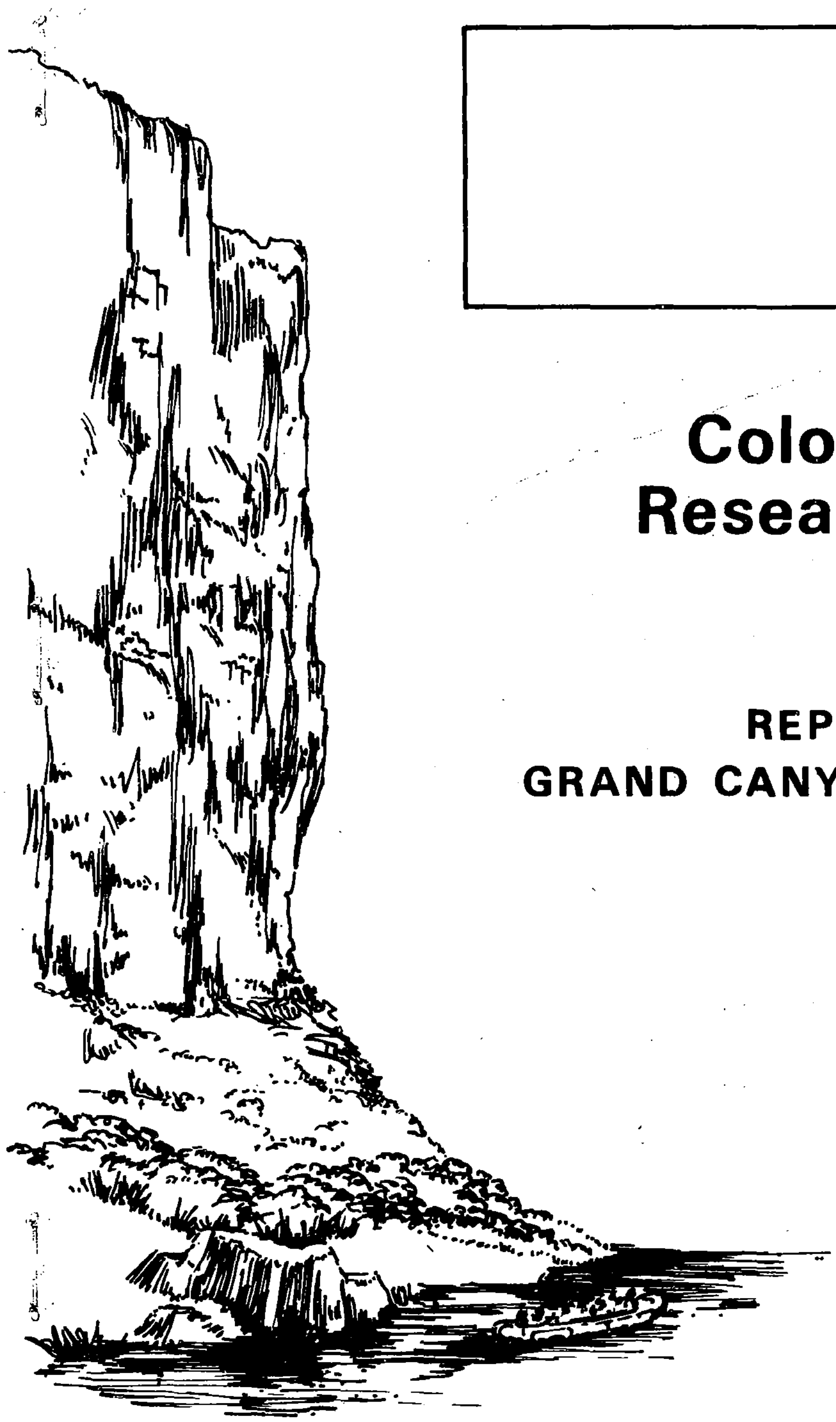

Colorado River Research Program

REPORT SERIES
GRAND CANYON NATIONAL PARK

United States
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COLORADO RIVER RESEARCH PROGRAM
Grand Canyon National Park
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The Colorado River Research Program was initiated by the National Park Service in 1974 to secure scientific data to provide a factual basis for the development and the implementation of a plan for appropriate visitor-use of the Colorado River from Lee's Ferry to Grand Wash Cliffs and for the effective management of the natural and cultural resources within the Inner Canyons. The intensified research program consists of a series of interdisciplinary investigations that deal with the resources of the riparian and the aquatic zones and with the visitor-uses including river-running, camping, hiking, and sight-seeing of these resources, as well as the impact of use and upstream development upon canyon resources and visitor enjoyment.

Final reports that result from these studies will be reproduced in a series of Program Bulletins that will be supplemented by technical articles published as Program Contributions in scientific journals.

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SURVEY OF BACTERIA, PHYTOPLANKTON AND TRACE CHEMISTRY OF THE LOWER COLORADO RIVER AND TRIBUTARIES IN THE GRAND CANYON NATIONAL PARK

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and Nancy L. Crane

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Report on Research Project

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Survey of Bacteria, Phytoplankton, and Trace Chemistry of the Lower Colorado River and Tributaries in the Grand Canyon National Park

Submitted to

Grand Canyon National Park
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by

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ABSTRACT

This baseline research program has established aquatic monitoring sites on the Colorado River and its major tributaries in the Grand Canyon National Park and vicinity that can be used for future reference.

The investigation has revealed total viable bacterial numbers of 10^2-10^5/ml in the Colorado River and 10^1-10^6/ml in the tributaries. The variability in these counts is attributable to sediment load and watershed characteristics. The highest numbers were usually recorded in early summer. Among the tributaries Diamond Creek had the highest bacterial numbers. Total coliform bacterial counts exceeded the desirable water quality level at numerous river and tributary sites throughout the year. During the summer period and especially at heavily used visitor sites such as Elves Chasm, Deer Creek, and Havasu Creek, the coliform levels exceeded 400/100 ml. The high coliform bacteria numbers raise the possibility of fecal contamination by warm-blooded animals and of a potential health hazard. Chlorination or other treatment of river and tributary water is recommended before use.

The phytoplankton population in the Colorado River was diverse, but sparse and decreased with distance downstream from Lee's Ferry. Numbers were never found to exceed 3,000/liter. A total of 122 species were identified with the common organisms being Asterionella formosa, Synedra ulna, Diatoma vulgare, Fragilaria crotonensis, and Rhoicosphenia curvata. Phytoplankton were also sparse in the tributaries and never exceeded 12,000 organisms/ml. A total of 137 species were identified in the tributaries with 71 being confined to tributaries. Common tributary species were Cocconeis pediculus, Diatoma vulgare and Synedra ulna. On the basis of phytoplankton numbers the Colorado River and its tributaries must be considered relatively unproductive.

The concentrations of 15 chemical elements, including several heavy metals were monitored. Boron, iron and zinc showed large temporal and spatial variations in the Colorado River and sodium levels increased 7-13% with distance downstream from Lee's Ferry. The tributaries differed chemically and showed large variations in boron, calcium, iron, magnesium, and manganese relative to flow. The Little Colorado River exceeded water quality standards for iron and manganese during flooding. Otherwise, the dissolved chemical quality of the River and tributaries was generally acceptable based on current water quality standards.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE | PAGE

LIST OF TABLES

TABLE PAGE

PREFACE

This investigation was initiated as a portion of a broad baseline research program on the aquatic ecosystem of the Colorado River and selected tributaries in the Grand Canyon National Park. This investigation was specifically designed (1) to establish monitoring sites, (2) to develop reliable field and laboratory procedures of analysis for bacteriological, trace chemical, and phytoplankton components of the aquatic system, (3) to obtain baseline information on the previous parameters as they relate to water quality of the Colorado River and its tributaries, and (4) to provide resource managers with information that may be useful in resource preservation and planning.

A paucity of data is available on major aspects of the aquatic biota of the Colorado River and its tributaries in the Park (Kubly, 1975). Even organisms of health significance have not received the desired attention. Bacteriological investigations have been restricted to spot surveys during only part of the summer (Slawson and Everett, 1974). The restricted surveys, however, have suggested that bacteria coliform levels often exceeded desirable water quality characteristics established by the Public Health Service. With continued use of the aquatic system as a means of transportation and potable water, the bacteriological characteristics of the water, both on a temporary and long-term basis, deserves considerable and continued attention.

Even less information has been available on the microscopic plant life (phytoplankton) suspended in the aquatic system. Data is limited to three surveillance sites on the entire Colorado River and to only the diatoms. Although this group of organisms might easily be ignored by those uninformed, their significance to the well-being of an aquatic system is undeniable. This group of organisms, including those that grow attached, are the primary producers upon which all levels of consumers are directly or indirectly dependent for organic biomass. Phytoplankton and benthic associations have also gained some prominence as biological indicators of water quality and may be useful as a means of evaluating the prevailing conditions in the system as well as future changes.

The characterization of chemical conditions of the Colorado River and its tributaries, although initiated at least 50 years ago (LaRue, 1925; Collins and Howard, 1927; Howard, 1930) has continued to be somewhat limited for elements generally occurring in trace quantities. The data that does exist is limited spatially to only a few River sites and often to one sampling (Kopp and Kroner, undated; Carlson, Everett and Qashu, 1971). No data has been available on the trace chemistry over a time period that permits reasonable evaluation of the influence of Glen Canyon Dam on the characteristics of the River. Additionally, no trace chemical data has been available on most of the tributaries of the Colorado River.

The necessity of this and other aquatic investigations is clearly pointed out by Toms (1975) who stated .... "Before there can be comprehensive management of a river system it is essential to have background information as to the quality of the river and its variability under a variety of natural conditions".

In this report frequent use and reference has been made to the major works of Hynes (1970) and Whitton (1975) on general river ecology. Primary taxonomic references used for the algae were Cleve-Euler (1968), Hustedt (1930), Prescott (1962) and U.S. D.I. (1966). Two works (Livingstone, 1963; Kopp and Kroner, undated), cited frequently in this report were useful in relating river and tributary chemistry to other river or aquatic systems.

The investigators on this project gratefully acknowledge the assistance of the National Park Service personnel Dr. R.R. Johnson and Mr. Norm Henderson for organizing several river trips and providing pertinent literature as needed. Gratitude is extended to Dr. Steven Carothers, his staff and the Museum of Northern Arizona for making river transportation available to us on several river trips. We also desire to acknowledge the assistance of Susan K. Siegel, Steve Fleckenstein, Sylvia Hill and Karen Cunningham for their technical assistance on this project.

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METHODS

Water samples were obtained during five float trips down the Colorado River from Lee's Ferry to Diamond Creek, a distance of 225 river miles (360 km). The trips occurred during 1975-1976 on the following dates: April 22 to May 5, June 3 to June 12, August 11 to August 21, November 18 to 25, and March 1 to 9. Samples were obtained from the Colorado River and from numerous convergent tributaries and springs. Sampling sites included those on the Colorado River above and below the major tributaries and springs as well as sites in the mouth of the tributaries. The various river, tributary and spring sites with their river mile location are provided in Tables 1 and 2 and are illustrated in Figure 1.

Bacteriological Methods

Total Viable Bacteria. Water samples were collected in sterile screw cap test tubes at a depth of ca. 10 cm below the water surface. Dilutions of 10^2, 10^4 and 10^6 were prepared with serial dilutions by aseptically adding a 0.1 ml sample volume to 10 ml of sterile distilled water. A 0.1 volume of raw samples and dilutions were then plated on sterile Plate Count Media (Difco) and allowed to incubate at air temperature for 4 days.

Total Coliform Bacteria. Water samples for evaluation of total coliform bacteria numbers were collected with sterile plastic, 50 ml Millipore syringes at an approximate depth of 10 cm below the surface.

Procedures recommended by the American Public Health Association (1971) were used for total coliform bacteria (TC) determinations. Total coliform counts were obtained by the membrane filter (MF) technique which involved using a Millipore HAWG 047 SO filter with a 0.45 µm pore size. Duplicate samples of volumes from 5-40 ml were filtered. The filters were placed on Millipore pads saturated with M-Endo Broth in 48 x 9.5 mm disposable, plastic petri plates. Plates were incubated at 35 C for 24 hr in a Millipore Portable Incubator (xx63 000 00) powered by two 6 or one 12 volt battery. After 24 hr incubation, coliform colonies recognizable as dark red or with a metallic sheen were enumerated.

Algological Methods

The suspended or planktonic algae occurring in the Colorado River and tributaries were sampled during the May and June samplings with a standard fine plankton towing net (No. 20). The net was suspended just below the surface in the current for 3-5 min depending on sediment load. The suspended material was concentrated into a 30 ml collection vial. Duplicate concentrated samples were obtained and a composite made in a 125 ml plastic bottle. Three milliliters of Meyers Iodine Solution were added to each sample for biological preservation. In the laboratory four 1 ml aliquots of the water samples were mounted in a Sedgewick-Rafter counting cell under a Wild M40 Inverted microscope. The phytoplankton species were identified and their relative abundance noted. All algae observed in the samples were recorded even though some were typically attached or benthic forms that had become detached.

Starting with the August sampling an attempt was made to better quantify the actual numbers of suspended algae in the River and tributaries. Forty gallons of water were filtered through the No. 20 plankton net and concentrated into a 30 ml vial. Duplicate samples were obtained, preserved and enumerated as described above.

Chemical Methods

Duplicate water samples from each site were collected from just below the surface with polypropylene beakers. The samples were filtered through acid-washed (1% HCl) membrane filters of 0.45 um pore size using Millipore 50 ml polypropylene syringes and 47 mm plastic Swinnex filter holders. Approximately 100 ml of filtered sample was placed in 125 ml polypropylene bottles for transport. In the laboratory, the samples were acidified with 1 ml of concentrated ultra-pure Ultrex HNO_3. All items coming in contact with the samples were washed three times each in 1% HCl and deionized-glass distilled water.

Boron (B) determinations were made on unacidified samples by the colorimetric Carmine Method and Hach Chemical Company (Ames, Iowa) prepackaged reagents. All other chemical elements were analyzed by Atomic Absorption Spectroscopy using a Perkin-Elmer Model 403. The major cations calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) were analyzed using standard flame atomization techniques (Perkin-Elmer, 1973). The trace elements cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), lead (Pb), molybdenum (Mo), and zinc (Zn) were analyzed using the HGA-2000 Graphite Furnace flameless attachment. To compensate for potential background absorption and matrix interference, a deuterium background corrector and standard additions were employed. Mercury analysis was performed only on the samples obtained during March 1-9, 1976 because of the delay in receiving the necessary analytical equipment. Mercury analysis were performed on a Coleman model MAS-1000 mercury analyzer according to manufacturer's recommended procedures.

DESCRIPTION OF STUDY AREA

Colorado River

The Colorado River has its source in the western slopes of the Rocky Mountains in northern Colorado. The 1400 mile (2240 km) length of the river has a total watershed area of about 250,000 square miles (647,500 km^2) which encompasses portions of seven states, Colorado, Wyoming, Utah, Nevada, New Mexico, California and Arizona. The river is divided into 2 basins. The upper basin being the Colorado River above Lee's Ferry, Arizona (Lat 36° 51' 53", long 111° 35' 15") and the lower basin below Lee's Ferry. Flow from the Colorado River and its tributaries in the upper basin is collected in Lake Powell above Glen Canyon Dam. At this point, the continued flow of the Colorado River is completely regulated by a series of impoundments. Waters released from Glen Canyon Dam flows 285 miles (465 km) in the main stem of the Colorado River to Lake Mead which is impounded by Hoover Dam. The Lower Colorado River Basin has a watershed area of 75,1000 square miles (194,509 km^2). This stretch of the Lower Colorado River passes through Glen Canyon National Recreation Area, Marble Canyon National Monument, Grand Canyon National Park and finally into the Lake Mead National Recreation Area. This report deals with a 225 mile (360 km) stretch of the Colorado River from Lee's Ferry, 16 miles (25.6 km) downriver from Glen Canyon Dam, to Diamond Creek, located on the Hualapai Indian Reservation.

The Colorado River through millions of years of erosive processes has created along this stretch an extensive network of canyons, steepwalls and gorges, forming the Grand Canyon. The deepest portion of the canyon is a mile deep (1.6 km) and 10 miles (16.2 km) wide. It divides the Colorado Plateau into the Kaibab Plateau (north rim) and the Coconino Plateau (south rim) (Fig. 1). These plateaus are the principle source for springs, seeps and tributaries which enter the Colorado River within the Grand Canyon National Park.

The Colorado River, itself, is characterized by long quiet pools, swift river currents and eddies, and considerable turbulence, the latter occurring primarily in the form of rapids. Through the Grand Canyon, the river drops approximately 2200 feet (671 m) in elevation in 280 miles (448 km). Most of this drop can be accounted for in the form of rapids which make up 10 percent of the total distance (Leopold, 1969). As stated previously, Glen Canyon Dam regulates the flow of the Colorado River from Lake Powell to Lake Mead. Water from the dam is released through gates which are located ca. 200 feet (60 m) below the fluctuating surface of Lake Powell. Released waters originating from the hypolimnion have resulted in a yearly maximum range of river temperature from 2 C to 18 C at Lee's Ferry (U.S.G.S., 1976). The average discharge for 10 years (1964-74) is 12,230 cfs (342 m^3/s). The maximum discharge of 27,700 cfs (775 m^3/s) for 1974 occurred in January and the minimum daily discharge of 1,410 cfs (39.5 m^3/s) occurred in March (U.S.G.S., 1974). One of the most notable characteristics of the Colorado River is its degree of turbidity. At Lee's Ferry, Arizona the mean concentration of suspended-sediment from October 1969 to September 1970 had a range of 2-124 mg/1. At the Colorado River near Grand Canyon, Arizona, it ranges from 6 to 47,100 mg/1 (U.S.G.S., 1976). The amount of turbidity of the Colorado River is dependent on the flow conditions of its tributaries, the main contributors of sediment being the Paria River and the Little Colorado River.

The relationship between the geology and the occurrence of water within the Grand Canyon is a very significant one. As the Colorado River cuts deeper into the earth's crust it exposes many different strata of rock formations. These strata can be classified as aquifers or as aquicludes. Aquifers are a water bearing strata of permeable rock, sand or gravel and aquicludes are rock units or layers of fine grained materials through which little or no water can move. The Kaibab limestone exposed at river mile 1 (1.6 km) is a formation which allows water to percolate downward where it encounters a massive buff limestone layer, the Toroweap formation. This formation is also an aquifer thus allowing waters to penetrate through to the Coconino sandstone. The Coconino sandstone is a aquifer and yields water to wells and springs. The lithologic character of the Coconino sandstone permits the continued downward percolation of ground water. The water continues to percolate until it reaches the Hermit shale below, which forms an aquiclude. Where the Hermit shale grades into siltstone and sandstone in the eastern part of the Grand Canyon, it permits the downward percolation of water, although the movement may not be very great (Metzger, 1961). Beneath the Hermit shale lies the Supai formation which is of alternating siltstone and fine-ground sandstone. This characteristic doesn't allow for the downward percolation of water but some movement does occur (Metzger, 1961). The Supai formation rests upon the Redwall limestone. One of the most recognizable features of this formation is the presence of solution channels that allows the transmission and storage of large quantities of ground water (Metzger, 1961). Blue Spring and Havasu Spring both issue from the Redwall limestone. Beneath the Redwall limestone occurs the Muav limestone formation. This unit overlies the Bright Angel shale and is the source of ground water for a number of springs. Ground water moves through the Muav readily via solution channels and most of the springs occurring along the south rim issue from this formation (Metzger, 1961). Water continues to percolate downward and encounters the Bright Angel shale; its most important hydrologic characteristic is the retardation of the downward movement of ground water. The small amount of water which does move downward percolates into the Tapeats sandstone.

Occurring readily in the Tapeats sandstone are seeps, some with very high salinity which often forms salt encrustations. Where Tapeats sandstone overlays Vishu schist, an igneous rock, deep disintegration occur along fractures. Ground water that moves downward through the Tapeats sandstone or along faults may proceed farther downward, but the amount of water available is very small (Metzger, 1961).

Tributaries

Paria River. The Paria River enters the Colorado

River 0.6 miles (0.96 km) below Lee's Ferry. Its watershed is 1,410 square miles (3651 km^2) and is located in northwest Arizona and drains remote areas of southern Utah. The river cuts along the Moenhopi shale and through Chinle formations. The maximum daily sediment concentrations from 1969-70 was 328,000 mg/l and the minimum was 5 mg/l (U.S.G.S., 1976). On occasion the Paria is known to go dry. Its average discharge is 30.4 cfs (0.85 m^3/s) (U.S.G.S., 1974). When in a flooding state, the Paria is a main contributor to the turbidity of the Colorado River.

Vasey's Paradise. Vasey's Paradise consists of springs which emit from the Redwall limestone located at mile 31.7 (50.7 km). Its discharge is estimated to be 0.3 to 10 cfs (0.008-0.28 m^3/s) (Johnson and Sanderson, 1968), which is dependent on groundwater activity. The mouth of the springs are located approximately 80 feet (24 m) from river level and terraced slopes located at the base of the springs are covered with lush vegetation.

Little Colorado River. The Little Colorado River is the main source of inflow to the Colorado River between Lee's Ferry and Lake Mead. The river begins in eastern Arizona near Greer and its mouth is located 61.5 miles (98.4 km) downriver from Lee's Ferry.

There are a number of springs which issue along the Little Colorado River, Blue Spring being the largest. It's source is located 13 miles (20.8 km) upstream from the mouth of the Little Colorado (Fig. 1). Other springs occur for 10 miles (16.2 km) below Blue Spring. Blue Spring is the principal area of natural discharge for ground waters of the Black Mesa hydrolic basin which has a 28,000 square mile (72,520 km^2) watershed. It discharges about 161,000 acre-feet per year (Cooley, 1963) or approximately 223 cfs (6.2 m^3/s) of characteristic turquoise-colored water. In contrast to this, flooding conditions occurring above Blue Spring in the Little Colorado watershed results in a brown, muddy, heavy sediment laden river. Suspended particulates increase significantly with discharge. In the Hopi Reservation, where a large area of the watershed is located, Cretaceous shale and sandstone are the main surface rocks. It is in this area that the Little Colorado is supplied with its sediment load. This results from the ease from which these formations are eroded (U.S.G.S., 1966). The gaging station at Cameron, Arizona monitors the flow of the Little Colorado River 32 miles (51.2 km) above Blue Spring and 45 miles (72 km) upriver from its mouth. Its average discharge is 228 cfs (6.4 m^3/s) and contributes 165,200 acre-ft/year to the Colorado River. Maximum discharge for 1974 was 1590 cfs (44.5 m^3/s) and the minimum recorded was no flow (U.S.G.S., 1974).

Bright Angel Creek. Bright Angel Creek enters the Colorado River at mile 87.5 (140 km). It has a watershed area of 101 square miles (261 km^2) located below the Kaibab Plateau on the north side of the Colorado River. The major contribution to the base flow of the creek is Roaring Springs Creek (Fig. 1). The springs are located 10 miles (16.2 km) upstream from the mouth and issue from solution channels high on a steep slope near the base of the Muav Limestone. The majority of the discharge is diverted into a number of main tributaries which in turn cascade down the slope into Roaring Springs Creek, which then in turn flows into Bright Angel Creek (Johnson and Sanderson, 1968). The base flow of Bright Angel Creek is about 21 cfs (0.58 m^3/s) and the average discharge is about 35 cfs (0.98 m^3/s). These values are based on 41 years of record Johnson and Sanderson (1968). Diversions above the gaging station began in June of 1970 for municipal supply at Grand Canyon Village (U.S.G.S., 1974). The average annual runoff at the mouth is 5 to 10 inches (12.8-25.6 m) and the creek contributes an average of 26,000 acre-feet per year to the Colorado River (U.S.G.S., 1966).

Shinumo Creek. Shinumo is a perennial stream that flows into the Colorado River at mile 108.5 (172.8 km). Three miles (4.8 km) from the mouth, White Creek, also a perennial stream, joins Shinumo. The source of Shinumo Creek is a spring located 12 miles (19.2 km) up from its mouth, Big South Spring located on the rim of the Kaibab Plateau (Fig. 1). Noble (1914) reported that the creek falls about 5400 feet (1647 m) (450 feet/mile = 85.7 m/km). The discharge of the creek is 4920 acre-feet/year (Arizona State Dept. of Health, 1968) and its discharge ranges from 5 to 15.5 cfs (0.14-2.43 m^3/s) (Johnson and Sanderson, 1968).

Elves Chasm. Elves Chasm is located at mile 116.5 (185 km) where Royal Arch Creek enters the Colorado River. The flow is very low, 0.1 to 0.5 cfs (.003-.01 m^3/s) (Johnson and Sanderson, 1968) with 183 acre-feet/year contributed to the Colorado River. Elves Chasm is characterized by waterfalls, lush vegetation and fern and moss covered travertine.

Tapeats Creek. Tapeats Creek originates below the Kaibab Plateau on the north side of the Colorado from Thunder Spring and enters the Colorado River at mile 133.6 (213.7 km). This spring emits from a cliff of Muav Limestone and near the base of the limestone. Flow from the spring forms the base flow of Thunder River which in turn joins Tapeats Creek about 2 miles (3.2 km) above its mouth. Tapeats Creek also has as its source springs which are located in the Tapeats Amphitheater. Tapeats contributes the largest inflow to the Colorado River from the north side of the canyon (Johnson and Sanderson, 1968). It is estimated that 55,000 acre-feet/year are contributed annually to the Colorado River systems. Tapeats Creek discharge ranges from 51 to 283 cfs (1.43-7.9 m^3/s) (Johnson and Sanderson, 1968).

Deer Creek. Deer Creek enters the Colorado River at mile 136.2 (218 km) and is characterized by a waterfall at its mouth. The creek is fed by several springs on the north side of the canyon, the major ones being Deer and Vaughn Springs. Its discharge is estimated to be 0.5-8 cfs (.014-.22 m^3/s) (Johnson and Sanderson, 1968).

Kanab Creek. Kanab Creek enters the Colorado River at mile 143 (228 km) and has a watershed area of more than 2000 square miles (5180 km^2) which is located on the north side of the canyon and drains areas of northern Arizona and southern Utah. Its discharge has been consistently low at 3 to 4 cfs (0.084-.112 m^3/s), with 2700 acre-feet/year contributed to the Colorado River.

Havasu Creek. Havasu Creek enters the Colorado River through a narrow canyon at mile 157 (251.2 km). Its sources are a series of springs (Havasu Springs) emitting from the Redwall Limestone. The springs are located about 10 miles (16 km) upstream from the mouth of the creek. The spring is a major discharge point for ground water moving toward the Colorado River from the Coconino Plateau (Cooley, 1963). Discharge measurements made at several places downstream from Havasu Springs indicate a base flow of about 64 cfs (1.8 m^3/s) or 46,300 acre-feet/year.

Diamond Creek. Diamond Creek discharges in the Colorado River at mile 225.8 (361.3 km) from the south side of the canyon and has a discharge rate of 1.47 cfs (0.041 m^3/s) (Johnson and Sanderson, 1968). Only three discharge measurements have been made of the flow in the creek. Some subsurface flow may enter the Colorado River through the alluvial fan at the mouth of the creek (Johnson and Sanderson, 1968). Much of the creeks watershed area is located in the Hualapai Indian Reservation with no information available as to the watershed area of Diamond Creek.

RESULTS AND DISCUSSION

Bacteriological Investigations

Colorado River. During the study period from May 1975 to March 1976, which involved five sampling trips, the total viable bacteria in the Colorado River ranged from 10^2 - 10^5 cells/ml (Fig. 2). The first 80 miles (128 km) of the Colorado River showed little variation in bacterial numbers with respect to time of year. However, the remainder of the river was quite variable. The lowest counts were recorded at mile 133.7 in November and March, whereas the highest values were observed primarily in May and June from mile 88 to mile 225. The majority of the bacteria in rivers is known to be of allochthonous origin (Wuhrmann, 1964). Therefore, the maximum counts in the Colorado River may be due to spring runoffs. If this is true, large concentrations of suspended matter may also be associated with the runoff and dense bacterial populations. Below mile 90 in May and June the sediment load of the river appeared to be high based on the color of the water, turbidity and Secchi disc values (Kubly and Cole, 1976). Yet, the suspended matter was high in May, but low in June (Kubly and Cole, 1976). Therefore, the total bacteria counts in the Colorado River seem to correlate better with the water color, turbidity, and Secchi disc values than with the actual amount of sediment the river is carrying. A familiar finding was reported by Koske, Krumm, Rheinheimer, and Szekielda (1955) in which turbidity and bacterial numbers paralleled each other in a river system.

The surface temperature range in the Colorado River was 7 C (45 F) to 15 C (59 F) (Kubly and Cole, 1976). It is difficult to say how this temperature regime may affect the microbial populations, even though Coleman, Campbell, Cook and Westlake (1974) observed no noticeable difference between total bacterial counts incubated at 5 C (41 F) and 25 C (77 F). The river water the bacteria were collected from ranged from 1 C (34 F) to 17 C (63 F). In contrast Cherry, Guthrie and Harvey (1974) concluded temperature was the most influential factor regulating the bacterial population they studied.

The total bacterial counts represent only those bacteria which were freely suspended in the water or adhering to soil particles or other debris carried by the flow. Wuhrmann (1964) has stated that the bacteria freely suspended in the water represent less than 1% of the total bacterial population, and the greater majority of the bacteria of a river are found in the mud or attached to surfaces of plants, animals, and stones. The number of total bacteria counted is also a minimum value for reasons due to the limitations of the plate count procedure. Media composition, especially in regard to inorganic components, greatly affects the bacterial count (Jones, 1970). In spite of these limitations, the total bacterial count for the Colorado River and its side streams are comparable to those found elsewhere (Blaise and Armstrong, 1973; Skinner, Adams, Richard and Beetle, 1974; Coleman et al. 1974). Pristine waters of the Rockies have been reported to have a similar range (Skinner et al. 1974) as well as studies in South Carolina by Cherry et al. (1974) and on the North Saskachewan River by Coleman et al. (1974).

Although total bacteria are not considered to be related to a specific health hazard as are the coliforms, elevated microbial populations have been associated with the presence of *Pseudomonas aeruginosa*, a bacterium which often is the cause of persistant ear and urinary infections (Hoadley, 1968).

The total coliforms in the Colorado River were extremely variable ranging from none detectable to more than 400 coliforms/100 ml (Fig. 3). The desirable criteria set by the Federal Water Pollution Control Administration (U.S.D.I., 1968) for raw surface waters is <100 coliforms/100 ml and the permissable limit is 10,000 coliforms/100 ml. Both desirable and permissable waters can be used for human consumption if treated; however there is a greater factor of safety in using water that meets the desirable criteria. In June, the Colorado River had levels below the desirable limit at all of the sampling sites except mile 225. In August and March, the total coliform values exceeded the desirable criteria in 70% of the sampling sites. All of the samples taken in November must be discounted except for mile 108.5 and mile 116.5 since the portable incubator was not functioning properly. The highest coliform counts observed were in June and August at mile 225 and in November and March at mile 108.5. In June, August, and March the river was carrying a large amount of suspended matter which may have had coliforms associated with it, whereas in November the river appeared to have little suspended matter. The rest of the sites which had coliforms above the desired limit during March, however, did correlate with elevated sediment loads. In contrast, during August the sites which had coliform levels above the desired criteria did not correlate with the suspended matter. The high coliform counts may have been a result of increased human usage since August is a popular month and coliform counts have been correlated with recreational usage (Hanes and Fossa, 1970; Robinton and Mood, 1966).

The effect of temperature on the viability of coliforms has been investigated. Hendricks (1972) studied six strains of enteric bacteria and found they grew little or not at all at 5 C (41 F) and 20 C (68 F). He also observed death of Salmonella senftenberg at 5 C (41 F) and 20 C (68 F) and for Enterobacter aerogenes and Proteus rettgeri at 5 C (41 F). Work by McFeters and Stuart (1972) showed Escherichia coli MH 3427 survival was inversely related to temperature between 5 C (41 F) and 15 C (59 F) in the lab. That is, 50% of the cells died in 4.5 days at 5 C (41 F), 3 days at 10 C (50 F), and 1.5 days at 15 C (59 F). In situ work with E. coli MH 3427 showed a decrease from 10^8 to 10^5 after five days in Middle Creek, whereas in Bozeman Creek they declined from 10^8 to 10^4 in five days. Their study also investigated a possible relationship between conductivity and coliform survival rates since the two creeks had different conductivity values (Middle = 95 umhos; Bozeman = 150 umhos). However, the coliform populations were so similar that no correlation could be made between conductivity levels and survival times for E. coli. Salinity has also been investigated as a parameter that might affect the survival of coliforms (Hanes and Fragala, 1967). They indicated the die off rates for E. coli and coliforms were similar at zero salinity levels but increasing salinity resulted in a greater death rate for E. coli than for coliforms. With regard to the previous studies, one might expect 50% of the coliforms at one point in the Colorado River to die off within five days. Therefore, the high densities in the river may be due to circumstances which occurred upstream several days earlier. High coliform counts should not be necessarily considered unusual for the Colorado River because undesirable levels have been observed in several high mountain watersheds (Stuart, Bissonnette, Goodrich, Walter, 1971; Carswell, Symons, Robeck, 1969). Large degrees of variability in microbial populations have also been reported in aquatic systems (Brierly et al. 1975). Although coliform bacteria have been used as an indicator of fecal pollution, it is important to keep in mind that they are found in all warm blooded animals plus in the soil, on plants and insects, in old sewage and in water polluted some time in the past (U.S.D.I., 1968). Since the percentage of fecal coliforms in a total coliform count can vary from 1 to 90% (U.S.D.I., 1968), a high coliform value does not automatically mean a greater chance of recovering a human pathogen. In fact the opposite can be true since Fair and Morrison (1967) found bacterial pathogens in clean waters high in the Colorado Rockies. Total coliform data, therefore, can not be used to determine the source of the coliforms. It is, however, a common useful parameter to investigate when evaluating water quality (Bauer, 1969; Walter and Bottman, 1967).

Tributaries. The total bacteria values in the eleven tributaries sampled ranged from 10^1 - 10^6 cells/ml (Fig. 4). The smallest range was recorded in Vasey's Paradise and Diamond Creek had the widest range. The Paria River, Little Colorado River, Bright Angel Creek, Shinumo Creek, Elves Chasm, and Kanab Creek showed similar ranges in their microbial populations. The largest counts in the Paria River, Little Colorado River, and Kanab Creek were observed in March and the second highest counts in May. Bright Angel Creek, Havasu Creek, and Diamond Creek reached their maximum in May and Shinumo Creek, Elves Chasm, and Tapeats Creek peaked in June. These data suggest higher total viable bacteria in the tributaries occur primarily from early to late spring months. In the Paria River, Little Colorado River, Bright Angel Creek, and Kanab Creek the elevated bacteria populations paralleled high suspended matter values which is common to spring runoffs. On the other hand, Elves Chasm and Diamond Creek showed very low suspended matter (<15 mg/l; Kubly and Cole, personal communication) during periods of large bacteria counts. Elves Chasm values may be due to heavy recreational use since it is a popular attraction site and the higher values occurred in June and August (Hanes and Fossa, 1970; Robinton and Mood, 1966). However, in Diamond Creek the relatively high water temperatures ($\bar{x}$ = 22.6 C or 73 F) may be influential on its microbial population. In summary, although large variations occurred in the total viable bacteria counts in the tributaries the values are within the limits reported on other mountain watersheds (Skinner et al. 1974; Coleman et al. 1974).

The total coliform density in the tributaries ranged from none to more than 400 coliforms/100 ml (Fig. 5). Characteristic of most of the tributaries is their extreme variability with respect to the time of year. It is important to notice, however, that in June, 50% of the tributaries met the desired criteria (<100 coliforms/100 ml) including such popular sites as the Little Colorado River, Bright Angel Creek, and Shinumo Creek. In contrast, all of the tributaries showed more than 100 coliforms/ml in August except for the Paria River and Vasey's Paradise. The sediment loads were low in all of the tributaries in August suggesting dense populations of coliforms can be recovered from clear waters. The water temperatures were fairly warm in all of the tributaries during August ($\bar{x}$ = 22.9 C or 73 F) compared to the Colorado River ($\bar{x}$ = 12.2 C or 54 F) which may be a factor although there are samples which have low numbers at elevated water temperatures (>20 C) and high numbers at low temperatures (<20 C). One is more likely to recover higher coliform counts in warm water, although warm water is not necessary for high densities to occur. Several studies have shown that a decline in water quality can be a result of naturally occurring or grazing animals in mountain streams which receive little human impact. Stuart et al. (1971) reported coliforms in a mountain watershed that was closed to the public and Fair and Morrison (1967) isolated <u>Salmonella</u> in a high mountain stream located in the Colorado Rockies. Higher numbers of fecal coliforms also have been observed in a watershed open to grazing in contrast to one that was closed (Kunkel and Meiman, 1967). These findings may account for the high coliform values in the Paria River, Little Colorado River, Kanab Creek, and Diamond Creek since cattle grazing does occur on their watersheds. Dense coliform numbers were also observed in Bright Angel Creek and Shinumo Creek but only in August. These values may be related to the presence of bathers in the creeks near the time of sampling. In June and August, Elves Chasm, Deer Creek, and Havasu Creek which are three popular attraction sites (Haas, Nielsen, and Shelby, 1976) had very high coliform populations. One may correlate this with increased visitor usage, although Deer Creek and Havasu Creek continued to have large coliform counts in March (a month when usage is extremely small). The viability of coliforms in mud has been investigated by Van Donsel and Geldreich (1971). They found that 50% of the coliforms from mud samples remained viable for six days at 20 C (68 F). This may be a factor in the persistence of high coliform levels during and following the heavy usage months. In Havasu Creek, the high numbers may be due to the poor sanitary conditions existing in the Supai village (Slawson and Everett, 1974).

Many aquatic studies have been done to determine the effect of recreational use (primarily boating, fishing, and picnicking) on water quality. A review of five investigations on more than 20 lakes throughout the country concluded that little or no deterioration in bacterial water quality occurs when recreation is permitted in or around the body of water (Carswell et al. 1969). In studies involving two streams (Stuart et al. 1971; Lee, Symons and Robeck, 1970) comparisons were made between open and closed watersheds relative to recreational use. Stuart et al. (1971) reported higher coliforms in the closed watershed and Lee et al. (1970) concluded no measurable influence could be determined based on the bacterial indicator population. Our study indicates the coliform levels may be influenced by recreational use, although we did observe undesirable coliform levels during low usage periods. In order to determine the source of the coliform contamination during low and high use periods, it will be necessary to determine fecal coliform/fecal streptococcus ratios (Geldreich, 1970).

The outbreak of acute gastroenteritis attributed to *Shigella sonnei* in 1972, the isolation of several *Salmonella* groups (Slawson and Everett, 1974) from pools at Elves Chasm, Kanab Creek, Havasu Creek and Deer Creek, and the levels of coliforms observed by Slawson and Everett (1974) and in this study definitely suggests that a potential health hazard exists to river travelers and hikers using the River or tributary waters for drinking or primary contact. The actual source(s) of bacterial contamination have not been documented, although limited fecal coliform/fecal streptococcus ratios indicate human contamination in Kanab Creek and Havasu Creek (Slawson and Everett, 1974). Both creeks are associated with stable communities that may not have adequate waste treatment facilities.

Contamination of the river and tributaries by recreational users (river travelers and hikers) and their wastes may also be a contributory factor to the level of coliforms observed since several heavily used tributaries had high coliform counts. Only an investigation involving samplings directly associated with the use of specific campgrounds and swimming areas can establish a relationship between river users and the quality and quantity of their contamination.

Because of the potential presence of pathogenic bacteria in the Colorado River, water consumed is usually chlorinated. The effect of chlorination upon total viable bacteria and total coliforms was evaluated (Table 3, 4). River runners use approximately 15 drops (1-2 ml) of chlorox per 4 gallons (15 liters) of water which is about 2.6 ppm chlorine. From Table 3, one can see the number of viable bacteria was reduced at concentrations from 1.3 ppm to 5.2 ppm chlorine. The number of total coliforms in the Colorado River (mile 225) was decreased to zero at these concentrations of chlorine (Table 4). Further investigations were carried out in the laboratory to confirm these field experiments. These findings (Table 5) suggest that the concentration the river runners use (2.6 ppm chlorine or 15 drops of chlorox per 4 gallons) is adequate since any reduced concentrations gave more variable coliform counts. It is recommended by the Public Health Service that drinking water should not exceed one coliform per 100 ml. At 2.6 ppm, this limit was met in two out of the three experiments and exceeded this limit slightly in the other experiment. The length of time after addition for effective bacteriocidal activity was also investigated (Table 6). After five minutes the coliform counts were greatly reduced; however, zero coliforms were not observed consistently until 30 minutes had passed. Therefore, it is recommended that at least five minutes and up to 30 minutes following chlorination is allowed before water is consumed.

Algological Investigations

Colorado River. Sampling for phytoplankton in the Colorado River revealed a total of 59 different genera and 122 species, representative of six major divisions (Table 7). The largest and most diverse group were the diatoms (Bacillariophyceae), a class belonging to the division Chrysophyta. The diatoms were represented by 27 different genera and 70 species, over half of the total phytoplankton diversity of the river. Two other classes of the division Chrysophyta were also represented in the Colorado River. Two genera and species of yellow-green algae (Xanthophyceae) and 1 genus of golden-brown algae (Chrysophyceae) were found. The green algae or Chlorophyta, represented the second most diverse group of phytoplankton with 19 different genera and 23 species. The blue-green algae (Cyanophyta) were represented by 7 genera and 22 species. The dinoflagellates within the division Pyrrhophyta were represented by a single genus and 2 species. One genus and species each of cryptomonads (Cryptophyta) and euglenoids (Euglenophyta) was represented in the River.

Although the river appears diverse, its diversity is rather low when compared with more productive river systems (Swale, 1969; Greenberg, 1964). Greenberg (1964), for instance, identified 95 different genera and an unspecified number of species in the Sacramento River of California. The 95 genera were distributed as follows: blue-greens, 15; greens, 38; flagellates, 13; and diatoms, 29.

The May sampling period proved to be the most diverse observed in the River with 37 genera and 58 species identified (Table 8). The diatoms were the most numerous and diverse group with 21 genera and 33 species. The division Cyanophyta had 4 genera and 13 species represented, whereas the Chlorophyta had 9 genera and species represented. The Cryptophyta, Pyrrhophyta, and Xanthophyceae each had only a single species present. Five species of diatoms occurred commonly in the river system during May. There were *Asterionella formosa*, *Fragilaria crotonensis*, *Synedra ulna*, *Rhoicosphenia curvata* and *Diatoma vulgare* with no one species dominant. Synedra ulna has been reported to be dominant at pollution surveillance stations on the Colorado River at Yuma and Page, Arizona and Loma, Colorado (U.S.D.I., 1966).

The sampling period during June proved not to be as diverse as May. Only 26 genera and 44 species were identified. The diatoms accounted for 58% of the genera with 15 and 68% of the species with 30. The number of genera and species of Chlorophyta was similar to the May sampling period with 8 genera and 9 species. Two genera and 4 species of blue-greens were identified, a large decrease (69%) in species numbers compared to May. One genus and species of Pyrrhophyta occurred. There were no representatives observed of the Xanthophyceae, Chrysophyceae, Euglenophyta, and Cryptophyta. The same five diatom species which occurred commonly in May also occurred in June. In addition, Cocconeis pediculus was frequent throughout the River's length. The chlorophytan algae Ulothrix tenerrima was present in all samples and the blue-green, Oscillatoria Agardhii, dominated the River samples.

August provided the second most diverse sampling period. Thirty-two genera and 45 species were identified (Table 8). As in the previous month's samples, the diatoms accounted for the majority of genera and species. Sixteen genera and 28 species were identified which represented 50% and 62% respectively of the total number. The highest number of genera and species of green algae (Chlorophyta) occurred during this sampling month with 9 genera and 10 species. The blue-greens (Cyanophyta) were represented by 3 genera and 4 species. Only a single species of each of the Chrysophyceae, Cryptophyta and Pyrrhophyta, and Euglenophyta occurred. The dominant organism in the river during this sampling was a diatom, Diatoma vulgare. It occurred at all sample sites on the river. Rhoicosphenia curvata occurred frequently throughout the river also. Synedra ulna continued to be a common occurring diatom, but its numbers decreased. Fragments of Ulothrix sp. and Cladophora glomerata were common also. Staurastrum sp. occurred in all samples but its numbers were low, less than 100/liter. Oscillatoria subbrevis and Oscillatoria limosa were the most common blue-greens in the river but their numbers were also less than 100/liter.

November provided the least diversity of all the sampling periods with 26 genera and 43 species observed. The diatoms had their largest proportion of the total diversity during this month with 17 genera 65% and 34 species 79% (Table 8). The green algae and the blue-green algae showed their diversity during November with only 6 genera and 6 species and 2 genera and 2 species, respectively. Only one species of Cryptophyta occurred with no representation of the Xanthophyceae, Chrysophyceae, Pyrrhophyta and Euglenophyta. No one species was dominant in number, but three species of diatoms occurred frequently. They were Navicula tripunctata, Cocconeis pediculus and Rhoicosphenia curvata. Diatoma vulgare occurred in all samples, but its numbers were low (less than 100/liter). Cladophora glomerata was common in all samples, but the number was also less than 100/liter. The blue-green algae, Oscillatoria subbrevis and Lyngbya versicolor, were relatively uncommon throughout the River's length.

Samples taken during March revealed a total of 28 genera and 43 species, a slight increase over the November samples. As in all the past samples, members of the Bacillariophyceae made up the bulk of the total diversity with 15 genera (54%) and 24 species (56%). The number of green algae remained low with 6 genera and 7 species. A major increase in blue-green species occurred in March when compared to November. Five genera and 10 species were identified. Only one species of Xanthophyceae and Cryptophyta occurred. No Chrysophyceae, Pyrrhophyta and Euglenophyta was observed in the samples. No species occurred in sufficient numbers to be considered dominant or frequent. All were rare with less than 100 organisms/liter. Five species of diatoms occurred in all samples, but in low numbers. They were Synedra acus, Cymbella affinis, Rhoicosphenia curvata, Diatoma vulgare and Cocconeis pediculus. Common green algae were Cladophora glomerata and Ulothrix sp. Although blue-green algal diversity increased in November, all species occurred in low numbers. Oscillatoria subbrevis occurred in 64% of the samples and was the most abundant.

The total number of phytoplankton in the Colorado River was quantified for August, November and March (Fig. 6). The numbers of organisms for each month was very low and reflective of a comparatively non-productive system. In August, a quantitative decrease in phytoplankton was exhibited. A decrease of 78% in organismal numbers occurred over the 225 miles (360 km) of the river from Lee's Ferry to Diamond Creek. Several investigators have observed the same results in their studies on other river and stream systems (Chandler, 1937; Williams, 1964; Hartman and Himes, 1961; Cushing, 1964). It is likely that this decrease is not caused by any one factor, but by several. In August, a sharp decrease from 1152 to 272 phytoplankton/liter was observed (Fig. 6). This decrease occurred over a 24-hour period and was associated with the Little Colorado flooding into the Colorado River. The flooding added greatly to the turbidity of the river. Measurements of turbidity taken from Lee's Ferry to mile 37.8 range from 1 to 55 J.T.U. (Kubly and Cole, 1976). These values reflect the degree of turbidity in the river when not influenced by flooding. Values ranging between 300 and 334 J.T.U. were obtained in the Colorado River channel at mile 132 and 213 when the Little Colorado River was in a flooding stage and added large quantities of sediment to the Colorado River (Kubly and Cole, 1976).

Turbidity may effect the number of phytoplankton in several ways. Ellis (1936) states that erosive silt in rivers acts as an opaque screen to all wavelengths of light, thus not allowing the phytoplankton to carry out photosynthesis. A five-year study of plankton population by the National Water Quality Network and a study carried out during the same time on stream-flow by the U.S. Geological Survey indicated that heavy stream flow, often accompanied by increased turbidity, is a prime factor governing plankton populations (Williams, 1964). Cushing (1964), Chandler (1937) and Hartman and Himes (1961) all report that mechanical destruction occurs to plankton by the grinding action of waters heavily laden with silt. The low phytoplankton numbers in the Colorado River may result, at least in part, from the abundance of rapids and often turbid water.

It has also been shown that sedimentation may be a contributing factor to decreasing phytoplankton numbers (Chandler, 1937). Chandler (1937) has stated that large quantities of suspended particles hastened the settling of plankton in the Maple River, Michigan. Analysis of bottom ooze indicated large quantities of plankton were settling out with the sediment in areas of quiet water. The rate of settling is variable and is dependent on the rate of current and the amount of suspended material in the water.

The most important relationship between phytoplankton and current is the influence of current in determining the length of time in which plankton can reproduce (Kofoid, 1903, 1908). There is a general agreement among limnologists that a minimum flow between 9 to 20 days is required to build up any appreciable lotic plankton crop (McGaha and Steen, 1974). On the average, water released from Lake Powell into the Colorado River channel travels 3 days until it flows into Lake Mead, a distance of approximately 285 miles (456 km). Because of this rapid flow, phytoplankton do not have sufficient time to build up noticeable populations. Kofoid (1903) also considered the fluctuations in a stream's hydrographic condition as the most immediately effective factor on the environment of stream plankton. Chandler (1937) has stated that water level is probably related to a plankton decrease in streams as well as dilutions from tributaries. Rising Colorado River levels in August, caused by the added volume of water from the flooding Little Colorado River, produced sharp declines in phytoplankton numbers.

Hydrographic stability has been described as conducive to high production, whereas instability is always destructive to plankton (Greenberg, 1964). This brings up the topic of the effects of impoundments on river systems. Hydroelectric, flood control and navigation dams alter stream conditions and the character and density of the biota (Williams, 1964). The source of water for the Lower Colorado River is water from the hypolimnion of Lake Powell released through Glen Canyon Dam. Planktonic organisms in the water are passed through turbines and therefore may be damaged or destroyed. At the depth of release (200 ft or 60 m), the phytoplankton population is probably very small and those present are likely not in a healthy physiological state. The phytoplankton contribution of Lake Powell to the Colorado River would, therefore, appear to be minimal.

The water released from the hypolimnion of Lake Powell has a low temperature that requires many miles of stream flow before it increases significantly. The Colorado River during August increased ca. 0.02 C (0.04 F) for every mile (1.6 km) traveled from Lee's Ferry to Diamond Creek (Kubly and Cole, 1976). It has been reported that in order for a healthy populous community of phytoplankton to exist, water temperature must be at least 12 C (54 F) (Knöpp, 1960).

In November, a 73% decrease in phytoplankton numbers occurred from Lee's Ferry to Diamond Creek (Fig. 6). The highest numbers of organisms, however, did not occur at Lee's Ferry (Fig. 6). An increase occurred from mile 0 to 29 and then a decrease. The numbers remained low until mile 66 (591 phytoplankton/liter). The number increased to a high of 941 phytoplankton/liter at mile 103 and then decreased to 40/liter at mile 120. A second peak of 593 phytoplankton/liter occurred at mile 136 and once again numbers decreased to a non-countable level at mile 173. During this sampling period no flooding took place in any of the tributaries, so turbidity can not account for the fluctuating numbers. Temperature also remained consistently low. The only other obvious fluctuating variables that may affect the phytoplankton population during this trip was river volume and turbulence. It may be that differences in discharge volume may be responsible for such variability in phytoplankton numbers. Discharge data for November, 1975 is not available at this time so no correlations will be made in this report.

The phytoplankton population in March was so small that the actual numbers could not be detected with our counting technique. During this sampling period there were fluctuating river volumes, periods of high turbidity and low temperatures, 8.1 C (46 F) to 9.0 C (48 F) (Kubly and Cole, 1976). The reason for such low numbers throughout the sampling period may be a result of the combination of limiting factors already discussed.

The phytoplankton composition of the Colorado River is similar to that in Lake Powell and Lake Mead. This is not surprising because water in the Lower Colorado River is released from Lake Powell. Stewart (1974) listed the twenty dominant phytoplankton species found in Warm Creek Bay, Lake Powell. From this list 9 genera and 8 species were found to be common to both the river and the lake.

The most common organisms were Asterionella formosa, Ceratium hirundinella and Fragilaris crotonensis. These are typically euplanktonic and indicative of lake systems. Their occurrence in the Colorado River is probably due to their being flushed from the lake during discharge through the dam. Their consistently low numbers in the river may be due to the factors already discussed. Staker, Hoshaw and Everett (1974) reported on the phytoplankton distribution in relation to water quality in Lake Mead. From their list of organisms, 34 genera and 22 species were found to be common both to the Colorado River and Lake Mead. The 22 species all belonged to the class Bacillariophyceae (diatoms). Over half of the diatoms reported in Lake Mead also appeared in the Colorado River from Lee's Ferry to mile 225. Six genera of Chlorophyta, 1 species of Pyrophyta and 5 genera of Cyanophyta were also common to both systems.

Other phycological work on the Colorado River has been carried out by U.S.D.I. (1966) and Williams (1964). Williams (1964) worked on the relationship between diatoms and water quality in a number of different river systems, including the Colorado River. In his report, he presented data on the density and abundance of the diatom species Diatoma vulgare, Gomphonema olivaceum, Navicula viridula, Synedra ulna, Surirella brightwelli and Surviella ovata. These plankters occurred in combined numbers of 400-1599/ml during 1960-62. The samples from the Colorado River were collected at Page, Arizona and Loma, Colorado. The samples from Page were taken prior to impoundment of the Colorado River by Glen Canyon Dam. When these samples were compared to river samples after impoundment, the previous species still occurred with the exception of Navicula viridula. The remaining 5 species had numbers that were drastically reduced to less than 1000/liter (Table 8).

The use of algae indicators of water quality conditions has gained momentum in the last decade and may be a tool of tremendous consequence in detecting changes in aquatic systems. To date, diatoms have been more commonly used as bioindicators and have been correlated with chemical characteristics and water quality of river and lake systems (Schoeman, 1973; Lowe, 1974). Diatoms occupy different nitches in the aquatic ecosystem and are known to respond to different chemical and physical parameters (Lowe, 1974). The dominant diatoms of the Colorado River may therefore be useful in further characterizing river conditions beyond the parameters monitored as well as indicators of subsequent change. The following will characterize the dominant diatoms as we know them from other habitats. Diatoma vulgare occurs in a wide pH range (6.4-8.3) in water with high nutrient concentrations, and is tolerant to small amounts of salt. It is oligosaprobic, which means it is found where oxidation of biodegradable compounds is complete and the concentration of inorganic nutrients is usually high. Diatoma vulgare is rheophilous, that is characteristic of running water, but may be found in standing water. It could be periphytic or epiphytic and occurs dominantly in the winter. Diatoma vulgare has a broad temperature range between 0 C (32 F) to 30 C (86 F). Rhoicosphenia curvata, a common diatom in the Colorado River, has a somewhat larger pH range (5.4-9.0). It also is eutrophic, a characteristic of water with high nutrient concentrations and can tolerate small amounts of salt. Its occurrence is related to a zone where oxidation of organic load is preceeding and to a zone where biodegradable compounds are oxidized completely. Rhoicosphenia curvata occurs where there is a high concentration of inorganic nutrients. It is common in both flowing and standing water and often epiphytic on Cladophora branches and lives optimally in oxygen rich water. Maximum numbers occur in the spring and over a temperature range of 15 C (59 F) or greater.

Synedra ulna inhabits waters with a pH range between 5.7 and 9.0. It also is characteristic of high nutrient concentrations in the water. It tolerates small amounts of salts and is common in both flowing and standing waters and is typically euplanktonic. It has spring, summer and fall maxima and has a temperature tolerance range of 0 C (32 F) to 30 C (86 F).

The type of habitat these organisms require are quite characteristic of the Colorado River. The Colorado River is rich in essential plant nutrients, has a range of river temperatures between 7 C (45 F) to 15.2 C (59 F), is less than slightly saline water, and high in dissolved oxygen (Kubly and Cole, 1976; U.S.G.S., 1970).

The phytoplankton species identified from the Colorado River during this investigation were also compared to Palmer's (1969) lists of organic pollution tolerant algae. Thirty-one genera or about 50% of Palmer's list of pollution tolerant genera are represented in the Colorado River. Further, 21 species found in the River also occur on Palmer's list of 80 organic pollution tolerant species. It should, however, be pointed out that Palmer's algal indices to organic pollution require that a species be present in numbers of 50/ml or greater. Because of the general low number of organisms found in the River, none of the indicator species occurring in the River reached this level. It is, therefore, difficult to either accept Palmer's indices or to completely ignore their significance for the River. Subsequent measurements of organic matter in the River would be desirable to ascertain the validity of Palmer's list of indicator species for the system.

Tributaries. A total of 51 genera and 137 species of phytoplankton were identified in eleven tributaries and springs of the Colorado River (Table 9).

Three major divisions of algae were represented. They were the Chrysophyta, Chlorophyta and Cyanophyta. Sixty-four percent of the genera (33) and 76% of the species (105) belonged to the Bacillariophyceae (diatoms), a class of the Chrysophyta. There were no representatives observed from the other classes of the division Chrysophyta. The division Cyanophyta (blue-green algae) were represented by 7 genera and 20 species and the third division, Chlorophyta (green algae), was represented by 11 genera and 12 species. Of the 51 genera and 137 species in the tributaries, 32 genera and 71 species were found only in the tributaries. The remaining genera and species were common to both the Colorado River and the tributaries. Four genera and 5 species of green algae, 4 genera and 6 species of blue-green algae, 24 genera and 60 species of diatoms (Bacillariophyceae) were only found in the tributaries.

Paria River. Three major divisions of algae were represented in the Paria River totaling 11 genera and 23 species. Nine genera and 18 species of diatoms and only one species of green algae (*Ulothrix tenerrima*) was represented. The blue-green algae were represented by only the genus *Oscillatoria* and four species *O. hamelii*, *O. limnetica*, *O. Agardhii* and *O. sp.* Samples obtained in May were collected from the Paria River during a flooding stage and were heavily laden with fine silt. From this period only 2 genera and 2 species, both diatoms, were identified, *Opephora* sp. and *Gomphoneis herculeana*. The fine silt load prevented detailed analysis of the sample. June samples proved to be more diverse. The Paria was not flooding at this time and as a result 7 genera and 9 species were identified, including, 6 genera and 6 species of diatoms, one species of green algae and 1 genus and 2 species of blue-green algae (Table 9). The most frequent alga was the diatom, *Diatoma vulgare*. August also proved to be a diverse month with 5 genera and 10 species representing the three divisions, Chrysophyta, Cyanophyta and Chlorophyta. The diatoms dominated this sampling period with 4 genera and 9 species. Only one species of blue-green algae, Oscillatoria Agardhii, was present. Frequently occurring diatom species were Nitzschia linearis, Nitzschia Kützingiana and Nitzschia dissipata (Table 7). In August, the Paria River had 606 phytoplankton/liter, the fifth most abundant in organisms of the tributaries. This value is not representative of a productive system and various factors may be contributing to the low numbers of organisms. Kubly and Cole (1976) reported a value of 732 mg/l of suspended matter in the river and a turbidity measurement of 92 J.T.U. during the time of our sampling. These values are quite high and as explained earlier, high turbidity and sedimentation may contribute to decreasing phytoplankton numbers. November samplings revealed only 3 genera and 4 species, representative of 2 divisions, Chrysophyta and Cyanophyta. Again the river was laden with sediment which prevented proper analysis of the sample. The species occurring were the diatoms Navicula tripuntuata, Synedra ulna, Navicula anglica and the blue-green Oscillatoria sp. In March, a heavy sediment load was again carried by the Paria River. Kubly and Cole (personal communication) reported 1546 mg/liter of suspended particulate matter being carried by the Paria River for the same period as sampled for phytoplankton. As a result only 3 genera and 4 species were identified. Two genera and 3 species were diatoms and 1 species blue-green. An attempt to quantify the numbers of phytoplankton failed because the number of organisms were too low to be detected by our counting methods.

The Paria River had five species, Gomphoneis herculeana, Nitzschia commutata, Nitzschia frustulum, Nitzschia Kützingiana and Opephora sp. which did not occur in the River or other tributaries. Nitzschia Kützingiana has been used as an indicator of water quality. The freshwater diatom occurs optimally in water which is slightly alkaline, pH 7.5-7.8 (Schoeman, 1973). Kubly and Cole (1976) reported the Paria River as having a pH range of 7.9-8.3. Nitzschia Kützingiana is indicative of eutrophic water and can tolerate small amounts of salt.

Vasey's Paradise. A total of 13 genera and 23 species of phytoplankton were collected from Vasey's Paradise. The diatoms were the most common with 9 genera and 18 species. The green algae were represented by two unidentified species of Spirogyra sp. and the blue-greens by two species of _Oscillatoria_ and one of _Anabaena_.

The diversity of phytoplankton in Vasey's Paradise was low during each sampling period (Table 9). In May, 3 diatom species were identified, _Cymbella cistula_, _Fragilaria intermedia_ and _Synedra nana_ together with one blue-green species _Oscillatoria nigra_. Reasons for this low diversity and in subsequent sampling periods is probably due to the fact that the distance and time the water flows from source to mouth is very short, a matter of feet and minutes. This does not allow enough time for a population to develop and reproduce. June samples revealed 5 genera and 6 species, all of which were diatoms. August samples revealed 6 genera and 8 species, of which 5 genera and 7 species were diatoms and 1 species was a green alga. In November, 6 genera and 6 species were collected which included 4 genera and 4 species of diatoms, 1 species each of green and blue-green algae. Sampling in March provided 4 species of diatoms (_Synedra ulna_, _Navicula tripuntuata_, _Navicula cryptocephala_ and _Nitzschia vitrea_), 1 green alga (_Spirogyra_ sp.) and 1 blue-green alga (_Anabaena_ sp.). An attempt to quantify the numbers of phytoplankton/liter failed for each sampling period because the number of organisms were much too low for our counting procedures. One species of diatom was restricted to Vasey's Paradise (_Cymbella microcephala_). The species, _Synedra nana_ which is found in Vasey's Paradise has been considered a potential bioindicator organism in that it occurs optimally at pH 5.5 and can tolerate small amounts of salts (Lowe, 1974). It's significance in Vasey's Paradise is not evident since Vasey's has a pH range of 8.1-8.3 (Kubly and Cole, 1976) and is low in salts.

Little Colorado River. The Little Colorado River proved to be among the most species diverse tributaries sampled. Eighteen genera and 35 species of phytoplankton were identified. The diatoms made up 88% (16) of the genera and 91% (32) of the species found. Sixteen of the 71 species that occurred only in tributaries occurred in the Little Colorado River. Thirteen of the 16 species were characteristic only of the Little Colorado River.

In May, large amounts of suspended solids in the Little Colorado River prevented phytoplankton analysis of the sample. A value of 14,260 mg/liter was recorded for suspended solids in the Little Colorado the day the river was sampled (Kubly and Cole, 1976). The Little

Colorado was not flooding during our June sampling period and values for suspended matter were low (22 mg/l; Kubly and Cole, 1976). Six genera and 10 species were identified, all of which were diatoms. In August there was a minimal amount of flooding. Kubly and Cole (1976) reported a value of 42 mg/liter of suspended matter in the Little Colorado River at the time of sampling. The diversity was reduced to 4 genera and 8 species. Once again the total diversity was made up of diatoms with Synedra ulna being the most common species. Phytoplankton numbers were 212/liter in August (Figure 7). November proved to be the most diverse sampling period. Eleven genera and 19 species were identified, of which 10 genera and 18 species were diatoms. Only one species of blue-green algae was collected (Oscillatoria subbrevis). Although the diversity was comparatively high, the numbers of organism occurring was low (22/liter). Sampling in November occurred when the Little Colorado River flow was influenced primarily by Blue Springs. Samples collected in March revealed 8 genera and 9 species. Five genera and 6 species of diatoms, (Navicula tripuntuata, Navicula sp., Achnanthes coarctata, Cymbella ventricosa, Cocconeis placentula and Rhoicosphenia curvata), one species of green algae (Spirogyra sp.) and one species of blue-green algae (Oscillatoria subbrevis) were obtained. Phytoplankton numbers were too low to be quantified by our method of counting. Large amounts of suspended particulate matter (1133 mg/liter) was being carried by the river on the day sampled (Kubly and Cole, 1976). The flooding condition and the high level of suspended particulates may account for the low numbers and diversity observed.

Certain of the diatoms found in the Little Colorado River are considered to be water quality indicators. The diatoms Amphiprora alata and Surirella striatula, which occurred in June and found only in the Little Colorado River, are characteristic of mesohalobous water, which is brackish-water with salt concentrations (chlorides) of 500 to 30,000 mg/liter (Lowe, 1974). Tropidoneis lipidoptera, which was found in November, is an indicator of higher salinity levels (above 30,000 mg/liter) (Lowe, 1974). Kubly and Cole (personal communication) reported a chloride concentration range for the Little Colorado River of 228 to 1292 mg/liter. A concentration of 1208 mg/liter was found in June at the time we sampled.

Bright Angel Creek. Bright Angel Creek proved to be the most phytoplankton diverse tributary sampled. A total of 22 genera and 37 species were identified. Fifteen genera (69%) and 28 species (75%) were diatom species. Four genera and 5 species of green algae and 3 genera and 4 species of blue-green algae were also represented in this tributary.

May samples were shown to be the least diverse of our sampling periods. Six genera and 7 species of diatoms and 2 genera and species of green algae occurred. Blue-green algae were not represented. The most frequently occurring alga during this period was the diatom *Cocconeis pediculus*. In June a slight increase in diversity was noted with 9 genera and 11 species identified. The green algae were represented by 2 genera and 2 species and the blue-green algae by 1 species. The diatoms continued to make up the majority of total species numbers with 6 genera and 8 species. The diatom *Diatoma vulgare* was the most common alga during June. August proved to be the period of greatest diversity that was sampled. Twelve genera and 13 species occurred. Eighty-three percent of the genera (10) and 76% of the species (10) were diatoms. One genus and species of green algae and one genus and 2 species of blue-green algae were observed. Total numbers of organisms in Bright Angel Creek reached 4593/liter in August (Fig. 7). This proved to be the highest value we observed in Bright Angel Creek. The dominant species was the diatom *Cymbella ventricosa* which numbered 1531/liter. Other diatoms, *Synedra ulna* and *Epithemia sorex* were quantified at 682/liter and 530/liter, respectively. Sampling in November yielded 9 genera and 11 species of phytoplankton. There were no representatives of green algae and only one genus and species of blue-greens. The remaining 8 genera and 10 species were diatoms. There were no dominant species and the phytoplankton totaled only 60 organisms/liter. March proved to be a diverse sampling period with 11 genera and 13 species. As in November, no green algae and only one species of blue-green algae were represented. The remainder of the genera and species were diatoms. During March, phytoplankton numbers totaled 457/liter (Fig. 7). The diatom *Diatoma vulgare* accounted for 23% of the total number of organisms (107/liter). *Anabaena* sp. a blue-green alga, attained numbers of 133/liter.

Several species were found only in Bright Angel Creek. They were the green algae *Closterium Cynthia* and *Closterium Diane*, the blue-green alga *Oscillatoria lacustris* and the diatoms *Fragilaria* sp., *Gomphonema ventricosum*, *Navicula gastrum* and *Navicula radiosa*.

One water quality indicator organism, the diatom *Epithemia sorex*, was found in Bright Angel Creek. This diatom is found in a pH range of 4.7 to 9.0 but occurs optimally at a range between 8.3 and 8.5. *Epithemia sorex* had its greatest abundance in August which occurred simultaneously with a pH of 8.7 (Kubly and Cole, 1976). *Epithemia sorex* is indicative of a eutrophic system and it can tolerate small amounts of salt (Lowe, 1974). It occurs in clean water habitats, but may also occur in polluted ones. This periphytic species is primarily characteristic of running water.

Shinumo Creek. Shinumo Creek proved to be a rather diverse tributary with a total of 21 genera and 33 species. The diatoms represented 80% of the total genera (17) and 84% (28) of the total species. Three genera and 4 species of green algae and 1 species of blue-green were also represented. May samples were the most diverse with 13 genera and 13 species. Ten genera and species of diatoms occurred, followed by 2 species of green algae and one species of blue-green algae. The diatoms *Diatoma vulgare* and *Cocconeis pediculus* were the most abundant species. June was the least diverse month sampled. Only six genera and species were collected, all of which were diatoms. In August 12 genera and 13 species were identified. The majority of the species were diatoms with 10 genera and 11 species. The green algae were represented by 2 genera and species. In August the phytoplankton numbered 1682/liter. The diatoms *Epithemia sorex* and *Cymbella ventricosa* reached numbers of 788/liter and 378/liter, respectively. Together, they accounted for 69% of the total number of organisms. November samples revealed 8 genera and species, all of which were diatoms. Quantification showed 51 phytoplanters/liter (Fig. 7). *Epithemia sorex* accounted for 49% of the total phytoplankton numbers with 25/liter. Samples collected in March were not very diverse with only 6 genera and 8 species, all of which were diatoms. The phytoplankton population in March was too low to be quantified by our counting methods.

Five species of diatoms were found only in Shinumo Creek. They were *Campylodiscus balatoneis*, *Campylodiscus hibernicus*, *Eunotia Grunowi*, *Neidium productum* and *Stauroneis Smithii*. *Stauroneis Smithii* has been used as an indicator of water quality (Schoeman, 1973). Because this species exists in such low numbers in Shinumo Creek it may not be a valid water quality indicator. It has a pH optimum of approximately 8.0 and favors oxygen-rich water (Schoeman, 1973). Epithemia sorex, who's autoecology has already been discussed, occurs frequently in Shinumo Creek and may be used as an indicator species of general quality. Cymbella ventricosa has also been used as an indicator of general water quality. Lowe (1974) stated that Cymbella ventricosa occupied a pH range of 5.3 to 8.5, with an optimum of 7.7-7.8. Kubly and Cole (1976, and personal communication) reported a pH range of 8.2-8.3 at Shinumo Creek for the time periods sampled. This species is tolerable to small amounts of salt and is characteristic of zones where oxidation of biodegradable compounds is complete. It is common to both flowing and standing water and is periphytic. Optimum growth of this species has been observed in summer and fall and can tolerate a wide range of temperature 0 C (32 F) to 30 C (86 F).

Elves Chasm. Sampling of phytoplankton algae in Elves Chasm revealed 22 genera and 30 species, the majority of which belonged to the class Bacillariophyceae (diatoms). Seventeen genera (77%) and 25 species (83%) were diatoms. Two species of green algae and three species of blue-green algae were also identified. May samples were dominated by diatoms (11 genera and 13 species) of which Biddulphia laevis, Diatoma vulgare and Cocconeis pediculus were the most common. Only one species of blue-green algae occurred (Oscillatoria limnetica). The diversity in June dropped slightly to 8 genera and 8 species. Again the majority of organisms were diatoms (6 genera and 6 species). Cocconeis pediculus was the most frequent diatom, Oscillatoria limnetica the only blue-green alga, and Tetraspora gelatinosa the only green alga. The entire phytoplankton population and diversity in August was made up of diatoms (10 genera and 10 species). Elves Chasm proved to have the largest phytoplankton population during August (Fig. 7). A total of 11,520 phytoplankton/liter were enumerated. Biddulphia laevis and Cocconeis pediculus accounted for 56% (6,487/liter) and 33% (3,850/liter) of the total number of organisms. Cocconeis pediculus was epiphytic on Biddulphia laevis. November samples exhibited a total diversity of 9 genera and 10 species. Only 6 species of green algae occurred (Spirogyra sp.) and the remaining genera and species were diatoms. Elves Chasm continued to be the tributary with the most abundant phytoplankton numbers during this sampling period (Fig. 7) with a total of 2,651 organisms/liter. Cocconeis pediculus was dominant with 1,700 individuals/liter and Biddulphia laevis was frequently encountered (950/liter). Together, these 2 species of diatoms accounted for 99% of the total numbers of organisms in November. The diversity in March was slightly lower than in November (8 genera and 9 species). Two species of blue-greens were represented along with 7 species of diatoms. The number of phytoplankton/liter was 71% lower than in November and 93% lower than in August. Epithemia sorex (a diatom) was the most abundant (424/liter) with Anabaena sp. (a blue-green alga) also present with 111/liter. Together they comprised 69% of the total numbers.

Phytoplankton which occurred only in Elves Chasm were Tetraspora gelatinosa (green algae) and the diatoms Anemoeoneis sphaerophora, Gomphonema angustatum and Pleurosigma delicatulum. The organisms found in this tributary that may be of some indicator value are Epithemia sorex (which has been discussed previously) and Biddulphia laevis. Lowe (1974) reports that B. laevis requires a pH of over 8.5 for optimum growth and is tolerable of salt concentrations from less than 500 mg/liter to 30,000 mg/liter. Kubly and Cole (1976) reported a range of total dissolved solids of 574 to 646 mg/liter for Elves Chasm.

Tapeats Creek. Tapeats Creek showed a plankton diversity of 16 genera and 29 species of algae. Diatoms continued to be the most highly represented division in the tributaries with 12 genera and 22 species of diatoms identified from Tapeats Creek. Blue-green algae and green algae were both represented by 2 genera and 5 species. May samples yielded a total of 8 genera and 10 species with the diatoms accounting for 6 genera and 7 species. The most prevalent diatom was Diatoma vulgare. Only one species of green algae was identified (Ulothrix tenerrima). The blue-greens were represented by 2 species, Oscillatoria articulata and Oscillatoria limnetica. June samples exhibited 7 genera and 8 species of diatoms, no representation of green algae and only one species of blue-green algae. The diatoms Cocconeis pediculus and Diatoma vulgare were the most common. The blue-green alga, Oscillatoria Agardhii, was the only representative of its division. The month of August proved not to be as diverse as May and June. The diatoms were represented by 6 genera and 7 species. Again no green algae were found and only one species of blue-green algae occurred in our samples. Synedra ulna and Cocconeis pediculus were the common diatoms. The single blue-green algae was Oscillatoria subbrevis. In November 8 genera and 10 species were identified. Five genera and 7 species were diatoms, with the common ones being Cocconeis pediculus and Rhoicosphenia curvata. The green algae were represented by 2 species, Ulothrix sp. and Rhizoclonium hieroglyphicum. The single blue-green alga was Oscillatoria subbrevis. Tapeats Creek possessed 7 genera and 8 species of phytoplankton in March. Anabaena sp. was the only representative of blue-green algae, whereas 6 genera and 7 species of diatoms occurred. Members of the division Chlorophyta were not found in our samples. The common organisms in the creek were the diatoms Diatoma vulgare and Nitzschia linearis. An attempt to quantify phytoplankton numbers showed that numbers were lower than our counting methods could determine in August, November, and March.

Four genera and 5 species of phytoplankton were found to occur only in Tapeats Creek during our sampling. One species was a green algae, Rhizoclonium hieroglyphicum and the remaining four were the diatoms Melosira islandica, Diatoma mesodon, Achnanthes affinis and Achnanthes linearis.

Tapeats Creek may be characterized, in part, by the presence of certain diatoms. Cocconeis pediculus grows optimumly in water systems with a pH of 8.5. The pH of Tapeats Creek is 8.3 (Kubly and Cole, 1976). It can tolerate a small amount of salt and occurs primarily in clean water habitats (Lowe, 1974). It occupies both flowing and standing water and is typically epiphytic. The two species of Achnanthes which occur in Tapeats Creek are indicative of oxygen rich water. Achnanthes linearis favors a constant supply of dissolved oxygen and oligotrophic waters. Dissolved oxygen values for Tapeats Creek are reported to be saturated (Kubly and Cole, personal communication).

Deer Creek. Deer Creek, in terms of phytoplankton species observed, was one of the least diverse of all the tributaries. Fourteen genera and 22 species were identified in the five sampling periods. The diatoms made up the majority of both genera and species with 9 genera and 16 species. Only one species of green algae was identified (Ulothrix tenerrima). Four genera and 5 species of blue-green algae were identified as follows: Lyngbya Birgei, Oscillatoria tenuis, Spirulina major, Spirulina subsalsa and Anabaena sp. May proved to be among the more diverse sampling periods. Nine genera and 10 species were identified. The division Chlorophyta was not represented. Bacillariophycean organisms were in the majority with 6 genera and species. The diatoms Cocconeis pediculus, Synedra ulna and Rhoicosphenia curvata were the most common. Four of the five blue-green algae species occurred at Deer Creek during May. They were Lyngbya Birgei, Oscillatoria tenuis, Spirulina major and Spirulina subsalsa. The June sampling provided 6 genera and 6 species, 4 species of which were diatoms, and 1 species each of green algae and blue-green algae. Common diatoms were Rhoicosphenia curvata and Cocconeis pediculus. The single green alga species that occurred was Ulothrix tenerrima and the single blue-green alga was Lyngbya Birgei. The August samples were the least diverse with 5 genera and species. All the species occurring in the phytoplankton were members of the class Bacillariophyceae (diatoms). The most prevalent species was Nitzschia linearis. Other species present were Rhiocosphenia curvata, Cocconeis pediculus, Diatoma vulgare and Cymbella ventricosa. Sampling in November revealed a higher number of species than in August. All of the 8 genera and 11 species that were identified were diatoms. Diatoma vulgare and Cocconeis pediculus again were the most prevalent species encountered. A total of 6 genera and species were identified in March at Deer Creek. Five genera and species of diatoms were identified (Synedra ulna, Navicula tripuntuata, Rhoicosphenia curvata, Cymbella affinis and Diatoma vulgare). The one non-diatom species was the blue-green alga Anabaena sp. Quantification of samples for August, November and March were attempted, but the number of organisms was lower than our counting methods could detect. Even though phytoplankton diversity and numbers were low in Deer Creek, 2 species were found only in its waters (Lyngbya Birgei, a blue-green alga and Nitzschia angularis, a diatom).

A number of the species occurring in Deer Creek have been used as special references to general water quality. Rhoicosphenia curvata is one such species.

It has an optimum occurrence at a pH of slightly above 8 and reaches its maximum in the Spring. Kubly and Cole (1976) reported a pH range for Deer Creek at 8.2-8.4. Rhoicosphenia curvata's presence typically infers a eutrophic system (Lowe, 1974). It is eurythermal and lives optimally in oxygen rich waters.

Kanab Creek. A total diversity of 17 genera and 35 species characterized Kanab Creek. The diatoms accounted for 12 of the genera (70%) and 29 of the species (82%). The green algae were represented by 2 genera and species and the blue-green algae by 3 genera and 4 species. The May sampling period revealed a diversity of 6 genera and 8 species including the diatoms Synedra ulna, Synedra acus, Rhoicosphenia curvata, Diatoma elongatum and Nitzschia lorenziana, the blue-green algae Spirulina major and Oscillatoria Hamelii, and the green alga Ulothrix tenerrima. Samples collected in June disclosed a total of 7 genera and 8 species. The Bacillariophyceae were represented by 5 genera and 6 species. The common diatoms were Rhoicosphenia curvata, Navicula exigua and Cymbella cistula. The chlorophytes and cyanophytes each had only one species occurring during this sample period (Spirogyra sp. and Oscillatoria subbrevis, respectively). Kanab Creek's entire diversity for the August sampling period was 6 genera and 8 species all of which were members of the class Bacillariophyceae. A total of 555 phytoplankton/liter occurred in the August samples. The most frequently occurring species were Nitzschia linearis (195/liter), Nitzschia capitellata (150/liter) and Synedra ulna (120/liter). These 3 species combined, totaled 1465/liter or 83% of the total number of phytoplankton in August. In November, only diatoms were collected in the plankton of Kanab. Eight genera and 11 species were identified. The common forms were Synedra ulna, Navicula anglica and Achnanthes coarctata. Samples which were collected in March revealed a total of 7 genera and 9 species. The blue-green algae were represented by 2 species, Lyngbya sp. and Oscillatoria subbrevis. There was no representatives of green algae. Five genera and 7 species of diatoms occurred with the common organisms being Diatoma vulgare and Navicula tripuntuata. Because of the scarcity of phytoplankton our counting method was unable to obtain measurable populations in November and March.

Six species of diatoms were confined to Kanab Creek. These included Achnanthes flexella, Cylindrotheca gracilis, Gomphonema sp., Gyrosigma attenuatum var. hippocampus, Gyrosigma spencerii and Nitzschia capitellata. With reference to water quality, Cylindrotheca gracilis proved very interesting. This diatom is an indicator of polluted waters. Schoeman (1973) lists it as occurring in water polluted by salt wastes. Cholnoky (1968) states that it is capable of inhabiting eutrophic brackish waters. Christiansen and Reimer (1968) who studied its ecology and distribution states that the total conductivity, concentration of sulfates, magnesium, calcium or some combination, may be of more significance to its growth and distribution than the chloride or sodium ions. Kanab Creek's water is of a sulfate type and has a calcium concentration greater than magnesium (Kubly and Cole, 1976). The conductance (25 C) of Kanab Creek is from 1300 to 1400 micromhos, indicative of a high ion concentration.

Havasu Creek. The total diversity of Havasu Creek compared to the other tributaries is low. Fourteen genera and 23 species were identified with the majority diatom species. Ten genera and 17 species were diatoms. One species was chlorophytan, and the remaining 3 genera and 5 species were cyanophytan. Samples in May disclosed 6 genera and 7 species. Four species were diatoms with Synedra ulna and Fragilaria aequalis the most common. Oscillatoria articulata and Oscillatoria tenuis were the blue-green algae observed. Only one green alga (Spirogyra sp.) was found. June samples were the least diverse with a total of only three genera and species. The diatoms, blue-green algae and green algae were each represented by only one species. They were Synedra kamtschatica, Chroococcus turgidus and Spirogyra sp., respectively. In August, 7 genera and 10 species were identified and all were diatoms. The most prevalent species in August were Achnanthes coarctata (150/1) and Navicula anglica (60/1). The total number of all the phytoplankton was 210/liter (Fig. 6). In November, the 9 genera and 10 species found were diatoms. Cocconeis pediculus and Nitzschia linearis were the most commonly encountered species. March samples revealed a total of 7 genera and 9 species. Anabaena sp. and Oscillatoria sp. were the blue-greens observed and Navicula anglica and Navicula tripuntuata were the most frequently encountered diatoms. The phytoplankton numbers in November and

March, occurred in such scarcity that they could not be quantified by our counting method.

Havasu Creek, had 2 species of diatoms which were confined to its water, Nitzschia angularis and Synedra kamtschatica. The diatom Achnanthes coarctata, which occurred in August, has been used to assess water quality by Lowe (1974) and Schoeman (1973). The species has been found in a pH range of 6.7-7.8 and has its optimum at less than 6. The pH range of Havasu Creek, however, is 8.2-8.3 (Kubly and Cole, 1976). It can tolerate small amounts of salt and is characteristic of standing water.

Diamond Creek. The total phytoplankton diversity of Diamond Creek was represented by 22 genera and 31 species. Blue-green algae were represented by the species Chroococcus turgidus, Merismopedia elegans var. major, Oscillatoria limosa and Lyngbya sp. Five species of green algae were identified (Zygnema sp., Spirogyra sp., Pediastrum integrum, Pandorina sp. and Ulothrix sp.). Thirteen genera and 22 species of diatoms were collected from Diamond Creek samples. The dominant diatom species were Biddulphia laevis, Cocconeis pediculus and Cymbella ventricosa. May samples disclosed a total of 10 genera and species. The diatoms and green algae both were represented by 4 genera and species. Biddulphia laevis was the dominant organism. No species of green algae were dominant. The blue-green algae were represented by 2 species, Chroococcus turgidus and Merismopedia elegans var. major. The latter species was a sub-dominant species during May. Samples taken in June showed a diversity of 7 genera and species. Three genera and species each of diatoms and green algae were identified. Spirogyra sp., Zygnema sp. and Pedistrum integrum represented the green algae and Biddulphia laevis, Cocconeis pediculus and Diatoma vulgare represented the diatoms. Only one species of blue-green algae occurred (Oscillatoria limosa). In August the population was made up entirely of 7 genera and 9 species of diatoms. A total of 5190 phytoplankton/liter occurred in August (Fig. 7). The following three diatoms were the most abundant: Gomphonema parvulum (2220/liter), Navicula tripuntuata (1140/liter) and Nitzschia palea (780/liter). These three species accounted for 80% of the total number of organisms in August which proved to be the most productive month sampled. November also proved to be comparatively productive. Total numbers of phytoplankton were 2128/liter (Fig. 7). Of the 11 genera and 12 species identified, 10 genera and 11 species were diatoms. Biddulphia laevis exhibited numbers of 1991/liter or 93% of the total number of organisms. Epithemia sorex was the second most abundant species at 82/liter. Lyngbya sp. was the single blue-green alga that occurred. Samples collected in March also revealed a diverse and productive system. Eight species of diatoms and 3 species of green algae occurred in March. The 3 species of green algae were Ulothrix sp., Spirogyra sp. and Zygnema sp. The dominant diatoms were Biddulphia laevis (525/liter) and Cocconeis pediculus (785/liter). These two species combined for 96% of the total number of organisms.

Five species of phytoplankton were found to be confined to Diamond Creek; Pandorina sp. (a green alga), Merismopedia elegans var. major (a blue-green), and 3 species of diatoms Gomphonema parvulum, Nitzschia microcephala and Nitzschia palea. Gomphonema parvulum which occurred as a dominant in August, has been used as an indicator of general water quality (Schoeman, 1973 and Lowe, 1974). This species occurs at a pH between 4.2-9.0 and reaches its optimum at 7.8-8.2. In August, the pH at the time of sampling was 8.3 (Kubly and Cole, 1976). Gomphonema parvulum tolerates small amounts of salt and its presence indicates water where oxidation of the organic load is proceeding. It is characteristic of running water, is periphytic, and a temperate water form, usually occurring between 15° and 30°C. Kubly and Cole (1976) reported a temperature range of 21.5° to 30.5°C in Diamond Creek for the time periods sampled. Schoeman (1973) describes Gomphonema parvulum as a facultative nitrogen heterotroph which is widely distributed and often dominant in polluted waters which are characterized by fluctuating concentrations of organic nitrogen compounds. Biddulphia laevis, Epithemia sorex and Cymbella ventricosa also occurred in Diamond Creek and their significance as water quality indicators has previously been discussed.

One species of diatom, Synedra ulna was common to all the tributaries. Several others, Cocconeis pediculus, Rhoicosphenia curvata, Cymbella ventricosa, Diatoma vulgare, Navicula tripuntata, and Nitzschia linearis, were common to 10 of the 11 tributaries. Beyond these diatom species the tributaries were generally rather distinct algologically. Bright Angel Creek demonstrated the greatest species diversity of the tributaries, whereas the Paria River, Vasey's Paradise, Deer Creek, and Havasu Creek had the least diversity. The Little Colorado River, on the other hand, possessed the largest number of characteristic species. The most productive tributaries, in terms of phytoplankton population size, were Bright Angel Creek, Elves Chasm and Diamond Creek. Vasey's Paradise, Tapeats Creek and Deer Creek were the least productive tributaries, perhaps due to the short distance from source to mouth.

Phytoplankton identified from the 11 tributaries sampled were compared to Palmer's (1969) list of organic pollution tolerant algae. Twenty-five genera or about 42% of Palmer's list of organic pollution tolerant genera appeared in the tributaries of the Colorado River. Sixteen of the 80 pollution tolerant species also appeared in the tributaries. Diamond Creek and Havasu Creek had the largest proportion of pollution tolerant organisms. Diamond Creek had 13 genera and 10 species and Havasu Creek had 14 genera and 9 species that occurred on Palmer's list. The Paria River, on the other hand, had the lowest number of pollution tolerant organisms with 8 genera and 4 species. Palmer's criterion that at least 50 organisms/ml of a species be present before the species is considered to be significant as an index to organic pollution was not met by the phytoplankton numbers in the tributaries. However, the fact that Diamond Creek had the largest number of organic pollution tolerant organisms, the highest bacterial counts and the dominant species Gomphonema parvulum (an organism characteristic of water where oxidation of organic load is proceeding and polluted waters with fluctuating levels of organic nitrogen compounds) suggests that Palmer's lists may be applicable to part or all of this aquatic system.

Among the tributaries, the relationship between physical-chemical characteristics and organisms that are considered to be useful bioindicators of water quality conditions appear to be significant. Further correlation of the abiotic and biotic components of the aquatic systems must await the availability of more data on nutrient levels and organic loading.

Chemical Investigations

Natural surface waters contain dissolved minerals that reflect the type of substrata the waters have contacted and the duration of contact. Natural streams may reflect the chemical characteristics of surface runoff, as well as ground water that enters the stream as a spring or seep. Streams may also be altered by the chemical composition of mine, irrigation, agricultural, or industrial waste or drainage waters.

Water quality standards and criteria established by various agencies are given in Table 10. The dissolved chemical elements in the Colorado River and its tributaries in the Grand Canyon National Park and environs are of important practical value with regard to water use and general water quality. The significance of each dissolved element that has been monitored in this study will be briefly presented.

Boron is essential for plant growth, but levels in excess of 1 ppm are damaging to citrus crops. The mean boron value for world rivers and lakes is 13 ppb (Livingstone, 1963).

Cadmium, typically a component of zinc-lead ores, primarily occurs as a sulfide and remains in solution at most pH's. Small quantities of cadmium can be a renal poison and can cause undesirable cardiovascular effects (Kroner and Kopp, 1965). The permissible limit for cadmium in water supplies is 10 ppb.

Calcium is common in all waters and can be quite high in waters that have been in contact with limestone, dolomite and gypsum. Together with magnesium, these are the cationic components of water hardness. The World Health Organization (1971) has set an upper limit of 200 ppm calcium for drinking water. The world mean calcium concentration for rivers and lakes is 15 ppm (Livingstone, 1963).

Chromium occurs in trace quantities in natural waters and can in certain forms have carcinogenic potential in the lungs, can accumulate in body tissue, and as chromate can be a skin sensitizer (Kroner and Kopp, 1965). The recommended permissible level for chromium in drinking water is 50 ppb.

Cobalt may occur in the minerals smaltite and cobaltite or as a phosphate or sulfate and is considered to be an essential nutrient for certain plants (U.S.G.S., 1976). There is no established standard for cobalt concentration. The mean value for the major rivers of North America is 0.89 ppb (Livingstone, 1963).

Copper, at low concentrations, is also considered to be an essential element. At higher concentrations it may cause emesis and liver damage, impart an undesirable taste to water, and be toxic to aquatic plants. The permissible limit for copper in water supplies is 1 ppm, whereas the mean value for ordinary rivers and lakes is around 10 ppb (Livingstone, 1963).

Iron is another element considered essential for both plants and animals that occurs commonly in natural waters. In the oxidized state it is insoluble. Natural surface waters usually carry less than 1 ppm of dissolved iron, with the mean value for river waters of the world being 0.67 ppm (Livingstone, 1963). Excessive iron concentrations causes reddish-brown stains on clothing and cookware and departs an undesirable taste to the water. Maximum permissible levels for iron is 0.3 ppm (E.P.A., 1973).

Lead rarely occurs in appreciable quantities in natural waters that are not contaminated by mine or industrial effluent. Concentrations of rainfall, however, have increased appreciably due to atmospheric contamination by gasoline engine exhausts. Lead may accumulate in body tissues and be toxic. The permissible upper limit for lead in drinking water is 50 ppb (U.S.D.I., 1968). The mean lead content in the world's lakes and rivers lies between 1 and 10 ppb (Livingstone, 1963).

Magnesium, a source of water hardness, is commonly dissolved from dolomite. It is an essential element for plants. At high concentrations it may have a cathartic effect. Recommended permissible level in drinking water is 150 ppm. The mean value of magnesium in the rivers and lakes of the world is 4.1 ppm (Livingstone, 1963).

Manganese, an element that is similar to iron in its chemical properties, is normally less abundant than iron in natural waters. Levels as low as 200 ppb can cause a brown or black stain on fabrics and fixtures (U.S.G.S., 1976). The maximum permissible level of manganese is 50 ppb. The mean value for river and lake waters of the world appears to fall between 10-50 ppb.

Mercury may be found in nature in the free form or a mercuric sulfide (HgS - cinnabar). Mercury compounds can readily be absorbed through the skin or through the gastrointestinal or respiratory tract (U.S.G.S., 1976). Mercury levels also are known to be concentrated through aquatic food chains with detrimental effects. The maximum permissible level of mercury is 1 ppb (World Health Organization, 1971).

Molybdenum is an essential element but may be toxic in certain forms and doses (Kroner and Kopp, 1965). There are, however, no recommended standards governing molybdenum concentrations in drinking water. The mean value of molybdenum in the major rivers of North America is 0.84 ppb (Livingstone, 1963).

Potassium is a common constituent of natural waters, but is rarely found in excessive concentrations. There are no recommended levels for potassium. The mean potassium value for the world's rivers is 2.3 ppb (Livingstone, 1963).

Sodium concentrations in natural waters may vary significantly because of its solubility. There are no recommended levels for sodium in drinking water supplies. The mean sodium values for river waters of the world is 6.3 ppm (Livingstone, 1963).

Zinc is relatively abundant in ores but is typically relatively low in natural waters. Oxides of zinc are only slightly soluble, but the chloride and sulfates are highly soluble. Zinc can impart taste and turbidity to water (Kroner and Kopp, 1965). The maximum desirable level of zinc in drinking water is 5 ppm (E.P.A., 1973) or 15 ppm (World Health Organization, 1971).

Colorado River. Chemical analysis of the Colorado River within and in the vicinity of the Grand Canyon was performed on samples collected at fifteen locations on each of five float trips as previously described. Table 11 provides a summary of the minimum, maximum and mean values for the various elements monitored. The results reveal that some dissolved chemical elements were relatively stable while others showed site and seasonal variation.

Boron concentrations were found to vary appreciably. Concentrations varied from 10 to 450 ppb with a mean of 246 ppb (Table 11). The levels observed were well within the recommended water quality standards (Table 10). The variation in the concentration with sampling period and site is further illustrated in Figure 8. The variability may in part be due to analytical precision at the levels occurring in the River although a previous study has also revealed rather large variations in the Colorado River. Samples taken at the Page municipal water treatment plant have shown a boron range from 86 to 228 ppb. Samples taken at the Boulder City intake of Hoover Dam gave a range of 90-620 ppb (Kopp and Kroner, undated).

Cadmium concentrations in the Colorado River were low throughout the investigation (Fig. 9) and ranged from none detectable to 1 ppb with a mean of 0.2 ppb. A previous survey was unable to detect cadmium since their detection limit was 20 ppb (Kopp and Kroner, undated). The concentrations measured were also well below the established drinking water standards (Table 10).

The major cation calcium varied in the Colorado River from 49 to 83 ppm, with a mean of 59 ppm. The highest values occurred during the May and June samplings (Fig. 10). Although the May and June values for calcium were higher than from the other three trips, the values during any one trip at various sites on the River were very similar. The values obtained are well within the international standards for drinking water established by the World Health Organization (Table 10).

The Colorado River had consistently low chromium levels (Fig. 11) with a mean of 1.4 ppb and a range of 0.8 to 4.0 ppb (Table 11). Kopp and Kroner (undated) have reported a chromium concentration range of 4-19 ppb in the Colorado River at Loma, Colorado. These values are well within the 50 ppb limit recommended for drinking water standards (Table 10).

Cobalt concentrations in the Colorado River were also low and relatively constant (Fig. 12). Concentrations ranged from none detectable to 14 ppb. The mean concentration was 4.4 ppb. No standards have been applied to cobalt levels in potable or recreational waters.

Copper concentrations, likewise were constant in the River, showing no noticeable site or seasonal variation (Fig. 13). Copper values varied from 2 to 11 ppb with a mean of 4.6 ppb. Copper concentrations in the Colorado River at Loma, Colorado and at Parker Dam ranged from 4-35 ppb and 4-20 ppb, respectively (Kopp and Kroner, undated). The maximum value recommended for drinking water is 1 or 1.5 ppm (Table 10).

The Colorado River was variable in iron concentration with values varying both on a spatial and temporal basis (Fig. 14). Concentrations, in general, were low ranging from 4 to 60 ppb. The mean iron concentration in the River was 23 ppb. An iron concentration range from 29-127 ppb has previously been reported in the Colorado River at Page (Kopp and Kroner, undated). The established water quality criteria have 300 ppb as the maximum acceptable value (Table 10). Although the River concentrations were variable, none approached the maximum acceptable standard.

As was the case with several other elements, lead concentrations were extremely stable in the River both in time and location in the River (Fig. 15). Lead concentrations ranged from 0.9 ppb to 7 ppb with a mean of 3.5 ppb. These concentrations were well below the 50 ppb set forth in the standards for drinking water (Table 10).

The major cation magnesium was also very constant in concentration throughout the River over the five sampling periods (Fig. 16). Magnesium concentration ranged from 23 ppm to 33 ppm. The mean magnesium concentration was 26.4 ppm, noticeably below the 150 ppm limit set for drinking water by the World Health Organization (Table 10).

Dissolved manganese levels in the River were stable with no values greater than 10 ppb (Fig. 17). The mean concentration was 3.4 ppb, although a range of 0.5 ppb to 9.0 ppb occurred (Table 11). Kopp and Kroner (undated) have reported a manganese range of 5.3-9 ppb at Page, Arizona. Concentration maximum established for drinking water by three of the four agencies that have set forth standards is 50 ppb (Table 10).

The limited monitoring of mercury revealed a mean concentration of 0.2 ppb in the Colorado River with a range of .2-.3 ppb (Table 11). All the analyses gave values that were well below the recommended level of 1 ppb. This basically agrees with measurements made in Lake Powell by Potter, Kidd, and Standiford (1975) who reported a mean mercury value of 0.01 ppb.

Molybdenum concentrations in the River ranged from 2 to 18 ppb (Fig. 18). The mean concentration was 6.9 ppb. These values were noticeably lower than those reported earlier by Kopp and Kroner (undated) in the Colorado River at Loma, Colorado. They reported a range from 20-444 ppb with a mean of 194 ppb. There are no established recommended levels for molybdenum in drinking water.

Potassium levels in the River were stable with a range of 3.1 ppm to 4.5 ppm and a mean of 3.8 ppm (Table 11). The March sampling gave values for potassium that were only slightly but consistently higher than those obtained from other sampling periods (Fig. 19). No standards have been established for potassium levels in drinking water.

The major cation sodium was also often higher in the Colorado River during the March sampling period than during the other sampling periods (Fig. 20). Sodium concentrations ranged from 55 to 95 ppm (Table 11). The mean sodium level was 75.2 ppm. There appeared to be a small increase downstream in sodium level perhaps on the order of 5 to 10 ppm which would represent a percentage increase of approximately 7-13%. The source of this increase is not obvious from the data. It appears to be gradual, perhaps from dissolution of substrate, evaporation and in part from contributions of the Little Colorado River. Figure 20 suggests that a greater proportional increase in sodium occurs during lower flow conditions when Blue Springs is the major source of Little Colorado water.

Zinc concentrations in the Colorado River were extremely variable (Fig. 21) ranging from 10 to 400 ppb, with a mean concentration of 110 ppb (Table 11). Variation existed on both a temporal and spatial basis. This variation was also evident in previous investigations. Kopp and Kroner (undated) reported a range of 3-77 ppb at Page, Arizona and a range of 10-259 ppb at Boulder City, Nevada. All the values obtained for zinc are well below the levels (5 ppm) set forth in drinking water standards (Table 10).

<u>Tributaries</u>. Trace chemical determinations in the tributaries of the Colorado River demonstrate considerable variability from tributary to tributary as well as on a seasonal basis. Boron levels ranged from a mean of 76 ppb in water from Vasey's Paradise to 346 ppm at Diamond Creek (Tables 13, 22; Fig. 22). The maximum value was 600 ppb and occurred at Diamond Creek in August, 1975. Maximum values were for the most part, found to occur in March and August. Permissible levels of boron are infrequently described by health agencies. The water quality criteria established by the U.S. Department of Interior (1968), however, did set 1 ppm (1000 ppb) as a standard not to be exceeded (Table 10). No values obtained for boron approached this concentration.

Cadmium levels were found to be extremely low (Fig. 23) with a mean range of 1.6 ppb in the Paria River (Table 12) to 0.18 ppb at Vasey's Paradise (Table 13). The maximum value (5.5 ppb) obtained occurred in the Paria River in August. All values obtained were well below the 10 ppb standards set forth by various agencies (Table 10).

Determined values for the major ion calcium varied greatly from tributary to tributary and with time of sampling (Fig. 24). The Paria River, Little Colorado River, and Kanab Creek showed seasonal and/or flow associated changes. The Paria River exhibited a range from a low of 38 ppm in June to a high of 108 ppm in November (Table 12). The Paria River had its highest concentration during its highest flow. The Little Colorado River had a concentration range from 53 to 118 ppm with the low in May and the maximum in June (Table 14). The maximum occurred during its lowest flow period, demonstrating the high calcium load of Blue Springs. Kanab Creek had a range of 118 to 157 ppm of calcium with the minimum value in August and the maximum in May (Table 20). Elves Chasm and Havasu Creek also had somewhat higher calcium values than the remainder of the tributaries, 64.6 ppm and 45 ppm, respectively (Tables 17, 21). The remainder of the tributaries had means between 30-40 ppm and demonstrated considerably less seasonal and/or flow variability in calcium levels. The calcium levels observed in the tributaries did not exceed existing standards (World Health Organization, 1971).

Values for chromium ranged from a mean of 2.1 ppb in the Paria River (Table 12) to 4.9 ppb (Table 14) in the Little Colorado River. The highest value obtained was 11.3 ppb in Kanab Creek in August (Fig. 25). This is well below the 50 ppb standard value put forth for public water supplies (Table 10). Mean values for most of the tributaries were less than 3 ppb chromium.

Cobalt values measured were below 20 ppb in all of the tributaries monitored, although considerable variability was evident (Fig. 26). Vasey's Paradise (0-18 ppb) and Kanab Creek (2.1-19 ppb) exhibited the greatest variability. The remainder of the tributaries typically had values below 10 ppb. No standards have been set for this element.

Copper concentrations in the tributaries were comparatively low (Fig. 27). The highest value obtained was 17.4 ppb (Table 14) and it occurred in November in the Little Colorado River. The mean for the Little Colorado River was 11.2 ppb. The Paria River, Tapeats Creek, Kanab Creek, and Diamond Creek also showed some variability in copper concentration (Fig. 27), although values were lower than that observed in the Little Colorado River. The remainder of the tributaries had mean values below 5 ppb. The levels of copper found were well below the 1.0 or 1.5 ppm recommended standards (Table 10).

Dissolved iron concentrations varied greatly between and within the tributaries relative to sampling period or season (Fig. 28). The Little Colorado River demonstrated a range from 7 to 1500 ppb (Table 14) with a mean of 323 ppb. The large variability is associated with its flow. The high value corresponded with high flow and sediment conditions. Lower values corresponded to low flow and reduced sediment loads. Other tributaries also showed some variability, i.e., Bright Angel Creek (13-86 ppb) and Shinumo Creek (23-78 ppb). Levels in the remainder of the tributaries averaged 20-30 ppb. Only the level observed (1500 ppb) in the May sampling exceeded the water quality standards (Table 10) which recommend less than 300 ppb).

Lead concentrations in the tributaries were consistently low, only exceeding 10 ppb once in the Paria River (Fig. 29). The maximum value observed was 13 ppb in March, 1976 (Table 12). The average lead concentration for the tributaries were less than 5 ppb. The values determined did not approach the 50 ppb standard put forth by various agencies (Table 10).

The concentration of magnesium varied greatly with tributary (Fig. 30). Kanab Creek had a high of 98 ppm in March, 1976 and demonstrated a mean of 80 ppm (Table 20). Kanab Creek exceeded all other tributaries in magnesium levels throughout the study period. Only two other tributaries had high values or large seasonal changes. The Paria River varied from 20.5 ppm in June to 67.5 ppm in November with a mean of 43.9 ppm. The Little Colorado River varied from 14 ppm in May to 70 ppm in November with a mean of 54.5 ppm. The remainder of the tributaries were comparatively stable in magnesium levels, but fell into two categories which included those stable between 10-20 ppm (Vasey's Paradise, Bright Angel Creek, Shinumo Creek, Tapeats Creek, Deer Creek Falls) and those stable around 40-50 ppm (Elves Chasm, Havasu Creek, and Diamond Creek). Only the World Health Organization (1971) has established standards that include magnesium (Table 10). The level set forth is 150 ppm and is well above any values obtained in the tributaries.

Manganese levels were low and stable (less than 10 ppb) in all the tributaries except the Paria River, Little Colorado River, and Diamond Creek (Fig. 31). The Paria River ranged from 1.3 ppb in June to 20.0 ppb in May (Table 12). The Little Colorado River ranged from a low of 3.6 ppm in June to 70 ppm in May. The high value in the Little Colorado River occurred during high discharge and exceeded the 50 ppb recommended maximum (Table 10). The mean value for the Little

Colorado, however, was only 17.6 ppm. Diamond Creek varied from 2.4 ppm in March, 1976 to 40 ppm in August, 1975 and had a mean of 11 ppm (Table 22).

Mercury values, although only obtained on samples collected during the March trip ranged from 0.3-0.6 ppb in all the tributaries except Shinumo Creek. Shinumo Creek yielded a value of 1.5 ppb, approximately three to five times the value found in most of the tributaries (Table 16). This exceeds the 1 ppb standard (Table 10) for drinking water set by the World Health Organization (1971) and approaches the 2.0 ppb set by the Environmental Protection Agency (1972). Since only one sampling period was monitored for mercury, one should reserve judgement on the validity of this measurement until additional samplings can be made.

Molybdenum was low (less than 10 ppb) in all of the tributaries except the Paria River, Little Colorado River and Bright Angel Creek which had highs of 10.9, 12.0 and 13.5 ppb, respectively (Fig. 32). The mean values of all the tributaries were less than 10 ppb (Tables 12, 14, 15). There are no established water quality standards for molybdenum.

Potassium values were stable in most of the tributaries (Fig. 33). Vasey's Paradise, Bright Angel Creek, Shinumo Creek, Tapeats Creek, and Deer Creek Falls all had potassium values of less than 1 ppm (Tables 13, 15, 16, 18, 19), whereas Elves Chasm and Havasu Creek had a mean of 3.0 and 4.3 ppm, respectively (Tables 17, 21). Kanab Creek, Diamond Creek had means of 5.8 and 5.4 ppm (Tables 20, 22) with some seasonal variability. The Paria River and Little Colorado River demonstrated greater seasonal variability (Fig. 33) than the other tributaries. The Paria River had a range from 3.2 to 5.5 ppm, whereas the Little Colorado River ranged from 4.4 to 6.3 ppm potassium. There are no recommended standards of water quality for potassium.

Sodium values in Vasey's Paradise, Bright Angel Creek, Shinumo Creek, Tapeats Creek, and Deer Creek Falls were constant and in the 3 to 5 ppm range, whereas Elves Chasm and Havasu Creek had a mean of 23.2 ppm and 31.2 ppm (Fig. 34). Kanab Creek had constant sodium values around 35 ppm except during the March sampling period when an increase to 61 ppm occurred. There was no obvious difference in flow in Kanab Creek during the sampling periods. Diamond Creek had appreciable quantities of sodium with a mean of 83.8 ppm (Table 22). Both the Paria River and the Little Colorado River demonstrated a large variation in sodium values (Fig. 34). The Paria had a range from 27 to 106 ppm, whereas the Little Colorado varied from 124 to 720 ppm. The Paria River had its highest sodium level during high discharge. The Little Colorado, on the other hand, had its highest values during its low discharge when Blue Springs was the primary contributor of water. There are no recommended standards for sodium.

The element zinc occurred with considerable variation with tributary and sampling period (Fig. 35). No values exceeded 500 ppb in the tributaries, although Elves Chasm and Tapeats Creek had maxima of 456 ppb and 350 ppb (Tables 17, 18). The range observed in the tributaries was from a minimum of 10 ppm in March at Vasey's Paradise to the 456 ppb in Elves Chasm in May. Although variability was the rule with zinc, in no case were the recommended drinking water standards (5 ppm) for zinc approached or exceeded (Table 10).

Since standards applied to drinking or potable water are as a rule more stringent than for other water uses, the dissolved chemical quality of the River and tributaries observed in this study must be described as acceptable. The only example of elements exceeding standards were in the Little Colorado during heavy flooding. The elements exceeding standards were iron and manganese, neither of which are known to be health hazards. The mercury value obtained for Shinumo Creek also exceeds recommended standards. Since only one sample was analyzed from this site, the validity of the value must await further sampling.

Two elements not monitored in this study, but of considerable interest in terms of water quality, are arsenic and selenium. The former was monitored by Kopp and Kroner (undated) in the Colorado River and was undetectable by their analytical techniques. Data on selenium levels in the River are sparse and are unavailable for the tributaries. Earlier reports summarized by Livingstone (1963) indicate the possibility of appreciable levels of selenium in the Colorado River system. Any future chemical monitoring of the River or tributaries should include these potentially toxic elements.

CONCLUSIONS

Total viable bacterial numbers in the Colorado River and tributaries ranged from 10^1 to 10^6/ml and were similar to those reported for other river systems. The broad range in viable bacterial numbers may be attributed to variations in sediment load and watershed characteristics. p. 11, 13-15

Total coliform bacterial numbers exceeded desirable water quality standards at several sampling sites on the Colorado River and in most of the tributaries throughout the year. p. 12, 15

During the summer heavily used visitor sites, such as Elves Chasm, Deer Creek, Kanab Creek, Havasu Creek, and Diamond Creek, generally had total coliform numbers that exceeded desirable water quality criteria. p. 15, 16

Consumption of untreated River and tributary waters present potential bacteriological health hazards. Chlorination or other treatment of River and tributary waters are recommended before use. p. 17

Chlorine levels of ca. 2.5 ppm or four drops of chlorox per gallon of raw River or tributary waters was found to reduce total coliform numbers to acceptable levels. p. 17

On the basis of phytoplankton numbers, the Colorado River and the eleven tributaries must be considered relatively unproductive. p. 20-23

A fairly diverse phytoplankton population occurred in the Colorado River with 122 species identified. One hundred and thirty-seven species of phytoplankton were discovered among the eleven tributaries. The phytoplankton flora of both the River and tributaries was dominated by bacillariophycean algae (diatoms). p. 18, 26

A number of diatoms that have been previously described as indicator organisms were found in the River and tributaries and may be of future use in accessing water quality changes in the Colorado River system. p. 24, 25, 40

Most of the fifteen chemical elements monitored in the Colorado River and tributaries remained relatively stable on a temporal and spatial basis. p. 43

A detectable increase in the concentration of the element sodium occurred with distance downstream from Lee's Ferry. p. 46

The eleven tributaries differed chemically in various degrees from each other and from the Colorado River. The Paria River, Little Colorado River, and Kanab Creek exhibited extremely large fluctuations in their chemistry that was associated with their flow conditions. p. 46, 47

The Little Colorado River, under flooding conditions, was found to exceed recommended standards of water quality for the elements iron and manganese. p. 48, 49

The dissolved chemical quality of the River and tributaries, based on the elements monitored, meets current water quality standards for drinking water. p. 46

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APPENDIX

Figures 1 - 35

Tables 1 - 22

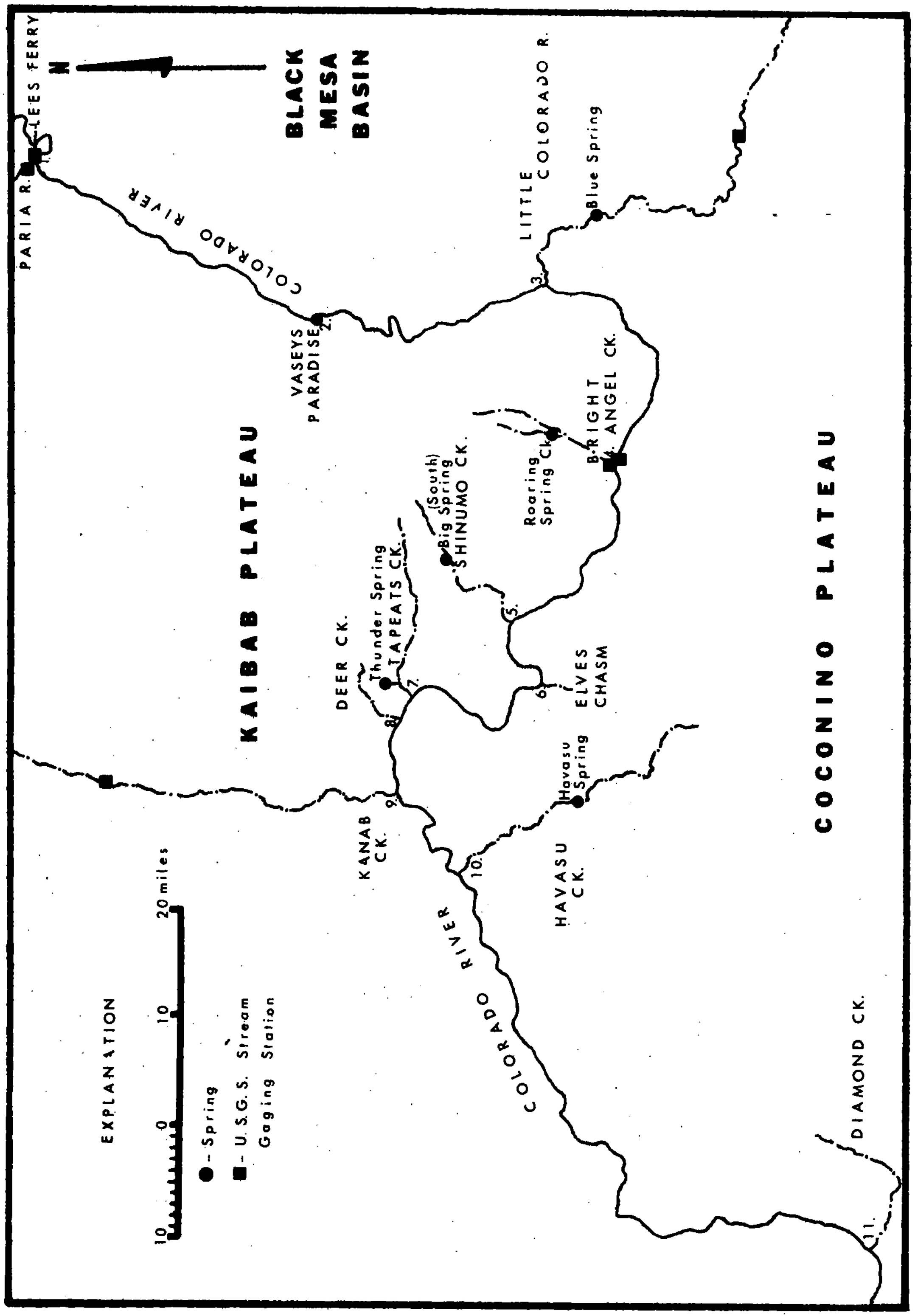

Fig. 1. Map of the Colorado River and the eleven major tributaries sampled.

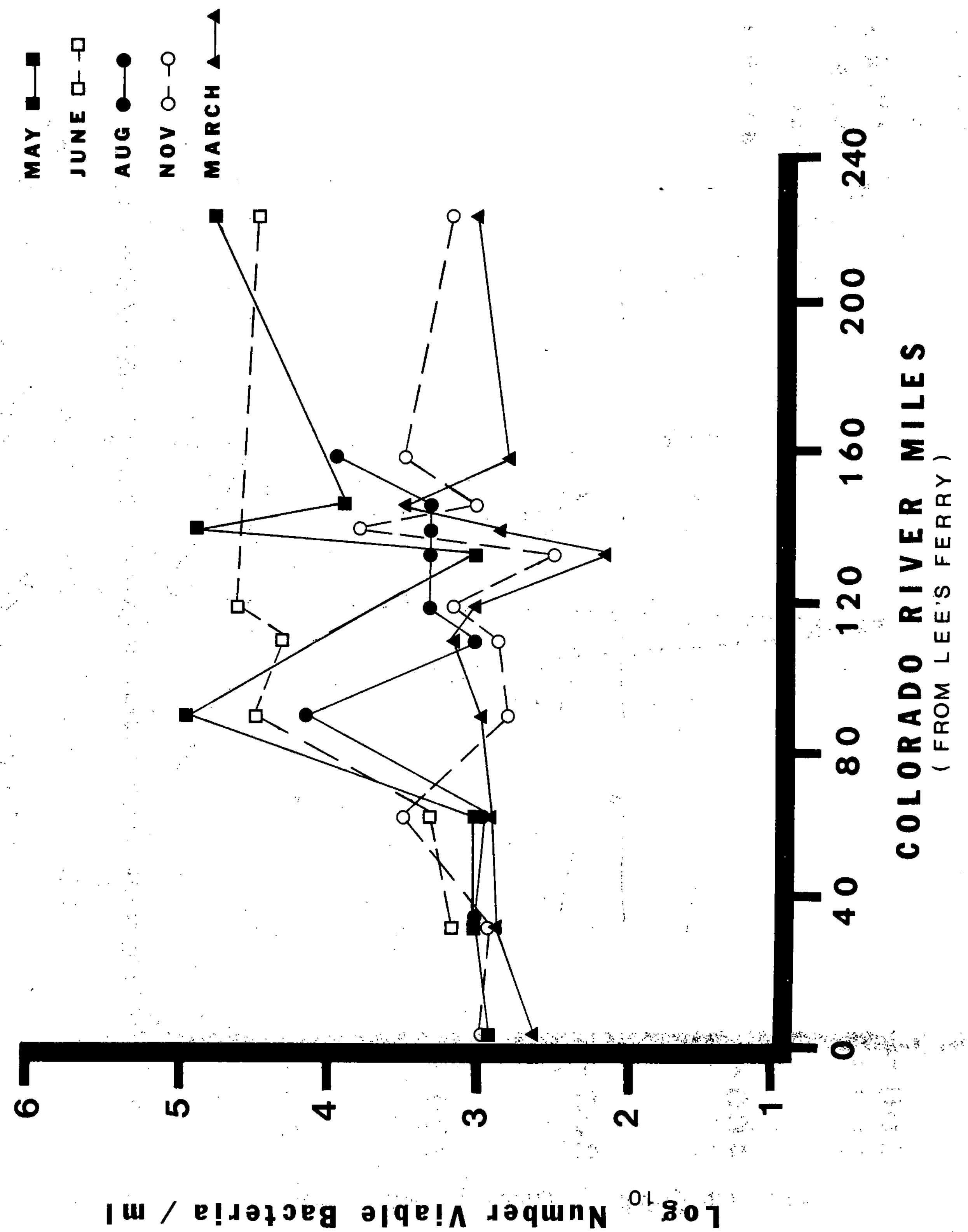

Fig. 2. Number of viable bacteria in the Colorado River.

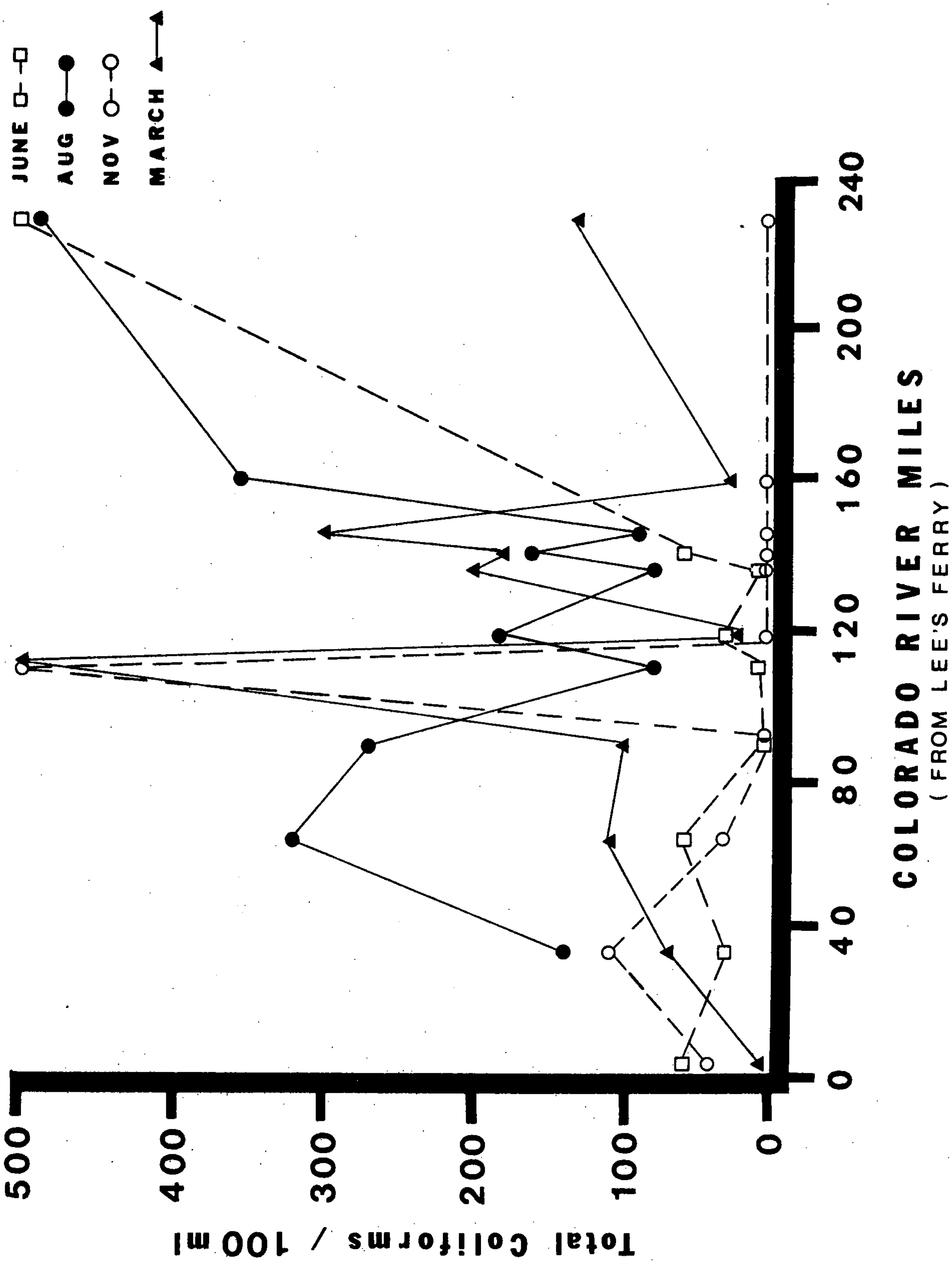

Fig. 3. Total coliform counts in the Colorado River.

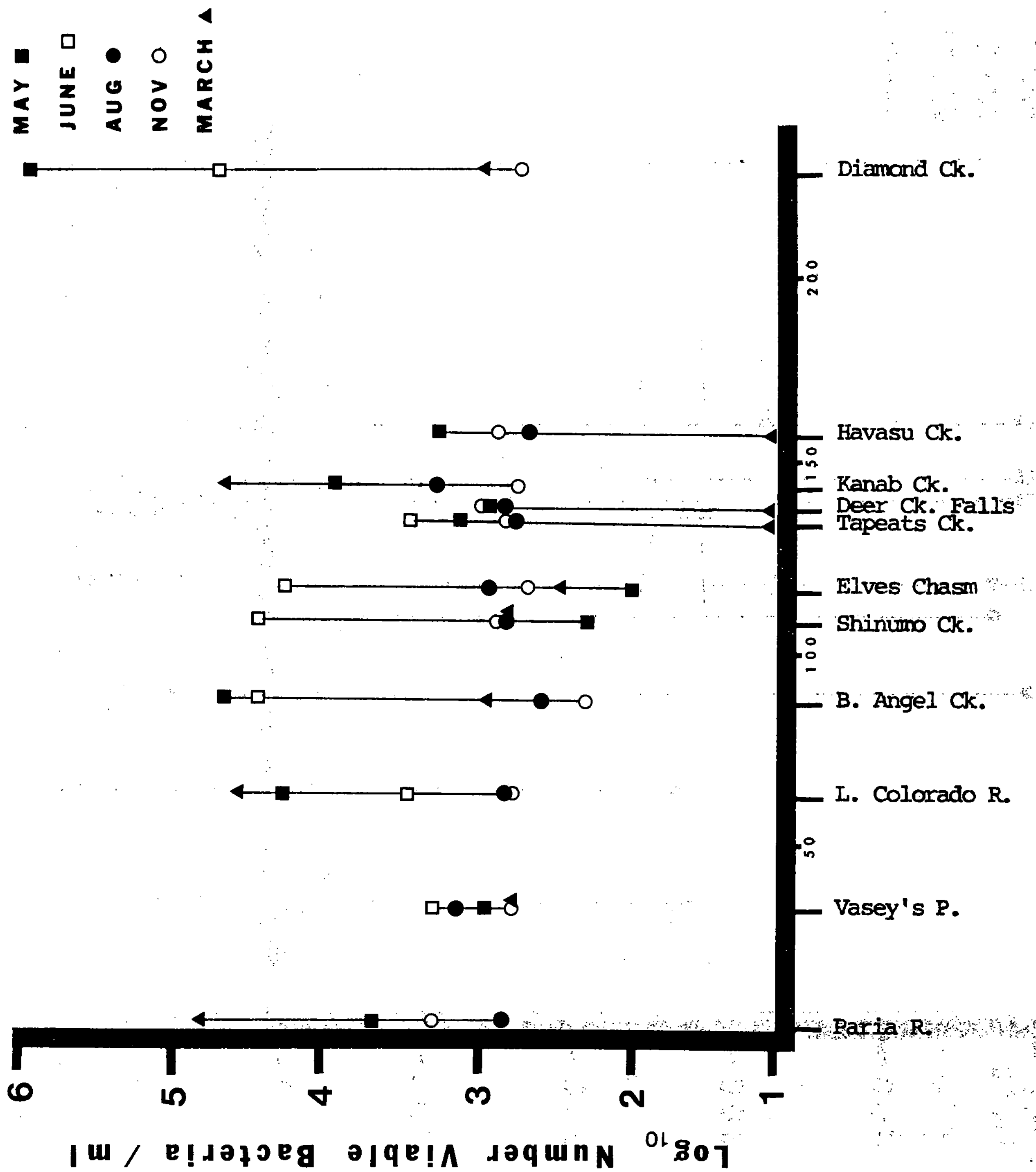

Fig. 4. Number of viable bacteria in tributaries of the Colorado River.

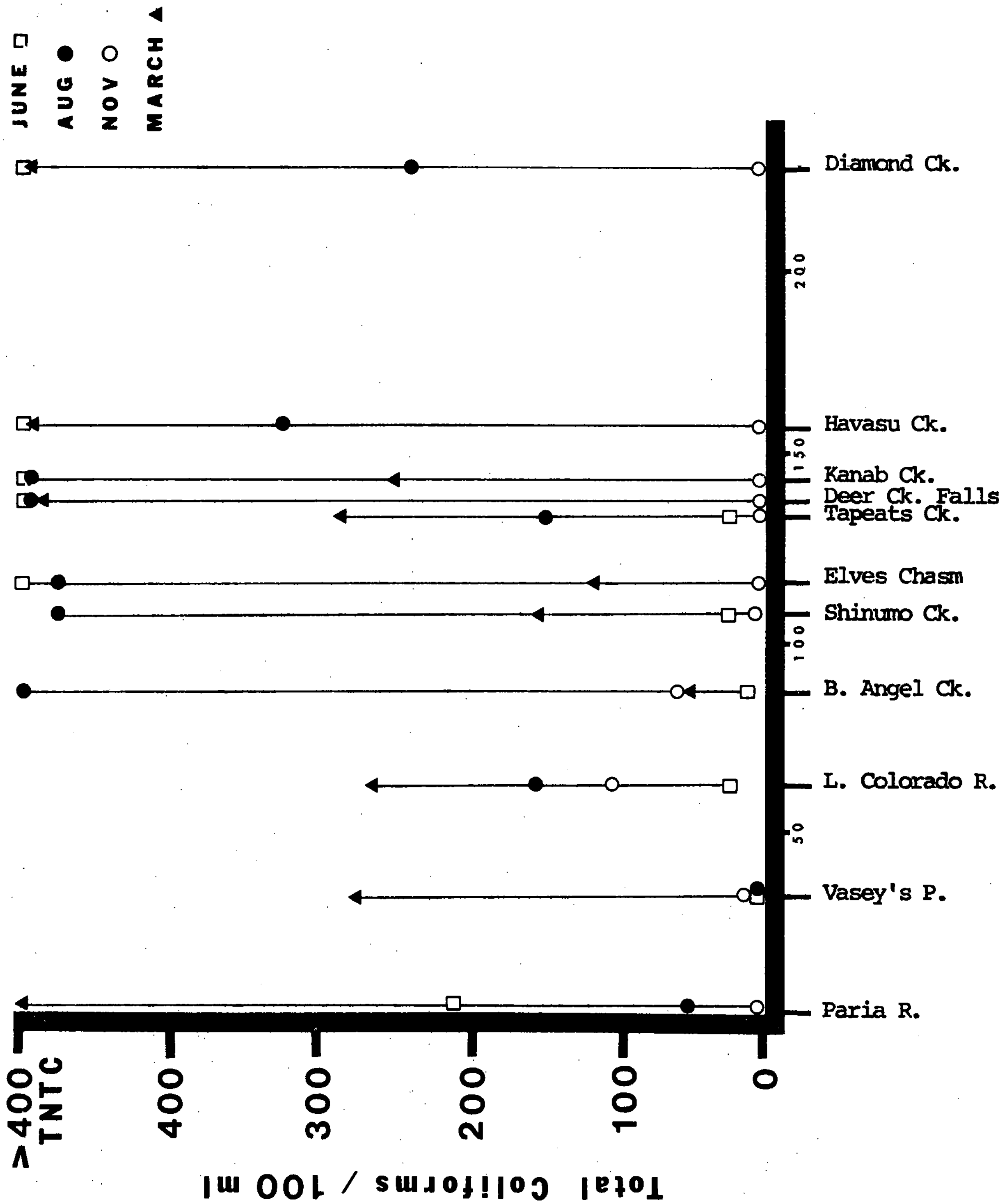

Fig. 5. Total coliform counts in tributaries of the Colorado River.

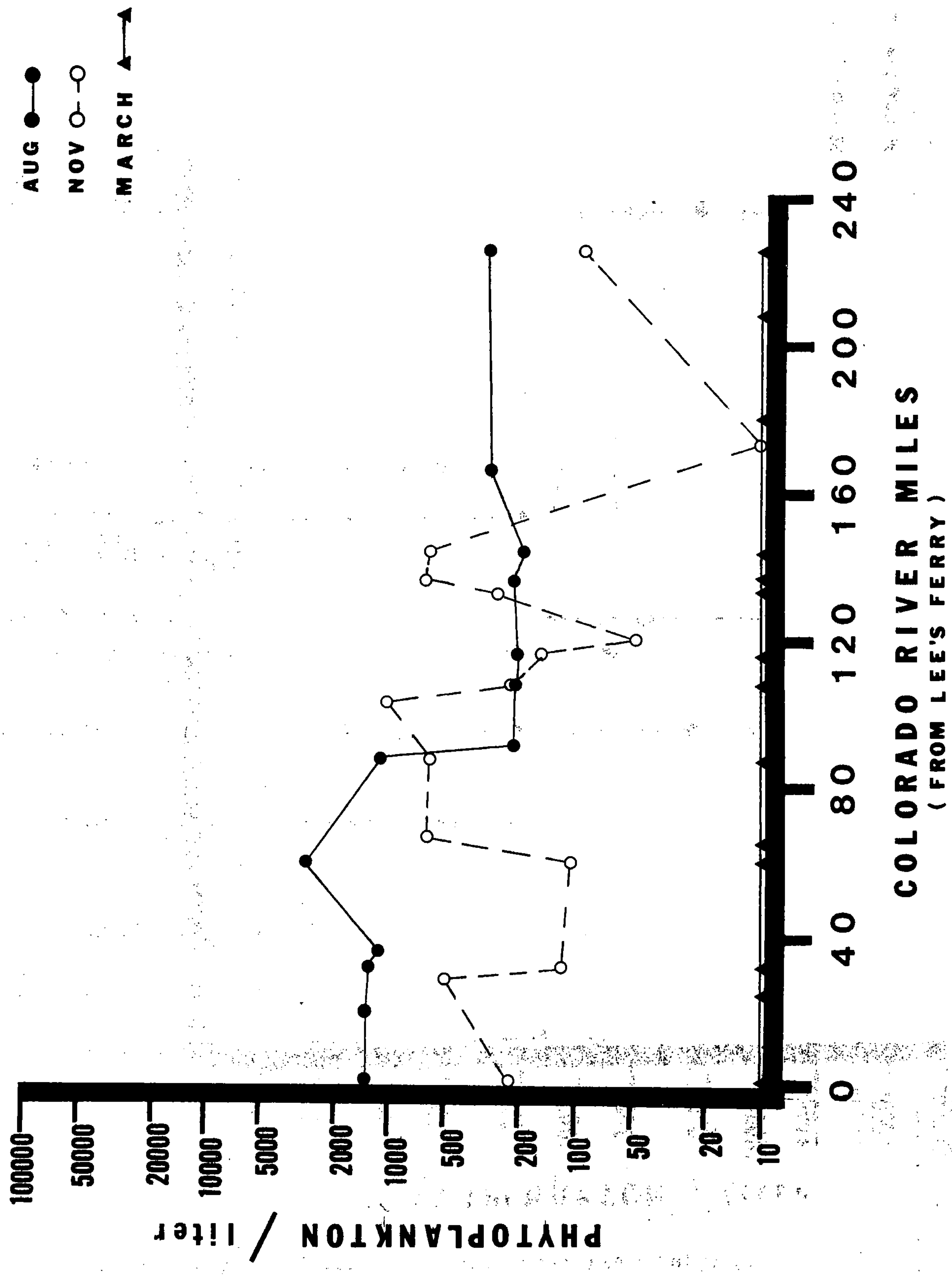

Fig. 6. Phytoplankton numbers in the Colorado River.

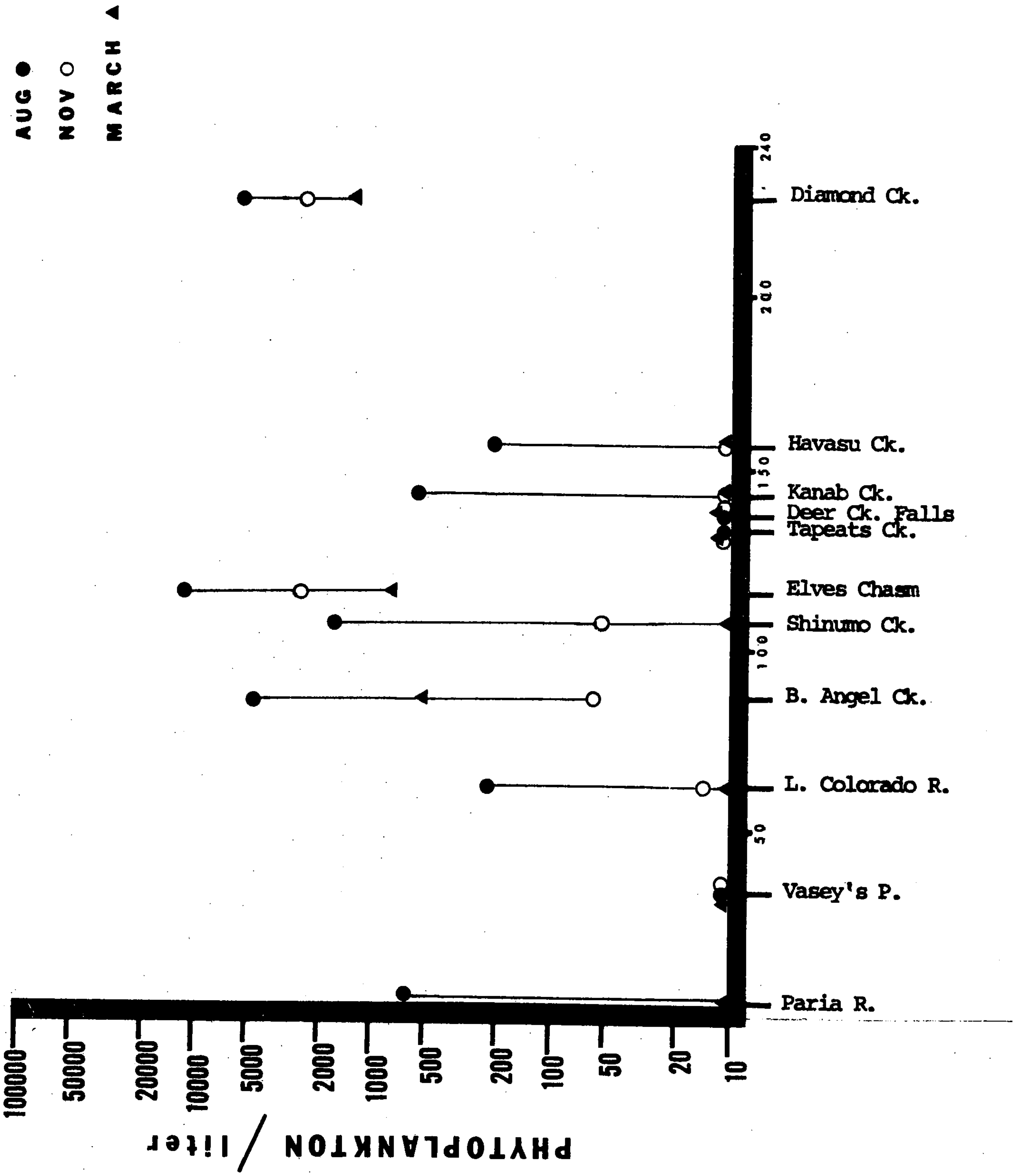

Fig. 7. Phytoplankton numbers in the tributaries of the Colorado River.

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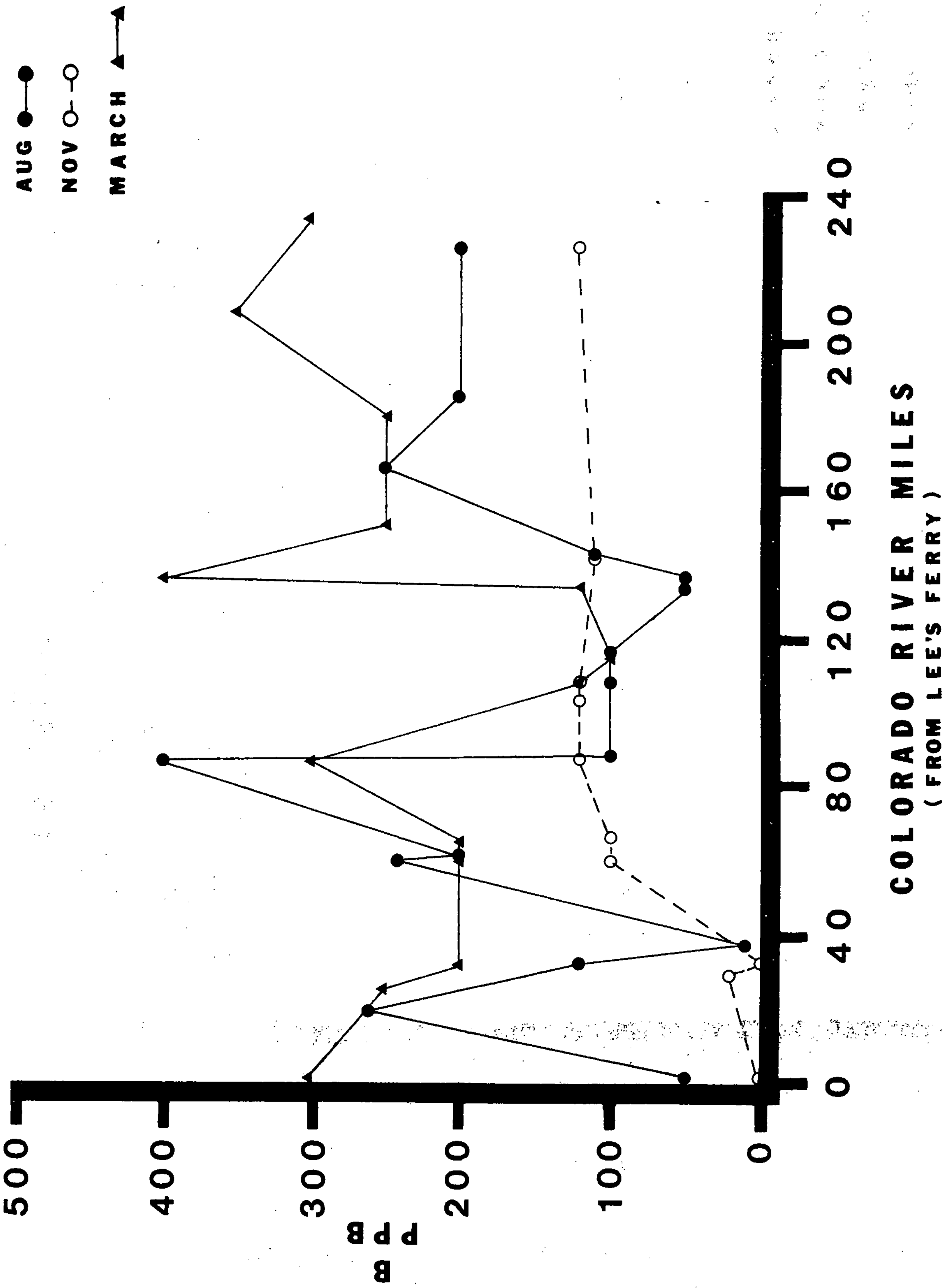

Fig. 8. Concentrations of boron in the Colorado River.

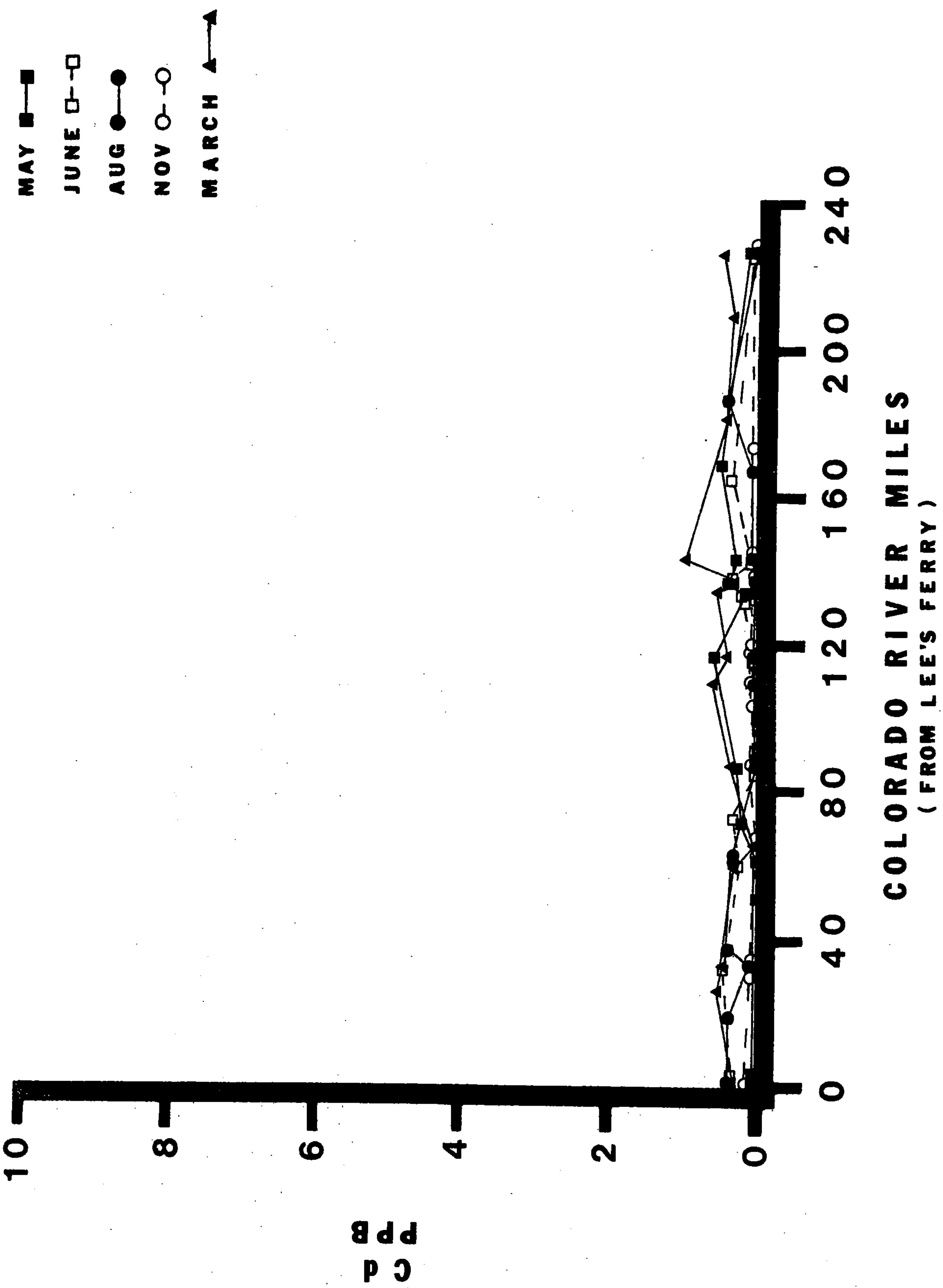

Fig. 9. Concentrations of cadmium in the Colorado River.

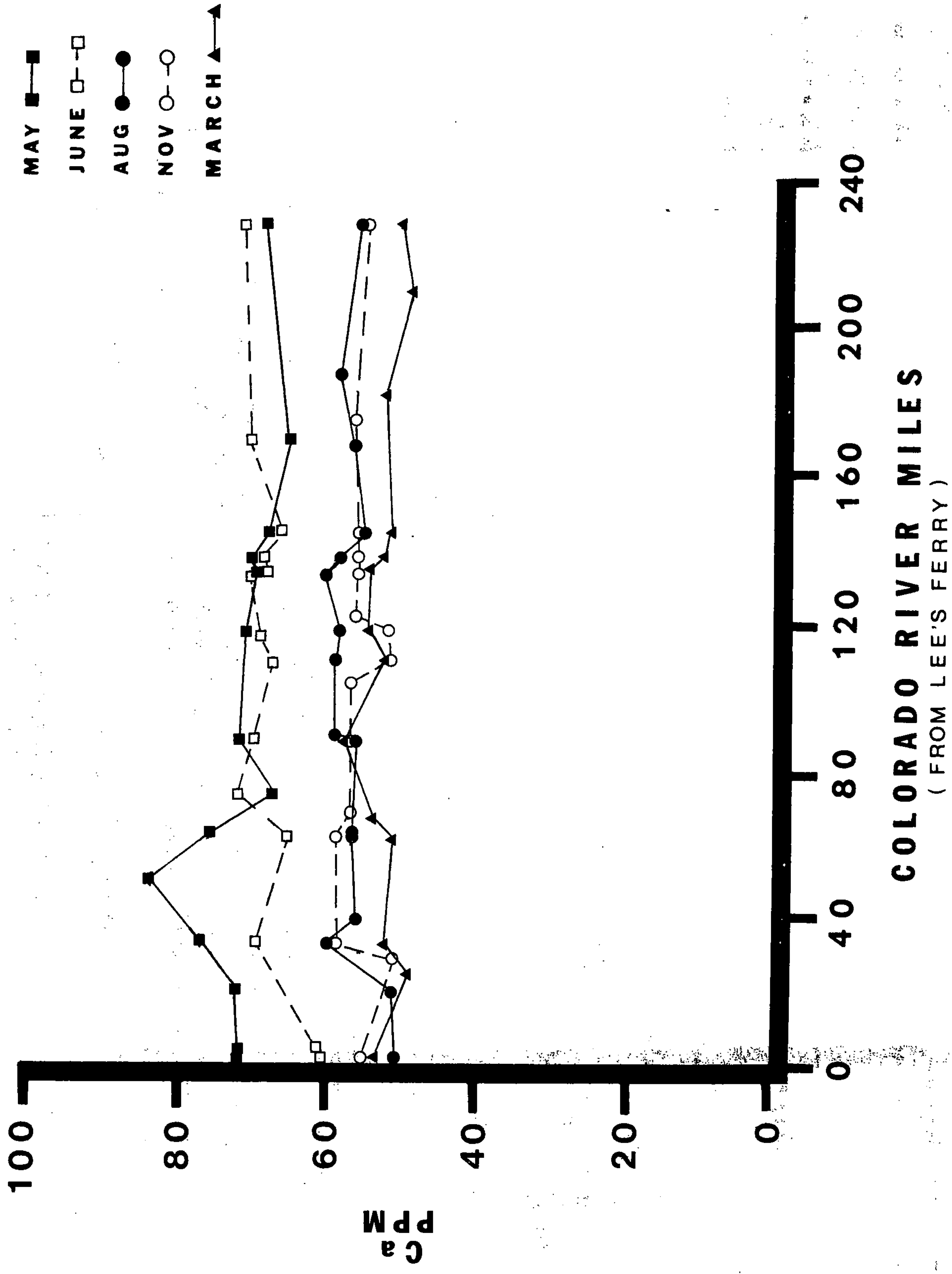

Fig. 10. Concentrations of calcium in the Colorado River.

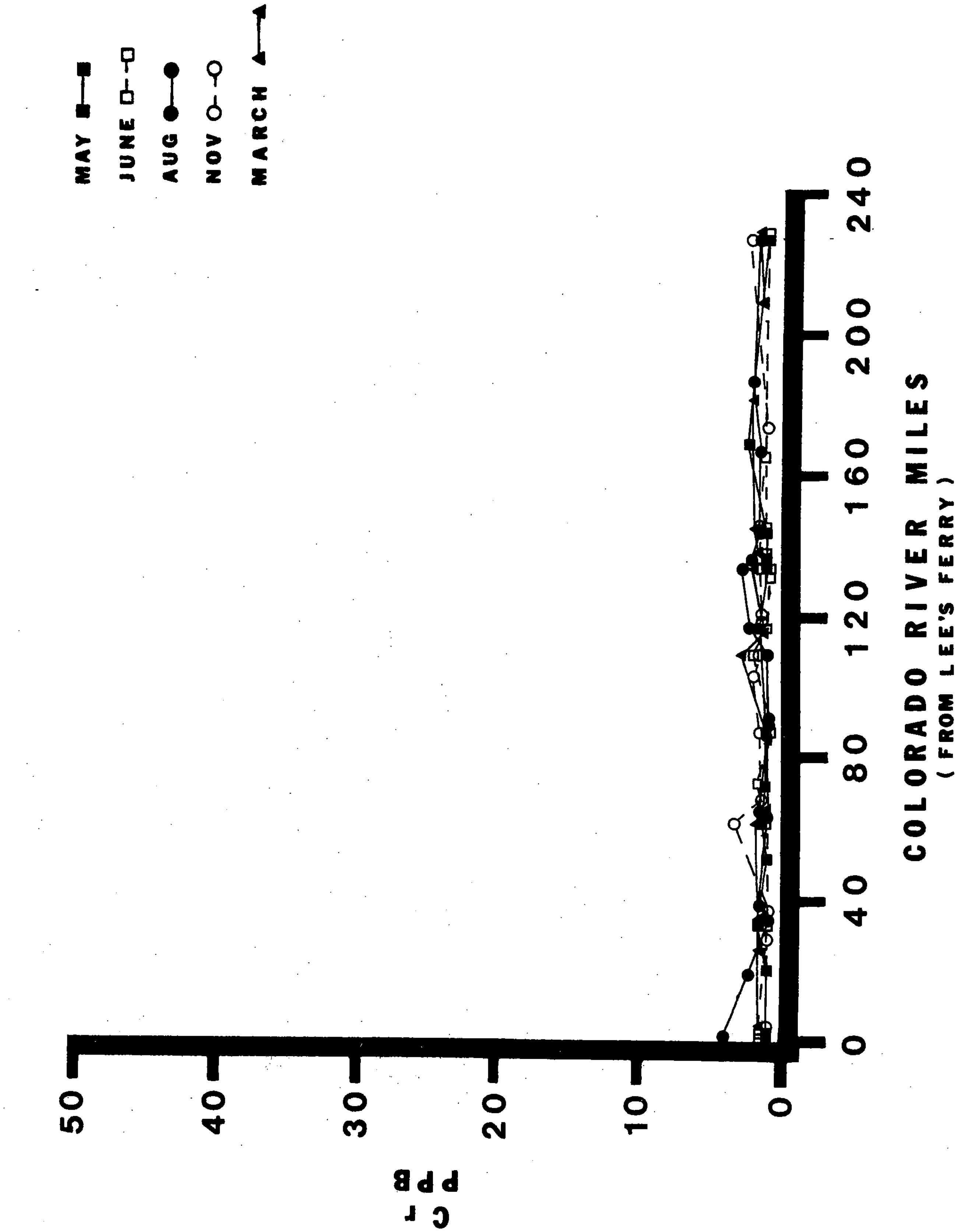

Fig. 11. Concentrations of chromium in the Colorado River.

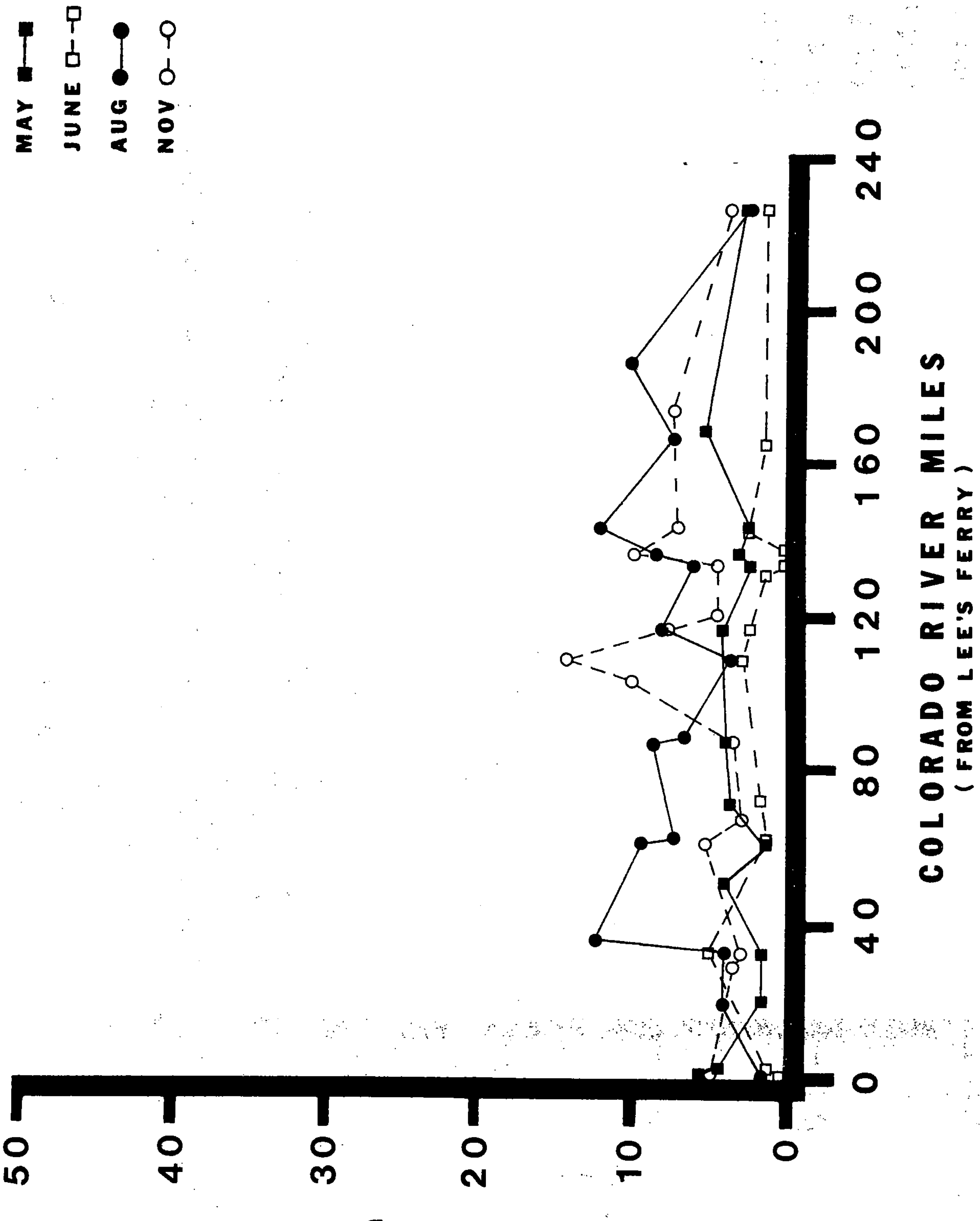

Fig. 12. Concentrations of cobalt in the Colorado River.

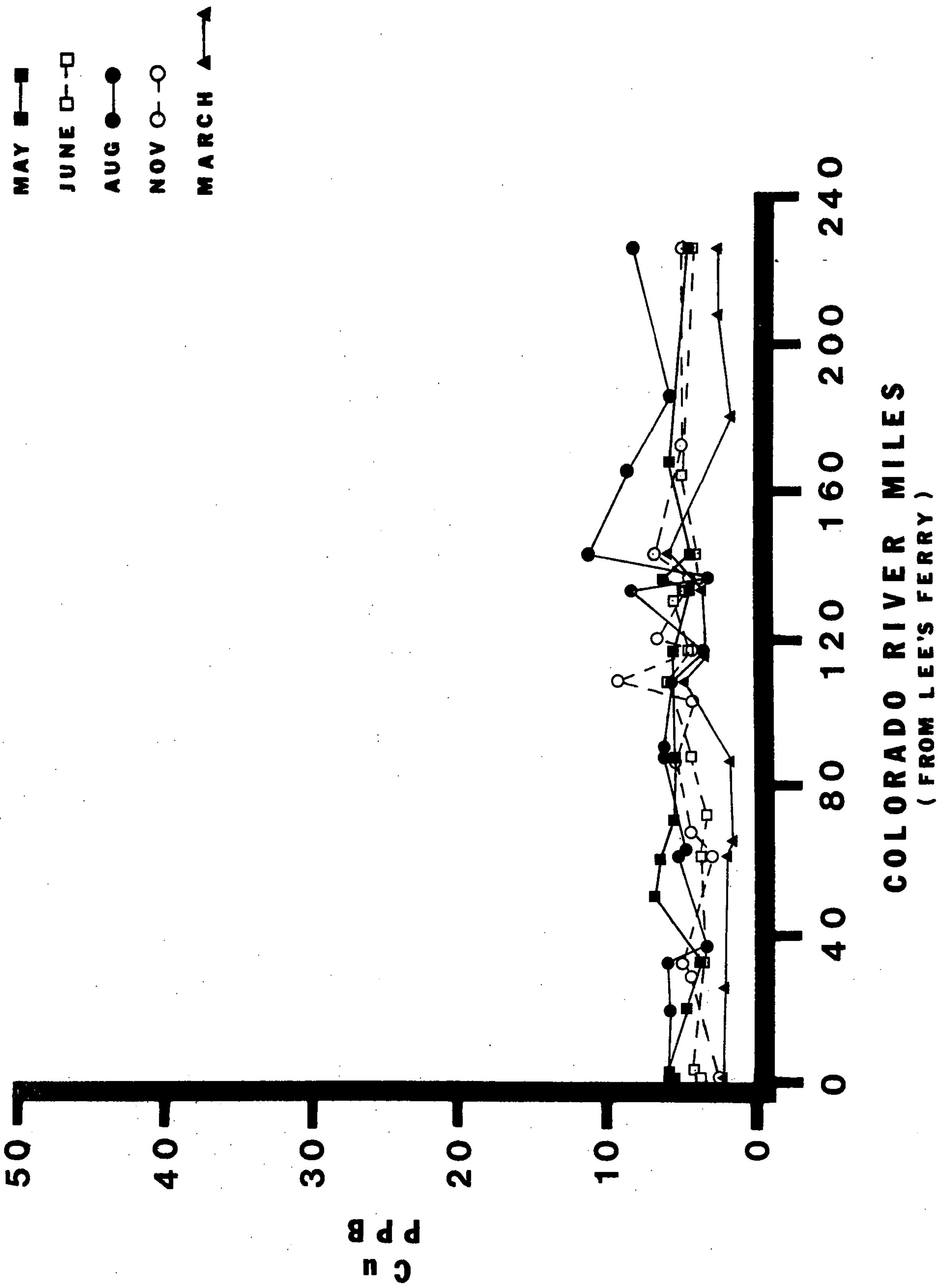

Fig. 13. Concentrations of copper in the Colorado River.

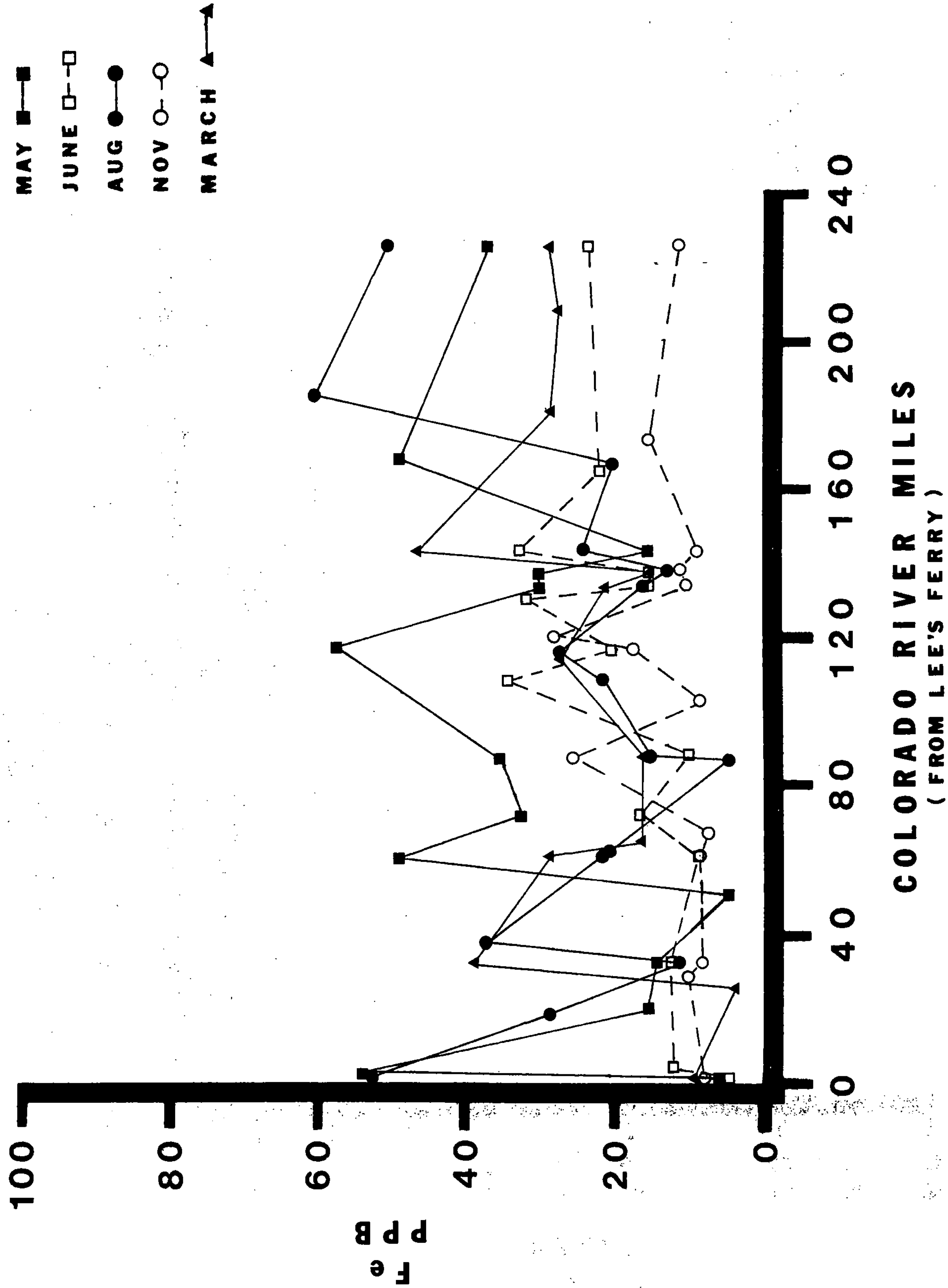

Fig. 14. Concentrations of iron in the Colorado River.

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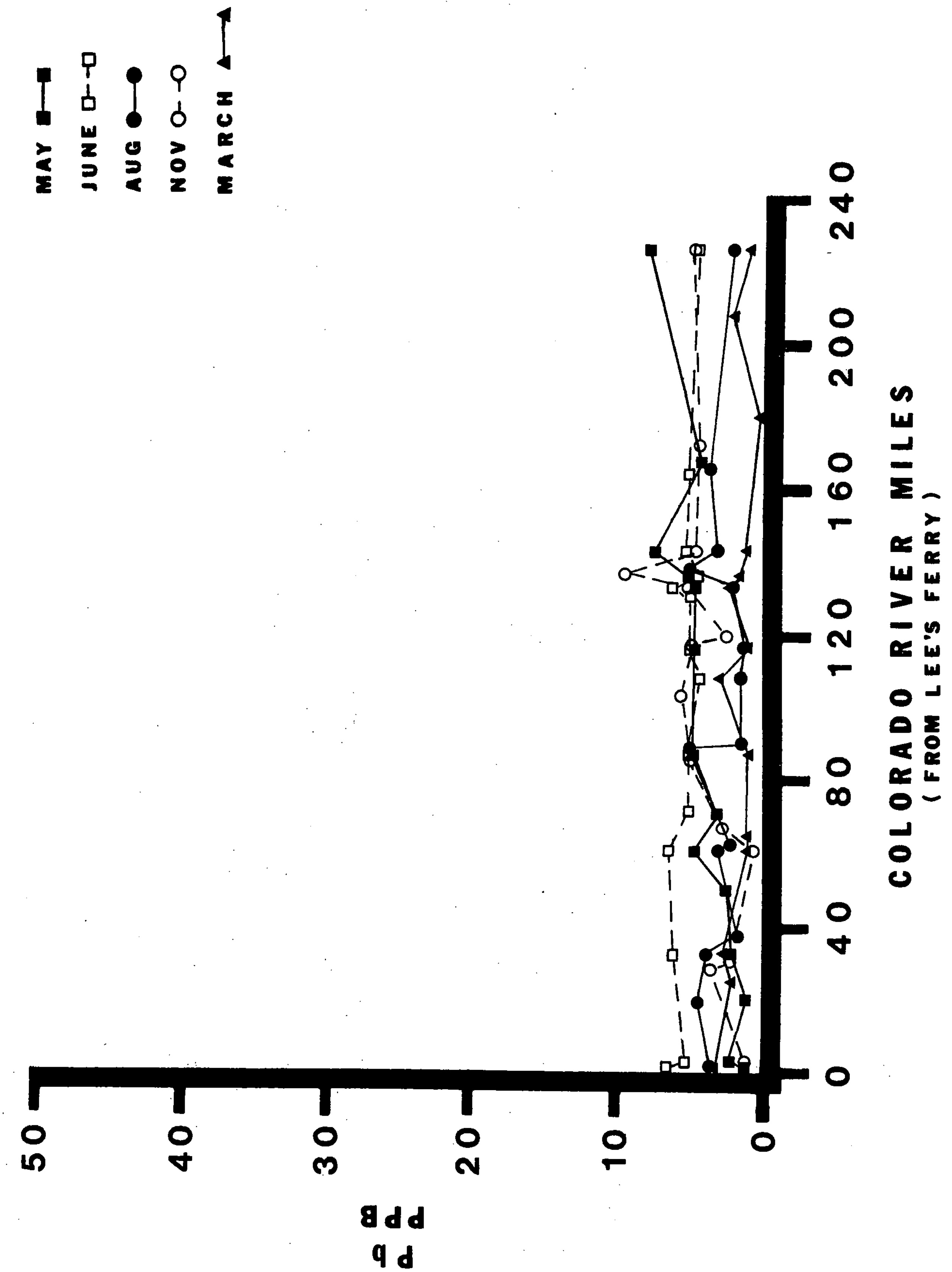

Fig. 15. Concentrations of lead in the Colorado River.

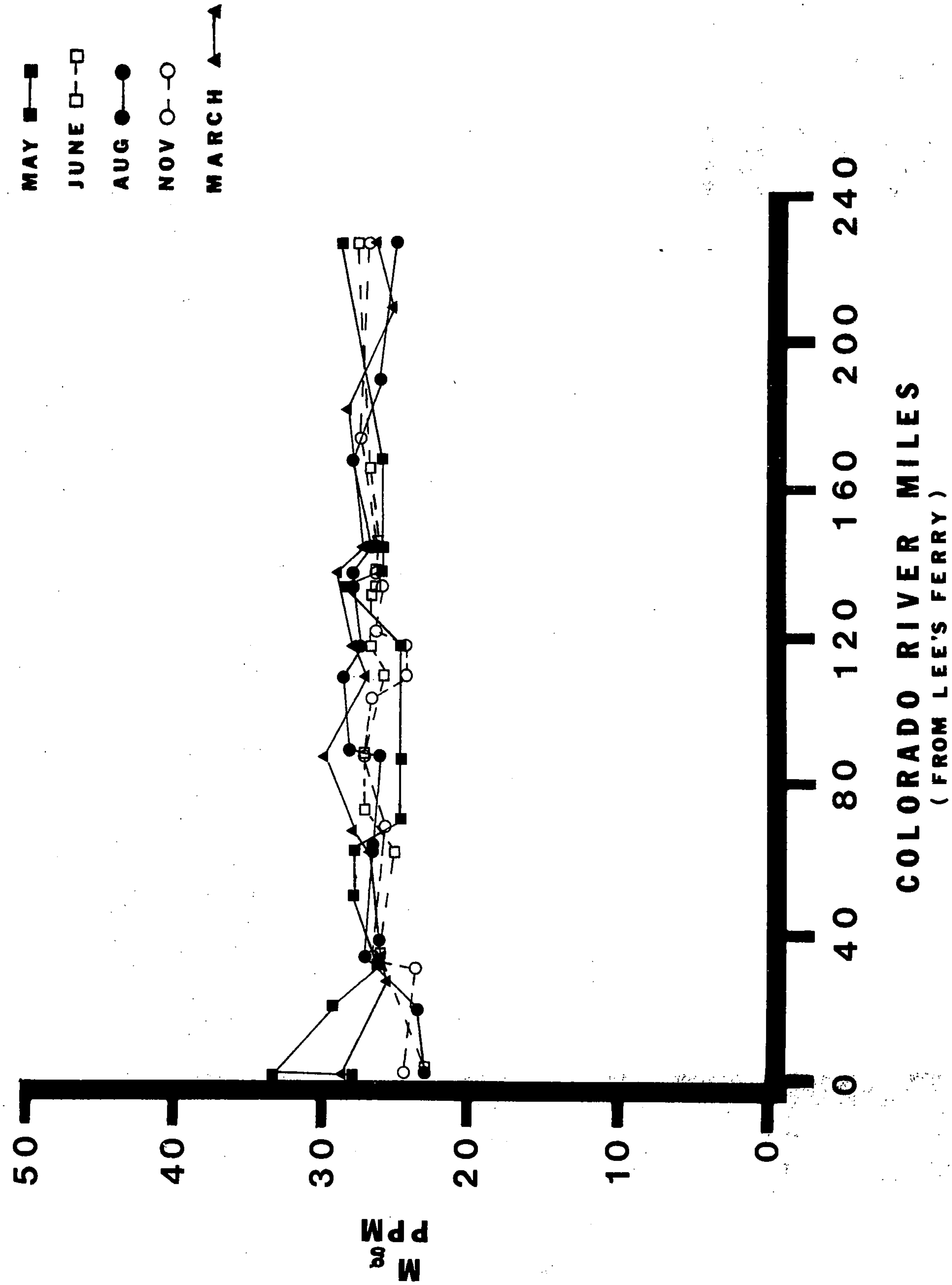

Fig. 16. Concentrations of magnesium in the Colorado River.

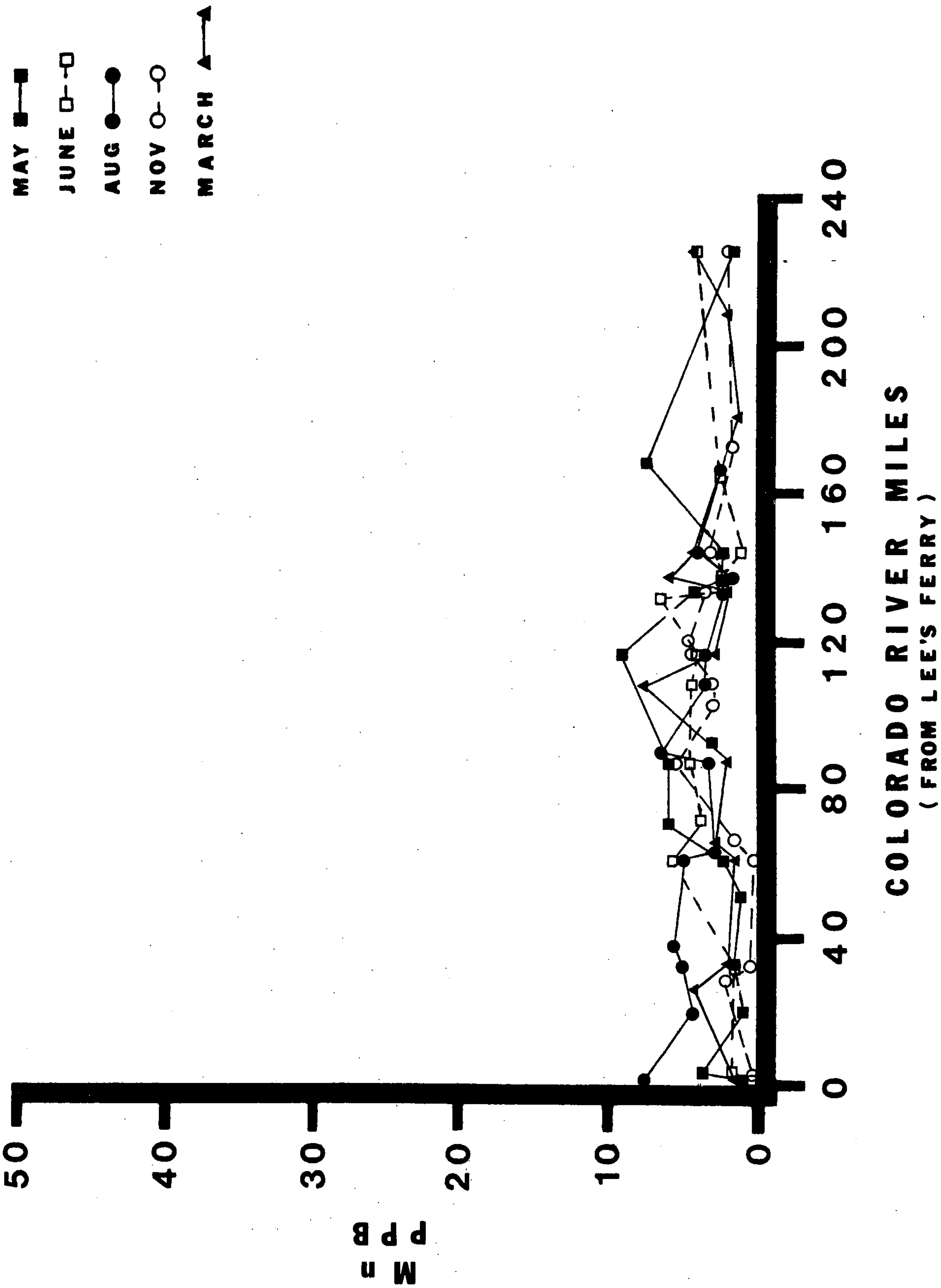

Fig. 17. Concentrations of manganese in the Colorado River.

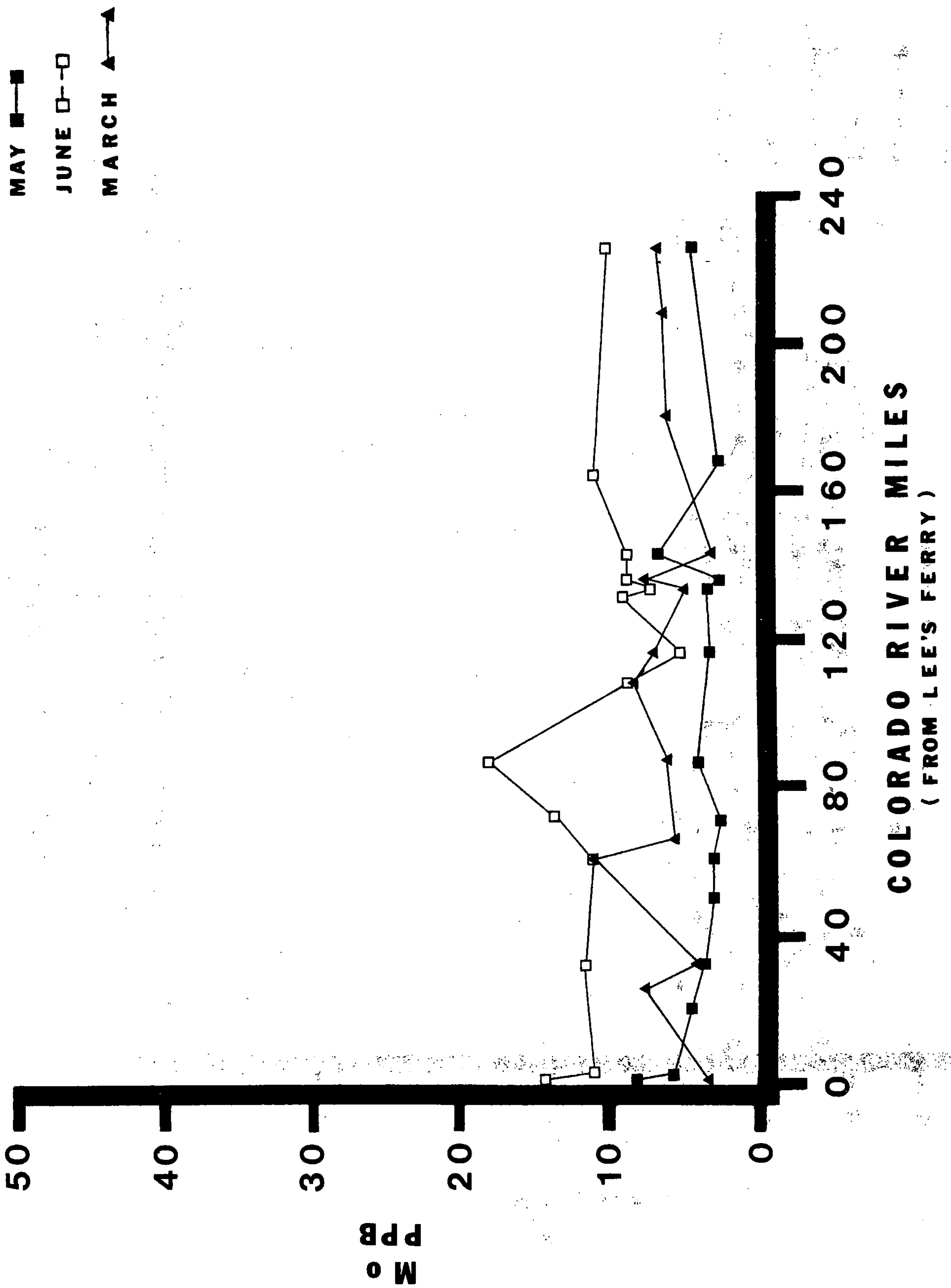

Fig. 18. Concentrations of molybdenum in the Colorado River.

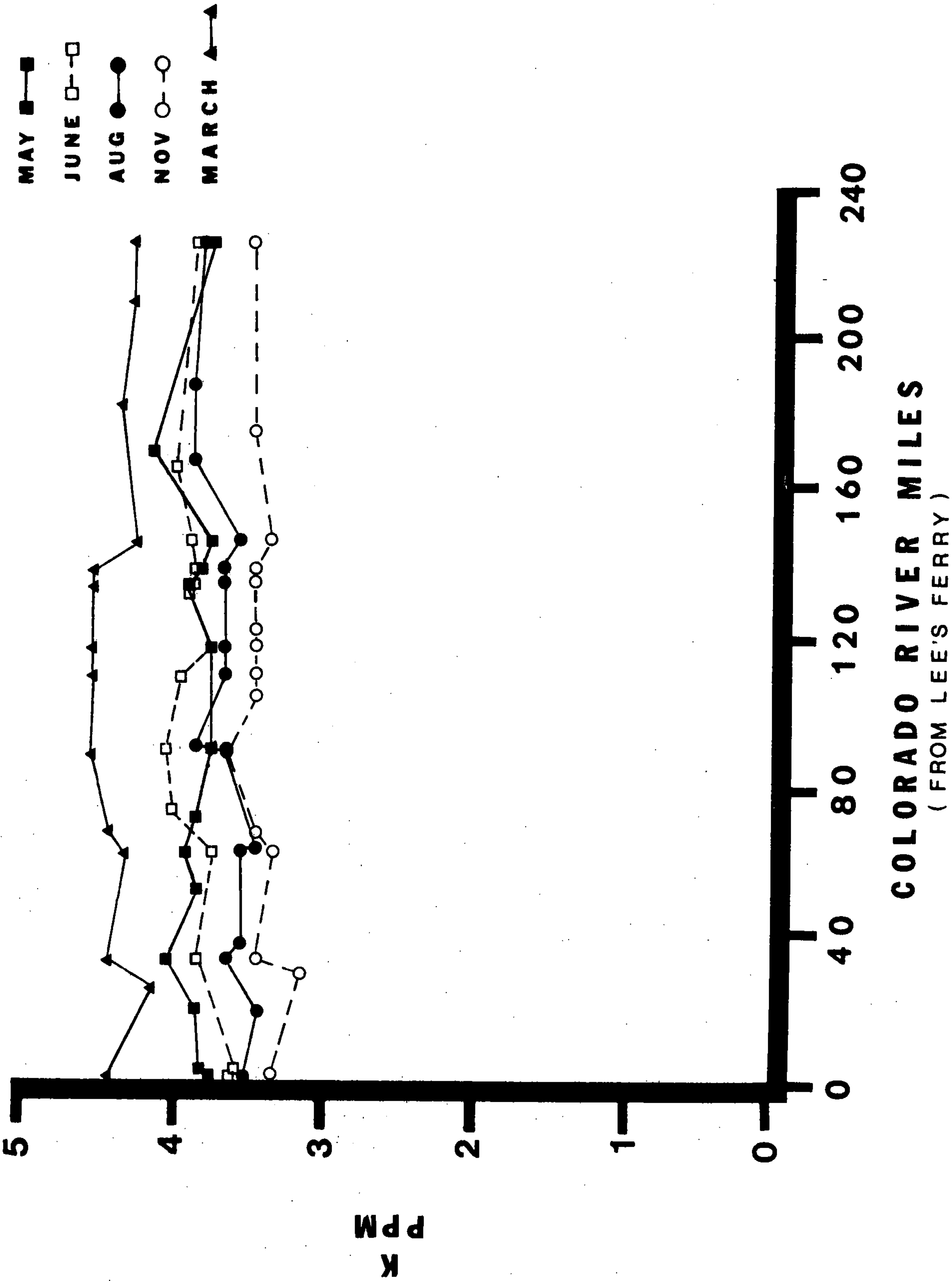

Fig. 19. Concentrations of potassium in the Colorado River.

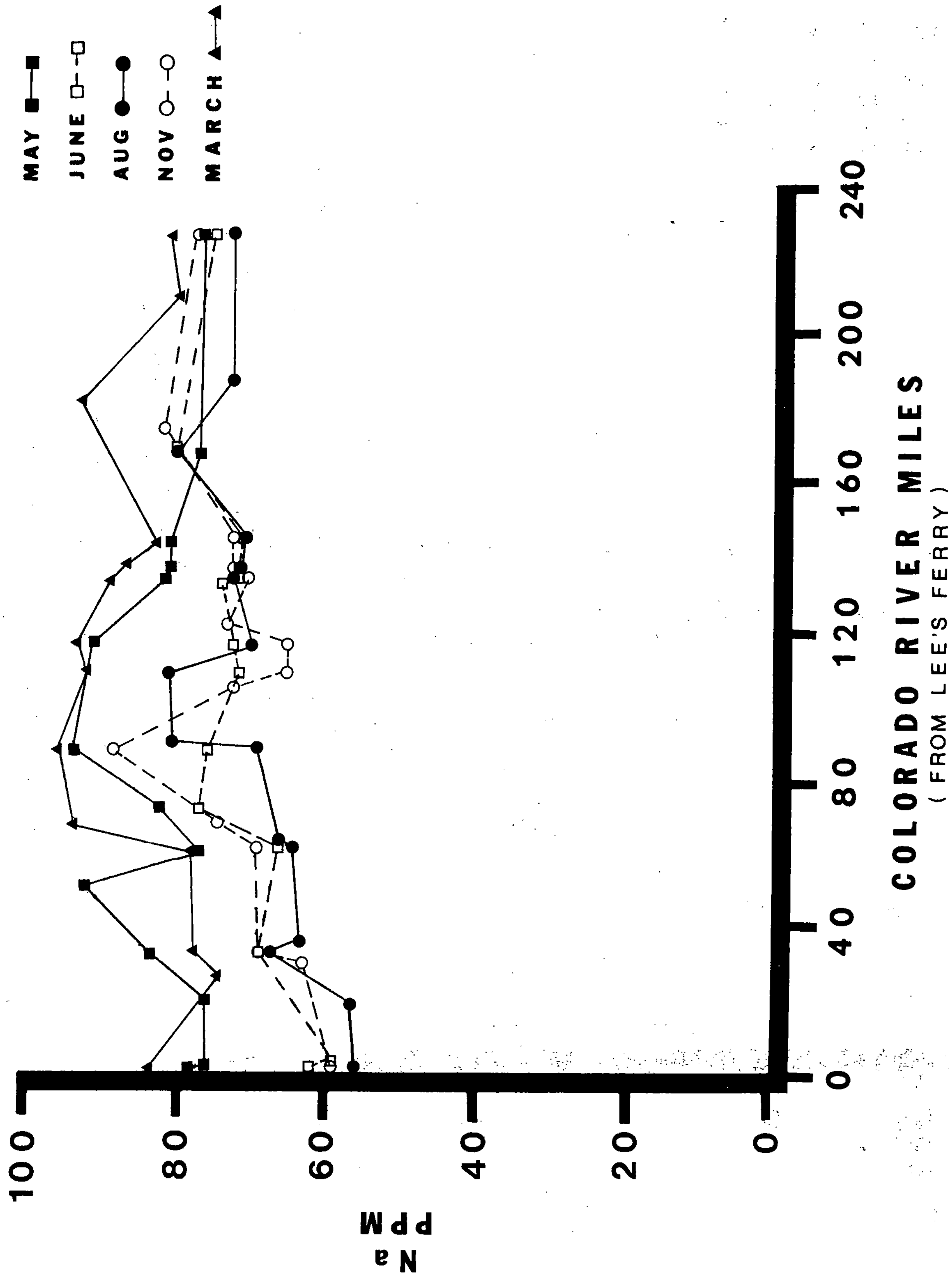

Fig. 20. Concentrations of sodium in the Colorado River.

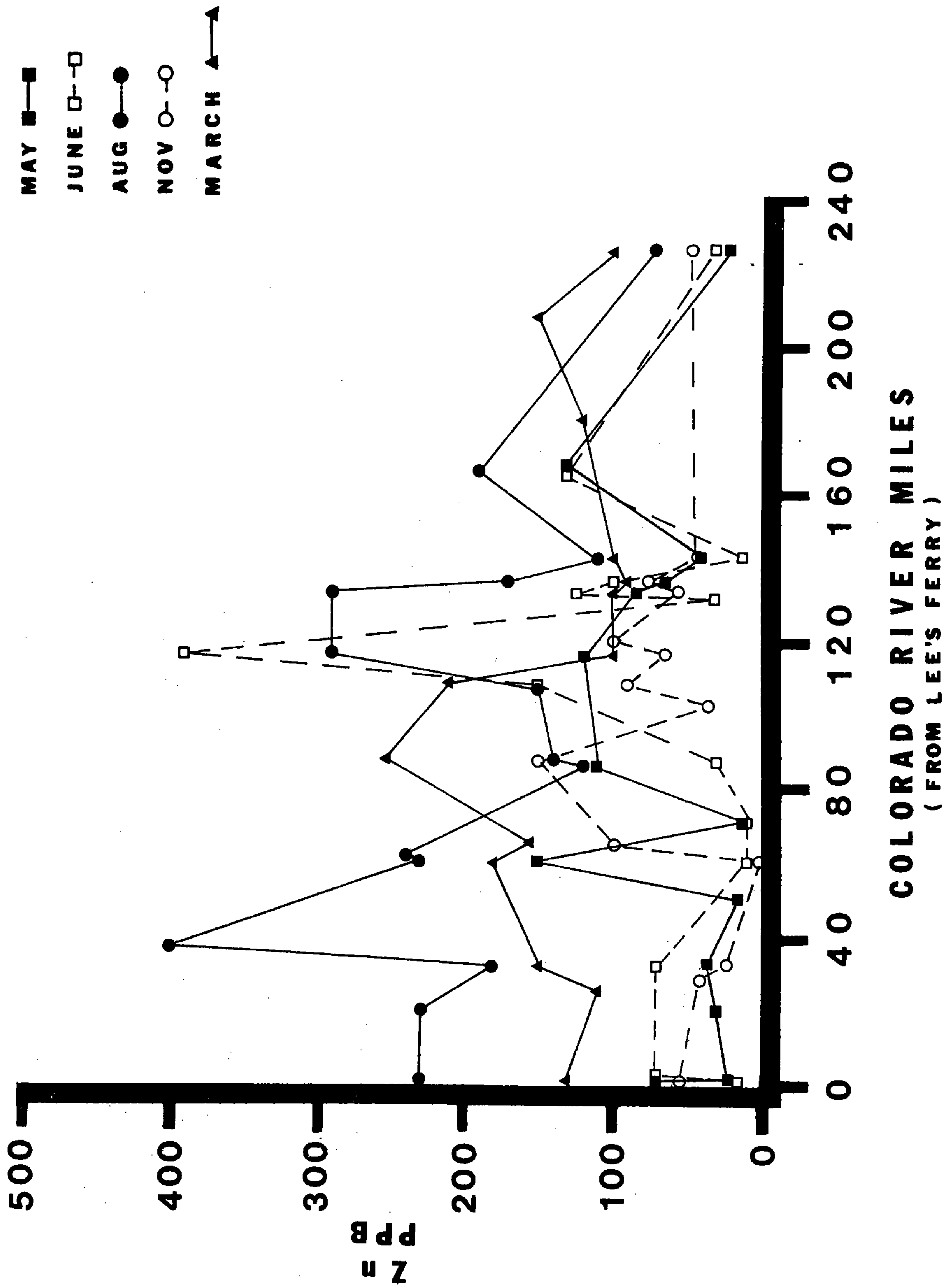

Fig. 21. Concentrations of zinc in the Colorado River.

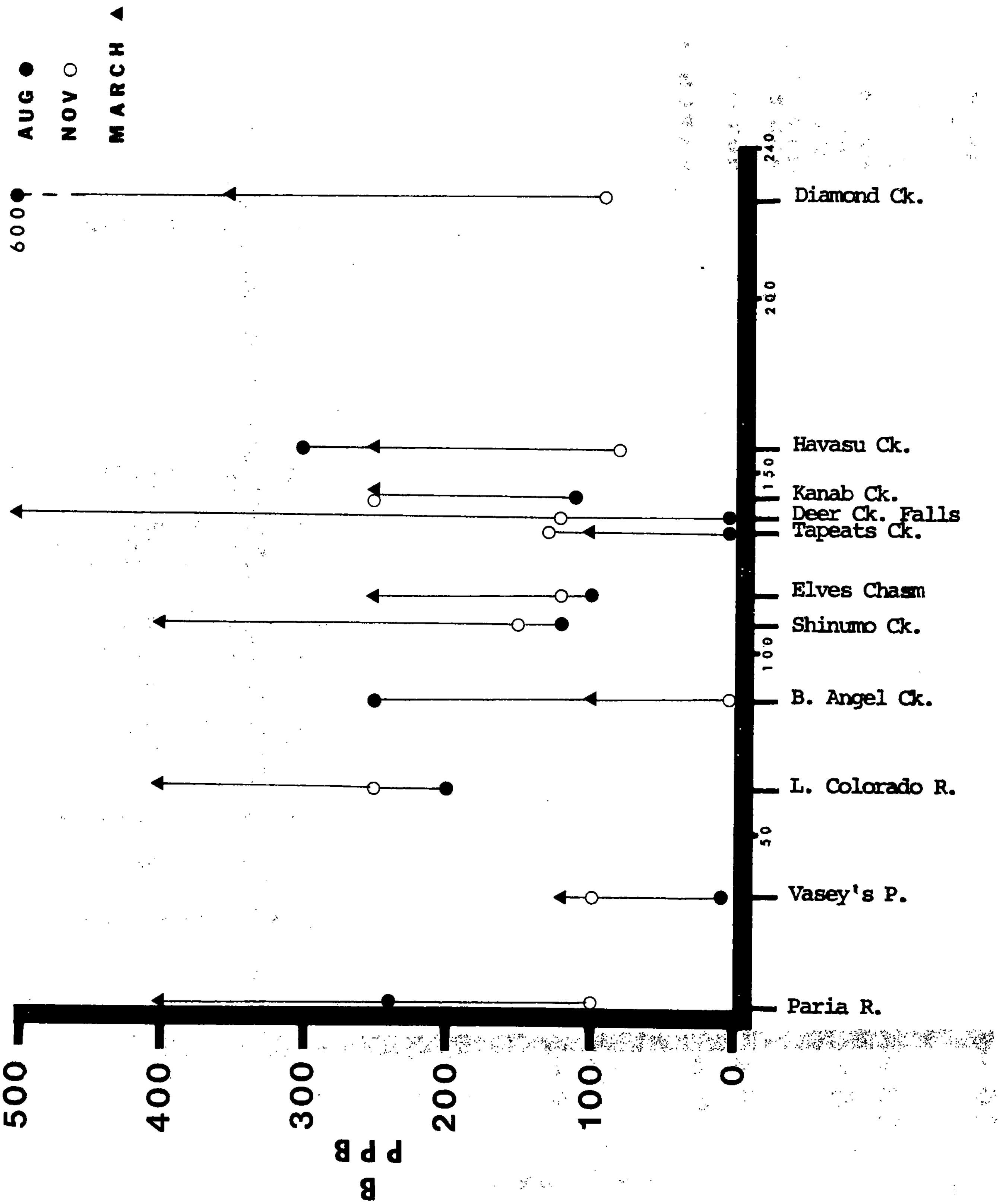

Fig. 22. Concentrations of boron in the tributaries of the Colorado River.

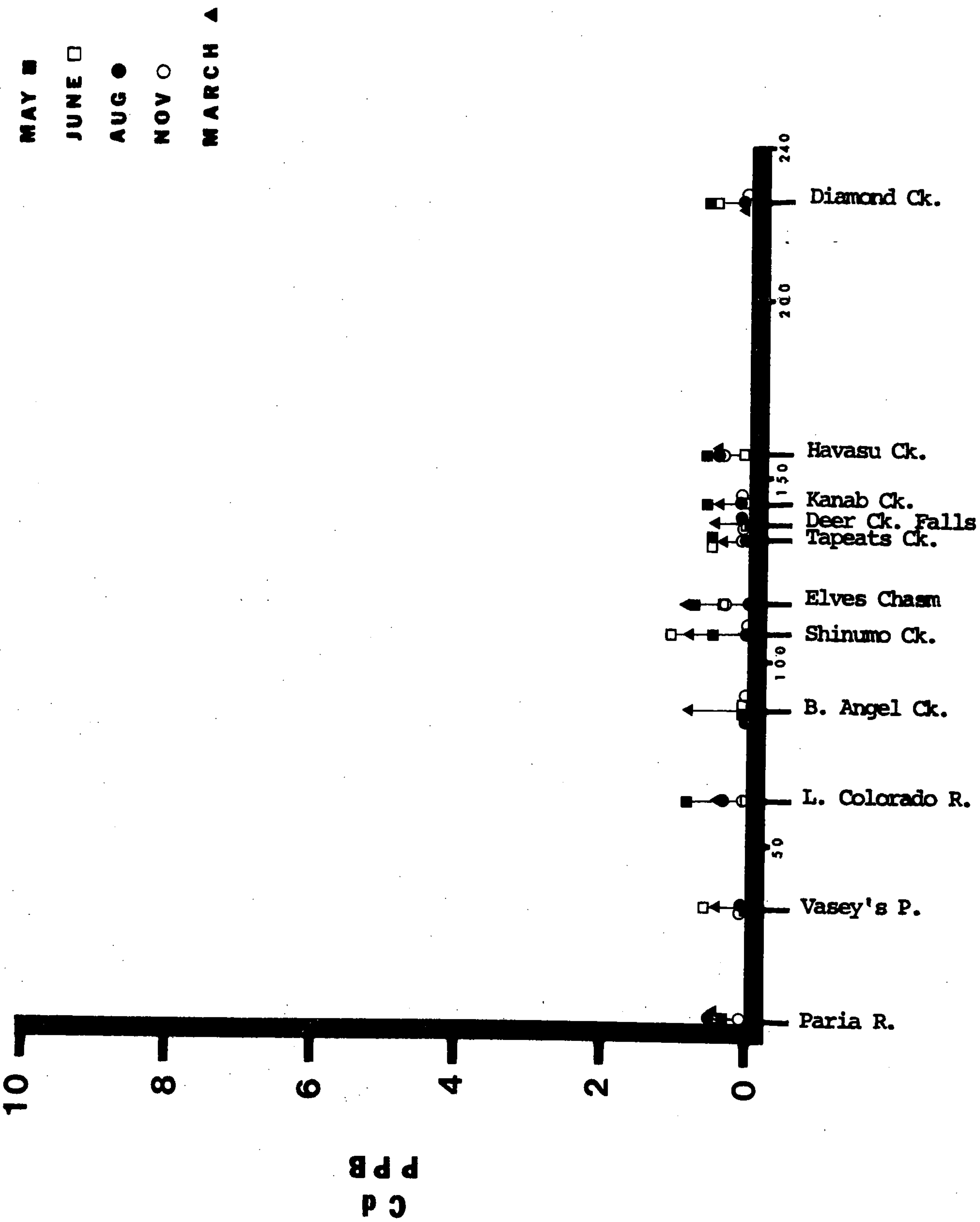

Fig. 23. Concentrations of cadmium in the triburaries of the Colorado River.

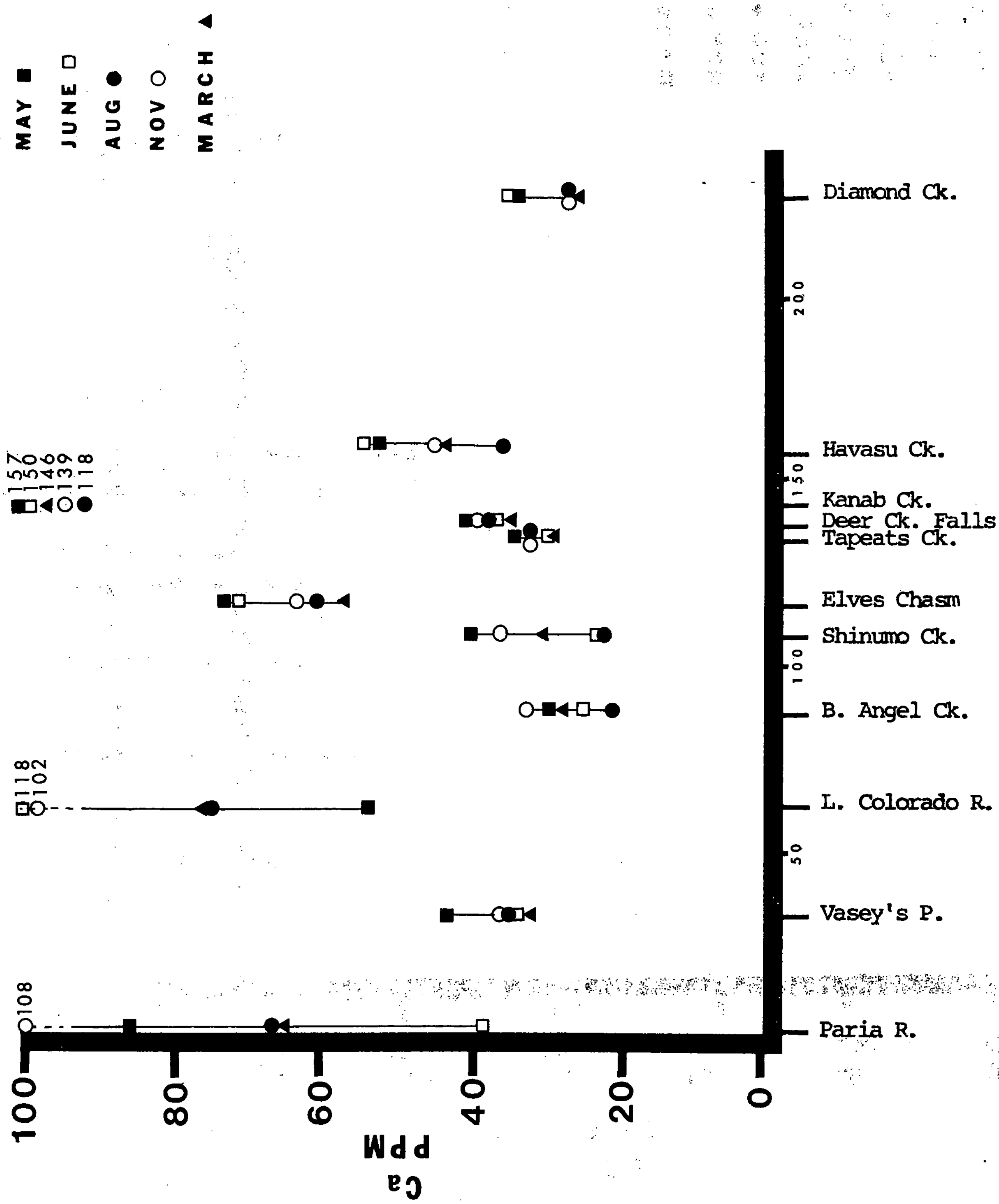

Fig. 24. Concentrations of calcium in the tributaries of the Colorado River.

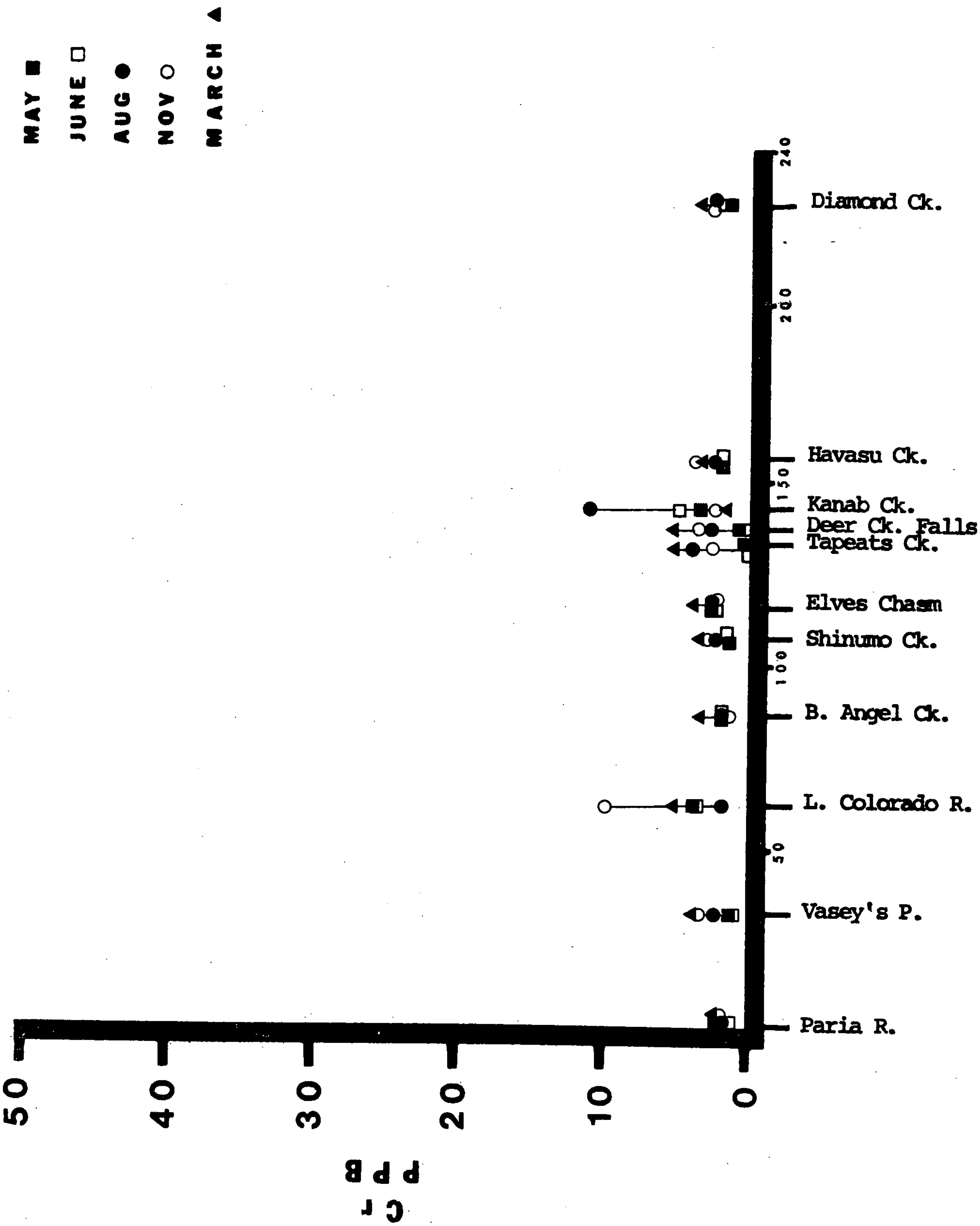

Fig. 25. Concentrations of chromium in the tributaries of the Colorado River.

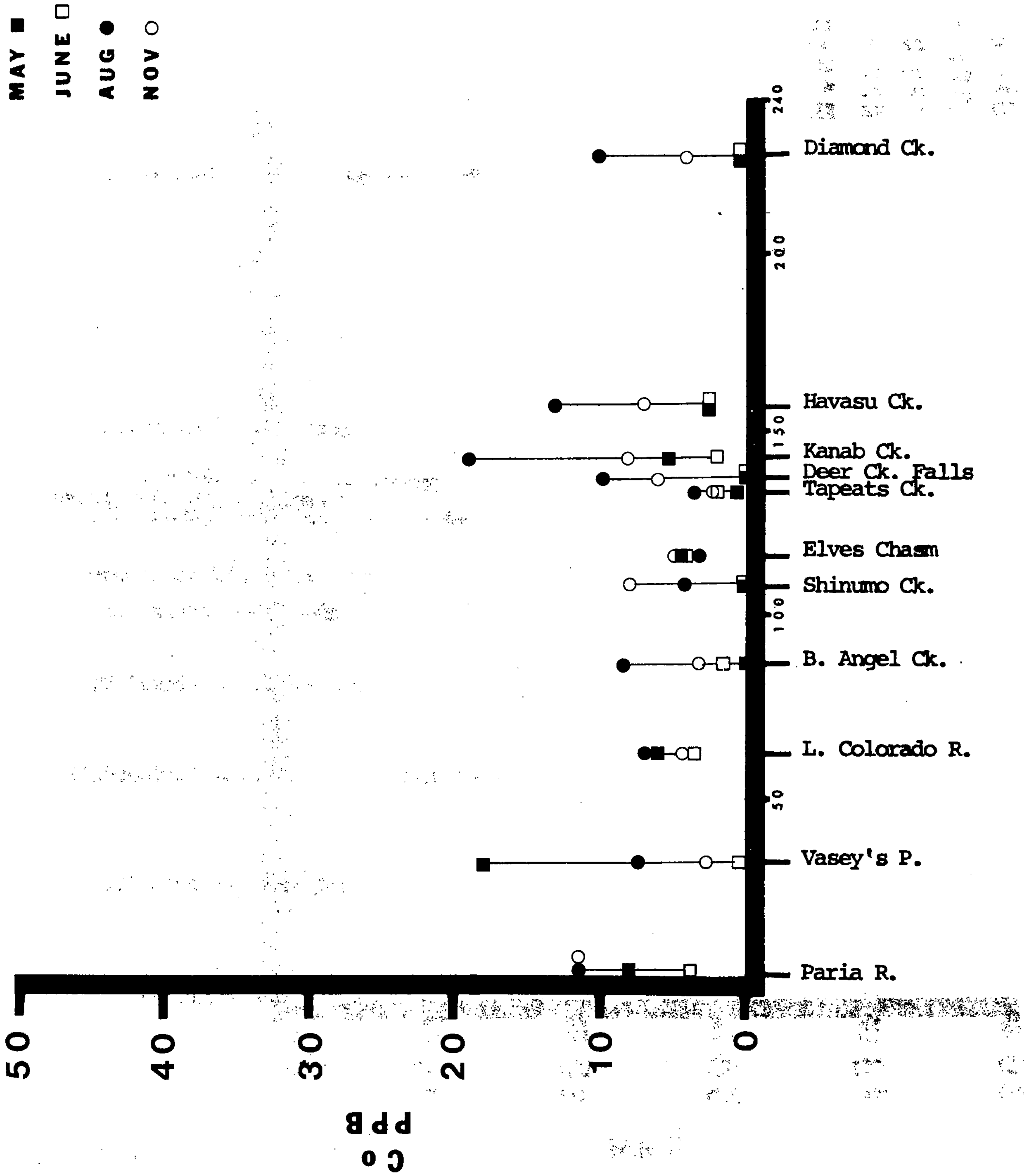

Fig. 26. Concentrations of cobalt in the tributaries of the Colorado River.

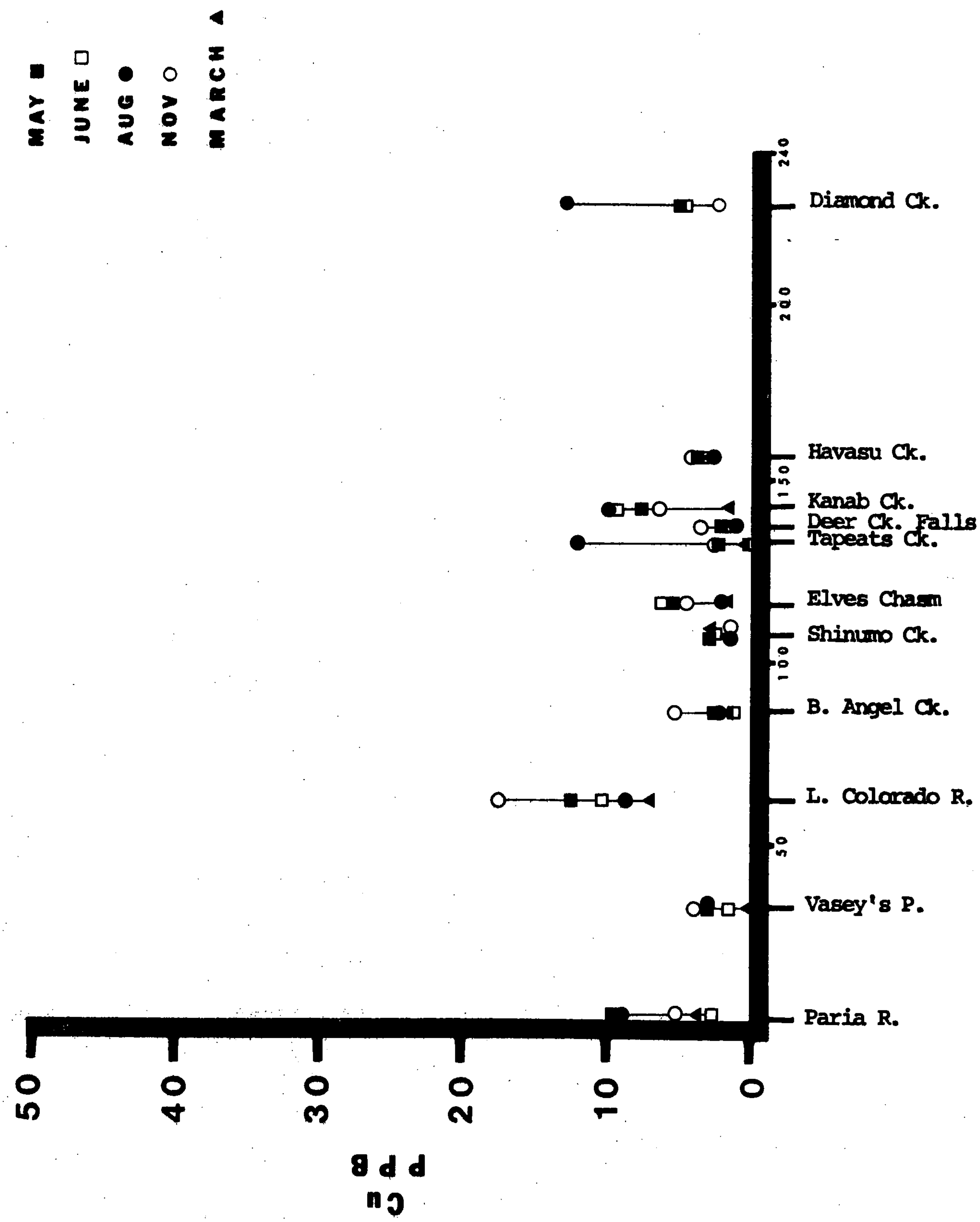

Fig. 27. Concentrations of copper in the tributaries of the Colorado River.

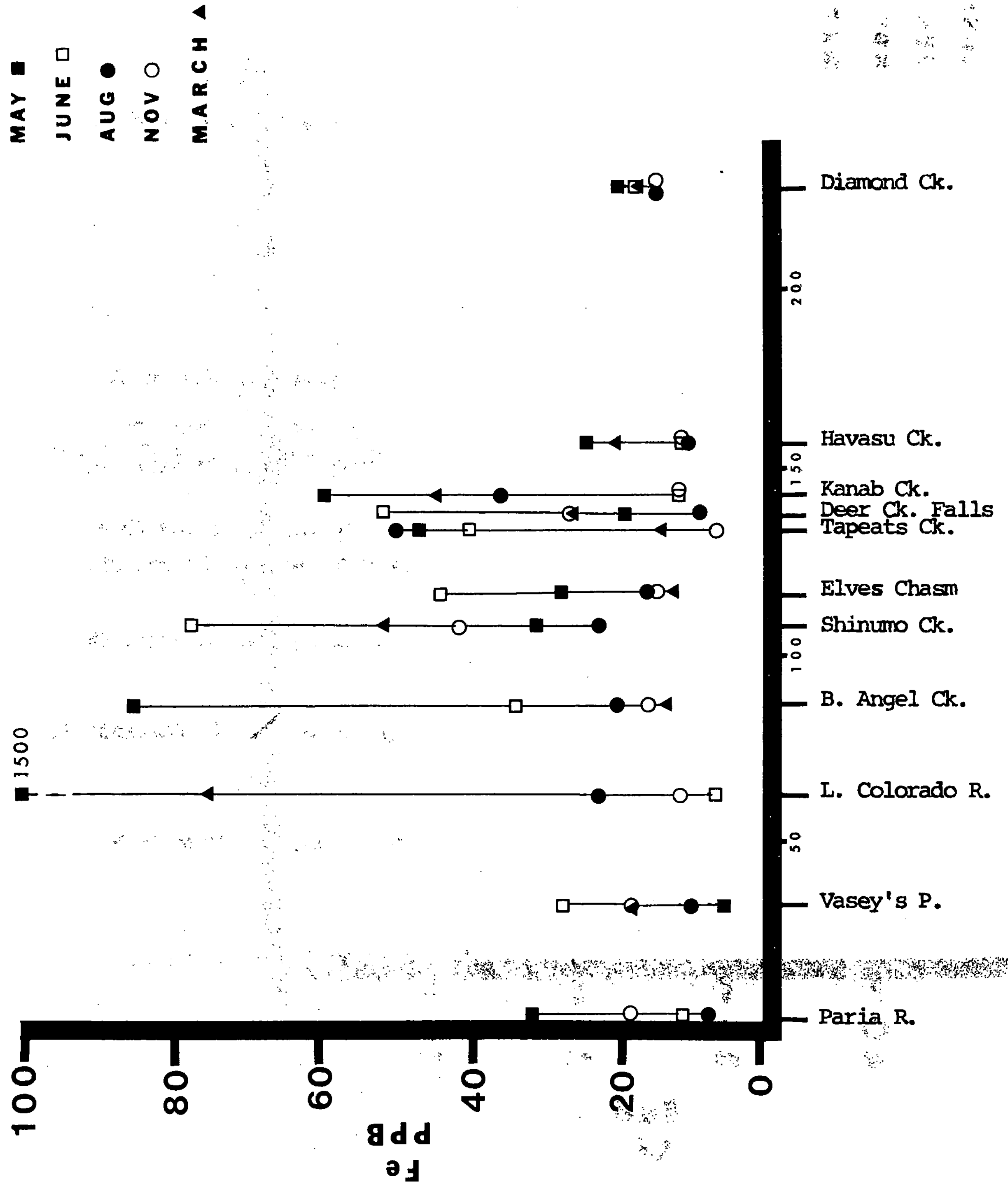

Fig. 28. Concentrations of iron in the tributaries of the Colorado River.

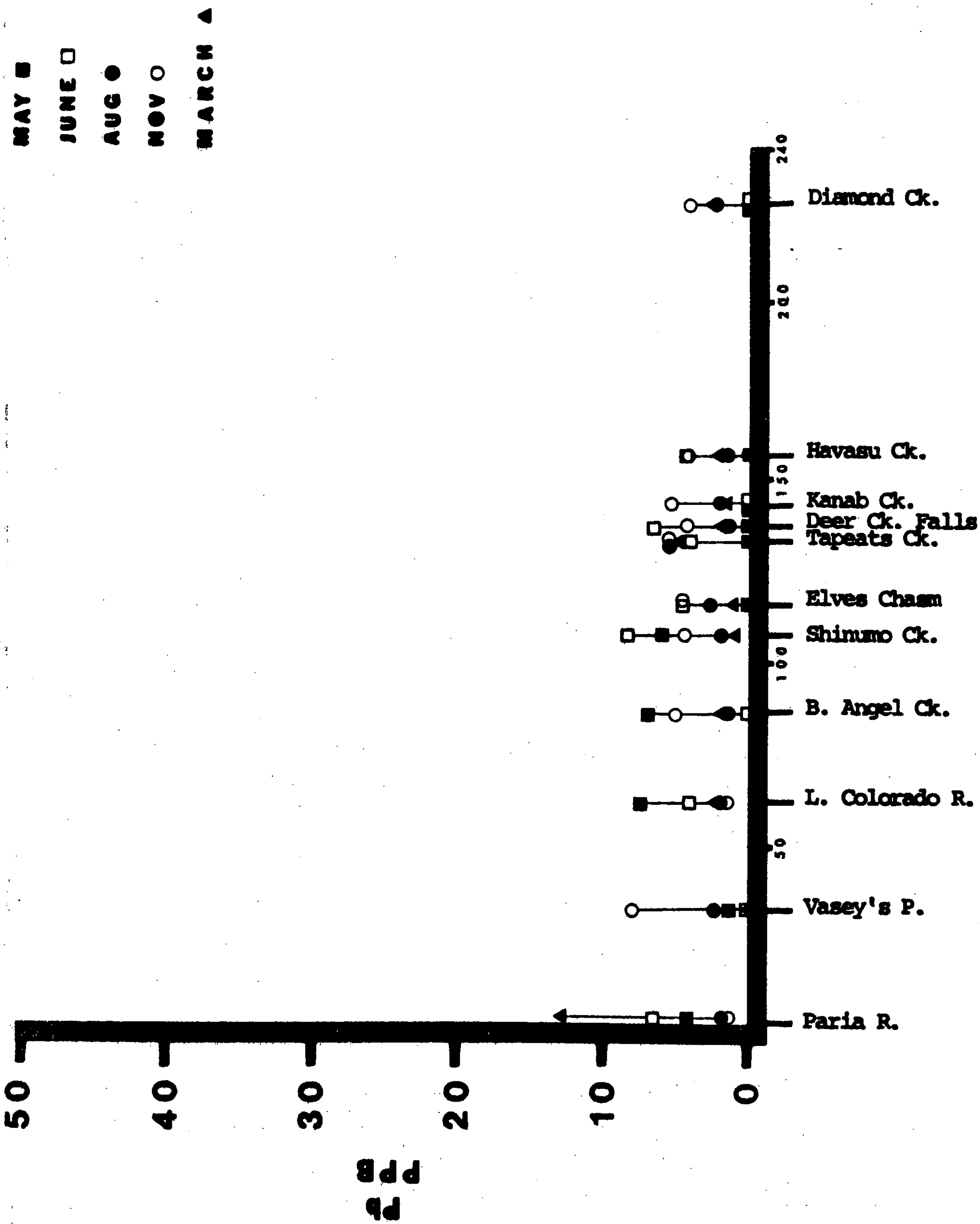

Fig. 29. Concentrations of lead in the tributaries of the Colorado River.

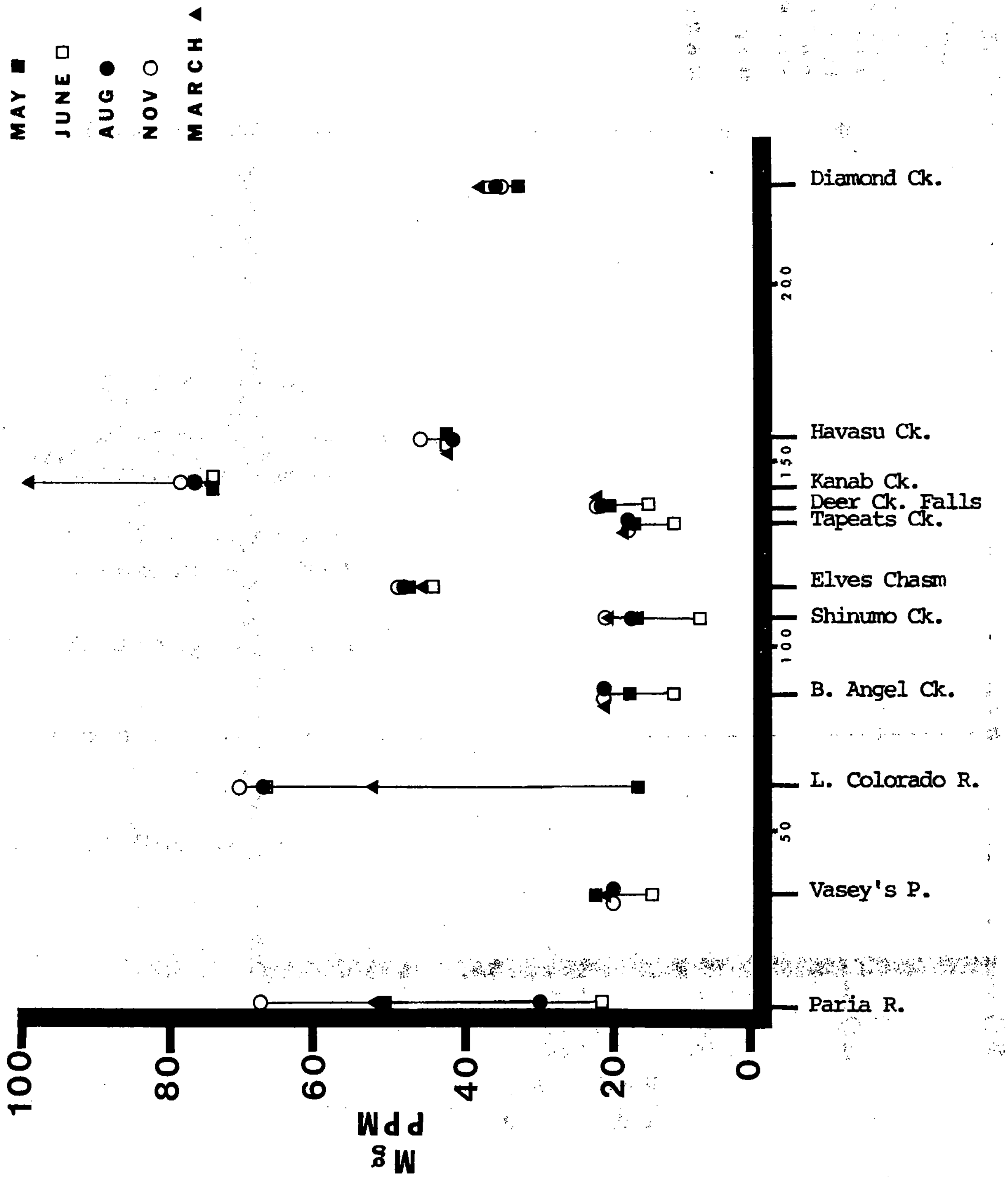

Fig. 30. Concentrations of magnesium in the tributaries of the Colorado River.

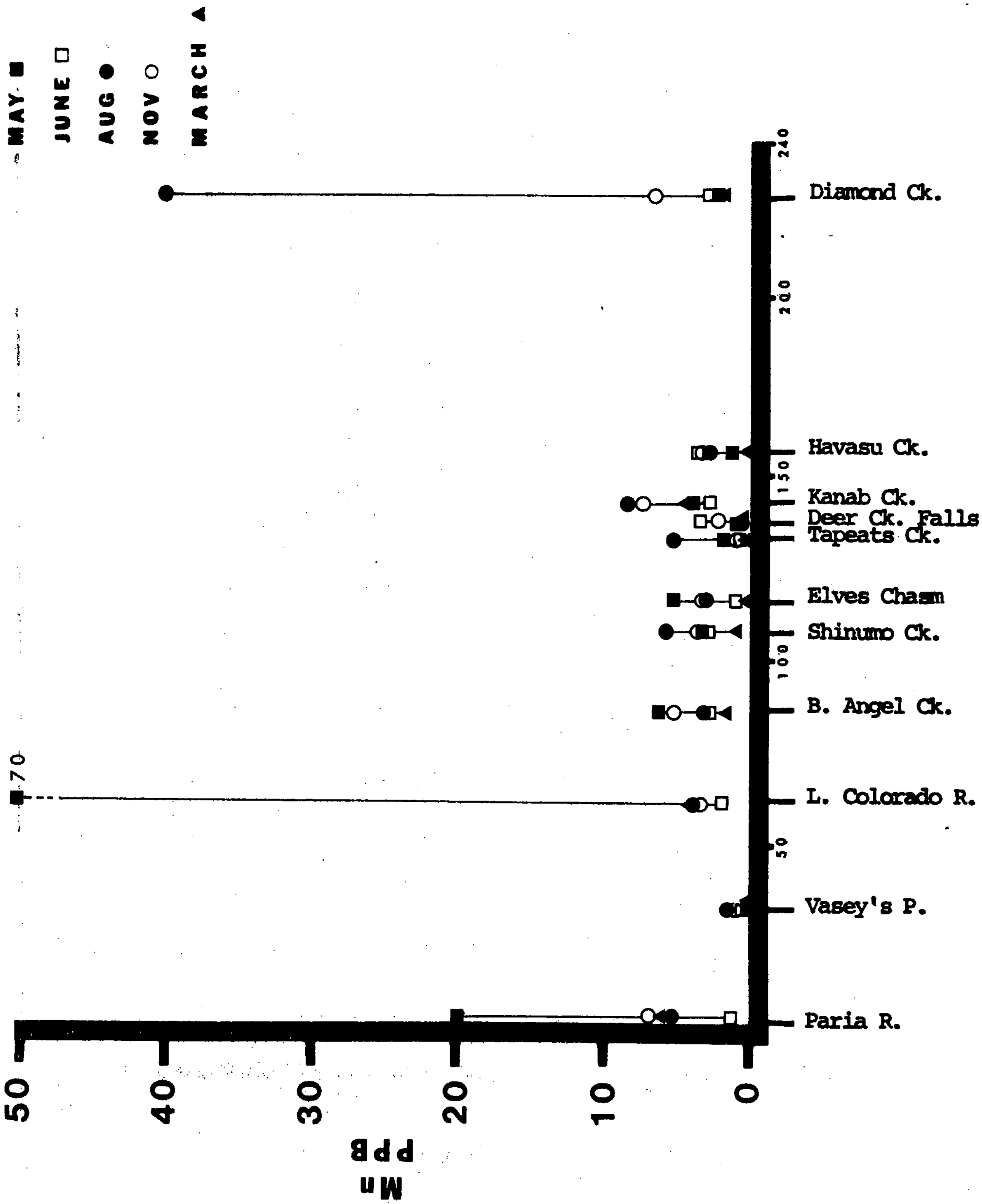

Fig. 31. Concentrations of manganese in the tributaries of the Colorado River.

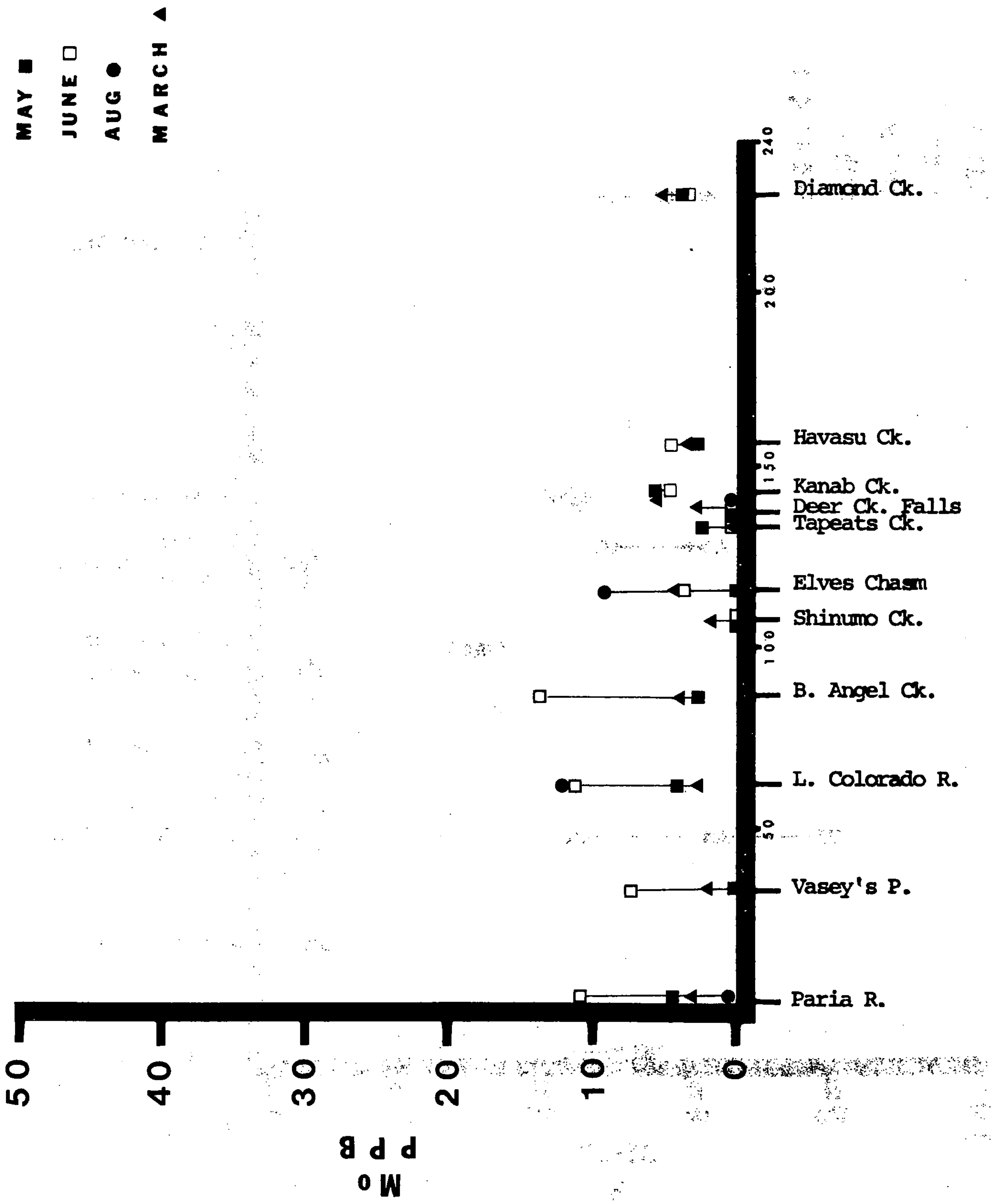

Fig. 32. Concentrations of molybdenum in the tributaries of the Colorado River.

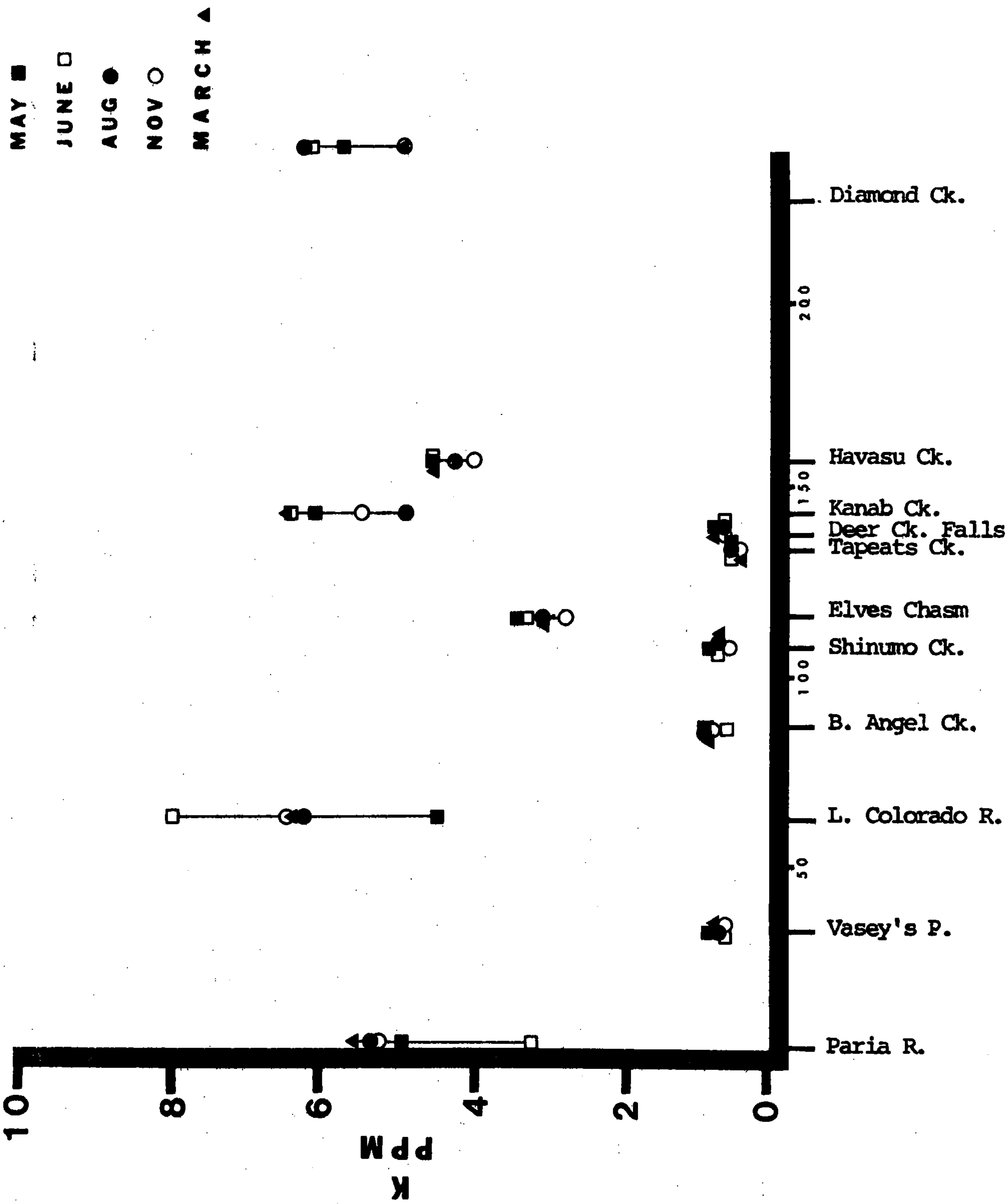

Fig. 33. Concentrations of potassium in the tributaries of the Colorado River.

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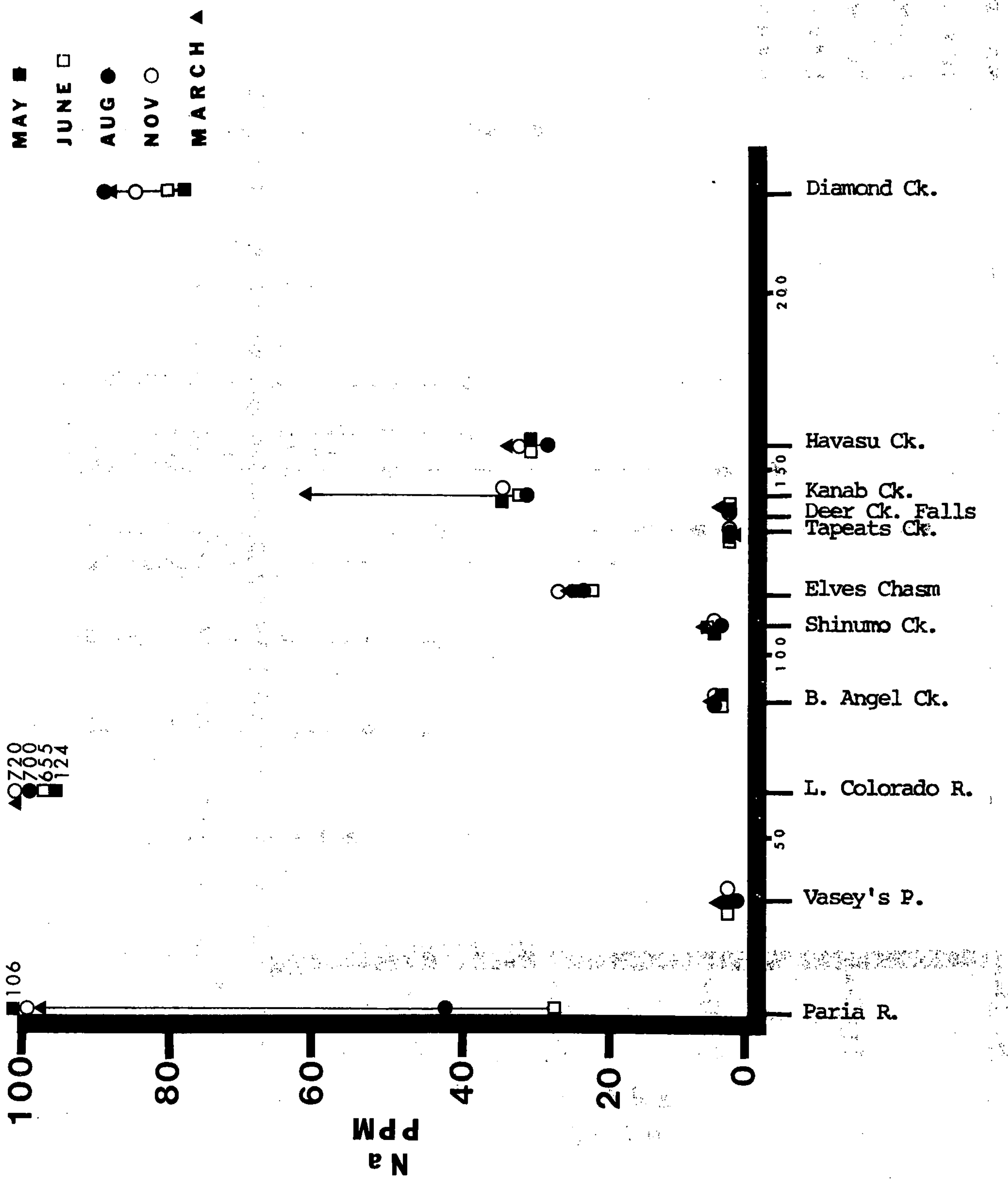

Fig. 34. Concentrations of sodium in the tributaries of the Colorado River.

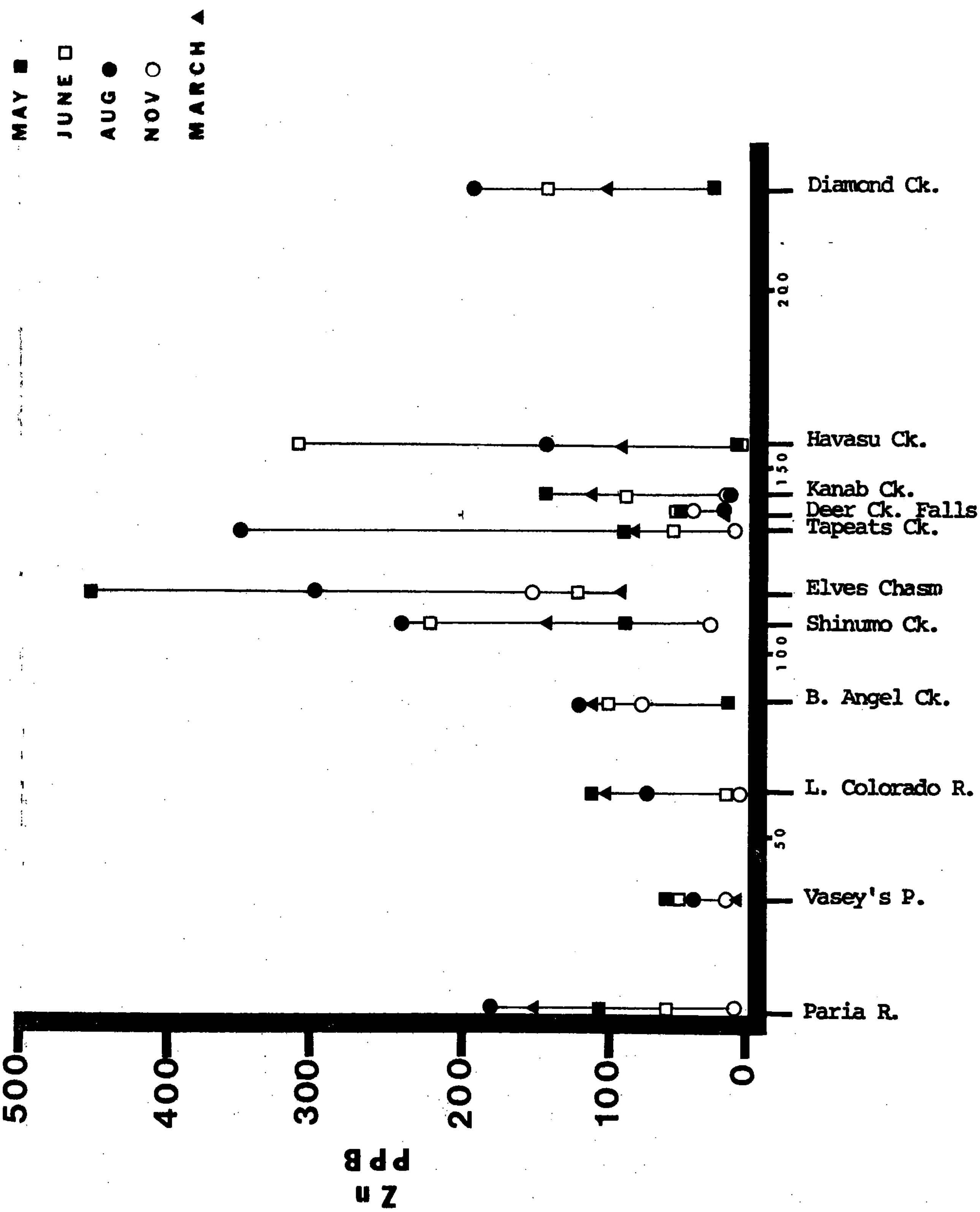

Fig. 35. Concentrations of zinc in the tributaries of the Colorado River.

Table 1. Sample sites on Colorado River in the Grand Canyon National Park and Vicinity[1].

Site	River Mile[1]	Site	River Mile[1]
1	0.0	17	103
2	1.0	18	108
3	18.3	19	116
4	19.0	20	120
5	25.0	21	132
6	29.0	22	133.7
7	32.0	23	136.3
8	37.8	24	143.7
9	50.0	25	145.5
10	61.0	26	156.9
11	61.2	27	164.5
12	66.0	28	166.6
13	71.0	29	168.0
14	72.0	30	173.0
15	87.0	31	180.0
16	88.5	32	225.0

[1] River miles measured downstream from Lee's Ferry (river mile 0.0)

Table 2. Major Tributaries and Springs sampled along the Colorado River in the Grand Canyon National Park and Vicinity[1].

Site	River Mile[1]
Paria River	.3
Vaseys Paradise	31
Little Colorado	61.5
Bright Angel Creek	87.7
Shinumo Creek	108.5
Elves Chasm	116.5
Tapeats Creek	133.7
Deer Creek Falls	136.3
Kanab Creek	143.7
Havasu Creek	156.9
Diamond Creek	225.6

[1] River miles measured downstream from Lee's Ferry (river mile 0.0).

Table 3. Effect of chlorination on total bacterial numbers in Colorado River water.

Water Sample	Chlorine (ppm)	Bacterial Numbers Before chlorination	Bacterial Numbers After chlorination
Mile 93.7	1.3	800	10
	2.6	1230	40
	5.2	1120	80
Mile 225	1.3	1150	10
	2.6	750	0
	5.2	660	0

Table 4. Effect of chlorination on total coliform bacterial levels in Colorado River water.

Water Sample	Chlorine (ppm)	Bacterial Numbers Before chlorination	Bacterial Numbers After chlorination
Mile 93.7	1.3	104	0
	2.6	126	0
	5.2	20	0

Table 5. Effect of chlorination on total bacterial coliforms per 100 ml (Tempe water).

Water Sample	Chlorine concentration (ppm) 0	.01	.12	.32	.65	1.3	2.6
1	TNTC	TNTC	TNTC	TNTC	-	20	8
2	TNTC	TNTC	TNTC	-	56	68	0
3	200	200	58	-	48	0	0

Table 6. Effect of time following chlorination (2.6 ppm) on total bacterial coliforms per 100 ml (Tempe water).

Water Sample	Control	Time after chlorination (min) 0	5	10	15	20	30
1	TNTC	32	-	12	4	0	0
2	184	4	0	0	0	-	0
3	200	0	4	0	0	4	0

Table 7. Checklist of phytoplankton species, their distribution, and abundance in the Colorado River and its tributaries in Grand Canyon National Park. The following were used to designate relative abundance of organisms/liter: (D) Dominant, 1000 or greater; (F) Frequent, 100-999; (R) Rare, less than 100.

CHRYSOPHYTA
CHRYSOPHYCEAE
Ochromonadales
(1) Genus Dinobryon Ehr.
1. sertularia Ehr.: (R), occurring in August at river miles 0 and 18, and in November at river miles 29, 32, 61 and 87.
XANTHOPHYCEAE
Tribonematales
(2) Genus Tribonema Derb. & Sol.
2. utriculosum (Kütz.) Hazen: (R), occurring in May with only single specimen found at river mile 133.
Mischococcales
(3) Genus Tetragoniella Pasch.
3. sp.: (R), occurring in March with single specimen at river mile 0.
BACILLARIOPHYCEAE
Centrales
(4) Genus Biddulphia Gray
4. laevis (E.) Hust.: (R), species found during May at three sites in the river, miles 133, 143 and 225. (D), occurring in Elves Chasm during May and August and in Diamond Creek in May, June and November. (F), at Diamond Creek in March and Elves Chasm in November.
(5) Genus Cyclotella Kütz.
5. sp.: (R), with only a single specimen at miles 108 and 137 in March, and in Kanab Creek in November.
(6) Genus Melosira Ag.
6. islandica O. Müll.: (R), only one specimen found in May in Tapeats Creek.
7. varians Ag.: (R), but occurring in May, June and August at all river sites and in March only at river miles 0 and 25. (R), in Tapeats Creek in May (R), in Bright Angel Creek, Shinumo Creek, Elves

Chasm and Tapeats Creek in August, and at Diamond Creek in March.

Pennales

(7) Genus Achnanthes Bory

8. affinis Grunow: (R), occurring in August in Tapeats Creek.
9. coarctata Breb.: (R), occurring in November along entire river. (R) in Elves Chasm and Kanab Creek and (F) in Havasu Creek in August. (R), occurring at Elves Chasm, Deer Creek, Kanab Creek and Havasu Creek in November, occurring at the Little Colorado River, Bright Angel Creek, Shinumo Creek, Havasu Creek and Diamond Creek in March.
10. flexella (Kütz.) Brun.: (R), only one specimen found in Kanab Creek in March.
11. lanceolata Breb.: (R), occurring only in March at river miles 0, 32, 61 and 87.
12. linearis W. Sm.: (R), occurring at Tapeats Creek in August.
13. minutissima Kütz.: (R), occurring in May at river mile 31 and in August at river mile 61. (R), occurring at Vaseys Paradise in June with only one specimen collected.

(8) Genus Achnanthidium Kütz.

14. sp.: (R), one specimen occurred in March at river mile 0.

(9) Genus Amphiprora Ehr.

15. alata Kütz.: (R), one specimen collected in the Little Colorado River in June.

(10) Genus Amphora Ehr.

16. ovalis Kütz.: (R), occurring in November at river miles 29, 87, 103 and 116, and in March with only one specimen at river mile 25. (R) in August in the Little Colorado River.

(11) Genus Anomoeoneis Pfitz.

17. serians var. brachysira (Breb.) Hust.: (R), occurring in June only at one river site mile 87 and in Bright Angel Creek.
18. exilis (Kütz.) Cl.: (R), occurring in May with only one specimen at mile 133. (R) in Shinumo Creek and Elves Chasm in May.
19. sphaerophora (Kütz.) Pfitz.: (R), occurring at Elves Chasm in May.

(12) Genus Asterionella Hass.

20. formosa Hass.: (R), occurring in May at river miles 1, 19, 50, 61, 143 and 168. Specimens are (F) in June, occurring along rivers entire length. (R),

occurring between river miles 0 and 61 in August. Specimens rarely observed at sites below mile 61, and only at river mile 136 and 143. No specimens occurred during November or March sampling.

(13) Genus Caloneis Cl.

21. amphisbaena (Bory) Cl.: (R), occurring in May with one specimen at river mile 61 and in November at river mile 32.

(14) Genus Campylodiscus Ehr.

22. balatonis Pant.: (R), occurring only in Shinumo Creek in May.

23. hibernicus (Ehr.) Grun.: (R), occurring only in Shinumo Creek in June.

(15) Genus Cocconeis Ehr.

24. diminuta Pant.: (R), occurring in Tapeats Creek, Deer Creek and Kanab Creek in November.

25. pediculus Ehr.: (R), a species which occurs during May, June and August at all river sites. (F), in November at river miles 87, 103, 134 and 143, (R) at all other river miles. (F), in Bright Angel, Shinumo Creek and Elves Chasm in May. (F), occurring at Vaseys Paradise, Elves Chasm, Tapeats, Deer and Diamond Creeks in June. (R) in August, occurring in all tributaries but the Paria River and Kanab Creek. (D) in August in Diamond Creek. (R) in November, occurring in all tributaries but the Paria River and Vaseys Paradise. (D) in November in Diamond Creek. (R), occurring in March in Bright Angel Creek, Shinumo Creek, Tapeats Creek and Havasu Creek. (D) in Diamond Creek in March.

26. placentula (Ehr.): (R), only one specimen found in March at river mile 116.

(16) Genus Cylindrotheca Rabh.

27. gracilis (Breb.) Grun.: (R), only one specimen found in Kanab Creek in August.

(17) Genus Cymbella Ag.

28. affinis Kütz.: (R), only one specimen was collected at river mile 116 in May. (R), in August, November and March throughout the entire river. (R), occurring in May at Shinumo Creek, in August at Kanab Creek, in November in the Little Colorado River, Tapeats Creek, and Diamond Creek, and in March in Bright Angel Creek, Elves Chasm and Deer Creek.

29. aspera (Ehr.) Cl.: (R), only one specimen collected in June at river mile 71.

30. caespitosa (Kütz.) var. ovata Grun.: (R), occurring in June from river mile 61 to 71.

31. <u>cistula</u> (Hempr.) Grun.: (R), occurring in May along the entire river. (R), occurring in May in Vaseys Paradise, Bright Angel Creek and Kanab Creek. One specimen occurred at Lees Ferry in August.
32. <u>hungarica</u> (Grun.) Pant.: (R), occurring in June at all sampling sites below river mile 87.
33. <u>incerta</u> Grun.: (R), single specimens occurring in June at river miles 71 and 87.
34. <u>laevis</u> Naeg.: (R), occurring in Paria River and Shinumo Creek in August.
35. <u>microcephala</u> Grun.: (R), occurring in Vaseys Paradise in August.
36. <u>parva</u> (W. Sm.) Cl.: (R), occurring in August at sites between river mile) and 136. (R) in November at sites 29, 66, 103, 108 and 134. (R), occurring in August in Havasu Creek.
37. <u>prostata</u> (Berk.) Cl.: (R), occurring in May at river miles 61 and 71 and in June at river miles 31, 132, 133, 136, 143 and 225. (R), occurring in May in Kanab Creek and in March in Bright Angel Creek.
38. <u>turgida</u> (Greg.) Cl.: (R), occurring in June at river miles 1, 61, 71, 87, 136 and 143 and in May in Deer Creek Falls.
39. <u>ventricosa</u> Kütz.: (R), occurring in August at river miles 136 and 143. (F) in November at river mile 103, all other sites (R) in November and March. (R) in August at Shinumo Creek, Deer Creek and Havasu Creek, in November in the Little Colorado River, Bright Angel Creek and Kanab Creek, and in March in the Little Colorado River and Havasu Creek. (D) in Bright Angel Creek in August (R) in Shinumo and Diamond Creeks.
40. <u>ventricosa</u> var. <u>semicircularis</u> (Lagst.) Cl.: (R), occurring in June at river miles 87, 108, 116, 132, in November at all river miles, and in March at river miles 0, 32, 61, 87, 116, 134 and 208. (R), occurring in June in Bright Angel, Shinumo Creek and Elves Chasm, in November in the Little Colorado River, Bright Angel Creek, Shinumo Creek, Elves Chasm, Deer Creek, and Havasu Creek, and in March in Bright Angel, Elves Chasm and Tapeats Creek.

(18) Genus <u>Denticula</u> Kütz.

41. <u>elegans</u> Kütz.: (R), occurring in June at all river sites, in March at river mile sites 0, 32, 87, 137 and in May in Tapeats Creek.

(19) Genus <u>Diatoma</u> De Candolle

42. anceps (Ehr.) Grun.: (R), only one specimen found at river mile 108 in November. (R), in August at Vaseys Paradise.
43. elongatum Ag.: (R), occurring in May at river miles 87, 116 and in June at river sites between mile 61 and 133 as well as in Vaseys Paradise, Bright Angel and Kanab Creek.
44. hiemale (Lyngb.) Heib.: (R), occurring in August at river miles 0, 32 and 61.2, (D) at miles 37 and 60. One specimen found in November at river mile 108. (R), occurring in August at Shinumo Creek and in March at Vaseys Paradise.
45. mesodon Kütz.: (R) in May in Tapeats Creek.
46. vulgare Bory: (R) in May at river miles 0, 133 and 143. (F) in June along entire river length. (D) in August at river miles 0, 18, 32, 37, 61, 87; (F) at miles 88, 116, 166, 225 and (R) at miles 108, 134, 136 and 143. (R) in November and March at all river miles. (F) in May in Shinumo Creek, Elves Chasm and Tapeats Creek, in June in the Paria River, Vaseys Paradise, Bright Angel Creek, Tapeats Creek, Deer Creek and Diamond Creek. (R) in August at Vaseys Paradise, Deer Creek and Diamond Creek but (D) in Bright Angel Creek. (R) in November in Vaseys Paradise, the Little Colorado River, Bright Angel Creek, Shinumo Creek, Deer Creek and Havasu Creek. (R), occurring in March at Elves Chasm, Tapeats Creek, Deer Creek, Kanab Creek and Havasu Creek but (D) in Bright Angel Creek.

(20) Genus Epithemia Breb.

47. argus Kütz.: (R), occurring in August at river miles 108, 116 and 136.
48. sorex Kütz.: (R), occurring in May with only one specimen at river mile 116. (R), occurring in August at miles 0, 108 and 116 and in November at miles 0, 103 and 108. (R), occurring in May in Shinumo Creek and in June in Tapeats Creek, the Little Colorado River, Bright Angel Creek, Shinumo Creek and in November in Diamond Creek. (F) in Bright Angel Creek and Shinumo Creek in August. (R) in Bright Angel Creek and (F) in Elves Chasm in March.
49. turgida (Ehr.) Kütz.: (R) one specimen collected in November at river mile 108.

(21) Genus Eunotia Ehr.

50. Grunowi A. Bg.: (R), occurring in Shinumo Creek in June.

(22) Genus Fragilaria Lyngb.

51. aequalis Heib.: (R), one specimen collected in May at river mile 225 and in June at river mile 0. (R) in Havasu Creek in May.
52. brevistriata Grun.: (R) one specimen collected in November at river mile 29. (R) in March in Bright Angel Creek.
53. crotonensis Kitton: (R), occurring in May, June and August at all river sites from mile 0 to 225. No occurrence in November and (R) occurrence in March at river miles 32, 61, 116, 143 and 225.
54. intermedia Grun.: (R), occurring in May at river miles 1, 50, 71, 133, 136 and in June at river miles 31, 61, 87 and 116. (R) in May in Vaseys Paradise, Elves Chasm and Tapeats Creek and in June at Elves Chasm.
55. leptostauron (E.) Hust.: (R) only one specimen in May at river mile 143. (R) in August at river miles 88, 108, 116, 136 and 166.
56. sp.: (R), occurring in Bright Angel Creek during November.
57. virescens Ralfs.: (R), occurring in June at Lees Ferry and in Tapeats Creek. Only one specimen at Lees Ferry.

(23) Genus Frustulia Ag.

58. vulgaris Thwaites: (R), occurring in November in Bright Angel Creek and Elves Chasm.

(24) Genus Gomphoneis Cl.

59. herculeana (Ehr.) Cl.: (R), occurring in May in Paria River.

(25) Genus Gomphonema Ag.

60. angustatum (Kütz.) Rabh.: (R), occurring in Elves Chasm in August.
61. constrictum Ehr.: (R), occurring in Paria River during August, in Elves Chasm in May, in Bright Angel and Shinumo Creeks in November, and in Bright Angel Creek in March.
62. olivaceum (Lyngb.) Kütz.: (R), occurring in May at river miles 31, 50, 61, 71, 116 in November at river miles 103 and 143, and in March at river mile 134. (R), occurring in Deer Creek in May and Bright Angel in June, in Havasu Creek in August, and in Bright Angel and Diamond Creeks in November.
63. parvulum Kütz.: (D), occurring in Diamond Creek in August.
64. sp.: (R), occurring in Kanab Creek in November.

65. ventricosum Greg.: (R), occurring only in Bright Angel Creek in June.

(26) Genus Gyrosigma Cl.

66. attenuatum var. hippocampus (W. Sm.) Cl.: (R), occurring in Kanab Creek during June.

67. balticum (Ehr.) Rabh.: (R), occurring in the Little Colorado River during June.

68. Spencerii (W. Sm.) Cl.: (R), occurring in Kanab Creek in November.

69. strigile W. Sm.: (R), occurring in the Little Colorado River during June.

(27) Genus Hantzschia Grun.

70. amphioxy (Ehr.) Grun.: (R), occurring in May at river mile 225 and in June at river mile 136. Only one specimen found at each site. (R), occurring in Havasu Creek in November.

(28) Genus Mastogloia Thwait.

71. Braunii Grun.: (R), one specimen occurring in May at river mile 133.

72. Grevillei W. Sm.: (R), one specimen occurring in November at river mile 116.

73. Smithii Thwait.: (R), one specimen occurring in August at river mile 0.

(29) Genus Meridion Ag.

74. circulare (Grev.) Ag.: (R), occurring in August at river mile 61 and in November at river miles 29, 61 and 108. (R), occurring in Bright Angel Creek in May, in Bright Angel Creek and Elves Chasm in August, and in the Little Colorado River in November.

(30) Genus Navicula Bory

75. anglica Ralfs.: (R), occurring in November at river miles 0 and 29, and in March at river mile 0. (R), occurring in Havasu Creek in August, in the Paria River, Little Colorado River, Kanab Creek and Havasu Creek in November, and in Shinumo and Havasu Creeks in March.

76. cryptocephala Kütz.: (R), occurring in November at river miles 66, 87, 108, 116, 120, 134, 136, 173, and in March at river miles 0 through 87 and at 116 and 208. (F) in August in Bright Angel Creek and (r) in Shinumo Creek. (R), occurring in Bright Angel Creek, Shinumo Creek, Elves Chasm, Tapeats Creek and Diamond Creek in November and in Vaseys Paradise, Shinumo and Kanab Creeks in March.

77. exigua (Greg.) O. Müll.: (R) with one specimen occurring at river mile 133 in May. (R) in

November at river miles 0, 29, 66, 108, 120 and 134 and in March at river miles 32, 108 and 137. (R) in June in the Paria River, Elves Chasm and Kanab Creek, and in March at Kanab Creek.

78. gastrum Ehr.: (R), occurring in May at Bright Angel Creek.
79. longirostris Hust.: (R) only one specimen occurring at river mile 108 in August.
80. minima Grun.: (R), occurring in the Little Colorado River in November.
81. radiosa Kütz.: (R), occurring in Bright Angel Creek in May.
82. sp.: (R), occurring during June at Bright Angel Creek, Shinumo Creek, Elves Chasm, Deer Creek and Kanab Creek.
83. sp.: (R), occurring in August in the Paria River and Little Colorado River, and in March in the Little Colorado River.
84. tripunctata (Müll.) Bory: (R), occurring in May at river miles 31, 116 and (F) in June throughout rivers length and (R) in August at all river miles. (R) during November occurring at all river miles between 0 and 225. (R) in March at river miles 65, 87, 116, 134, 137, 143, 180 and 225. (R) in the Paria River, Elves Chasm, Tapeats Creek, Kanab Creek and Havasu Creek during August but (D) in Diamond Creek, (R) in the Paria River, Vaseys Paradise, Little Colorado River, Elves Chasm, Tapeats Creek, Deer Creek and Diamond Creek, during November and occurring in all tributaries and springs except the Paria River during March.
85. viridula Kütz.: (R), occurring in Vaseys Paradise in June, and in Havasu Creek in March.

(31) Genus Neidium Pfitz.

86. dubium (Ehr.) Cl.: (R), one specimen occurring at river mile 0 in August.
87. productum (W. Sm.) Cl.: (R), occurring in Shinumo Creek during August.

(32) Genus Nitzschia Hass.

88. acicularis W. Sm.: (R), occurring in August in Havasu Creek.
89. amphibia Grun.: (R), one specimen occurring at river miles 0 and 103 in November. (D), in Diamond Creek in August and (R) in Bright Angel Creek in March.
90. angularis W. Sm.: (R), occurring in Deer Creek in November.

91. capitellata Hust.: (F), occurring in Kanab Creek in August.
92. commutata Grun.: (R), occurring in the Paria River in August.
93. dissipata (Kütz.): (R) at river miles 0 and 61 in November. (F) in August in the Paria River and (R) in Tapeats Creek.
94. filiformis (W. Sm.) Hust.: (R), occurring at river miles 116, 136, 168 and 225 in May and at river miles 61, 108, 133 and 143 in June. One specimen was collected at river mile 134 in November. (R) in Elves Chasm and Diamond Creek in May and in the Little Colorado River in June. (R), in Elves Chasm in August, and in Bright Angel and Shinumo Creeks in March.
95. frustulum Kütz.: (R) in August in the Paria River.
96. holsatica Hust.: (R) in November in the Little Colorado River.
97. Kützingiana Hilse.: (F) in August in the Paria River.
98. laevissima Grun.: (R), occurring in November in the Little Colorado River.
99. linearis W. Sm.: (R), occurring at river miles 18, 32, 88, 108, 116 and 225 in August, at river miles 29 to 87, 108, 136, 225 in November, in March at River miles 0 to 61, 116 and 143. (F) in August in the Paria River, Bright Angel Creek and Kanab Creek, but (R) in Shinumo Creek, Elves Chasm, Deer Creek and Havasu Creek. (R) in November at Vaseys Paradise, Shinumo Creek, Deer Creek, Kanab Creek, Havasu Creek and Diamond Creek. (R) in March at Elves Chasm, Tapeats Creek and Diamond Creek.
100. longissima (Breb.) Ralfs.: (R), occurring in the Little Colorado River during June.
101. longissima var. closterium (W. Sm.) V.H.: (R), occurring in the Little Colorado River during November.
102. longissima var. reversa Grun.: (R), occurring in the Little Colorado River during November.
103. Lorenziana Grun.: (R), occurring in Deer Creek and Kanab Creek during May, and in the Little Colorado River during November.
104. microcephala Grun.: (F), occurring in Diamond Creek during August.
105. palea (Kütz.) W. Sm.: (F), occurring in Diamond Creek during August.
106. paradoxa (Gmel.) Grun.: (R), occurring in the Little Colorado River in June.

107. *sigmoidea* (Ehr.) W. Sm.: (R), occurring at river miles 143, 168 and 225 in May. One specimen observed at river mile 61 in June, and at river miles 32 and 208 in March. (R), in Shinumo Creek in May.

108. *spectabilis* W. Sm.: (R), occurring in the Little Colorado River in June.

109. *tryblionella* Hant.: (R), one specimen found in May at river mile 143.

110. *vermicularis* (Kütz.) Grun.: (R), one specimen found in June at river mile 87. (R) in August in the Little Colorado River and Kanab Creek.

111. *vitrea* Norm.: (R), in August at the Little Colorado River, in November at Tapeats Creek, Deer Creek and Kanab Creek, in March at Vaseys Paradise.

(33) Genus *Opephora* Petit

112. sp.: (R), one specimen collected in the Paria River during May.

(34) Genus *Pinnularia* Ehr.

113. *appendiculata* (Ag.) Cl.: (R), one specimen identified from river mile 29 in November.

114. sp.: (R), one specimen from river mile 31 in June, and (R) in the Little Colorado River in June.

(35) Genus *Pleurosigma* Cl.

115. *delicatulum* W. Sm.: (R), occurring in May and November at Elves Chasm.

(36) Genus *Rhoicosphenia* Grun.

116. *curvata* (Kütz.) Grun.: (F), occurring at all river miles in May and June. (R) in August at river miles 32, 37, 61, 87, 88, 108, 116, 134, 136, 143, 166 and (F) at river miles 0, 18, 61 and 225. (R) in November at river miles 0, 29, 32, 61, 116, 120, 173, 225 and (F) at river miles 66, 87, 103, 108, 134, 136 and 143. (R), occurring in March at all river miles. (R), occurring in August in Vaseys Paradise, the Little Colorado River, Bright Angel Creek, Elves Chasm, Deer Creek and Diamond Creek and in November in the Little Colorado River, Bright Angel Creek, Elves Chasm, Tapeats Creek, Deer Creek, Kanab Creek, and Diamond Creek, and in March in the Little Colorado River, Shinumo Creek, Tapeats Creek and Deer Creek.

(37) Genus *Stauroneis* Ehr.

117. *anceps* Ehr.: (R), one specimen occurring at river mile 87 in August.

118. *Smithii* Grun.: (R), occurring in August in Shinumo Creek.

(38) Genus <u>Surirella</u> Turp.

119. *angusta* Kütz.: (R), one specimen occurring at river mile 87 in August.

120. *brightwelli* W. Sm.: (R), one specimen occurring at river mile 0 in November.

121. *ovalis* Breb.: (R), one specimen occurring at river mile 136 in May. (R), in the Paria River during June.

122. *ovata* Kütz.: (R), with one specimen occurring at river mile 65 in March. (R), in November in Diamond Creek.

123. sp.: (R), occurring in Kanab and Shinumo Creeks in March.

124. *striatula* Turp.: (R), occurring in the Little Colorado River during June and November.

(39) Genus *Synedra* Ehr.

125. *actinastioides* Lemm.: (R), occurring in June in Tapeats Creek and in March at Diamond Creek.

126. *acus* Kütz.: (R), occurring throughout the rivers length in May, June, November and March. (R), occurring in Elves Chasm, Kanab Creek and Diamond Creek in May, and in Havasu Creek in November.

127. *berolinensis* Lemm.: (R), occurring in Kanab Creek in June.

128. *kamtschatica* Grun.: (R), occurring in Havasu Creek in June.

129. *nana* Meist.: (R), one specimen occurring in May at river mile 143 and at river miles 61 and 87 in June. In November single specimens occurred between river miles 116 and 136. (R), in May in Vaseys Paradise, in August in the Little Colorado River.

130. *rumpens* Kütz.: (R), occurring in August in Vaseys Paradise.

131. *tenera* var. *genuina* Cl.: (R), occurring in June at river miles 0, 1, 31, 71, 87, 116 to 143 and 21, and in the Paria River.

132. *ulna* (Nitz.) Ehr.: (F), occurring in May and June at all river sites. (R) in March at river miles 25, 32, 61, 87, 108, 116, 137, 180 and 225, in August at river miles 0, 18, 32, 37, 61, 61.2, 87, 88, 108, 116, 136, 143, and in November at river miles 29, 61, 66, 120, 136 and 225. (R) in August at Elves Chasm, Shinumo Creek, Tapeats Creek, Havasu Creek and Diamond Creek, but (F) in the Little Colorado River, Bright Angel and Kanab Creek. (R), in November in the Paria River,

Vaseys Paradise, the Little Colorado River, Shinumo Creek, Elves Chasm, Deer Creek, Kanab Creek, Havasu Creek and Diamond Creek, and in March in Bright Angel Creek, Elves Chasm, Deer Creek, Kanab Creek, Diamond Creek, and Vaseys Paradise.

(40) Genus Tropidoneis Cl.

133. lepidoptera (Greg.) Cl.: (R), one specimen found in the Little Colorado River in November.

CHLOROPHYTA
CHLOROPHYCEAE
Volvocales

(1) Genus Carteria Dies.

1. Klebsii (Dang.) Dill.: (R), with only one specimen occurring in June at mile 0.

(2) Genus Chlamydomonas Ehr.

2. sp.: (R), with only one specimen occurring in June at miles 0, 1 and 31. Only one specimen was found at these sites.

(3) Genus Pandorina Bory

3. morum (Muell.): (R), with only one specimen occurring in August at river mile 61.

4. sp.: (R), in May in Diamond Creek.

Tetrasporales

(4) Genus Tetraspora Link

5. gelatinosa (Vauch.) Desv.: (R), occurring in Elves Chasm in June.

Chlorococcales

(5) Genus Cerasterias Rein.

6. staurastroides West & West: (R), with only one specimen in August at river miles 0, 18 and 32.

(6) Genus Lagerheimia (De Toni) Chod.

7. subsalsa Lemm.: (R), with only one specimen found in March at river mile 134.

(7) Genus Pediastrum Mey.

8. duplex var. clathratum (Br.) Lagh.: (R), with only one specimen found in August at river mile 32.

9. integrum Naeg.: (R), with only one specimen found at river mile 120. (R), occurring in May and June in Diamond Creek.

(8) Genus Scenedesmus Mey.

10. bijuga (Turp.) Lagh.: (R), with only one specimen found in March at river mile 87.

11. opoliensis Richt.: (R), occurring in May, with only one specimen found at river mile 116.

12. _quadricauda_ var. _maximus_ West & West: (R), occurring in March with only one specimen found at river mile 108.

Ulotrichales

(9) Genus _Microspora_ Thur.

13. _floccosa_ (Vauch.) Thur.: (R), occurring in May with only one specimen found at river mile 1.

(10) Genus _Ulothrix_ Kütz.

14. _tenerrima_ Kütz.: (R), occurring in May and June at all river sites. (R), in May at Bright Angel Creek, Shinumo Creek, Tapeats Creek, Kanab Creek and Havasu Creek, and in June in the Paria River and Deer Creek.

15. sp.: (R), occurring in August at all river sites, in November at river miles 0, 29, 32, 66, 116, 136 and in March at all river sites. (R), occurring in Vaseys Paradise and Shinumo Creek in August, in Vaseys Paradise in November, and Diamond Creek in March.

Chaetophorales

(11) Genus _Gomontia_ Born. & Elah.

16. sp.: (R), single specimen found at river mile 87 in June.

(12) Genus _Leptosira_ Borzi

17. sp.: (R), single specimen found at river mile 61 in June.

(13) Genus _Stigeoclonum_ Kütz.

18. _flagelliferium_ Kütz.: (R), with only one specimen found in May at river mile 1, and in June at river mile 87. (R), occurring in May in Shinumo Creek.

19. sp.: (R), occurring in November with only one specimen occurring at river mile 143.

Zygnematales

(14) Genus _Closterium_ Nitz.

20. _Cynthia_ var. _jenneri_: (R), occurring in Bright Angel Creek in June.

21. _Dianae_ Ehr.: (R), occurring in Bright Angel Creek in June.

22. sp.: (F), occurring in November at river mile 66.

(15) Genus _Mougeotia_ Ag.

23. sp.: (R) in May with only one specimen found at river mile 71. (R), occurring in March in Bright Angel Creek.

(16) Genus _Mougeotiopsis_ Palla

24. sp.: (R), occurring in May with only one specimen found at river mile 71.

(17) Genus _Spirogyra_ Link

25. sp.: (R), occurring in May at river mile 1, in June at river miles 87 and 143, in August at river miles 0, 32, 37, 87, 136 and 166, in November at river miles 108 and 136. (R), occurring in May in Havasu and Diamond Creeks, in June in Kanab Creek, Havasu Creek and Diamond Creek, in August in Vaseys Paradise, Shinumo Creek, in November in Elves Chasm, and in March in Diamond Creek, Vaseys Paradise and Little Colorado River.

(18) Genus Staurastrum Mey.

26. sp.: (R), occurring in May at river miles 19, 61, 71 and 225, in June at river miles 0, 31, 108, 136 and 225, and in August at river miles 0 to 87, 108, 136 to 225. (R), occurring in Bright Angel Creek in May and in August.

(19) Genus Zygnema Ag.

27. sp.: (R), occurring in August at river miles 0 and 37, and in May, June and March in Diamond Creek.

Cladophorales

(20) Genus Cladophora Kütz.

28. glomerata Kütz.: (R), occurring at all river stations in May, June, August, November and March.

(21) Genus Rhizoclonium Kütz.

29. hieroglyphicum (Ag.) Kütz.: (R), occurring in November in Tapeats Creek.

CYANOPHYTA

Chroococcales

(1) Genus Chroococcus Näeg.

1. sp.: (R), occurring in August with only one specimen found at river mile 61.
2. turgidus (Kütz.) Näeg.: (R), occurring in Diamond Creek in May and in Havasu Creek in June.

Chamaesiphonales

(2) Genus Chamaesiphon Br. & Grun.

3. incrustans Grun.: (R), occurring in March at river miles 65, 134, 137, 180 and 225.

(3) Genus Merismopedia Mey.

4. elegans var. major G. M. Sm.: (D), occurring in Diamond Creek during May.

Oscillatoriales

(4) Genus Lyngbya Ag.

5. aerugineo-caerulea (Kütz.) Gom.: (R), occurring in May at river mile 1, in June at river mile 136, in March at river miles 25 and 32 with single specimen found at each site.

6. aestuarii (Mert.) Liebm.: (R), with only single specimen found in May at river mile 133.
7. Birgei G. M. Sm.: (R), occurring at Deer Creek in May and June.
8. epiphytica Hier.: (R), with only single specimen occurring in March at river mile 0.
9. limnetica Lemm.: (R), with single specimen found in March at river mile 0.
10. versicolor (Wartm.) Gom.: (R), occurring in November at river miles 116, 120 and 134.
11. sp.: (R), occurring in August at river miles 87, 88, 108, 116, 136, 143, 166; in Vaseys Paradise and Diamond Creek in November and Kanab Creek in March.

(5) Genus Oscillatoria Vauch.

12. Agardhii Gom.: (R) in June at all river sites and in Tapeats Creek. (R), in August in the Paria River.
13. angustissima West & West: (R), occurring in March at river miles 0 to 61, 87, 116, 134 and in the Little Colorado River in March.
14. articulata Gard.: (R) in May at river miles 0, 19 to 71, 116, 133, 168, and in Tapeats Creek and Havasu Creek.
15. Hamelii Fremy: (R), occurring in May with only one specimen at river mile 143 and in Kanab Creek. (R), in the Paria River in June.
16. lacustris (Kleb.) Geit.: (F), occurring in August in Bright Angel Creek.
17. limnetica Lemm.: (R), occurring in May with only one specimen found at river mile 116, and in June at river miles 0 and 31. (R), in May in Tapeats Creek and Elves Chasm, and in June in the Paria River and Elves Chasm.
18. limosa (Roth) C. A. Ag.: (R), occurring in May at river miles 1, 19, 136, 143, 225, in June at river miles 61, 71, 87, in August at river miles 0 to 61, 87, 108, 116, 225, and in March at river miles 25, 116 and 143. (R) also in Diamond Creek in June.
19. nigra Vauch.: (R), occurring in May with single specimens found at river miles 1, 31 to 71 and 116. (R), in Vaseys Paradise in May.
20. sp.: (R), occurring in November in the Paria River, and in March in Havasu Creek.
21. subbrevis Schmid.: (R), occurring in May with single specimen found at river mile 133. (R), occurring in August at all river sites, in November at river miles 61, 66, 103, 134 and 173, and in March at river mile sites 0 to 61, 108, 116, 137

to 180. (R), in Kanab Creek in June, in Bright Angel Creek and Tapeats Creek in August, in Vaseys Paradise, the Little Colorado River and Bright Angel Creek in November, and in Kanab Creek in March.

22. tenuis C. A. Ag.: (R) in May with single specimens found at river miles 133 and 225. (R), in May in Deer Creek and Havasu Creek.

(6) Genus Spirulina Turp.

23. major Kütz.: (R), occurring in May with single specimens found at river miles 19 and 143. (R) in May in Deer Creek and Kanab Creek.
24. subsalsa Oerst.: (R), occurring in May with a single specimen found at river mile 133. (R) in May in Deer Creek.
25. sp.: (R), occurring in March with single specimens found at river miles 25 and 32. (R) in March at Elves Chasm.

Nostocales

(7) Genus Anabaena Bory

26. sp.: (R), occurring in May with a single specimen found at river mile 133, and in March with single specimen found at river miles 87, 108, 137 and 143. (R) in March in the Little Colorado River, Bright Angel Creek, Tapeats Creek, Deer Creek and Havasu Creek and (F) in Elves Chasm.

(8) Genus Nodularia Mert.

27. Harveyana (Thw.) Thur.: (R), occurring in May in Bright Angel Creek and Shinumo Creek.
28. spumigena Mert.: (R), occurring in May with a single specimen found at river mile 1.

CRYPTOPHYTA

(1) Genus Cryptomonas Ehr.

1. ovata Ehr.: (R), with single specimen found at river mile 50 in May.

PYRRHOPHYTA

Dinokontae

(1) Genus Ceratium Schr.

1. carolinianum (Bail.) Jorg.: (R), with single specimen found at river mile 71 in May.
2. hirundinella (O. F. Muell.) Dujard.: (R), occurring in June at river miles 0, 31, 61, 71, 108 to 136

and 225, and in August at river miles 0 to 37, 87, 88, 136, 166 and 225.

EUGLENOPHYTA

Colaciales

(1) Genus Colacium Ehr.

1. sp.: (R), occurring in August at river mile 143.

Table 8. Representation of phytoplankton genera and species of various algal divisions in the Colorado River during May, June, August, November and March, 1975-76. G = genera S = species.

	May		June		Aug.		Nov.		March	
	G	S	G	S	G	S	G	S	G	S
Chrysophyta										
Xanthophyceae	1	1	0	0	0	0	0	0	1	1
Chrysophyceae	0	0	0	0	1	1	0	0	0	0
Bacillariophyceae	21	33	15	30	16	28	17	34	15	24
Chlorophyta	9	9	8	9	9	10	6	6	6	7
Cyanophyta	4	13	2	4	3	4	2	2	5	10
Cryptophyta	1	1	0	0	1	1	1	1	1	1
Pyrrhophyta	1	1	1	1	1	1	0	0	0	0
Euglenophyta	0	0	0	0	1	1	0	0	0	0
TOTAL	37	58	26	44	32	45	26	43	28	43

Table 9. Representation of divisions, genera, and species of phytoplankton in the tributaries of the Colorado River during May, June, August, November and March, 1975-76.

	CHRYSOPHYTA					CHLOROPHYTA					CYANOPHYTA				
	M	J	A	N	M	M	J	A	N	M	M	J	A	N	M
PARIA R.															
Genera	2	5	4	2	-	0	1	0	0	-	0	1	1	1	-
Species	2	6	9	3	-	0	1	0	0	-	0	2	1	1	-
VASEYS R.															
Genera	3	5	5	4	3	0	0	1	1	1	1	0	0	1	1
Species	3	6	7	4	4	0	0	1	1	1	1	0	0	1	1
L. COLORADO															
Genera	-	6	4	10	5	-	0	0	0	1	-	0	0	1	2
Species	-	10	8	18	6	-	0	0	0	1	-	0	0	1	2
BR. ANGEL															
Genera	6	6	10	8	10	2	2	1	0	0	0	1	1	1	1
Species	7	8	10	10	13	2	2	1	0	0	0	1	2	1	1
SHINUMO															
Genera	10	6	10	8	6	2	0	2	0	0	1	0	0	0	0
Species	10	6	11	8	8	2	0	2	0	0	1	0	0	0	0
ELVES															
Genera	11	6	10	8	6	0	1	0	1	0	1	1	0	0	2
Species	13	6	10	9	7	0	1	0	1	0	1	1	0	0	2
TAPEATS															
Genera	6	7	6	5	6	1	0	0	2	0	1	1	1	1	1
Species	7	8	7	7	7	1	0	0	2	0	2	1	1	1	1
DEER CK.															
Genera	6	4	5	8	5	0	1	0	0	0	3	1	0	0	1
Species	6	4	5	11	5	0	1	0	0	0	4	1	0	0	1
KANAB															
Genera	4	5	6	8	5	1	1	0	0	0	1	1	0	0	2
Species	5	6	8	11	7	1	1	0	0	0	2	1	0	0	2
HAVASU															
Genera	4	1	7	9	5	2	1	0	0	0	1	1	0	0	2
Species	4	1	10	10	7	2	1	0	0	0	2	1	0	0	2
DIAMOND															
Genera	4	3	7	10	7	4	3	0	0	3	2	1	0	1	0
Species	4	3	9	11	8	4	3	0	0	3	2	1	0	1	0

Table 10. Surface water criteria for public water supplies by agency.

Element	USHEW: Drinking Water Standards 1962	USDI: Water Quality Criteria 1968	WHO: International Standards for Drinking Water, 1971	EPA Water Quality Criteria 1972
Boron	-	1 ppm	-	-
Cadmium	10 ppb	10 ppb	10 ppb	10 ppb
Calcium	-	-	200 ppm	-
Chromium	50 ppb	50 ppb	-	50 ppb
Cobalt	-	-	-	-
Copper	1 ppm	1 ppm	1.5 ppm	1 ppm
Iron	300 ppb	300 ppb	1000 ppb	300 ppb
Lead	50 ppb	50 ppb	100 ppb	50 ppb
Magnesium	-	-	150 ppm	-
Manganese	50 ppb	50 ppb	500 ppb	50 ppb
Mercury	-	-	1 ppb	2 ppb
Molybdenum	-	-	-	-
Potassium	-	-	-	-
Sodium	-	-	-	-
Zinc	5 ppm	5 ppm	15 ppm	5 ppm

Table 11. Colorado River: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	10.	400.	160.	August March
Cadmium (ppb)	0.	1.	.2	March
Calcium (ppm)	49.	83.	59.	May
Chromium (ppb)	0.8	4.0	1.4	August
Cobalt (ppb)	0.	14.	4.4	November
Copper (ppb)	2.	11.	4.6	August
Iron (ppb)	4.	60.	23.	August
Lead (ppb)	0.9	7.	3.5	November
Magnesium (ppm)	23.	33.	26.4	May
Manganese (ppb)	0.5	9.	3.4	May
Mercury (ppb)	0.2	0.3	.23	March
Molybdenum (ppb)	2.	18.	6.9	June
Potassium (ppm)	3.1	4.5	3.8	March
Sodium (ppm)	55.	95.	75.2	March
Zinc (ppb)	10.	400.	110.	August

Table 12. Paria River: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	100.	400.	246.	March
Cadmium (ppb)	.3	.5	.36	August
Calcium (ppm)	38.	108.	72.	November
Chromium (ppb)	1.3	2.6	2.1	March
Cobalt (ppb)	4.1	11.5	8.8	August November
Copper (ppb)	2.6	9.8	6.3	April
Iron (ppb)	9.5	32.	18.	April
Lead (ppb)	1.7	13.	5.5	March
Magnesium (ppm)	20.5	67.5	43.9	November
Manganese (ppb)	1.3	20.0	9.3	April
Mercury (ppb)	1.0	1.0	1.0	March
Molybdenum (ppb)	.7	10.9	4.8	June
Potassium (ppm)	3.2	5.5	4.8	March
Sodium (ppm)	27.	106.	74.8	April
Zinc (ppb)	12.	180.	101.4	August

Table 13. Vasey's Paradise: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	10.	120.	76.	March
Cadmium (ppb)	0.	.6	.26	June
Calcium (ppm)	31.	43.	35.8	April
Chromium (ppb)	1.1	4.0	2.5	March
Cobalt (ppb)	0.	18.	7.1	April
Copper (ppb)	9.0	4.1	2.6	November
Iron (ppb)	6.0	28.	16.6	June
Lead (ppb)	.5	8.2	3.2	November
Magnesium (ppm)	14.	21.5	19.4	April
Manganese (ppb)	.4	1.8	.9	August
Mercury (ppb)	.5	.5	.5	March
Molybdenum (ppb)	2.0	7.3	4.6	June
Potassium (ppm)	.6	.8	.7	April
Sodium (ppm)	2.0	4.0	3.1	March
Zinc (ppb)	10.	60.	36.6	April

Table 14. Little Colorado River: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	200.	400.	283.	March
Cadmium (ppb)	.1	.8	.36	April
Calcium (ppm)	53.	118.	84.	June
Chromium (ppb)	2.0	10.	4.9	November
Cobalt (ppb)	3.4	7.0	5.3	August
Copper (ppb)	6.9	17.4	11.2	November
Iron (ppb)	7.	1500.	323.	April
Lead (ppb)	1.4	7.7	3.6	April
Magnesium (ppm)	14.	70.	54.5	November
Manganese (ppb)	3.6	70.	17.6	April
Mercury (ppb)	.4	.4	.4	March
Molybdenum (ppb)	2.6	12.0	7.4	August
Potassium (ppm)	4.4	7.9	6.3	June
Sodium (ppm)	124.	720.	584.	November March
Zinc (ppb)	10.	110.	62.6	April

Table 15. Bright Angel Creek: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	0.	250.	116.	August
Cadmium (ppb)	.1	.8	.28	March
Calcium (ppm)	22.	33.	27.4	November
Chromium (ppb)	1.6	3.5	2.3	March
Cobalt (ppb)	0.	8.4	3.4	August
Copper (ppb)	1.5	5.6	2.8	November
Iron (ppb)	13.	86.	34.2	June
Lead (ppb)	1.5	6.8	3.8	April
Magnesium (ppm)	11.5	21.5	18.2	November
Manganese (ppb)	3.0	6.3	4.2	April
Mercury (ppb)	.5	.5	.5	March
Molybdenum (ppb)	2.7	13.5	6.7	June
Potassium (ppm)	.6	.9	.8	April August
Sodium (ppm)	3.	5.	3.9	March
Zinc (ppb)	19.	120.	85.2	August

Table 16. Shinumo Creek: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	120.	400.	223.	March
Cadmium (ppb)	0.	1.1	.51	June
Calcium (ppm)	22.	39.	30.	April
Chromium (ppb)	1.5	3.7	2.4	March
Cobalt (ppb)	0.	8.0	3.1	November
Copper (ppb)	1.5	2.8	2.2	April March
Iron (ppb)	23.	78.	45.	June
Lead (ppb)	1.0	8.5	4.4	June
Magnesium (ppm)	7.5	20.	16.4	November March
Manganese (ppb)	2.2	5.8	3.6	August
Mercury (ppb)	1.5	1.5	1.5	March
Molybdenum (ppb)	1.8	1.8	1.8	March
Potassium (ppm)	.6	.8	.7	April
Sodium (ppm)	3.	6.	4.4	March
Zinc (ppb)	8.5	240.	127.	August

Table 17. Elves Chasm: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	100.	250.	156.	March
Cadmium (ppb)	.3	.9	.44	May
Calcium (ppm)	56.	73.	64.6	May
Chromium (ppb)	2.5	4.0	2.8	March
Cobalt (ppb)	3.1	5.0	4.2	November
Copper (ppb)	1.9	6.2	4.2	June
Iron (ppb)	12.	45.	23.5	June
Lead (ppb)	1.2	4.7	3.3	June November
Magnesium (ppm)	44.5	49.	46.9	November
Manganese (ppb)	1.2	5.6	3.0	May
Mercury (ppb)	.4	.4	.4	March
Molybdenum (ppb)	3.6	9.0	5.5	August
Potassium (ppm)	2.7	3.3	3.0	May
Sodium (ppm)	21.	25.	23.2	November March
Zinc (ppb)	90.	456.	223.	May

Table 18. Tapeats Creek: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	100.	130.	115.	November
Cadmium (ppb)	.1	.6	.51	May, June
Calcium (ppm)	30.	35.	32.	May
Chromium (ppb)	1.0	5.2	2.8	March
Cobalt (ppb)	.9	3.5	2.2	August
Copper (ppb)	1.1	12.0	3.9	August
Iron (ppb)	14.	47.2	31.9	May
Lead (ppb)	4.3	5.5	5.0	August November
Magnesium (ppm)	11.	18.5	16.5	November
Manganese (ppb)	.6	5.5	2.0	August
Mercury (ppb)	.4	.4	.4	March
Molybdenum (ppb)	.5	3.2	1.8	May
Potassium (ppm)	.4	.5	.48	May, June
Sodium (ppm)	3.	3.	3.	August,March May,June,Aug Nov, March
Zinc (ppb)	55.	350.	117.	August

Table 19. Deer Creek Falls: Summary of trace elements and major cations.

Element	Observed Values Min.	Observed Values Max.	Mean	Month of Highest Observed Value
Boron (ppb)	120.	500.	310.	March
Cadmium (ppb)	.1	.5	.19	March
Calcium (ppm)	34.	41.	37.	May
Chromium (ppb)	1.3	5.2	2.9	March
Cobalt (ppb)	0.	10.	4.0	August
Copper (ppb)	1.9	3.6	2.5	November
Iron (ppb)	10.	52.2	26.9	June
Lead (ppb)	1.4	6.8	3.7	June
Magnesium (ppm)	14.3	22.5	19.9	November
Manganese (ppb)	1.3	3.5	1.9	June
Mercury (ppb)	.3	.3	.3	March
Molybdenum (ppb)	0.	2.7	1.35	March
Potassium (ppm)	.6	.7	.64	May March
Sodium (ppm)	3.	4.	3.2	March
Zinc (ppb)	20.	55.	37.4	June

Table 20. Kanab Creek: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	110.	250.	203.	November March
Cadmium (ppb)	0.	.60	.28	May
Calcium (ppm)	118.	157.	142.	May
Chromium (ppb)	1.6	11.3	4.8	August
Cobalt (ppb)	2.1	19.0	8.5	August
Copper (ppb)	1.8	10.0	7.0	August
Iron (ppb)	13.	59.	33.	May
Lead (ppb)	1.5	5.3	3.0	November
Magnesium (ppm)	74.	98.	80.	March
Manganese (ppb)	3.0	8.8	6.4	March
Mercury (ppb)	.6	.6	.6	March
Molybdenum (ppb)	4.4	5.4	5.0	May March
Potassium (ppm)	4.8	6.4	5.8	March
Sodium (ppm)	32.	61.	39.	March
Zinc (ppb)	18.	140.	74.	May

Table 21. Havasu Creek: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	80.	300.	210.	August
Cadmium (ppb)	.2	.6	.38	May
Calcium (ppm)	34.	55.	45.	June
Chromium (ppb)	2.0	4.0	2.8	November
Cobalt (ppb)	2.6	13.0	6.3	August
Copper (ppb)	2.5	4.2	3.5	November
Iron (ppb)	11.	24.9	15.9	May
Lead (ppb)	1.4	4.7	3.2	June
Magnesium (ppm)	41.5	46.	42.9	May June
Manganese (ppb)	1.3	3.8	2.7	June
Mercury (ppb)	.3	.3	.3	March
Molybdenum (ppb)	2.7	4.4	3.4	June
Potassium (ppm)	3.9	4.5	4.3	May, June March
Sodium (ppm)	28.	33.	31.2	November March
Zinc (ppb)	11.	310.	112.	June

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Table 22. Diamond Creek: Summary of trace elements and major cations.

Element	Observed Values Min.	Max.	Mean	Month of Highest Observed Value
Boron (ppb)	90.	600.	346.	August
Cadmium (ppb)	.10	.60	.30	May
Calcium (ppm)	26.	36.	29.8	June
Chromium (ppb)	1.6	3.4	2.3	March
Cobalt (ppb)	0.	10.0	3.5	August
Copper (ppb)	2.5	13.0	6.3	August
Iron (ppb)	15.	21.1	17.3	May
Lead (ppb)	2.4	4.2	3.1	November
Magnesium (ppm)	33.	36.5	35.1	June
Manganese (ppb)	2.4	40.	11.	August
Mercury (ppb)	.3	.3	.3	March
Molybdenum (ppb)	3.0	5.0	3.8	March
Potassium (ppm)	4.8	6.2	5.4	August
Sodium (ppm)	78.	89.	83.8	August
Zinc (ppb)	25.	190.	113.	August

RECOMMENDATIONS

from Project Entitled

Survey of Bacteria, Phytoplankton,
and Trace Chemistry of the Lower Colorado
River and Tributaries in the Grand
Canyon National Park

by

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July 15, 1976

Contract Number CX821060007

RECOMMENDATIONS

The presence of coliform bacteria in the Colorado River and selected tributaries indicate fecal contamination from warm-blooded animals in the watershed and/or from river runners and hikers. Further evaluation such as obtaining fecal coliform/fecal streptococcus ratios are required to determine source(s) of contamination. An intensive short term monitoring period at selected tributaries such as Deer Creek, Elves Chasm, Kanab Creek, Havasu Creek, and Diamond Creek is recommended. The monitoring should include periods of heavy river runner and hiker use. Should the contamination be primarily from human sources, restriction of recreational use of certain tributaries by river runners or hikers should be forthcoming. p. 12-17

Chlorination of drinking and potable water is recommended as a precaution against coliform contamination. Four drops of chlorox per gallon of river or tributary water (chlorine concentration of ca. 2.5 ppm) followed by at least a five minute or more desirably a 30 minute waiting period is recommended. p. 17, 18

It is recommended that the presence of algal bioindicators be monitroed as a supplement to any future water quality assessment program on the Colorado River system. Bioindicators tend to be indicative of prevailing conditions and less subject to temporary changes of transient deterioration of aquatic conditions. p. 24-26, 40

The flow of the Colorado River allows it to absorb the high salt contents of the tributaries (including the Little Colorado River and Blue Springs) without a significant or obviously detrimental increase. Diversion of Blue Springs does not appear to be warranted as a significant salinity reducing measure. p. 45, 46, 50

Excessive iron and manganese levels were associated only with flooding conditions in the Little Colorado River and are not considered typical conditions requiring remedy. p. 47-49

Mercury levels in Shinumo Creek should be further evaluated since the single measurement performed exceeded water quality standards. p. 49

Two elements of potential toxicity not investigated in this study, arsenic and selenium, should also be monitored to complete a broad chemical inventory on the Colorado River and tributaries. Selenium was reported to be high in the Colorado River and some of its tributaries in the 1930's prior to establishment of selenium standards. p. 50