AN EVALUATION OF SEDIMENTS IN THE MIDDLE RIO GRANDE, ELEPHANT BUTTE RESERVOIR AND CABALLO RESERVOIR AS POTENTIAL SOURCES FOR TOXIC MATERIALS

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by

Carl J. Popp and Donald K. Brandvold
Department of Chemistry

Thomas R. Lynch
Department of Biology

and

Lynn A. Brandvold
New Mexico Bureau of Mines and Mineral Resources

New Mexico Institute of Mining and Technology

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ABSTRACT

The distribution of a large number of priority pollutant trace metal and organic species in water and sediments in surface waters in the Middle Rio Grande region of New Mexico has been surveyed. Study sites include Socorro and San Marcial along the Rio Grande to determine delivery of trace substances and Elephant Butte and Caballo Reservoirs. Elephant Butte Reservoir is the repository for suspended sediments collected by the Rio Grande while Caballo Reservoir provides a control site. In addition to sediments and water, limnological data was collected on the reservoirs, radionuclide and particle size analysis was performed on the sediments and a limited number of fish were surveyed for trace metals and organics.

The sediments carry elevated levels of the metals Hg, Cd, As, Se, and U and fish may be biomagnifying Hg, Pb, and V through the food chain. Mercury levels in fish are high enough to warrant concern from a health standpoint.

Detectable levels of 18 different chlorinated organic pesticides were found in samples of water and bottom sediments. These pesticides were found predominantly in association with suspended particulates or with fine particles in the bottom sediments. Pesticides were detected more frequently in the Fall than in the Spring. Because of heavy sediment inputs contaminated by adsorbed pesticides, the calculated annual input to Elephant Butte Reservoir lies between 900-11,000 kg for each of the seven most frequently detected pesticides.

Keywords: trace metals, trace organics, trace substances, water quality, fish tissues, chlorinated organic pesticides, pesticides, liminology, radionuclides, water chemistry, river sediments, reservoir sediments, suspended sediments, priority pollutants, Middle Rio Grande

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I. INTRODUCTION

A. Statement of Problem

Previous studies on the Rio Grande have indicated that large quantities of trace metals and an unknown quantity of organic compounds are transported downstream by suspended sediments. Some of these metals are at concentrations an order of magnitude higher than their mean concentrations in the earth's crust. In addition, chlorinated hydrocarbon pesticides have been detected on suspended particulates at several stations between Corrales and Monticello Point.

The sediments carried by the Rio Grande, downstream of Cochiti Lake, are eventually deposited in Elephant Butte Reservoir where the trace metals and organic compounds have the potential to accumulate. Published reports indicate that heavy metals and chlorinated organics are often reversibly bound to suspended particulates and bottom sediments. These compounds often reach their highest concentrations on fine-textured particles or particulate organic materials. Because of their small masses these particles would be deposited only in deep basins or areas of low turbulence. The bottom sediments may thus act as sinks for these materials but the potential for, and conditions of release into the overlying water are largely unknown. It is conceivable that these toxic materials may be mobilized as the result of changes in water chemistry or biological activity. The extent to which these materials may enter the food chain and bioaccumulate is also largely unknown.

In view of the heavy known inputs of trace metals into Elephant Butte Reservoir, intense use of the water by agricultural interests, recreational use of the reservoir, the detection of chlorinated hydrocarbon pesticides in river water and the ability of both metals and organics to accumulate in food chains, it is important to know whether these materials are being effectively buried in the bottom sediments or whether they present a potential problem in terms of ecological or public health. The accumulation of heavy metals and persistent organics by bottom sediments may be beneficial to overall water quality on a short-term basis, but the potential for, and the consequences of, long-term release also need to be considered.

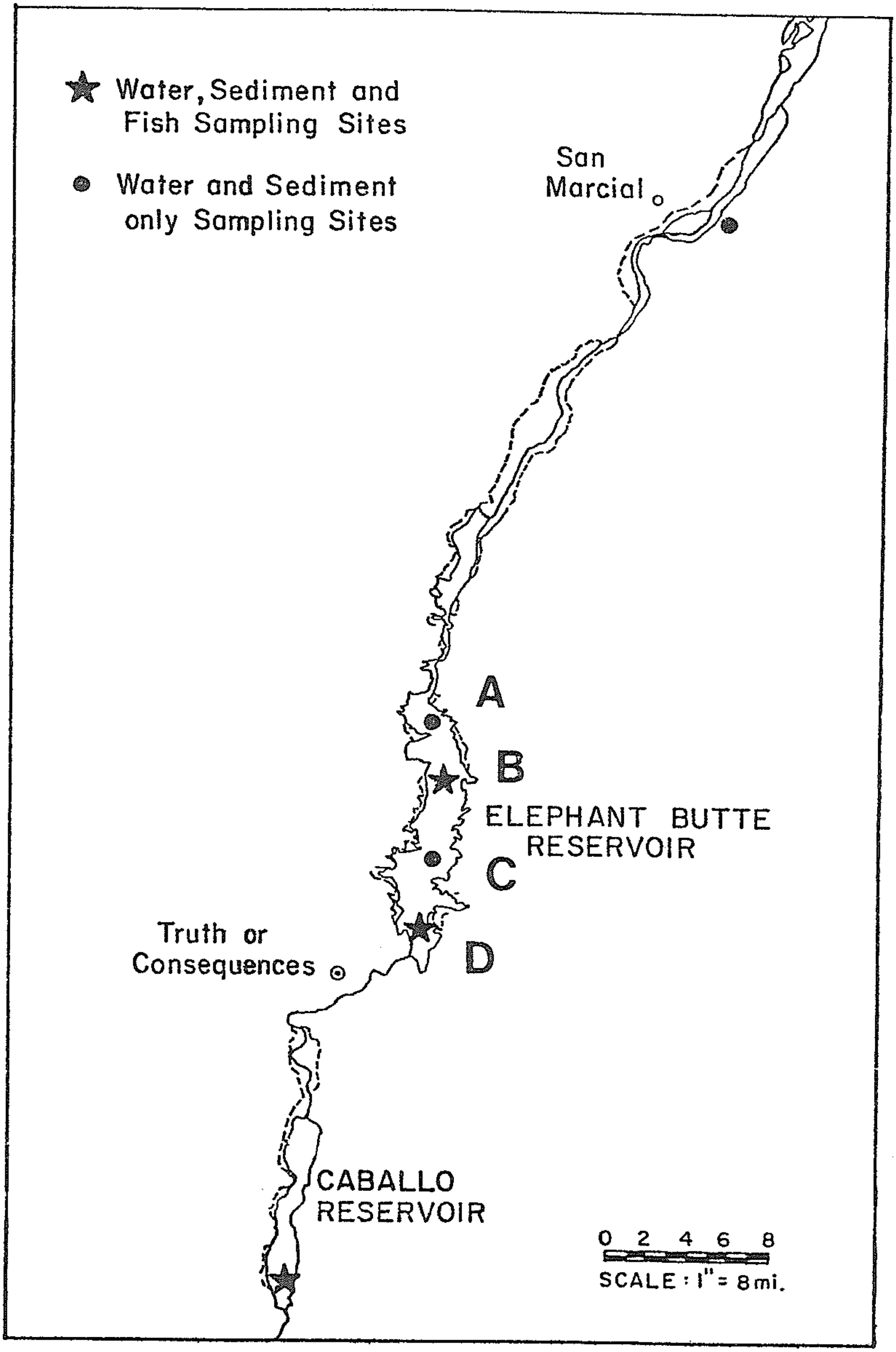

Figure 1. Sample sites.

B. Project Objectives

1) To determine the concentrations and relative distributions of the priority pollutant trace metals and synthetic organic compounds listed in Appendix A in the water, suspended particulates, and bottom sediments of Elephant Butte and Caballo Reservoirs.

2) To determine the deposition patterns of trace metals and organics (from 1) in both reservoirs as a function of distance from point of inflow, depth, sediment particle size, sediment organic content, and sediment cation exchange capacity.

3) To determine the impact of sediment deposition in the reservoirs on downstream water quality.

4) To determine the extent of seasonal changes in the distribution of the metals and organics as a result of changes in runoff patterns, evaporation rates, dissolved oxygen profiles, pH, and oxidation-reduction changes.

5) To determine whether the trace metals and synthetic organics are available to, and being accumulated by the biota of the reservoirs. Emphasis was placed on fish species of major commercial and recreational importance. The fish studied were carp (Cyprinus carpio), white bass (Morone chrysops), and gizzard shad (Dorosoma cepedianum). The shad are an important forage fish for species such as white bass.

6) To determine the sedimentation rate and the distribution of toxic substances with depth in the sediment using the radionuclides lead-210 and cesium-137.

7) To determine the presence of radionuclides such as uranium, thorium, and radium in buried sediments.

C. Trace Substance Transport

Trace metal transport in the Middle Rio Grande is known to occur in association with suspended sediments (Popp et al. 1980; Popp and Laquer 1980). Eventually the suspended sediments are deposited in Elephant Butte Reservoir. The average yearly suspended sediment load delivered to Elephant Butte Reservoir is 10,000,000 tonnes (Bureau of Reclamation 1976) and as a result the potential metal loading may be high. For example, calculations based on metal analysis of suspended sediments (Popp and Laquer 1980) and flow data (U.S.G.S. 1978) indicate that 2200 kg of lead, 200 kg of mercury and 1500 kg of arsenic may be delivered at the confluence of the Rio Grande and the Rio Puerco (100 km upstream from Elephant Butte Reservoir). In addition, metal concentrations in the suspended sediments of the Rio Grande above Elephant Butte have been compared to their average crustal abundances. Concentrations of arsenic, mercury, molybdenum, and selenium are at least an order of magnitude greater in the river sediments than their mean concentrations in the earth's crust (Popp and Laquer 1980: Brandvold et al. 1980). The work by Popp and Laquer (1980) showed that the metals were mainly associated with the crystalline phase of the suspended sediments rather than dissolved in the water. The crystalline phase is composed of the highly mineralized material that remains after sequential extraction for exchangeable cations and hydrous metal oxide associated cations.

Radionuclide accumulation may be occurring in the reservoir because of the influence of the large suspended sediment loads from the Rio Puerco which drains the Grants Mineral Belt. Intense uranium mining and milling activity has been in progress in the area for a number of years. There were 35 active mines in the area as of 1978 and five mills (by 1977) capable of handling 21,000 tonnes of ore per day (Perkins 1979). This activity produces mill tailings and mine water which may increase the mobility of radionuclides and heavy metals associated with the uranium deposits. The Rio Puerco has been estimated to contribute more than 50% of the sediment load to the Rio Grande at its confluence while carrying less than 16% of the water (Waite et al. 1972; Popp and Laquer 1980). These suspended sediments are deposited in Elephant Butte Reservoir and may provide a sink for the radioactive material.

Trace metals are known to accumulate in the bottom sediments of aquatic ecosystems and often reach concentrations several orders of magnitude higher than the overlying water. Patterns of trace metal accumulation in bottom sediments often reflect proximity to the source of the pollution. Coggins et al. (1979) found that concentrations of trace metals in the sediment cores of a reservoir receiving mine tailings runoff decreased with distance from the source. Concentrations of arsenic, mercury, and copper in the bottom sediments of a series of interconnected lakes decreased with distance from a gold-mining operation (Moore et al. 1979). Turner and Lindberg (1978) also found a decreasing gradient of mercury in the surface sediment from the point of inflow to the outflow of a main channel reservoir being polluted by wastes from chlor-alkali plant. However, decreasing concentrations of trace metals with distance from a point source does not always occur. Mercury concentrations in the sediments of the LaHave River and estuary, Nova Scotia, were found to increase with distance from a municipal sewer outfall (Cranston and Buckley 1972). The authors attributed this pattern to mercury adsorption onto fine particles which were eventually deposited as a result of salinity-related flocculation and sedimentation as a result of slowing current velocities. Working in Elephant Butte Reservoir, Kidd et al. (1974) found decreasing concentrations of mercury in water and increasing concentrations in the bottom sediments with distance from the point of water inflow. However, Potter et al (1975) were unable to detect a mercury gradient in the bottom sediments of Lake Powell, a Colorado River main channel impoundment. Clearly, much additional work needs to be done to determine those chemical, hydrological, and sedimentological factors that control trace metal distributions in rivers and reservoirs.

Trace metal enrichment of bottom sediments has been attributed to adsorption on, or complex formation with organic materials, ion-exchange reactions, and adsorption onto hydrous metal oxides and fine particulates. In some cases suspended crystalline material may settle out. All the above materials will tend to be deposited in areas of low current velocity and minimum turbulence such as in deep basins or in backwater areas. Physical and chemical conditions in the overlying water associated with changes in pH, dissolved oxygen profiles, redox potentials and density gradients may result in the solubilization of these metals. Many of these trace metals become highly soluble under reducing conditions although they may again be precipitated if sufficient hydrogen sulfide is generated to form insoluble metallic sulfides. Biological methylation also represents a tranformation which may increase the mobility of some metals such as As, Hg, Cd, and Se (Ridley et al. 1977; Manahan 1979).

Very little is known with regard to the behavior of metals in natural systems once these materials have been deposited in bottom substrates. Several studies have shown that recently deposited materials are often rapidly mixed with deeper sediment layers possibly as a result of the biological activity of benthic organisms (Eganhouse et al. 1978; Cranston 1976). This activity also presents the potential for incorporation into the lower trophic levels of aquatic food chains. Work by Kidd et al. (1974) in Elephant Butte Reservoir and by Potter et al. (1975) in Lake Powell indicated that predatory fish were accumulating large amounts of mercury even though very low levels were found dissolved in the water. In the latter investigation the mercury was thought to result from the natural weathering of rocks in the watershed followed by trophic level magnification. Work by Brandvold et al. (1973) on Rio Grande water in the Bosque del Apache Wildlife Refuge and by Popp et al. (1980) along the Middle Rio Grande indicated high levels of mercury not only in fish tissues but also in the water. A statewide survey of mercury in New Mexico surface waters by L. Brandvold (1978) reported values in the 0.2-2.0 parts per billion (ppb) range for total mercury which also were higher than those reported by Kidd et al. (1974). Bioaccumulation of several different metals in the tissues of aquatic species sampled between Albuquerque and the upper end of Elephant Butte Reservoir was reported by Popp et al. (1980) although toxic levels were not noted for any of the metals analyzed.

The extent of contamination of the middle Rio Grande and its reservoirs by synthetic organic compounds and their distribution between water, sediments, and aquatic biota is largely unknown. The potential contamination of the water by organic pesticides is high because of the heavy reliance on irrigated agriculture along extensive stretches of the river. In the study by Popp et al. (1980) a number of chlorinated hydrocarbon pesticides were found in water samples taken upstream from Elephant Butte Reservoir. The most commonly occurring species were the DDT metabolites (DDE and DDD), lindane, and dieldrin. In some cases concentrations of these materials were higher than EPA recommendations. The chlorinated hydrocarbons were found to be assoiated with the suspended particulates at concentrations greater than 1000 times that of water. Similar sediment/water distributions of these compounds have been reported by other workers (Miles and Harris 1971; Miles 1976; Oloffs et al. 1973).

Because of their hydrophobic nature these organic compounds will tend to accumulate at interfaces at the surface of suspended particulates and bottom sediments when introduced into aquatic systems (Cope 1966; Gerakis and Sficas 1975). Two factors which favor the association of hydrophobic organic compounds with suspended particulates and bottom sediments are small particle size and high concentrations of organic matter (Browman and Chesters 1977; Karickhoff and Brown 1978; Hetling et al. 1978; Wilber and Hunt 1979; Schrader and Furbish 1978). These compounds may in turn become heterogeneously distributed in aquatic systems depending on the nature and quantity of available surfaces, differential distribution of various sizes of particulates, water volume/bottom surface area ratios, biological productivity of the system, etc.

Since sorption onto sediments tends to stabilize these chlorinated compounds, significant accumulation could be occurring in the reservoirs which could persist for years (Pionke and Chesters 1973). It has been speculated that contaminated bottom sediments may also act as reservoirs of these materials which can buffer concentrations in the overlying water (Frank et al. 1974; Baughman and Lassiter 1978). These materials may also be capable of entering aquatic food chains via direct contact with, or ingestion of, contaminated sediments by bottom-dwelling organisms and by direct uptake of solubilized material from the water (Halter and Johnson 1977; Weininger 1978; Ramamoorthy et al. 1977; Lynch 1979).

In the future, reservoirs will "silt up" and a present and future potential exists for continuous long-term release of material deposited with the sediments. This hypothesis is based on literature research which indicates that the binding of synthetic organic chemicals to particles often behaves similar to the reversible adsorption - desorption equilibrium exchange reactions. In addition, metal species bound to sediments may be solubilized as a result of changes in pH, redox potential microbial activity, etc. (Manahan 1979).

D. Sediment Dating and Radionuclides

The use of radionuclides with relatively short half-lives, such as Pb-210 and Cs-137, to date recent sediments and establish anthropogenic inputs of metals is now well-established. This subject has been reviewed by Krishnaswami and Lal (1978). Robbins and Edgington (1975, 1976) have used both Pb-210 and Cs-137 to establish anthropogenic inputs of lead from coal and gasoline use to Lake Michigan sediments. Benninger (1978) has used Pb-210 to determine lead fluxes in Long Island Sound, and Smith and Walton (1980) have used Cs-137, as well as pollen assemblages, to determine the sedimentation rate in a fjord in Quebec. Determination of Pb-210 by direct gamma ray spectrometry, by far the simplest method (and the method used in this study) has been discussed by Gaggeler et al. 1976) and refined by Schery (1980) for direct measurement on untreated (except for drying) samples.

Cs-137 is an artificial isotope with a half-life of 30 years, and has been added to surface sediments through atmospheric nuclear testing. The amount of Cs-137 added has varied from year to year, and reached a maximum during the periods of greatest atmospheric testing in 1958 and 1963 (Krishnaswami and Lal 1978). Studies of sediment cores in lakes, estuaries, and marshes have revealed the presence of similar spikes in the levels of Cs-137 and other fallout radionuclides. Robbins and

Edgington (1975) and other researchers have demonstrated that these maxima correspond to the periods of peak atmospheric testing, and that it is therefore possible to accurately date these levels in the cores.

The presence of Cs-137 can be determined by gamma ray spectrometry (Robbins and Edgington 1975). The gamma counting is done directly on oven-dried samples, using a lithium-drifted germanium (GeLi) detector to count the 661 KeV Cs-137 gamma rays. Counting is usually done over a long (12-14 hour) period because of the low levels of Cs-137 present.

Lead-210 is a naturally occurring isotope and is an intermediate product in the Uranium-238 decay series. Its half-life of 22.3 years makes it ideal for the dating of samples less than 100 years old. An advantage of using this isotope is the low solubility of lead, and hence its low mobility in sediments.

Atmospheric Pb-210 is produced by the decay of Rn-222, and is introduced into the soil by both dry and wet deposition. After the sediments are buried, no further input of atmospheric Pb-210 can take place. The activity of the Pb-210 in the sediments will therefore decline as a function of age, assuming that the lead in the sediments is immobile and insoluble. A steady background concentration of Pb-210 (supported lead) is reached when the added Pb-210 has decayed and indicates Pb-210 is being produced within the core only by the radioactive decay of its progenitors in the U-238 decay series.

E. Study Area

The Rio Grande watershed which comprises an area of about 128,150 km^2 (49,440 square miles) is the most significant source of surface and subsurface water in New Mexico (Figure 1). The Rio Grande basin in New Mexico extends southward from Colorado to Texas bisecting the state and eventually forms the international border between Texas and Mexico. Flow is derived primarily from snowmelt in the central mountains of northern New Mexico and southern Colorado and from intermittent but locally heavy thunderstorms during July and August. At most points in the Rio Grande basin, there is a direct connection between surface and groundwater. The aquifer within the Rio Grande valley varies from 300-900 m(1000-3000 ft.). The water table depth fluctuates in response to precipitation, irrigation, river stage and pumping from domestic and municipal wells. Average annual discharge in the Rio Grande varies considerably but the usable annual surface water supply is estimated to be 0.67 km^3 (540,000 acre-feet), all of which is fully appropriated and utilized (Rio Grande Compact). Water used for irrigation constitutes New Mexico's largest use, amounting to more than 80 percent of total withdrawals for all purposes (Bureau of Reclamation 1976).

Elephant Butte and Caballo Reservoirs are main channel impoundments on the Rio Grande which are maintained for power generation, irrigation, and flood control by the Federal Bureau of Reclamation. Both reservoirs are used extensively for water-oriented recreation and support a significant sport fishery in a water-poor area. Some commercial fishing is allowed in Elephant Butte Reservoir for rough fish species with about 15 tons caught annually (personal communication, New Mexico Department of Game and Fish).

Elephant Butte, the northernmost of the two reservoirs, is located in Sierra County, six kilometers (five miles) northeast of the city of Truth or Consequences in southcentral New Mexico. This reservoir which has a drainage area of 76,260 km^2 (29,445 mi^2) is formed by a concrete dam which was closed on January 6, 1915. Original storage capacity was 3.25 km^3 (2,638,900 acre-feet) which had been reduced to 2.60 km^3 (2,109,000 acre-feet) in 1974 by sedimentation (U.S.G.S. 1978). Volume has varied from a maximum of 2.84 km^3 (2,302,800 acre-feet) in June 1942 to a minimum of 0.01 km^3 (9,900 acre-feet) in August 1954 (U.S.G.S. 1978). The volume was approximately 1.48 km^3 (1,200,000 acre-feet) in June 1980 and the reservoir has been maintained at about one million acre-feet for several years due to above average winter moisture supplies.

Elephant Butte Reservoir has been classified as oligotrophic on the basis of its morphometry and low standing crops of plankton and benthos by Jester (1972) although Kidd and Johnson (1971) classify the lake as eutrophic because of its nutrient content and phytoplankton community structure. Silt suppresses production of benthos in approximately 40 percent of the bottom area. Primary production is low which is probably due to light limitation caused by the presence of suspended particulates rather than by nutrient limitations. The depth at which one percent of the incident light remains varies from 0.36 m (1.19 ft.) at Monticello Canyon near the upstream end of the reservoir to 1.12 m (3.69 ft.) at the dam (Dave Tague, New Mexico Environmental Improvement Division, personal communication). The benthos is of low diversity and consists primarily of chiromid larvae (Diptera, Chironomidae) and oligochaete worms (Annelida, Oligochaeta). It is thought that the primary direction of energy flow to the fish community is through the phytoplankton - zooplankton community rather than from the benthos (personal communication, Dr. Richard Cole, Department of Fishery and Wildlife Sciences, New Mexico State University). However, the lake is known to support large populations of smallmouth buffalo (Ictiobus bubalus), river carpsucker (Carpiodes carpio), and carp (Cyprinus carpio) all of which are benthic omnivores.

The fish assemblage of Elephant Butte Reservoir consists of approximately 30 species representing 11 families. The assemblage includes seven commonly occurring species of piscivorous fishes which rely heavily on gizzard shad (Dorosoma cepedianum) for forage. Gizzard shad are filter feeding fish of open water which utilize zooplankton.

Caballo Reservoir is located in Sierra County 36.4 km (22.6 miles) south of the city of Truth or Consequences. The reservoir is formed by an earthfill dam which was closed on February 8, 1938. The reservoir has a drainage area of 79,510 km^2 (30,700 mi^2) which includes all but 250 km^2 (96.5 mi^2) of the drainage area assigned to Elephant Butte (U.S.G.S. 1978). As of 1958, the reservoir had a storage capacity of 0.42 km^3 (344,000 acre-feet); daily storage volume has varied from a maximum of 0.43 km^3 (347,000 acre-feet) in March 1942 to a minimum of 1.4×10^{-4} km^3 (118 acre-feet) in October 1938 (U.S.G.S. 1978). During water year 1978, the last for which data are available, storage volume varied between 0.01-0.07 km^3 (10,470 to 58,290 acre-feet). The terrain surrounding Caballo Reservoir is similar to that of Elephant Butte but the impoundment is located in a shallow basin of poor shoreline development. Water levels in the reservoir vary markedly especially during the summer months when the demands of irrigated agriculture are high. No published information is available with regard to the water chemistry or the biology of the reservoir as neither the State Environmental Improvement Division nor the U.S.G.S. obtain this type of data on a regular basis for this reservoir. However, Dr. Richard Cole (Department of Fishery and Wildlife Sciences, New Mexico State University) and Mr. Jerry Wisdom (District Fisheries Biologist, New Mexico Department of Fish and Game) believe that the biological community is essentially the same as in Elephant Butte. Biological productivity in Caballo Reservoir is limited to a significant extent by the frequency and degree of water level fluctuation.

There are a number of features associated with the study site which combine to create a favorable situation for the study of the movement of toxic materials in aquatic systems. These features are summarized below:

a) The heavy sediment load for the Rio Grande and its associated trace metal concentration: Heavy sediment loads are characteristic of many southwestern rivers and data derived from the study may have wide application for the Colorado River and other southwestern drainage systems.

b) The close proximity of the two reservoirs to each other and the resulting small watershed associated exclusively with Caballo Reservoir: Elephant Butte thus acts as a sediment trap which improves the quality of the water being delivered to Caballo Reservoir. Additional inputs to Caballo Reservoir from its watershed are minimal.

c) Age of the reservoirs: An evaluation of changes in agricultural practices and mining activities on the watershed and their effect on water quality is possible based on sediment dating. The location of the uranium mining activity in the Rio Puerco - Rio Grande drainage with its associated runoff containing uranium and its degradation products created a unique possibility for dating sediments.

d) Low population density and minimal development of industry in the watershed: Data obtained will provide a baseline for comparison in future years as human population growth in the watershed is expected to grow rapidly in the next 20-40 years.

e) Morphometric differences between the two reservoirs: Elephant Butte has an irregular shoreline and extensive areas of deep basins whereas Caballo Reservoir has a nearly uniform shoreline, is relatively shallow and is subject to complete vertical mixing by wind action.

f) Intensive use of water for irrigated agriculture in the Rio Grande Valley: This feature has the potential of introducing large quantities of pesticides into the system via irrigation return flows.

II. PROCEDURES, METHODS, AND MATERIALS

A. Sample Sites

The sampling stations were located as shown in Figure 1. In addition, the Rio Grande was sampled at Socorro, about 25 miles (40 km) north of San Marcial. The State of New Mexico Environmental Improvement Division conducts a sampling program along the river down to San Acacia (22 km north of Socorro).

The sites at Socorro and San Marcial were used to identify substances being transported into the reservoir system by the river during the study period. The system at San Marcial collects water from the Low-Flow Channel and from the irrigation return system which terminates just north (upstream) of San Marcial. This sampling site indicated which agricultural chemicals were entering the river and were available for delivery to Elephant Butte.

Because the suspended sediments settle out in Elephant Butte Reservoir, four sampling sites were located at the upper, upper-middle, lower-middle, and lower sections of the reservoir. Fluctuating water levels were considered in determining sample sites in the reservoir because the volume of Elephant Butte has varied from 0.06 km^3 (50,000 acre feet) to over 1.48 km^3 (1,200,000 acre feet) in the last 10 years. Sites were chosen so that water was always present. The northernmost site at Elephant Butte was part of the reservoir only for the first two sample collections due to fluctuating water levels. Thereafter, lowered water levels confined the water to a narrow channel.

Caballo Lake was sampled at one site near the dam. Relatively little sediment is carried into Caballo compared to Elephant Butte and the distribution and mobilization phenomena may be considerably different for the two impoundments. However, occasional heavy sediment inputs may occur from arroyos located between Elephant Butte and Caballo Reservoir. Caballo may serve as a control for Elephant Butte because sources of contaminated sediments should be minimal.

At each of the five reservoir sampling sites, water and sediment samples were collected along the central axis of the reservoirs. Where water depths permitted, one set of water samples was obtained directly beneath the surface, and another set collected at approximately one meter above the bottom. Bottom sediment grab samples were also collected at these points. The river samples were collected from the west bank as conditions permitted. Because the river water was well-mixed due to turbulent flow, little cross sectional variation in water chemistry and sediment distribution would be expected.

Four major sample collections for sediments and water were made. These took place late in the fall (October 1981-November 1982) and in the spring (May 1981 and 1982) in addition to a reconnaisance trip in September 1981. Fishes were collected in fall 1981 and spring 1982.

Boats and motors for reservoir sampling were rented. A typical pontoon boat is shown in Figure 2.

B. Sampling Methods for Water, Sediment, and Fish

1. Water

Water samples were collected with a messenger-activated Kemmerer bottle (2.2 ℓ) which was constructed of inert PVC plastic (Figure 3). Water which was destined for trace metal analysis was placed in acid-washed plastic bottles which contained a small quantity of redistilled nitric acid to prevent loss of species to the container walls. Water samples destined for chlorinated hydrocarbon analysis were placed in acetone/hexane-rinsed, four-liter, amber-glass bottles secured with aluminum foil or Teflon-lined screw caps.

The total number of water samples was (1 at Socorro + 1 at San Marcial + 4 sites x 2 depths in Elephant Butte + 1 site x 2 depths in Caballo x 4 trips) = 48. In addition, two extra sets of water samples were collected at each reservoir site in the first two sample trips between the west shore and the centerline (2 trips x 5 sites x 2 depths = 20). Total samples = 68.

2. Sediment

Samples of bottom sediment were collected with a Ponar bottom-grab sampler (petite version, 232.3 cm^2), and placed in quart-sized Mason jars (Figures 4,5). The samples were cooled on crushed ice in the field and were frozen upon return from the field.

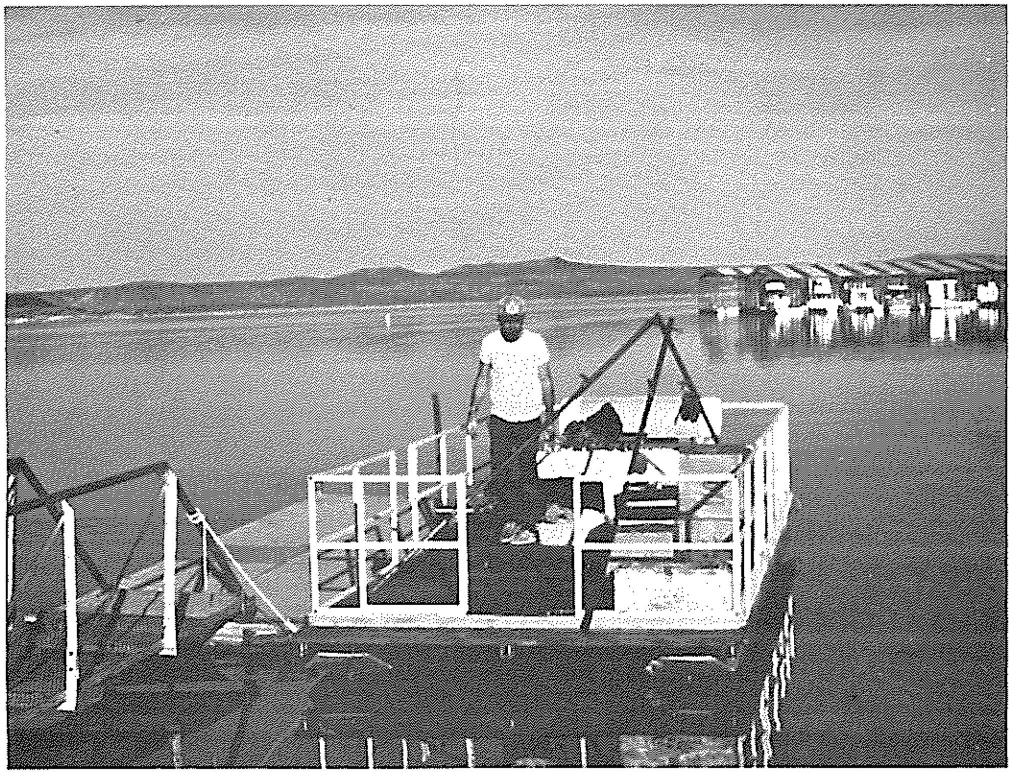

Figure 2. Pontoon boat used for sampling Elephant Butte Reservoir.

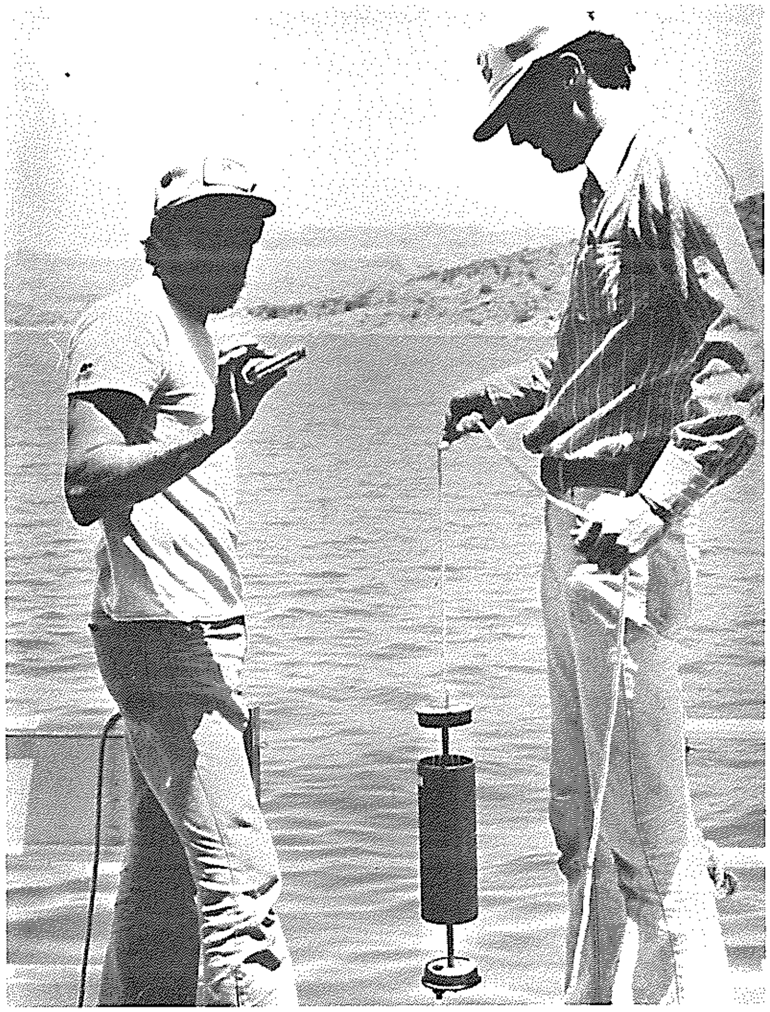

Figure 3. Kemmerer water sampler. Dr. T. Lynch (r.) holds sampler in open position. Note marks on rope at one foot intervals to measure depth. Dr. C. Popp (l) holds "messenger" which slides down rope to trigger closure.

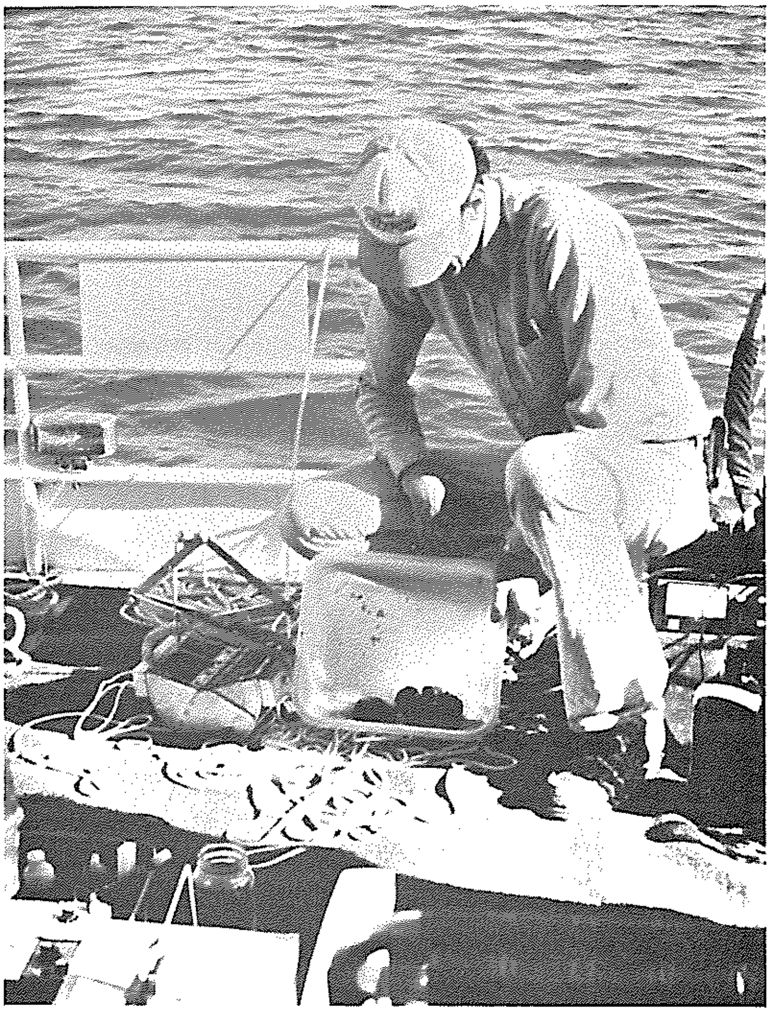

Figure 4. Dr. T. Lynch with Ponar dredge showing rocks collected at site in Elephant Butte with no sediment accumulation.

Figure 5. Dredge shown collecting cans at depths >30 m. The cans would occasionally lodge in the dredge and prevent the jaws from closing necessitating multiple dropping and and retrieval of the dredge to collect a sample.

Sediment samples were also obtained for trace metal analysis of the interstitial water. These samples were placed in 250 ml wide-mouth polyethylene bottles, filled to the top to exclude air, capped, and placed on ice. Exclusion of air is necessary to prevent oxidation of reduced species.

Bottom sediment coring was attempted with a Classmate K.B. Core sampler designed to maintain the integrity of the core so that the strata could be dated. However, data which was obtained from the Bureau of Reclamation (1972) indicated that about 15 m (40-50 feet) of sediment had accumulated in Elephant Butte since 1916. The sampling effort was abandoned because the coring device was only capable of obtaining a 45 cm core. Also, despite its considerable weight ($\sim$20 kg) the device failed to penetrate more than 5-10 cm into the bottom sediments.

Total sediment samples were seven sites x 4 trips = 28. In addition sediment samples were collected on an East-West transect at each reservoir site as described above (10 sites x 2 trips = 20). Total sediment samples = 48.

3. Fish

Fish were collected by gillnetting and electroshocking in cooperation with personnel from the New Mexico Department of Game and Fish and the Department of Fish and Wildlife, New Mexico State University (Figures 6,7). Two collections were conducted in Elephant Butte Reservoir; one in mid-October 1981 and one early July 1982. Fish were obtained from Caballo only during late October 1981. In Elephant Butte, fish were collected at two locations; one near the dam and state park boat launching ramp, the other from the north end in the vicinity of Monticello Point. Fish collected in Caballo Reservoir were obtained in the vicinity of the state park boat launching ramp. Every effort was made to obtain at least ten individuals of each species for each site. Only individuals greater than two years old were sampled on the assumption that if a material was going to bioaccumulate it should do so in older individuals. These fish should have larger lipid deposits and thus accumulate greater body burdens. Also, older fish tend to inhabit deeper waters than younger fish and may therefore be exposed to higher contaminant concentrations. At the time of collection, fish for metal analysis were placed in plastic bags and labeled.

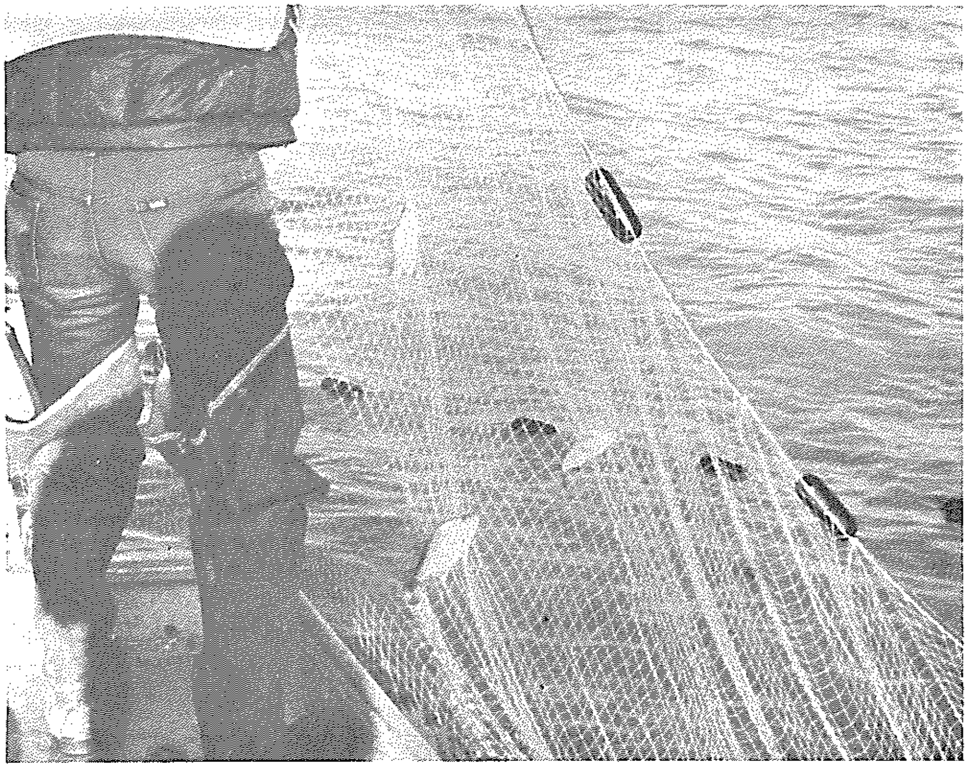

Figure 6. Gill net with shad.

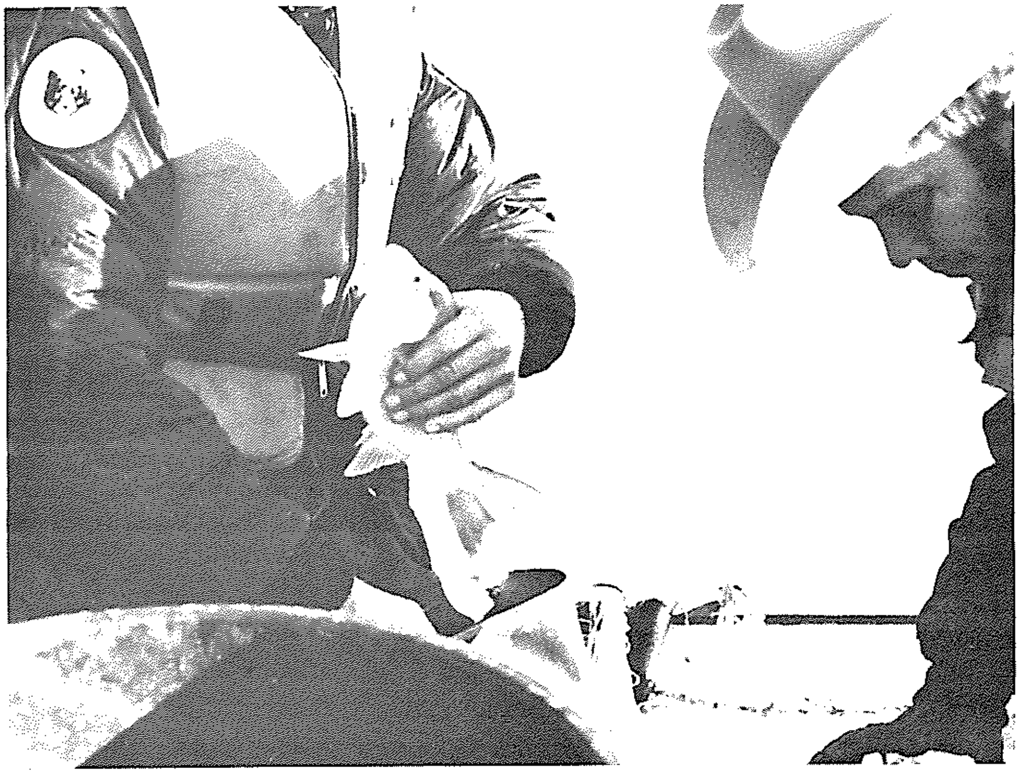

Figure 7. White bass collected from gill net with cooperation of New Mexico Department of Game and Fish personnel.

Fish for organic chemical analysis were wrapped in aluminum foil. All fish were then placed in coolers containing crushed ice and frozen upon arrival at the laboratory.

C. Physical Analysis

1. Water

The physical parameters determined in the field were pH, oxidation-reduction potential (Eh), temperature, dissolved oxygen (D.O.) concentration, and specific conductance. The pH and Eh values were determined with an Orion Model 407 portable pH and specific ion meter. Dissolved oxygen concentration and temperature were determined with a YSI Model 57 Oxygen Meter and combination probe (Yellow Springs Instrument Company, Yellow Springs, Ohio) while specific conductance was measured with a YSI Model 33 Salinity-Conductivity Meter (Figure 8). Usually, the probes for D.O. and conductivity were lowered into the water using long cables. When depth exceeded 50 feet, all parameters were measured immediately as water samples were brought to the surface.

Nonfilterable residues (suspended solids) and its volatile matter were determined gravimetrically in the laboratory following procedures in Methods for Chemical Analysis of Water and Wastes (1979). Prior to gravimetric analysis, 100 ml of each water sample were filtered through a pre-combusted, pre-tared, Whatman GF/F glass fiber filter (pore size = 0.7 μm). The data were then corrected to mg solids/ℓ.

Sechi disk visibility was determined using a 20.3 cm (8 in.) diameter disk (Figure 9). The disk was lowered into the water until it disappeared and the depth was noted. The disk was then raised until it reappeared and the depth was noted. The average of the two readings was taken as the final Secchi disk visibility depth.

2. Sediment sieving

Freeze dried sediments were wet-sieved and redried for analysis. Percentages of the 230(-)(<63μ), 80-230(-)(63-180μ), and 80(+)(>180μ) fractions were calculated on a dry weight basis. Stainless steel sieves were used to avoid contamination by copper which occurs if brass sieves are used.

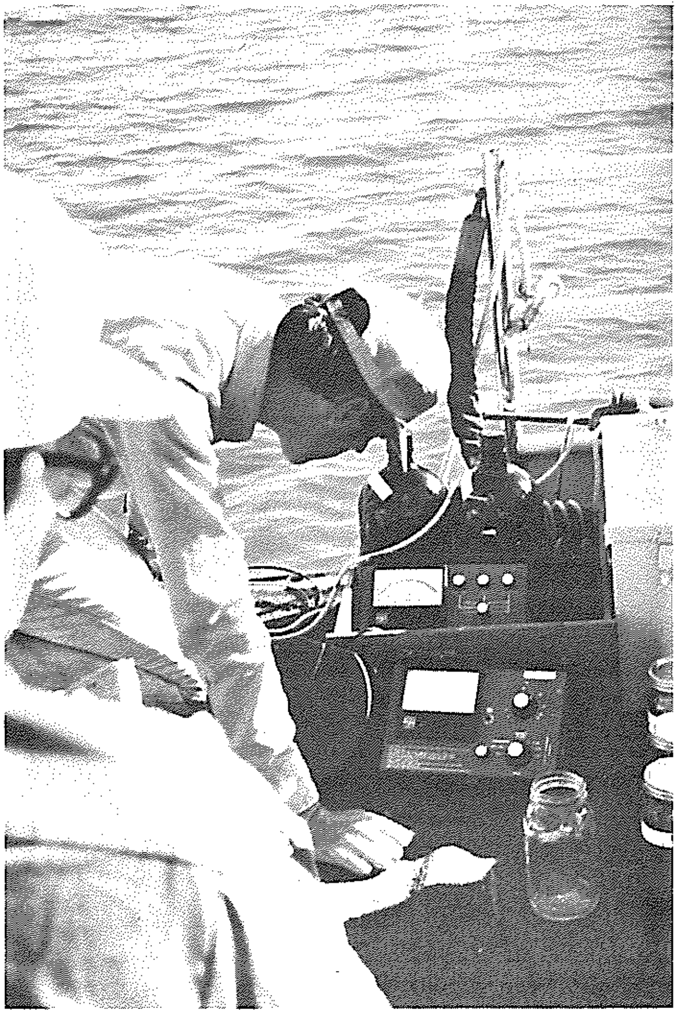

Figure 8. Dr. Lynch with oxygen and conductivity meters.

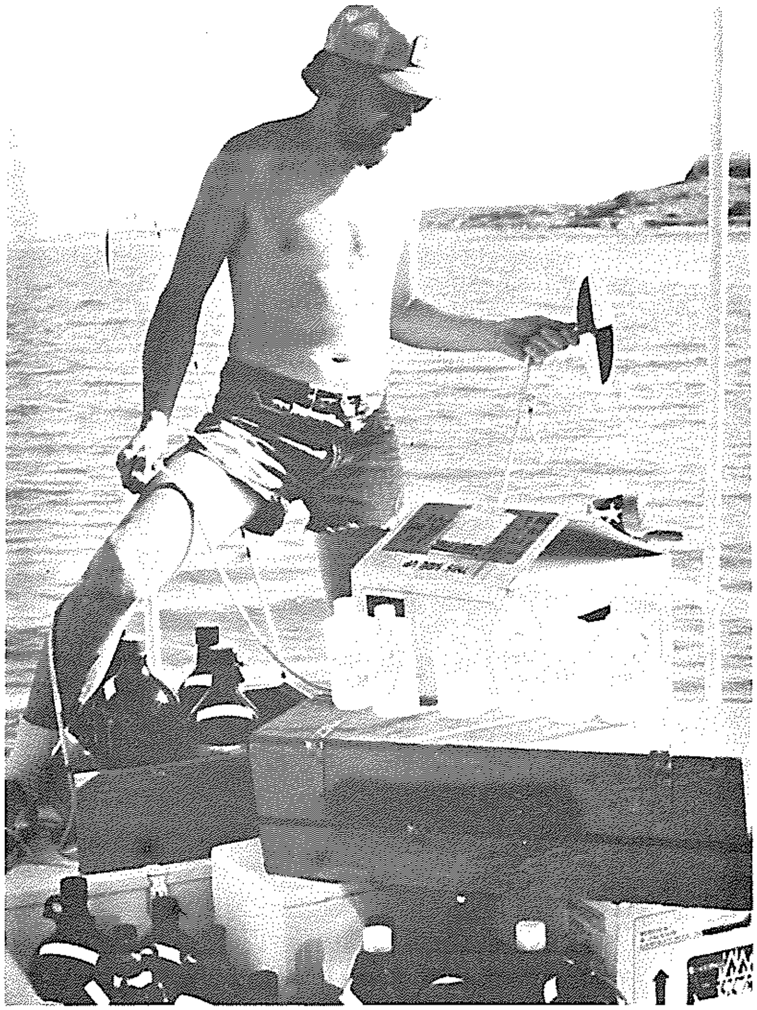

Figure 9. Dr. C. Popp with Secchi disk used to determine light penetration. Note brown bottles for samples to be subjected to organic extraction. Polyethylene bottles were used for samples to be analyzed for trace metals.

D. Trace Metals

1. Water

The surface water chemistry is described in the literature (Popp and Brandvold 1980; Hernandez et al. 1976). Heavy metals analyzed in the water and sediment (suspended and bottom) included the EPA Priority Pollutants; mercury, cadmium, chromium, copper, lead, and arsenic which are also considered important potential pollutants by the State of New Mexico Environmental Improvement Division (personal communication). In addition, selenium, uranium, vanadium, and molybdenum were measured because previous studies have shown high concentrations of these metals in the sediments. Also, molybdenum is present largely as a dissolved species which may increase its mobility (Popp and Laquer 1980; Popp and Brandvold 1980). Trace metal analysis was performed on 0.45μ filtered water samples preserved with 2-3 drops of redistilled nitric acid. Whole water digestions (EPA 1979) were also analyzed for trace metals. Acid was not added to water samples until after they were filtered.

2. Sediment extraction

Suspended and bottom grab sediments were subjected to selective extractive procedures to determine the extent of partitioning of the metals among the various portions of the sediment. Sediment used for chemical analysis was freeze dried using a Labconco Freeze Dryer 5 in order to prevent volatile species from escaping.

The metals in sediments were fractionated into segments labeled: exchangeable, organic, hydrous metal oxide, and crystalline for which a number of procedures are available (Gibbs 1977; Holmgren 1967; Tessler et al. 1979; Popp and Laquer 1980). The extraction procedure used followed that of Popp and Laquer (1980) in order to provide consistent data for comparison. Because an organic phase could be important in reservoir sediments, a step for organic extraction following the procedure of Tessler et al. (1979) was added.

The general extraction procedure was as follows: A 5 g sample of the freeze dried sediment was used for extraction with the same sample carried through all steps of the procedure.

Fraction 1: Exchangeable. Shake with 100 mL of 1M ammonium acetate followed by filtration through 0.45μ cellulose filters.

Fraction 2: Hydrous metal oxide. Shake with 100 mL 0.04M hydroxylamine hydrochloride in 25% V/V acetic acid followed by 0.45μ filtration.

Fraction 3: Organic. Shake with 3 mL .02M nitric acid and 5 mL 30% hydrogen peroxide (pH adjusted to 2.0 with HNO_3) heat to 85°C for 2 hours with occasional agitation. Repeat above, cool, add 5 mL of 3.2M ammonium acetate in 20% V/V HNO_3. Agitate for 30 minutes, filter (0.45μ) and dilute to 100 mL.

Fraction 4: Crystalline Residue. Dry remaining sediment which has changed from dark brown to gray and digest as described below.

3. Sediment digestion

Dried or otherwise previously treated sediment samples were weighed into Teflon beakers. Samples were heated to dryness two times with 15 mL portions of HF and two times with 5 mL of HNO_3 and 15 mL $HClO_4$. Then 10 mL of redistilled HNO_3 and 30 mL of distilled water were added and the samples warmed to effect solution of salts. If a colored residue remained the sample was heated to dryness, and retreated with HF, HNO_3, and $HClO_4$. If a colorless residue remained it was filtered off, then samples were diluted to 100 mL.

4. Analysis

All of the metals except mercury and uranium were analyzed using atomic adsorption (A.A.) spectrophotometry in either the flame (Cu, Pb, Mn, Fe, Cr), carbon furnace (Mo, V, Cd), or hydride generator mode (Se, As). A hydride/EDL (Perkin-Elmer MS-10) system was available for As and Se. A Perkin-Elmer 403 A.A. spectrophotometer and HGA 2000 graphite furnace were used as well as a Perkin-Elmer 403 A.A. and a Varian Model 1250 A.A. for flame analysis. Mercury was analyzed using a MAS-50 mercury analyzer manufactured by Coleman Instruments. Uranium was determined by the colorimetric dibenzoylmenthane method of Horton and White (1958). Total metal concentrations were determined by summation of the partitioned metals in addition to total sediment digestions. Sensitivities for the various metals are summarized below.

Element	Method	Sensitivity Solid Sample µg/g	 Water Sample µg/L
Arsenic	Hydride	0.07	2.0
Cadmium	Furnace	0.01	0.3
Chromium	Flame	10	300
Copper	Flame	7	200
Lead	Flame	17	500
Lead	Furnace	0.03	1.0
Mercury	Flameless A.A.	0.03	1.0
Molybdenum	Furnace	0.03	1.0
Selenium	Hydride	0.07	2.0
Uranium	Spectrophotometric	7	200
Vanadium	Flame	7	200
Iron	Flame	100	3000
Manganese	Flame	100	3000

Table 1. Trace Metal Sensitivities.

5. Radionuclide analysis

The samples were counted in 450 mL Marinelli beakers for about 12 hours using a (GeLi) detector (Ortec Company) coupled with a Nuclear Data Company system 6600 computer and software packages. The samples were sealed and allowed to equilibrate for 2 weeks. Long counting periods were necessary, because of the low counting efficiency for Pb-210 in this energy range. In addition to Pb-210 and Cs-137, other radionuclides in the uranium and thorium decay series such as Ra-226, Pb-214, Bi-214, Th-234, Ac-228, and Pb-212 were detected by this procedure.

6. Fish tissue digestion

Because of the possible loss of some substances on drying, wet weights were used. Representative samples were dried and the average water loss calculated (80% ± 5%).

For all metals except mercury, the following procedure was used: to one gram of tissue (wet weight) was added 10 mL of concentrated HNO_3. The sample was heated gently until the tissue was dissolved. The solution was cooled and 5 mL of 30% H_2O_2 added. This was then heated gently and gradually brought to boiling. The sample was then cooled and diluted.

For mercury the following procedure was used: to one gram of tissue was added 50 mL H_2O, 10 mL H_2O, 10 mL H_2SO_4, and 5 mL HNO_3. After cooling 1.5 g $KMnO_4$ and 0.5 g $K_2S_2O_8$ were added. This was digested at 60°C. After cooling 1.5 g hydroxylamine hydrochloride was added and the sample diluted to 100 mL.

7. Interstitial water

Water collected which is closely associated with pore space in benthic sediments (interstitial water) was collected by squeezing the sediments under an inert atmosphere. A device was constructed according to Sasseville et al. (1974) which could squeeze two samples simultaneously. The device was placed under N_2 atmosphere in a plastic glove bag and samples were squeezed through filter paper into polyethylene vials and acidified with 2-3 drops of redistilled HNO_3 (Mattinson 1972) which preserved the trace metals for A.A. analysis.

E. Chemical Analysis - Organic Compounds

1. Water and suspended particulates

Prior to extraction, the samples were shaken and a one liter aliquot was removed. The aliquot was filtered through a Whatman GF/F glass fiber filter which had been previously combusted at 550°C for one hour. The filters were wrapped in aluminum foil and frozen until analyzed.

An additional 100 mL aliquot was removed from the sample bottle and filtered through pretared, precombusted, glass fiber filters. The filters were dried at 105°C overnight, cooled in a desicator for 24 hours and reweighed to determine the quantity of suspended solids in the water samples. The filters were ashed at 550°C for two hours, cooled in a desicator and reweighed. Loss on ignition was used as a measure of sample organic matter content.

The filtered water (1000 mL) was extracted once with 200 mL of pesticide grade methylene chloride in a separatory funnel. The extract was condensed to about 5 mL by evaporation on Snyder columns, and then quantitatively transferred to glass vials. The vials were stored in a freezer until the extracts could be analyzed by gas chromatography.

The filters were ground with a mortar and pestle in the presence of methylene chloride-extracted anhydrous sodium sulfate. The resulting free-flowing powder was Soxhlet extracted for four hours with 150 mL of acetone/hexane. The extracts were condensed by evaporation on Snyder columns, transferred to scintillation vials and placed in a freezer until they could be analyzed.

2. Sediment extraction

Prior to extraction, the sediments were defrosted, mixed thoroughly and 150 mL were removed and lyophilized (Labconco Freeze Dryer 5) to dryness.

An additional unknown volume of the sediment was wet sieved through sieves of 0.125 mm and 0.063 mm mesh size openings. This resulted in three fractions designated as sand (>0.125 mm), very fine sand (0.063 - 0.125 mm) and silt-clay (<0.063 mm). The silt and clay passing through the 0.063 mm mesh sieve were collected in buckets and transferred to one gallon wide-mouth jars. The suspended particulates were allowed to settle for 24-72 hours after which the water was decanted. All fractions were lyophilized until dry. The fractionated and intact sediment samples were weighed, dispensed into solvent-washed cellulose extraction thimbles and Soxhlet extracted for four hours using 150 mL of acetone/hexane (1:1, V/V).

Acetone was removed from the extracts by transferring the extracts to 1000 mL separatory funnels which contained 300 mL of distilled water and 25 mL of a saturated aqueous sodium sulfate solution. The hexane was removed and placed in a 250 mL separatory funnel. The aqueous layer was extracted with 20 mL of 15% methylene chloride in hexane. The mixture was shaken for two minutes and the layers were allowed to separate. The aqueous layer was discarded and the hexane layer was added to the first extract. Distilled water (100 mL) was added to the extracts, the mixture was shaken and the layers allowed to separate. The aqueous layer was discarded and the extract washed a second time. The extracts were then condensed to about 5 mL by evaporation on a rotary evaporator. The sample extracts were cleaned-up on activated, Florisil columns using the standard method (EPA 1977). Prior to activation, the Florisil was Soxhlet extracted for four hours with methylene chloride.

The presence of electron-capturing sulfur compounds in the extracts necessitated their removal prior to chromatographic analysis for the pesticides. This was accomplished using the clean-up technique recommended by EPA (1977).

The extracts were then transferred to glass vials and stored in a freezer until they could be quantified by gas chromatography.

3. Fish tissues

Prior to extraction, the tissue was weighed and then ground with a mortar and pestle in the presence of solvent-washed anhydrous sodium sulfate until a free-flowing powder resulted. The powder was quantitatively transferred to a hexane-washed cellulose extraction thimble. The sample was Soxhlet extracted for four hours using 150 mL of pesticide grade hexane. The extracts were evaporated to a volume less than 100 mL on a rotary evaporator. The extract volume was adjusted to exactly 100 mL and a 10 mL aliquot was removed for lipid analysis. The remaining 90 mL was condensed to approximately 2 mL and transferred quantitatively to Florisil columns. The extracts were cleaned-up using standard techniques (EPA 1977). The column eluates were condensed on a rotary evaporator, quantitatively transferred to glass vials and stored in a freezer until analyzed by gas liquid chromatography.

4. Lipid analysis

The 10 mL aliquot of the fish tissue extract was placed in pretared aluminum weighing pans. The extracts were dried in a vacuum oven at 70°C until all solvent had evaporated. The pans were placed in desicators for 24 hours and then reweighed. Amount of lipid in the entire extract was then calculated and is reported as a percentage of the wet body weight.

5. Gas chromatographic analysis

Sample extracts were removed from the freezer and allowed to reach room temperature. The extracts were quantitatively transferred to graduated centrifuge tubes, and the volume was adjusted to exactly 1 mL. One milliliter of 1 ppm aldrin was then added as an internal standard.

After preliminary analytical screening, samples were analyzed by capillary gas chromatography using temperature programming. The instrument was a Tracor 565 GC. The conditions were as follows:

Columns: fused silica 30 meters by 0.25 mm
Phase: Either SE-30 or SE-54 (0.25μm thick)
Detector: Nickel-63 electron capture
Carrier: Helium at 0.6 mL/min
Make-up Gas: Nitrogen at 60 mL/min
Inlet Temperature: 220°C
Detector Temperature: 350°C
Temperature Program:

Initial temperature	150°C
Initial hold	1 minute
Program rate	8°C/min
Final temperature	230°C
Final hold	23 minutes

Integrator: HP3390A

The sample volume was 1-2 mL. Aldrin at a concentration of 1 ppm was used as an internal standard. The temperature program listed above was decided upon after running standards of individual pesticides and a mixture containing 21 chlorinated hydrocarbon pesticides that might be present in the samples. The above program gave good separation in a reasonable time period. Minimum detection limits under the conditions used were determined and are listed in Table 2.

F. Fish Dissection

Whole fish were removed from freezer storage, and were partially thawed in warm water. Total lengths and weights were recorded. Scale samples for age determination were removed just posterior to the anterior edge of the dorsal fin in the vicinity of the lateral line. The fish were then dissected and samples of muscle, liver, and kidney were removed. Sex of the fish was also recorded. The samples were individually wrapped in aluminum foil (organic analysis) or in plastic freezer bags (trace metal analysis), labeled and refrozen.

Compound	Detection Limit in ppb
α-BHC	18
β-OHC	35
Lindane	14
Heptachlor	16
Aldrin	10
Heptachlor epoxide	13
γ-chlordane	15
Op^1-DDD	22
Endosulfan I	35
α-chlordane	91
pp^1-DDE	63
Dieldrin	31
Op^1-DDE	29
Endrin	94
Endosulfan II	66
pp^1-DDD	21
op^1-DDT	27
Kepane	37
pp^1-DDT	23
Methoxychlor	52
Mirex	25

Samples were run in duplicate.

Table 2. Gas chromatography sensitivities.

G. Quality Control

Duplicate analyses were run on a random selection of all samples. Spike and recovery samples were run for trace metals and organics and corrections were made if recovery was <90%. E.P.A. Quality Control trace metal standard samples were always run to check precision on water samples. National Bureau of Standards Sediment Standards 1645 and 1646 (estuary and river sediments) were also digested and analyzed to determine analytical precision.

Individual pesticide and PCB standards were obtained from U.S.E.P.A. and commercial suppliers. E.P.A. mixtures of pesticides for water pollution quality control and water supply were run as quality controls. Mixtures of 13 and 21 pesticides as well as individual arochlor standards were purchased from Supelco, Incorporated. Standards were also prepared by our laboratory. Correction for blank samples was made for digested or extracted samples.

III. RESULTS AND DISCUSSION

A. Water Chemistry - Trace Metals

1. Filtered water and whole water digestions - surface vs bottom waters

Average heavy metal values in surface and bottom filtered water samples are listed in Table 2. Standard deviations for these averages are shown in Appendix A. There appears to be very little difference between dissolved species in the surface and bottom water. None of the metals exceed the New Mexico maximum contaminant levels (MCL) for drinking water (New Mexico Environmental Improvement Board 1981) however, mercury comes very close. The limit for mercury is 2 ppb and at several sites the average value is greater than 1 ppb. Mercury levels generally decrease from inlet to dam as previously observed by Kidd et al. (1974). Arsenic, mercury, vanadium, and molybdenum concentrations are slightly lower in Elephant Butte Reservoir than in the river while copper values are slightly higher in the reservoir than in the river. The dissolved trace metal levels are about the same as those found by Popp and Laquer (1980) in upstream waters except that arsenic and selenium values are lower in this study.

Average values for metals in surface and bottom whole water samples are listed in Table 4. Standard deviations are shown in Appendix A. Cadmium appears to be associated with the sediments since cadmium values are higher in the whole water samples than the filtered samples, particularly in the bottom whole water samples. Mercury is about the same in surface and bottom filtered samples and surface whole water samples but higher in the bottom whole water samples indicating an association between mercury and the heavier sediments. The cadmium and mercury data only suggest trends however, because the data is limited and the standard deviations are high. There are occasional high values for arsenic, copper, chromium, and molybdenum which are probably not significant because they have associated high standard deviations. (See Appendix A).

Arsenic, copper, molybdenium, selenium, and vanadium values are very similar between filtered and whole water indicating that they are present as soluble forms. Chromium is present in higher amounts in whole water indicating that it is present in insoluble as well as soluble forms.

	Rio Grande*		Elephant Butte				Caballo	
	Soc.	S.M.	A	B	C	D	Cab.	
As		25	11	8	9	9	12	Surface
			11	9	8	8	41	Bottom
Cd	<.01	.73	.39	.20	1.1	.8	.32	Surface
			.20	1.6	.6	.15	.35	Bottom
Cu		6	36	16	18	20	17	Surface
			20	19	17	23	12	Bottom
Cr	141	1.4	1.8	2.4	.95	6.9	7.1	Surface
			11	6.8	5.8	2.9	12	Bottom
Hg		1.5	.51	1.2	.44	.44	.62	Surface
			.88	.83	.63	1.1	.57	Bottom
Mo		13	6.7	5.0	4.6	5.8	3.7	Surface
			3.9	5.0	4.0	4.1	5.2	Bottom
Pb	4.9	4.8	5.9	3.9	4.7	5.5	7.2	Surface
			2.8	4.7	5.3	3.7	6.3	Bottom
Se		1.0	1.4	.07	.41	2.2	2.1	Surface
			1.0	1.7	1.4	.11	.07	Bottom
V		27	7.8	11	12	12	14	Surface
			16	11	12	12	16	Bottom

*Shallow - no distinction between surface and bottom

Table 3. Trace metals in filtered water as a function of depth
Bottom samples were collected within 1 m of the bottom.
Values in ppb (μg/L) and are the average of 4 sampling trips.

2. Filtered water and whole water digestions in reservoir waters-E/W transects

Average metal values for cross-sectional sites in filtered water are compared in Tables 5, 6. Standard deviations for these values are listed in Appendix B. The higher cadmium values found in the east sites for whole water samples are also found for the other sites for whole water. Mercury, copper, and chromium also appear to be consistently higher at the east bottom sites in Elephant Butte. Cadmium which seems to be associated with the sediments does not exhibit this trend so that it appears that mercury, copper, and chromium are associated with the coarser sediments which drop out in midreservoir (east sites).

3. Interstitial water

Water which is closely associated with sediments below the sediment-water interface is called interstitial or pore water. The reducing environment may be conducive to solubilization of certain trace metals which are more soluble in the reduced state (i.e. Fe^{2+} vs Fe^{3+}). It is also in this reducing region that biological methylation may take place for species as mercury, arsenic, and selenium. Interstitial water values for this study area are shown in Table 7. Because surface sediments from the river sites (Socorro, San Marcial) are aerobic, the pore water values should be, and are, similar to the surface water values. However, within the reservoirs the metals Cd, Cu, Cr, Pb, and V exhibit consistently higher values in the interstitial water than found for filtered bottom water. In the case of Cd, the pore water values are about an order of magnitude greater than those found in the water column. These metals may then be more easily incorporated into benthos and hence into the food chain. There appears to be little difference between interstitial water values for sediments from the E sites (Table 8) compared to averages from all sites (Table 7).

	A			B			C			D			Cab		
	E	M	W	E	M	W	E	M	W	E	M	W	E	M	W	
As	11	11	11	8.4	11	9.8	8.9	13	12	9.2	13	10	12	16	13	Surface
	11	13	15	9.4	13	16	8.2	14	12	8.5	14	8.9	41	12	12	Bottom
Cd	.39	.33	.37	.20	.33	.30	1.1	.42	.37	.80	.50	.62	.32	.41	.34	Surface
	.20	.33	.50	1.6	.36	.33	.60	.40	.37	.15	.15	.15	.35	.34	.45	Bottom
Cu	36	7.4	9.2	16	7.4	6.5	18	8.4	15	20	5.8	16	17	16	9.8	Surface
	20	12	20	19	9.5	10	17	17	19	23	28	10	12	15	20	Bottom
Cr	1.8	3.4	1.5	2.4	1.2	1.2	.95	15	1.1	6.9	3.5	.32	7.1	2.0	1.3	Surface
	11	1.8	2.3	6.8	1.2	1.2	5.8	1.4	1.0	2.9	2.2	.32	12	1.8	1.6	Bottom
Hg	.51	.27	.26	1.2	.56	.42	.44	.24	.16	.44	.22	.12	.62	.07	.17	Surface
	.88	.24	.76	.83	.39	.33	.63	.28	.25	1.1	1.8	.12	.57	.43	.07	Bottom
Mo	6.7	7.4	6.1	5.0	14	6.5	4.6	11	3.2	5.8	5.4	7.6	3.7	5.5	6.7	Surface
	3.9	5.8	6.4	5.1	5.7	5.7	4.0	5.6	6.6	4.1	6.2	9.6	5.2	6.5	6.5	Bottom
Pb	5.9	5.3	2.5	3.9	2.6	8.0	4.7	9.0	.93	5.5	5.4	29	7.2	8.8	2.4	Surface
	2.8	1.5	9.2	4.7	1.7	1.3	5.3	3.5	1.7	3.7	1.8	7.2	6.3	4.1	4.3	Bottom
Se	1.4	<.1	<.1	.07	.11	<.1	.41	.11	.11	2.2	6.3	<.1	2.1	.11	.11	Surface
	1.1	6.3	.10	1.7	<.1	<.1	1.4	<.1	<.1	.11	16	.11	.07	.11	.11	Bottom
V	<7.8	<7.8	<7.8	11	<7.8	<7.8	12	<7.8	8.9	12	<7.8	<7.8	14	<7.8	<7.8	Surface
	16	13	13	11	<7.8	8.3	12	<7.8	<7.8	12	11	<7.8	16	13	<7.8	Bottom

Table 5. Trace metals in filtered surface and bottom water in reservoirs - E/W transects at Elephant Butte sites A-D, Caballo site Cab. Values in ppb.

	A			B			C			D			Cab		
	E	M	W	E	M	W	E	M	W	E	M	W	E	M	W	
As	10	26	6.0	18	9.3	4.8	110	15	16	2.8	3.9	3.2	11	6.2	2.6	Surface
	14	9.4	7.6	6.0	2.0	5.8	6.3	6.3	16	8.1	7.7	1.0	37	19	4.5	Bottom
Cd	3.4	6.9	2.2	5.8	1.6	.75	.71	.40	.66	1.1		3.7	1.5	.75	3.1	Surface
	1.1	14	13	7.5	3.4	1.8	12	1.1	.66	5.2	3.6	11	1.4	5.1	4.1	Bottom
Cu	3.1	6.9	14	51	23	45	12	33	11	22	11		17	10	20	Surface
	31	16	32	220	11	22	230	14	0.0	85	12		30	15	18	Bottom
Cr	9.9	21	13	26	4.5	16	8.8	13	7.2	44	13	45	170	41	26	Surface
	62	190	140	12	21	11	390	20	120	19	140	12	88	73	16	Bottom
Hg	.29	.59	.56	.11	.44	.53	.32	.96	.44	.13	.31	.40	1.2	.76	.30	Surface
	.55	.48	.38	.92	.75	.57	2.1	.57	.08	2.3	.04	.25	2.0	1.4	1.5	Bottom
Mo	5.6	4.4	6.0	160	4.5	5.9	7.0	3.3	2.9	15	3.8	5.9	10	3.2	4.6	Surface
	10	7.0	8.3	12	3.1	2.2	11	5.9	2.7	9.0	3.6	2.3	11	3.7	2.6	Bottom
Pb	11	110	11	4.1	9.4	14	30	5.8	24	43	5.9	8.5	86	8.8	13	Surface
	44	24	19	21	8.8	3.0	11	12	4.5	7.3	44	8.9	20	20	17	Bottom
Se	<1	<1	<1	.58	<1	<1	<.1	<1	<1	<.10	<1		<.1	.80	<1	Surface
	1.3	<1	<1	<.1	<1	<1	.55	<1	<1	2.1	<1		<.1	<1	<1	Bottom
V	5.0	4.4	6.2	13	4.2	4.3	12	4.4	4.6	12	4.5	<7.8	16	4.8	5.0	Surface
	33	5.0	5.3	13	15	5.3	16	5.7	5.3	14	5.7	<7.8	17	5.3	<7.8	Bottom

Table 6. Trace metals in whole water digestions. Surface and bottom waters on E/W transects in Elephant Butte sites A-D and Caballo site Cab. Values in ppb.

	Rio Grande		Elephant Butte				Caballo
	Soc	SM	A	B	C	D	
As	17	6.1	8.7	3.7	10	22	13
Cd	.1	6.0	16	7.3	5.9	14	22
Cu	45	24	53	46	30	27	62
Cr	7.5	11	25	38	16	21	31
Mo	2.5	2.9	5.0	3.7	4.5	2.6	5.0
Pb	2.8	7.0	13.1	9.4	13	18	31
Se	all <1 ppb						
V	-	61	39.1	50	29	60	40

Table 7. Trace metals in interstitial water samples obtained by squeezing sediments under a N_2 atmosphere. Values in ppb (μg/L).

	Elephant Butte				Caballo
Element	A	B	C	D	CAB
As	7.4		8.9	22	14
Cd	18	1.4	2.8	14	28
Cu	51	25	22	27	88
Cr	38	7.6	17	21	16
Mo	5.8	4.0	2.8	2.6	6.5
Pb	18	7.6	11	18	31
Se	<.1 ppb				
V	45		29	60	36

Table 8. Trace metals in interstitial water. East sites. Values in ppb (μg/L).

B. Water Chemistry - Organics

Gas chromatographic analysis of surface water samples indicated the occasional presence of peaks corresponding to 18 different pesticide standards (Table 9). Because of the length and separation ability of the capillary columns, we have assigned the identity of unknown sample peaks to those pesticide standards having the same retention time. This identity assignment is reasonable but should not be considered as definitive in the absence of mass spectrographic analysis. The frequency of occurrence of the various pesticides in whole water surface samples varied from a low of 8.4% for alpha chlordane to a high of 90.4% for heptachlor. The most commonly detected pesticides in declining order of occurrence were heptachlor, kepone, p,p'-DDD, heptachlor epoxide, alpha BHC, lindane, endrin, and methoxychlor. These pesticides were detected in at least 30% of all whole water surface samples. It is interesting to note that five of the eight represent compounds or metabolites of compounds that have been banned by the EPA. Alpha BHC, endrin, and methoxychlor were detected more frequently as dissolved materials whereas lindane, heptachlor epoxide, p,p'-DDD, and kepone were found more frequently in association with suspended particulates. Heptachlor was found nearly as often in the dissolved phase as in the particulate. In those samples where the pesticides were detected in both the particulate and dissolved phases, the pesticide associated with the suspended sediments accounted for greater than 99% of the pesticide concentration. The tendency of many of the chlorinated hydrocarbon insecticides to adsorb onto suspended particulates has been extensively documented in the literature

The compilation of data from bottom water samples indicated similar frequencies of occurrence and similar distribution patterns of pesticides between dissolved and suspended phases when compared to surface water samples (Table 10).

The mean concentration of selected pesticides in surface and bottom water samples are presented in Tables 11 and 12 respectively. The means were calculated using values only from those samples in which a pesticide was actually detected. The statistical means are therefore overestimates of the true mean as they do not reflect the large number of zero values

Pesticide	Composite Sample	Particulate Phase	Dissolved Phase
alpha BHC	61.4	35.4	43.4
beta BHC	26.5	19.5	10.8
Lindane	47.0	40.2	16.9
Heptachlor	90.4	75.6	71.1
Heptachlor Epoxide	62.7	50.0	25.3
gamma chlordane	18.1	11.0	9.6
o,p'-DDD	10.8	2.4	9.6
Endosulfan I	14.5	7.3	8.4
alpha Chlordane	8.4	2.4	4.8
p,p'-DDE	19.3	15.9	4.8
Dieldrin, o,p'-DDE	26.5	20.7	4.8
Endrin	36.1	9.7	27.7
Endosulfan II	10.8	2.4	7.2
p,p'-DDD	63.9	56.1	10.8
o,p'-DDT	21.7	17.1	3.6
Kepone	72.3	61.0	15.7
p,p'-DDT	25.3	14.6	15.7
Methoxychlor	31.3	7.3	24.1

Table 9. Frequency of occurrence (%) of chlorinated organic pesticides in surface water samples from the Rio Grande, Elephant Butte and Caballo Reservoirs.

Pesticide	Composite Sample	Particulate Phase	Dissolved Phase
alpha BHC	65.7	37.1	45.7
beta BHC	14.3	14.3	5.7
Lindane	42.9	37.1	14.3
Heptachlor	91.4	85.7	68.6
Heptachlor Epoxide	65.7	60.0	20.0
gamma Chlordane	20.0	11.4	8.6
o,p'-DDD	2.9	0.0	2.9
Endosulfan I	8.6	5.7	2.9
alpha Chlordane	5.7	2.9	2.9
p,p'-DDE	14.3	14.3	0.0
Dieldrin, o,p'-DDE	20.0	20.0	0.0
Endrin	28.6	5.7	22.9
Endosulfan II	5.7	2.9	2.9
p,p'-DDD	65.7	62.9	8.6
o,p'-DDT	20.0	17.1	2.9
Kepone	77.1	71.4	8.6
p,p'-DDT	17.1	14.3	11.4
Methoxychlor	34.3	11.4	28.6

Table 10. Frequency of occurrence (%) of chlorinated organic pesticides in bottom water samples from Elephant Butte and Caballo Reservoirs. Samples were collected approximately 0.3 m above the bottom.

Pesticide	Rio Grande			Elephante Butte			Caballo		
	Fall	Spring	X	Fall	Spring	X	Fall	Spring	X
alpha BHC	45.3 (28.0)	463.0 (0)	254.2	51.0 (89.7)	97.3 (146.9)	74.1	95.7 (87.9)	47.5 67.1	71.6
Lindane	52.7 (32.4)	525.0 (0)	288.9	440.7 (795.2)	327.7 (332.3)	384.2	147.6 (137.0)	170.0 (244.3)	158.8
Heptachlor	1057.7 (1089.9)	261.0 (0)	659.4	277.3 (435.2)	363.4 (796.7)	320.4	508.0 (921.4)	382.3 (336.7)	445.2
Heptachlor Epoxide	37.0 (9.6)	94.5 (0)	65.7	279.7 (522.7)	97.5 (123.7)	188.6	164.5 (249.8)	50.0 (0)	107.3
Endrin	63.1 (74.9)	0	63.1	100.8 (207.0)	1.2 (1.4)	51.0	59.6 (53.1)	0.10 (0)	29.9
p,p'-DDD	6897.5 (11293.8)	463.3 (213.9)	3680	165.0 (92.4)	100.3 (80.0)	132.5	1007.5 (1144.7)	90.7 (84.4)	549.1
Kepone	109675.0 (21837.0)	62821.0 (165099.0)	86248	126.1 (109.7)	120.2 (85.1)	123.1	353.3 (97.1)	96.8 (105.9)	225.1
Methoxychlor	270.0 (209.0)	0	270.0	16.5 (48.6)	4.3 (0)	10.4	53.1 (74.8)	0	53.1

Table 11. Mean concentrations (ng/ℓ) of selected pesticides in surface water samples. Standard deviations in parenthesis. Only samples in which a pesticide was detected were used in the computations.

	Elephant Butte			Caballo		
Pesticides	Fall	Spring	X̄	Fall	Spring	X̄
Alpha BHC	73.4	76.7	75.1	19.6	35.7	27.7
	(104.4)	(103.97)		(27.7)	(61.8)	
Lindane (BHC)	101.5	121.8	111.7	52.0	44.0	48.0
	(98.1)	(101.6)		(60.2)	(62.2)	
Heptachlor	285.7	269.0	227.4	274.6	806.8	540.7
	(381.9)	(235.0)		(390.5)	(1033.7)	
Heptachlor epoxide	463.3	110.8	287.1	60.0	51.0	55.5
	(967.2)	(96.2)		(23.4)	(47.9)	
p,p'-DDD	307.4	407.6	357.5	232.7	125.9	179.3
	(325.2)	(608.3)		(70.7)	(0)	
Kepone	363.8	558.1	461.0	314.0	113.1	312.6
	(473.5)	(635.0)		(66.8)	(76.3)	
Methoxychlor	82.2	0	41.1	277.3	0	136.6
	(177.6)	(0)		(0)	(0)	

Table 12. Mean concentrations (ng/ℓ) of selected pesticides in bottom water samples. Standard deviations in parenthesis. Only samples in which a pesticide was detected were used in the computations.

encountered in the samples. The mean values for selected pesticides in surface water samples were usually less than 0.5 μg/L. However, five mean values in excess of 1 μg/L were noted; two for p,p'-DDD, two for kepone, and one for heptachlor. Mean values for selected pesticides in bottom water samples were also generally less than 0.5 μg/L with no samples exceeding the 1.0 μg/L level. The standard deviations from the means are wide and make meaningful interstitial comparisons difficult. Intersample variability can be explained in part by seasonal and annual differences in hydrological, chemical, and biological conditions within and between the sampling stations. One possible dissimilarity between pesticide concentrations at the three major areas of study is worthy of notation. Concentrations of heptachlor, p,p'-DDD, kepone, and methoxychlor were substantially higher in river water samples than in samples from either reservoir. This difference was especially evident in the fall sample collection.

Aqueous pesticide concentrations can be better represented by a frequency analysis of the sample data for various ranges of concentrations. Frequency distributions of selected pesticides in surface and bottom water samples are presented in Tables 13 and 14 respectively. Pesticide concentrations ranged from non-detectable to values in excess of 500 μg/L, a span exceeding more than three orders of magnitude. Consistent differences between pesticide concentrations in the Rio Grande, Elephant Butte, or Caballo Reservoirs are not apparent in either method of analysis.

When the frequency of occurrence of the pesticides was analyzed for seasonal effects, it was apparent that the percentage of samples containing detectable levels of pesticides increased during the Fall compared to the Spring (Tables 15 and 16). This trend was especially evident in the surface water samples and also occurred but with slightly less consistency in the bottom water samples. This finding may indicate continuing usage, albeit illegal, of these compounds on the watershed during the growing season or alternatively, a significant source of residual contamination. If the pesticides in water are being derived from a non-point source, lower frequency of occurrence (Table 15) and lower mean values (Table 16) in the Spring samples may be the result of

	Concentration Range (ng/ℓ)						
Pesticide	N.D.	0-0.0	1.0-9.9	10.0-49.9	50.0-99.9	100-499	>500
alpha-BHC							
River	42.9	0.0	0.0	14.3	28.6	14.3	0.0
E.B.	40.0	26.6	6.7	3.3	10.0	13.3	0.0
CAB.	37.5	25.0	0.0	0.0	12.5	25.0	0.0
Lindane							
River	37.5	0.0	0.0	12.5	12.5	12.5	25.0
E.B.	60.0	0.0	6.7	0.0	3.3	23.3	6.7
CAB.	12.5	25.0	0.0	0.0	12.5	50.0	0.0
Heptachlor							
River	28.6	0.0	0.0	14.3	14.3	28.6	28.6
E.B.	6.7	16.7	3.3	13.3	6.7	46.7	13.3
CAB.	12.5	25.0	0.0	12.5	12.5	0.0	37.5
Heptachlor Epoxide							
River	28.6	0.0	0.0	57.1	0.0	14.3	0.0
E.B.	46.7	3.3	0.0	20.0	13.3	10.0	6.7
CAB.	25.0	0.0	0.0	62.5	0.0	0.0	12.5
Endrin							
River	57.1	14.3	0.0	14.3	0.0	14.3	0.0
E.B.	63.3	26.7	3.3	0.0	0.0	3.3	3.3
CAB.	50.0	25.0	0.0	0.0	12.5	12.5	0.0
p'p-DDD							
River	12.5	0.0	0.0	12.5	0.0	12.5	62.5
E.B.	46.7	0.0	3.3	0.0	16.7	33.3	0.0
CAB.	12.5	12.5	12.5	0.0	0.0	37.5	25.0
Kepone							
River	12.5	0.0	0.0	0.0	25.0	25.0	37.5
E.B.	30.0	6.7	6.7	0.0	16.7	40.0	0.0
CAB.	25.0	12.5	0.0	0.0	12.5	50.0	0.0
Methoxychlor							
River	57.1	0.0	0.0	0.0	0.0	28.6	14.3
E.B.	66.7	23.3	6.7	0.0	0.0	3.3	0.0
CAB.	75.0	12.5	0.0	0.0	0.0	12.5	0.0

Table 13. Frequency (%) of selected pesticides in surface water samples occurring in various concentration ranges. N.D. indicates not detected.

		Concentration Range (ng/ℓ)					
Pesticide	N.D.	0-0.0	1.0-9.9	10.0-49.9	50.0-99.9	100-499	>500
alpha BHC							
E.B.	33.3	25.9	0.0	14.8	3.7	22.2	0.0
CAB.	37.5	37.5	0.0	12.5	0.0	12.5	0.0
Lindane							
E.B.	55.5	3.7	0.0	11.1	0.0	3.7	0.0
CAB.	37.5	25.0	0.0	12.5	12.5	12.5	0.0
Heptachlor							
E.B.	11.1	3.7	0.0	11.1	22.2	37.0	14.8
CAB.	0.0	12.5	0.0	12.5	0.0	37.5	37.5
Heptachlor Epoxide							
E.B.	25.9	3.7	0.0	18.5	14.8	29.6	7.4
CAB.	25.0	12.5	0.0	25.0	37.5	0.0	0.0
p,p'-DDD							
E.B.	29.6	3.7	0.0	0.0	14.8	40.7	11.1
CAB.	50.0	0.0	0.0	0.0	0.0	50.0	0.0
Kepone							
E.B.	25.9	3.7	0.0	0.0	7.4	40.7	22.2
CAB.	12.5	12.5	0.0	0.0	0.0	75.0	0.0
Methoxychlor							
E.B.	63.0	29.6	0.0	0.0	0.0	7.4	0.0
CAB.	87.5	0.0	0.0	0.0	0.0	12.5	0.0

Table 14. Frequency (%) of selected pesticides in bottom water samples occurring in various concentration ranges. N.D. indicates not detected.

Pesticide	Rio Grande		Elephant Butte		Caballo	
	Fall	Spring	Fall	Spring	Fall	Spring
alpha BHC	75.0	33.3	68.7	50.0	75.0	50.0
Lindane	75.0	50.0	43.7	28.6	100.0	75.0
Heptachlor	100.0	33.3	100.0	85.7	100.0	75.0
Heptachlor Epoxide	75.0	66.7	75.0	28.6	100.0	50.0
Endrin	75.0	0.0	56.3	16.7	75.0	25.0
p,p'-DDD	100.0	75.0	75.0	28.6	100.0	75.0
Kepone	100.0	75.0	87.5	50.0	75.0	75.0
Methoxychlor	75.0	0.0	56.3	7.1	50.0	0.0

Table 15. Percent of surface water samples containing detectable levels of selected pesticides according to season and major sampling location.

Pesticide	Elephant Butte		Caballo	
	Fall	Spring	Fall	Spring
alpha BHC	73.3	58.3	50.0	75.0
Lindane	46.7	41.7	75.0	50.0
Heptachlor	100.0	75.0	100.0	100.0
Heptachlor Epoxide	100.0	41.7	75.0	75.0
p,p'-DDD	93.3	35.7	75.0	25.0
Kepone	66.7	75.0	75.0	100.0
Methyoxychlor	66.7	0.0	25.0	0

Table 16. Percent of bottom water samples containing detectable levels of selected pesticides according to season and reservoir.

dilution by the heavy spring runoff and the absence of a significant irrigation return flow at this time of year. This observation should be evaluated in more detail in future research efforts.

The mean concentrations of selected pesticides associated with the suspended particulates of surface water samples are presented in Table 17. The mean concentration on the suspended sediments are approximately three orders of magnitude higher than the concentrations of the same pesticides in the dissolved phase of the surface water samples. Chlorinated organic pesticides are well known for their sorption onto particulates which is due to their low water solubilities and their resulting hydrophobicity. (Baughman and Lassiter 1978).

Mean concentrations of pesticides on suspended particulates are generally higher for Elephant Butte and Caballo Reservoir samples than for Rio Grande samples with the exception of kepone. Several possible hypothesis are available to explain this observation. If a constant amount of pesticide is available and adsorption onto particulates occurs, then the larger quantity of suspended sediments in the river samples (Table 17) would effectively dilute the amount of pesticide available for adsorption. Therefore concentrations on the particles should be higher in the reservoirs than for the river samples. Alternatively, the particles remaining in suspension in the reservoirs would have a lower mean density and presumably either smaller size and/or higher organic content. As particle size decreases, the surface area available for adsorption increases relative to the volume of the particle. There would thus be more adsorptive surface per unit of particle mass and therefore a higher concentration of particles. An increase in the organic matter content is also commonly observed among slow settling and colloidal particulates. There is some evidence that this was also true for the Elephant Butte suspended particulates. Both small particle size and high organic matter content have been shown to enhance the concentration of hydrophobic xenobiotics (Browman and Chesters 1977).

Mean concentrations of pesticides on suspended particulates were also higher in Elephant Butte than in Caballo Reservoir. It would appear that the water being discharged to Caballo is lower in pesticide content and that Elephant Butte, in addition to trapping sediments, is

Pesticide	Rio Grande Fall	 Spring	 $\bar{X}$	Elephant Butte Fall	 Spring	 $\bar{X}$	Caballo Fall	 Spring	 $\bar{X}$
Alpha BHC	0.055 (0.051)	0.324 (0.051)	0.190	0.349 (0.490)	22.43 (42.8)	11.39	2.591 (0)	1.189 (1.67)	1.89
Lindane (BHC)	0.124 (0.070)	0.432 (0.063)	0.278	57.81 (73.42)	100.74 (103.64)	79.28	2.523 (0)	4.57 (5.95)	3.55
Heptachlor	2.66 (4.28)	0.258 (0.078)	1.46	65.76 (94.64)	140.42 (299.04)	103.09	1.136 (0)	13.09 (13.23)	7.11
Heptachlor epoxide	0.072 (0.093)	0.237 (0.105)	0.155	12.80 (15.38)	52.35 (111.62)	32.58	0.909 (0)	1.114 (1.04)	1.012
Endrin	0.028 (0.031)	0.600 (0)	0.314	8.311 (16.58)	0.569 (0.738)	4.44	1.705 (0)	0.031 (0)	0.868
p,p'-DDD	2.145 (1.814)	0.969 (0.852)	1.557	25.704 (23.369)	52.122 (90.711)	38.913	33.50 (0)	2.837 (2.377)	18.169
Kepone	456.14 (910.43)	2.628 (4.444)	229.38	13.96 (11.16)	51.49 (76.86)	32.73	7.50 (0)	3.51 (4.44)	5.51
Methoxychlor	0.972 (1.563)	0 (0)	0.486	0.018 (0.015)	2.146 (0)	1.082	0.005 (0)	0 (0)	0.003

Table 17. Mean concentrations (μg/g) of selected pesticides on suspended particulates from surface water samples. Standard deviations in parenthesis. Only samples in which a pesticide was detected were used in the computations.

also removing pesticides from the water column. However, one cannot say with certainty that this is in fact the case because the concentrations of suspended solids increased in Caballo Reservoir when compared to the samples from the Long Point and Rattlesnake Island locations of Elephant Butte (Table 18). The higher concentrations of suspended solids in Caballo Reservoir probably result from resuspension of the bottom sediments due to the effects of wind and wave activity in conjunction with the reservoir's shallow depth.

These particulates could effectively lower the concentration on each particle due to competition for a fixed quantity of pesticide in much the same manner as suggested for the river samples.

C. Sediments

1. Particle size distribution in sediments

Wet sieving of sediments was performed to determine the size distribution and results are shown in Tables 19 and 20. The data shown in Table 19 illustrate the effect on size distribution of bottom sediments as a river enters a reservoir. The Socorro and San Marcial (Rio Grande) sites have predominantly larger sizes (>180μ, 63-180μ) as the finest material is carried downstream. Once in the reservoir (sites A-D) the smallest sizes predominate (<63μ). During sample trips 2 and 3 site A was reservoir water due to the high level of Elephant Butte and smaller sizes predominated (<63μ). When the water level dropped, site A became a river site with a strong current and particle sizes of deposited sediments increased accordingly. The size distributions in Elephant Butte are similar to those reported by the Bureau of Reclamation (1969). Site D exhibited somewhat unusual trends in that a bimodal distribution was found for trips 4 and 5. This could be due to influx of sediment from a side canyon or strong bottom currents.

The values in Table 19 were determined in the reservoirs as a function of distance from the center line (E) to the west shore (sites M-middle and W-west) from samples collected on sampling trips 2 and 3. Several times one sample could not be collected because the bottom was rocky possibly indicating a strong current which prevented deposition. The

Station	Fall 1980	Spring 1981	Fall 1981	Spring 1982
Socorro	240	116	2022	1150
San Marcial	184	12	2353	1285
Elephant Butte				
Narrows	5.3*	17.3*	423	195
Monticello Pt.	9.3*	3.0+	3.0	11
Long Pt.	0.0+	6.5+	4.0	2.0
Rattlesnake Is.	0.0*	7.0+	0	3.0
Caballo	44	26.3*	17	20

*mean of 3 samples

+mean of 2 samples

Table 18. Mean concentrations (mg dry wt./ℓ) of suspended particulates in surface water samples. * indicates the mean of three samples, + indicates the mean of two samples. All other values represent individual data points.

Size	Date	Rio Grande		Elephant Butte Reservoir				Caballo Reservoir
		Socorro	San Marcial	A	B	C	D	
(>180µ)	1(9/80)	-	-	-	0.5	1.0	-	-
	2(10/80)	2.6	-	0	1.8	-	2.2	1.0
	3(5/81)	61.0	54.4	0.3	4.3	0.3	0.5	1.3
	4(11/81)	8.7	51.7	16	6.4	0.5	25.6	0.7
	5(5/81)	7.6	56.5	15.9	1.1	0.5	26.2	0.1
(63-180µ)	1(9/80)	-	-	-	6.3	20.5	-	-
	2(10/80)	64.4	-	2.8	36.4	-	17.5	18.8
	3(5/81)	38.9	26.8	11.3	49.9	4.9	11.8	21.3
	4(11/81)	35	34.7	75	43.1	2.9	15.2	2.5
	5(5/81)	44.5	34.0	72.9	50	2.9	15.8	0.1
(<63µ)	1(9/80)	-	-	-	93.2	78.5	-	-
	2(10/80)	28.9	-	96.2	60.8	-	81.3	75.9
	3(5/81)	0.1	18.8	89.4	45.8	94.8	87.7	77.4
	4(11/81)	55.8	7.6	8.4	50.5	96.6	59.5	96.7
	5(5/81)	46.9	7.4	8.2	48.1	95.6	58	99.9

Table 19. Particle size distributions as percentage dry weight in sediments from the river and reservoir sites. The reservoir sites were the E (east) or center line sites.

Size	Date	Elephant Butte Reservoir[a]								Caballo Reservoir		
		B		C			D			CAB		
		E	M	E	M	W	E	M	W	E	M	W
(>180μ)	1(9/80)	0.5	-	1.0	-	-	-	-	-	-	-	-
	2(10/80)	1.8	1.2	-	-	76.1	2.2	-	-	1.0	-	-
	3(5/81)	4.3	0	0.3	-	1.7	0.5	39.7	-	1.3	1.4	6.2
	4(11/81)	6.4	-	0.5	-	-	25.6	-	-	0.7	-	-
	5(5/82)	1.1	-	0.5	-	-	26.2	-	-	0.1	-	-
(63-180μ)	1(9/80)	6.3	-	20.5	-	-	-	-	-	-	-	-
	2(10/80)	36.4	11.5	-	-	16.6	17.5	-	-	18.8	-	-
	3(5/81)	49.9	17.8	4.9	-	19.9	11.8	35.6	-	21.3	31.1	22.9
	4(11/81)	43.1	-	2.9	-	-	15.2	-	-	2.5	-	-
	5(5/82)	50	-	2.9	-	-	15.8	-	-	0.1	-	-
(<63μ)	1(9/80)	93.2	-	78.5	-	-	-	-	-	-	-	-
	2(10/80)	60.8	84.5	-	-	4.5	81.3	-	-	75.9	-	-
	3(5/81)	45.8	82.2	94.8	-	78.1	87.7	24.7	-	77.4	67.5	70.9
	4(11/81)	50.5	-	96.6	-	-	59.5	-	-	96.7	-	-
	5(5/82)	48.1	-	95.6	-	-	58	-	-	99.8	-	-

Table 20. Particle size distribution as percentages dry weight within sediments in reservoirs. The center of the reservoir is labeled E; M and W sites are on transects from the center to the west shore. Sites B (W), C (M), and D (W) had rocky bottoms and did not yield sediment samples.

[a] Site A is not included because it was part of the reservoir for only two trips due to fluctuations in water levels.

size distribution at each site in Caballo Reservoir was remarkably similar along the transect and for each sample period with most of the distribution (>75%) in the silt-clay (<63μ) fraction. The distribution is not so simple in Elephant Butte with the largest amount of fine material present at the M (middle) site at B (upper reservoir) and at the E (east) sites at C and D (lower reservoir).

Seasonal trends in particle size distribution can be seen by examining Table 21. In the spring when runoff is greatest, the larger particle sizes predominate in the river while in the fall smaller sizes predominate. The greatest standard deviations in particle sizes are shown at Socorro and site A (Narrows) in Elephant Butte. The Socorro site may be more affected by irrigation or channelization than San Marcial while site A (Narrows) fluctuates between a river and reservoir site due to water level changes. The Caballo Reservoir sediment size distribution showed some difference between fall 1980, spring 1981, fall 1981, and spring 1982 with a greater proportion of the intermediate size (63-180μ) material found during the earlier period. The water levels were lower in Caballo during the earlier sampling periods and wave action may have caused larger particles to be entrained from the bottom.

2. Trace metals in sediments

Average values for trace metals in bottom sediments from the river sites and east (E) reservoir sites are shown in Table 22. Several trends are apparent in examining the data including, (1) higher mercury values in the reservoir sediments (correlated to higher organic content - see Table 23) (Kidd et al. 1974, Potter et al. 1975); and (2) an increasing concentration trend for the elements uranium, iron, and manganese from the San Marcial site down through Elephant Butte Reservoir. The trends for U, Fe, and Mn may be due to finer grain size particles finding their way farther down through the reservoir (see Sec. III C, Table 19) and association of U with the hydrous metal oxide phase. For U, Fe, and Mn, the grain size-concentration correlation is also borne out by examining the data in Table 24 which shows the ratio of the element in the 230- fraction to that element in the total sample. The 230-/total ratios are consistently about 1.0 or greater for U, Fe, and Mn and since the

Table 21. Percentage particle size distribution in sediments as a function of season.

Sampling Time	Rio Grande		Elephant Butte				Caballo
	Socorro	San Marcial	Narrows	Monticello Pt.	Long Pt.	Rattlesnake Is.	
				Particle Size > 180 μ			
Fall 1980	2.6	---	0.0	1.8	1.0	2.2	1.0
Spring 1981	61.0	54.4	0.3	4.3	0.3	0.5	1.3
Fall 1981	8.7	51.7	16.0	6.4	0.5	25.6	0.7
Spring 1982	7.6	56.5	15.9	1.1	0.0	26.2	0.0
mean	20.0	54.2	8.1	3.4	0.5	13.6	0.7
std. dev.	27.5	2.4	9.1	2.4	0.4	14.2	0.5
				Particle Size 63-180 μ			
Fall 1980	64.4	---	2.8	36.4	20.5	17.5	18.8
Spring 1981	38.9	26.8	11.3	49.9	4.9	11.8	21.3
Fall 1981	35.0	34.7	75.0	43.1	2.9	15.2	2.5
Spring 1982	44.5	34.0	72.9	50.0	2.9	15.8	0.1
mean	45.7	31.8	40.5	44.9	7.8	15.1	10.7
std. dev.	13.1	4.4	38.8	6.5	8.5	2.4	10.9
				Particle Size < 63 μ			
Fall 1980	28.9	---	96.2	60.8	78.5	81.3	75.9
Spring 1981	0.1	18.8	89.4	45.8	94.8	87.7	77.4
Fall 1981	55.8	7.6	8.4	50.5	96.6	59.5	96.7
Spring 1982	46.9	7.4	8.2	48.1	95.6	58.0	99.9
mean	32.9	11.3	50.5	51.3	91.4	71.6	87.5
std. dev.	24.6	6.5	48.9	6.6	8.6	15.1	12.6

	Soc	SM	A	B	C	D	CAB
As	5.6	6.6	9.1	5.4	4.5	3.1	8.3
Cd	2.3	0.66	2.5	4.0	2.7	2.0	3.6
Cr	44	28	40	28	53	42	42
Cu	19	20	23	35	19	20	37
Hg	0.68	0.98	3.3	8.1	3.0	2.9	2.5
Pb	49	33	48	41	55	57	55
Mo	2.7	1.4	0.76	0.98	1.5	1.5	1.7
Se	0.04	0.18	0.09	0.12	0.34	0.16	0.16
U	200	180	180	200	230	250	280
V	87	83	80	40	110	67	83
Fe	2.37	1.96	2.67	2.96	3.84	3.16	3.18
Mn	400	230	280	300	410	450	1070

Table 22. Trace metals in sediments - East sites in reservoirs. Values in ppm dry weight except Fe(%).

Station	Fall 1980	Spring 1981	Fall 1981	Spring 1982	$\overline{X}$	S
Socorro	--	0.29	2.89	1.79	1.66	1.31
San Marcial	0.87	1.35	2.47	0.38	1.27	0.89
Elephant Butte Narrows	7.14*	6.05$^+$	5.14	0.76	4.77	2.80
Monticello Pt.	5.71$^+$	4.33$^+$	2.71	3.63	4.09	1.26
Long Pt.	3.57$^+$	6.02	6.35	5.83	5.44	1.27
Rattlesnake Is.	6.46	4.69$^+$	2.37	4.48	4.50	1.67
Caballo	6.55*	7.07*	5.51	6.34	6.37	0.65

Table 23. Organic content of sediments as percentage dry weight. * = mean of three samples, + = mean of two samples.

	Soc	SM	A	B	C	D	CAB
As	2.7	0.47	0.82	0.94	2.3	2.0	0.84
Cd	0.04	1.4	2.7	2.3	0.32	0.41	0.58
Cu	0.44	2.1	1.4	1.2	1.3	1.2	1.3
Cr	0.52	1.5	1.4	1.3	0.85	0.71	1.3
Hg	2.0	0.55	0.06	0.14	0.16	0.05	0.10
Mo	6.3	0.64	0.24	2.7	4.7	1.7	1.8
Pb	0.48	0.60	0.49	0.56	0.46	0.61	1.0
Se	-	0.14	3.8	<0.83	<0.29	0.63	0.88
V	-	1.3	1.2	1.7	0.35	2.2	0.08
%Fe	1.1	1.5	1.3	0.89	0.76	3.84	1.0
Mn	0.98	2.4	1.9	1.3	0.86	1.4	0.92
U	0.44	0.86	1.2	0.85	0.63	-	0.57

Table 24. Ratios of concentrations of metals in 230-(<63μ) sediment fraction to metals in total sediments. Values >1 indicate preference of trace metal for finer grained material.

230- fraction is such a large proportion of the reservoir sediments, such a relationship is not surprising.

Trace metal values found in sediments in Caballo Reservoir are about the same as those in Elephant Butte with the exception of manganese which is higher in Caballo (x2.5). In general the trace metal values are similar to crustal abundance values given by Krauskopf (1979) with some notable exceptions. The elements Cd (x10), Hg (x100), Pb (x5), and U (x100) are present in considerably higher concentrations than in average crustal material. These same trends for Cd and Hg in the Rio Grande have previously been noted by Popp and Laquer (1980) while Pb values were slightly lower. Uranium was not reported by Popp and Laquer but these trends may not be surprising due to the highly uranium rich Grants Mineral Belt which drains into the Rio Grande and hence into Elephant Butte. A recent study by Brandvold et al. (1981) showed similar high values for uranium in whole sediments (270 ppm in the Rio San Jose and 55 ppm in the Rio Puerco) in addition to the same trends for higher values of Hg, Cd, and Pb. Efficient regional transport of suspended sediments to Elephant Butte Reservoir is probably responsible for these elevated reservoir values. Because sediments are not delivered from Elephant Butte to Caballo in which high levels of these metals are also found, a general regional enrichment of these four metals (U, Cd, Hg, and Pb) is suggested.

Concentrations of trace metals in finer grained sediments (<63μ size) are shown in Table 25. No startling trends were evident in comparing trace metals in 230- to trace metals in whole sediments although some general trends were observed. Mercury, lead, and uranium had generally lower concentrations in the smaller size fraction while molybdenum, vanadium, and iron had higher concentrations in the 230- fraction. Usually trace metals are concentrated as particle size decreases due to large increases in surface area. However this trend may not be apparent until very small clay-sized (<2μ) material is considered and clays were not analyzed in this study. E/W transect trace metal concentrations shown in Table 26 do not show any consistent distribution trends.

	Soc	SM	A	B	C	D	CAB
Ag	15	3.1	7.5	5.1	10.5	6.1	7.0
Cd	0.10	0.90	6.7	10.4	0.86	0.81	2.1
Cr	23	41	58	33	45	30	54
Cu	8.3	42	33	46	25	23	48
Hg	1.4	0.54	0.20	1.2	-	1.4	0.25
Pb	23	20	24	23	25	35	55
Mo	-	2.9	1.1	2.6	7.1	2.6	3.1
Se	-	0.10	0.34	<0.10	<0.10	<0.10	0.14
U	88	160	200	170	80	-	160
V	170	110	96	68	70	150	87
%Fe	2.70	3.10	3.40	2.60	2.94	3.84	3.30
Mn	390	540	120	390	360	630	990

Table 25. Trace metals in 230- (<63µ) size fractions at east (E) sites. Values in ppm dry weight except Fe(%).

	Elephant Butte							Caballo		
	B			C		D		Boat Ramp		
	E	M	W	E	W	E	M	E	M	W
As	5.1	3.3	3.5	10.5	9.4	6.2	1.5	7.0	4.9	5.6
Cd	10.4	8.5	-	0.86	1.3	0.81	-	2.1	2.1	0.41
Cr	33	47	74	45	38	30	-	54	46	56
Cu	46	21	86	25	72	23	17	48	56	39
Hg	1.2	0.16	-	-	-	1.4	-	0.25	0.78	0.88
Mo	2.6	4.4	1.6	7.1	-	2.6	22	3.1	1.9	-
Pb	23	55	-	25	37	35	-	55	42	52
Se	<0.1	<0.1	-	<0.1	-	-	-	0.14	-	-
V	68	36	17	80	105	150	-	87	20	83
U	170	180	-	70	550	-	-	160	205	274
Fe	2.60	2.80	-	2.94	3.50	-	-	3.30	3.54	3.49
Mn	390	390	-	360	493	-	-	990	1080	1100

Table 26. Trace metals in 230-(<63µ) bottom sediments on E/W transects in Elephant Butte and Caballo Reservoirs. Values in ppm dry weight.

3. Trace metal distribution in sediment phases

Selective sediment extractions were performed to determine trace metal distribution within the sediment phases labeled exchangeable (EX), hydrous metal oxide (HMO), organic (ORG), and crystalline (XL). The EX sites are usually on clays, the HMO phase is primarily iron and manganese hydrous oxides, the ORG phase would be metals associated with organic material and XL phase refers to highly insoluble mineral matter which would be the most stable and inert phase for trace metals. The percentages of trace metals in the XL phases at the various sites are shown in Table 27. The results are highly variable but some general trends can be observed. In both the reservoir and river sediments the elements As, Cr, Cu, Pb, U, and Fe are present primarily in the resistant crystalline phase. The metals Cd, Mo, Fe, V, and Mn exhibit variable behavior but are generally less than 60% abundant in the XL phase. The phase distributions for these elements are shown in Table 28. The major phases in which Cd and V are found are HMO and XL while Mo is found primarily in the ORG and XL phases. The Cd and V distribution is similar to that found by Popp and Laquer (1980) in Rio Grande water while Mo behavior is different. Popp and Laquer (1980) found Mo primarily in the HMO phase in the river sediments but apparently the higher organic content (see Table 23) in the reservoir sediment allows partitioning into the organic phase (Table 28). However, Popp's study was confined to distribution within the suspended sediment load in the rivers which would have a much higher proportion of small particles so the results are not directly comparable.

D. Sediments - Organics

Analysis of bottom sediment samples revealed the presence of all 18 pesticides for which the samples were examined (Table 29). The majority of the pesticides however were detected in less than 30% of the sediment samples. The most commonly detected pesticides, in approximately declining frequency of occurrence, were heptachlor, heptachlor epoxide, kepone, alpha BHC, beta BHC, lindane, and one designated as an unseparated mixture of dieldrin and o,p'-DDE. Fractionation of the bottom sediments into a silt-clay particle size fraction (i.e. diameter <0.063 mm) followed by gas chromatographic

	Soc	SM	A	B	C	D	CAB
As	61	54	75	80	118	71	76
Cd	2	89	48	15	41	38	30
Cr	100	75	90	77	92	109	98
Cu	68	60	61	68	68	55	81
Pb	100	85	88	63	78	96	82
Mo	12	36	113	38	100	87	42
Se	-	111	-	42	32	44	25
U	76	74	51	64	81	87	73
V	61	23	42	12	54	72	48
Fe	104	81	96	72	86	92	98
Mn	45	51	43	40	33	40	17

Table 27. Percentages of trace metals in the crystalline phase. Values >100 are within the standard error for the analyses.

	Rio Grande		Elephant Butte				Caballo
	Soc	SM	A	B	C	D	CAB
Cd							
EX	0.05	0.04	0.23	0.09	0.12	0.05	0.09
HMO	0.10	0.15	0.71	0.72	3.8	0.44	0.88
ORG	0.04	0.07	0.25	0.47	0.82	0.05	0.09
XL	0.05	0.59	1.2	0.59	1.1	0.75	1.1
Mn							
HMO	9.3	10	190	10	7.5	14	21
XL	180	120	120	120	140	180	185
Mo							
EX	0.80	0.06	0.65	0.28	0.23	0.12	0.10
HMO	-	0.01	0.94	0.02	0.09	0.04	0.05
ORG	0.04	0.10	0.89	0.33	0.08	0.20	0.86
XL	0.34	0.51	0.86	0.37	1.5	1.3	0.72
Se							
EX	-	0.02	-	0.06	0.01	0.06	-
HMO	-	0.07	-	0.07	0.04	-	-
ORG	-	0.02	-	0.03	0.11	0.33	-
XL	-	0.20	0.20	0.05	0.16	0.07	0.02
V							
EX	0.3	0.25	0.20	0.27	0.10	0.86	0.27
HMO	5.6	6.7	15	11	12	9.9	13
ORG	1.2	0.51	1.3	0.90	0.69	0.18	0.70
XL	53	19	34	4.6	60	48	40

Table 28. Distribution of selected trace metals in various sediment phases. Values in ppm dry weight.

Pesticide	Intact Sample	Silt-Clay Fraction
alpha BHC	44	54.2
beta BHC	44	37.5
Lindane	32	37.5
Heptachlor	72	79.2
Heptachlor Epoxide	64	62.5
gamma Chlordane	20	29.2
o,p'-DDD	4	8.3
Endosulfan I	4	4.2
alpha Chlordane	28	20.8
p,p'-DDE	24	25.0
Dieldrin, o,p'-DDE	32	33.3
Endrin	16	25.0
Endosulfan II	8	8.3
p,p'-DDD	16	16.7
o,p'-DDT	8	4.2
Kepone	64	75.0
p,p'-DDT	4	25.0
Methoxychlor	24	16.7

Table 29. Frequency of occurrence (%) of chlorinated organic pesticides in bottom sediment samples from the Rio Grande, Elephant Butte, and Caballo Reservoirs.

analysis revealed the dominance of the same pesticides as cited above. Only slight changes in the frequency of detection and some reordering on the basis of detection frequency were observed when this particle size fraction was analyzed. Only those pesticides which were detected in 30% or more of the samples were subjected to further data analysis. It is interesting to note the relatively low frequencies of detection associated with the various isomers of DDT and those of its breakdown products, DDD and DDE. Of equal interest is the obvious persistance of these materials in the natural environment nearly ten years after their use was banned by the EPA and nearly 16 years after peak sales were recorded (Matsumura 1975).

The mean concentration of seven selected pesticides were (with five exceptions) less than 25 μg/g (Table 30). All mean concentrations were less than 90 μg/g. These mean values are known to be overestimates of the true mean because only those samples in which a pesticide was detected were used in the computation of the means. Thus the means do not reflect the frequently large numbers of samples in which the pesticide of interest was not detected. These concentrations are low but should not be considered insignificant in view of the large quantities of sediment carried by the Rio Grande and deposited behind the dam at Elephant Butte. A 1969 report by the Bureau of Reclamation(1972) calculated the sediment input to Elephant Butte Reservoir to be in excess of 9000 acre-feet per year at a density of 59-62 pound/cubic foot. This corresponds to an input of 1.05×10^{10} kg to 1.10×10^{10} kg of sediment each year. The U.S.G.S. (1978) estimated the annual mean input of sediment to Elephant Butte to be 10 million tons per year (9.08×10^{9} kg). Using these figures and the general range of concentrations detected on the suspended particulates (0.1 - 1.0 μg/g) we estimate the annual loading to Elephant Butte to be in the range of 900-11,000 kg for each of the seven most frequently occurring pesticides. However, pesticide and sediment inputs of this magnitude should result in sediment pesticide concentrations ranging from 99 ng/g (ppb) to 1.2 g/g (ppm). Based on the findings presented in Table 30 these concentrations are not attained in the bottom sediments of Elephant Butte Reservoir. Either we have overestimated the inputs of pesticides,

Pesticide	Rio Grande			Elephant Butte			Caballo		
	Fall	Spring	X	Fall	Spring	X	Fall	Spring	X
alpha BHC	4.2 (3.7)	1.3 0.7	2.8	8.8 (0)	3.2 (1.0)	5.0	3.2 (0)	0 (0)	1.6
beta BHC	4.3 (0.3)	4.0 (0)	4.2	9.4 (4.6)	4.3 (2.0)	6.8	6.1 (0)	0 (0)	3.1
Lindane	1.9 (0)	8.3 (0.1)	5.1	2.2 (1.8)	2.3 (2.1)	2.3	0	0	0
Heptachlor	58.5 (78.6)	4.4 (1.2)	31.5	21.4 (18.9)	22.5 (19.0)	21.9	19.1 (0)	23.1 (0)	21.1
Heptachlor Epoxide	1.3 (0)	0.6 (0.4)	1.0	5.8 (5.4)	2.3 (0.4)	4.0	4.0 (0)	5.0 (0)	4.6
Dieldrin, o,p'-DDE	2.8 (0)	0	1.4	2.6 (0.4)	19.9 (26.3)	11.3	27.0 (0)	11.6 (0)	19.3
Kepone	8.6 (0.1)	7.2 (1.7)	7.9	28.1 (16.1)	24.2 (8.6)	26.2	26.1 (0)	80.6 (0)	53.4

Table 30. Mean concentrations (ng/g) of selected pesticides in bottom sediment samples. Standard deviations in parenthesis. Only samples in which a pesticide was detected were used in the computations.

underestimated the input of sediments, or the pesticides are disappearing from the system. Disappearance of the pesticides from the system may occur as the result of physical, chemical, or biological transformations. More detailed research is needed to establish which of the above possibilities are operational in this system.

There is some evidence that the sediment pesticide concentrations may be higher in Elephant Butte Reservoir than in the Rio Grande (Table 29) but the data at present are inconclusive. Additional sample analysis and statistical treatment of the data is needed before a conclusion can be reached on this point. Sediment pesticide concentrations in Elephant Butte and Caballo Reservoirs were comparable.

Because a large percentage of the bottom sediment samples were negative for even the frequently detected pesticides, a more representative presentation of pesticide concentrations than calculated mean values is shown in Table 31. This method of tabulation clearly shows the large number of negative samples and the heterogeneity of the concentrations in the positive samples. Where detected, pesticide concentrations often ranged over two to three orders of magnitude in the same section of the river-reservoir complex. The sample heterogeneity is indicative of seasonal, spatial, and hydrological changes at each sampling station. Close examination of Table 31 indicates that the river sediments are more contaminated with alpha BHC, beta BHC, and lindane than sediments from either reservoir. The reservoir sediments appear to be more contaminated with heptachlor, heptachlor epoxide, and kepone than Rio Grande sediments. This dichotomy between the river and the reservoir sediment pesticides may be due to differences in their particle size distribution (Table 29). The reservoir sediments below the Narrows contain much higher percentages of silt and clay-sized particles than do the river sediments. When pesticide concentrations in the silt-clay fraction of the various samples are examined (Table 32), the river and reservoir sediment pesticide concentrations are more equitably distributed.

E. Fish-Trace Metals

Values found for trace metals in muscle tissue of fish (shad, white bass, and carp) are shown in Table 33. In order to survey the trace

	Concentration Range (ng/g)					
Pesticide	N.D.	0-0.9	1-9.9	10-49.9	50-99.9	100-500
alpha BHC						
River	20.0	20.0	60.0	0	0	0
E.B.	76.5	0	23.5	0	0	0
CAB.	66.7	0	33.3	0	0	0
beta BHC						
River	40.0	0	60.0	0	0	0
E.B.	58.8	0	35.3	5.9	0	0
CAB.	66.7	0	33.3	0	0	0
Lindane						
River	40.0	40.0	20.0	0	0	0
E.B.	76.5	11.8	5.9	0	0	0
CAB.	100.0	0	0	0	0	0
Heptachlor						
River	20.0	0	60.0	0	0	20
E.B.	35.3	0	17.6	41.2	5.9	0
CAB.	33.3	0	0	66.7	0	0
Heptachlor Epoxide						
River	40.0	40.0	20.0	0	0	0
E.B.	41.2	0	47.1	11.8	0	0
CAB.	33.3	0	66.7	0	0	0
Dieldrin, o,p'-DDE						
River	80.0	0	20.0	0		
E.B.	76.5	0	17.6	5.9		
CAB.	33.3	0	0	66.7		
Kepone						
River	20.0	0	80.0	0	0	
E.B.	47.1	0	0	52.9		
CAB.	33.3	0	0	33.3	33.3	

Table 31. Frequency (%) of selected pesticides in bottom sediment samples occurring in various concentration ranges. N.O. indicates not detected.

	Concentration Range (ng/g)						
Pesticide	N.D.	0-0.9	1-9.9	10 49.9	50-99.9	100-499	>500
alpha BHC							
River	16.7	0	66.7	16.7			
E.B.	42.9	14.3	28.6	14.3			
CAB.	100	0	0	0			
beta BHC							
River	50.0	0	33.3	16.7			
E.B.	57.1	0	21.4	21.4			
CAB.	100	0	0	0			
Lindane							
River	66.7	0	50.0	0			
E.B.	57.1	7.14	28.6	7.14			
CAB.	75.0	0	25.0	0			
Heptachlor							
River	16.7	0	33.3	16.7	0	0	0
E.B.	21.4	0	21.4	28.6	7.14	21.4	14.3
CAB.	50.0	0	0	25.00	25.0	0	0
Heptachlor Epoxide							
River	33.3	0	50.0	16.7			
E.B.	35.7	0	57.1	7.14			
CAB.	75.0	0	0	25.0			
Dieldrin, o,p' DDE							
River	66.7	0	16.7	16.7	0	0	
E.B.	64.3	0	28.6	0	0	7.14	
CAB.	75.0	0	25.00	0	0	0	
Kepone							
River	33.3	0	16.7	33.3	16.7	0	
E.B.	21.4	0	7.14	64.3	0	7.14	
CAB.	50.0	0	0	25.00	25.00		

Table 32. Frequency (%) of selected pesticides in the silt-clay fraction of bottom samples occurring in various concentration ranges. N.E. indicates not detected.

	Shad Muscle		Carp Muscle		White Bass Muscle	
	EB	CAB	EB	CAB	EB	CAB
As	0.42	0.58	2.7	0.64	0.27	0.12
Cd	0.21	0.21	0.20	0.54	0.30	<0.00
Cu	0.45	0.33	2.3	0.25	0.08	0.57
Cr	0.87	1.2	2.8	2.5	0.53	1.6
Hg	<0.01	0.19	0.61	0.47	0.63	<0.00
Mo	0.63	0.82	4.3	1.0	1.1	0.02
Pb	0.16	3.3	0.82	0.10	7.5	0.12
Se	0.42	2.3	2.5	0.25	0.91	0.52
V	<0.1	<0.1	<0.1	<0.1	1.32	<0.1

Table 33. Trace metal analyses of fish tissue from Elephant Butte and Caballo Reservoirs. Selected larger individuals. Values in ppm wet weight.

metal situation, larger and hence older individuals were selected. These larger individuals would be expected to exhibit the highest concentrations and hence be indicative of any potential problem areas. Shad are a forage species for white bass and a comparison of these two species would represent biomagnification effects. In Elephant Butte fish, white bass show approximately one order of magnitude greater values compared to shad for the metals mercury, lead, and vanadium. These trends do not hold for Caballo fish. In general the values found in carp in this study were similar to those found in carp in the Rio Grande above Elephant Butte by Popp et al. (1980). Carp (Cyprinus carpos) was the only similar species in both studies.

Because mercury has been recognized to be a potential problem in Elephant Butte (Kidd et al. 1974) and the Rio Grande above Elephant Butte (Popp et al. 1980) a larger number of individuals was analyzed for mercury and the results are shown in Table 34. The samples are also broken down in Table according to their location in Elephant Butte (upper vs lower reservoir). Higher mercury values were found in shad and white bass in the lower section of Elephant Butte and white bass had greater concentrations than shad (x3 upper reservoir)(x4 lower reservoir). Mercury concentrations of white bass and shad muscle in Caballo were about the same. Mercury values in carp muscle were on a par with those found for carp in the Rio Grande above Elephant Butte (Popp et al. 1980) and were very similar in both Elephant Butte and Caballo. On an average wet weight basis the mercury standard of 1.0 ppm is not exceeded but larger individuals have the potential for exceeding the standard.

Trace metal analysis of kidney and liver tissue from the selected larger individuals are shown in Table 35. No shad data is shown because of the small size of the organs. Mercury values in white bass kidney and liver are in the same range as found by Potter et al. (1975) in Lake Powell large mouth bass which was chosen for comparison because white bass were not sampled. The values for Hg in kidney and liver are also in the ranges reported by Kidd et al. (1974) for Elephant Butte Reservoir. Comparison of white bass liver values between Caballo and Elephant Butte show very small differences and no general trends. A

	Shad	White Bass	Carp
Upper Reservoir	0.04±0.07	0.13±0.15	0.35±0.23
Elephant Butte	(24)	(21)	(8)
Lower Reservoir	0.11±0.36	0.49±0.22	0.27±0.11
Elephant Butte	(17)	(7)	(2)
Caballo Reservoir	0.10±0.10	0.14±0.31	0.34±0.18
Dam Site	(7)	(11)	(15)

Table 34. Mercury analysis of fish muscle tissue in Elephant Butte and Caballo Reservoirs. Values in ppm wet weight. No. in parentheses indicates number of individuals. Standard deviations shown (±). Upper Reservoir is approximately at Site B and Lower Reservoir is approximately at Site D (See Figure 1).

	Elephant Butte		Caballo	Elephant Butte
	White Bass Kidney	White Bass Liver	White Bass Liver	Carp Liver
As	3.7	1.5	0.72	0.54
Cd	0.32	0.13	0.07	1.0
Cu	1.8	23	50	1.5
Cr	0.64	0.40	0.18	0.91
Hg	0.13	0.35	0.52	-
Mo	0.38	0.63	0.52	-
Pb	10	0.83	-	0.30
Se	2.4	3.0	3.1	1.6
V	0.07	0.25	<0.1	<0.1

Table 35. Metal analysis of fish tissue from Elephant Butte and Caballo Reservoirs - selected larger individuals. Values in ppm wet weight.

more detailed set of Hg analyses data for kidney and liver tissues is shown in Table 36. Again these mercury values are in the ranges found by Kidd et al. (1974).

	Carp Kidney		White Bass Liver
	Elephant Butte	Caballo	Elephant Butte
	0.25(7)	0.69(4)	1.6(7)
range	0.07-0.82	0.06-1.7	0.21-4.8

Table 36. Mercury analyses in fish liver and kidney tissue from Elephant Butte and Caballo Reservoirs. Values in ppm wet weight. Number of individuals shown in parentheses.

F. Fish - Organics

Analysis of the fish tissues is incomplete at the present time but is in progress. As part of a preliminary screening, 33 fish tissue samples were selected. The muscle (13), liver (10), and kidney (10) samples were selected from the largest male and female of each of the three species at each reservoir. The preliminary qualitative analysis indicated that pesticide concentrations are very low in all tissues of all species. Quantitation of pesticides in a much larger sample of tissues from the three fish species is in progress and the results will be amended to this report as soon as they become available.

G. Limnological Analysis

The limnological data obtained on the fall 1980 and spring 1981 sampling trips are presented for all sampling stations in Tables 37 and 38 respectively. Data presented for the reservoirs were obtained from the center of the reservoirs. The fall 1980 data indicate that the lake was nearly isothermal, that the surface and mid-depth waters were well oxygenated but the bottom water oxygen levels were severely reduced. Data (not shown) obtained from more detailed depth profiles at each station indicated a rapid onset of oxygen depletion at depths greater than 24 m (80 feet). A decline in the redox potential (Eh) is

Station (depth m)	Temp (°C)	D.O. (mg/ℓ)	conductivity (mho)	pH	Eh (mv)	HCO_3^- (mg/ℓ)	$CO_3^=$ (mg/ℓ)	Hardness (mg/ℓ)	Secchi Depth (m)
San Marcial	10	10.2	610	8.4	463	179	0	255	
Narrows									
surface	18	8.4	650	8.7	353	137	17.1	240	0.40
mid (2.1)	17	6.4	625						
bottom (4.6)	16.5	6.6	650	8.5	353	137	17.1	230	
Monticello Pt.									
surface	18	6.8	400	8.7	333	103	17.1	180	1.37
mid (8.5)	18	6.2	450						
bottom (17.4)	18	6.3	470	8.7	283	120	0	175	
Long Pt.									
surface	20	7.8	450	8.5	263	103	17	185	2.44
mid (18.3)	18.5	6.5	450	8.5					
bottom (30.2)	18.0	2.3	450	7.9	93	154	0	170	
Rattlesnake Is.									
surface	20	7.9	450	8.6	253	103	17	200	1.98
mid (20.1)	19	6.7	420	8.4					
bottom (38.4)	17.5	1.0	490	7.7	93	154	0	175	
Caballo - Boat ramp									
surface	15	8.0	650	8.5	333	171	0	245	0.09
mid									
bottom (3.6)	14.5	7.5	650	8.4	353	171	0	245	

Table 37. Limnological data collected on the fall 1980 sampling trip.

Station (depth m)	Temp °C	D.O. (mg/ℓ)	Conductivity (mho)	pH	Eh (mv)	HCO^- (mg/ℓ)	$CO_3^=$ (mg/ℓ)	Hardness (mg/ℓ)	Secchi Depth (m)
Socorro 5/27/81	26	8.0	690	8.0				210	
San Marcial	20.5	7.4	1000	7.0	313	171	0	306	
Narrows									
surface	24	9.4	700	7.3	303	171	0	215	0.28
mid (1.8)	18	8.0	420						
bottom (3.6)	17.7	5.2	500	7.4	283	205	0	218	
Monticello									
surface	23	9.1	500	7.4	266	154	0	174	2.13
mid (9.1)	17.5	7.4	490						
bottom (17.4)	15	4.0	430	7.5	306	154	0	172	
Long Ft.									
surface	18	8.4	440	7.4	253	137	0	172	1.83
mid (15.2)	16.5	6.0	410						
bottom (31.1)	14.5	4.5	420	7.5	263	128	0	168	
Rattlesnake Is.									
surface	23	8.8	460	7.8	323	137	0	168	1.98
mid (15.2)	16.7	5.5	395						
bottom (28.0)	15.5	4.7	390	7.7	323	137	0	168	
Caballo									
surface	20.5	7.6	500	6.9	246	137	0	176	0.20
bottom (10.7)	19	7.5	380	6.8	166	154	0	172	

Table 38. Limnological data collected on the spring 1981 sampling trip.

also apparent in the bottom waters. This deoxygenation of the hypolimnetic waters in the fall is probably a remnant of a situation that developed during the summer months under conditions of thermal stratification and microbial degradation of organic matter. Vertical mixing during the late fall, winter, and early spring induced by isothermal temperatures and wind action on the surface reaerated the hypolimnetic waters and elevated the redox potential by the following spring (Table 38). Reducing conditions do not appear to develop in Caballo Reservoir due to its relatively shallow depth and frequent vertical mixing.

Both reservoirs have well buffered waters of alkaline pH and moderate hardness due primarily to the presence of Ca^{++} ions. Elephant Butte Reservoir below the Narrows has lower conductivity than the Rio Grande or Caballo Reservoir. The water chemistry of the Narrows section of Elephant Butte Reservoir was heavily influenced during both sampling trips by the chemical and sediment inputs from the river. The suspended sediments had settled out and the Secchi disk transparency had improved considerably by the time the water had reached Monticello Point. Changes in conductivity, bicarbonate and carbonate alkalinity, and hardness had also stabilized to levels more characteristic on the other reservoir sampling stations at Monticello Point.

H. Radionuclide Distribution in Bottom Sediments

Because of the great depth of sediments deposited in Elephant Butte Reservoir ($\sim$10-20 m)(Bureau of Reclamation 1970), the sediment coring device was not effective in collecting sediment cores. Also, the large volume of water present for this study period procluded hand augering of core samples in the upper end of the reservoir. Data for radionuclide analysis is shown in Table 39. The elements Pb-210, Ra-226, and Th-234 are daughters in the U-238 decay series and show levels in accord with stream sediments draining the Grants Mineral Belt(Popp et al. 1983). The fact that Caballo Reservoir has about the same levels as Elephant Butte and receives no sediment from Elephant Butte indicates that these materials have a high regional distribution. However, more detailed core analysis needs to be done to answer the question. The

	Rio Grande		Elephant Butte			Caballo
Radionuclide	Soc	SM	B	C	D	CAB
Cs-137	0.26	0.067	0.19	0.39	0.20	0.71
Pb-210	1.61	0.99	1.55	2.08	1.68	2.70
Ra-226	2.71	1.62	2.05	2.70	2.82	2.67
Th-234	1.20	0.82	1.06	1.22	1.09	1.00
Ac-228	1.40	0.88	0.39	1.82	1.53	0.70

Table 39. Radionuclide activities in sediments. Values in pCi/g dry weight.

low values at San Marcial are probably due to the larger grain size (less absorption surface) of the material analyzed (see Tables 19 to 21). The Cs-137 isotope is an artifical radionuclide whose presence results from fallout and the relatively low values in the Rio Grande and Elephant Butte sediments indicate dilution with older, Cs-137 free erosional material (Popp et al. 1983). The high values for Cs-137 and Pb-210 in Caballo Reservoir indicate less dilution of atmospheric fallout than shown in Elephant Butte. This is consistent with the fact that Pb-210 is high in Caballo while Ra-226 and Th-234 are about the same levels as the upstream sites.

It may be possible to accurately age date sediments in Caballo by this procedure but one may have to settle for pre- and post-1950 dates for Elephant Butte sediments.

IV. CONCLUSIONS AND RECOMMENDATIONS

Large amounts of trace metals are delivered to Elephant Butte Reservoir due to the heavy suspended sediment load in the Rio Grande. Most of the metal concentrations are present at levels which are close to average crustal abundance. However, the trace metals Hg, Cd, U, As, and Se exhibit elevated concentrations in the sediments both in Elephant Butte and Caballo Reservoirs. Caballo Reservoir does not receive sediments from the upstream Rio Grande which implies a regional elevation for the trace metals.

Concentrations of trace metals in the water column are about average for regional surface water. The metals Cd, Cu, Cr, Pb, and V are elevated in interstitial water within the bottom sediments and therefore have the potential to diffuse into the water column.

Fish tissues exhibit levels of Hg which may potentially exceed health regulations in larger fish while Pb and V show possible biomagnification in Elephant Butte but not in Caballo Reservoir.

Radionuclide analysis of the sediments reveals values which reflect the presence of uranium mineralization upstream from the reservoirs.

Low levels of at least 18 different chlorinated organic pesticides were tentatively identified in samples of water, suspended particulates, bottom sediments, and fish tissues. Consistent differences in the mean concentrations of pesticides were not observed among water samples from the Rio Grande, Elephant Butte, and Caballo Reservoirs.

Pesticides, when present in water samples, were predominantly associated with the suspended particulates. Mean concentrations of pesticides on suspended particulates were generally higher in the reservoir samples than in the river samples and higher in Elephant Butte samples than in Caballo.

Pesticides in the bottom sediments of the river and reservoirs were usually less than 25 ng/g. The bulk of the pesticides associated with the bottom sediments of the reservoirs was found in the silt-clay fraction which comprises the bulk of the sediment samples. Concentrations of pesticides in Elephant Butte and Caballo Reservoir sediments were comparable.

Calculations based on our data and on sediment inputs to Elephant Butte Reservoir indicate a heavy annual input of pesticides. For unknown reasons, pesticide concentrations in the bottom sediments were lower than predicted.

On the basis of this study, the following recommendations are made:

(1) A more detailed study of fish should be made to determine the extent of the mercury contamination although in general trace metals do not appear to be elevated in fish. Lead and vanadium show possible biomagnification and should receive more study.

(2) The radionuclide data indicates the strong possibility for radioactive dating of the sediments in both reservoirs. Subsequent analysis of the core material for trace substances may provide historical documentation of anthropogenic inputs within the past 60-70 years.

(3) That the increased frequency of occurrence of pesticides in the Fall samples be investigated more thoroughly to determine the specific conditions leading to this observation.

(4) That the specific factors responsible for the heterogeneity of the pesticide concentrations in the water and sediment samples be investigated in more detail. Such information is needed to better understand the environmental fate and dynamics of the pesticides.

(5) That the annual loading of pesticides to Elephant Butte Reservoir be studied more thoroughly to determine sources, more precise estimates of inputs and the fate of these materials.

(6) That the mechanisms of "disappearance" of the pesticides from Elephant Butte be explored and quantified.

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VI. ACKNOWLEDGEMENTS

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Appendix A

Trace metals, pesticides, and other organic compounds determined in the water, suspended particulates, and bottom sediments of the Middle Rio Grande.

Trace Metals

- Arsenic
- Cadmium
- Copper
- Chromium
- Mercury
- Lead
- Molybdenum
- Selenium
- Uranium
- Vanadium

Pesticides

- Aldrin
- Dieldrin
- Total DDT
    - o,p - DDE
    - p,p' - DDE
    - o,p - DDD
    - p,p' - DDD
    - o,p - DDT
    - p,p' - DDT
- Chlordane
    - cis isomer of chlordane
    - trans isomer of chlordane
    - cis isomer of nonachlor
    - trans isomer of nonachlor
- Endrin
- Methoxychlor
- Hexachlorobenzene
- Hexachlorocyclohexane
    - alpha isomer
    - gamma isomer
- Mirex
- Heptachlor
- Toxaphene
- Strobane
- Endosulfan
- Kepone
- Kelthane

Other Organics

- Polychlorinated biphenyls (PCB)
- Pentachlorophenol

Appendix B

Average values and standard deviations for heavy metals at east stations in filtered water

Values in ppb

	Rio Grande		Elephant Butte				Caballo	
	Soc.	S.M.	A	B	C	D	Cab.	
As		25±11	11±2.6	8.4±2.7	8.9±3.9	9.2±5.5	12±8.6	Surface
			11±5.3	9.4±4.6	8.2±4.2	8.5±5.3	41±60	Bottom
Cd	<.01 (1)	.73±.56	.39±.13	.20±.17	1.1±1.4	.80±1.2	.32±.19	Surface
			.20±.24	1.6±1.2	.60±.23	.15±.13	.35±.25	Bottom
Cu		6.2±3.4	36±38	16±16	18±16	20±23	16±11	Surface
			20±13	19±12	17±19	23±22	12±4.6	Bottom
Cr	141 (1)	1.4±1.7	1.8±1.8	2.4±3.7	.95±1.6	6.9±7.3	7.1±6.7	Surface
			11±16	6.8±7.0	5.8±5.4	2.9±4.6	12±14	Bottom
Hg		1.5±2.7	.51±.46	1.2±.97	.44±.58	.44±.65	.62±.87	Surface
			.88±.53	.83±.59	.63±.61	1.1±.92	.57±.58	Bottom
Mo		13±9.8	6.7±1.2	5.0±2.7	4.6±4.5	5.8±1.4	3.7±4.1	Surface
			3.9±3.0	5.1±4.0	4.0±2.5	4.1±2.9	5.2±3.5	Bottom
Pb	4.9±2.6	4.8±3.7	5.9±6.2	3.9±5.3	4.7±5.1	5.5±4.6	7.2±11.6	Surface
			2.8±6	4.7±5.0	5.3±5.2	3.7±1.9	6.3±6.2	Bottom
Se	0 (1)	1.0±.96	1.3 (1)	.07±.06	.41±.64	2.2±2.6	2.1±2.6	Surface
			1.0±1.3	1.7±2.9	1.4±2.2	.11±.01	.07±.06	Bottom
V		27 (1)	<7.8±0.0	11±5.0	12±7.6	12±7.3	14±9.8	Surface
			16±8.2	11±6.0	12±7.8	12±8.0	16±9.4	Bottom

Appendix B

Average values and standard deviations for heavy metals at east stations in whole water

Values in ppb

	Rio Grande		Elephant Butte				Caballo	
	Soc.	S.M.	A	B	C	D	Cab.	
As	11 (1)	14±8.4	10±14	18±29	110±208	2.8±1.4	11±11	Surface
			14±12	6.0±3.8	6.3±8.3	8.1±8.3	37±52	Bottom
Cd	2.3(1)	1.3±1.5	3.4±4.7	5.8±6.0	.71±.97	1.1±2.3	1.5±2.9	Surface
			1.0±.95	7.5±12.9	12±16	5.2±6.8	1.4±1.9	Bottom
Cu	81 (1)	71±70	3.1±4.4	51±79	12±10	22±32	17±26	Surface
			31±35	220±370	230±460	85±140	30±33	Bottom
Cr		52±.2	9.9±6.8	26±34	8.8±8.0	44±36	171±99	Surface
			62±33	11.8±9.3	390±457	19±14	88±84	Bottom
Hg		2.0±3.0	.29±.09	.11±.13	.32±.29	.13±.03	1.2±1.2	Surface
			.55±.00	.92±.45	2.1±3.5	2.3±2.8	2.0±1.1	Bottom
Mo	5.5±1.7	4.2±2.3	5.6 (1)	160±280	7.0±9.3	15±10	10±8.8	Surface
			10±7.4	12±7.9	11±12	9.0±7.0	11±8.4	Bottom
Pb	174 (1)	30±35	11±2.1	4.1±3.8	30±31	42±79	86±157	Surface
			44±64	21±5.9	11±9.9	7.3±3.8	20±7.1	Bottom
Se			<1 (1)	.58±.59	<.1±0.0	<.1±0.0	<.1±0.0	Surface
			1.3 (1)	<.1±0.0	.55±.64	2.1±2.7	<.1±0.0	Bottom
V		11±11	5.0±4.0	13±14	12±13	12±14	15±18	Surface
			33.±48	13±15	16±19	14±16	17±20	Bottom

Appendix C

Average values and standard deviations for heavy metals at all stations in whole water

Values in ppb

	A			B			C		
	E	M	W	E	M	W	E	M	W
As	10±14	26±35	6.0±5.4	18±29	9.3±10	4.8±1.2	110±210	15±18	16 (1)
	14±12	9.4±10	7.6 (1)	6.0±3.8	2.0±.70	5.8±4.6	6.3±8.3	5.3±2.9	16 (1)
Cd	3.4±4.7	6.9±5.7	2.2±2.9	5.8±6.0	1.6±2.2	.75±1.1	.71±.97	.40±.56	.66±.93
	1.1±.95	14±19	13±18	7.5±13	3.4±4.9	1.8±2.5	12±16	1.1±.86	.66±.93
Cu	3.1±4.4	6.9±9.7	14±20	51±79	23±33	45±63	12±10	33±47	11±16
	31±35	16±22	32±45	220±370	11±15	22±38	230±460	14±20	20 (1)
Cr	9.9±6.8	21±21	13±10	26±34	4.5±5.5	16±13	8.8±8.0	13±11	7.2±10
	62±35	190±250	140±46	12±9.3	21±22	11±2.5	390±460	20±24	120±190
Hg	.29±.09	.59±.33	.56±.31	.11±.13	.44±14	.53±.03	.32±.29	.96±.66	.44±.16
	.55±.00	.48±.07	.38±.22	.92±.45	.75±.36	.57±.33	2.1±3.5	.57±.43	.08±.03
Mo	5.6 (1)	4.4±1.7	6.0 (1)	160±280	4.5±1.7	5.9 (1)	7.0±9.3	3.3±.20	2.9±2.5
	10±7.4	7.0 (1)	8.3 (1)	12±7.9	3.1±.10	2.2±.80	11±12	5.9±1.7	2.7±2.2
Pb	11±2.1	110±140	11±10	4.1±3.8	9.4 (1)	14±8.1	30±31	5.8±1.4	24±15
	44±64	24±13	19 (1)	21±5.9	8.8±3.9	3.0±4.3	11±9.9	12±3.2	4.5±6.3
Se	<1 (1)	<1 (1)	<1 (1)	.58±.59	<1 (1)	<1 (1)	<.1±0.0	<1 (1)	<1 (1)
	1.3 (1)	<1 (1)	<1 (1)	<.1±0.0	<1 (1)	<1 (1)	.55±.64	<1 (1)	<1 (1)
V	5.0±4.0	44±49	6.2±2.3	13±15	4.2± 5.1	4.3±5.0	12±13	4.4±4.9	4.6±4.5
	33±48	5.0±4.0	5.3±3.6	13±15	15±18	5.3±3.6	16±19	5.7±3.0	5.3±3.6

	D			Cab			
	E	M	W	E	M	W	
As	2.8±1.4	3.9±3.1	3.2 (1)	11±11	6.2±1.1	2.6±.20	Surface
	8.1±8.3	7.7±9.3	1.0 (1)	37±52	19 (1)	4.5±4.2	Bottom
Cd	1.1±2.3		3.7 (1)	1.5±2.9	.75±1.1	3.1±4.3	Surface
	5.2±6.8	3.6±4.5	11 (1)	1.4±1.9	5.1±7.2	4.1±4.1	Bottom
Cu	22±32	11±16		17±26	10±14	20±28	Surface
	85±140	12±16		30±33	15±21	18±25	Bottom
Cr	44±36	13±22	45±61	170±99	41±40	26±30	Surface
	19±14	140±130	12±18	88±84	73±56	16±21	Bottom
Hg	.13±.03	.31±.05	.40 (1)	1.2±1.2	.76±.20	.30±.08	Surface
	2.3±2.8	.04±.06	.25 (1)	2.0±1.1	1.4±1.6	1.5±1.1	Bottom
Mo	15±10	3.8±3.2	5.9 (1)	10±8.8	3.2±.04	4.6±2.0	Surface
	4.0±7.0	3.6±3.4	2.3 (1)	11±8.4	3.7±3.1	2.6±2.0	Bottom
Pb	43±79	5.9±3.1	8.5 (1)	86±160	8.8±12	13±12	Surface
	7.3±3.8	44±42	8.9 (1)	20±7.1	20±15	17±3.6	Bottom
Se	<.1±0	<1 (1)		<.1±0.0	.80 (1)	<1 (1)	Surface
	2.1±2.7	<1 (1)		<.1±0.0	<1 (1)	<1 (1)	Bottom
V	12±14	4.5±4.6	<7.8 (1)	16±18	4.8±4.2	5.0±4.0	Surface
	14±16	5.7±3.0	<7.8 (1)	17±20	5.3±3.6	<7.8 (1)	Bottom

Appendix C

Average values and standard deviations for heavy metals at all stations in filtered water

Values in ppb

	A			B			C		
	E	M	W	E	M	W	E	M	W
As	11±2.6 11±5.3	11±1.4 13±3.3	11±2.0 15±4.3	8.4±2.7 9.4±4.6	11±.90 13±2.3	9.8±1.7 16±7.9	8.9±3.9 8.2±4.2	13±6.6 14±2.9	12±1.4 12±1.4
Cd	.39±.13 .20±.24	.33±.04 .33±.06	.37±.21 .50±.22	.20±.17 1.6±1.2	.33±.23 .36±.21	.30±.03 .33±.27	1.1±1.4 .60±.23	.42±.41 .40±.38	.37±.26 .37±.26
Cu	36±38 20±13	7.4±7.3 12±12	9.2±7.8 20±24	16±16 19±12	7.4±4.8 9.5±7.3	6.5±4.6 10±11	18±16 17±19	8.4±5.9 17±19	15±1.9 19±18
Cr	1.8±1.8 11±16	3.4±4.0 1.8±2.1	1.5±1.5 2.3±2.0	2.4±3.7 6.8±7.0	1.2±1.3 1.2±1.7	1.2±1.4 1.2±1.5	.95±1.6 5.8±5.4	15±20 1.4±1.5	1.1±1.5 1.0±.78
Hg	.51±.46 .88±.53	.27±.22 .24±.23	.26±.25 .76±1.0	1.2±.97 .83±.59	.56±.23 .39±.47	.42±.25 .33±.38	.44±.58 63±61	.24±.34 .28±.04	.16±.13 .25±.23
Mo	6.7±1.2 3.9±3.1	7.4±3.1 5.8±1.8	6.1±1.4 6.4±2.9	5.0±2.7 5.1±4.0	14±17 5.7±2.6	6.5±6.2 5.7±2.7	4.6±4.5 4.0±2.5	11±9.9 5.6±2.8	3.2±2.3 6.6±4.2
Pb	5.9±6.2 2.8±.60	5.3±6.4 1.5±1.7	2.5±2.0 9.2±13	3.9±5.3 4.7±5.0	2.6 (1) 1.7 (1)	8.0±10 1.3±1.5	4.7±5.1 5.3±5.2	9.0±11 3.5±.50	.93±.11 1.7±1.5
Se	1.4 (1) 1.1±1.3	<.1 (1) 6.3 (1)	<.1 (1) .10 (1)	.07±5.0 1.7±2.9	.11 (1) <.1 (1)	<.1 (1) <.1 (1)	.41±.63 1.4±2.3	.11 (1) <.1 (1)	.11 (1) <.1 (1)
V	<7.8±0.0 16±8.2	<7.8±0.0 13±4.6	<7.8±0.0 13±0.0	11±5.0 11±6.0	<7.8±0.0 <7.8±0.0	<7.8±0.0 8.3±.80	12±7.6 12±7.8	<7.8±0.0 <7.8±0.0	8.9±1.5 <7.8±0.0

	D			Cab			
	E	M	W	E	M	W	
As	9.2±5.5 8.5±5.3	13±6.3 14±2.4	10 (1) 8.9 (1)	12±8.6 41±60	16±1.9 12±5.5	13±1.5 12±7.9	Surface Bottom
Cd	.80±1.2 .15±.13	.50±.05 .15 (1)	.62 (1) .15 (1)	.32±.19 .35±.25	.41±.10 .34±.06	.34±.11 .45±.09	Surface Bottom
Cu	20±23 23±22	5.8±3.5 28±10	16 (1) 10 (1)	17±11 12±4.6	16±6.6 15±1.2	9.8±7.0 20±15	Surface Bottom
Cr	6.9±7.3 2.9±4.6	3.5±4.5 2.2±.20	.32 (1) .32 (1)	7.1±6.7 12±14	2.0±1.4 1.8±.50	1.3±1.3 1.6±1.1	Surface Bottom
Hg	.44±.65 1.1±.92	.22±.08 1.8±1.7	.12 (1) .12 (1)	.62±.87 .57±.58	.07±.08 .43±.56	.17±.18 .07±.10	Surface Bottom
Mo	5.8±1.4 4.1±2.9	5.4±3.1 6.2±4.7	7.6 (1) 9.6 (1)	3.7±4.1 5.2±3.5	5.5±3.0 6.5±4.3	6.7±4.1 6.5±4.3	Surface Bottom
Pb	5.5±4.6 3.7±2.0	5.4±7.1 1.8±1.9	29±38 7.2±6.6	7.2±12 6.3±6.2	8.8±11 4.1±5.4	2.4±3.0 9.3±8.4	Surface Bottom
Se	2.2±2.6 .11±.01	6.3 (1) 16 (1)	<.1 (1) .11 (1)	2.1±2.6 .07±.06	.11 (1) .11 (1)	.11 (1) .11 (1)	Surface Bottom
V	12±7.3 12±8.0	<7.8±0.0 11±3.8	<7.8±0.0 <7.8±0.0	14±9.8 16±9.4	<7.8±0.0 13±0.0	<7.8±0.0 <7.8±0.0	Surface Bottom