significantly elevated metabolite equivalents for all three PAHs. McDonald (1992) notes that naphthalene and phenanthrene biliary metabolites serve as indicators of PAH exposure but are not themselves particularly toxic or carcinogenic, whereas B(a)P metabolites are at low levels but are carcinogenic, being typically associated with anthropogenic combustion activities. Elevated levels of B(a)P metabolites in fish bile have been correlated with hepatic lesions and inhibited ovarian development in other studies (McDonald 1992).

The New Mexico Ecological Services Office is concerned that PAHs in the San Juan River may threaten the recovery of the Colorado squawfish and the razorback sucker. If contaminated river-bottom sediments were resuspended, adsorbed PAH compounds could subsequently be released and made biologically available (Shomo and Hamilton-McLean 1992). Furthermore, the transport of PAH compounds to the San Juan River and its tributaries could be influenced by irrigation return flows (Blanchard 1991).

4.12.2 OIL AND NATURAL GAS - BACKGROUND

Within the San Juan basin, there are over 20,000 oil and gas wells and numerous petroleum and gas processing facilities (Petty et al. 1992). The locations of gas processing plants, oil refineries, and gas and oil fields are shown to give a general picture of areas of concern (Figure 40) (Blanchard et al. 1993). Each well and processing facility has the potential to contaminate groundwater, surface water, or both, as do oil and gas pipelines.

Oil and gas wells and facilities are located adjacent to and throughout the basin's irrigation projects, increasing the likelihood of oil and gas contaminant transport to the San Juan River and its tributaries. In 1990, researchers for the San Juan Reconnaissance Investigation noted that natural gas and

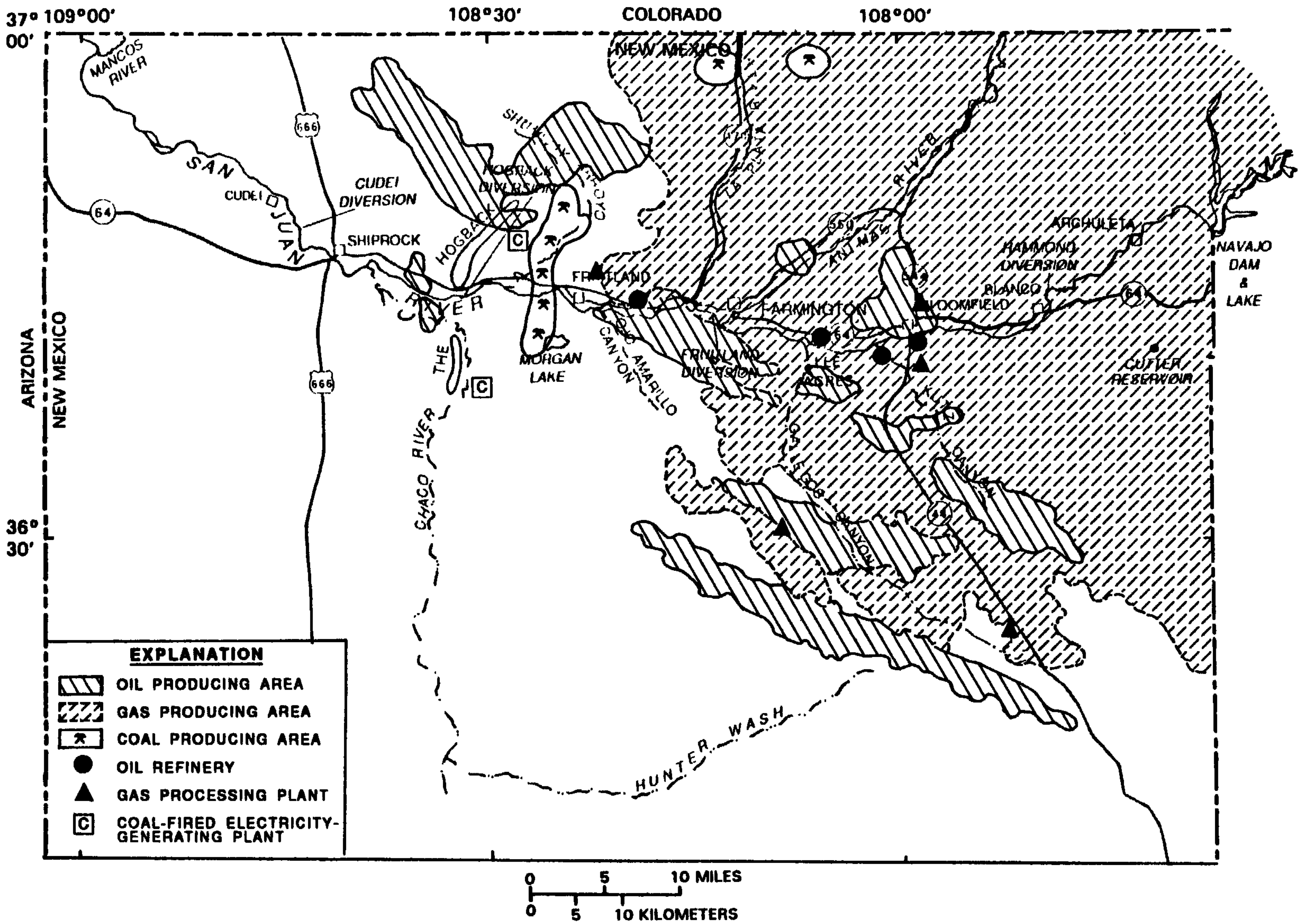


Figure 40. Energy resource areas and production activities in the San Juan River basin.
(Taken from Blanchard et al. 1993)

Table 76: Acute toxicity of aromatic hydrocarbons in freshwater animals

Compound	Species	Conc (ppm)	Effect (LC50)
Benzene	*Gambusia affinis* (mosquitofish)	386	96 h
	Marone saxatilis (striped bass)	5 8	96 h
Toluene	*Gambusia affinis* (mosquitofish)	1180	96 h
	Marone saxatilis (striped bass)	7 3	96 h
	Carassius auratus (goldfish)	22 80	96 h
Dimethylnaphthalenes	*Cyprinodon variegatus* (sheep's-head minnow)	5 1	24 h
Xylenes	*Carassius auratus* (goldfish)	16.94	96 h
m-Xylene	*Marone saxatilis* (striped bass)	9 2	96 h
o-Xylene	*Marone saxatilis* (striped bass)	11 0	96 h
p-Xylene	*Marone saxatilis* (striped bass)	2 0	96 h
Ethylbenzene	*Marone saxatilis* (striped bass)	4.3	96 h
1,3,5,-Trimethylbenzene	*Carassius auratus* (goldfish)	12 52	96 h
Fluorene	*Cyprinodon variegatus* (sheep's-head minnow)	1 68	96 h
Dibenzothiophene	*Cyprinodon variegatus* (sheep's-head minnow)	3 18	96 h
Naphthalene	*Gambusia affinis* (mosquitofish)	150	96 h
	Cyprinodon variegatus (sheep's-head minnow)	2 4	24 h
1-Methylnaphthalene	*Cyprinodon variegatus* (sheep's-head minnow)	3 4	24 h
2-Methylnaphthalene	*Cyprinodon variegatus* (sheep's-head minnow)	2 0	24 h
Phenanthrene	*Gambusia affinis* (mosquitofish)	150	96 h
Benz[a]anthracene	*Lepomis macrochirus* (bluegill)	1 0	87% mortality in 6 months

Modified from Neff 1979

Table 77: High performance liquid chromatography (HPLC) bile analyses for Animas River fish

File #	Sample ID	QA/QC Batch #	Cat #	Organism	Benzo[a]pyrene Ng/g wet weight	Naphthalene Ng/g wet weight	Phenanthrene Ng/g wet weight
J6122	Vial 1	QAC - 0337	B. of Recl	Fish	240	63000	21000
J6123	Vial 2	QAC - 0337	B. of Recl	Fish	110	32000	9600
J6124	Vial 3	QAC - 0337	B. of Recl	Fish	<100	18000	5900
J6125	Vial 4	QAC - 0337	B. of Recl	Fish	<100	19000	6400
J6126	Vial 5	QAC - 0337	B. of Recl	Fish	300	76000	25000
J6127	Vial 6A	QAC - 0337	B. of Recl	Fish	290	73000	24000
J6128	Vial 7	QAC - 0337	B. of Recl	Fish	750	200000	52000
J6129	Vial 8	QAC - 0337	B. of Recl	Fish	730	190000	55000
J6130	Vial 9	QAC - 0337	B. of Recl	Fish	300	87000	27000

Taken from McDonald 1992

oil pads and oil refineries were located within each of the four DOI-sponsored irrigation projects in the review area. Brine discharged to the surface from well pads was observed to be intermixed with irrigation return flows (Blanchard 1991). Within the New Mexico portion of the basin, the principal oil and gas fields are located north of the San Juan River from the eastern boundary of San Juan County to the Hogback, and south of the river both east of Gallegos Canyon and west of the Chaco River (O'Brien 1991).

Development of oil and gas in the basin has the potential to contaminate surface and groundwater not only with PAHs but also with salts. The water that is produced from well operations typically has TDS concentrations ranging from 1,200-295,000 mg/l (Upper Colorado Region State-Federal Inter-Agency Group 1971). Most of this produced water is reinjected into wells to help maintain reservoir pressures or as a means of disposal, and this reinjection can lead to contamination of shallow, fresh groundwater systems (Wilson 1981, Stone et al. 1983, U.S. Geological Survey 1993). Produced water may also be discharged to holding ponds for evaporation, it may be disposed of on the surface, or it may go directly to other uses such as irrigation (Upper Colorado Region State-Federal Inter-Agency Group 1971). In 1967, the San Juan basin oil-field operations produced 63,236 acre-feet (about 7.8 million m^3) of water (Melancon et al. 1979). In 1978, oil wells in the basin produced an average of 8.1 ft^3/sec of water, and gas wells produced 0.1 ft^3/sec; of the total quantity, approximately 6 ft^3/sec was reinjected, with the remainder likely evaporating (Stone et al. 1983).

Produced water may contain other contaminants in addition to salts. For instance, some produced water from oil wells has been found to contain volatile organic compounds (VOCs) (New Mexico Energy, Minerals, and Natural Resources Department 1991). The high permeability of the alluvium in many oil-field areas allows contaminants, particularly benzene, toluene, ethylbenzene, and xylene (BTEX) to migrate into the groundwater (New Mexico Energy, Minerals, and Natural Resources Department 1993). Recently, New Mexico recognized that Naturally Occurring Radioactive Material (NORM) is present in produced water from oil wells. The New Mexico Oil Conservation Division (OCD) found that water from older rock formations had elevated levels of NORMS as well as high salt concentrations. Current OCD regulations are expected to provide adequate protection for freshwater until better information concerning NORMs is acquired (New Mexico Energy, Minerals, and Natural Resources Department 1993). Because oilfield equipment may corrode with age, mechanical integrity testing of all producing and injection wells is required by the OCD (New Mexico Energy, Minerals, and Natural Resources Department 1993).

Sediment waste mixtures are also produced at oil production sites. The sediment-water mixture, aptly named tank-bottoms, is heavier than oil and settles to the bottom of the tanks. The volume of tank bottoms is several hundred times less than that of produced water, yet it contains highly concentrated hydrocarbons and metals. The tank bottoms are treated with heat and chemicals at oil reclamation facilities in order to extract additional crude oil; in New Mexico, treatment can reduce the volume of waste by up to two-thirds, recovering two barrels of oil for every three barrels of waste (New Mexico Energy, Minerals, and Natural Resources Department 1991).

New Mexico, Utah, and Colorado have each promulgated extensive rules and regulations for the development of oil and gas (Colorado Oil and Gas Conservation Commission 1993, New Mexico Energy, Minerals, and Natural Resources Department 1993, Utah Board of Oil, Gas, and Mining 1993a, Utah Board of Oil, Gas, and Mining 1993b). These regulations are far too extensive and detailed for comprehensive review in this document. In each case, discharges to surface water are heavily restricted but fewer precautions are taken for the protection of groundwater.

The New Mexico OCD has acknowledged that the New Mexico portion of the San Juan basin suffers from oil- and gas-related groundwater problems but has stated that limited sampling at contamination sites shows attenuation of the dissolved phase occurring away from the contamination source. The OCD has noted that the combination of dilution, sorption, and natural biodegradation probably prevent direct subsurface transport of contaminants to surface water unless contamination occurs at the water's edge (Boyer 1991).

New Mexico has designated a "Vulnerable Area" within the San Juan basin within which disposal of oil and gas wastes in excess of 5 barrels/day onto either the ground surface or into unlined pits is prohibited (New Mexico Energy, Minerals, and Natural Resources Department 1993). By 1996, alluvial areas within 50 feet of all major tributaries to the San Juan, Animas, and La Plata rivers in New Mexico will be protected from such discharges. The Vulnerable Area, as expanded in 1993, includes Ojo Amarillo Canyon and Gallegos Canyon. The area was expanded in response to unrefuted evidence of groundwater contamination from small volume discharges to unlined pits in alluvial fill.

As of 1991 there were apparently no federal or state agencies systematically monitoring inorganic contamination from oil and gas wells in the basin, and a 1992 survey of agencies found none monitoring PAHs in the environment either (Roy and Hamilton 1991, Wall 1992).

On July 20, 1993, Region 2 of the FWS issued a Biological Opinion to the BLM concerning the Bureau's ongoing and proposed oil and gas leasing and development activities. That opinion found that those activities were likely to jeopardize the continued existence of the Colorado squawfish and razorback sucker through degradation of the aquatic habitat in the San Juan River. Degradation was considered likely to result from the introduction of PAHs to the San Juan River (Fowler-Propst, personal communication).

As components of the reasonable and prudent alternative, the BLM is required to do the following:

1. Establish an extensive monitoring system to collect suspended sediment and water samples on perennial streams and bottom sediments on ephemeral channels (approximately 172 sampling sites) This system will be used to provide information on distribution of PAHs on Public Lands and will be used to identify those small subwatersheds or reaches of ephemeral channels that may exhibit concentrations of PAHs.

2. Phase I sampling (above) is designed to allow an estimate of types and volumes of PAHs moving through the system. Areas of concentration and contaminant source identification will be investigated in Phase II. Results from this effort will be correlated with any other water quality programs and with ongoing investigations of the native and endangered fish fauna of the San Juan River basin.

3. Soil and air samples will be taken at identified sites to define background levels of PAHs and atmospheric input to the system.

4. Phase III will consist of long term monitoring for PAHs at sites identified in the first two phases.

5. The results of the monitoring efforts will be used immediately to apply remedial actions through changes in stipulations or Best Management Practices. If, at any time during the data gathering efforts of the first phase, "hot spots" are identified, remedial efforts will be implemented immediately to halt the introduction of contaminants to the San Juan River or to Navajo Reservoir. Such efforts may include cessation of production at problem wells or in problem areas, and the effective sealing of those wells or other measures to prohibit further contamination. This information will also be applied to other watersheds or channel reaches with high PAH levels (Fowler-Propst, personal communication).

4.12.3 OIL EXTRACTION AND REFINEMENT

New Mexico, Colorado, and Utah each compile their own production statistics for oil as well as gas, and as such it is difficult to achieve a precise accounting of total basin production. The best way to assess each state's contribution to the basin's oil production is generally to examine county statistics.

All three states have combined their oil and gas statistics; the gas statistics in tables appearing in this section will be discussed separately in the GAS EXTRACTION AND REFINEMENT section (4.12.4).

New Mexico has two oil producing regions, in the southeast and northwest corners of the state. In 1991, the most recent year for which statistics have been compiled, the southeast region produced the bulk of the state's oil, with the northwest region contributing less than 7% of the state's total (Table 78) (New Mexico Energy, Minerals, and Natural Resources Department 1992). The New Mexico Energy, Minerals, and Natural Resources Department (1992) has reported that a total of 735 wells, both oil and gas, were completed in the northwest region in 1991; unfortunately, the number of oil and gas wells are not listed separately. Total oil production in the northwest region has been declining since 1987; from 1990 to 1991 the region's production fell by 13% (Table 79). Much of New Mexico's oil production comes from small producers, with over 20% of the state's total production generated by stripper wells that produce less than 10 barrels of oil per day (New Mexico Energy, Minerals, and Natural Resources Department 1992).

Within the Colorado portion of the San Juan basin, four counties produce oil: Archuleta, Dolores, La Plata, and Montezuma. It must be noted, though, that only a very small portion of Dolores County is in the basin. In 1991, Montezuma County produced the most oil of the four counties with 793,186 billion barrels (Bbls) (Table 80) (Colorado Oil and Gas Conservation Commission 1993). Relatively few oil wells were completed in 1991; in total, three were completed in Dolores County, four in La Plata County, one in Montezuma County, and none in Archuleta County (Table 81). The number of producing oil wells in these counties is not available for 1991, but together over 2,030 oil and gas wells produced in the four counties. In 1991 a total of 24,190,065 Bbls of water were injected in the four counties, both for disposal and enhanced recovery (Colorado Oil and Gas Conservation Commission 1993).

Utah compiles its oil and gas statistics on a monthly basis. As of April 1993, 920 oil and gas wells were active in San Juan County, Utah, and in that month 535,429 Bbls of oil were produced. The cumulative total for all active wells in San Juan County was 243,407,392, and the cumulative total for all active and abandoned wells together was 463,865,616 Bbls. From all oil and gas wells, both active and inactive, 1,037,335,197 Bbls of water have been produced cumulatively in San Juan County (Table 82). San Juan County has produced about 44% of the state's total oil and about 32% of the state's water. The Greater Aneth Oil Field, which covers about 125 mi^2, has alone produced over 80% of all San Juan County oil and over 90% of the San Juan County water (Spangler 1992, Utah Division of Oil, Gas, and Mining 1993a).

Once crude oil is pumped from a well, it is transported by gathering pipelines operated by oil refineries, or it is gathered and shipped to crude oil pipeline tank farms for transportation to distant refineries. In many remote oil-producing areas, there are no pipelines to tank farms and crude oil is trucked to the nearest refinery (New Mexico Energy, Minerals, and Natural Resources Department 1991). Within New Mexico, there are 15 crude oil pipelines and nine petroleum product pipelines (as listed in Table 83 and shown in Figure 41) (New Mexico Energy, Minerals, and Natural Resources Department 1992). The Texas-New Mexico pipeline, which runs from Farmington to southeastern New Mexico and into Texas, is the state's primary carrier of crude oil (New Mexico Energy, Minerals, and Natural Resources Department 1992). Crude oil pipelines can pose a serious contamination hazard. In October 1972, for example, a broken 41 centimeter pipeline spilled over one million liters of crude oil into the San Juan River (Melancon et al. 1979).

Within the New Mexico portion of the San Juan basin there are two operating oil refineries, both in Bloomfield. The Bloomfield Refining Company plant has a capacity of 16,800 Bbls/day, and the Thriftway Marketing Company plant has a capacity of 7,500 Bbls/day (Table 84). Several abandoned refineries are also located on the north bank of the San Juan River between Farmington and Shiprock (Figure 40) (Roy 1990, New Mexico Energy, Minerals, and Natural Resources Department 1992, Blanchard et al. 1993). In terms of petroleum and petroleum-product contamination, refineries pose the second greatest threat to soil and water in New Mexico after storage and handling. From 1972-1984,

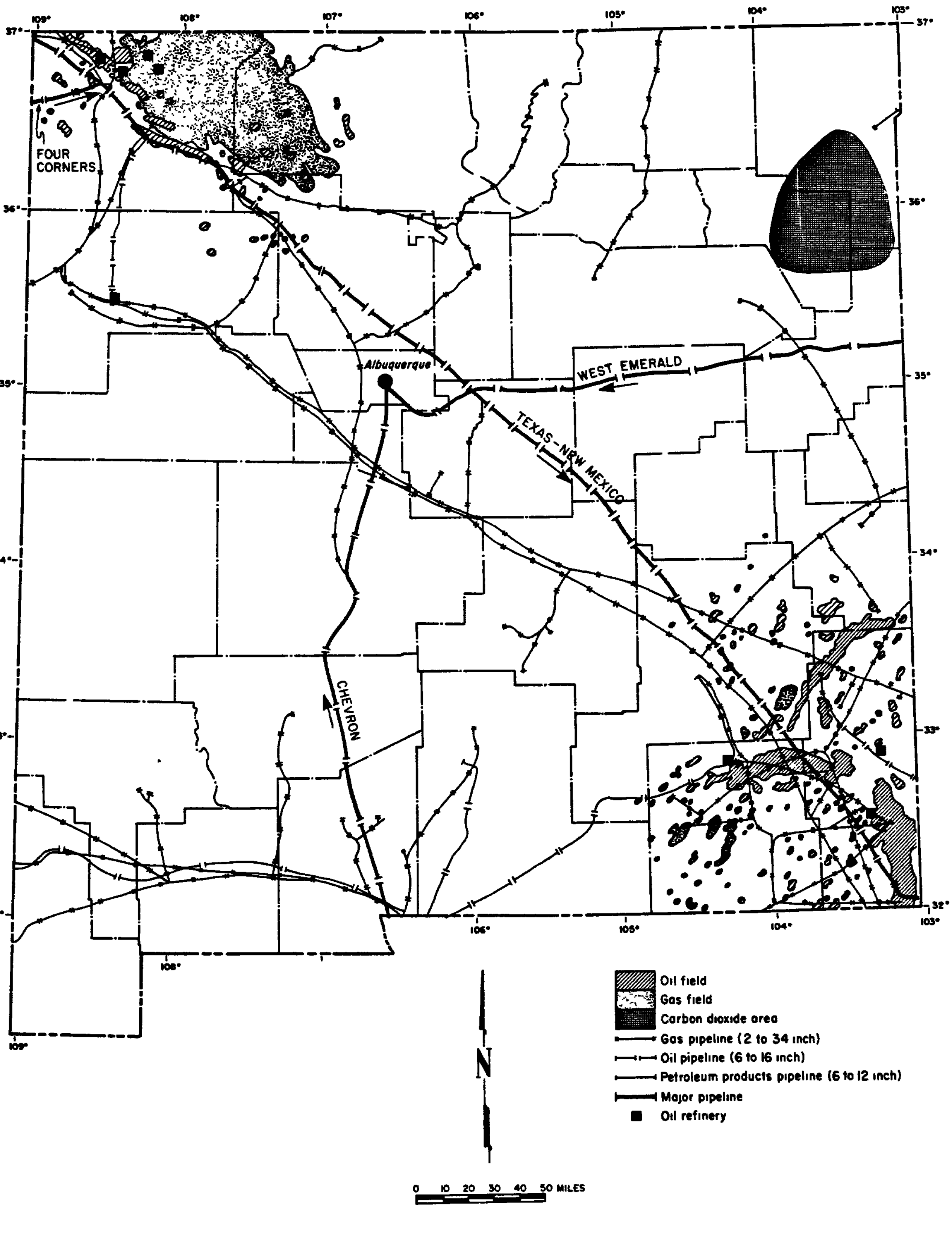


Figure 41. Map of oil and gas pipelines in New Mexico (Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992)

Table 78: New Mexico crude oil and condensate production for 1991 ranked by county

Rank	County	Location	Oil and Condensate (Bbls)	1990-91% Increase-Decrease	% of Total State Production
1	Lea	SE	43,855,192	-4.6	62.3
2	Eddy	SE	19,554,594	+36.0	27.8
3	Rio Arriba	NW	2,160,773	-21.4	3.1
4	San Juan	NW	2,087,972	-6.7	3.0
5	Chaves	SE	1,428,733	+7.1	2.0
6	Roosevelt	SE	774,822	-8.4	1.1
7	McKinley	NW	342,252	-4.6	0.5
8	Sandoval	NW	212,108	+5.1	0.3
1991 State Total Oil Production			70,416,446	+3.5	100

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

Table 79: Comparison of 1990 and 1991 oil production in New Mexico

	Oil production (barrels)			
	1990	1991	Increase	Decrease
Crude Oil				
Southeast	60,283,200	63,313,018	3,029,818	
Northwest	4,061,738	3,487,882		573,856
Total	**64,344,938**	**66,800,900**	**2,455,962**	
Condensate				
Southeast	2,224,748	2,300,323	75,575	
Northwest	1,485,682	1,315,223		170,459
Total	**3,710,430**	**3,615,546**		**94,884**
Total Oil				
Southeast	62,507,948	65,613,341	3,106,405	
Northwest	5,547,420	4,803,105		744,315
Total	**68,055,368**	**70,416,446**	**2,361,078**	

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

Table 80: Colorado oil and gas production statistics by county

County	No. of Prod Wells	1991 Production Oil (Bbls)	1991 Production Gas (Mcf)	1991 Sales Oil (Bbls)	1991 Sales Gas (Mcf)	Cumulative Production Thru December 31,1991 Oil (Bbls)	Cumulative Production Thru December 31,1991 Gas (Mcf)
Adams	978	1,126,266	17,860,294	1,106,239	16,836,837	51,746,543	311,476,577
Arapahoe	120	275,754	1,706,514	268,976	1,404,166	29,306,005	80,301,864
Archuleta	34	39,654	4565	39,621	1902	6,873,189	483,734
Archuleta*	0	0	6908	0	0	0	272,405
Baca	109	238,676	3,653,439	238,722	3,267,066	4,063,491	116,300,327
Bent	27	2463	1,613,363	1912	1,574,404	220,123	30,648,143
Boulder	139	93,196	2,217,003	80,328	2,144,082	1,544,800	20,520,691
Cheyenne	274	6,115,334	7,111,391	6,110,143	0	45,163,661	30,870,309
Delta	1	290	71,311	211	67,422	1595	89,474
Denver	21	18,634	347,125	17,740	343,760	2,971,579	40,481,127
Dolores	30	303,834	1,112,347	305,202	924,703	4,493,628	26,699,623
Elbert	102	235,293	1,079,043	235,137	944,246	6,612,548	28,228,429
Fremont	44	24,285	1825	24,013	0	15,159,707	12,505
Garfield	333	6111	15,444,322	5499	15,252,553	69,713	136,877,142
Garfield*	51	0	2,580,108	0	2,516,553	0	7,721,690
Gunnison	9	361	186,678	262	186,678	4082	1,516,568
Huerfano	0	0	0	0	0	4253	38,521
Huerfano**	28	0	69,968,424	0	69,928,796	0	621,704,758
Jackson	81	198,639	210,573	200,633	127,157	15,793,106	10,627,361
Jackson**	7	0	1,379,783	0	928,673	0	672,028,864
Jefferson	0	0	0	0	0	15,275	3820
Kiowa	94	332,224	1,601,968	329,517	1,503,346	14,486,945	48,849,627
Kit Carson	6	92,723	535,619	91,348	527,958	759,100	1,034,706
La Plata	1008	64,102	30,338,923	62,633	29,491,404	1,860,158	1,104,280,461
La Plata*	525	0	43,917,217	0	42,399,846	0	90,685,866
Larimer	172	276,045	608,338	275,555	532,155	18,247,778	31,290,807
Las Animas	0	0	0	0	0	0	2,337,121
Las Animas*	0	0	38,145	0	0	0	455,149
Las Animas***	0	0	0	0	0	0	53,000
Lincoln	12	151,967	29,852	151,990	0	2,361,153	366,031
Logan	171	392,719	550,161	396,536	386,882	107,661,528	205,207,722

Table 80 (Cont): Colorado oil and gas production statistics by county

County	No. of Prod Wells	1991 Production Oil (Bbls)	1991 Production Gas (Mcf)	1991 Sales Oil (Bbls)	1991 Sales Gas (Mcf)	Cumulative Production Thru December 31,1991 Oil (Bbls)	Cumulative Production Thru December 31,1991 Gas (Mcf)
Mesa	134	2447	4,458,189	2387	4,246,690	66,033	119,495,968
Mesa*	17	0	267,673	0	212,906	0	433,771
Moffat	242	692,527	16,993,336	680,214	16,403,928	62,889,756	711,379,919
Moffat*	1	0	0	0	0	0	0
Montezuma	68	793,186	1,658,446	787,910	1,164,566	12,799,054	27,594,661
Montezuma**	37	0	207,522,248	0	207,435,049	0	1,345,366,330
Montrose	0	0	0	0	0	0	58,092
Morgan	107	215,491	713,358	213,022	636,702	89,577,883	200,790,541
Phillips	2	0	4327	0	4327	0	111,660
Pitkin	0	0	0	0	0	0	12,629,822
Prowers	36	4218	1,417,849	3886	1,403,183	304,536	25,973,834
Rio Blanco	1280	13,186,152	34,623,908	13,177,036	29,312,915	862,447,387	1,482,892,330
Rio Blanco*	12	0	1,206,607	0	858,017	0	1,333,911
Rio Grande	0	0	0	0	0	1,855	0
Routt	29	113,662	195,700	110,246	105,820	6,885,179	6,066,442
San Miguel	11	544	526,388	547	492,267	184,985	35,435,785
Sedgwick	3	2823	279,456	2741	279,456	81,410	6,862,024
Washington	452	1,165,817	2,343,247	1,195,383	2,156,475	145,648,967	87,729,309
Weld	5666	5,332,532	91,463,772	5,262,841	86,906,010	128,890,087	1,175,857,530
Yuma	623	0	10,047,026	0	9,766,203	16,069	117,276,808
Totals	12,418	31,497,969	251,009,656	31,378,430	228,395,263	1,639,213,171	6,238,697,415
CO2 Totals**	72	0	278,870,455	0	278,292,518	0	2,639,099,952
Coal Gas Tot.*	606	0	48,016,658	0	45,987,322	0	100,902,792
Hel Totals***	0	0	0	0	0	0	53,000

Taken from Colorado Oil and Gas Conservation Commission 1992

Table 81: Calendar Year 1991 well completions, Colorado

County	Well Permits	Wildcat					Development					Total					Re-complete		Com-mingled		Multiple		Ex-producers		
		Oil	Gas	Dry	Other	Total	Oil	Gas	Dry	Other	Total	Oil	Gas	Dry	Other	Total	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Total
Adams	53	0	0	3	0	3	18	24	4	0	46	18	24	7	0	49	0	1	1	0	0	1	16	6	22
Arapahoe	14	0	0	1	0	1	4	0	5	0	9	4	0	6	0	10	0	0	0	0	0	0	11	1	12
Archuleta	5	0	0	1	0	1	0	2	4	0	6	0	2	5	0	7	0	0	0	0	0	0	0	0	0
Baca	10	0	0	1	0	1	3	0	0	0	3	3	0	1	0	4	0	0	0	0	0	0	0	6	6
Bent	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boulder	13	0	0	0	0	0	5	15	0	0	20	5	15	0	0	20	0	0	0	0	0	0	3	1	4
Cheyenne	93	2	0	27	0	29	22	0	22	3	44	24	0	49	3	73	0	0	0	0	0	0	3	0	3
Crowley	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denver		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	4
Dolores	1	1	0	1	0	2	2	0	0	0	2	3	0	1	0	4	2	0	0	0	1	0	1	0	1
Elbert	5	0	0	1	0	1	0	1	3	0	4	0	1	4	0	5	0	0	0	0	0	0	4	2	6
Fremont	7	0	0	0	0	0	3	0	6	0	9	3	0	6	0	9	0	0	0	0	0	0	3	0	3
Garfield	36	0	7	1	0	8	0	42	2	0	44	0	49	3	0	52	0	0	0	0	0	9	0	3	3
Gunnison	2	0	1	0	0	1	0	1	0	0	1	0	2	0	0	2	0	0	0	0	0	0	0	0	0
Huerfano	4	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Jackson	6	1	0	1	0	2	4	0	1	0	5	5	0	2	0	7	0	0	0	0	0	0	1	0	1
Jefferson	2	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Kiowa	46	4	0	14	0	18	5	2	11	0	18	9	2	25	0	36	0	0	0	0	0	0	6	2	8
Kit Carson	8	0	0	6	0	6	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0	0	0	0	0
La Plata	128	0	0	0	0	0	4	187	2	4	193	4	187	2	4	193	0	0	0	0	0	0	1	7	8
Larimer	6	1	0	1	0	2	4	0	0	0	4	5	0	1	0	6	0	0	0	0	0	0	3	0	3
Las Animas		0	0	0	0	0	0	8	0	0	8	0	8	0	0	8	0	0	0	0	0	0	0	0	0
Lincoln	7	1	0	4	0	5	0	0	0	0	0	1	0	4	0	5	0	0	0	0	0	0	1	0	1
Logan	13	1	0	5	0	6	3	0	1	0	4	4	0	6	0	10	0	0	0	0	0	0	27	0	27
Mesa	20	1	0	1	0	2	0	8	1	0	9	1	8	2	0	11	0	0	0	0	0	0	0	5	5
Moffat	19	0	0	2	0	2	6	12	1	1	19	6	12	3	1	21	0	0	0	0	0	0	3	1	4
Montezuma	8	1	1	3	0	5	0	1	1	0	2	1	2	4	0	7	0	0	0	0	0	0	2	0	2
Montrose	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morgan	13	0	0	5	0	5	3	0	3	0	6	3	0	8	0	11	0	0	0	0	0	0	11	3	14
Otero	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Park	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 81 (Cont): Calendar Year 1991 well completions, Colorado

County	Well Permits	Wildcat Oil	Wildcat Gas	Wildcat Dry	Wildcat Other	Wildcat Total	Development Oil	Development Gas	Development Dry	Development Other	Development Total	Total Oil	Total Gas	Total Dry	Total Other	Total Total	Re-complete Oil	Re-complete Gas	Com-mingled Oil	Com-mingled Gas	Multiple Oil	Multiple Gas	Ex-producers Oil	Ex-producers Gas	Ex-producers Total
Phillips		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prowers	10	0	0	6	0	6	0	0	1	0	1	0	0	7	0	7	0	0	0	0	0	0	1	6	7
Rio Blanco	33	0	1	1	0	2	7	19	8	0	34	7	20	9	0	36	0	0	0	0	1	1	12	10	22
Rio Grande	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Routt	4	0	0	1	0	1	2	1	2	0	5	2	1	3	0	6	0	0	0	0	0	0	1	1	2
San Miguel	2	1	0	1	0	2	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	0	0	0	0
Sedgwick	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Washington	28	1	0	12	0	13	5	6	5	0	16	6	6	17	0	29	0	0	0	0	0	0	50	0	50
Weld	656	5	2	9	1	16	281	218	13	2	512	286	220	22	3	528	0	1	22	15	10	6	44	6	50
Yuma	60	0	3	6	0	9	1	29	6	0	36	1	31	12	0	44	0	0	0	0	0	0	1	0	1
State Total	1319	20	15	117	1	152	383	576	103	12	1062	402	590	216	13	1208	2	2	23	15	12	17	211	62	273

Taken from Colorado Oil and Gas Conservation Commission 1992

Table 82: Utah Summary Production Report, April 1993

County	Active wells		Monthly	Year-to-date	Cumulative	Abandoned	Total Cum
Beaver	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Box Elder	12	Oil (Bbl)	0	0	2665	0	2665
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	72	0	72
Cache	2	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Carbon	59	Oil (Bbl)	0	16	1529	142,976	144,505
		Gas (Mcf)	76,180	211,745	62,658,013	16,177,887	78,835,900
		Water (Bbl)	93,388	294,860	1,738,958	429	1,739,387
Daggett	18	Oil (Bbl)	46	1080	116,615	222,746	339,361
		Gas (Mcf)	44,857	600,210	61,542,688	97,914,713	159,457,401
		Water (Bbl)	0	233	287,713	155,985	443,698
Davis	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Duchesne	817	Oil (Bbl)	540,039	2,100,958	198,347,823	28,122,770	226,470,593
		Gas (Mcf)	1,464,286	5,912,584	321,700,155	44,106,242	365,806,397
		Water (Bbl)	1,550,069	6,071,993	281,890,269	38,067,367	319,957,636
Emery	68	Oil (Bbl)	1157	3961	555,762	8411	564,173
		Gas (Mcf)	99,288	372,253	16,332,581	43,364,484	59,697,065
		Water (Bbl)	936	2175	97,155	4624	101,779
Garfield	36	Oil (Bbl)	24,246	93,931	22,983,699	1,256,401	24,240,100
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	845,539	3,401,115	304,379,064	15,556,162	319,935,226
Grand	564	Oil (Bbl)	29,783	113,707	4,763,221	624,617	5,387,838
		Gas (Mcf)	661,686	2,558,599	229,444,628	32,715,452	262,160,080
		Water (Bbl)	2142	8159	5,237,534	1,731,386	6,968,920
Iron	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Juab	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Kane	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Millard	1	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Morgan	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Piute	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0

Table 82 (Cont): Utah Summary Production Report, April 1993

County	Active wells		Monthly	Year-to-date	Cumulative	Abandoned	Total Cum
Rich	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	5,497,846	5,497,846
		Water (Bbl)	0	0	0	4401	4401
Salt Lake	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
San Juan	920	Oil (Bbl)	535,429	2,137,623	243,407,392	220,458,224	463,865,616
		Gas (Mcf)	2,287,748	9,189,437	769,753,187	287,156,798	1,056,909,985
		Water (Bbl)	2,927,804	11,431,996	684,153,919	353,181,278	1,037,335,197
Sanpete	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	3,027,183	3,027,183
		Water (Bbl)	0	0	0	0	0
Sevier	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Summit	85	Oil (Bbl)	392,521	1,594,081	131,777,248	20,402,446	152,179,694
		Gas (Mcf)	19,103,256	73,846,866	1,722,349,032	83,703,051	1,806,052,083
		Water (Bbl)	605,673	2,092,664	61,389,899	12,243,536	73,633,435
Tooele	2	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Uintah	1657	Oil (Bbl)	284,009	1,155,480	155,983,628	34,823,241	190,806,869
		Gas (Mcf)	6,144,229	25,017,202	686,863,840	86,875,767	773,739,607
		Water (Bbl)	2,403,384	14,283,341	1,418,963,510	93,740,501	1,512,704,011
Utah	1	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Wasatch	1	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Washington	16	Oil (Bbl)	0	0	730	4044	4774
		Gas (Mcf)	0	0	16,388	49,164	65,552
		Water (Bbl)	0	0	17,928	22,342	40,270
Wayne	4	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
Weber	0	Oil (Bbl)	0	0	0	0	0
		Gas (Mcf)	0	0	0	0	0
		Water (Bbl)	0	0	0	0	0
			Monthly	Year-to-date	Cumulative		
Active totals:	4263	Oil (Bbl)	1,807,230	7,200,837	757,940,312		
		Gas (Mcf)	29,881,530	117,708,896	3,870,660,512		
		Water (Bbl)	8,428,935	37,586,536	2,758,156,021		
Abandoned totals:	8158	Oil (Bbl)			306,065,876		
		Gas (Mcf)			700,588,587		
		Water (Bbl)			514,708,011		
State totals	12,421	Oil (Bbl)			1,064,006,188		
		Gas (Mcf)			4,571,249,099		
		Water (Bbl)			3,272,864,032		

Taken from Utah Division of Oil, Gas, and Mining 1993a

Table 83: Crude oil and petroleum product pipelines in New Mexico as of 1 November 1992

Company	Pipeline contents	
	Crude	Petroleum products
All American Pipeline Company	X	
AMOCO Pipeline Company	X	
ARCO Pipe Line Company	X	
Chevron Pipeline Company		X
Ciniza Pipeline Inc.	X	
Continental Pipeline Company		X
El Paso Natural Gas Company		X
Four Corners Pipeline Company	X	
Kerr-McGee Pipeline Corporation	X	
MAPCO Inc.		X
Matador Pipelines, Inc.	X	
Midland-Lea, Inc.	X	
Mobil Pipe Line Company	X	
Navajo Pipeline Company		X
Odessa Gas Pipeline Company		X
San Juan Pipeline System	X	
Santa Fe Pipeline Company	X	
Shell Pipeline Corporation	X	
Southern Pacific Pipelines, Inc.		X
Standard Transpipe Corporation		X
Texas-New Mexico Pipeline Company	X	
Texaco Pipeline, Inc.	X	
West Emerald Pipeline Corporation		X

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

Table 84: Characteristics of oil refineries in New Mexico, 1991

Operator	Plant	Runs to Stills		Capacity	Employees
		Bbls/Year	Bbls/Day	Bbls/Day	
Bloomfield Refining Company	Bloomfield	8,797,410	24,102	16,800	89
Giant Refining	Ciniza	12,968,035	35,529	20,000	108
Navajo Refining Company	Artesia	15,481,770	42,416	60,000	368
Thriftway Marketing Company	Bloomfield	1,174,766	3,219	7,500	6
Total		38,421,981	105,266	104,300	571

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

refineries were responsible for 66% of all petroleum-product losses to the environment in New Mexico (Jercinovic 1985).

4.12.3.1 BLOOMFIELD REFINING COMPANY REFINERY

The oil refinery operated by the Bloomfield Refining Company has been cited by the EPA for contamination of the groundwater, surface water, and soil at the facility. The refinery is located on a bluff approximately 100 feet above and immediately south of the San Juan River. The size of the entire facility is 287 acres. The Hammond Ditch, an unlined channel for Hammond Project irrigation water supply, borders all but the southern side of the oil facility process area (Figure 42) (Groundwater Technology, Inc. 1993). Six to 40 feet below the ground surface is perched, shallow groundwater which flows to the northwest and west, toward the Hammond Ditch and the San Juan River.

The Hammond Ditch influences groundwater flow on the refinery site. During the non-irrigation season the refinery operators dike the ditch in order to maintain a year-round mounding effect which inhibits groundwater flow to the north (Groundwater Technology, Inc. 1993). During the irrigation season, when water deliveries are made from the ditch, seepage from the canal moves underneath the refinery and flushes the contaminated soils (U.S. Bureau of Reclamation 1993b) According to Greg Lyssy of the EPA (personal communication), there are known seeps above the river in the bluff, but to the best of his knowledge no contamination from the refinery has yet reached the river. At least one EPA document, though, specifically cites the refinery for contamination of the river with organics and inorganics (Lyssy 1993).

The original refinery facility was built in the late 1950s and began operation in 1963 (Lyssy 1993, Groundwater Technology, Inc. 1993). Prior to the EPA citation, the refinery operators were aware that storage tanks were leaking hazardous materials such as benzene and toluene to the environment, causing groundwater and soil contamination (Hawley, personal communication; Lyssy, personal communication). In November 1980 the operators, as required by law, reported to the EPA that hazardous waste was handled at the facility (Lyssy, personal communication). In 1982 the facility illegally disposed of hazardous waste in an unlined pit, leading to the EPA citation (Lyssy 1993).

Under the Resource Conservation and Recovery Act (RCRA), the EPA has negotiated an Administrative Order on Consent with the Bloomfield Refining Company for the remediation of the contamination; the Order effective date was December 31, 1992 (Lyssy 1993). For the long term, the Order requires the refinery to determine the extent of the contamination, both laterally and vertically, and to formulate a remediation plan (Lyssy, personal communication). Interim measures include: 1) the addition of two new recovery wells to the existing onsite recovery program in order to inhibit off-site seepage of separate phase hydrocarbons (SPH); 2) the continuation of SPH recovery in order to remove the source of hydrocarbons to groundwater beneath the site; and 3) the continuation of facility maintenance, monitoring, and inspection schedules to prevent releases of product to the environment (Groundwater Technology, Inc. 1993). The period from initiation of the Order to completion is usually from 3-5 years (U.S. Bureau of Reclamation 1993b).

4.12.3.2 LEE ACRES LANDFILL

Lee Acres Landfill, located approximately six miles east-southeast of Farmington, is a facility on BLM land that has been identified as a National Priority List site as a result of groundwater contamination with VOCs (Figure 43) (McQuillan and Longmire 1986, Roy 1990, O'Brien 1991). Unrestricted dumping of hazardous materials into unlined waste storage pits has contaminated nearby shallow aquifers with such hydrocarbon compounds as toluene, benzene, 1,1,1-trichloroethane, ethylbenzene, naphthalene, and phenanthrene (O'Brien 1987). Directly to the south of the landfill is the

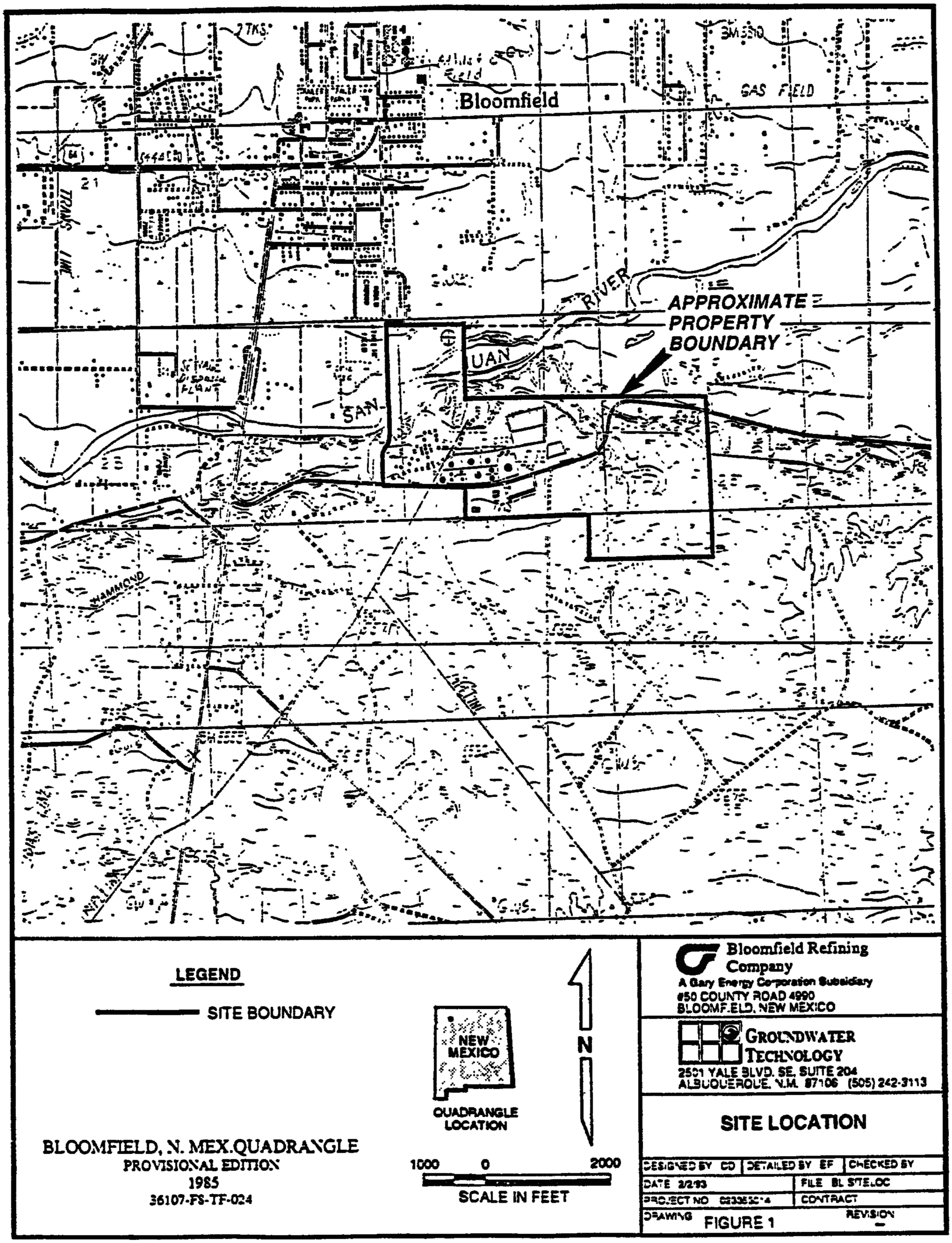


Figure 42. Site location, Bloomfield Refinery. (Taken from Groundwater Technology, Inc 1993)

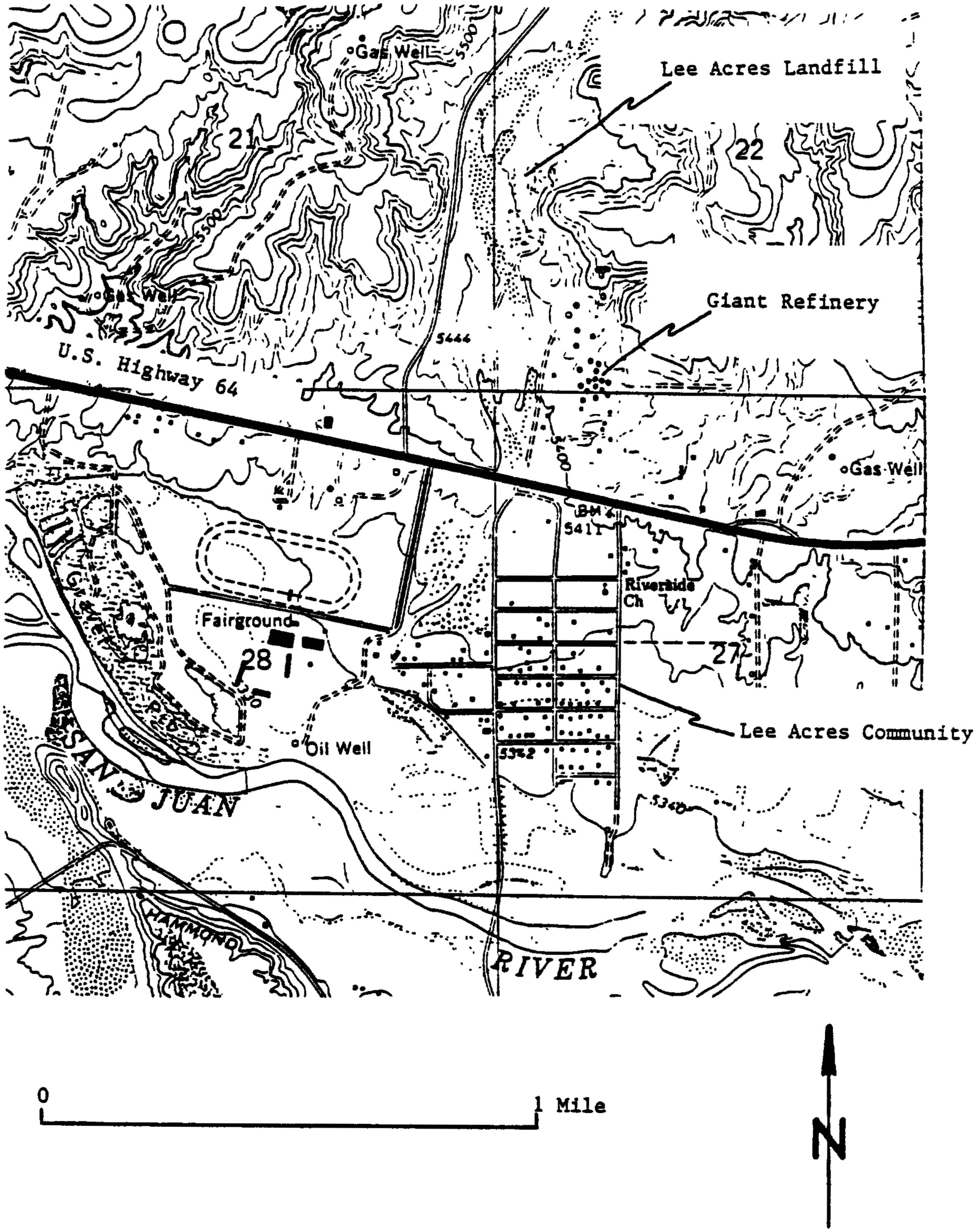


Figure 43. Location of Lee Acres Landfill and Lee Acres Community.
(Taken from McQuillan and Longmire 1986)

inactive Giant Oil Refinery (McQuillan and Longmire 1986, O'Brien 1991). The quantity and quality of waste discharges from the refinery are unknown, as are the impacts of these discharges on the surface and groundwater quality in the vicinity (McQuillan and Longmire 1986, O'Brien 1991).

The landfill consists of an undetermined number of buried solid-waste trenches and four unlined liquid-waste lagoons. Hazardous waste fluids were dumped into two of the four lagoons, and oil-stained soil is present in some areas within the landfill. The wastes included waters from oil and gas fields in the region, spent acid, septage, waste oil, chlorinated solvents, and dead animals. Liquid waste disposal was prohibited after the northernmost active lagoon emitted hazardous quantities of hydrogen sulfide gas in April 1985. The chemistry of the landfill lagoon water is similar to the wastewater produced in the oil and gas fields of the region, although the presence of certain chlorinated VOCs indicates that other industrial wastes were also discharged to the lagoon (McQuillan and Longmire 1986).

When measured by McQuillan and Longmire (1986), the TDS concentrations of the waste fluids were typically greater than 5000 mg/l. Private supply wells in the Lee Acres community had TDS concentrations of 828-4323 mg/l, with the highest values occurring in the vicinity of the arroyo near which the landfill is situated. With at least one exception, VOCs were not detected in the supply wells (Appendices 23a-b) (McQuillan and Longmire 1986).

In 1987, Peter et al. (1987) conducted groundwater testing in the vicinity of the landfill as well as limited surface water testing of the San Juan River (Appendices 24a-b). VOCs including toluene and benzene were detected in water from five samples. Toluene and benzene are constituents of grease, oil, and gasoline, but it is not known if their presence in three sites upgradient from the landfill was a result of drilling. Two groundwater samples downgradient from the landfill contained detectable levels of degradation by-products of 1,1,1,-trichloroethane and 1,1-dichloroethane, but no VOCs were detected in the San Juan River upstream or downstream from the study area (Peter et al. 1987). More recent sampling by the BLM has not confirmed the presence of VOCs at landfill groundwater sites (O'Brien 1987).

4.12.4 NATURAL GAS EXTRACTION AND PROCESSING

Two types of natural gas are extracted in the San Juan basin: casinghead and dry gas. Casinghead gas is derived from oil wells, whereas dry wells contain no liquid. An important type of dry gas is coalbed methane gas, which is natural gas created during the formation of coal and trapped in coal beds. New technology made available less than a decade ago has rendered extraction of this gas economically feasible (New Mexico Energy, Minerals, and Natural Resources Department 1992, New Mexico Energy, Minerals, and Natural Resources Department 1993). The San Juan basin contains an estimated 81 trillion cubic feet (tcf) of coal gas in place, 65-70% of which is in New Mexico. The San Juan basin is the second largest gas field in the United States, and the further expansion of coalbed methane production is expected to double the basin's ultimate gas recovery. The New Mexico portion of the basin is itself the largest coalbed methane producing region in the world (New Mexico Energy, Minerals, and Natural Resources Department 1993).

In 1991 New Mexico became the nation's fourth largest natural gas producer with an annual total of 1.02 tcf (New Mexico Energy, Minerals, and Natural Resources Department 1993). In that year, the northwest quadrant of the state produced about 54% of the state's total, with San Juan County producing 29% and Rio Arriba County producing 25% (Table 85) (New Mexico Energy, Minerals, and Natural Resources Department 1992). Within the northwest quadrant, gas production increased by 47,317,065 thousand ft^3 (1,339,857 thousand m^3) from 1990 to 1991, with 51,433,759 thousand ft^3 (1,456,428 thousand m^3) gained in dry gas and the difference lost in casinghead gas production (Table 86) (New Mexico Energy, Minerals, and Natural Resources Department 1992). As previously noted, a total of 735 wells, both oil and gas, were completed in the northwest region in 1991; many of these were drilled in 1990 in the Fruitland coal seams (New Mexico Energy, Minerals, and Natural Resources Department 1992).

As with oil, gas is produced in the Colorado portion of the San Juan basin in Archuleta, Dolores, La Plata, and Montezuma counties. In 1991, two gas wells were completed in Archuleta County; none

Table 85: New Mexico dry and casinghead gas production for 1991 ranked by county

Rank	County	Location	Gas-MCF	1990-91% Increase-Decrease	% of Total State Production
1	San Juan	NW	294,170,013	+10.6	28.9
2	Rio Arriba	NW	258,102,878	+8.1	25.3
3	Lea	SE	247,934,976	+0.8	24.2
4	Eddy	SE	184,114,815	+7.9	18.1
5	Chaves	SE	29,830,839	-21.4	2.9
6	Roosevelt	SE	2,946,952	-22.0	0.3
7	Sandoval	NW	1,929,100	-9.8	0.2
8	McKinley	NW	203,563	-31.1	0.02
1991 State Total Gas Production			1,019,233,136	+5.6	100

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

Table 86: Comparison of 1990 and 1991 gas production in New Mexico

	Gas production (thousand cubic feet)			
	1990	1991	Increase	Decrease
Dry				
Southeast	291,023,271	280,504,727		10,518,544
Northwest	477,548,484	528,982,063	51,433,759	
Total	**768,571,755**	**809,846,790**	**41,275,035**	
Casinghead				
Southeast	167,233,782	184,322,855	17,089,073	
Northwest	29,540,005	25,423,491		4,116,514
Total	**196,773,787**	**209,746,346**	**13,012,559**	
Total Gas				
Southeast	458,257,053	464,827,582	6,570,529	
Northwest	507,088,489	554,405,554	47,317,065	
Total	**965,345,542**	**1,019,233,136**	**53,887,594**	

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

were completed in Dolores County; and two gas wells were completed in Montezuma County. La Plata County, as opposed to the others, experienced a dramatic increase in its number of wells, with 187 new wells completed (Table 87) (Colorado Oil and Gas Conservation Commission 1993). In 1991 La Plata County was first in coalbed methane production, with a total of 505 wells producing 43,917,217 million ft^3 (1,243,585 million m^3) of gas (Colorado Oil and Gas Conservation Commission 1993).

As previously noted, Utah compiles its gas and oil statistics on a monthly basis. In April 1993 San Juan County produced 2,287,748 million ft^3 (64,781 million m^3) of natural gas, or about 7% of the state's total for the month. In total, all San Juan County wells have produced, over time, 1,056,909,985 million ft^3 (29,928,076 million m^3) of gas, which is about 23% of the state's total (Utah Division of Oil, Gas, and Mining 1993a). Utah's statistics do not specify types of gas wells, but because there is no coal production in San Juan County there are likely few or no coalbed methane wells.

An accounting from the late 1970s found that more than 70% of natural gas produced in the U.S. originated from wells containing only natural gas (Eiceman 1987); with the production of coalbed methane this percentage has undoubtedly increased. However, where natural gas is found together with oil, gas will almost always rise to the top with oil underneath and salt water remaining at the bottom. The majority of the water is separated from the oil and gas in a field separator unit, resulting in produced water. Heavier hydrocarbons and remaining water vapor are stripped from the gas by a sudden pressure drop and are subsequently isolated in a phase separator. The resulting gas may still contain light hydrocarbons, some condensate, impurities, and some water. Light and heavy hydrocarbons are recovered from the gas for use in fuels or petrochemical feedstock or in order to reduce disruptions in the gas flow through pipelines. The remaining water and acid gas impurities must be removed to prevent pipeline freeze-ups and corrosion of equipment; this removal is conducted both in field and at gas processing plants (Figure 44) (Eiceman 1987).

The produced water and other wastes, such as drilling fluid, may be stored in open-air pits or holding reservoirs. In waste disposal pits near natural gas wells, a hydrocarbon phase is often found with the produced water; this is probably the result of faulty field separators (Eiceman 1987). Coalbed methane production generates even larger quantities of water than does casinghead or other dry gas wells. As of 1991 the produced water from coalbed methane wells in New Mexico had not been found to contain appreciable amounts of dissolved hydrocarbons or high concentrations of NORMs. However, coalbed methane wells do increase the chance of methane contamination of groundwater, which has been documented in the San Juan basin (New Mexico Energy, Minerals, and Natural Resources Department 1991). The disposal of gas well and processing plant wastes in surface pits was carried out widely from 1930-1970s and is still practiced in the Southwest, especially in New Mexico (Eiceman 1987). The New Mexico Energy, Minerals, and Natural Resources Department (1991) concedes that many conventional gas well sites still have open pits, but notes the tightening of disposal regulations by both the OCD and the BLM. Newer gas wells, particularly coalbed methane wells, discharge all waste fluids to tanks in which they are trucked to state-approved disposal sites (New Mexico Energy, Minerals, and Natural Resources 1991).

The risk of groundwater and soil contamination from surface pits is a factor of pit construction and location. Most gas well operators in New Mexico who dispose of wastes in surface pits use temporary plastic liners to minimize fluid loss to the environment (New Mexico Energy, Minerals, and Natural Resources Department 1991). At least as late as 1987, though, unlined shallow earthen pits were used in northwest New Mexico. Seepage from unlined evaporation pits and the subsequent contamination of groundwater has been widely reported; in an unlined pit in Utah, for example, 93% of the produced water seeped into the soil with only 7% evaporating. Evaporation from pits has been determined to be as low as 5%, even in the Southwest, with large water losses to seepage. The potential for groundwater contamination is increased where natural gas wells and associated surface pits are located in floodplains and river valleys, a practice that is especially common in New Mexico (Eiceman 1987).

Eiceman (1987) has investigated hazardous waste pollution from natural gas disposal pits in the San Juan basin. The contents of six waste pits from Cuba, Archuleta, Flora Vista, and Aztec, New Mexico were sampled for PAHs, large molecular-weight alkanes, and VOCs (Tables 88 and 89).

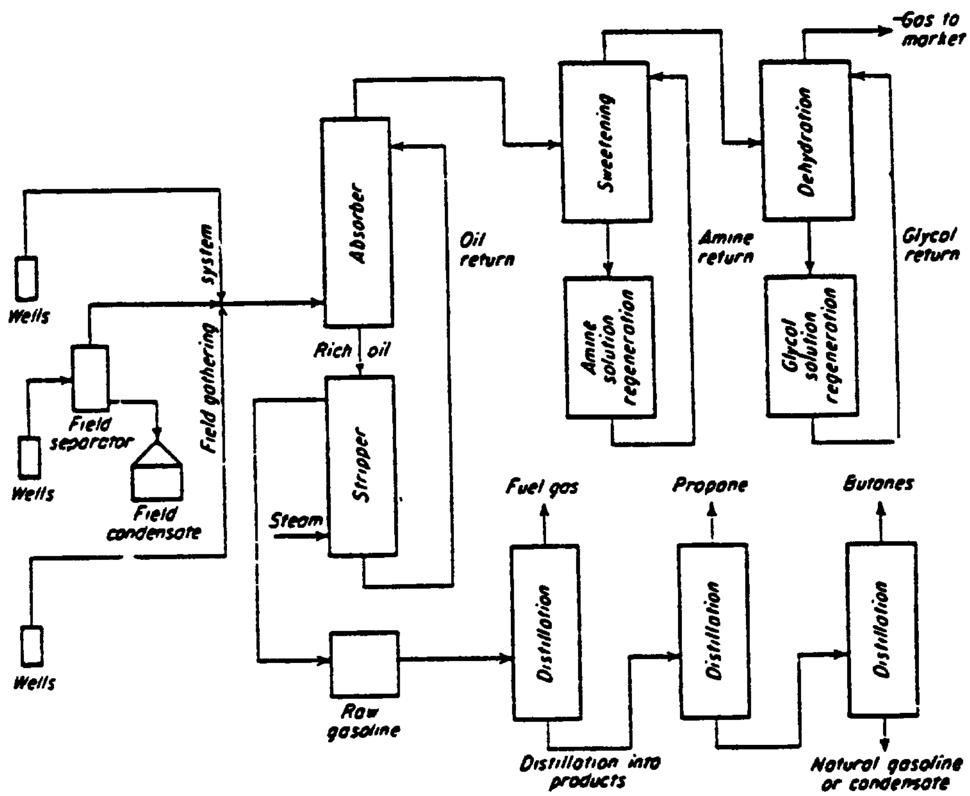


Figure 44. Simplified flow diagram of gas processing. (Taken from Eiceman 1987)

Table 87: Coalbed methane production for 1991, Colorado

County	Number of producing wells	Gas (Mcf)
La Plata	505	43,917,217
Garfield	52	2,580,108
Rio Blanco	11	1,206,607
Mesa	16	267,673
Las Animas	0	38,145
Archuleta	0	6,908
Moffat	1	0

Taken from Colorado Oil and Gas Conservation Commission 1992

Table 88: Concentrations of PAH in aqueous phase of waste pits from natural gas production

	(Concentration in μg/l)				
Compound	Cuba	Archuleta	Flora Vista IE	Bloomfield	Flora Vista 1E (A)
Naphthalene	850	480	ND	ND	500
C1-Naphthalene	770	390	ND	ND	1900
C2-Naphthalene	1300	2500	ND	ND	4200
C3-Naphthalene	1400	2400	ND	ND	3600
Biphenyl	680	480	ND	ND	450
C1-Biphenyl	850	720	ND	ND	1400
C2-Biphenyl	1000	1700	ND	ND	1400
C3-Biphenyl	1100	920	ND	ND	960
Anthracene	200	430	3.5	130	530
C1-Anthracene	290	560	5.2	ND	1900
C2-Anthracene	260	380	ND	ND	2200
C3-Anthracene	180	170	ND	ND	1700
Fluorene	82	140	ND	ND	320
C1-Fluorene	180	360	ND	ND	650
C2-Fluorene	140	390	ND	ND	870
C3-Fluorene	78	430	ND	ND	650
Pyrene	13	200	300	ND	410
C1-Pyrene	65	130	1400	ND	260
C2-Pyrene	46	100	ND	ND	280
C3-Pyrene	33	160	ND	ND	280
Benzopyrene	ND	ND	ND	ND	ND
C1-Benzopyrene	ND	ND	ND	ND	ND
C2-Benzopyrene	ND	ND	ND	ND	ND
C3-Benzopyrene	ND	ND	ND	ND	ND
TOTAL	9517	14,740	1709	130	24,460

ND = Not Detected

Taken from Eiceman 1987

Table 89: Concentrations of PAH in non-aqueous phase of waste pits from natural gas production

Compound	Cuba	Archuleta	Flora Vista IE	Flora Vista IE(A)	Flora Vista	Aztec
	(Concentration in mg/kg)					
Naphthalene	160	23	240	80	375	ND
C1-Naphthalene	110	22	290	410	250	ND
C2-Naphthalene	1500	190	4700	1000	2600	1100
C3-Naphthalene	1600	170	3400	590	1200	360
Biphenyl	54	23	390	72	230	ND
C1-Biphenyl	230	86	1200	250	450	33
C2-Biphenyl	420	120	1100	280	300	160
C3-Biphenyl	320	85	650	270	45	130
Anthracene	130	52	220	17	150	26
C1-Anthracene	240	66	400	120	280	33
C2-Anthracene	140	34	290	130	200	15
C3-Anthracene	99	23	190	79	99	14
Fluorene	27	11	66	30	38	8
C1-Fluorene	39	27	130	61	56	10
C2-Fluorene	36	54	84	86	41	10
C3-Fluorene	30	56	19	92	32	10
Pyrene	24	10	26	13	13	6
C1-Pyrene	24	8.6	24	28	13	5
C2-Pyrene	10	8.6	19	30	12	ND
C3-Pyrene	9	11	11	33	11	ND
Benzopyrene	ND	ND	ND	ND	ND	ND
C1-Benzopyrene	ND	ND	ND	ND	ND	ND
C2-Benzopyrene	ND	ND	ND	ND	ND	ND
C3-Benzopyrene	ND	ND	ND	ND	ND	ND
TOTAL	5202	1,055	13,449	3451	11,895	1920

ND = Not Detected

Taken from Eiceman 1987

Concentrations in the aqueous phase of waste pits were as high as 10-50 mg/l (ppm) for VOCs and 25 mg/l for total PAHs. Non-aqueous phase concentrations were much larger, with PAH concentrations of 1,050-13,500 mg/kg (ppm). The non-aqueous phase may comprise as much as 50% or more by volume of a waste pit's contents; thus, any assessment of waste pit material must include both phases. It is possible for PAH compounds to be adsorbed onto the bottom soil in disposal pits and to remain in the soil after water has percolated through, posing a long-term groundwater hazard. For this reason, abandoned or inactive pits must not be discounted as potential hazards to water quality.

Eiceman (1987) selected one waste pit in the Duncan Oil Field west of Farmington for analysis of PAHs in the soil at groundwater level. The study area was on the San Juan River floodplain and was similar to nearby floodplain sites on which over 1,500 other wells were located. Nine test pits were drilled at the site (Figure 45). The results indicated that PAHs were present in the soil down-gradient from the waste pit and suggested that PAHs in the soil system had limited mobility (Table 90). The author, however, noted that the pit was only 10 years old and that in earlier studies PAHs were found at depths of up to 1.8 meters from the pit bottom, or 2.5 meters from the land surface. In the area of the Duncan Oil Field, groundwater is encountered from 1-1.5 meters below the land surface, making contamination by PAHs possible (Eiceman 1987).

The transport of natural gas via pipelines from the field to processing plants has its own contaminant hazards. Small leaks due to corrosion, improper welds, or mechanical failure generally are undetected and may result in significant contamination over the course of time. Large pipeline breaks, usually the result of damage by excavation crews, may discharge up to 40,000 liters of gas product before the flow can be stopped (Jercinovic 1982). The more extensive the pipeline system and the older it is, the greater the chance of product discharge and subsequent soil, groundwater, or surface water contamination. In New Mexico, two major pipeline projects were completed in 1992, thereby increasing the transport capacity out of the basin As of November 1, 1992, there were 16 natural gas pipelines in New Mexico (listed in Table 91 and shown in Figure 41) (New Mexico Energy, Minerals, and Natural Resources Department 1992).

Contamination from natural gas pipelines may also result from the discharge of water used in the process of hydrostatic testing. Hydrostatic testing is the method by which natural gas pipelines are cleaned and tested for structural defaults. The method of testing involves filling the pipeline with water from local sources, pressurizing it, and then dropping the pressure in order to locate flaws in the pipeline at certain pressures. The water used for the testing is then removed with the aid of a metal or plastic pig which also serves to clean condensate from the pipelines. In some cases, a pig is forced through the pipeline prior to the testing to remove a large portion of the condensate in advance. The wastes from this dry-pigging process most likely contain higher concentrations of those materials otherwise found in discharge water following testing (Eiceman et al. 1983, Eiceman et al. 1984).

New pipelines are expected to contain virtually no condensate, whereas pipelines 2-15 years in age may contain significant volumes of condensate composed of large molecular-weight organic compounds (Eiceman et al. 1984, Eiceman 1987). These compounds may include PAHs, benzenes, and alkylated derivatives (Eiceman et al. 1984, Eiceman et al. 1985). Hydrostatic testing can produce as much as 2 million liters of discharge water containing potentially hazardous concentrations of these compounds. Historically, this water was discharged onto the ground surface or into unlined holding ponds or rivers (Jercinovic 1982, Eiceman et al. 1983, Eiceman et al. 1984). Discharge onto the ground surface and into holding ponds poses the hazard of groundwater contamination, and discharge to rivers results in contamination similar to that of oil spills (Jercinovic 1982, Eiceman et al. 1984).

Eiceman et al. (1983) analyzed the discharge water from two old natural gas pipelines in the Southwest. Five samples from the two pipelines had total VOC concentrations of 150 mg/l, 20 mg/l, 13 mg/l, 10 mg/l, and 7 mg/l, although the authors noted that fresh samples would have higher concentrations. In one sample, over 40 partially resolved VOCs were detected. Three classes of organic compounds based on benzene, disulfides, and alkanes were detected in the samples. Eiceman et al. (1984) analyzed several of the same samples and detected in the discharge water over 100 PAHs and alkylated PAHs. The concentrations of these compounds in three samples from one pipeline are listed and compared to

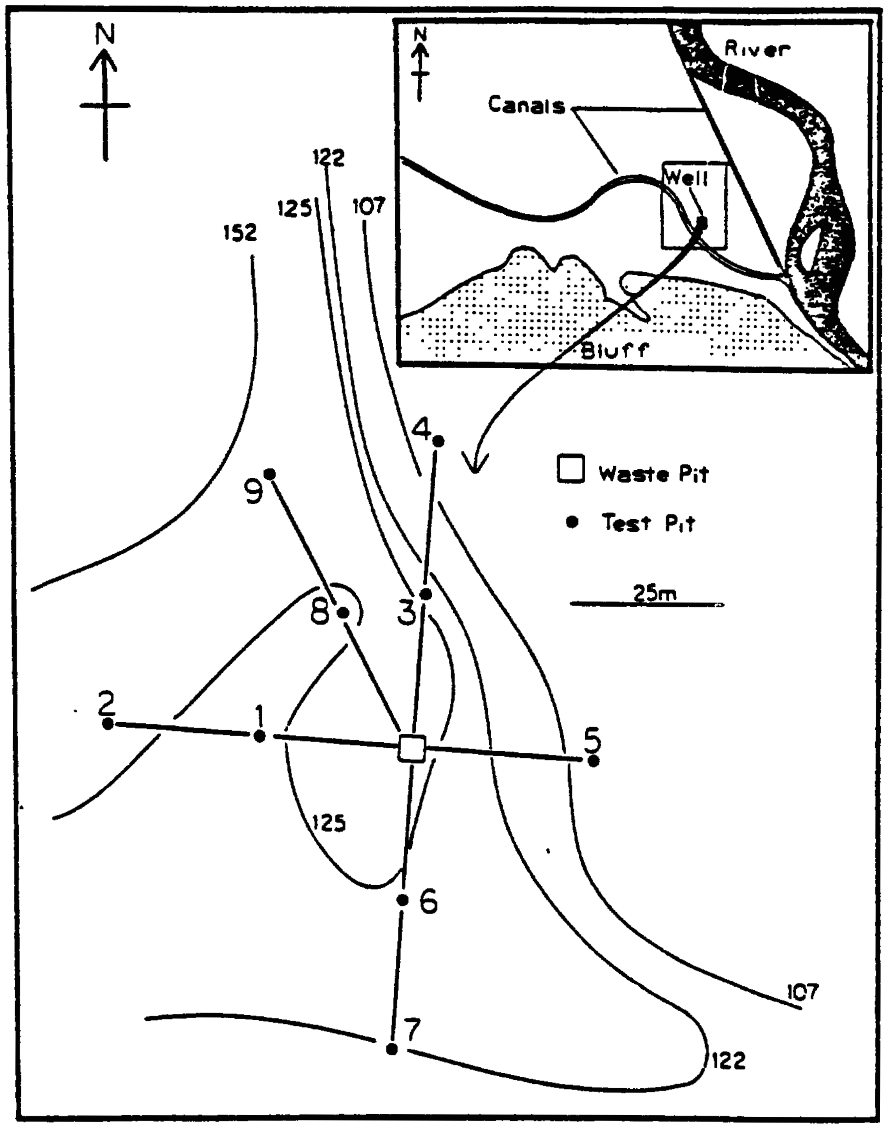


Figure 45. Map of Eiceman (1987) test site in Duncan Oil Field, northwestern New Mexico. (Taken from Melancon et al. 1979)

Table 90: Concentrations (μg/kg) of PAH in soils at Duncan Oil Field test site

Compound	Mass (amu)	Test Pit Number 1	2	3	4	5	6	7	8	9
Naphthalene	128.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
C1-Naphthalene	142.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
C2-Naphthalene	156.1	240	ND	ND	ND	ND	ND	ND	ND	ND
C3-Naphthalene	170.1	230	9.1	ND	9.8	ND	3.9	6.1	530	1.0
C4-Naphthalene	184.1	18	39	480	80	10	29	31	280	7.2
Biphenyl	154.1	8.4	ND	7.9	ND	2.8	ND	ND	13	ND
C1-Biphenyls	168.1	32	ND	58	15	ND	2.3	ND	18	0.18
C2-Biphenyls	182.1	830	0.53	40	6.5	ND	5.9	3.1	680	0.62
C3-Biphenyls	196.1	1300	11	70	10	ND	16	7.3	730	0.47
C4-Biphenyls	210.1	1900	0.92	750	230	37	0.16	83	110	
Fluorene	116.1	2.9	ND	0.66	0.032	ND	ND	ND	0.52	0.076
C1-Fluorenes	180.1	4.9	ND	3.9	0.25	1.2	0.61	0.28	13	0.10
C2-Fluorenes	194.1	68	12	38	0.78	ND	2.85	0.82	120	0.22
C3-Fluorenes	208.1	110	89	130	19	5.5	18	9.4	170	11
C4-Fluorenes	222.1	53	4.5	88	0.42	0.72	0.43	0.26	80	0.10
Anthracene*	178.1	0.51	ND	0.25	0.068	0.16	0.14	0.10	0.69	0.12
C1-Anthracenes	192.1	0.0020	0.15	7.1	0.034	0.20	0.088	0.058	18	0.032
C2-Anthracenes	206.1	19	5.4	20	0.70	0.23	1.4	0.56	22	0.39
C3-Anthracenes	220.1	24	0.85	26	0.078	0.084	0.21	0.11	27	0.14
C4-Anthracenes	234.1	8.3	2.3	10	0.44	0.55	0.57	0 26	9.8	0.15
Pyrene**	202.1	2.8	0.056	12	0.030	0.072	0.024	0.043	1.6	0.056
C1-Pyrenes	216.1	6.2	0.013	33	0.0080	0.034	0.017	0.012	5.2	ND
C2-Pyrenes	230.1	1.4	0.39	17	0.033	0.042	0.056	0.023	4.3	0.010
C3-Pyrenes	244.1	0.41	0.39	17	ND	0.014	ND	ND	0.80	ND
C4-Pyrenes	258.1	0.19	0.074	6.7	ND	0.012	0.004	0.20	ND	
Summed concentrations		4900	270	2000	370	59	89	140	3400	22

ND = Not Detected

Data satisfactory to two (2) significant figures

* Including phenanthrene

** Including benzanthracene

Taken from Eiceman 1987

Table 91: Natural gas transmission pipelines in New Mexico as of 1 November 1992

Company	Interstate/Intrastate Company
Associated Natural Gas	Intrastate
Brazos Gas Transmission, Ltd.	Intrastate
Comanche Gas Gathering	Intrastate
El Paso Natural Gas Company	Interstate
Gas Company of New Mexico	Intrastate
Llano, Incorporated (Hadson New Mexico, Inc.)	Intrastate
Maple Gas Corporation	Intrastate
Natural Gas Pipeline Company of America	Interstate
Northern Natural Gas Company	Interstate
Northwest Pipeline Corporation	Interstate
Pelto Oil Company	Intrastate
Phillips Petroleum Company	Intrastate
Raton Transmission Company	Interstate
Transwestern Pipeline Company (Enron, Inc.)	Interstate
West Texas Gas, Inc.	Interstate
Westar Transmission Company	Intrastate

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

concentrations in natural gas (Table 92) (Eiceman et al. 1984.) It was found that total PAH content decreased throughout the dewatering process from 32,000 $\mu g/l$ at the beginning to less than 8,000 $\mu g/l$ toward the end (Eiceman et al. 1984).

New Mexico, Colorado, and Utah each have their own regulations for hydrostatic testing discharge releases. In New Mexico, discharges from old pipelines always require individual permits and no releases may be made to surface water or the ground surface. Options for disposal include transporting the water to holding ponds at gas processing plants or injecting it into a specified class of well. Discharge of water from new pipelines requires an individual permit if more than 100,000 gallons of water is released, whereas a blanket permit can cover smaller releases. Water from new pipelines may be released to surface water or may be put to such uses as agriculture (Brown, personal communication). Colorado has no specific regulations for the disposal of discharge water; discharges simply must not degrade surface or groundwater beyond state standards (Pott, personal communication). In Utah, a pipeline operator must request permission to dispose of discharge water from hydrostatic testing, and permits are granted on a case-by-case basis, depending on the material used for the testing and the volume of discharge. All discharges to Utah surface waters must be permitted (Moellmer, personal communication).

Only limited information exists concerning the contamination hazards posed by natural gas processing plants, where such products as butane and propane are distilled. In New Mexico there were, as of late 1991, nine operating plants in the northwest quadrant. The intake and production statistics for these plants are listed (Table 93) (New Mexico Energy, Minerals, and Natural Resources Department 1992). Additionally, there are several abandoned gas processing plants in the area. Gasoline leaked from one abandoned New Mexico refinery has been suspected of contaminating a nearby private well, where benzene concentrations were as high as 0.28 mg/l, or 28 times the New Mexico groundwater standard (Jercinovic 1985, New Mexico Water Quality Control Commission 1991). Colorado has four gas processing plants in Montezuma, Dolores, and La Plata counties. The intake and production of these plants are listed (Table 94) (Colorado Oil and Gas Conservation Commission 1993). No processing plants are noted in Utah's Oil and Gas Production statistics (Utah Division of Oil, Gas, and Mining 1993a).

4.12.5 NON-FUEL MINERALS MINING

Portions of San Juan basin surface waters have been severely impacted by metals mining. Within the entire Upper Colorado River basin, it has been estimated that abandoned and active mines have eliminated 120 miles of fisheries. Some of the most heavily polluted areas include the Animas River and two of its tributaries, Cement and Mineral creeks. As a result of pollution from inactive mines, primarily uranium, vanadium, zinc, and lead, the surface water in the San Juan Mountains of San Juan County, Colorado, is among the most polluted in the entire Upper Colorado River basin (Upper Colorado Region State-Federal Inter-Agency Group 1971, Melancon et al. 1979).

Toxic mine drainage results when surface runoff or shallow groundwater percolates through mine spoils or worked ore bodies and subsequently experiences a decrease in pH, an increase in heavy metals and salts, or both (Upper Colorado Region State-Federal Inter-Agency Group 1971, Melancon et al. 1979, U.S. Bureau of Reclamation 1992b, Yahnke, personal communication). Higher surface water flows lead to greater erosion and flushing of mine tailings (U.S. Bureau of Reclamation 1992b). Irrigation return flows may provide one source of increased flows, although large-scale irrigation is not present in the upper San Juan basin where extensive metals mining has historically occurred (Melancon et al. 1979). Although such processes as sorption and cation exchange would normally retain trace elements that infiltrated shallow aquifers, chronic infiltration could exhaust these mechanisms and result in significant groundwater contamination (Gallaher and Goad 1981).

Heavy metal pollution, acid water, and silt from the Silverton mining district have eliminated all aquatic life for the first several miles of the upper Animas River (U.S. Fish and Wildlife Service 1993). Specifically, elevated levels of iron, manganese, copper, lead, zinc, silver, and arsenic, combined with low pH, have eliminated fish, bottom organisms, and insects (Upper Colorado Region State-Federal Inter-Agency Group 1971, U.S. Bureau of Reclamation 1976, U.S. Bureau of Reclamation 1979). From 1970-

Table 92: Amounts of PAHs and alkylated PAH in samples of discharge water from hydrostatic testing of natural gas pipelines and in natural gas supplies to the laboratory

		(Concentration in µg/l)*			
Compound	Max. no. of isomers detected**	A1	A2	A4	Natural gas (µg/cubic meter)*
Naphthalene	1	86	57	150	11
C1-Naphthalene	2	990	99	1900	147
C2-Naphthalene	5	2200	1300	2200	79
C3-Naphthalene	7	4000	190	610	44
C4-Naphthalene	11	5000	150	170	17
Biphenyl***	1	120	78	540	12
C1-Biphenyl	3	250	78	160	4
C2-Biphenyl	7	1100	59	160	20
C3-Biphenyl	5	2400	66	130	9.5
C4-Biphenyl	4	2000	78	790	5.3
Fluorene	1	100	7	33	2.1
C1-Fluorene	2	1100	18	17	1.7
C2-Fluorene	4	2900	46	36	2.5
D3-Fluorene	5	3000	64	40	3.8
C4-Fluorene	8	2200	71	30	3.8
Anthracene	3	320	40	52	2.6
C1-Anthracene	2	740	68	48	4.2
C2-Anthracene	4	860	120	72	5.5
C3-Anthracene	7	90	21	46	3.6
C4-Anthracene	10	750	78	20	1.1
Pyrene	3	860	46	22	2.3
C1-Pyrene	5	400	24	15	0.6
C2-Pyrene	5	280	26	16	0.6
C3-Pyrene	6	300	26	15	0.7
C4-Pyrene	3	250	24	17	0.8
Total	114	32,356	2834	7649	384.7

* Data only satisfactory to two (2) significant figures

** These numbers may vary slightly based upon resolution and assignment of identity

*** Quantified versus naphthalene. All others quanitified versus deuterated PAH of same structure

Taken from Eiceman et al. 1984

Table 93: Intake and production from gas processing plants in northwest New Mexico, 1991

Company/Plant	Total Gas Intake (Mcf)	Production Bbls Gasoline	Production Bbls Butane	Production Bbls Propane
Bannon Energy Inc.				
South Blanco	1,781,988	24,399	35,218	52,675
Conoco, Inc.				
San Juan	176,965,040	1,218,402	1,733,609	3,483,963
El Paso Natural Gas Co.				
Blanco	174,945,773	---	---	---
Chaco	71,453,904	199,677	256,753	264,065
Greenwood Holdings, Inc.				
Gallup	64,819	---	---	---
Meridian Holdings, Inc.				
Wingate	---	1,236,580	1,765,267	2,557,561
Phelps Dodge Refining Corp				
Gavilan	288,893	---	---	383
Sun Terra Gas Processing Co.				
Kutz Canyon	33,818,798	242,491	345,975	696,941
Lybrook	19,734,647	68,547	242,887	534,247
Western Gas Processors				
San Juan River	11,888,432	---	---	---
NW Total	490,942,294	2,990,996	4,379,819	7,589,935

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

Table 94: Intake and production from Colorado gas processing plants in the San Juan basin, 1991

	Cutthroat Northern Montezuma County Celsius Energy Company		Cutthroat Southern Montezuma County Celsius Energy Company		Dove Creek Dolores County Celsius Energy Co.		San Juan La Plata County Northwest Pipeline Corp.	
	Intake (Mcf)	Products (Bbls)	Intake (Mcf)	Products (Bbls)	Intake (Mcf)	Products (Bbls)	Intake (Mcf)	Products (Bbls)
Cumulative	1,338,934	146,771	1,313,613	148,033	11,314,780	734,141	2,126,518,624	37,953,038
January	31,221	3,584	69,471	4,930	62,523	1,988	6,670,958	177,263
February	36,366	4,059	56,786	4,141	49,642	1,928	6,744,429	193,364
March	41,380	4,750	62,559	4,199	48,218	1,670	7,350,758	221,966
April	24,985	2,634	51,846	3,263	40,676	1,532	6,782,270	128,159
May	37,761	4,428	59,789	4,127	44,728	1,828	6,150,976	160,345
June	37,355	4,283	58,287	3,975	81,996	3,969	6,050,587	143,147
July	37,571	3,862	36,572	2,325	98,174	5,607	5,888,561	165,183
August	35,735	2,690	58,088	3,539	97,992	4,788	5,227,627	87,233
September	40,979	4,355	38,089	2,451	65,751	3,270	5,442,897	173,534
October	33,326	3,533	35,677	2,099	130,101	8,730	7,428,210	218,730
November	47,725	6,052	44,201	3,332	135,489	8,147	4,173,304	107,834
December	48,551	6,280	36,291	3,264	127,671	8,027	4,826,658	214,924
Totals: 1991	452,955	50,510	607,656	41,645	982,961	51,484	72,737,235	1,991,682
New Cumulative	1,791,889	197,281	1,921,269	189,678	12,297,741	785,625	2,199,255,859	39,944,720

Taken from Colorado Oil and Gas Conservation Commission 1992

1976, pH values in Mineral Creek ranged from 5.1 to 8.8, and a value of 4.0 was recorded in Cement Creek in the mid-1960s (Melancon et al. 1979). Where the river enters Animas Canyon, about eight kilometers downstream from Silverton, tributary streams dilute the Animas to the extent that more resilient aquatic organisms can survive; all tributaries in the canyon support fish life except Ten Mile Creek. According to the FWS, by about 24 km above Durango, where the river enters the Animas Valley, heavy metal concentrations are low enough that they apparently no longer restrict aquatic life (U.S. Fish and Wildlife Service 1993). However, the CDOW has found that although trout can survive in the Animas at Durango, successful reproduction of trout in this reach is rare. Brown trout may spawn, but heavy metals pollution and siltation cause near total mortality of the developing eggs. As a result, the trout fishery at Durango must be maintained by regular stocking (Japhet, personal communication).

The extent of mine tailings pollution at a given point in time is largely dependent on flows. From 1977-1980, high flows in the Animas resulted in significant mine tailings pond failure, with a large input of heavy metals upstream of the proposed Durango Pumping Plant (U.S. Bureau of Reclamation 1992a). Blanchard et al. (1993) report that during the similar period from 1975-1980, Farmington municipal water intake from the Animas River was suspended twice because of accidental heavy metal contributions from mining areas in the river's headwaters (Blanchard et al. 1993). Likewise, a decrease in zinc and cadmium concentrations in the Animas from 1980 to 1992 has been associated with lower flows in the river (U.S. Bureau of Reclamation 1992a).

New Mexico, Colorado, and Utah have each promulgated their own rules and regulations for non-fuel minerals mining, but these are too extensive for review in this document (Colorado Mined Land Reclamation Board 1991a, Colorado Mined Land Reclamation Board 1991b, Utah Division of Oil, Gas, and Mining 1992). These regulations apply to current mining activities, but abandoned mines evidently cause the bulk of heavy metal contamination in the San Juan basin. In an attempt to deal with contamination from these abandoned mines, Colorado is seeking damages through National Pollutant Discharge Elimination System (NPDES) suits from companies owning mining properties (Department of the Interior 1987). There have apparently been few attempts to reclaim those abandoned mine sites that persist in contaminating the river system.

4.12.6 URANIUM MINING AND MILLING

Uranium mining and milling have historically been significant activities in the San Juan basin, particularly in the geologic Paradox basin of Utah and Colorado. Water pollution may result from both mining and milling, although contamination from mining is rare whereas contamination from milling is common. Mill wastewaters are not only radioactive but also contain large TDS concentrations and are either highly acidic or alkaline. Highly radioactive solid wastes are also generated during uranium milling activities. In order to extract 1.8 kg of uranium, over a ton of ore is dumped as tailings and 3,275 liters of wastewater are generated. In fact, 95% or more of uranium ore processed becomes solid waste (Upper Colorado Region State-Federal Inter-Agency Group 1971). Uranium mill tailings piles are easily eroded and can yield effluent with radium-226 concentrations that exceed surface water quality standards (Melancon et al. 1979). Tailings may also contain selenium, molybdenum, and vanadium (San Juan Basin Regional Uranium Study 1980). Radium-226 is the major radiological pollutant resulting from uranium mining and milling, but standards for both uranium and radium-226 are usually based on chemical toxicity rather than radiological hazards (Upper Colorado Region State-Federal Inter-Agency Group 1971).

It is generally accepted that radium-226 sorbs easily to sediments and that stream sediments act as radium reservoirs (Gallaher and Goad 1981). Kunkler (1979) reports that some river sediments may have a nearly infinite capacity to sorb radium-226. One sediment sample collected from the Animas River near the inactive uranium mill at Durango had radium-226 activity of 800 pCi/g. According to Kunkler (1979), one liter of this sediment would have the activity of several thousand liters of millpond acid. Highly contaminated sediments may desorb radium-226, and the release of radium from sediments is stimulated by increased velocities and turbulence (Valdez et al. 1992). Studies have indicated that algae and some aquatic animals can assimilate radium-226, although the mechanism for assimilation is not known.

Uranium mining and milling within the San Juan basin have come to a standstill as a result of recent changes in market demand. Underground uranium mining in the U.S. stopped in late 1990 and early 1991 when the White Mesa mill at Blanding, Utah went on standby; among the affected mines were those in the Uravan mineral belt of southwestern Colorado and southeastern Utah (Chenoweth 1992). New Mexico still produces uranium, although only a small fraction has ever been produced within the San Juan basin. New Mexico's primary uranium-producing area is the Grants Mineral Belt, which is within the geologic San Juan basin but sits just to the south of the San Juan River basin. Within the San Juan River basin, a limited amount of uranium mining has occurred near Shiprock (O'Brien 1987). No uranium is presently being mined in either Colorado or Utah (Chenoweth 1992, Utah Division of Oil, Gas, and Mining 1993b).

Although there are currently no active uranium mills in the basin, contaminant hazards from historic milling activity may remain. The White Mesa mill was, prior to 1990, a significant producer of uranium as well as vanadium; in 1989 it received ore from more than 20 separate mines, approximately 15 of which were in the Uravan mineral belt (Chenoweth 1989, Chenoweth 1990). The most productive uranium period in the basin, though, was much earlier, from 1944-1966. In those years, 13 properties in Monument Valley, which straddles the Utah-Arizona border, produced 322,802.07 pounds of uranium oxide (Figure 46). By 1966 all of the economic ore was mined out in the valley and the mines have been inactive since (Chenoweth 1991). Up through 1965 there were seven mills in operation in the upper Colorado River basin, including mills in Moab, Mexican Hat, and Shiprock (Upper Colorado Region State-Federal Inter-Agency Group 1971).

The mill that has received the most attention in the basin is perhaps the uranium mill on the Animas River at Durango (*see* ANIMAS-LA PLATA section 4.8.6 for further background and data). From 1948 to 1963 the mill was in continuous operation, processing 500 tons of ore a day for recovery of vanadium as vanadium oxide and uranium as uranium oxide. In 1958 and 1959, studies were conducted on the effects of the mill on Animas River fauna. It was found that populations of bottom organisms in the river above the mill were similar to those in the Florida River and Lightner Creek. The west side of the Animas, conversely, supported no bottom fauna, and several large dead suckers were observed lodged in the middle of the river. The study revealed that bottom fauna populations, as well as insects important as fish food, were virtually eliminated by mill wastes for almost 30 miles downstream from the mill site. In 1959 the mill instituted pollution abatement measures that evidently led to limited water quality improvement (Anderson et al. 1963).

About 98% of radium-226 in uranium ore remains undissolved through the milling process. If ore solids are discharged to the surface water, radium may leach out for many years. This is apparently the mechanism by which dissolved-radium levels became elevated in the Animas River. In 1958, Animas River water near the Durango uranium mill had dissolved radium concentrations of 12.6 micromicrogram/l (12.6 picogram/l); in comparison, unpolluted Colorado River basin water at that time averaged 0.2 micromicrograms/l. Likewise, the natural background radium-226 concentration in sediments within the Colorado River basin averaged 1.6 micromicrograms/gram, whereas Animas River sediment contained 800 micromicrograms/gram (Anderson et al. 1963).

Anderson et al. (1963) conducted fish bioassays on composite samples of juvenile fish and on individual suckers from the Animas River as well as from the San Miguel and Dolores rivers. Radium-226 concentrations were determined in the fish (Table 95) as well as in associated algae, water, and sediment samples from each site (Table 96). The natural radium-226 content of juvenile fish from unpolluted water averaged 0.44 micromicrograms per gram of ash, with a range of 0.1-0.9 In comparison, juvenile suckers from several polluted locations had 3.4-47 micromicrograms per gram of ash, or about 10-100 times the levels in fish from unpolluted sites (Anderson et al. 1963).

As noted in section 4 8.6, radium-226 levels in the Animas River at Durango declined significantly with closure of the mill in 1963. No information is apparently available concerning historic

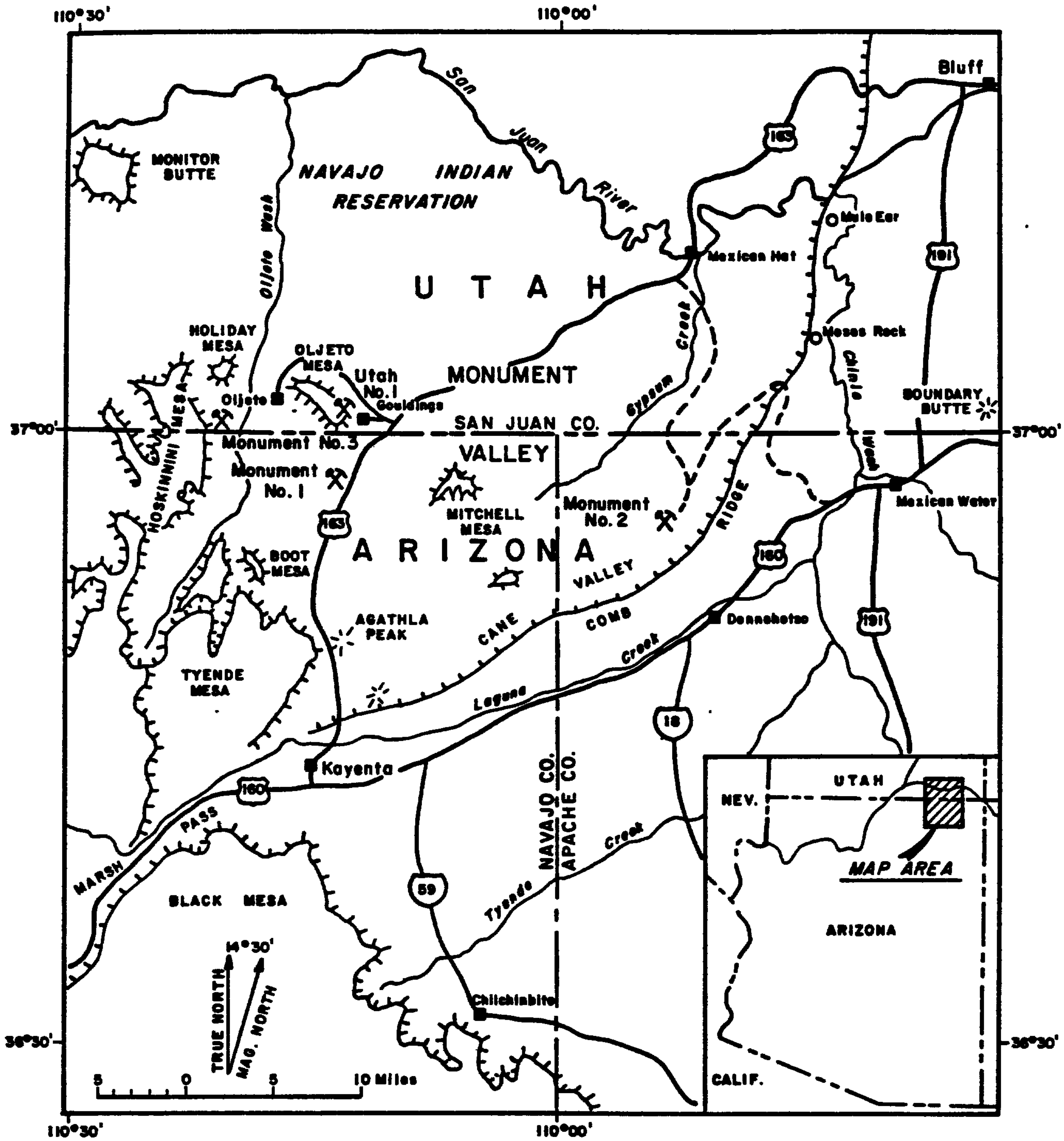


Figure 46. Map of Monument Valley showing the location of early carnotite leases. (Taken from Chenoweth 1991)

Table 95: Radium-226 content in fish, as measured by Anderson et al. (1963)
Single determinations

Location	Station No.*	Type*	Radium-226***
Animas River, 1958	1	juvenile suckers (10)	0.4
		juvenile brook trout (10)	0.1
		juvenile dace (10)	0.9
		juvenile sculpin (10)	0.2
		juvenile fathead (10)	0.6
	2	juvenile brook trout (5)	3.4
		juvenile suckers (10)	24
		juvenile dace (10)	19
		juvenile sculpin (10)	4.5
		juvenile fathead (10)	10
San Miguel River, 1956	1	juvenile suckers (9)	0.6
		juvenile dace (6)	0.3
	3	juvenile suckers (10)	14
		juvenile bonytails (6)	5.7
		juvenile dace (6)	10.6
Dolores River, 1956	11	juvenile suckers (10)	47
Animas River, 1958	1	sucker flesh	0.1
		sucker skeleton	5.0
	2	sucker flesh	1.4
		sucker skeleton	8.9
	5	sucker flesh	0.9
		sucker skeleton	7.7
San Miguel River, 1956	1	sucker skeleton	0.2
	3	sucker skeleton	1.7

* Refer to Table 96 for station locations and concentration of radium-226 in associated water and sediment.

** Numbers in parentheses refer to number of individuals in the composite sample. Lack of parentheses implies only a single individual analyzed.

*** Micromigrograms per gram of ashed weight.

Taken from Anderson et al. 1963

Table 96: Radium in algae, water, and sediment, as measured by Anderson et al. (1963)
Results of single determinations

Location	Station No.	Radium-226 concentration		
		Algae*	Water**	Sediment#
Animas River -	1	10 (17)	0 5	1.5
1.0 mile above		3.6 (31)	0.6	1.8
pollution		3.0 (24)	0 5	1 7
(summer 1958)		2.8 (17)	0.7	1.8
Florida River (tributary)	3	2.0 (6)	0.1	1.2
(summer 1958)		2.9 (54)	0.7	1.4
		4.9 (21)	0.2	2.4
		8.2	0.3	1.1
Animas River -	2	400	10 5	230
2.0 miles below		180 (1600)	15.5	240
pollution		61## (4070)	9.1	100
(summer 1958)		530 (4170)	15.5	115
Animas River -	4	96	7.2	
23 miles below		210 (2380)	8.4	60
pollution		190 (860)	5.7	46
(summer 1958)		110 (1250)	7.4	49
Animas River -	5	93 (780)	8.1	49
28 miles below		115 (960)	8.7	57
pollution		57 (820)	6.3	23
(summer 1958)		93 (1080)	7.2	19
Animas River -	6	14 (55)	2.9	32
59 miles below		13 (110)	3 4	29
pollution		23 (190)	2 8	13
(summer 1958)		30 (110)	2.7	10
Animas River -	1	3.3	0 1	1.1
April 1959	3		0 1	1.1
	2	880	24	600
	4	500	19	250
	5	390	16	140
	6	100	6 7	44
San Miguel River -				
(1956) above pollution	1	2.2 (14)	0.2	1 2
(1955)	none	5	0.3	
Animas River -				
(1955) above pollution	1	6	0.2	
Animas River -				
(1955) 0.5 mile below pollution	none	660 (2600)	3.3	
San Miguel River -				
(1955) 1.0 mile below pollution	none	560 (1420)	9 4	
San Miguel River -				
(1956) 4.4 miles below pollution	2	3500 (10,500)	22	2100
San Miguel River -				
(1956) 8 9 miles below pollution	3	200	7.2	7 8
Dolores River -				
(1956) 38 miles below pollution	11	350	32	24

* Micromicrograms per gram of ashed weight. Parenthetical figure is gross alpha activity in micromicrocuries per gram
** Two-week composite samples. Micromicrograms dissolved per liter
\# Micromicrograms per grams of dry weight
\## This result clearly eronneously low

Taken from Anderson et al. 1963

contamination of other mills that operated in the San Juan basin. Because all of the mills were closed by 1969, the chance of ongoing contamination has presumably decreased with time (Melancon et al. 1979). As of 1983, radioactive values within the San Juan basin were generally within the limits of surface water standards (Roybal et al. 1983). Median concentrations of dissolved radium-226 are similar throughout the basin, although about 58% of all San Juan basin radium originates from the Animas River basin, which constitutes only 10.5% of the San Juan basin's total drainage area (Goetz and Abeyta 1987). Recent sampling of the Dolores River by Valdez et al. (1992) found sediment radium concentrations to range from 6.2-8.0 pCi/g, with one far outlying value of 20.4 pCi/g. These values are 3-3.3 times background radiation levels. Since the closure of the Uravan Mill in 1970, radium sediment concentrations have gradually decreased in the Dolores, although existing radium has apparently migrated downstream (Valdez et al. 1992). The effect of Dolores River radium on the San Juan River basin is undetermined.

4.12.7 COAL MINING

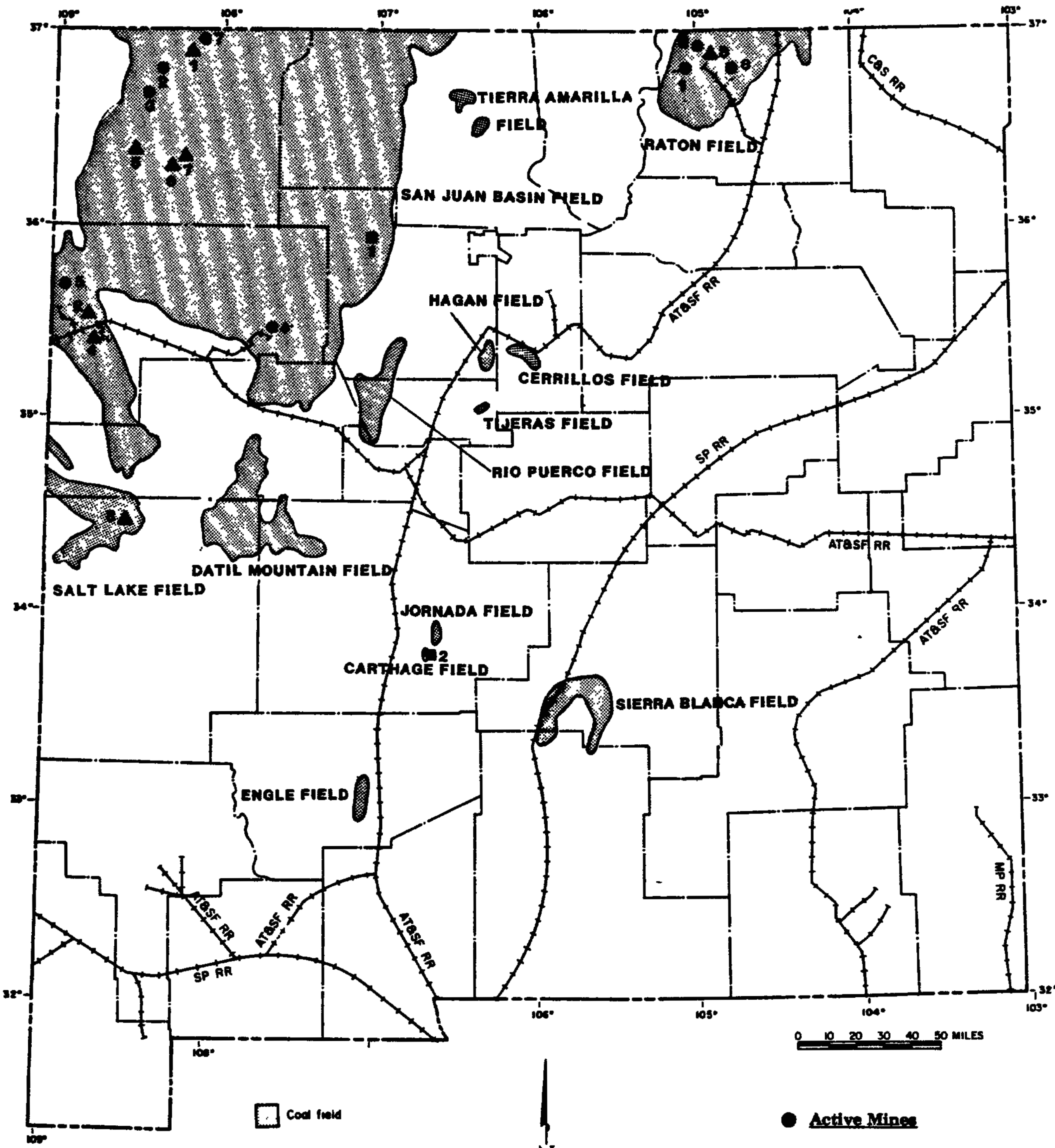
Within the San Juan River basin, the Mesaverde Group, the Fruitland Formation, and the Dakota Sandstone are the primary sources of coal (Roybal et al. 1983). The Fruitland Formation is the most productive, particularly for strip mining (Stone et al. 1983). Strippable coal deposits cross the San Juan River in the western part of the basin and are also located in the southern part of the basin in the Chaco River area (Roybal et al. 1983, Goetz and Abeyta 1987).

There are currently four active coal mines in the San Juan River basin, three in New Mexico and one in Colorado (New Mexico Energy, Minerals, and Natural Resources Department 1992, Colorado Division of Mines 1993). The two largest, the San Juan and Navajo mines, are both strip mines in New Mexico within the Fruitland Formation (Figure 47) (New Mexico Energy, Minerals, and Natural Resources Department 1992). The Navajo Mine is located south of the San Juan River along the Chaco River, and the San Juan Mine is north of the San Juan River near Shumway Arroyo (Melancon et al. 1979). The La Plata Mine, also a strip mine in the Fruitland Formation, is located just north of La Plata, New Mexico (Stone et al. 1983, New Mexico Energy, Minerals, and Natural Resources Department 1992). Four additional mines are either permitted or under reclamation within the New Mexico portion of the basin. The only active mine in Colorado is the underground King Coal Mine, located near Hesperus; two additional mines have recently become inactive, the Chimney Rock and Carbon Junction Mines, in Archuleta and La Plata counties, respectively (Ranney, personal communication). There is no coal mining in the Utah portion of the basin (Grubaugh-Littig, personal communication).

The New Mexico portion of the San Juan basin contains at least 180 billion tons of coal resources and nearly 9.5 billion tons of surface-minable reserves (New Mexico Energy, Minerals, and Natural Resources Department 1993). Coal production statistics for New Mexico coal mines from 1986-1991 are listed to show recent trends (Table 97) (New Mexico Energy, Minerals, and Natural Resources Department 1992). No yearly statistics are available for the King Coal Mine in Colorado, but from January through April 1993 the mine produced 57,675 tons of coal (Colorado Division of Mines 1993).

Coal is transported either by rail or truck, although the Navajo and San Juan Mines are both mine-mouth operations with their associated powerplants located on the same site (New Mexico Energy, Minerals, and Natural Resources Department 1993). The transport of coal can pose serious contamination problems ranging from erosion during road construction to spillage of waste products (Melancon et al. 1979, Gernard et al. 1983).

Coal mining operations, particularly strip mines, have the potential for significant surface water contamination. Mine drainage poses the largest hazard, as it can be acid and high in dissolved solids. Acid mine drainage is generally not of concern in the San Juan basin because overburden high in carbonates results in alkaline drainage that neutralizes the acids formed by the oxidation of pyrite in coal (Upper Colorado Region State-Federal Inter-Agency Group 1971, New Mexico Governor's Energy Taskforce 1975, Gernard et al. 1983). Alkaline conditions, though, may enhance the transport of contaminants such as molybdenum, fluorine, boron, arsenic, selenium, sulfate, cadmium, and mercury.



● **Active Mines**

1. York Canyon Surface (Pittsburg & Midway Coal Mining Co.)
2. San Juan (San Juan Coal Company - BHP Minerals)
3. Navajo (BHP Minerals)
4. Lee Ranch (Santa Fe Pacific Coal Corporation)
5. McKinley (Pittsburg & Midway Coal Mining Co.)
6. Cimarron Underground (Pittsburg & Midway Coal Mining Co.)
7. La Plata (San Juan Coal Company - BHP Minerals)
8. Ancho Surface (Pittsburg & Midway Coal Mining Co.)

▲ **Permitted or Under Reclamation**

1. Black Diamond (Baroid Drilling Fluids, Inc.)
2. Mentmore (Carbon Coal Company)
3. Fence Lake No. 1 (Salt River Project)
4. Carbon No. 2 (Carbon Coal Company)
5. Burnham (Consolidation Coal Company)
6. De-Na-Zin (Yampa Mining Company)
7. Gateway (Yampa Mining Company)
8. York Canyon Underground (Pittsburg & Midway Coal Mining Co.)

■ **Permit Revoked**

1. Arroyo No. 1 (Arroyo Mining Co., Inc.)
2. Tres Hermanos (Cactus Industries)

Figure 47. Map of coal mines and major coal fields in New Mexico. (Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992)

Table 97: Coal production, in tons, by mine in New Mexico, 1986-1991

County	Mine	1986	1987	1988	1989	1990	1991
Catron	Fence Lake #1	NP	100,036	Closed	Closed	Closed	Closed
Colfax	York Canyon Surface	928,574*	920,617*	621,030*	454,922*	579,931*	790,267*
Colfax	Cimarron (Upper York Exploration)**	570,436*	604,807*	221,810*	45,036*	72,961*	25,056*
Colfax	York Canyon #1**	193,983*	NP	NP	NP	NP	NP
McKinley	McKinley	4,798,744	3,563,360	5,092,179	5,841,496	5,738,231	5,234,896
McKinley	Mentmore	401,399*	Closed	Closed	Closed	Closed	Closed
McKinley	Lee Ranch	1,525,615	1,972,971	2,107,104	2,341,709	2,704,889	4,116,702
San Juan	Navajo	6,841,000	7,343,000	9,087,000	8,874,000	8,670,000	7,385,000
San Juan	San Juan	5,215,966	3,128,220	2,847,000	4,737,379	4,572,231	2,920,611
San Juan	De-Na-Zin	31,378	51,185	106,113	Closed	Closed	Closed
San Juan	Gateway	188,168	172,324	116,485	Closed	Closed	Closed
San Juan	La Plata	594,643	1,628,034	1,538,133	1,467,309	1,908,093	1,054,097

NP = No production

* Tons remaining after washing

** Underground mines

Taken from New Mexico Energy, Minerals, and Natural Resources Department 1992

Unlike acidity, high TDS concentrations are a significant problem in San Juan basin coal mine drainage. Studies of Navajo Mine suggest that spoils runoff is particularly high in sodium and chloride, and high TDS concentrations recorded in Shumway Arroyo have been attributed in part to drainage from the San Juan Mine (McWhorter et al. 1975, Melancon et al. 1979). Sediment loads in mine drainage also tend to be elevated and can be as much as 1000 times greater than in undisturbed areas (Gernard et al. 1983).

Strip mining, which predominates in the San Juan basin, must necessarily disturb large areas of land, resulting in high rates of erosion. Strippable coal deposits are normally those at least 0.9 meters thick with less than 76 meters of overburden and dipping less than 8° (Kelley 1981). The process of strip mining includes the clearing of vegetation and then the cutting of a trench through the overburden to expose the coal. Next, the overburden is placed next to the trench to form a spoil bank. After the coal is extracted from the first trench, a second trench is cut and its overburden is dumped in the first trench. The final result is a high spoil bank, a series of ridges, and an open trench at the end (New Mexico Governor's Energy Task Force 1975). State and Federal regulations require that strip mines in semiarid landscapes be restored to predesignated conditions in order to reduce erosion and sediment yield from the areas, but even properly reclaimed land may produce runoff with extremely high sediment loads (Wells and Rose 1981, Gernard et al. 1983).

Water is used for a variety of purposes in coal mining. Strip mining requires approximately 54.2-61.8 thousand liters of water per kilogram of coal mined (Melancon et al. 1979). The irrigation of reclaimed lands is also a major water user; more than 2,000 acre-feet (2.5 million m^3) of water a year had been used at the Navajo Mine by 1983 for this purpose. Water is also used for washing coal and controlling dust on mine roads (Stone et al. 1983).

Limited data exists for the effects of San Juan basin coal mines on basin surface water quality. As part of an Environmental Impact Statement prepared by the BLM for coal leasing alternatives in the New Mexico portion of the basin, surface runoff from reclamation plots at the San Juan and Navajo Mines was collected immediately downslope from the plots. The data show that the concentrations of most chemical constituents were within the range found in streamflows, with pH values slightly lower and some trace element concentrations slightly higher in streamflows (Appendix 25a) (U.S. Bureau of Land Management 1984). Further data also suggest that the reclamation of mined tracts has succeeded in decreasing sediment yield (Appendix 25b) (U.S. Bureau of Land Management 1984).

Goetz et al. (1987) attempted to determine the effects of coal mine and power generation effects on water quality in the San Juan basin above Shiprock. Surface runoff from the San Juan Mine and runoff from part of the Navajo Mine drain to the San Juan River, and the Chaco River receives the remainder and majority of runoff from the Navajo Mine. Because coal mining began in the study area in 1963, Goetz et al. divided historic data into pre- and post-1963 periods. Runoff samples were collected from mine-reclamation plots at both the San Juan and Navajo Mines as well as at the San Juan River. The available data did not permit the researchers to separate the effects of the coal mines from those of urbanization, agriculture, and other basin developments.

Severson and Gough (1981) compiled similar but more detailed data than Goetz et al. (1987) for reclaimed plots at the San Juan Mine (Appendix 26). The data indicate that mine spoil had extractable copper, iron, lead, and zinc levels 3-5 times greater than those of the associated topsoil. The combination of runoff and shallow groundwater affected by leachate has potentially increased concentrations of these elements in the San Juan River (Goetz et al. 1987).

4.12.8 COAL-FIRED POWERPLANTS

Until the 1960s, the San Juan basin contained little industrial activity outside of mining. With the development of the Four Corners and San Juan powerplants and their associated coal mines, energy-related business grew dramatically (Joseph and Sinning 1977). The two powerplants are extremely large: the Four Corners plant has a generating capacity of 2,269 megawatts, and the San Juan plant has a capacity of 1,710 megawatts (New Mexico Energy, Minerals, and Natural Resources Department 1992). Fossil fuel combustion is the largest energy-related source of trace element emissions to the atmosphere, and these elements may contaminate surface water through wet or dry deposition (Hunn et al. 1987). Coal is enriched in selenium and arsenic, and the two San Juan powerplants may be adding these elements and others to the basin's water. Moreover, blowdown water from the Four Corner Powerplant's cooling reservoir is released to the San Juan River via Chaco Wash and is further adding contaminants to the system (National Fisheries Contaminant Research Center et al. 1991).

The Four Corners plant and the Navajo Mine together make up the world's largest contiguous coal mine and electrical power generating complex (Stone et al. 1983). The plant, located near Fruitland, began operation in 1963 and utilizes pulverized coal for its generating units (Wiersma and Crockett 1978, Melancon et al. 1979). The plant has relatively short stacks; two are 76 meters high and two are 91 m (Wiersma and Crockett 1978). The only study conducted on trace element soil concentrations around the plant measured for zinc, lead, copper, and cadmium (Wiersma and Crockett 1978). Comparing the Four Corners soil concentrations to those of other powerplants, the study concluded that only cadmium was elevated. However, the study did not compare the soil concentrations to background concentrations elsewhere in the San Juan basin, nor did it measure for trace elements of special concern such as selenium, arsenic, and mercury.

The Four Corners plant withdraws 29,000 acre-feet (35.7 million m^3) of water per year from the San Juan River and returns about 12,000 acre-feet (14.8 million m^3) of water (U.S. Bureau of Reclamation 1993). Water is used largely for boiler feed and for supplying Morgan Lake, a 1,200 acre man-made lake that serves as the Four Corners plant cooling reservoir (New Mexico Water Quality Control Commission 1976, Stone et al. 1983). When TDS concentrations in the lake reach 1100-1200 mg/l, the lake is blown down; this blow down results in a return to the San Juan River of approximately 7,300 acre-feet (9.0 million m^3) of water per year (U.S. Bureau of Reclamation 1976, New Mexico Water Quality Control Commission 1976). The lake is blown down approximately every three months (Melancon et al. 1979).

Constituents in plant effluent discharged to Morgan Lake include, among others, lime, alum, salt, sulfuric acid, and sodium hydroxide (Melancon et al. 1979). A fair amount of data has been compiled on the lake's water quality. The U.S. Bureau of Reclamation (1976) has compiled trace element data for the lake ecosystem compartments (Table 98), for the water quality of seepage from Morgan Lake (Table 99), and for the water quality of surface runoff from the facility (Table 100). Morgan Lake fish have been found to contain high levels of mercury in their flesh, which may be a result of high mercury emissions from the plant's stacks. In 1971, the plant released approximately 1,900 kg of mercury to the air (Melancon et al. 1979).

The Four Corners facility includes five ash settling ponds that are used to eliminate particulates from ash effluents but which also may contain thickeners and hydrobins. Seepage and decant water from the ponds flow through the ground or are discharged directly to Chaco Wash. On average, Chaco Wash receives about 140-200 acre-feet (173,000-247,000 m^3) per month of fly ash pond decant water (U.S. Bureau of Reclamation 1976, New Mexico Water Quality Control Commission 1976).

The water that the plant withdraws from the San Juan River has a TDS concentration of about 350 mg/l, while the water that is returned to the river has a concentration of about 720 mg/l. Estimates of the increase in TDS levels in the San Juan River at Shiprock as a result of the powerplant range from 5-54 mg/l (U.S. Bureau of Reclamation 1976, New Mexico Water Quality Control Commission 1976, Melancon et al. 1979). The EPA has waived the powerplant from meeting zero-discharge standards because the return flow water quality is apparently acceptable and because it would be impractical to contain the return flows (U.S. Bureau of Reclamation 1993).

The Chaco River is naturally ephemeral, but as a result of Four Corners Powerplant discharges there is now perennial flow in the last 12.5 miles of the river (Myers and Villanueva 1986, Goetz et al. 1987, Liebermann et al. 1989). The base flow in the river is maintained at 15 ft^3/sec. Occasional, intense rainfall supplies additional flow. The mean annual dissolved solids concentration in the river is 801 mg/l (Liebermann et al. 1989). Upstream from the powerplant Chaco River water is dominated by sodium

Table 98: Selected trace element concentrations in ppm in Morgan Lake ecosystem

Element	"Intake" lake water	Net Plankton	Aquatic plants	Largemouth bass liver	Largemouth bass flesh	Bluegill sunfish liver	Bluegill sunfish flesh	Channel catfish liver	Channel catfish flesh	Tilapia liver	Tilapia flesh	Sediment
Arsenic	<0.01	0.57	1.8	<0.06	<0.03	0.09	0.08	1.1	<0.04	<3	<3	2.7
Antimony	0.007	<60	<20	<3	<3		<3		<3	<3	<3	
Aluminum	0.35	>2,000	>1,000	20	21	20	3		10		3	100,000
Beryllium	<0.1	7	1	<0.1	<0.1		<0.1		<0.1	<1	<1	<1
Boron	2	60	30	8	2	<0.3	<0.3		4		0.3	160
Bismuth	<0.1	<10	<10	<1	<1	<0.3	<0.3		<1		<0.3	<10
Barium	<3	300	80	<10	<10	<10	<10		<10			
Cadmium	<0.001	<60	<20	<3	<3		<3		<3	<3		
Chromium	<0.02	40	60	<2	<2		<2		<2	2	1	105
Copper	0.1	35	70	15	2	90	3		2		2	120
Calcium	93	>1,000	>1,000	200	500		>500		>500			>50,000
Cobalt	<1	15		<1	<1		<1		<1			28
Fluoride	2.3	24	21	10	1.7		7.7	28	3.5			65
Iron	<0.1	>1,000	>1,000	230	13	940	4		13	940	6	50,000
Lead	<0.001	50	25	0.5	0.5		1.5		0.5	0.3	0.3	16.9
Manganese	<0.1	100	200	4	0.6		1.5		1	0.5	<0.5	390
Magnesium	43	4,000	>5,000	150	300		600		400	100	200	10,000
Mercury	<0.001	1.4	0.04	0.39	0.18	7.7	0.18	0.6	<0.02	<0.2		<0.05
Silicon	4	>1,000	>1,000	40	55	20	30		38		20	100,000
Selnium	0.001	3.4	11.3	0.4	0.4	2.2	0.3	6.4	0.1			5.4
Tin	<0.1	>20	<20	<1	<1	2	<1		<1	2	<1	<30
Titanium	<0.1	>1,000	>1,000	1	<1	2	2		2		2	30,000
Vanadium	<0.1	60	25	10	<0.5		<0.5		<0.5	8	<0.3	65
Zinc	<1	150	50	8	8	22	7		5	22	6	40
Zirconium	<0.1	200	80	<1	3		3		10			300

Taken from U.S. Bureau of Reclamation 1976

Table 99: Water quality of seepage from Morgan Lake and ash ponds (including ash pond effluent)

Constituent		Ash pond seepage 1971#	Ash pond seepage 1971#	Ash pond seepage 1973*	Ash pond effluent** 1971##	Ash pond effluent** 1972-73#	Morgan Lake seepage 1973
pH		8.3	7.9	7.9	11.3	8.47	7.7
Ca	(ppm)	500	430	335	240	563	332
Mg	(ppm)	1000	1100	1023	0.1	102	2900
Na	(ppm)	2100	2200	3965	170	294	9920
K	(ppm)	23	20	91	6.6		115
F	(ppm)	1.4	0.7	0.5	1.0		1.4
Sr	(ppm)	2.8		4.7	0.8		7.3
Ba	(ppm)	0.04		<1	0.12		<1
B	(ppm)	0.24		0.7	1.0		<0.1
Li	(ppm)	0.64		0.57	0.08		0.93
Si	(ppm)	8.1	8.3	14	14	51	17
Zn	(ppb)	<22		103	<22		60
Cu	(ppb)	<25		3.4	<3		13
Pb	(ppb)	<5		0.89	<5		<0.25
Bi	(ppb)	<0.40		<0.5	<0.4		<0.5
As	(ppb)	<120		<5	<120		<5
Co	(ppb)	<1		<1	<1		<1
Mn	(ppb)	20		443	<5		38
Fe	(ppb)	160		244	60		115
Sb	(ppb)	<12		<0.6	<12		<0.6
Cd	(ppb)	<25		0.42	<25		<0.1
Ni	(ppb)	20		<1	3		7
Mo	(ppb)	6		3.6	30		12.5
Hg	(ppb)	0.5	0.0	<1	0.0		<1
TDS	(ppm)	13,300	13,900	9898	1100	3248	20,345

* Average of 4 samples
** Average of 16 samples
\# Arizona Public Service Company files
\## U.S. Geological Survey, Albuquerque, NM, open files

Taken from U.S. Bureau of Reclamation 1976

Table 100: Water quality of runoff, impoundments, and shallow wells upstream (south and east) of powerplant, 1973

Constituent		Runoff**	Impoundment**	Shallow well#
pH				7.68
Ca	(ppm)	388	125	153
Mg	(ppm)	41	14	31
Na	(ppm)	1292	323	631
K	(ppm)	80	69	11
F	(ppm)	1.13	81	1.8
Sr	(ppm)	2.9	0.4	2.7
Ba	(ppm)	<1	<1	<1
B	(ppm)		<0.1	<0.1
Li	(ppm)	0.04	0.05	0.07
Si	(ppm)	11	12	14
Zn	(ppb)	86	133	167
Cu	(ppb)	33	18	4.8
Pb	(ppb)	30	0.43	0.82
Bi	(ppb)	6.6	2.4	0.94
As	(ppb)	<5	<5	<5
Co	(ppb)	<1	<1	<1
Mn	(ppb)	4.4	20	415
Fe	(ppb)	71	76	100
Sb	(ppb)	<0.6	<0.6	<0.6
Cd	(ppb)	5.9	1	0.9
Ni	(ppb)	3.8	<1	4.6
Mo	(ppb)	<3	3.5	3.8
Hg	(ppb)	<1	<1	<1
TDS	(ppm)	2750##	1100##	2609

* Average of surface runoff of two samples of Chaco River water, one on a small arroyo and one in Cottonwood Arroyo during a flash flood, September 1973

** Average of three small imoundments near the lease, 1973

\# Average of 17 dug wells in and around the lease that represent base flow in the arroyos and Chaco Wash

\## Estimated

Taken from Bureau of Reclamation 1976

bicarbonate and sodium sulfate; downstream, calcium sulfate and sodium sulfate predominate (Goetz et al. 1987).

Due to operational modifications, the San Juan Powerplant, located 7.5 km northwest of Farmington, poses fewer water quality hazards than does the Four Corners plant. The San Juan plant began operations in 1973 but only recently complied with NPDES requirements by ceasing discharges to the San Juan River (U.S. Bureau of Reclamation 1993). Prior to compliance, plant discharge to the river created a perennial flow in the last five miles of Shumway Arroyo (Myers and Villanueva 1986, Goetz et al. 1987). As an indication of the powerplant's effects, from 1974 to 1975 the average TDS concentration in Shumway Arroyo was 5,576 mg/l. The San Juan Powerplant diverts water from the San Juan River and stores it in a reservoir with a total capacity of 1300 acre-feet (1.6 million m^3). Most of the water for the plant is consumed; a large portion of it evaporates in the plant cooling tower, and small amounts of water are used to handle waste ash (Melancon et al. 1979).

With the exception of thermal pollution, trace elements have received the most attention as potential pollutants from powerplants. There is no direct thermal discharge from either the San Juan or Four Corners powerplants, although the decrease in water volume below the plants would necessarily lead to more rapid heating during the day and cooling during the night (Melancon et al. 1979). Gernard et al. (1983) have suggested a ranking of the relative potential for damage to aquatic ecosystems by trace elements identified in powerplant effluent: Cd, Hg > As, Cr, Pb, Se, Z > Ba, Cu, Mn > Co, Mo, Ni. Other researchers, however, have focused on selenium as the primary element of concern from coal-fired powerplants (*see* SELENIUM section 4.7.1 for further information). Selenium is concentrated in coal and even further concentrated in the ash that remains after combustion; furthermore, selenium readily leaches out of solid wastes, leading to high levels of the element in powerplant disposal waters (Lemly 1985, Baumann and Gillespie 1986).

Belews Lake, the North Carolina powerplant cooling reservoir mentioned previously, provides perhaps the best documented case of selenium contamination from a coal-ash disposal basin. Effluent entering Belews Lake from the disposal basin had selenium concentrations of 100-200 μg/l, but the lake water averaged only 10 μg/l. Biota in the basin, though, rapidly accumulated selenium, from 500 times the waterborne concentration in periphyton to over 4000 times in fish visceral tissue. Within two years only one species of fish, a mosquitofish, maintained a reproducing population in the lake (Baumann and Gillespie 1986, Lemly 1985). Lemly (1985) has recommended that ash be pretreated for selenium before disposal in order to eliminate the risk of selenium contamination.

In the San Juan basin, the only evidence for selenium contamination from powerplants comes from water data collected at Shumway Arroyo and Chaco Wash near Waterflow, New Mexico. Each of these stations registered unusually high selenium concentrations from 1978-1980, and the levels have been attributed to the discharge of wastewater from the two major powerplants (Keller-Bliesner Engineering and Ecosystems Research Institute 1991).

Other potential contaminants from the powerplants are PAHs and biocides. Coal-fired powerplants generally emit larger amounts of PAHs than do gas or oil-fired units (Neff 1979). To date, there have apparently been no investigations of San Juan or Four Corners powerplant PAH contributions to basin surface water. Biocides, including chlorine and chloramines, are used to control fouling on the inside surfaces of powerplants and can be toxic to aquatic organisms at extremely low concentrations. Under some conditions they may also cause the formation of chlorinated hydrocarbons (Gernard et al. 1983).

Goetz and Abeyta (1987) have found trends in water quality constituents from October 1973 through September 1981 at 14 of 36 stations in the San Juan basin upstream of Shiprock. Five of the 14 stations are downstream from the discharges of the San Juan and Four Corners powerplants. It is suggested that the trends may reflect changes in power or coal production rates or in water-discharge practices. As an example of the effect of the powerplants on water quality, the authors note that the largest specific conductance value of 6,570 microsiemens per centimeter (μS/cm) was from Shumway Arroyo downstream from the San Juan plant, while upstream from the plant the median concentration over the study period was 850 μS/cm.

4.13 POINT SOURCE DISCHARGERS

Within the San Juan basin the San Juan and Four Corners powerplants constitute the single largest point source contributors, but there are numerous smaller point source dischargers as well. Permitted dischargers include wastewater treatment plants, animal confinement facilities, Indian boarding schools, recreation areas, sand and gravel operations, trailer parks, laundries, and slaughter houses. It is generally agreed that the smaller point source dischargers normally cause only localized changes in water quality; these changes would not have contributed to the overall decline of native fishes in the basin (New Mexico Water Quality Control Commission 1976, Joseph and Sinning 1977). Powerplants and wastewater treatment plants, on the other hand, may have more significant effects. An exact accounting of all permitted point source dischargers in the basin is not within the scope of this document.

Each state has its own system of issuing discharge permits. New Mexico does not have the authority to issue NPDES permits and these are instead administered by the EPA Region VI. In Utah, the EPA drafts major industrial permits while minor industrial permits are drafted by the State. Colorado has been given full authority to issue NPDES permits (U.S. Department of the Interior 1987). In general, point source discharges must meet criteria for such parameters as bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), and fecal coliform bacteria, none of which necessarily has direct bearing on fish health.

The New Mexico Department of the Environment has conducted a number of intensive water quality surveys of the San Juan River and has attempted to identify the effects of wastewater treatment plants along the river. A survey conducted in November 1984 of 65 miles of the San Juan River in New Mexico found that total ammonia levels below the Farmington wastewater treatment plant were approaching levels recommended for the protection of aquatic life (Smolka 1985). The author of the study noted that during periods of low streamflow and low water temperature, ammonia levels would become critical to both fish and invertebrates. The study also identified elevated total phosphorus, total ammonia, and total nitrate-nitrite levels below the Farmington treatment plant. At the time of the survey the Farmington plant discharged not only the most effluent of all wastewater treatment plants along the San Juan River but also the wastewater with the highest nutrient levels. The author suggested that river oxygen levels were high and constant enough to handle such nutrient loadings (Smolka 1985).

From May through September 1991 the New Mexico Department of the Environment conducted another survey of the San Juan River and included the Animas River near its confluence with the San Juan. Lead was at levels above detection in two of five effluent samples taken from the Bloomfield wastewater treatment plant and from two of three samples from the Farmington treatment plant. All lead concentrations were below New Mexico's acute and chronic criteria. Six of eight samples from the Shiprock treatment plant exceeded the acute ammonia criterion for coldwater fisheries (New Mexico Department of the Environment 1992). The water quality data collected by the New Mexico Department of the Environment for 1984 and 1991, as well as for a 1990 San Juan River survey and a survey of the Animas and La Plata rivers in 1989, is found in the appendices (Appendices 7a-c, 8d-g, 9a-b, and 10) (Smolka 1985, New Mexico Department of the Environment 1990, 1991, 1992).

Although PAHs have been identified in sewage treatment plant effluent (*see* section 4.10.1), there have apparently been no PAH analyses conducted on effluent from plants in the San Juan basin. PAH concentrations in municipal effluents vary, but a range of values for different effluents is given for reference (Table 101) (National Research Council of Canada 1983).

Table 101: PAHs in municipal effluents [in $\mu g/l$]

Compound	Domestic effluents	Sewage Dry weather	Heavy rain	Sewage (high % industry)
Fluoranthene	273-2416	352	16,350	2660-3420
Pyrene	1763	254	16,050	2560-3120
Benz[a]anthracene	167-319	25	10,360	343-1360
Benzo[b]fluoranthene	114-202	39	9,910	525-870
Benzo[j]fluoranthene	37-205	57	10,790	1100-1740
Benzo[k]flouranthene	31-193	22	4,180	336-460
Benzo[a]pyrene	38-74	1	1,840	100-368
Benzo[ghi]perylene	40-219	4	3,840	120-480
Indeno[1,2,3-cd]pyrene	22-238	17	4,980	476-930

Terms such as domestic effluents, sewage, etc. were not defined in the original reference. It is assumed that "domestic effluents" comprise all solid and liquid organic wastes produced by residents and delived to a treatement facility and that "sewage" designates a combination of domestic effluent and collected surface runoff.

Taken from National Research Council of Canada 1983, after Borneff and Kunte 1965

4.14 SYNOPSIS OF RESULTS

A compilation of all contaminants and water quality studies conducted in the basin, arranged geographically, shows significant data gaps (Tables 102, 103 and 104). Blank boxes in the tables represent areas where research has not been conducted for a particular contaminant or source. Not all boxes should be filled, considering that each contaminant source is not present in all portions of the basin; conversely, the extent to which the tables are filled may be misleading because they are dominated by a few investigations covering broad study areas.

When examined by river reach or lake (Table 103), it is evident that the San Juan River from Navajo Reservoir to the confluence of the Mancos River has been sampled the most extensively. Because of the Animas-La Plata Project, the Animas and La Plata rivers have also been investigated fairly thoroughly. This review found that the Utah portion of the basin has been largely neglected, with no research having been conducted in Cottonwood Wash, Chinle Creek, or the small portion of the San Juan River from Mexican Hat to the San Juan arm of Lake Powell. In the San Juan River above Navajo Reservoir; the Navajo River; the Piedra River; Navajo Reservoir; Los Pinos River; the Florida River; Chinde Wash; and the San Juan River from Cottonwood Wash to Mexican Hat, only one study each has been conducted. Almost without exception, sites other than those on the San Juan River or its tributaries (Table 104) are each represented by a single study or a series of studies performed by a single agency.

Examination of the review tables by contaminant or source illustrates the types of research that have not yet been performed. There was no attempt to distinguish between those contaminants that pose the most serious hazards, such as PAHs, and those that are probably of lesser significance, such as uranium.

Trace element concentrations in water have been investigated most widely, but research in all other categories has been patchy (Table 103). Since the presence of disease is highly correlated with contamination, disease is perhaps one of the more important factors to be investigated. The only tributary to the San Juan that has been studied for disease is the Animas River. Three studies have produced data on pesticides and PCBs, one of which was conducted nearly a decade ago Two studies have analyzed PAHs, and one of the two was conducted at a single site. A moderate amount of data has been collected on trace element concentrations in fish, but fish have only been sampled in the Animas and La Plata rivers, Lake Powell, and the San Juan River from Navajo Reservoir to the Mancos River.

When considering sites other than those on the San Juan River and its tributaries (Table 104), it is more informative to review the data by contaminants and sources, because contaminants nearly always originate on land rather than in rivers and streams themselves. Only one study, conducted on the DOI-sponsored irrigation projects in New Mexico, examined pesticides and PCBs, and two studies of limited scope examined PAHs on basin lands. The oil, natural gas, metals mining, uranium, coal mining, powerplants, and point sources columns of the table are virtually empty, and there have apparently been no studies of grazing or logging in the basin.

Table 102: Types of data collected at USGS gaging stations in the San Juan basin, 1991 and 1992 water years

Station No.	Station name/location	Types of data collected: Physical chemical	Trace element	Suspended sediment	Radio-isotope	Pesticide & PCB
09355500	San Juan River near Archuleta, NM	X				
09363500	Animas River near Cedar Hill, NM	X	X*	X		
09364500	Animas River at Farmington, NM	X	X	X		
09367500	San Juan River at Farmington, NM	X	X**		X	
09365000	La Plata River near Farmington, NM	X	X**	X	X	
09367500	San Juan River near Fruitland, NM	X				
09368000	San Juan River at Shiprock, NM	X	X	X	X	X
09371010	San Juan River at Four Corners, CO	X				
09352900	Vallecito Creek near Bayfield, CO	X	X	X	X	
09354500	Los Pinos River at La Boca, CO	X	X	X		X
09355000	Spring Creek at La Boca, CO	X	X			
09371500	McElmo Creek near Cortez, CO	X				
09371520	McElmo Creek above Trail Canyon near Cortez, CO	X				
09372000	McElmo Creek near Colorado-Utah State Line, CO	X				
09378600	Montezuma Creek near Bluff, UT	X		X		
09379500	San Juan River near Bluff, UT	X	X	X		

* Trace element data do not include selenium

** Trace element data do not include mercury

Compiled from Borland et al. 1992, Cruz et al. 1992, ReMillard et al. 1992, ReMillard et al. 1993, Ugland et al. 1992, Ugland et al. 1993

Table 103: Synopsis of investigations by river reach or lake

River reach or lake	Disease	Temperature*	Sediment*	Salinity*	Groundwater
San Juan River above Navajo Reservoir		S. Ute Tribe 1993			
Navajo River		S Ute Tribe 1993			
Piedra River		S. Ute Tribe 1993			
Navajo Reservoir		NM Dept Env 1990			
San Juan River from Navajo Reservoir to confluence with Animas River	Blanchard et al 1993 Herman 1991a			Thorn 1993	Thorn 1993
Los Pinos River		S Ute Tribe 1993			
Canyon Largo			NM Dept Env 1992	BR 1993	
Florida River		S Ute Tribe 1993			
Animas River above confluence with Florida River, and tributaries	Herman 1991b - Alkali Creek	S Ute Tribe 1993			USGS 1993a
Animas River below confluence with Florida River	Japhet 1993 - Purple Cliffs area Japhet 1993 - Bondad	S Ute Tribe 1993	Gellis 1992 - at Farmington		USGS 1993a
La Plata River and tributaries		S Ute Tribe 1993			

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Disease	Temperature*	Sediment*	Salinity*	Groundwater
San Juan River from confluence with Animas River to Shiprock	Shanks 1993 - from Hogback down Blanchard et al. 1993 Herman 1991a			Thorn 1993	Thorn 1993
Chaco River					Thorn 1993 Myers & Villanueva 1986
Chinde Wash					
San Juan River from Shiprock to confluence with Mancos River	Shanks 1993 Shanks 1993 - secondary channels Blanchard et al. 1993 Herman 1991a			Thorn 1993	Thorn 1993
Mancos River					
San Juan River from confluence with Mancos River to confluence with McElmo Creek (Aneth)	Shanks 1993 Shanks 1993 - secondary channels				
McElmo Creek & tributaries					
San Juan River from confluence with McElmo Creek to confluence with Montezuma Creek	Shanks 1993 Shanks 1993 - secondary channels				Avery 1986 Spangler 1992 Kimball 1992 USGS & UT Div Oil, Gas, & Mining 1993
Montezuma Creek					Avery 1986 Spangler 1992 Kimball 1992 USGS & UT Div Oil, Gas, & Mining 1993
San Juan River from confluence with Montezuma Creek to confluence with Cottonwood Wash (Bluff)	Shanks 1993 Shanks 1993 - secondary channels				

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Disease	Temperature*	Sediment*	Salinity*	Groundwater
Cottonwood Wash					
San Juan River from confluence with Cottonwood Wash to Mexican Hat	Shanks 1993				
Chinle Creek					
San Juan River from Mexican Hat to San Juan arm of Lake Powell					
San Juan arm of Lake Powell and Lake Powell		Waddell & Wiens 1992			

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Pesticides/PCBs*	Trace elements (water)*	Trace elements (fish)	Trace elements (soil/sediment)	Trace elements (vegetation)
San Juan River above Navajo Reservoir		S. Ute Tribe 1993			
Navajo River		S Ute Tribe 1993			
Piedra River		S Ute Tribe 1993			
Navajo Reservoir		NM Dept Env 1990			
San Juan River from Navajo Reservoir to confluence with Animas River	O'Brien 1986 Blanchard et al. 1993	Blanchard et al. 1993 BIA 1993 - Archuleta,Bloomfield, Lee Acres, Flora Vista, Highway 371 Bridge NM Dept Env 1991 NM Dept Env 1992 Smolka 1986	O'Brien 1986 Blanchard et al. 1993	Blanchard et al. 1993	Blanchard et al 1993
Los Pinos River		S Ute Tribe 1993			
Canyon Largo					
Florida River		S Ute Tribe 1993			
Animas River above confluence with Florida River		BR 1992c S Ute Tribe 1993	BR 1993		
Animas River below confluence with Florida River	O'Brien 1986 - NM NM Dept Env 1992 - Farmington	NM Dept Env 1990 NM Dept Env 1991 NM Dept Env 1992 Smolka 1986 S Ute Tribe 1993	O'Brien 1986		
La Plata River and tributaries		BIA 1993 BR 1992c NM Dept Env 1990 NM Dept Env 1991 NM Dept Env 1992 Smolka 1986 S Ute Tribe 1993	BR 1992b		

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Pesticides/PCBs*	Trace elements (water)*	Trace elements (fish)	Trace elements (soil/sediment)	Trace elements (vegetation)
San Juan River from confluence with Animas River to Shiprock	O'Brien 1986 Blanchard et al. 1993	Blanchard et al. 1993 BIA 1993 - Kirtland, Hogback, Shiprock NM Dept Env 1991	O'Brien 1986 Blanchard et al. 1993	Blanchard et al 1993	Blanchard et al 1993
Chaco River		Keller-Bliesner & ERI 1991 BIA 1993			
Chinde Wash		Keller-Bliesner & ERI 1991			
San Juan River from Shiprock to confluence with Mancos River	Blanchard et al 1993 NM Dept Env 1992	Blanchard et al 1993	Blanchard et al 1993	Blanchard et al 1993	Blanchard et al 1993
Mancos River		BIA 1993 BR 1992c			
San Juan River from confluence with Mancos River to confluence with McElmo Creek (Aneth)		BIA 1993 - Four Corners, Aneth			
McElmo Creek & tributaries		BIA 1993			
San Juan River from confluence with McElmo Creek to confluence with Montezuma Creek					
Montezuma Creek		BIA 1993			
San Juan River from confluence with Montezuma Creek to confluence with Cottonwood Wash (Bluff)		BIA 1993 - Bluff			

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Pesticides/PCBs*	Trace elements (water)*	Trace elements (fish)	Trace elements (soil/sediment)	Trace elements (vegetation)
Cottonwood Wash					
San Juan River from confluence with Cottonwood Wash to Mexican Hat		BIA 1993 - Mexican Hat			
Chinle Creek					
San Juan River from Mexican Hat to San Juan arm of Lake Powell					
San Juan arm of Lake Powell and Lake Powell		Kidd & Potter 1978 Waddell & Wiens 1992	Bussey et al 1976 Lowe et al 1985 Schmitt & Brumbaugh 1990 Waddell & Wiens 1992	Kidd & Potter 1978 Waddell & Wiens 1992	Kidd & Potter 1978

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Mercury*	Selenium*	PAHs	Metals mining	Uranium
San Juan River above Navajo Reservoir					
Navajo River					
Piedra River					
Navajo Reservoir					
San Juan River from Navajo Reservoir to confluence with Animas River	Blanchard et al 1993	Blanchard et al. 1993	Blanchard et al 1993 - fish		
Los Pinos River					
Canyon Largo					
Florida River					
Animas River above confluence with Florida River		BR 1992a, BR 1992b, BR 1992c - water		FWS 1993 - no primary data	Anderson et al. 1963 - bottom orgs, fish, veg, water (at Durango U mill)
Animas River below confluence with Florida River			Japhet 1993 - fish at Bondad		
La Plata River and tributaries		BR 1992a, BR 1992b, BR 1992c - water			

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Mercury*	Selenium*	PAHs	Metals mining	Uranium
San Juan River from confluence with Animas River to Shiprock	Blanchard et al 1993	Blanchard et al. 1993	Blanchard et al. 1993 - fish		
Chaco River					
Chinde Wash					
San Juan River from Shiprock to confluence with Mancos River	Blanchard et al. 1993	Blanchard et al 1993	Blanchard et al 1993 - fish		
Mancos River	CDOW 1991 - fish	BR 1992a, BR 1992b, BR 1992b - water			
San Juan River from confluence with Mancos River to confluence with McElmo Creek (Aneth)					
McElmo Creek & tributaries	CDOW 1991 - fish				
San Juan River from confluence with McElmo Creek to confluence with Montezuma Creek					
Montezuma Creek					
San Juan River from confluence with Montezuma Creek to confluence with Cottonwood Wash (Bluff)					

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 103 (Cont.): Synopsis of investigations by river reach or lake

River reach or lake	Mercury*	Selenium*	PAHs	Metals mining	Uranium
Cottonwood Wash					
San Juan River from confluence with Cottonwood Wash to Mexican Hat					
Chinle Creek					
San Juan River from Mexican Hat to San Juan arm of Lake Powell					
San Juan arm of Lake Powell and Lake Powell	EPA study, as described in Melancon et al 1979				

* Does not include USGS data. See Table 102 for USGS gaging stations where data were collected.

Table 104: Synopsis of investigations by area other than river reach

Other	Groundwater	Pesticides/PCBs	Trace elements (water)	Trace elements (fish)	Trace elements (soil/sediment)
San Juan DOI reconnaissance area		Blanchard et al. 1993		Blanchard et al. 1993	Blanchard et al. 1993
NIIP		Blanchard et al 1993	Blanchard et al. 1993 Keller-Bliesner & ERI 1991		Keller-Bliesner & ERI 1991
Southern Ute Reservation	Hutchinson & Brogden 1976		Hutchinson & Brogden 1976 Southern Ute Tribe 1993		
Ute Mountain Ute Reservation					
Dolores Project			Butler et al 1991	Butler et al 1991	
Hammond Project			Blanchard et al 1993		
Mancos Project area			Butler et al. 1991		
Animas-La Plata Project area			BR 1992a		BR 1992a, BR 1992b
Ridges Basin Reservoir					BR 1992a
Southern Ute Reservoir					BR 1992a
Narraguinnep Reservoir					
McPhee Reservoir					
Totten Reservoir					
Puett Reservoir					
Summit Reservoir					
Vallecito Reservoir					
Four Corners powerplant			BR 1992a		

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Groundwater	Pesticides/PCBs	Trace elements (water)	Trace elements (fish)	Trace elements (soil/sediment)
San Juan Mine					
Navajo Mine					
Lee Acres landfill	McQuillan & Longmire 1986 Peter et al. 1987				
Bloomfield refinery					
Dolores River *				Valdez et al 1992	
Natural gas fields at Archuleta, Flora Vista, & Aztec, NM					
Duncan Oil Field, NM					
Aneth Oil Field, UT					
Bloomfield WWTP outfall					
Farmington WWTP outfall					
Shiprock WWTP outfall					
Aztec WWTP outfall					

* Because the Dolores River is not within the San Juan River basin, a comprehensive literature search was not performed on it and the information in this chart does not represent all that is available for the river.

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Trace elements (vegetation)	Mercury	Selenium	Grazing/Logging	PAHs
San Juan DOI reconnaissance area	Blanchard et al. 1993		Blanchard et al 1993		
NIIP	Keller-Bliesner & ERI 1991		Keller-Bliesner & ERI 1991		Keller-Bliesner & ERI 1991 - water
Southern Ute Reservation					
Ute Mountain Ute Reservation					
Dolores Project					
Hammond Project					
Mancos Project area					
Animas-La Plata Project area		BR 1992b - soils	BR 1992a, BR 1992b, BR 1992c - soils, water, fish		
Ridges Basin Reservoir					
Southern Ute Reservoir					
Narraguinnep Reservoir		CDOW 1991			
McPhee Reservoir		CDOW 1991			
Totten Reservoir		CDOW 1991			
Puett Reservoir		CDOW 1991			
Summit Reservoir		CDOW 1991			
Vallecito Reservoir		CDOW 1991			
Four Corners powerplant		BR 1976			

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Trace elements (vegetation)	Mercury	Selenium	Grazing/Logging	PAHs
San Juan Mine					
Navajo Mine					
Lee Acres landfill					
Bloomfield refinery					
Dolores River *		CDOW 1991 - fish			
Natural gas fields at Archuleta, Flora Vista, & Aztec, NM					Eiceman 1987 - natural gas waste pits
Duncan Oil Field, NM					Eiceman 1987
Aneth Oil Field, UT					
Bloomfield WWTP outfall					
Farmington WWTP outfall					
Shiprock WWTP outfall					
Aztec WWTP outfall					

* Because the Dolores River is not within the San Juan River basin, a comprehensive literature search was not performed on it and the information in this chart does not represent all that is available for the river.

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Oil	Natural gas	Metals mining	Uranium	Coal mining
San Juan DOI reconnaissance area					
NIIP					
Southern Ute Reservation					
Ute Mountain Ute Reservation					
Dolores Project					
Hammond Project					
Mancos Project area					
Animas-La Plata Project area				BR 1992b - Durango pumping plant (groundwater)	
Ridges Basin Reservoir					
Southern Ute Reservoir					
Narraguinnep Reservoir					
McPhee Reservoir					
Totten Reservoir					
Puett Reservoir					
Summit Reservoir					
Vallecito Reservoir					
Four Corners powerplant					

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Oil	Natural gas	Metals mining	Uranium	Coal mining
San Juan Mine					BR 1984 Severson & Gough 1981
Navajo Mine					BR 1984
Lee Acres landfill	McQuillan & Longmire 1986 Peter et al. 1987 - groundwater				
Bloomfield refinery	Groundwater Tech 1993 - no data				
Dolores River *				Valdez et al. 1992	
Natural gas fields at Archuleta, Flora Vista, & Aztec, NM		Eiceman 1987 - natural gas waste pits			
Duncan Oil Field, NM		Eiceman 1987			
Aneth Oil Field, UT					
Bloomfield WWTP outfall					
Farmington WWTP outfall					
Shiprock WWTP outfall					
Aztec WWTP outfall					

* Because the Dolores River is not within the San Juan River basin, a comprehensive literature search was not performed on it and the information in this chart does not represent all that is available for the river.

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Powerplants	Point sources
San Juan DOI reconnaissance area		
NIIP		
Southern Ute Reservation		
Ute Mountain Ute Reservation		
Dolores Project		
Hammond Project		
Mancos Project area		
Animas-La Plata Project area		
Ridges Basin Reservoir		
Southern Ute Reservoir		
Narraguinnep Reservoir		
McPhee Reservoir		
Totten Reservoir		
Puett Reservoir		
Summit Reservoir		
Vallecito Reservoir		
Four Corners powerplant	Wiersma & Crockett 1978 - Four Corners soil	

Table 104 (Cont.): Synopsis of investigations by area other than river reach

Other	Powerplants	Point sources
San Juan Mine		
Navajo Mine		
Lee Acres landfill		
Bloomfield refinery		
Dolores River *		
Natural gas fields at Archuleta, Flora Vista, & Aztec, NM		
Duncan Oil Field, NM		
Aneth Oil Field, UT		
Bloomfield WWTP outfall		NM Dept Env 1991 NM Dept Env 1992 Smolka 1986
Farmington WWTP outfall		NM Dept Env 1991 NM Dept Env 1992 Smolka 1986
Shiprock WWTP outfall		NM Dept Env 1991 NM Dept Env 1992 Smolka 1986
Aztec WWTP outfall		NM Dept Env 1990

* Because the Dolores River is not within the San Juan River basin, a comprehensive literature search was not performed on it and the information in this chart does not represent all that is available for it.

5. DISCUSSION

If water quality is adversely affecting San Juan basin aquatic ecosystems, then protection of the ecosystems and their native fish fauna depends upon piecing together information on contaminants, sources, and effects. This review has documented an imbalance of information in these three areas. There is a surplus of abiotic data identifying potential contaminants and a dearth of biotic data linking those contaminants to fish health. This is to be expected because it is far easier to identify water quality problems than to quantify their effects on fish health, particularly when the effects are chronic rather than acute.

A moderate amount of research has been conducted on contaminant sources in the basin. The reconnaissance investigations of DOI-sponsored irrigation projects have been among the most comprehensive studies and have succeeded in identifying many areas of contaminants input. Sources other than irrigation, though, have received little attention. Oil, gas, and coal activities are widespread and abundant in the basin, yet there has been no recent research aimed at determining their effects on surface water quality. This research gap is particularly significant because elevated PAH levels have been recorded in basin fish, and fossil fuels are the most probable sources of PAHs. Some studies have focused on sites that are known to generate contaminants, such as mines and powerplants, but there has been no attempt to determine the effects of these contaminants on surface water quality. Future research endeavors must be coordinated so that connections may be made between contaminants, sources, and effects; otherwise, there will be little basis on which to make informed management decisions. The following discussion, which roughly follows the order of the RESULTS section, offers suggestions to help guide future research efforts.

Little is known regarding the extent to which San Juan basin native fish species are exposed to surface water contaminants. Contaminants such as selenium and PAHs concentrate in backwaters, which are used by several native taxa during certain ontogenetic stages; however, neither specific areas of backwater contamination nor the extent of backwater use by fish in the basin has been determined. Of the small amount of contaminants research conducted on Colorado squawfish and razorback sucker, none has been performed in the San Juan basin. Furthermore, it has not been determined if Colorado squawfish, a top-level predator, is accumulating higher levels of contaminants than other fish species.

The limited disease studies in the basin have shown an apparently high incidence of stress-mediated disease in flannelmouth sucker, as well as in common carp and channel catfish in some instances. Because flannelmouth sucker is considered rare in other portions of the Colorado River basin and has been classified as a Category 2 species by the FWS (U.S. Fish and Wildlife Service 1991b), it is important to determine if the species is in fact highly diseased and, if so, which contaminants may be responsible for the outbreaks.

The EPA has established standards for many contaminants in water based on toxicity studies on various freshwater fish taxa. However, there are no standards for PAH compounds. Furthermore, no toxicity data exist for any San Juan basin native fish species. While EPA standards give an indication of toxic concentrations, toxicities may vary widely among fish species, and it is possible that San Juan basin natives have different tolerances for certain contaminants.

The EPA has not issued standards for contaminant concentrations in soils, sediment, food items, or fish tissue. Currently, levels of concern in these media are determined from studies conducted outside the basin. For fish tissue, values found in the basin are often compared to NCBP means and 85th percentile concentrations; for sediment, basin values are compared to those at NIWQP study areas; and for soils, western states values are used for comparison. Although no better comparative data exist, they do not necessarily serve as good indicators of contamination. The baseline values have no correlation to fish health and may in fact represent contaminated systems themselves. Likewise, the practice of determining contamination by counting the number of samples exceeding detection levels may be convenient but is not necessarily valid unless the detection levels are set with regard to fish toxicity data.

Of the two reservoirs that are on the San Juan River, Navajo Reservoir is more important to fish health in the basin as it serves as a potential contaminants source. Far more data, though, have been generated on contaminants in Lake Powell. The ongoing FWS study of Lake Powell fish, sediment, and water quality should provide a good analysis of contaminants in the reservoir. While data are intermittently collected in Navajo Reservoir, there are no comprehensive studies being conducted there. Pre- and post-reservoir studies of Navajo Reservoir have not been able to separate the effects of the reservoir from those of concurrent basin developments. A study that determined the quality of inflow and outflow water might provide useful results, as might a study that compared outflow water quality to known fish tolerances.

There has been no research conducted to determine if current sediment levels in the basin are adversely affecting the native fish fauna. Due to historically turbid conditions, it has been suggested that high sediment levels are probably not of major concern to the natives. Sediment may be more important as a transport and storage mechanism for contaminants, particularly selenium, PAHs, and possibly some pesticides.

A fair amount of effort by the Colorado River Salinity Control Forum has been directed at locating salinity sources in the basin, but the effort has been motivated by concerns for irrigation water quality in California rather than for fish health The studies have thus resulted in much information on salinity sources and loading but virtually no data on the biotic effects of salinity. A single study has been conducted on the tolerance of Colorado squawfish to salinity; if salinity data for basin surface water are to be useful, similar tolerance data must be determined for the razorback sucker and other rare basin natives. However, until salinity levels are shown to affect fish health, an investigation of specific trace elements known to be at toxic levels might constitute a better use of resources.

Like salinity, groundwater in the basin has been investigated fairly extensively, but the implications of groundwater quality on surface water quality have not been determined. To protect human health, studies have been promulgated to identify major sources of groundwater contamination and those aquifers that are particularly vulnerable. There have been no studies that have attempted to determine if contaminated groundwater poses a significant hazard to the San Juan River and its tributaries, or if it acts instead as a minor point source contributor.

Only two studies have generated significant data on pesticides and PCBs in the basin. O'Brien (1987) concluded that chlorohydrocarbon compounds did not pose a serious hazard to basin fish. Blanchard et al. (1993), sampling bottom sediment and fish over a decade later, detected several chlorohydrocarbon compounds. While chlorohydrocarbons may pose a decreased hazard over time, other pesticides are still widely used. Considering the very limited data concerning pesticides and PCBs in the basin, an end to inquiry at this point would perhaps be premature, especially because no toxicity data exist for pesticides in basin fish.

O'Brien's (1987) investigation of trace elements in the New Mexico portion of the basin concluded that selenium, chromium, copper, and lead may have posed a hazard to basin fish. Comparison to NCBP values showed selenium concentrations to be the most elevated, but because synergistic effects may result from combinations of trace elements and physical conditions, future research should not discount the other elements of concern

With the exception of the recent sampling of reservoir and river fish by the CDOW (1991), the emphasis of mercury studies has largely been on human health. Future studies must evaluate fish mercury levels in reference to toxic concentrations to fish rather than to humans. Reservoirs have received the bulk of attention in mercury studies. If reservoir water is found to have elevated mercury levels, it must then be determined if the mercury poses hazards only to reservoir fish or if the effects are further-reaching, affecting basin fish in river and stream reaches. Finally, mercury sources in the basin should be investigated more fully. It is known that the emissions from coal-fired powerplants contain a large volume of mercury, but the contributions to basin waters by the Four Corners and San Juan powerplants have not been quantified. Furthermore, the possibility that soil mercury levels in areas of gas development may be elevated due to leaks from mercury-containing manometers should be explored.

Selenium has been studied more fully than any other contaminant in the San Juan basin. Selenium contamination has been documented in all media and areas of high selenium have been identified. Additional work is needed to determine the effects of various levels of selenium on the basin's fishes. Such data exist for razorback sucker, but that research was conducted in the Green River basin. For selenium as well as most other contaminants, chronic toxicity appears to pose the greatest hazard to fish health. In particular, reproductive impairment may be a factor in population declines. Several studies proposed or underway will attempt to determine the levels of selenium that cause reproductive impairment in basin natives. The results of this research will dictate the direction of further work.

The San Juan DOI Reconnaissance Investigation (Blanchard et al. 1993), as previously mentioned, is a comprehensive study of contaminants in the basin. Now completed, those results can be used in the formulation of management decisions. The same applies to the additional research conducted on the NIIP. Areas of high selenium have been located, and management agencies must now determine how to mitigate currently high levels in biota, soils, sediment, and water on the project areas and in the San Juan River. Both the Reconnaissance Investigation and the NIIP Biological Assessment (Keller-Bliesner Engineering and Ecosystems Research Institute 1991) noted that irrigation has the potential to transport contaminants from oil and gas activities within the project areas. Neither study made a comprehensive investigation of contamination by the by-products of fossil fuel extraction and transport activities. As irrigation return flows serve to move contaminants to the San Juan River, such contamination deserves further attention.

Because the reconnaissance investigations for the Dolores and Pine River projects have not been released, it is difficult to make suggestions for future research. An important question to be answered regarding the Dolores Project is to what extent contaminant levels in the Dolores River will affect the San Juan River basin as a result of transbasin water transport. The Pine River Project area is primarily located on the Southern Ute Reservation. The Southern Ute Tribe has recently begun regular collections of water quality data on the reservation, and these data serve as the best source of information for that area until the reconnaissance investigation is finalized.

A large volume of contaminants data has been collected for the proposed Animas-La Plata Project, and future data collection efforts are planned to address concerns raised by the FWS and EPA. A substantial amount of contaminants data will eventually be generated, but it cannot be properly evaluated without adequate toxicity data for the fish species in question.

No studies have documented the effects of grazing or logging on basin water quality. The BLM has apparently conducted its own studies to determine the quality of its grazed lands. Results from these studies should be used to determine if further research is warranted. Logging may be less of a concern because it occurs largely in the higher elevations outside the range of the basin's rare native fishes. Because both logging and grazing result in increased erosion and subsequent sedimentation, their threat to fish health cannot be fully evaluated until the effects of sediment on fish are first determined.

There are few data available on PAHs, even though they are recognized as potentially significant contaminants. Until PAH toxicity data are determined for basin fish, it will be difficult to evaluate any water, sediment, or fish data. Currently, the range of values associated with effects in fish is large, rendering a precise evaluation of data difficult. PAH analyses are expensive, so it important that future research efforts be coordinated and studies be strategically located.

As previously mentioned, very few basin studies have focused on surface water contamination caused by oil and gas development. This may represent the largest research gap for contaminants in the basin. State agencies in both New Mexico and Colorado are attempting to take strong actions to protect both surface and groundwater during extraction activities, but these actions normally do not pertain to abandoned wells, of which there are thousands. Future research may be best directed at abandoned wells, for active wells are highly regulated and may pose less of a contaminant threat.

The only oil refinery in the basin that has apparently been cited for contaminating surface or groundwater is the Bloomfield Refinery, which has been working with the EPA to mitigate the contamination. However, neither the refinery nor the EPA knows if the adjacent San Juan River has been contaminated. Considering that contaminants, including hydrocarbons, are likely to be in groundwater at the site, water quality inputs to surface water need to be monitored regularly to identify and terminate future contamination episodes if they occur. The same suggestions apply to the Lee Acres landfill, where groundwater contamination has been documented but its effects, if any, on the San Juan River have not been determined.

No data exist concerning natural gas processing plants in the basin and their waste disposal. Eiceman (1987) documented contamination of groundwater from well disposal pits, and Animas River fish disease observations suggest that the surface water has been contaminated by natural gas wells. Additional work is needed to determine where natural gas activities are acting as contaminants sources. Hydrostatic testing of natural gas pipelines is probably not a concern because in recent years there has been an increased awareness concerning the proper disposal of the generated liquids. However, Colorado and Utah have not promulgated specific standards for water disposal and instead make decisions on a case-by-case basis.

Metals mining in the basin, particularly in the upper Animas basin, has eliminated fish life in several river and stream reaches. Abandoned mines pose perhaps the most serious problem, because rehabilitation of sites is not easily accomplished. One issue that should be addressed is whether the status quo of contaminated streams in Colorado should be maintained. Three stream reaches have not been classified as fisheries because their fish fauna have been eliminated by mines contamination; there is no mandate, therefore, to improve the water quality, despite the fact that the reaches once supported fish.

The mining and milling of uranium in the basin may have historically caused contamination in the basin, but the magnitude of the present threat is unclear No mining or milling currently occur in the basin, but if the uranium market improves contamination could once again become a problem. Research is needed to determine how much radionuclide contamination remains in the basin from past activities. Fish toxicity data are also needed for radionuclides, in order to give meaning to any data that are collected. Finally, it is important to determine the effect of elevated uranium levels in the Dolores River on San Juan basin water.

Strip mining is one of the most destructive activities to terrestrial ecosystems, yet its specific effect on the basin's water quality is unknown. It is known that the reclamation of strip mines has some effect on reducing erosion, but some amount of erosion and contamination by trace elements remains. State and federal agencies should perhaps work with coal mines, particularly the San Juan and Navajo mines, to monitor runoff and to develop mitigation strategies.

Agencies should also work with powerplants to monitor the quality of emissions and wastewater and to quantify their effects on the San Juan and Chaco rivers. Selenium, mercury, and PAHs are the contaminants of greatest concern. The Bureau of Reclamation (1976) measured the quality of effluent from the Four Corners plant and water in its cooling reservoir, Morgan Lake, but no attempt was made to determine the effects of the powerplant on the San Juan River. Wiersma and Crockett (1978), studied the effects of emissions from the Four Corners plant and compared soil around the plant to soil around other coal-fired powerplants, but not to soil in other parts of the basin. It is not so important to know whether the basin powerplants are acting as inordinate polluters compared to other powerplants as it is to know whether they are polluting at all, and if so, to what extent.

While powerplants may be the most significant point source polluters in the basin, wastewater treatment plants may also pose hazards of large magnitude. The only data concerning WWTP effluent is from yearly New Mexico Department of the Environment surveys. The results from these surveys should be examined closely to determine if the treatment plants are consistently meeting current effluent standards. Future monitoring efforts should also measure for PAHs, as effluent elsewhere has been found to contain significant levels of the compounds.

There are obviously more research needs than resources available to address them, so priorities must be established. Determination of toxicities of various contaminants to fish species is crucial, yet it must be remembered that contaminants and water quality parameters can work synergistically. Contaminants sources are difficult to trace, but until they are identified management recommendations cannot be made. Water quality is the easiest to determine, but it can change temporally and spatially. Furthermore, contaminated sediment and food items may be as important as water quality to fish health.

With so many needs, researchers should be careful not to duplicate their efforts. All future contaminants research in the basin should, if possible, use the same techniques to produce data of comparable units. Too many previous studies cannot be compared to each other due to different methodologies and detection levels.

With the exception of the DOI reconnaissance investigations, which have been cooperative efforts between a number of federal and state government agencies, contaminants research in the San Juan basin has not been well coordinated. The agencies that are working to protect and revive basin fish populations need, together, to set priorities for future work so that sampling efforts compliment each other, providing as complete a picture of contaminants in the basin as is possible.

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APPENDICES 1-3

GLOSSARY

Absorption. Process by which pesticides are taken into plant tissues by roots or foliage (Ware 1983). The penetration of one substance into or through another (Messer and Post 1982).

Acid mine drainage. Any acidic water draining or flowing on, or having drained or flowed off, any area of land affected by mining (Messer and Post 1982).

Acute toxicity. The toxicity of a material determined at the end of 24 hours; toxicity that causes injury or death from a single dose or exposure (Ware 1983).

Acre-foot. The quantity of water needed to cover 1 acre to a depth of 1 foot (New Mexico Water Quality Control Commission 1976).

Adsorption. Chemical and/or physical attraction of a substance to a surface. Refers to gases, dissolved substances, or liquids on the surface of solids or liquids (Ware 1983).

Aerosol. Colloidal suspension of solids or liquids in air (Ware 1983). A suspension of liquid or solid particles (in a gas) of such size that they tend to remain suspended for an indefinite period (Messer and Post 1982).

Alkaline. The condition of a water solution having a pH concentration greater than 7.0 and having properties of a base (Messer and Post 1982).

Alluvium. Material such as earth, sand, gravel, or other rock or mineral materials transported by and deposited by flowing water (Messer and Post 1982).

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield quantities of water to wells and springs (Messer and Post 1982).

Aromatic hydrocarbon. An unsaturated cyclic hydrocarbon containing one or more six-carbon rings (Messer and Post 1982).

Aromatics. Solvents containing benzene or compounds derived from benzene (Ware 1983).

Ash. Theoretically, the inorganic salts contained in coal; practically, the solid residue remaining after coal is burned (Messer and Post 1982).

Base flow. Groundwater inflow to the river. Portion of stream discharge that is derived from natural storage (BR 1992a).

Bioaccumulation. The uptake and retention of nonfood substances by a living organism from its environment, resulting in a build-up of the substances in the organism (BR 1992a).

Bioassay. A determination of the concentration of a given material by comparison with a standard preparation; or the determination of the quantity necessary to affect a test animal under stated laboratory conditions (Messer and Post 1982).

Biochemical oxygen demand (BOD). A measure of the living and non-living organic demand for oxygen imposed by wastes of various kinds. A high BOD may temporarily, or permanently, so deplete oxygen in water as to kill aquatic life. The determination of BOD is perhaps most useful in evaluating impact of wastewater on the receiving water bodies (New Mexico Water Quality Control Commission 1976).

Biological opinion. Document which states the opinion of the U.S. Fish and Wildlife Service as to whether a Federal action is likely to jeopardize the continued existence of a threatened or endangered species or result in the destruction or adverse modification of critical habitat (BR 1992).

Biomagnification. The increase in concentration of a pollutant in animals as related to their position in a food chain, usually referring to the persistent, organochlorine insecticides and their metabolites (Ware 1983). The enhancement of a substance (usually a contaminant) in a food web such that the organisms eventually contain higher concentrations of the substances than their food sources (BR 1992a).

Biota. All living organisms of a region (Messer and Post 1982).

Blowdown. The removal of a portion of poor quality water and its replacement with an equal volume of better quality such that the quality of the final mixture of water in the system (cooling) remains within the required limits (BR 1976).

Bottom ash. The solid residue left from the combustion of a fuel which falls to the bottom of the combustion chamber (Messer and Post 1982).

Brine. Water saturated with salt (Messer and Post 1982).

Carcinogen. A substance that causes cancer in animal tissue (Ware 1983).

Carnotite. Ore of uranium and vanadium (Morris 1992).

Cation. A positively charged ion (Messer and Post 1982).

Chemical oxygen demand (COD). A quick (and only approximate) measure of loads of oxidizable matter in water. Results cannot be used interchangeably with BOD values. However, COD can quickly identify water with very low or very high BOD potential (New Mexico Water Quality Control Commission 1976).

Chronic toxicity. The toxicity of a material determined beyond 24 hours and usually after several weeks of exposure (Ware 1983).

Coal. A solid, combustible material consisting of amorphous elemental carbon with various amounts of organic and inorganic compounds (Messer and Post 1982).

Coal-fired. A power generating facility using bituminous coal as a source of energy (BR 1976).

Condensate. Liquid hydrocarbon obtained by the combustion of a vapor or gas produced from oil or gas wells and ordinarily separated at a field separator and run as crude oil. Or any liquid converted from its gaseous phase (Messer and Post 1982).

Contaminant. Any agent or action that infects or makes impure by introducing foreign or undesirable material (Morris 1992). In this review, any material with the potential to impair fish health or reproduction.

Cubic foot per second (ft^3/s). The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is approximately equivalent to 7.48 gallons per second or 0.02832 cubic meters per second (Roybal et al. 1983).

Curie. A curie measures the radioactivity level of a substance; i.e., it is a measure of the number of unstable nuclei that are undergoing transformation in the process of radioactive decay. One curie equals the disintegration of 3.7×10^{10} (37 billion) nuclei per second, which is approximately the rate of decay of one gram of radium (San Juan Basin Regional Uranium Study 1980).

Depletion. To permanently remove water from a system for a specific use (BR 1992a).

Discharge. The volume of water (or more broadly, volume of fluid plus suspended material) that passes a given point within a given period of time (Roybal et al. 1983).

Dissolved oxygen. The amount of free (not chemically combined) oxygen in water. It is often used as an indicator of pollution by organic wastes (Upper Colorado Region State-Federal Inter-Agency Group 1971).

Dissolved solids. Theoretically, the anhydrous residues of the dissolved constituents in water. Actually, it is the difference between the total and suspended solids in water (Messer and Post 1982)

Diversion. A process which, having return flow and consumptive use elements, turns water from a given path (BR 1992a).

Edema. A swelling of cells, tissues, or body cavities, caused by an abnormal accumulation of fluid (Morris 1992).

Ephemeral creek. A creek that carries water only during and immediately after precipitation (BR 1992a).

Erosion. The general process or the group of processes whereby the materials of the Earth's crust are loosened, dissolved, worn away, and simultaneously moved from one place to another, by natural agencies, which include weathering, solution, corrosion, and transportation (Roybal et al. 1983).

Floodplain. A strip of relatively flat alluvium that borders a stream and is subject to repeated flooding (BLM 1984).

Fly ash. All solids, ash, cinders, dust, soot, or other partially incinerated matter that is carried in or removed from a gas stream. Fly ash is usually associated with electric generating plants (Messer and Post 1982).

Full irrigation service land. Irrigable land now receiving, or to receive, its sole and generally adequate water supply through facilities which have been or are to be constructed by, rehabilitated by, or replaced by the BR (BR 1992a).

Furunculosis. A serious skin disease marked by boils or successive crops of boils (Morris 1992).

Groundwater. Phreatic water or subsurface water occupying the zone of saturation (Messer and Post 1982). Subsurface water, especially water in saturated materials that exist below the water table (Stone et al. 1983)

Hydrocarbon. An organic compound consisting exclusively of the elements carbon and hydrogen. The principal types are aliphatic (straight-chain) and cyclic (closed ring) (Messer and Post 1982).

Infiltration. The downward entry of water into the soil (BLM 1984).

Inflow. Water that flows into a body of water (BR 1992a).

LC_{50}. Lethal dose 50; the amount of a given toxic substance that will elicit a lethal response in 50% of the test organisms (Morris 1992)

Leachate. Liquid that has percolated through a medium and has extracted dissolved or suspended materials from it (Messer and Post 1982).

Leaching. The movement of a substance downward through soil as a result of water movement (Ware 1983). Extraction of dissolved or suspended materials from a solid by a liquid (Messer and Post 1982).

Lordosis. An abnormal forward curvature of the lumbar spine (Morris 1992).

Milling. Grinding and crushing ore, often to remove waste constituents (Messer and Post 1982).

Mine drainage. Any water discharged from a mine-affected area, including runoff, seepage, and underground mine water (Messer and Post 1982).

Mine-mouth. A steam electric power plant located within a short distance of an extraction operation and to which the mineral is transported from the mine by a conveyor system, slurry pipeline, or truck (Messer and Post 1982).

Mutagen. Substance causing genes in an organism to mutate or change (Ware 1983).

National Pollutant Discharge Elimination System. Means the Federal permitting system authorized under section 402 of the Federal Water Pollution Control Act including any State or interstate program which has been approved by the Administrator pursuant to Section 402 of the Act (New Mexico Water Quality Control Commission 1976).

Natural gas. A natural occurring mixture of hydrocarbon gases found in porous geologic formations beneath the earth's surface, often in association with petroleum. (The principal constituent of natural gas is methane) (Messer and Post 1982).

Necrosis. Localized or general death of plant or animal tissue, often characterized by a brownish or black discoloration (Messer and Post 1982). Death of tissue, plant or animal (Ware 1983).

Nonpoint source. Any nonconfined area from which pollutants are discharged into a body of water, i.e., agricultural runoff, urban runoff, and sedimentation from construction sites (Messer and Post 1982).

Nuclide. Any species of atom that exists for a measurable length of time. A radionuclide is the same as a radioactive nuclide, a radioactive isotope, or a radioisotope (San Juan Basin Regional Uranium Study 1980).

Organochlorine insecticide. Insecticide that contains carbon, chlorine, and hydrogen, for example, DDT, chlordane, lindane (Ware 1983).

Organophosphate pesticides. Insecticides (also one or two herbicides and fungicides) derived from phosphoric acid esters (Ware 1983).

Overburden. Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal, and are removed in surface mining (Messer and Post 1982).

Oxidation. Originally meant a reaction in which oxygen combines chemically with another substance, but term now includes any reaction in which electrons are transferred (Messer and Post 1982).

PAH. A hydrocarbon molecule with two or more fused aromatic rings; acronym for polycyclic aromatic hydrocarbon, synonymous with PNA (Morris 1992).

Perennial creek. A creek with continuous streamflow in a channel throughout the year (Roybal et al. 1983).

PCB. Any of a group of toxic, chlorinated aromatic hydrocarbons used in a variety of commercial applications, including paints, inks, adhesives, electrical condensers, batteries, and lubricants (an acronym for polychlorinated biphenyl) (Morris 1992)

pH. Measure of hydrogen-ion activity in solution. Expressed on a logarithmic scale 0 (highly acidic) to 14 (highly basic), with 7 neutral (New Mexico Water Quality Control Commission 1982).

Picocurie (piC). A unit of radioactivity equal to one-trillionth of a curie. One curie is the activity of a radionuclide decaying at the rate of 3.7×10^{10} disintegrations per second (Morris 1992).

PNA. A hydrocarbon molecule with two or more fused aromatic rings; acronym for polynuclear aromatic hydrocarbon, synonymous with PAH (Morris 1992).

Point source. A stationary emitting point of a pollutant, e.g., a stack or a discharge pipe; in contrast to a nonpoint source.

Polynuclear. Chemically polycyclic especially with respect to the benzene ring, used chiefly of aromatic hydrocarbons that are important as pollutants and possibly as carcinogens (Messer and Post 1982).

Pulverized coal. Coal that has been ground to a powder, usually of a size where 80% passes through a #200 U.S.S. sieve (Messer and Post 1982).

Pyrolysis. Thermal decomposition of organic compounds in the absence of oxygen. As for example the extraction of kerogen from crushed oil shale by the application of heat (Messer and Post 1982).

Recharge. Addition of water to an aquifer. Occurs naturally from infiltration of rainfall and of water flowing over earth materials that allow water to infiltrate below land surface (New Mexico Water Quality Control Commission 1976).

Reclamation. The process of converting mined land to its former or other productive uses; includes backfilling, grading, highwall reduction, top-soiling, planting, revegetation and other work to restore an area of land affected by mining (Messer and Post 1982).

Reinjection. To return a flow, or portion of flow, in a process (Messer and Post 1982).

Residue. Trace of a pesticide and its metabolites remaining on and in a crop, soil, or water (Ware 1983).

Runoff. All precipitation that does not soak into the ground, evaporate immediately, or is used by vegetation becomes runoff. This flows down slopes and forms streams (Messer and Post 1982). The part of the precipitation that appears in surface streams that are not regulated by dams or diversions (Roybal et al. 1983).

Salinity. (1) The relative concentration of salts, usually sodium chloride, in a given water. (2) A measure of the concentration of dissolved mineral substances in water (Messer and Post 1982).

Sediment. Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice, and has come to rest on the earth's surface (Messer and Post 1982).

Sedimentary. Formed by deposition of sediment (Stone et al. 1983).

Seepage. Movement of water through soil without forming definite channels. This term is often used to refer to the liquid lost through the bottom of a waste pond (Messer and Post 1982).

Sewage. Liquid-carried wastes of a community from domestic, service-industry, and industrial sources (used synonymously with wastewater herein) (Upper Colorado Region State-Federal Inter-Agency Group 1971)

Shale. Clastic sedimentary rock composed mainly of clay and displaying fissility (Stone et al. 1983).

Siemens. The SI electromagnetic unit of conductance. One siemens is the conductance at which a potential of one volt forces a current of one ampere (Morris 1992)

Silt. Finely divided particles of soil or rock that are often carried in cloudy suspension in water and eventually deposited in sediment (Messer and Post 1982).

Siltation. Small sized sedimentary particles of soil carried by surface runoff into lower levels (Messer and Post 1982).

Sorption. A general term for the various processes by which one substance bins to another, especially the processes of absorption or adsorption (Morris 1992).

Specific conductance. A measure of the ability of a water to conduct an electrical current. It is the reciprocal of the electrical resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specific temperature. The standard measurement is expressed in micromhos (μmhos) per centimeter (cm) at 25 degrees Celsius. Specific conductance is related to the type and concentration of ions in solution and can be used to approximate the dissolved-solids concentration in water. Estimates of the dissolved-solids concentration in milligrams per liter (mg/l) range from 60 to 85% of the specific-conductance value in μmhos per cm at 25 degrees Celsius (Roybal et al. 1983).

Spoil. All overburden material removed, disturbed, or displaced from over the coal by excavating equipment, blasting, augering, or any other means. Spoil is the soil and rock that has been removed from its original location (Messer and Post 1982).

Stack. A chimney associated with a power plant for the purpose of discharging gases into the atmosphere (Messer and Post 1982).

Strip mining. Refers to a procedure of mining that entails the complete removal of all material from over the coal to be mined in a series of rows or strips; also referred to as open-cut, open-pit, or surface mining (Messer and Post 1982).

Suspended solids. Small particles of solid pollutants that resist separation by conventional means. Suspended solids (along with BOD) is used as a measurement of water quality and an indicator of waste-treatment-plant efficiency.

Tailings. Waste material derived when the raw mineral or ore is processed to improve its quality or liberate other components. Tailings are usually associated with hard rock mining (Messer and Post 1982).

Teratogen. Substance that causes physical birth defects in the offspring following exposure of the pregnant female (Ware 1983).

Total dissolved solids (TDS). The amount of solids in both solution and suspension (Messer and Post 1982). TDS is used as a measure of the mineral content or salinity of water (Upper Colorado Region State-Federal Inter-Agency Group 1971).

Total recoverable concentration. The total concentration of a given constituent in a representative water-suspended sediment mixture. The total concentration is the sum of the dissolved concentration and the concentration recovered from the suspended sediment by a prescribed partial, but not complete, chemical digestion of the suspended sediment (Roybal et al. 1983).

Total suspended solids (TSS). The amount of solids, both organic and inorganic, in suspension in the water. Includes such things as silt, suspended oil, and animal wastes (Messer and Post 1982).

Toxicant. A poisonous substance, such as the active ingredient in pesticide formulations, that can injure or kill plants, animals, or microorganisms (Ware 1983). A substance that kills or injures living organisms by its chemical or physical actions, or by altering the environment of the organisms (Messer and Post 1982).

Trace elements. Chemical elements that normally are present in minute (trace) quantities. Includes metals and nonmetals (Messer and Post 1982).

Turbidity. A measure of water clarity. Light penetration is reduced in turbid waters. High turbidity indicates high suspended solids (Messer and Post 1982).

Underground mining. Removal of coal being mined without the disturbance of the surface (Messer and Post 1982).

Volatilization. Vaporization (Ware 1983).

Wastewater. That water for which disposal is more economical than use at the time and point of its occurrence (Upper Colorado Region State-Federal Inter-Agency Group 1971).

Wastewater treatment plant. Any mechanical or non-mechanical plant used for the purpose of treating, stabilizing, or holding waters (Upper Colorado Region State-Federal Inter-Agency Group 1971).

Young-of-the-year (YOY). A fish in its first growing season belonging to the age-group 0 which has usually reached the fingerling stage (Robison and Buchanan 1988).

Zooplankton. The animal portion of the plankton. Protozoa and other animal microorganisms living unattached in water (Messer and Post 1982).

ABBREVIATIONS

ANOVA. Analysis of variance

B(a)P. Benzo(a)pyrene

Bbls. Billion barrels

BIA. Bureau of Indian Affairs, U.S. Department of the Interior

BLM. Bureau of Land Management, U.S. Department of the Interior

BOD. Biological Oxygen Demand

BR. Bureau of Reclamation, U.S. Department of the Interior

°C. Degrees Celsius

COD. Chemical Oxygen Demand

CRSP. Colorado River Storage Project

DO. Dissolved oxygen

DOE. Department of Energy, U.S. Department of the Interior

DOI. U.S. Department of the Interior

DSFES. Draft Supplement to the Final Environmental Statement

EIS. Environmental Impact Statement

EPA. Environmental Protection Agency, U.S. Department of the Interior

FES. Final Environmental Statement

FWS. U.S. Fish and Wildlife Service, U.S. Department of the Interior

GERG. Geochemical Environmental Research Group

HPLC. High Performance Liquid Chromatography

LC_{50}. Lethal concentration for 50% of a population

MCF. Thousand cubic feet

MFO. Mixed-function oxidase

MVIC. Montezuma Valley Irrigation Company

NASQAN. National Stream-Quality Accounting Network

NCBP. National Contaminants Biomonitoring Program

NIIP. Navajo Indian Irrigation Project

NIWQP. National Irrigation Water-Quality Program

NORM. Naturally Occurring Radioactive Material

NPDS. National Pollutant Discharge Elimination System

NPS. U.S. National Park Service, U.S. Department of the Interior

NWQSS. National Water Quality Surveillance System

OCD. Oil Conservation Division, New Mexico

PAH. Polycyclic aromatic hydrocarbon

PCB. Polychlorinated biphenyl

piC. Picocuric

PNA. Polynuclear aromatic hydrocarbon

RCRA. Resource Conservation and Recovery Act

S. Siemens, the SI electromagnetic unit of conductance

SPH. Separate phase hydrocarbon

Tcf. Trillion cubic feet

TDS. Total dissolved solids

TSS. Total suspended solids

UDWR. Utah Division of Wildlife Resources

UMTRA. Uranium Mill Tailings Remedial Action

UNM. University of New Mexico

USGS. U.S. Geological Survey, U.S. Department of the Interior

VOC. Volatile organic compound

YOY. Young-of-year

CONVERSION TABLE		
	Units	Concentration
Water:	mg/l	ppm
	ug/l	ppb
	ng/l	0.001 ppb or 1 ppt
Food, soil, or sediment:	ug/g	ppm
	mg/kg	ppm
	mg/g	ppb
	ug/kg	ppb
	ng/g	ppb
	pg/g	ppt
	ng/kg	ppt
	pg/g	ppt
	* 1 percent	10,000 ppm

* Usually associated with oil or grease in sediments, etc.

ABBREVIATIONS		
g	=	gram
mg	=	milligram
ug	=	microgram
ng	=	nanogram
kg	=	kilogram
pg	=	picogram
l	=	liter
u	=	micro
pico	=	one trillionth
ppm	=	parts per million
ppb	=	parts per billion
ppt	=	parts per trillion