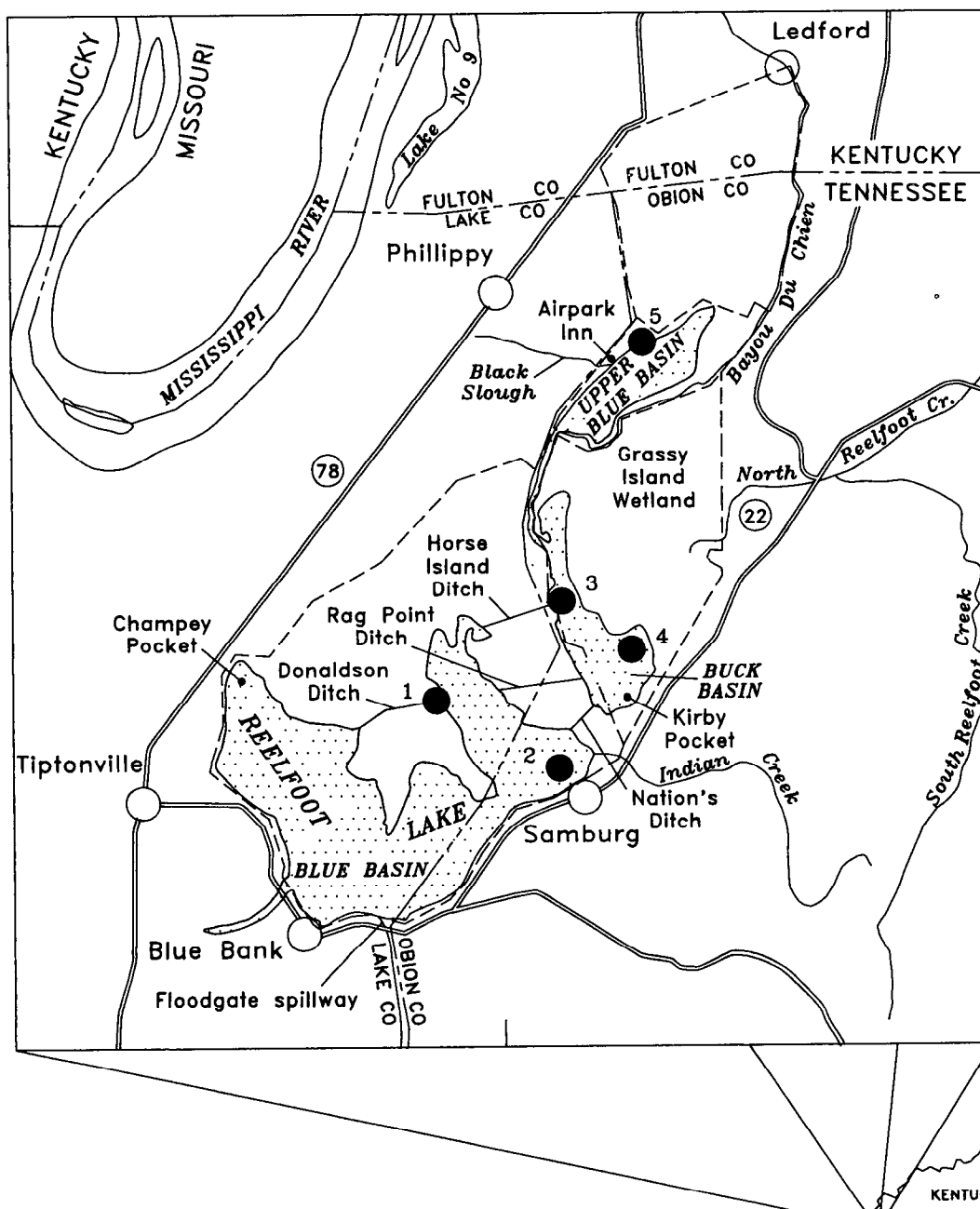


CHARACTERIZATION OF BOTTOM-SEDIMENT, WATER, AND ELUTRIATE CHEMISTRY AT SELECTED STATIONS AT REELFOOT LAKE, TENNESSEE



Prepared by the
U.S. GEOLOGICAL SURVEY

in cooperation with the
U.S. FISH AND WILDLIFE SERVICE



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By Robert E. Broshears

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

For those readers who may prefer to use metric units rather than the inch-pound units used in this report, conversion factors are listed below:

| Multiply | By | To obtain |
|-----------------|-----------|------------------|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| pound (lb) | 0.4536 | kilogram |
| gallon (gal) | 3.785 | liter |

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) — a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Use of the brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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ABSTRACT

*To better understand and predict the potential effect of dredging on water quality at Reelfoot Lake, chemical analyses were conducted on samples of lake water, bottom sediment, and elutriate water. Chemical analyses were conducted on samples of lake water, bottom sediment, and elutriate water collected at five stations in the lake during November 1988. Lake water was of the calcium magnesium bicarbonate type with an average dissolved-solids concentration of 120 milligrams per liter. Trace constituents were present in bottom sediments at concentrations representative of their average relative abundance in the earth's crust. Elutriate waters prepared by mixing bottom sediment and lake water had suspended-solids concentrations as high as 2,000 milligrams per liter which exerted significant oxygen demand. Trace constituents in the unfiltered elutriate waters were elevated with respect to lake water; elevated concentrations were attributable to the increased suspended-solids concentrations. Concentrations of total-recoverable copper, lead, and zinc in many elutriate waters exceeded U.S. Environmental Protection Agency's water-quality criteria for the protection of freshwater aquatic life. The toxicity of elutriate waters, as measured by a 48-hour bioassay with *Ceriodaphnia dubia*, was low.*

INTRODUCTION

Reelfoot Lake in northwestern Tennessee (fig. 1) is a valuable resource that is threatened by natural processes and man's activity. The natural aging of the lake has been accelerated by erosion of adjacent uplands, nutrient and sediment runoff from local agricultural areas, and waste-water discharge from lake-side communities (Tennessee Wildlife Resources Agency, 1985). During the past several decades, these processes have caused deterioration in the quality of the lake's sport fish and waterfowl habitat. In response, State and Federal agencies are seeking new management strategies for the lake.

Decisions concerning management options for Reelfoot Lake will be guided by an understanding of the physical, chemical, and biological processes that determine water quality. The U.S. Fish and Wildlife Service is contemplating a program of in-lake channelization that would involve dredging as much as 5 feet of lake bottom material. The effects of dredging on aquatic life in the lake will be influenced by many site-specific factors, including the extent, timing, and mechanisms of dredging and species-specific habitat needs and ability to survive short-term stresses.

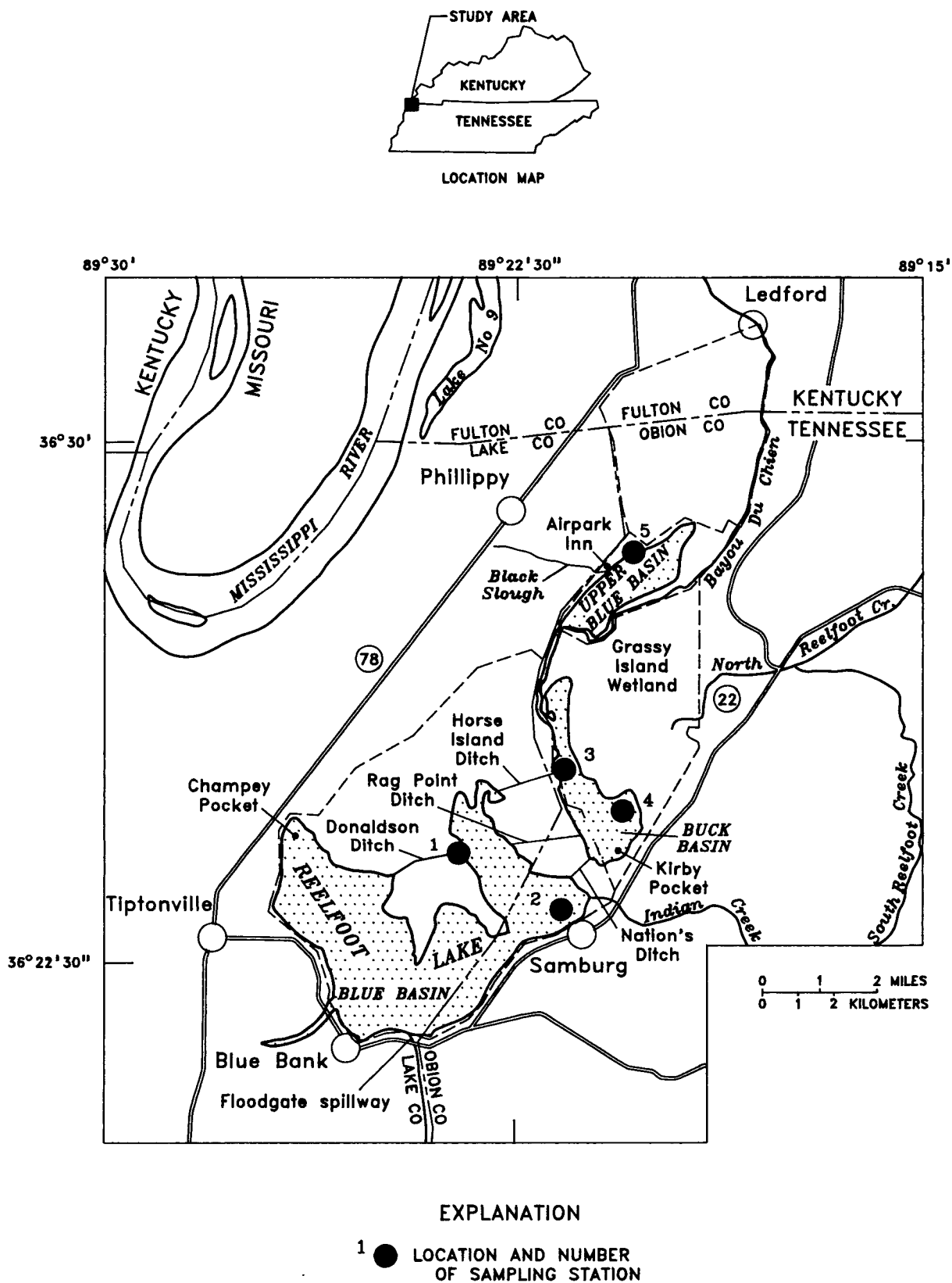


Figure 1.--Sampling stations at Reelfoot Lake.

The Tennessee Department of Health and Environment has reported concentrations of nutrients and several toxic trace metals in lake water that exceed U.S. Environmental Protection Agency's water-quality criteria (Denton, 1987). Trace elements characteristically are associated with sediments, and their solubility may be enhanced in the anaerobic environment of buried bottom materials. Sediments may also be enriched in nitrogen and phosphorus species derived from decaying vegetation. Accordingly, dredging of the lake bottom could increase concentrations of these critical constituents in the water column, with a corresponding degradation in water quality.

Purpose and Scope

In 1988, the U.S. Geological Survey (USGS) entered into a cooperative agreement with the U.S. Fish and Wildlife Service (USFWS) to conduct a preliminary characterization of bottom sediment and water chemistry at Reelfoot Lake. The purpose of this report is to describe sample collection and processing during the investigation and to present the results of chemical analyses of bottom sediment and water. The scope of the investigation was limited to the collection of samples in November 1988 from five stations and the analysis of selected inorganic constituents in sediment cores, column water, and elutriate water. Elutriate water was produced by mixing bottom sediments and lake water. A bioassay was performed for the elutriate water only.

Description of the Study Area

Reelfoot Lake was formed after the earthquakes of 1812 (New Madrid) that shook northwestern Tennessee. Variable uplift and subsidence altered local drainage patterns and contributed to the formation of the lake (fig. 1), which today covers about 15,500 acres (Robbins,

1985). Highly erodible loess bluffs parallel the lake's eastern shoreline; the Mississippi River lies approximately 3 miles to the west. The lake provides abundant habitat for wildlife, including bald eagles, mallards, Canada geese, wood ducks, and white-tailed deer. It also supports recreational and commercial fishing. Popular catches include bass, crappie, bluegill, and catfish.

The early hydrology of Reelfoot Lake was dominated by natural cycles of flood and drought. Water levels rose in concert with those in the Mississippi River. Silt deposition alternated with scouring before a levee completed in 1920 effectively isolated the lake from the river. Since 1931, a spillway at the southern end of the lake has maintained a pool elevation near 282.2 feet above sea level.

Agriculture and lake-side development have increased sediment and nutrient loading to the lake, thereby accelerating its natural aging. This loading, combined with the maintenance of a static pool elevation, has led to the development of a layer of unconsolidated muck on the lake bottom which is several feet thick in many areas of the lake.

A potential lake-management strategy calls for lowering the pool elevation to promote consolidation of the muck (Hoos and others, 1988). The plan requires the deepening of channels to facilitate drainage along strategic flow paths. Concern exists that dredging these channels may lead to the release of toxic constituents from the dredged material.

The lake has been the subject of several investigations by State and Federal agencies and was classified by the U.S. Environmental Protection Agency (1976) as being "highly eutrophic." A study by the Tennessee Department of Public Health (1982) identified the effects of nonpoint sources of pollution on lake quality, including the effects of sediment loading resulting from agriculture and stream channelization (Denton, 1986).

Nutrient loading to the lake was estimated at 64,370 kilograms per year (kg/yr) of total phosphorus and 334,760 kg/yr of total nitrogen (FTN Associates, 1987). Historically, point sources of pollutants in the basin include septic tanks and feedlots (U.S. Environmental Protection Agency (1976). Measurements of sediment oxygen demand range from 0.057 to 0.267 grams of oxygen per square meter per hour (Hoke S. Howard, U.S. Environmental Protection Agency, written commun., 1989). Concentrations of cadmium, chromium, copper, lead, mercury, nickel, and zinc in the lake or its tributaries have exceeded Federal and State water-quality criteria (Denton, 1987).

Storm-event sampling of the major tributaries to Reelfoot Lake indicates that most nutrient and sediment loading is associated with high-flow events (Jerry Garrett, U.S. Geological Survey, written commun., 1989). From October 1987 through September 1989, samples were collected at North Reelfoot Creek, South Reelfoot Creek, and Running Slough. During this period, about 98 percent of the annual suspended-sediment load of 373,000 tons was transported by storm events. The mean-annual load of total nitrogen during the period was 227,000 kg; the mean annual load of total phosphorus was 59,000 kg.

SAMPLE COLLECTION AND PROCESSING

In October 1988, five sampling locations were selected by the USFWS and the USGS (fig. 1). Each of these stations represents an area where relatively shallow water overlies mucky bottom material. Samples of lake water and bottom-sediment cores were collected at each of these stations in November 1988.

Lake water was collected by lowering a weighted, vertically mounted, uncapped glass bottle through the water column. Water samples

were analyzed for major and minor inorganic constituents and nutrient species by the USGS water-quality laboratory. Field measurements of dissolved oxygen, specific conductance, pH, and water temperature were made.

Three sediment cores were collected at each sampling station with a Wildco hand corer. This sampling device consists of a stainless-steel barrel equipped with a liner tube made of cellulose acetate butyrate. The liner tube is 2 inches in diameter. The core barrel was inserted manually into the lake bottom material and then slowly withdrawn. During withdrawal, the sediment core was held in place within the liner tube by an eggshell core catcher fixed to the lower end of the tube and a flutter valve at the upper end of the steel barrel. The liner tube was removed from the sampler, and water overlying the sediment core was slowly drained. Lengths of recovered core sample varied because of differences in the texture of the bottom material and in the degree of compaction after core removal. Cores were maintained in a vertical position during transport to a lakeside laboratory, where they were immediately frozen.

Two frozen cores from each station were sectioned into vertical increments of 10 to 14 inches. One set of vertical increments from each station was analyzed by the USGS soils laboratory for solid-phase concentrations of selected inorganic constituents. A second set of vertical increments was used for elutriate tests. The third frozen core from each station was reserved for the analysis of organic constituents by the USFWS at a later date.

Elutriate tests were performed at Memphis State University within 72 hours of sample collection. Water samples were chilled prior to the tests; bottom-material samples were permitted to thaw before the tests began. The wet weight of the sediment-core increment was determined. This sediment and a weight of unfiltered lake water equal to four times the sediment wet weight

were placed in a 4-liter Erlenmeyer flask. Sediment and water were mixed for 30 minutes at room temperature on an orbital shaker at approximately 100 revolutions per minute. After the mixture was allowed to settle for 60 minutes, the elutriate water was siphoned from the flask. Unfiltered elutriate water was analyzed by the USGS for selected inorganic constituents.

The elutriate water was also used for a bioassay. *Ceriodaphnia dubia*, a cladoceran crustacean, were exposed individually to 25-percent dilutions of the elutriate water. Mortality in 10 replicate bioassays was recorded after 48 hours.

BOTTOM-SEDIMENT CHEMISTRY

Concentrations of solid-phase inorganic constituents varied little among stations (table 1). Also, at each station, constituent concentrations showed little variability with depth of the sediment core. Individual elements were not present in concentrations that would indicate unnatural sources of contamination. Concentrations of each element generally were representative of their relative abundance in the earth's crust (Mason, 1958; Hem, 1985).

Table 1.—Concentrations of solid-phase inorganic constituents in discrete vertical increments of sediment cores collected at Reelfoot Lake, November 1988

[$\mu\text{g/g}$, micrograms per gram; %, percent by weight; <, less than the indicated reporting level]

| Station name Vertical increment in inches below sediment- water interface | Alum- inum % | Cal- cium % | Iron % | Potas- sium % | Magne- sium % | Sodi- um % | Phos- phorus % | Sul- fur % | Tita- nium % |
|------------------------------------------------------------------------------------|--------------------|-------------------|-----------|---------------------|---------------------|------------------|----------------------|------------------|--------------------|
| 1. Donaldson Ditch | | | | | | | | | |
| 0 to 14 | 6.9 | 0.81 | 3.2 | 2.1 | 0.83 | 0.78 | 0.08 | <0.05 | 0.30 |
| 14 to 28 | 5.9 | 1.9 | 2.4 | 2.0 | .89 | .97 | .07 | .05 | .27 |
| 2. Samburg | | | | | | | | | |
| 0 to 12 | 6.4 | 1.1 | 3.7 | 1.8 | .93 | .75 | .1 | .07 | .34 |
| 12 to 24 | 7.3 | .72 | 4.6 | 1.9 | .86 | .65 | .13 | < .05 | .35 |
| 24 to 36 | 6.1 | .61 | 3.3 | 1.9 | .62 | .85 | .1 | < .05 | .31 |
| 3. Horse Island Ditch | | | | | | | | | |
| 0 to 12 | 7.8 | .86 | 4.4 | 1.9 | .92 | .33 | .18 | .21 | .36 |
| 12 to 23 | 6.1 | .83 | 2.8 | 1.9 | .69 | .85 | .09 | < .05 | .27 |
| 23 to 35 | 6.1 | 1.1 | 3.0 | 1.9 | .84 | .84 | .09 | < .05 | .27 |
| 4. Buck Basin | | | | | | | | | |
| 0 to 14 | 9.0 | .69 | 7.0 | 1.7 | 1.0 | .27 | .21 | .12 | .38 |
| 14 to 28 | 8.4 | .81 | 4.1 | 2.0 | 1.1 | .42 | .07 | .12 | .36 |
| 5. Upper Blue Basin | | | | | | | | | |
| 0 to 10 | 7.0 | 1.1 | 4.0 | 1.7 | .86 | .39 | .26 | .28 | .29 |
| 10 to 22 | 7.3 | .98 | 4.4 | 1.8 | .90 | .38 | .29 | .29 | .29 |
| 22 to 32 | 7.0 | .82 | 3.2 | 2.1 | .85 | .79 | .08 | < .05 | .31 |
| Average composition, earth's crust | | | | | | | | | |
| (From Mason, 1958) | 8.1 | 3.6 | 5.0 | 2.6 | 2.1 | 2.8 | 1.2 | .05 | .4 |
| (From Hem, 1985) * | 7.9 | 3.6 | 4.2 | 2.6 | 1.8 | 2.8 | 1.1 | .04 | .4 |

* igneous rocks only

Table 1.—Concentrations of solid-phase inorganic constituents in discrete vertical increments of sediment cores collected at Reelfoot Lake, November 1988—Continued

[$\mu\text{g/g}$, micrograms per gram; %, percent by weight; <, less than the indicated reporting level]

| Station name Vertical increment in inches below sediment- water interface | Arsen- ic ($\mu\text{g/g}$) | Bar- ium ($\mu\text{g/g}$) | Beryl- lium ($\mu\text{g/g}$) | Bis- muth ($\mu\text{g/g}$) | Cad- mium ($\mu\text{g/g}$) | Cer- ium ($\mu\text{g/g}$) | Chro- mium ($\mu\text{g/g}$) | Co- balt ($\mu\text{g/g}$) |
|------------------------------------------------------------------------------------|-------------------------------------|--------------------------------------|---------------------------------------|-------------------------------------|---------------------------------------|------------------------------------|--------------------------------------|---------------------------------------|
| 1. Donaldson Ditch | | | | | | | | |
| 0 to 14 | 5.8 | 740 | 2 | <10 | <2 | 64 | 64 | 14 |
| 14 to 28 | 4.9 | 810 | 2 | <10 | <2 | 57 | 50 | 11 |
| 2. Samburg | | | | | | | | |
| 0 to 12 | 8.4 | 660 | 2 | <10 | <2 | 70 | 62 | 14 |
| 12 to 24 | 9.5 | 720 | 2 | <10 | <2 | 77 | 71 | 15 |
| 24 to 36 | 8.6 | 720 | 2 | <10 | <2 | 63 | 55 | 12 |
| 3. Horse Island Ditch | | | | | | | | |
| 0 to 12 | 11 | 620 | 2 | <10 | <2 | 72 | 80 | 18 |
| 12 to 23 | 4.5 | 710 | 2 | <10 | <2 | 58 | 55 | 12 |
| 23 to 35 | 4.6 | 730 | 2 | <10 | <2 | 57 | 56 | 12 |
| 4. Buck Basin | | | | | | | | |
| 0 to 14 | 18 | 660 | 2 | <10 | <2 | 95 | 91 | 19 |
| 14 to 28 | 10 | 680 | 3 | <10 | <2 | 74 | 89 | 15 |
| 5. Upper Blue Basin | | | | | | | | |
| 0 to 10 | 12 | 580 | 2 | <10 | <2 | 61 | 73 | 14 |
| 10 to 22 | 9.3 | 610 | 2 | <10 | <2 | 59 | 76 | 14 |
| 22 to 32 | 6.4 | 750 | 2 | <10 | <2 | 67 | 66 | 14 |
| Average composition, earth's crust (From Mason, 1958) | 2 | 400 | 2 | 0.2 | 0.2 | 46 | 200 | 23 |
| (From Hem, 1985) * | 1.8 | 595 | 3.6 | | .19 | 130 | 198 | 23 |
| Station name Vertical increment in inches below sediment- water interface | Cop- per ($\mu\text{g/g}$) | Euro- pium ($\mu\text{g/g}$) | Gal- lium ($\mu\text{g/g}$) | Hol- mium ($\mu\text{g/g}$) | Lan- thanum ($\mu\text{g/g}$) | Lead ($\mu\text{g/g}$) | Lith- ium ($\mu\text{g/g}$) | Mangan- ese ($\mu\text{g/g}$) |
| 1. Donaldson Ditch | | | | | | | | |
| 0 to 14 | 23 | <2 | 17 | <4 | 36 | 14 | 35 | 600 |
| 14 to 28 | 18 | <2 | 14 | <4 | 33 | 13 | 30 | 520 |
| 2. Samburg | | | | | | | | |
| 0 to 12 | 25 | <2 | 15 | <4 | 33 | 19 | 29 | 1,100 |
| 12 to 24 | 31 | <2 | 18 | <4 | 40 | 18 | 34 | 1,200 |
| 24 to 36 | 21 | <2 | 14 | <4 | 34 | 15 | 26 | 1,100 |
| 3. Horse Island Ditch | | | | | | | | |
| 0 to 12 | 32 | <2 | 21 | <4 | 38 | 29 | 48 | 1,400 |
| 12 to 23 | 19 | <2 | 14 | <4 | 33 | 12 | 33 | 490 |
| 23 to 35 | 19 | <2 | 15 | <4 | 32 | 12 | 32 | 970 |
| 4. Buck Basin | | | | | | | | |
| 0 to 14 | 44 | 2 | 23 | <4 | 48 | 28 | 42 | 1,900 |
| 14 to 28 | 27 | <2 | 21 | <4 | 41 | 16 | 51 | 440 |
| 5. Upper Blue Basin | | | | | | | | |
| 0 to 10 | 27 | <2 | 18 | <4 | 34 | 21 | 42 | 1,600 |
| 10 to 22 | 28 | <2 | 19 | <4 | 33 | 23 | 44 | 1,600 |
| 22 to 32 | 23 | <2 | 17 | <4 | 37 | 16 | 36 | 610 |
| Average composition, earth's crust (From Mason, 1958) | 45 | 1 | 15 | 1 | 18 | 15 | 30 | 1,000 |
| (From Hem, 1985) * | 97 | 2.3 | 18 | 2.4 | 48 | 16 | 32 | 937 |

* igneous rocks only

Table 1. — Concentrations of solid-phase inorganic constituents in discrete vertical increments of sediment cores collected at Reelfoot Lake, November 1988 — Continued

[$\mu\text{g/g}$, micrograms per gram; %, percent by weight; <, less than the indicated reporting level]

| Station name Vertical increment in inches below sediment- water interface | Mercury ($\mu\text{g/g}$) | Molybdenum ($\mu\text{g/g}$) | Neodymium ($\mu\text{g/g}$) | Nickel ($\mu\text{g/g}$) | Niobium ($\mu\text{g/g}$) | Scandium ($\mu\text{g/g}$) | Selenium ($\mu\text{g/g}$) | Strontium ($\mu\text{g/g}$) |
|------------------------------------------------------------------------------------|---------------------------------|-----------------------------------|----------------------------------|--------------------------------|---------------------------------|----------------------------------|---------------------------------|----------------------------------|
| 1. Donaldson Ditch | | | | | | | | |
| 0 to 14 | 0.06 | <2 | 32 | 30 | 8 | 10 | 0.7 | 160 |
| 14 to 28 | .06 | <2 | 28 | 24 | 6 | 8 | .3 | 190 |
| 2. Samburg | | | | | | | | |
| 0 to 12 | .14 | <2 | 33 | 34 | 7 | 10 | .4 | 120 |
| 12 to 24 | .12 | <2 | 37 | 40 | 8 | 12 | .6 | 110 |
| 24 to 36 | .10 | <2 | 30 | 30 | 6 | 9 | .4 | 120 |
| 3. Horse Island Ditch | | | | | | | | |
| 0 to 12 | .12 | <2 | 33 | 41 | 10 | 13 | 1.0 | 99 |
| 12 to 23 | .04 | <2 | 29 | 27 | 7 | 9 | .6 | 170 |
| 23 to 35 | .04 | <2 | 29 | 27 | 7 | 9 | .6 | 160 |
| 4. Buck Basin | | | | | | | | |
| 0 to 14 | .16 | <2 | 45 | 53 | 11 | 16 | 1.0 | 80 |
| 14 to 28 | .12 | <2 | 35 | 39 | 10 | 14 | 1.0 | 120 |
| 5. Upper Blue Basin | | | | | | | | |
| 0 to 10 | .12 | <2 | 30 | 35 | 9 | 12 | 1.2 | 110 |
| 10 to 22 | .12 | <2 | 30 | 35 | 9 | 12 | 1.2 | 110 |
| 22 to 32 | .08 | <2 | 31 | 31 | 7 | 10 | .7 | 160 |
| Average composition, earth's crust (From Mason, 1958) (From Hem, 1985) * | .5 .33 | 1 1.2 | 24 56 | 80 94 | 24 20 | 5 15 | .09 .05 | 450 368 |
| ----- | | | | | | | | |
| Station name Vertical increment in inches below sediment- water interface | Tantalum ($\mu\text{g/g}$) | Thorium ($\mu\text{g/g}$) | Tin ($\mu\text{g/g}$) | Uranium ($\mu\text{g/g}$) | Vanadium ($\mu\text{g/g}$) | Ytterbium ($\mu\text{g/g}$) | Yttrium ($\mu\text{g/g}$) | Zinc ($\mu\text{g/g}$) |
| 1. Donaldson Ditch | | | | | | | | |
| 0 to 14 | <40 | 12 | <10 | <100 | 110 | 3 | 23 | 83 |
| 14 to 28 | <40 | 10 | <10 | <100 | 78 | 2 | 20 | 60 |
| 2. Samburg | | | | | | | | |
| 0 to 12 | <40 | 10 | <10 | <100 | 95 | 3 | 24 | 97 |
| 12 to 24 | <40 | 13 | <10 | <100 | 110 | 3 | 26 | 120 |
| 24 to 36 | <40 | 10 | <10 | <100 | 85 | 2 | 21 | 81 |
| 3. Horse Island Ditch | | | | | | | | |
| 0 to 12 | <40 | 11 | <10 | <100 | 130 | 3 | 26 | 120 |
| 12 to 23 | <40 | 10 | <10 | <100 | 85 | 2 | 20 | 70 |
| 23 to 35 | <40 | 10 | <10 | <100 | 86 | 2 | 21 | 69 |
| 4. Buck Basin | | | | | | | | |
| 0 to 14 | <40 | 16 | <10 | <100 | 150 | 3 | 32 | 160 |
| 14 to 28 | <40 | 14 | <10 | <100 | 150 | 3 | 25 | 110 |
| 5. Upper Blue Basin | | | | | | | | |
| 0 to 10 | <40 | 11 | <10 | <100 | 120 | 3 | 22 | 110 |
| 10 to 22 | <40 | 12 | <10 | <100 | 120 | 3 | 22 | 120 |
| 22 to 32 | <40 | 10 | <10 | <100 | 110 | 3 | 24 | 85 |
| Average composition, earth's crust (From Mason, 1958) (From Hem, 1985) * | 2 2 | 10 11 | 3 2.5 | 2 2.8 | 110 149 | 3 4.8 | 40 41 | 65 80 |

* igneous rocks only

WATER CHEMISTRY

Concentrations of major and minor inorganic constituents and properties of lake water were relatively consistent among stations (table 2). Water was of the calcium magnesium bicarbonate type and was moderately hard. Concentrations of dissolved solids averaged about 120 milligrams per liter (mg/L). Comparisons of concentrations of trace metals in filtered (0.45-micrometer filter) and unfiltered samples revealed that a sizable fraction of these constituents are associated with particulate matter. Primary water-quality standards established by the State of Tennessee (Tennessee Department of Health and Environment, 1988) were not exceeded in any of the samples. For the unfiltered samples, the secondary water-quality standard for iron [300 micrograms per liter ($\mu\text{g/L}$)] was exceeded at 4 of 5 sites and manganese exceeded the secondary standard (50 $\mu\text{g/L}$) at all stations. Concentrations of nitrogen and phosphorus species generally were low. Most nitrogen was present in association with organic material.

ELUTRIATE CHEMISTRY

Elutriate tests provide an index of short-term chemical degradation that may occur when bottom material is mixed with overlying water during dredging or other channelization activity. Because the mechanics of mixing in a field situation will vary with site-specific conditions and the types of equipment used, concentrations of constituents measured in elutriate tests may differ from concentrations that will occur during an actual dredging operation. Also, elutriate tests do not determine the longer term chemical behavior or biological effects of the constituents that are measured. Accordingly, the results of this study represent only a preliminary indication of conditions that may result from dredging at Reelfoot Lake.

The physical and chemical properties of the unfiltered elutriate waters contrasted sharply with those of lake water (table 3). Perhaps the most striking observation was the decline in the concentration of dissolved oxygen, which decreased by as much as 8.0 mg/L. For each station, bottom material derived from deeper sections of the core exerted a higher oxygen demand than did the uppermost vertical increment. This oxygen demand can be attributed to the oxidation of sulfides and reduced species of iron and manganese. Values of pH also dropped during all elutriate tests. This change may be attributable to the release of organic acids from bottom material, or the evolution of hydrogen ions during the oxidation of sulfides.

Unfiltered elutriate waters had suspended-sediment concentrations of approximately 2,000 mg/L (Stephen J. Klaine, Memphis State University, written commun., 1989). Concentrations of trace elements in elutriate waters reflected the high levels of suspended material (table 3). Aluminum and iron — principal constituents of the minerals that compose local silts and clays — were dominant. Concentrations of most trace elements occurred in approximately the same ratios as their concentrations in the bulk bottom material.

Concentrations of several total-recoverable trace elements in the elutriate waters exceeded water-quality criteria for freshwater with a hardness of 100 mg/L as calcium carbonate (U.S. Environmental Protection Agency, 1986). For the protection of freshwater aquatic life, the 1-hour average concentration of total recoverable copper should not exceed 18 $\mu\text{g/L}$ more than once every 3 years (U.S. Environmental Protection Agency, 1986). This recommended concentration of copper was exceeded in all elutriate samples. Similarly, the 1-hour average concentration of total-recoverable lead should not exceed 82 $\mu\text{g/L}$ more than once every 3 years (U.S. Environmental Protection Agency, 1986). This concentration of lead was exceeded in 4 of the

Table 2. — Concentrations of major and minor inorganic constituents and properties of water collected at Reelfoot Lake, November 1988

[mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; <, less than the indicated reporting level]

| Constituent or Property | Station 1 Donaldson Ditch | Station 2 Samburg | Station 3 Horse Island Ditch | Station 4 Buck Basin | Station 5 Upper Blue Basin |
|---------------------------------------------|---------------------------------|----------------------|---------------------------------------|----------------------------|-------------------------------------|
| Calcium, mg/L | 22 | 21 | 29 | 23 | 27 |
| Magnesium, mg/L | 10 | 9.9 | 3.5 | 11 | 11 |
| Sodium, mg/L | 4.2 | 3.9 | 7.3 | 4.2 | 5.5 |
| Potassium, mg/L | 4.3 | 3.6 | 6.1 | 3.6 | 4.6 |
| Alkalinity, mg/L as CaCO ₃ | 95 | 94 | 108 | 98 | 100 |
| Chloride, mg/L | 4.9 | 4.3 | 5.5 | 5.4 | 6.1 |
| Sulfate, mg/L as SO ₄ | 7.3 | 6.3 | 6.8 | 7.4 | 8.5 |
| Fluoride, mg/L | .20 | .20 | .20 | .20 | .20 |
| Silica, mg/L as SiO ₂ | .83 | .97 | 4.6 | 1.8 | 2.4 |
| Aluminum, dissolved, µg/L | <10 | <10 | <10 | <10 | <10 |
| Aluminum, total recoverable, µg/L | 180 | 450 | 250 | 330 | 420 |
| Arsenic, dissolved, µg/L | 2 | 1 | 2 | 1 | 2 |
| Arsenic, total, µg/L | 4 | 3 | 3 | 2 | 3 |
| Barium, dissolved, µg/L | 46 | 49 | 130 | 60 | 67 |
| Barium, total recoverable, µg/L | 100 | 100 | 100 | 100 | 100 |
| Beryllium, dissolved, µg/L | <.5 | <.5 | <.5 | <.5 | <.5 |
| Beryllium, total recoverable, µg/L | <10 | <10 | <10 | <10 | <10 |
| Cadmium, dissolved, µg/L | 1 | <1 | 1 | <1 | <1 |
| Cadmium, total recoverable, µg/L | <1 | <1 | <1 | <1 | <1 |
| Chromium, dissolved, µg/L | <1 | <1 | <1 | <1 | <1 |
| Chromium, total recoverable, µg/L | <1 | 2 | <1 | <1 | 1 |
| Cobalt, dissolved, µg/L | <3 | <3 | <3 | <3 | <3 |
| Cobalt, total recoverable, µg/L | 1 | <1 | 2 | 1 | 1 |
| Copper, dissolved, µg/L | 2 | 1 | 3 | 4 | 2 |
| Copper, total recoverable, µg/L | 5 | 6 | 5 | 6 | 8 |
| Iron, dissolved, µg/L | 55 | 18 | 26 | 44 | 46 |
| Iron, total recoverable, µg/L | 850 | 1,100 | 990 | 1,100 | 80 |
| Lead, dissolved, µg/L | <5 | <5 | <5 | <5 | <5 |
| Lead, total recoverable, µg/L | <5 | 9 | <5 | <5 | <5 |
| Lithium, dissolved, µg/L | <4 | <4 | 9 | <4 | <4 |
| Manganese, dissolved, µg/L | 49 | 3 | 16 | 44 | 150 |
| Manganese, total recoverable, µg/L | 280 | 290 | 210 | 120 | 250 |
| Mercury, dissolved, µg/L | <.1 | .2 | <.1 | <.1 | <.1 |
| Mercury, total recoverable, µg/L | 1.0 | .20 | <.10 | .10 | .10 |
| Molybdenum, dissolved, µg/L | <10 | <10 | <10 | <10 | <10 |
| Molybdenum, total recoverable, µg/L | <1 | <1 | <1 | <1 | <1 |
| Nickel, dissolved, µg/L | <1 | 3 | <1 | <1 | 2 |
| Nickel, total recoverable, µg/L | 2 | 3 | 2 | 2 | 4 |
| Selenium, dissolved, µg/L | <1 | <1 | <1 | <1 | <1 |
| Selenium, total, µg/L | <1 | <1 | <1 | <1 | <1 |
| Silver, dissolved, µg/L | 1.0 | <1.0 | <1.0 | 1.0 | 1.0 |
| Silver, total recoverable, µg/L | <1 | <1 | <1 | 1 | 1 |
| Strontium, dissolved, µg/L | 86 | 84 | 140 | 88 | 100 |
| Vanadium, dissolved, µg/L | <6 | <6 | 8 | <6 | <6 |
| Zinc, dissolved, µg/L | 15 | 8 | 9 | 8 | 7 |
| Zinc, total recoverable, µg/L | <10 | <10 | <10 | <10 | <10 |
| Nitrogen, organic, total, mg/L as N | 2.5 | 3.1 | 2.0 | 1.0 | 1.4 |
| Nitrogen, ammonia, dissolved, mg/L as N | .020 | <.010 | .040 | .060 | .080 |
| Nitrogen, ammonia, total, mg/L as N | .020 | .020 | .030 | .070 | .070 |
| Nitrogen, nitrite plus nitrate, mg/L as N | <.100 | <.100 | <.100 | <.100 | <.100 |
| Phosphorus, total, mg/L | .190 | .250 | .170 | .080 | .180 |
| Phosphorus, dissolved, mg/L | .010 | .020 | .020 | .020 | .020 |
| Phosphorus, ortho, dissolved, mg/L as P | .020 | .010 | .010 | <.010 | .020 |
| pH, field, standard units | 7.7 | 7.8 | 7.5 | 7.5 | 7.2 |
| Dissolved oxygen, mg/L | 7.2 | 9.9 | 6.9 | 8.1 | 5.8 |
| Specific conductance, µS/cm at 25 °C | 225 | 210 | 225 | 230 | 220 |
| Dissolved solids, residue at 180 °C, mg/L | 118 | 110 | 119 | 120 | 125 |
| Dissolved solids, sum of constituents, mg/L | 114 | 110 | 120 | 118 | 132 |
| Hardness, mg/L as CaCO ₃ | 96 | 93 | 87 | 100 | 110 |

Table 3. — Concentrations of selected inorganic constituents and properties of unfiltered elutriate water produced by mixing bottom sediments and lake water from Reelfoot Lake, November 1988

[All values in micrograms per liter unless otherwise noted; <, less than the indicated reporting level; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; --, indicates no data; mg/L, milligrams per liter]

| Station number and name Source of sediment, vertical increment in inches below sediment- water interface | Specific conduct- ance ($\mu\text{S}/\text{cm}$ at 25 °C) | Dissolved oxygen (mg/L) | Change in dissolved oxygen during elutriation (mg/L) | pH (standard units) | Change in pH during elutriation (standard units) |
|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------|---------------------------|--------------------------------------------------------------|
| 1. Donaldson Ditch | | | | | |
| 0 to 14 | 245 | 3.0 | -5.6 | 6.75 | -0.69 |
| 14 to 28 | 305 | 0.6 | -8.0 | 6.95 | - .49 |
| 2. Samburg | | | | | |
| 0 to 12 | 200 | 1.0 | -6.4 | 7.25 | - .21 |
| 12 to 24 | 215 | .2 | -7.2 | 6.81 | - .65 |
| 24 to 36 | 242 | .2 | -7.2 | 6.90 | - .56 |
| 3. Horse Island Ditch | | | | | |
| 0 to 12 | 195 | 3.3 | -4.6 | 6.61 | - .89 |
| 12 to 23 | 205 | 3.2 | -4.7 | 6.51 | - .99 |
| 23 to 35 | 195 | 2.8 | -5.1 | 6.61 | - .89 |
| 4. Buck Basin | | | | | |
| 0 to 14 | 195 | .8 | -6.3 | 6.63 | -1.01 |
| 14 to 28 | 190 | .6 | -6.5 | 6.49 | -1.15 |
| 5. Upper Blue Basin | | | | | |
| 0 to 10 | 210 | 5.9 | -1.3 | 6.93 | - .65 |
| 10 to 22 | 325 | 2.0 | -5.2 | 6.70 | - .88 |
| 22 to 32 | 340 | .8 | -6.4 | 6.90 | - .68 |

| Station number and name Source of sediment, vertical increment in inches below sediment- water interface | Aluminum, total | Arsenic, total | Barium, total | Beryllium, total | Cadmium, total | Chromium, total |
|----------------------------------------------------------------------------------------------------------------------|--------------------|-------------------|------------------|---------------------|-------------------|--------------------|
| 1. Donaldson Ditch | | | | | | |
| 0 to 14 | 52,000 | 17 | 1,000 | <10 | 1 | 57 |
| 14 to 28 | 42,000 | 16 | 1,100 | <10 | 1 | 48 |
| 2. Samburg | | | | | | |
| 0 to 12 | 72,000 | 9 | 1,200 | <10 | <1 | 76 |
| 12 to 24 | 70,000 | 42 | 4,600 | 10 | <1 | 330 |
| 24 to 36 | 60,000 | 16 | 10,000 | 30 | <1 | 690 |
| 3. Horse Island Ditch | | | | | | |
| 0 to 12 | 30,000 | 23 | 2,200 | 10 | <1 | 140 |
| 12 to 23 | 87,000 | -- | 1,400 | <10 | <1 | 89 |
| 23 to 35 | 30,000 | 23 | 2,000 | 10 | <1 | 150 |
| 4. Buck Basin | | | | | | |
| 0 to 14 | 56,000 | 13 | 1,000 | <10 | <1 | 54 |
| 14 to 28 | 10,000 | 15 | 3,000 | 10 | <1 | 219 |
| 5. Upper Blue Basin | | | | | | |
| 0 to 10 | 20,000 | 8 | 500 | <10 | 2 | 23 |
| 10 to 22 | 40,000 | 14 | 900 | <10 | 1 | 44 |
| 22 to 32 | 33,000 | -- | 600 | <10 | 1 | 38 |

Table 3. — *Concentrations of selected inorganic constituents and properties of unfiltered elutriate water produced by mixing bottom sediments and lake water from Reelfoot Lake, November 1988—Continued*

[All values in micrograms per liter unless otherwise noted; <, less than the indicated reporting level; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; --, indicates no data; mg/L, milligrams per liter]

| Station number and name Source of sediment, vertical increment in inches below sediment- water interface | Cobalt, total | Copper, total | Iron, total | Lead, total | Mercury, total recover- able | Manganese, total |
|----------------------------------------------------------------------------------------------------------------------|----------------------|------------------|--------------------|------------------|---------------------------------------|---------------------|
| 1. Donaldson Ditch | | | | | | |
| 0 to 14 | 5 | 39 | 63,000 | 17 | -- | 2,000 |
| 14 to 28 | 6 | 62 | 52,000 | 30 | 0.50 | 1,400 |
| 2. Samburg | | | | | | |
| 0 to 12 | 6 | 60 | 94,000 | 27 | < .10 | 3,300 |
| 12 to 24 | 50 | 300 | 70,000 | 400 | -- | 15,000 |
| 24 to 36 | 30 | 1,000 | 30,000 | 600 | -- | 28,000 |
| 3. Horse Island Ditch | | | | | | |
| 0 to 12 | 20 | 200 | 30,000 | 86 | < .10 | 4,100 |
| 12 to 23 | 10 | 62 | 84,000 | 42 | < .10 | 1,400 |
| 23 to 35 | 30 | 200 | 50,000 | 56 | < .10 | 1,600 |
| 4. Buck Basin | | | | | | |
| 0 to 14 | 6 | 49 | 75,000 | 18 | < .10 | 2,900 |
| 14 to 28 | 40 | 290 | 40,000 | 200 | -- | 6,300 |
| 5. Upper Blue Basin | | | | | | |
| 0 to 10 | 3 | 29 | 20,000 | 10 | < .10 | 1,300 |
| 10 to 22 | 7 | 40 | 40,000 | 17 | < .10 | 2,100 |
| 22 to 32 | 7 | 33 | 39,000 | 7 | -- | 1,300 |
| ----- | | | | | | |
| Station number and name Source of sediment, vertical increment in inches below sediment- water interface | Molybdenum, total | Nickel, total | Selenium, total | Silver, total | Zinc, total | |
| 1. Donaldson Ditch | | | | | | |
| 0 to 14 | <1 | 37 | <1 | <1 | 320 | |
| 14 to 28 | 6 | 39 | <1 | 1 | 219 | |
| 2. Samburg | | | | | | |
| 0 to 12 | 8 | 53 | <1 | <1 | 370 | |
| 12 to 24 | <5 | 300 | -- | <1 | 1,700 | |
| 24 to 36 | <5 | 120 | -- | <1 | 3,300 | |
| 3. Horse Island Ditch | | | | | | |
| 0 to 12 | <1 | 89 | <1 | <1 | 540 | |
| 12 to 23 | 7 | 55 | -- | | 330 | |
| 23 to 35 | <1 | 109 | <1 | <1 | 660 | |
| 4. Buck Basin | | | | | | |
| 0 to 14 | 8 | 41 | <1 | <1 | 230 | |
| 14 to 28 | <5 | 300 | -- | <1 | 1,100 | |
| 5. Upper Blue Basin | | | | | | |
| 0 to 10 | 6 | 27 | <1 | <1 | 100 | |
| 10 to 22 | <1 | 40 | <1 | <1 | 190 | |
| 22 to 32 | 6 | 33 | -- | <1 | 230 | |

13 elutriate samples. The concentration of total-recoverable zinc should not exceed 117 $\mu\text{g/L}$ at any time (U.S Environmental Protection Agency, written commun., 1989). This concentration of zinc was exceeded in 12 of the 13 elutriate samples.

Although concentrations of trace elements in the unfiltered elutriate water exceeded some water-quality criteria, their bio-availability may be limited because they are associated with particulate matter. Limited bio-availability may be one reason why very little toxicity was demonstrated in the 48-hour bioassays with *Ceriodaphnia dubia*. In half of the bioassays, no mortality was observed (table 4). Mortality exceeded 10 percent only in the diluted elutriate water prepared from the shallowest bottom sediments collected near Samburg (fig. 1, station 2).

Table 4. — *Percent mortality of Ceriodaphnia dubia following exposure to 25-percent dilutions of unfiltered elutriate water produced by mixing bottom sediments and lake water from Reelfoot Lake, November 1988*

| Station number and name Source of sediment, vertical increment in inches below sediment- water interface | Percent mortality of 10 replicates after exposure for 48 hours |
|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| 1. Donaldson Ditch | |
| 0 to 14 | 10 |
| 14 to 28 | 0 |
| 2. Samburg | |
| 0 to 12 | 30 |
| 12 to 24 | 0 |
| 24 to 36 | 0 |
| 3. Horse Island Ditch | |
| 0 to 12 | 10 |
| 12 to 23 | 0 |
| 23 to 35 | 10 |
| 4. Buck Basin | |
| 0 to 14 | 0 |
| 14 to 28 | 10 |
| 5. Upper Blue Basin | |
| 0 to 10 | 0 |
| 10 to 22 | 0 |
| 22 to 32 | 10 |
| Control | 0 |

SUMMARY

To better understand and predict the potential effect of dredging on water quality at Reelfoot Lake, chemical analyses were conducted on samples of lake water, bottom sediment, and elutriate water. Samples of water and sediments were collected during November 1988 at five stations in the lake and analyzed for inorganic constituents including nutrients and trace metals. Additionally, elutriate samples obtained by mixing native lake water with sediment samples were analyzed for selected trace elements and oxygen demand.

The results of the investigation showed that:

1. Concentrations of inorganic constituents in the water and sediments did not vary significantly among the five sampling sites. There were no significant changes in the concentration of inorganic constituents with depth of the cored sediments.
2. The concentrations of trace elements in the sediments were typical of values in surface soils, with no toxic concentrations detected.
3. The principal ions in the water were calcium, magnesium, and bicarbonate. Dissolved-solids concentrations averaged 120 mg/L.
4. Trace elements and nutrients in the water were associated with particulate matter, and did not occur at concentrations exceeding water-quality criteria for the protection of aquatic life.
5. Elutriate samples from the mixing of lake water and sediments exerted oxygen demands as high as 8 mg/L. Deeper sections of cored sediment samples

exhibited higher oxygen demands than shallower sections of the sediment cores.

6. Maximum recommended concentrations for the protection of aquatic life for cop-

per, lead, and zinc were exceeded in several of the elutriate samples. However, 48-hour toxicity tests of the elutriate with *Ceriodaphnia dubia* resulted in mortality rates less than 10 percent.

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