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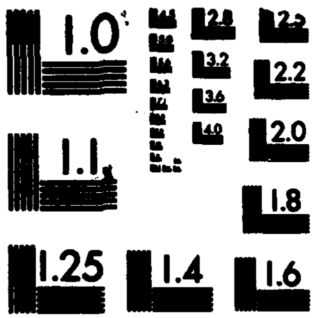

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The distribution, accumulation, and quality of reservoir sediment is influenced by any number of factors, which include morphology, hydrology, preimpoundment conditions, and water quality. Sediment core samples were obtained from four U. S. Army Corps of Engineers reservoirs (Red Rock, DeGray, Eau Galle, and West Point Lakes) for the purpose of identifying the physical and chemical characteristics of their sediments. Sediment characteristics at Eau Galle Lake are greatly influenced by morphological conditions, while

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sediment characteristics at the other three reservoirs are dominated by hydrologic conditions. All four reservoir systems contain some local factors (e.g., tributaries, bridges) which cause deviations in expected sediment conditions.

While these four reservoirs differ in size, shape, operation, and trophic condition, they all exhibit two distinguishable sedimentary zones: (1) a transport zone, which is dominated by turbulent processes (e.g., flow, wind) and characterized by a large median particle size; low moisture content; and low sediment nutrient, metal, and organic matter concentrations and (2) an accumulation zone, which is not affected by turbulence and is characterized as having a small median particle size; high moisture content; and high concentrations of sediment nutrients, metals, and organic matter.

PREFACE

The studies described in this report were sponsored by the Office, Chief of Engineers (OCE), U. S. Army, as part of the Environmental and Water Quality Operational Studies (EWQOS) Work Unit VIIA and were managed by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The OCE Technical Monitors for EWQOS were Mr. Earl Eiker, Mr. John Bushman, and Mr. James L. Gottesman.

Work was conducted by the Limnological Studies Team (LST) under the direction of Dr. J. Harrison, Chief of the Environmental Laboratory (EL), and under the general supervision of Mr. D. L. Robey, Chief of Ecosystem Research and Simulation Division (ERSD). Program Manager of EWQOS was Dr. J. L. Mahloch.

This report was written by Mr. R. C. Gunkel, Jr., Dr. R. F. Gaugush, Dr. R. H. Kennedy, Dr. G. E. Saul, Mr. J. H. Carroll, and Ms. J. Gauthey. Excellent support was provided by the U. S. Army Engineer Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, U. S. Department of Agriculture, and the Southwest Watershed Research Center, Tucson, Arizona, in the analyses of sediment chemistry and particle size, respectively. This report was reviewed by Drs. D. Gunnison, J. M. Brannon, and R. L. Chen.

The Commanders and Directors of WES during these studies and the preparation of this report were COL J. L. Cannon, CE; COL N. P. Conover, CE; and COL T. C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

A COMPARATIVE STUDY OF SEDIMENT QUALITY IN FOUR RESERVOIRS

PART I: INTRODUCTION

1. The transport and deposition of sediments is a problem of major concern to reservoir management, since the accumulation of sediment in reservoirs threatens their economic, recreational, and aesthetic value. Of the reservoirs built prior to 1935 in the midwestern, southeastern, and southwestern United States, 33 percent have lost from one-fourth to one-half their original capacity, 14 percent have lost from one-half to three-quarters of their original capacity, and about 10 percent have had all usable storage depleted by sediment deposition (U. S. Department of Agriculture 1973). In addition to losses in storage volume, accumulating sediments also have a significant impact, directly or indirectly, on reservoir water quality (see, for example, Thornton et al. 1981). While sediments were assessed to be the major water pollutant in 1960, they were also cited as a major carrier for other water quality constituents (U. S. Senate Select Committee on National Water Resources 1960). These constituents include pesticides and other organic residues, nutrients, and pathogenic organisms.

2. The distribution, deposition, quantity, and quality of material transported to a reservoir depends on a number of factors and will vary among reservoirs. These factors include watershed size and topography, geologic characteristics, land use patterns, basin morphology, hydrology, and influent material settling characteristics. Mainstream reservoirs, for instance, are often long and relatively narrow, suggesting that advective transport plays a dominant role in sediment distribution. Such reservoirs should exhibit pronounced longitudinal gradients in suspended material concentrations and sediment accumulation. Sediment deposition should be greatest near the tributary inflow, since carrying capacity declines as the tributary enters the reservoir. Differences should also be apparent in the size of particles deposited along the length of the reservoir, with progressively finer particles

being deposited at downstream locations. Advective transport should also influence the deposition of particulate material produced within the reservoir.

3. Sediment distribution in reservoirs less influenced by tributary flow or at locations distant from the inflow are influenced more by local conditions. Reservoirs which are influenced less by flow may be more lakelike in morphology and exhibit sediment deposition by focusing. Focusing is the accumulation of fine particulate matter in the deepest portions of a lake. Davis (1973) and Davis and Brubaker (1973) studied the deposition, resuspension, and redeposition of pollen grains in Frains Lake, Michigan. They found that smaller pollen grains were initially deposited preferentially on the littoral sediments, but during fall circulation the pollen was resuspended and deposited over the entire basin. This resuspension and deposition led to a higher net accumulation rate in the deepest sediments because a smaller portion of deep sediments are resuspended during periods of circulation. Net accumulation rates for pollen and sediment in the deepest region of this lake were ten times greater than in littoral regions. Wetzel et al. (1972) have also reported a net movement of small particles from the littoral to the deeper portions of the basin in Lawrence Lake, Michigan.

4. Hakanson (1977) hypothesized that: (a) fine particulate matter will not be deposited in "high energy environments" (i.e., littoral regions or areas of turbulence), (b) deposition of all particulate matter will be influenced to a large degree by hydrological flow patterns and bottom topology, and (c) the rate of deposition will increase with increasing depth. He went on to demonstrate that in Lake Vanern, Sweden, particles from 0.6 to 20 μm in diameter (fine silts and clays) accumulate only in sediments at depths greater than 40 m (i.e., in the two deepest basins in the lake). Hakanson's (1977) studies also demonstrated a correspondence between sediment water content and patterns in sediment distribution. Accumulation regions in Lake Vanern had water contents of approximately 75 percent for surficial (0-1 cm) sediments and 60-70 percent for sediments 9-10 cm below the sediment/water

interface. Sediments in zones of erosion and transportation were found to have lower (40-50 percent) water contents. In addition, it was demonstrated that the concentration of variables associated with particulate matter varied proportionally with moisture content.

5. Sedimentation patterns in reservoirs can often be associated with water quality characteristics. Thornton et al. (1981) and Kennedy et al. (1982) have observed a relationship between longitudinal gradients in water quality (a characteristic of many reservoirs) and sediment transport and deposition. High concentrations of inorganic particulates can reduce light availability near inflows and thus influence algal production (Soballe 1981, Kennedy et al. 1982). The association of dissolved substances, such as phosphorus, with suspended solids may act to reduce or buffer dissolved concentrations (Gloss et al. 1980) thus influencing nutrient availability. Canfield and Bachmann (1981), in comparing data for several natural and man-made lakes, suggest that phosphorus sedimentation rates in lakes which, because of their geographic location, receive high suspended solid loads will be higher than expected for otherwise similar lakes. Longitudinal differences in sediment deposition and quality may also affect exchanges at the sediment/water interface. For instance, sediment phosphorus release rates for Occoquan Reservoir, Virginia, which were correlated with sediment phosphorus content, were highest near the tributary inflow (To and Randall 1975). Thus, it seems reasonable to expect similarities between patterns in water quality and patterns in sediment deposition and quality.

6. Presented here are results of four comprehensive surveys of sediment quality in four U. S. Army Corps of Engineers (CE) reservoirs differing in size, operation, and trophic condition. The surveys were conducted to provide information concerning potential relationships between sediment characteristics and reservoir morphometry, hydrodynamics, and water quality.

PART II: SITE DESCRIPTIONS

Lake Red Rock

7. Lake Red Rock, a flood control reservoir located in south-central Iowa approximately 64 km southeast of Des Moines, Iowa (Figure 1), was created in 1969 by impoundment of the Des Moines River. Saylorville Dam impounds the Des Moines River approximately 114.2 km upstream from Red Rock Dam, and since the summer of 1977 the two dams have jointly provided flood protection along the lower 344 km of the Des Moines River.

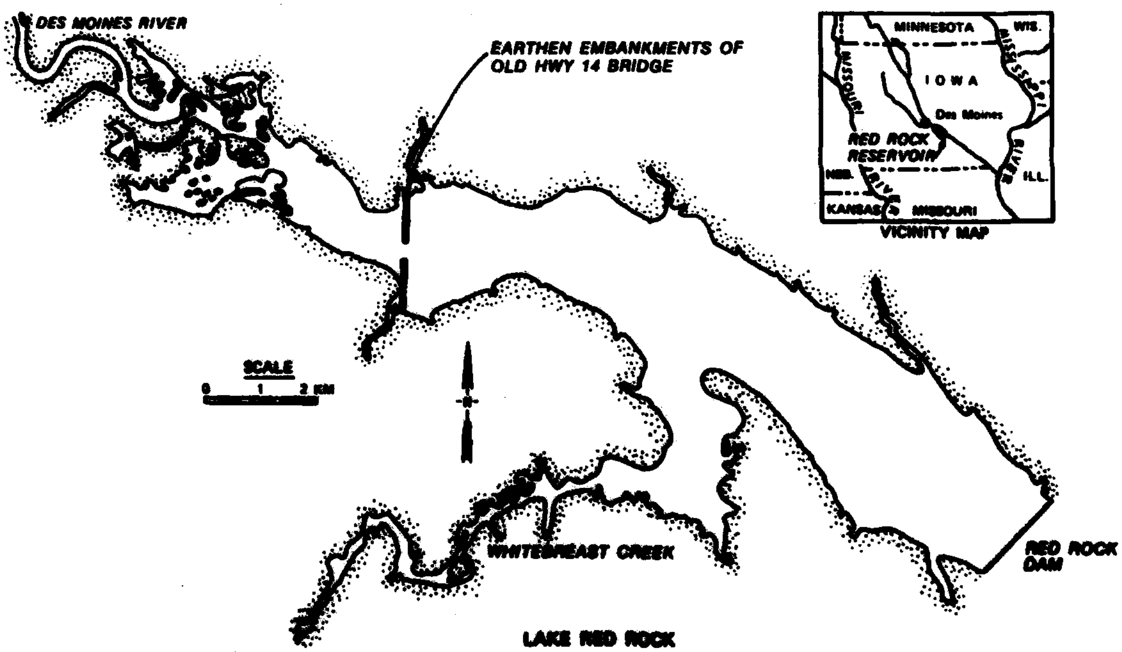

Figure 1. Map and location of Lake Red Rock

8. Red Rock Dam is an earthen-embankment structure with a concrete ogee valley spillway. Water withdrawal by the ogee section is accomplished using five tainter gates (12.5 by 13.7 m) and fourteen low-elevation (210 m msl) conduits. At normal pool elevation (221 m msl), the reservoir has me[illegible] and maximum depths of 3.1 and 10.5 m, respectively. Alt[illegible] [illegible]mally 12.4 km long, pool length increases to a

maximum of 54 km at flood storage pool. The surface area and pool volume also increase substantially during flood detention. Other physical features are presented in Table 1.

Table 1

Physical Characteristics for Red Rock, DeGray, Eau Galle, and West Point Lakes

Characteristics*	Lake Red Rock	DeGray Lake	Eau Galle Lake	West Point Lake
Elevation, m msl	221	124.4	286.5	193.6
Surface area, km^2	25.5	54.2	0.6	104.8
Volume, 10^6 m^3	78.4	808	1.9	745.7
Maximum depth, m	10.5	60	9	31
Mean depth, m	3.1	14.9	3.2	7.1
Reservoir length, km	12.4	32	1	53
Shoreline length, km	96.7	333	4	844.7
Shoreline development ratio	5.4	12.8	1.5	23.3
Drainage area, km^2	31,916	1173	166	5535
Residence time, yr	0.02	1.4	0.07	0.17

* Based on conservation pool elevation.

9. Agriculture is the predominate landuse in the 31,916-km^2 watershed; however, significant point-source loadings to the Des Moines River occur near the city of Des Moines (Baumann et al. 1974). The Des Moines River is the primary inflow to Lake Red Rock, and in general is highly turbid, nutrient-rich, and high in dissolved and suspended solids. Whitebreast Creek, a relatively minor tributary, is located on the south shore of the lake. Earthen embankments, which were left in place following relocation of the Highway 14 bridge on the Des Moines River immediately upstream from the lake's headwaters, continue to constrict flow through a 250-m wide channel at pool elevations less than 221 m msl; at higher pool elevations, these embankments are inundated. The area upstream of the Highway 14 bridge is a flat region of wetlands and river meanders.

10. High suspended solid loads carried by the Des Moines River coupled with reductions in flow in the broad headwater area have resulted in the deposition of large quantities of sediment and the formation of an extensive submerged delta. This area of the reservoir is characteristically shallow and subject to changes in bottom topography following high flows. Variations in pool elevation, turbidity, and continuous sediment deposition prevent the growth of rooted vegetation on the delta or along the reservoir shore.

11. Lake Red Rock, which may be classified as eutrophic with respect to both nutrient (0.2-6 mg of phosphorus (P)/L and 1-17 mg of nitrogen (N)/L) and chlorophyll *a* concentrations (0-320 μg/L), is typically turbid and during runoff events exhibits excessive suspended sediment concentrations (Kennedy et al. 1981). The reservoir exhibits weak density stratification in summer, due in part to high suspended solids concentrations in bottom waters. Although aerobic conditions are generally maintained throughout the water column, low dissolved oxygen concentrations (ca. 4 mg/L) often occur in bottom waters during stratified periods. Mean annual values for selected water quality constituents are presented in Table 2.

12. A relatively short theoretical hydraulic residence time (ca. 7 days) and high turbidity prevent the development of a true lacustrine phytoplankton community in Lake Red Rock (Soballe 1981). Despite high nutrient loads, this impoundment is an algal sink and the phytoplankton standing crop must be continually renewed by riverine inputs to maintain observed chlorophyll levels. A notable exception occurred, however, during the spring of 1979 when flows were abnormally high and above-normal pool elevations were maintained until late spring. The increase in residence time fostered decreases in turbidity, allowing the development of a true lacustrine phytoplankton community (Baumann et al. 1980).

DeGray Lake

13. DeGray Lake, a multipurpose reservoir in south-central Arkansas, was formed in August 1969 by impoundment of the Caddo River

Table 2

Water Quality Characteristics of Red Rock, DeGray, Eau Galle, and West Point Lakes

Variable*	Red Rock**	DeGray†	Eau Galle††	West Point‡
Dissolved oxygen	10.4	8.3	11.7	5.0
Temperature, °C	14.1	19.1	9.2	20.4
Specific conductance, μmhos/cm	649	--	312	--
Turbidity, NTU	31.7	3.0	4.8	7.9
Total alkalinity	213.7	--	152.3	15.2
Total carbon	61.7	--	47.4	--
Total inorganic carbon	51.3	--	35.2	--
Total organic carbon	9.0	5.5	7.4	4.64
Total phosphorus	0.86	0.011	0.091	0.04
Soluble reactive phosphorus	0.48	0.001	0.026	--
Total nitrogen	6.30	--	1.65	0.78
Ammonia nitrogen	0.33	0.02	0.08	0.15
Nitrate nitrite nitrogen	5.05	--	0.7	--
Total manganese	--	0.05	0.13	0.22
Dissolved manganese	--	0.04	0.03	--
Total iron	0.22	0.07	0.36	0.71
Dissolved iron	--	0.07	0.13	--
Total solids	480.9	44.9	207.9	--
Dissolved solids	--	38.3	149.9	--
Suspended solids	88.9	--	9.9	--
Chlorophyll α, μg/L	23.7	--	31.9	--

* Mean annual values in mg/L, unless otherwise noted.
** Mean surface values from one near-dam station for years 1969-1980.
† Mean epilimnetic values (0-6 m) from one station for years 1977-1981.
†† Mean surface values (0-2 m) from six lake stations for years 1978-1981.
‡ Mean surface values from one near-dam station (unpublished 1975-1981 data from William W. Walker, Environmental Engineer, Concord, Mass.

(Figure 2). DeGray Dam, located 12.7 km upstream of the confluence of the Caddo and Ouachita Rivers, provides power generation (conventional and pumped-storage), flood control, and flow augmentation. Water withdrawal through the earthfilled structure is possible from three different levels using twelve 41-m^2 portals in the intake tower. While releases in the first 10 years of operation were from the uppermost gates, a deep-release regime was instituted in 1979 to assess the impacts of hypolimnetic withdrawal on fish populations and downstream conditions. The reservoir has a surface area of 54.2 km^2 and a volume of 8.08×10^8 m^3 at conservation pool (124.4 m msl). In addition, the reservoir has a complex shoreline, a length of 32 km, and mean and maximum depths of 14.9 and 60 m, respectively. Other physical features are listed in Table 1.

14. The 1173-km^2 watershed is 70 percent mixed forest and 30 percent agricultural land (cultivated fields, pastures, meadows, and abandoned fields), with minimal urban and residential development. The Caddo River is the major drainage in the watershed and supplies approximately 70 percent of the inflow to DeGray Lake. Although having a mean annual flow of only 13 m^3/sec, the river exhibits extreme fluctuations in flow (2-740 m^3/sec). These fluctuations are of significance since Kennedy et al. (1983) have determined that elevated flow events

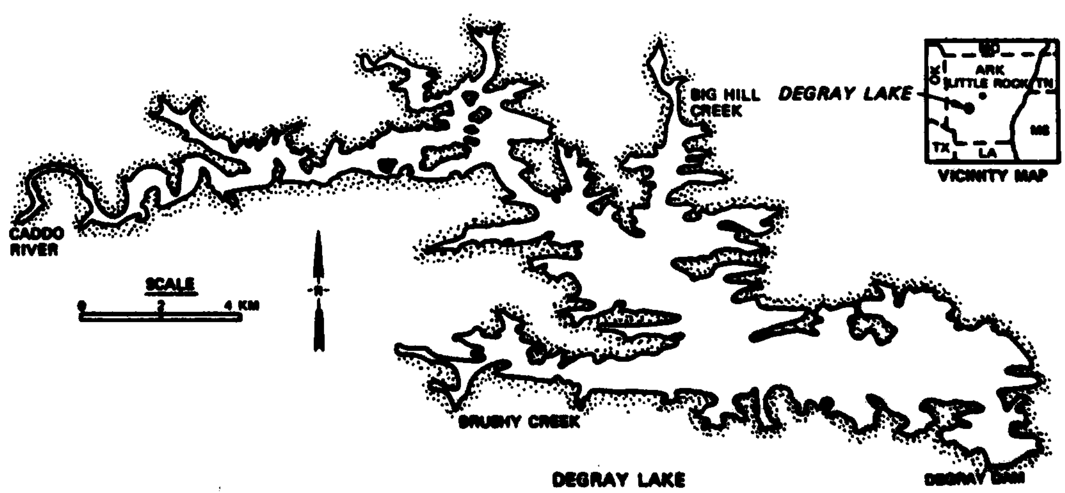

Figure 2. Map and location of DeGray Lake

accounted for 88 percent of the river's annual phosphorus load during a total of only 73 days in 1980. Secondary streams enter the reservoir at various points along its length, the two most prominent streams being Big Hill and Brushy Creeks. The entire watershed lies along the south flank of the southern Ouachita Mountains and is composed of two topographic regions (Albin 1965). The first is characterized by east-west ridges ranging in elevation from 150 m msl in the east to more than 600 m msl in the west. Soils in this portion of the watershed are generally well drained, and the bedrock is dominated by complexly folded and faulted shale, sandstone, and novaculite. The second region, in which DeGray Dam and Lake are located, is characterized by nonmountainous east-west ridges rising 75 m above intervening valleys. Soils here are also well drained, and the bedrock is primarily sandstone and shale.

15. DeGray Lake is a warm monomictic reservoir. Stratification generally begins in middle to late June and persists until December or early January. During the first six years of impoundment, severe anaerobic conditions existed in the hypolimnion, due presumably to the presence of a large pool of oxidizable, terrestrial material; this included inundated soils of high organic content, forest litter, and standing timber. Since 1976, hypolimnetic oxygen deficits have been greatly reduced. Mean annual values for total and dissolved iron and manganese and for ammonia nitrogen, which were also high during the years following impoundment, have declined from 1977 through 1981. Hypolimnetic anoxia since 1976 has been restricted to shallow headwater areas and deep areas near the dam. A persistent metalimnetic dissolved oxygen minimum during periods of stratification appears to be related to the occurrence of density flows and the entrance into the reservoir of allochthonous organic loads at intermediate depths. Density currents following storm events are easily distinguishable by in situ measurements of transmittance (Nix 1973) and turbidity (Ford and Johnson 1981) and have been noted to have lower specific conductance, lower calcium, and higher coliform bacteria levels (Thornton et al. 1980). Another process which may contribute to metalimnetic oxygen

depletion is the entrainment of hypolimnetic water containing reduced manganese (Nix 1981). Mean annual values for selected water quality constituents are presented in Table 2.

16. DeGray Lake exhibits pronounced longitudinal gradients in water quality, a phenomenon not unexpected for lakes strongly influenced by advective transport and unidirectional flows (Thornton et al. 1980, 1982; Baxter 1977). In general, turbidity and total phosphorus concentrations in the epilimnion, metalimnion, and hypolimnion decrease with distance downstream. Epilimnetic chlorophyll *a* concentrations, while decreasing in a downstream direction in summer and fall, are low and relatively uniform during winter. Thornton et al. (1982) report mean epilimnetic total phosphorus concentrations for headwater stations ranging from 0.03 to 0.04 mgP/L during four intensive surveys in 1978-79. Concentrations decreased to approximately 0.01 mgP/L at midreservoir and then remained unchanged from midreservoir to dam. Mean epilimnetic turbidity values, which were lowest during the summer low-flow period, exhibited longitudinal changes similar to those for total phosphorus. Based on these data, trophic state classification of DeGray Lake becomes ambiguous. For instance, when Vollenweider's (1968) criteria are used to classify lakes with respect to phosphorus and chlorophyll concentrations, DeGray Lake could be classified as either oligotrophic, mesotrophic, or eutrophic depending on the location of a single sampling station: the headwater area is eutrophic, the midreservoir is mesotrophic, and the lower reservoir is oligotrophic. DeGray Lake is not unique in this regard, as similar classification problems have arisen in other reservoirs (e.g., Hannan et al. 1981; Higgins et al. 1981).

Eau Galle Lake

17. Eau Galle Lake, created in September 1968 by impoundment of the Eau Galle River, is located in west-central Wisconsin approximately 80 km east of Minneapolis-St. Paul, Minnesota (Figure 3). The project's primary purpose is to provide flood control protection for the

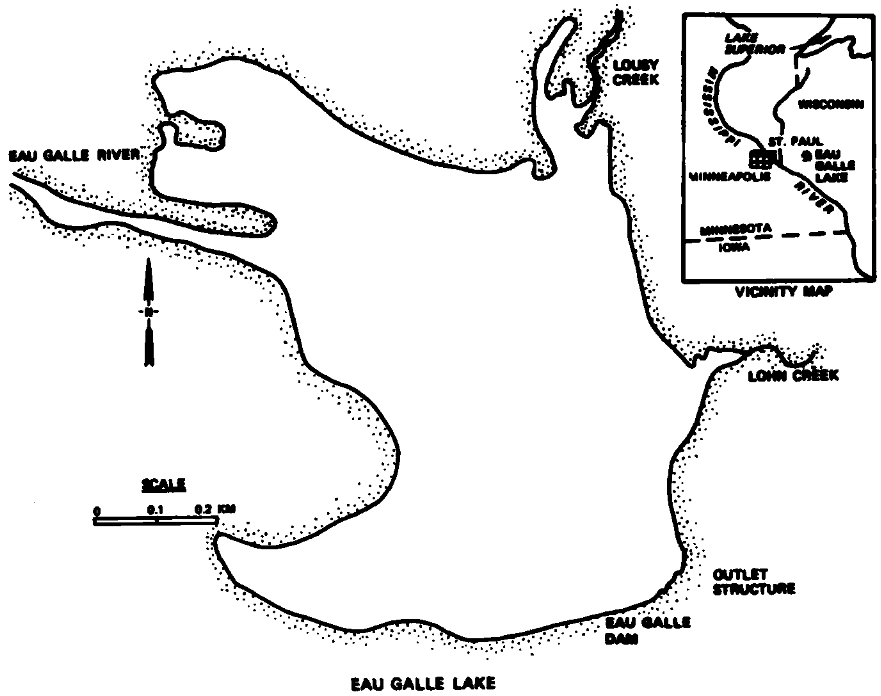

Figure 3. Map and location of Eau Galle Lake

village of Spring Valley and other low-lying areas downstream. Additionally, the reservoir provides (a) fish and wildlife habitat and (b) recreational facilities.

18. The Eau Galle Dam, a rolled-earth and rock-filled structure, was constructed, in part, using material excavated from a borrow area located near the center of the present reservoir. These activities are reflected in the morphometry of the lake, which is deepest at its center. Normal releases and low-level releases for dewatering or drawdown of the conservation pool are accomplished using a gated outlet conduit. Surface withdrawal during periods of high flow occur by means of an uncontrolled morning-glory intake structure. An uncontrolled emergency spillway is located near the right abutment of the dam.

19. Eau Galle is a small, shallow, and somewhat circular-shaped reservoir. At normal pool elevation (286.5 m msl), the reservoir is 1 km in length and has a surface area and volume of 0.6 km^2 and 1.9 $\times 10^6$ m^3, respectively. Mean and maximum depths are 3.2 and 9 m,

respectively. The regularity of the 4-km shoreline is indicated by the shoreline development ratio of 1.5. Additional physical characteristics are listed in Table 1.

20. Landuse in the 166-km^2 Eau Galle watershed is primarily agricultural (crops and dairy pasture). Several small communities are the only urban development in the area. High, steeply sloping hills surround the reservoir, with outcroppings of dolomite and sandstone bordering the valley at various points to form cliffs. Alluvial deposits, which predominate in the lowlands, are generally fine-grained sandy or silt loams underlain by gravels and sands of granitic and dolomitic material. Soils found in the uplands are characterized as a thin blanket of clays, silty clays, and clayey silts overlying granular soils (U. S. Army Engineer District, St. Paul 1964). Although cultivated areas of the watershed are susceptible to erosion, a comparative study of sedimentation conducted between 1972 and 1977 (U. S. Army Engineer Division, North Central 1979) indicated that sediment accumulation in the reservoir has been minimal.

21. The Eau Galle River accounts for approximately 85 percent of the total inflow for Eau Galle Lake. Mean annual flow for 1978-1981 was 0.6 m^3/sec, with a range of 0.02 to 32.3 m^3/sec. Large fluctuations in flow normally occur during spring runoff, following snow melt, and during summer storm events. These large rises in the river are expected to contribute significantly to the total annual loading of sediment and nutrients to the reservoir. Secondary streams, which account for the other 15 percent of flow, are Lousy and Lohn Creeks.

22. Eau Galle Lake is a dimictic reservoir, characterized by high nutrient concentrations, hypolimnetic anoxia, periodically intense algal blooms, and the development of macrophytes in littoral areas. Fall turnover occurs in late September through early October, and ice cover usually begins in December and persists until late March. Mean annual values for selected water quality constituents are presented in Table 2.

23. Because of the relatively small size and circular shape of Eau Galle Lake, longitudinal gradients are not as distinct nor dominant

as in other reservoirs considered in this study. However, during high runoff periods inflowing water moves from the river mouth directly to the outflow structure. Significant differences in water quality characteristics between flow-dominated portions of the pool and adjacent areas may exist during these periods. During normal flow periods, the dominant spatial patterns in water quality appear to be associated with differences between littoral and pelagic regions of the reservoir (Saul et al. 1983).

West Point Lake

24. West Point Lake is a multipurpose reservoir providing flood control, hydroelectric power, recreation, fish and wildlife habitat, and flow regulation for downstream navigation. The reservoir was formed in 1975 by impoundment of the Chattahoochee River approximately 80 km southwest of Atlanta, Georgia, on the Georgia-Alabama border (Figure 4). West Point Dam is a concrete gravity-type structure with rolled earth-fill embankments joining high ground on the east and west banks of the river. The concrete portion of the structure consists of a powerhouse and a gated ogee spillway located in the main river channel. The intake structure provides hypolimnetic releases for power generation, while additional epilimnetic releases occur periodically through the gated ogee spillway. However, remnants of a cofferdam built during construction appear to act as a skimming weir, forcing primarily epilimnetic and metalimnetic waters to be discharged through the penstocks.

25. West Point Lake is long, narrow, and dendritic (Table 1). At normal pool elevation (193.6 m msl), the reservoir has a surface area of 104.8 km^2 and a volume of 745.7×10^6 m^3. Mean and maximum depths are 7.1 and 31 m, respectively. A shoreline development ratio of 23.3 reflects the irregularity of the 844.7-km shoreline, which includes numerous coves and embayments located along the reservoir. Two highway bridges and one railroad bridge span the reservoir's main pool and associated earthen abutments constrict the reservoir at these

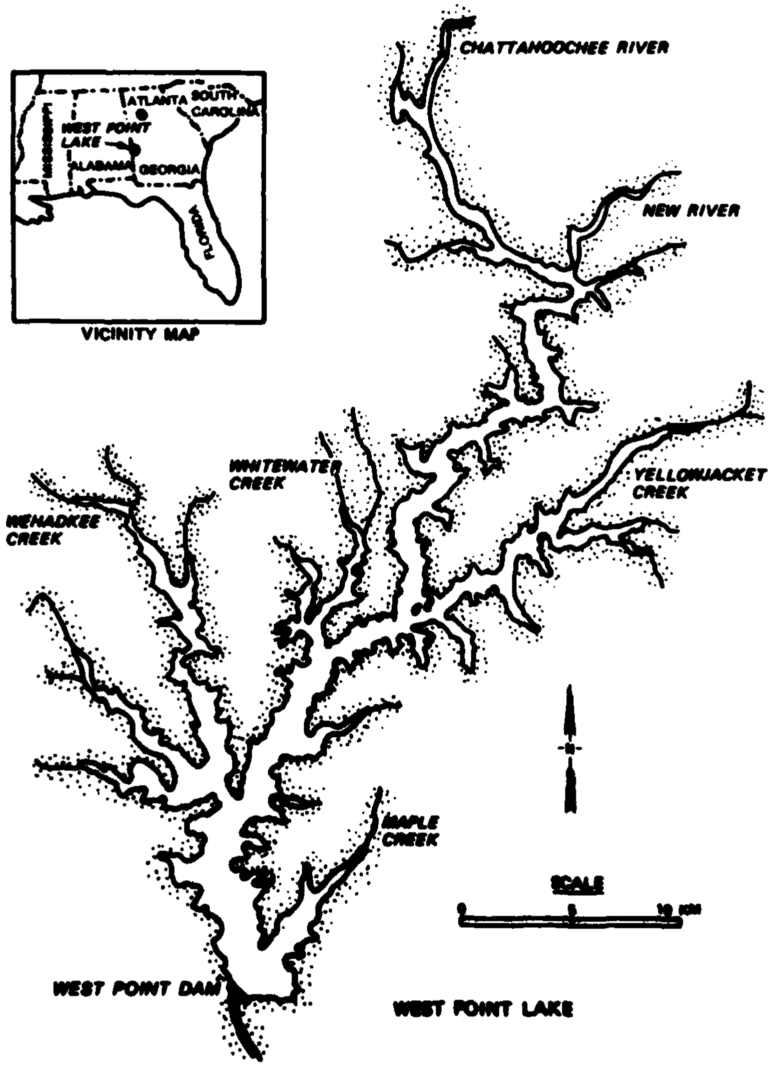

Figure 4. Map and location of West Point Lake

locations. Bridges also span several of the larger embayments.

26. Landuses in the 5535-km^2 watershed above West Point Dam include agriculture (70 percent) and residential/industrial development (30 percent). The Chattahoochee River, which originates in the Blue Ridge Mountains in northern Georgia, flows southwesterly to West Point and receives significant point-source discharges from over 50 percent of the metropolitan Atlanta area. Other tributaries entering the reservoir include New River and Wehadkee Creek, which drain predominately forested and pastured watersheds, and Yellowjacket Creek, which receives urban and industrial point- and nonpoint-source loadings. Combined, these streams represent only 6 percent of the reservoir's annual water income.

27. Lowland soils in the watershed are well to poorly drained alluvial sediments, while the upland areas of the watershed consist of well drained soils formed from weathered granite, gneiss, or mica schist underlain with a reddish clayey subsoil. The drainage basin as a whole exhibits a high rate of soil erosion, which leads to characteristically turbid conditions in the Chattahoochee River and major portions of the reservoir. Additionally, wind-wave erosion of the shoreline increases turbidity in the reservoir.

28. West Point Lake is a warm monomictic reservoir exhibiting weak thermal stratification and characterized by high nutrient and suspended solids concentrations and frequent algal blooms. The onset of stratification typically occurs in May-June. Isothermal conditions prevail from December through late March or April. During periods of stratification, hypolimnetic anoxia develops in Yellowjacket and Wehadkee Creek embayments and in lower reaches of the reservoir's major basin. Partial impoundment of hypolimnetic water behind the cofferdam may influence the severity of oxygen depletion in downstream areas of the reservoir by increasing the retention time of hypolimnetic water. During anoxic periods, the tailwaters produce detectable hydrogen sulfide odors and staining due to the oxidation of reduced iron and manganese. Other limnological characteristics are presented in Table 2.

29. Flow from the Chattahoochee River exerts a significant

effect on conditions in the reservoir (Kennedy et al. 1982; Thornton et al. 1981). Riverine flows are observed in the headwater region and, during periods of high flow, as far downreservoir as the confluence with Yellowjacket Creek. Coincident with these flows are high suspended solid, nutrient, and organic concentrations. As flows dissipate downreservoir, water clarity increases and often results in high algal production at midreservoir. Gradients in nutrient concentrations are also observed (Kennedy et al. 1982). During stratified periods, highly turbid inflows have been observed to extend well into the midreservoir region as interflows. During nonstratified periods, inflows appear to be vertically well mixed.

PART III: METHODS AND MATERIALS

Sample Collection

30. Sediment collection was accomplished using a single-barrel Wildco Core Sampler (Wildco Supply Co., Saginaw, Mich.) fitted with polyethylene liners. A core sampler was preferred over a grab sampler because the primary objective of the study was to compare the chemical and physical properties of surficial sediments. The core sampler provided a means for identifying the top 10 cm of the sediment; the depth of penetration of a grab sampler depends on a number of factors, including sediment texture and density, angle of impact, and height of free-fall (Plumb 1981), and was therefore not suitable for this study.

31. Coring techniques differed slightly depending on water column depth. At shallow stations, the core sampler was pushed into the sediment using an aluminum pole; at deeper stations the core sampler was allowed to free-fall. Both techniques required that care be taken to ensure that the core liners were not overfilled so that the top sediments would not be lost. It was also necessary to retain the overlying water in each liner to maintain sample integrity.

Lake Red Rock

32. Sampling consisted of obtaining one core per station, with nine replications chosen at random. The core liners were capped upon retrieval and stored vertically in the dark at 4°C until analysis. Analyses for percent sand, silt, clay, and organic matter were conducted within a few weeks of sample collection.

33. Analyses of samples collected at Lake Red Rock differed from those used during subsequent studies at the three other sites. Size fractions were determined using a standard hydrometer and glass sedimentation cylinder. Sediments were divided into three size fractions based on timed hydrometer readings: 50 μm and larger (sand), 2-50 μm (silt), and 2 μm and smaller (clay). Results of duplicate analyses are expressed as a percent. Organic matter was determined for oven-dried (105°C) samples by weight loss after combustion at 550°C (American

Public Health Association (APHA) 1971). The weight difference was recorded as percent organic matter. The samples were not rehydrated.

34. Sediment accumulation was calculated using data from two sediment range surveys conducted in 1968 and 1976 by the U. S. Army Engineer District, Rock Island, and the Geometric Elements from Cross Section Coordinates Program (GEDA) developed by the U. S. Army Engineer Hydrologic Engineering Center (HEC), Davis, California. Sediment range surveys determine cross-sectional changes of bottom profiles along range (or transect) lines, the number and location of which are dependent on the size and shape of the reservoir. In general, a series of range lines is established to subdivide the reservoir and its major tributaries into representative segments, the volumes of which can be calculated geometrically based upon cross-sectional area and distances between ranges. Differences in water volume between the two surveys were equated to sediment accumulation for each segment during the period 1968-1976. This also allowed for the estimation of an average annual sedimentation rate for each reservoir segment.

DeGray, Eau Galle, and West Point Lakes

35. Procedures followed during studies at these sites were identical. Two core samples were collected at each station: one for particle size analysis and the other for interstitial water and sediment chemistry analysis. After each drop and recovery of the core sampler, liners were removed, sealed with polyethylene caps, and stored vertically at 4°C in the dark. Sample processing began within 2-4 hours. Initial observations, including sediment color and texture, the presence of large particulate material (e.g., leaves, twigs), and amount of sediment recovered, were recorded, and each sediment core was photographed for future reference. The top 10 cm of one of the two cores collected at each sampling station was extruded from the core liner, placed in a plastic bag, and gently mixed for several minutes. Subsamples were then placed in 35-ml plastic vials, sealed, and shipped on ice by Air Express to the USDA Southwest Watershed Research Center in Tucson, Arizona, for particle size analysis.

36. Sediment cores for interstitial water and sediment analyses were transferred to a glove bag for processing in a nitrogen atmosphere. The glove bag was flushed several times with nitrogen before being finally filled and sealed. A constant flow of nitrogen gas maintained pressure in the bag and prevented the introduction of atmospheric gas. Monitoring of the glove bag atmosphere was accomplished using a Hydrolab System 8000 (Hydrolab Corp., Austin, Tex.), the oxygen probe of which was inserted in a small, partially water-filled reservoir in the bag's gas exhaust line. Exhaust gases were monitored constantly during sample handling, and "dissolved" oxygen levels were consistently below the equivalent of 0.5 mg/L.

37. After the glove bag was sealed, a 10-cm section was cut from the top of each core using a specially designed sampling device (Figure 5). Each core liner was inserted into the circular collar at the bottom of the sampling device and secured. Sediment was then extruded up through the hole in the cutting blade and into the upper tube, while

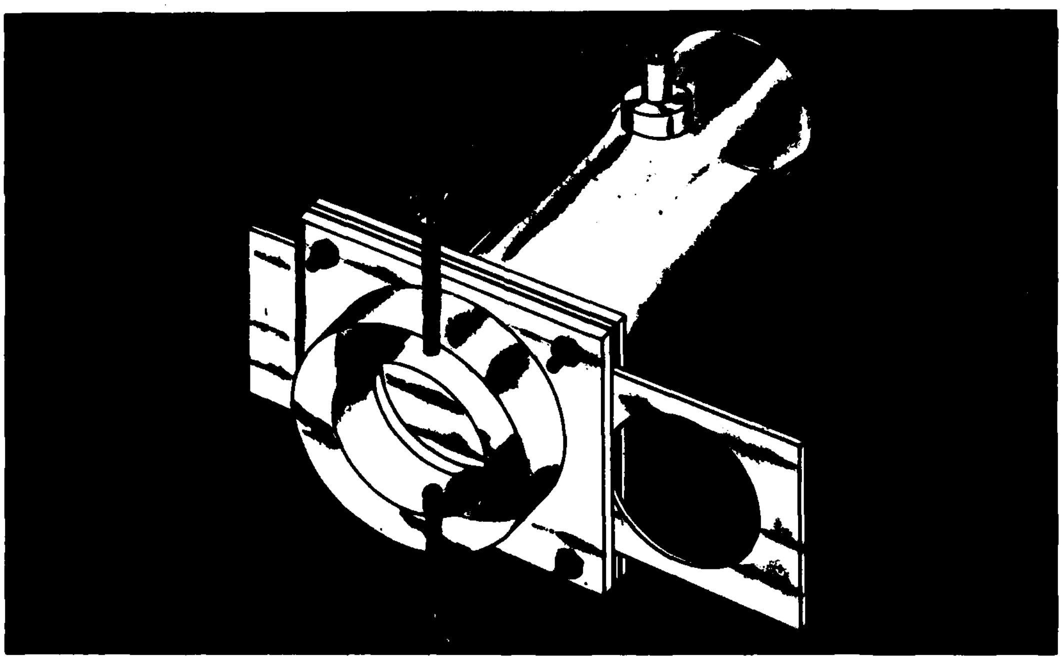

Figure 5. Sampling device used for cutting a 10-cm top section of sediment from core liners for interstitial water and sediment analyses

overlying water was removed through the water port by suction. A 10-cm sample was cut and isolated from the sediment core by sliding the cutting blade through the sediment. Samples were placed in Whirl-Pak bags (Nasco, Inc., Ft. Atkinson, Wisc.), flushed with nitrogen, and sealed. The sealed bags were then removed from the glove bag, placed in plastic centrifuge cups, and centrifuged for 10 minutes at 10,000 rpm.

38. After centrifugation, samples were transferred to a second glove bag, which was flushed and filled with nitrogen in the same manner as the first. Sample bags were opened, and the interstitial water supernatant was decanted into 50-ml polypropylene syringes. Each syringe was fitted with a 47-mm filter holder, and the supernatant was filtered through a prewashed, 0.4-μm Nucleopore polycarbonate filter (Nucleopore Corp., Pleasanton, Calif.). Filtrates were collected in two clean 30-ml polyethylene bottles: one filled almost full, flushed with nitrogen, and sealed; the other filled with about 20 ml and acidified with 50 μl of concentrated hydrochloric acid. Sediment pellets were flushed with nitrogen, resealed in Whirl-Pak bags, and immediately frozen. These samples remained frozen until immediately prior to chemical analysis.

39. The interstitial water and sediment samples were transported to the U. S. Army Engineer Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, by air within a few days of sampling; interstitial water samples were shipped on ice, and sediment samples were shipped on dry ice. The Eau Galle samples were shipped at the end of the study, since samples were collected over a period of only two days. However, during the West Point and DeGray studies interstitial water samples were shipped halfway through the study and again at the end to avoid long holding times. The frozen sediment samples were stored and shipped at the end of each study.

Analytical Methods

Particle size analysis

40. Particle size analyses were performed at the USDA Southwest

Watershed Research Center, using a MicroTrac Particle-Size Analyzer (Leeds and Northrop, North Wales, Pa.). The MicroTrac uses low-angle forward-scattering of laser light to measure 13 particle size fractions between 1.9 and 176 μm. Summary data are also calculated, including particle diameters at the 10th, 50th, and 90th percentiles; mean diameter of the volume distribution; calculated mean specific surface area; and a value of representative sample concentration. The MicroTrac Particle-Size Analyzer was chosen over more conventional methods because it required simple sample preparation, maintained the integrity of the particle, and provided a large amount of data. Conventional methods (i.e., sieving, hydrometer, pipet, etc.) require numerous preparational procedures which prove to be tedious and time-consuming and which may affect particle integrity. The MicroTrac requires only a small sample in aqueous suspension and is capable of analyzing ten samples per hour.

Interstitial water
<u>analyses (nonacidified sample)</u>

41. Nonacidified samples were analyzed immediately following arrival at CRREL. Ammonium, nitrate, and soluble reactive phosphorus concentrations were determined using the Technicon Autoanalyzer II (AA II system) (Technicon Instruments Corp., Atlanta, Ga.). Ammonium concentrations were determined colorimetrically by the salicylate modification of the automated phenate method (APHA 1975); nitrate analyses were performed by the automated cadmium reduction method (APHA 1975). Nitrite was not determined because it was expected to be insignificant. Soluble reactive phosphorus was determined by the molybdate method (APHA 1975). Total inorganic carbon analyses were performed on an OIC Carbon Analyzer (Oceanography International Corp., College Station, Tex.) with a Horiba PIR-2000 infrared detector.

Interstitial water
<u>analyses (acidified sample)</u>

42. Digestions for total phosphorus, total nitrogen, and total organic carbon were performed upon arrival at CRREL. The analyses for total iron and manganese were begun as soon as possible after arrival.

Total phosphorus values were determined following persulfate digestion (Jeffries et al. 1979) by the automated molybdate method using an AA II system. Total nitrogen values for persulfate-digested (Raveh and Avnimelech 1979) samples were determined by the automated salicylate method on an AA II system following reduction with Devarda's Alloy. The analysis of total organic carbon followed persulfate oxidation using an ampule modification as described in the operations manual for the OIC 0524 B Total Carbon System. Analyses were performed on an OIC Carbon Analyzer. Total iron and manganese concentrations were determined by atomic absorption spectroscopy using a Perkin-Elmer Model 403 AA and HGA-2200 Heated Graphite Atomizer (Perkin-Elmer Corp., Norwalk, Conn.).

Sediment analysis

43. Sediment pellets were thawed for two days at 4°C and then warmed to room temperature. Each sample was hand-blended for two minutes to mix samples thoroughly, and a portion of each removed from its storage bag, weighed, and dried at 108°C for 20 hours. Dried samples were reweighed and heated an additional hour to ensure that all water had been removed. No significant change in weight was found. Moisture content was calculated as weight loss expressed as a percent of sediment dry weight. Dried samples were then ground to a fine powder with a mortar and pestle and subsampled for specific analyses.

44. Analysis for total phosphorus was by wet persulfate digestion as outlined by Raveh and Avnimelech (1979), and concentrations were measured by the molybdate method. Determination of total nitrogen followed persulfate digestion (Raveh and Avnimelech 1979), reduction to ammonium with Devarda's Alloy and measurement by the salicylate method. Total organic carbon was analyzed by the persulfate oxidation infrared method as outlined in the Oceanography International (OIC) instruction manual. Total inorganic carbon was determined from carbon dioxide liberated upon acidification with 6 percent phosphoric acid and was analyzed as described above for organic carbon. Total iron and manganese concentrations were determined by atomic absorption spectroscopy following sample digestion with nitric and hydrochloric acids. More detailed

discussions of analytical methods can be found in Jenkins et al. (1981).

Precision of analyses

45. Analytical precision for the methods used in the analysis of interstitial water and sediment is summarized in Tables 3 and 4. Samples for determining precision were analyzed in an identical manner and at the same time as the reservoir samples. Precision for interstitial water samples was initially measured using soil-solution samples. As interstitial waters became available, they were composited for tests of precision. Sediment composites from reservoir samples were used to evaluate the precision of sediment chemical methods.

Table 3

Analytical Precision for Interstitial Water Analyses

(from Jenkins et al. 1981)

Variable	Composite Sample	Mean, mg/L	Number of Replicates	Standard Deviation, mg/L	Relative Std. Deviation, %
Ammonium nitrogen	Soil solution	0.07	12	0.01	14
	DeGray composite	2.00	10	0.01	0.5
Nitrate nitrite nitrogen	Filtered wastewater	0.04	10	0.01	25
Soluble reactive phosphorus	Soil solution	0.04	12	0.01	25
	DeGray composite	0.16	10	0.01	6
Total inorganic carbon	DeGray sample	9.5*	10*	1.8*	19
Total phosphorus	Soil solution	0.03	13	<0.01	<33
	DeGray composite	0.07	6	0.01	14
Total nitrogen	Soil solution	12.3	11	0.1	0.8
Total organic carbon	Filtered water	1.3*	13*	0.1*	8
	Filtered water	1.7*	14*	0.3*	18
Total iron	DeGray composite	9.21	15	0.15	1.6
Total manganese	DeGray composite	5.24	4	0.15	3

* Each replicate reported for inorganic and organic carbon was a mean of two trials; thus, the standard deviations are for means with two replicates.

Table 4

Analytical Precision for Sediment Analyses

(after Jenkins et al. 1981)

Variable	Mean, mg/g	Number of Replicates	Standard Deviation, mg/g	Relative Std. Deviation, %
Total phosphorus	0.986	10	0.044	4.5
	1.536	10	0.083	5.4
	0.604	10	0.021	3.5
Total nitrogen	2.488	10	0.102	4.1
	2.020	10	0.164	8.1
	1.843	10	0.134	7.3
Total organic carbon	20.5	14	2.6	12.7
	17.9	13	1.5	8.4
Total inorganic carbon	6.7	6	0.3	4.5
Total iron	22.6	10	0.6	2.7
Total manganese	0.855	10	0.017	2.0

PART IV: RESULTS AND DISCUSSION

46. Sediment core samples were collected during February and March 1980 at Eau Galle, West Point, and DeGray Lakes. Samples from Lake Red Rock were collected in February 1979. Stations at all four reservoirs were selected to coincide with those established during previous water quality studies or to incorporate site-specific characteristics. The study at Eau Galle involved sampling 35 stations during the period 1-2 February; the West Point and DeGray studies involved 60 stations sampled during 25-28 February and 57 stations sampled during 16-21 March, respectively. Fifty-six stations were sampled at Lake Red Rock over the period 13-15 February. Particle size and chemistry data for all four reservoirs appear in Appendix A and are discussed below.

Lake Red Rock

47. The deposition of suspended sediments transported by the Des Moines River and Whitebreast Creek has had a significant impact on Lake Red Rock. A comparison of sediment range information indicates that 20 percent of the original 1.1×10^4 ha-m of storage below 221 m msl filled with sediment between 1968 and 1976. Although the recent impoundment of the Des Moines River above Des Moines by Saylorville Dam was anticipated to reduce sediment inputs by 14 percent (U. S. Army Engineer District, Rock Island 1979), it is currently projected (Karim and Croley 1979) that a complete loss of storage capacity below 221 m msl will occur by the year 2014 (i.e., 35 years after impoundment). Such an anticipated change, which would greatly reduce the project's value as a flood and flow control facility, has prompted evaluation of reservoir regulation changes which would increase conservation pool above its present level (Rock Island District 1979).

48. Sediment accumulation within the reservoir varied longitudinally and laterally (Figure 6) and, in general, was highest in headwater areas and river channel (thalweg). Accumulation depths at Range 7, immediately below the old Highway 14 bridge, ranged from a maximum of

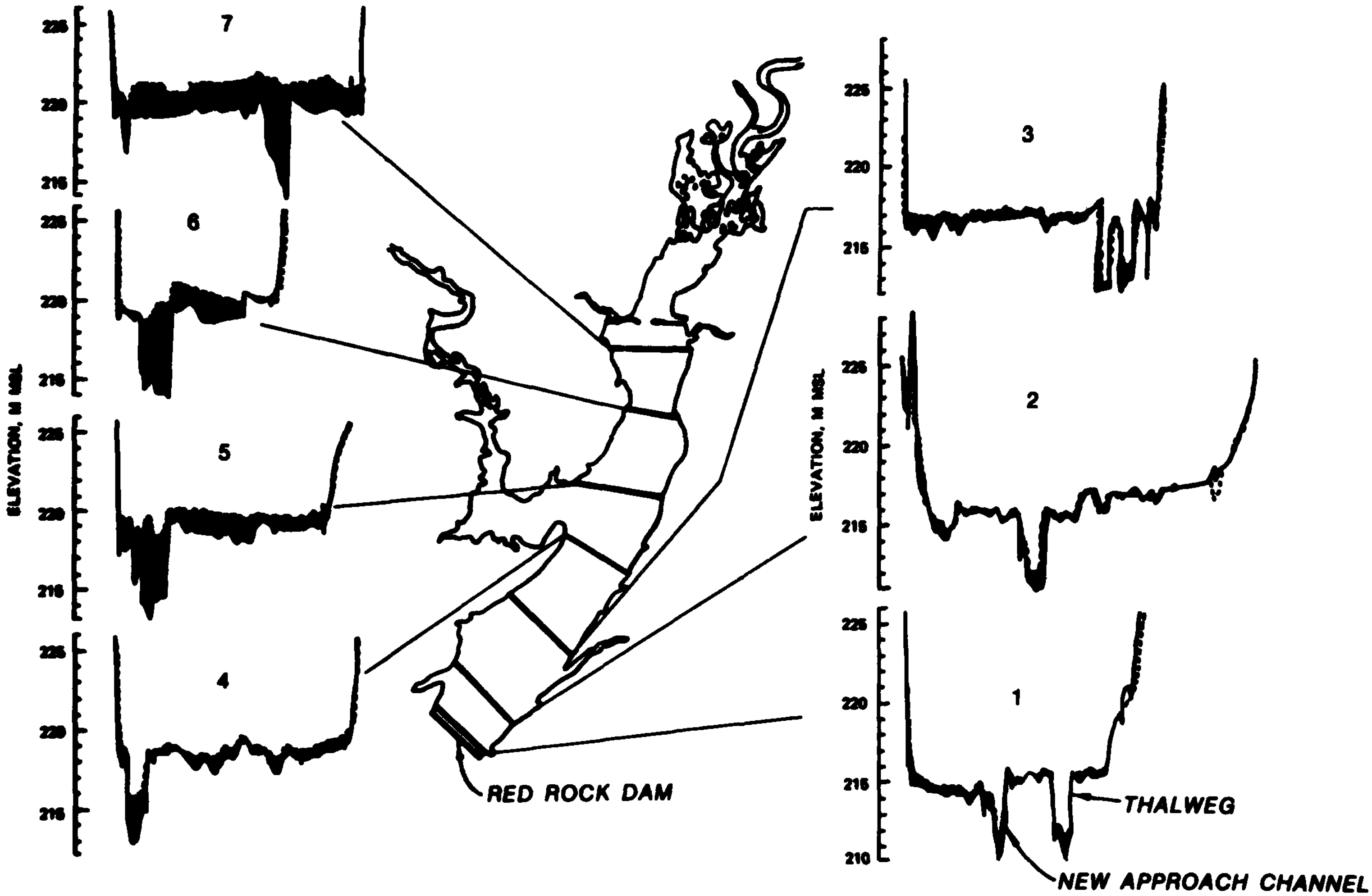

Figure 6. Lake Red Rock bottom elevations recorded during sediment range surveys conducted in 1968 (solid line) and 1976 (dashed line). Sediment accumulation is indicated by shading. Range or transect numbers are indicated on each profile

6.1 m in the thalweg to approximately 1.0-1.5 m across the remainder of the transect. Accumulation depth decreased markedly between Ranges 7 and 4, with the most abrupt change occurring near Range 5. According to these limited data, the submerged delta apparently extended approximately 4.8 km downreservoir from the location of the Des Moines River inflow and occupied approximately 9 km^2 of the reservoir headwater area. Accumulation depths in the vicinity of the dam (Range 1) varied from 0.3 to 1.2 m, with maximum accumulation occurring in the thalweg and the new approach channel.

49. Average sedimentation rates (cm/yr) were calculated for each sediment range segment by considering the surface area of each segment and changes in volume occurring between 1968 and 1976, the years for which survey data were available. Marked differences between the delta (Ranges 5-7) and areas below the delta (Ranges 1-5) are apparent (Figure 7). Rates upreservoir averaged 18-19 cm/yr, while those downreservoir from the delta averaged only 1.5-3.0 cm/yr. The effect of reduced flow rate imposed by impoundment is clear, since the rate upstream from the old Highway 14 bridge (Ranges 7-8) was only 7.9 cm/yr. This reflects a higher rate of flow in the river and the effects of riverbed scour.

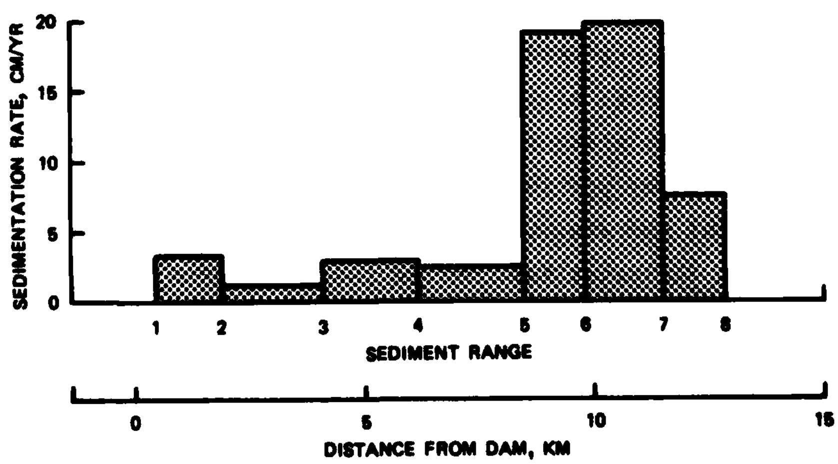

Figure 7. Average sedimentation rates for Lake Red Rock range sections. Rates are based on changes in volume between 1968 and 1976; bar widths represent distance between ranges

50. Similar longitudinal changes were observed for water-column suspended solid concentrations during the period 6 June-31 October 1978 (Baumann et al. 1979). Suspended solid concentrations in the river in the vicinity of the old Highway 14 bridge, which were strongly influenced by flow rate, averaged 190 mg/L. Concentrations downreservoir at Range 4 and near the dam averaged 54 and 31 mg/L, respectively, indicating a significant loss of suspended material in the shallow delta area. Sediment trap efficiency, or the percent of inflow suspended sediment retained by the reservoir basin, was approximately 84 percent during this period. This is higher than the expected trap efficiency (48-72 percent) for reservoirs of similar residence time (Stall 1981), possibly reflecting the effects of scour and resuspension on observed suspended sediment concentrations of the river in the vicinity of the old Highway 14 bridge.

51. This pattern of decrease in suspended sediment concentration along the length of the reservoir is little affected by storm events. Kennedy et al. (1981) report suspended solid concentrations before, during, and following the passage of high-turbidity stormwater through the reservoir in 1979. Prior to the entrance of stormwater, concentrations in headwater areas averaged 230 mg/L and decreased exponentially downreservoir to a low of 40 mg/L in the vicinity of the dam. The arrival of stormwater increased concentrations in the upstream portion of the reservoir an average of 1600 mg/L; however, concentrations decreased precipitously along the length of the delta and were relatively unchanged in the lower portion of the reservoir. Concentrations following the passage of the stormwater returned to prestorm levels. Mass-balance analysis indicates that during the storm over 90 percent of the inflow suspended solids were retained in the reservoir by sedimentation, a vast majority of which apparently occurred upreservoir. This observation is consistent with the patterns in average sediment accumulation rates mentioned above.

52. Once deposited, sediments may have been redistributed by flow- or wave-generated resuspension and resettling; this is of particular significance in shallow, upreservoir areas and may account for the

relatively uniform distribution of sediments here. Observations made during the 1979 storm event suggest extensive scour of sediments in the immediate vicinity of the river inflow. During low-flow periods, inflows confined by submerged levees may have followed eroded channels in the delta (Wright 1978). However, as flows increased seasonally or in response to storm events, submerged levees may have been overtopped and possibly eroded, resulting in topographical changes in the delta.

53. Core samples collected at 56 stations throughout Lake Red Rock (Figure 8) allowed characterization of the relative distributions of sand, silt, and clay. These are indicated in Figure 9. While distributions varied considerably within ranges, there exists an identifiable pattern among ranges for the distributions of silts and clays. The pattern reflects both preimpoundment conditions and the effects of flow regime.

54. Overall, sands represented a relatively small percentage of the samples. Notable exceptions occurred at stations in the vicinity

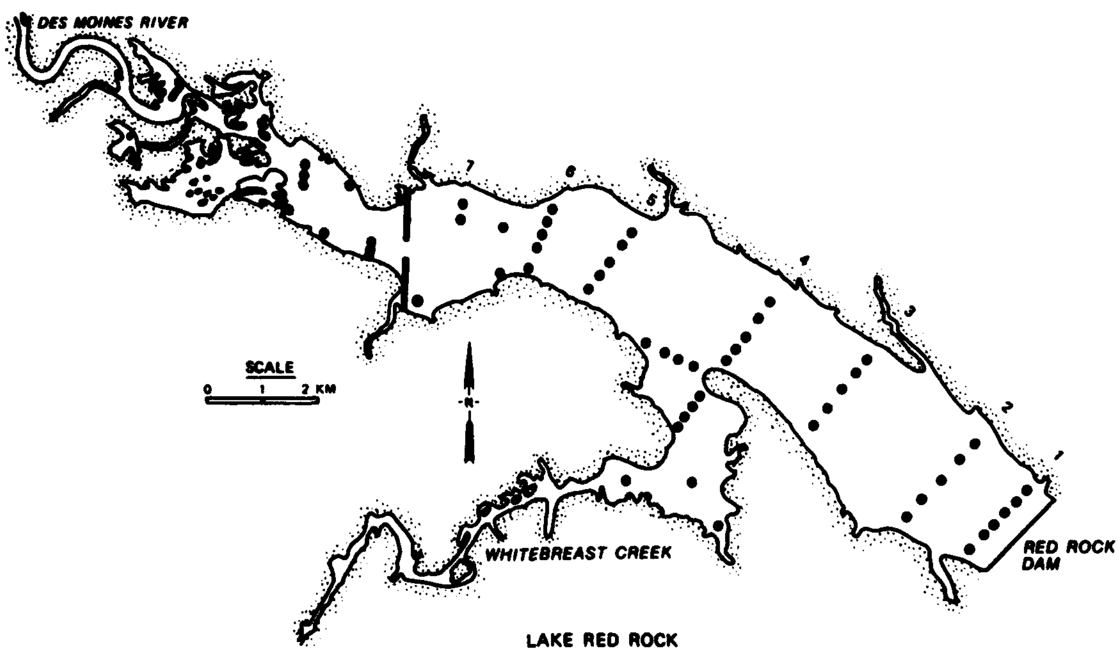

Figure 8. Lake Red Rock sampling station locations for sediment supply conducted 13-15 February 1979; approximate locations of ranges are indicated by their numbers

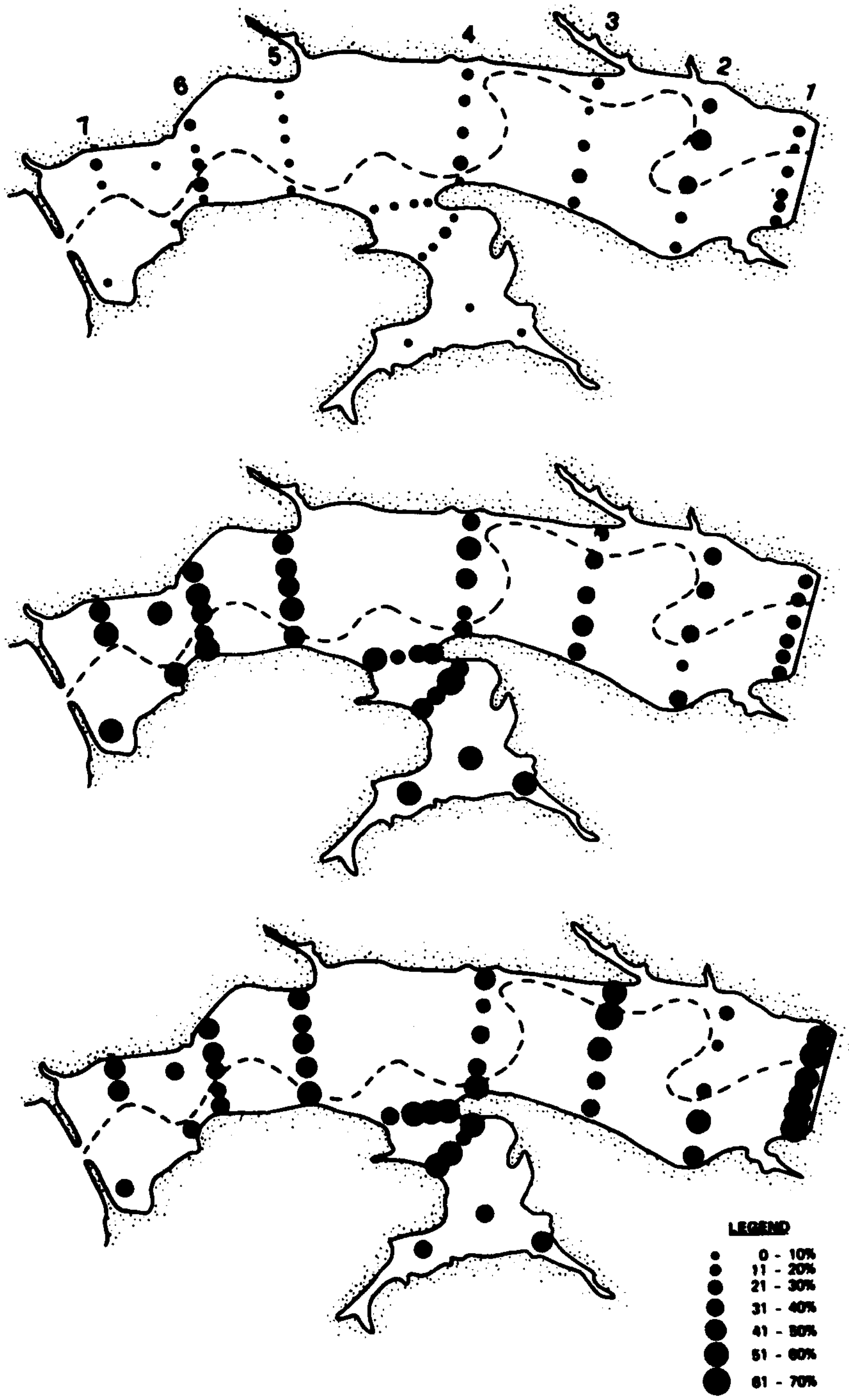

Figure 9. Percent sand (upper), silt (middle), and clay (lower) of Lake Red Rock sediments. Dashed line indicates location of old river channel; approximate locations of ranges are indicated by their numbers

of the thalweg on Range 2 and, to a lesser extent, on Ranges 4 and 6 and were related to preimpoundment conditions. Aerial photographs of the project site prior to reservoir filling (Rock Island District 1965) indicate the presence of light-colored deposits at several locations along the old river channel (Figure 10). The correspondence between

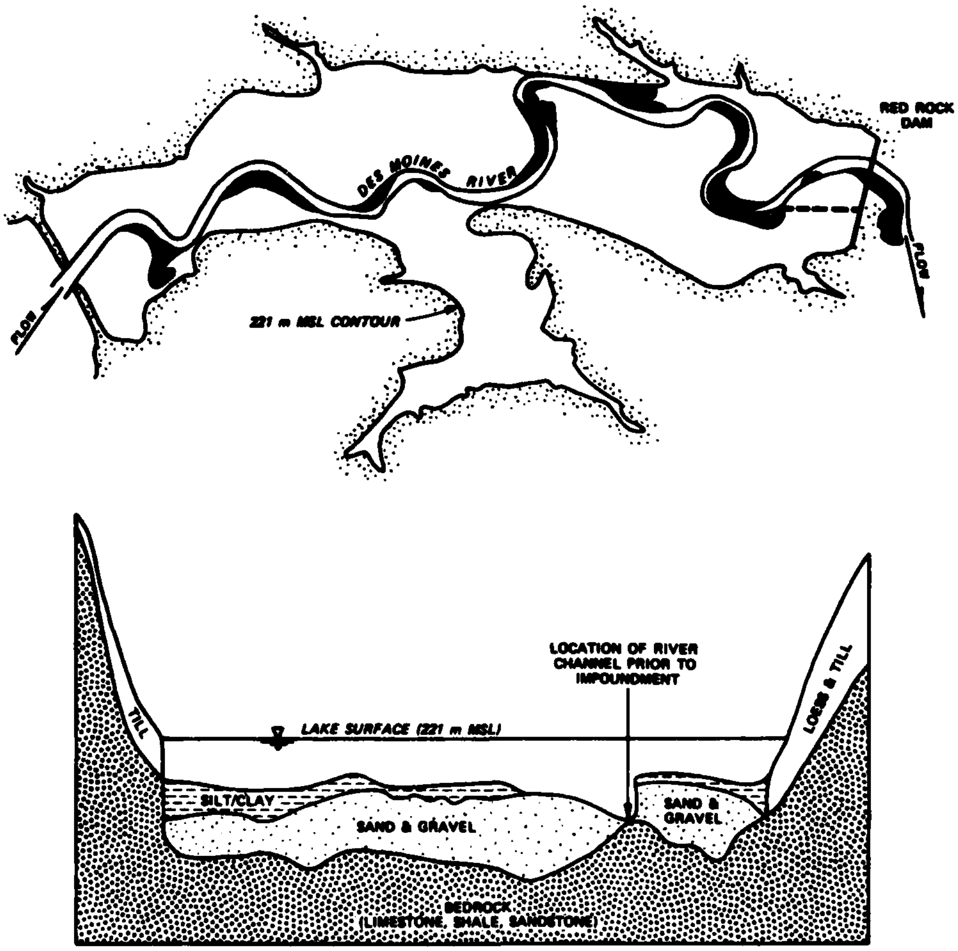

Figure 10. Location of the Des Moines River and light-colored deposits (shaded) identified from aerial photographs of the Lake Red Rock site prior to impoundment (top). The contour line approximates the lake's present boundary. Location of the present approach channel is indicated by the dashed line. Geologic profile taken along the Red Rock Dam site prior to impoundment, viewed from downstream (bottom). Present lake level and location of river channel are indicated (from Rock Island District 1965)

photographic observations and a preimpoundment geologic profile (Rock Island District 1960) along the center axis of the present dam (Figure 10) indicates that these light-colored areas were sandy point bars at river meanders. The flood plain in the vicinity of the dam prior to impoundment consisted of sand and gravel overlain with silts and clays deposited during floods; coarser materials would have predominated in or near the channel because a continuous flow prevented the deposition of fine material. Thus, the distribution of sand-size material in the present reservoir sediments appears to be more related to preimpoundment conditions than to the effects of processes occurring since impoundment.

55. Silt-size particles predominated at headwater stations of the main pool and Whitebreast Creek embayment, while clays were most abundant at downreservoir stations (Figure 9). Considering only those stations located in the main pool, percent silt declined linearly from approximately 55 percent at headwater stations to approximately 25 percent near the dam (Figure 11). Percent clay in the upper half of the reservoir increased with distance downreservoir but was highly variable in downreservoir areas less than 7 km from the dam (Figure 11). The point at which sediment composition changed from predominantly silt to predominantly clay occurred approximately 8 km upreservoir from the dam. This corresponds to the downstream edge of the submerged delta (see Figure 6).

56. Patterns in suspended solid particle size distribution observed during the 1979 storm event (Kennedy et al. 1981) correspond well with patterns observed for sediment particle size. Median particle sizes prior to and following passage of the storm hydrograph ranged from 9-10 μm (silt and clay) at stations immediately downreservoir from the river's inflow at the abandoned Highway 14 bridge to 2-4 μm (primarily clay) at stations near the dam. As with suspended solid concentrations, median particle size decreased markedly in the area of the delta but was relatively constant in the lower portion of the reservoir.

57. Particle size distributions of sediment were reflective of

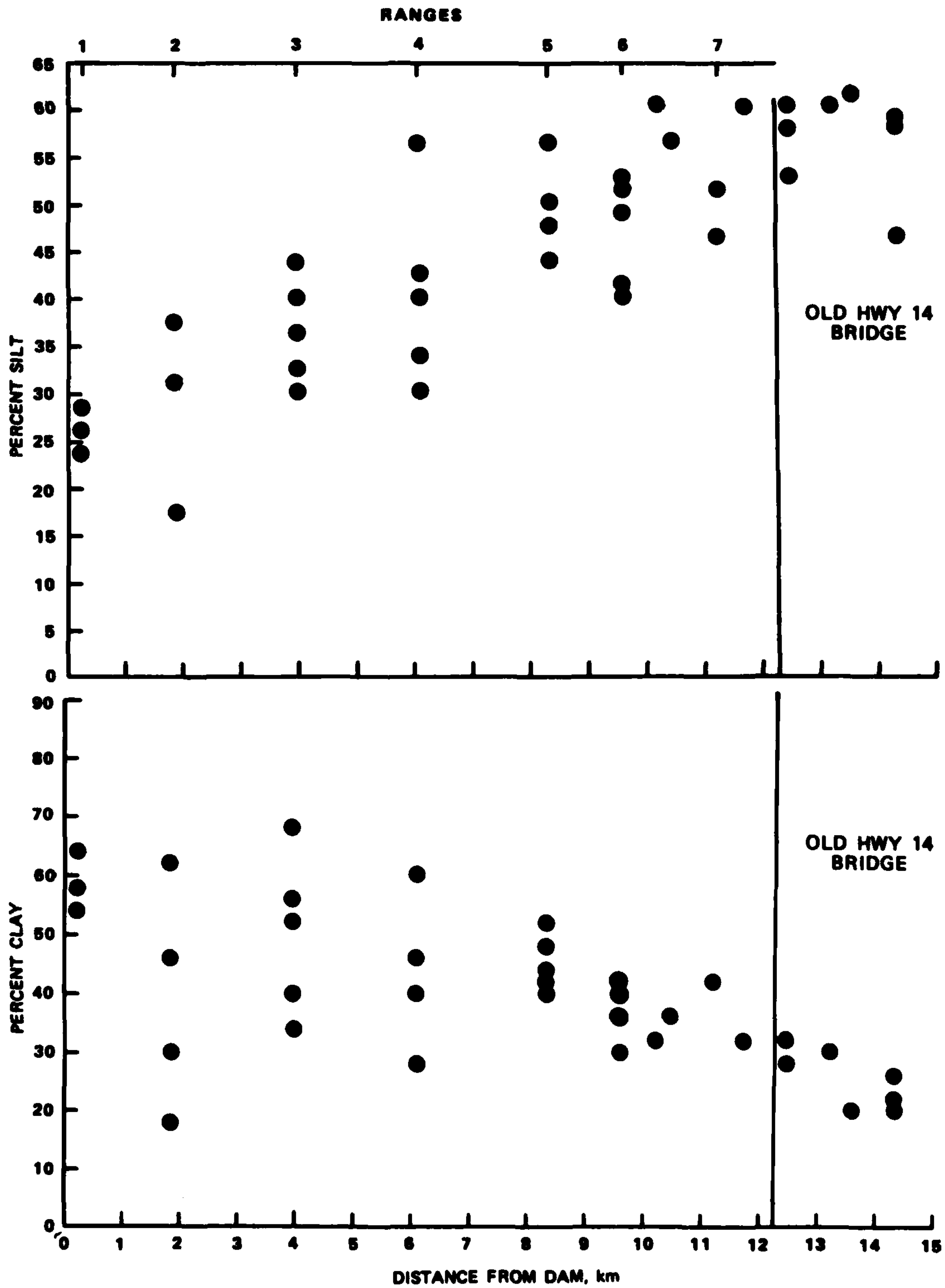

Figure 11. Percent silt (upper) and clay (lower) of sediment collected at various distances above Red Rock Dam. Vertical line indicates the location of the old Highway 14 bridge

observed inreservoir flow patterns. Changes in specific conductivity associated with the inflow of storm water in July 1979 (Kennedy et al. 1981) provided a means by which flow patterns and areas of conveyance could be delineated (Figure 12). Constricted by bridge embankments, river water entered the reservoir as a well-defined jet directed towards the south shore. Inflow water, although somewhat more dispersed, continued downreservoir toward the north shore and, later, to the outlet structure on the southern half of the dam. The flow pattern in downreservoir areas was apparently influenced more by the withdrawal of water through gates at depths of 9-11 m than by river flow. High percentages of silt at stations near the north shore at Range 4 and high percentages of clay downreservoir at stations along the north and south shores at Ranges 3 and 2 (Figure 9), respectively, were consistent with this observed flow pattern. Thus, in general, progressively smaller particles were deposited as inflowing river water slowed along a path between the inflow and a midreservoir location along the north shore. The remaining fine particles were further subjected to sedimentation as water was drawn to the south shore and the outlet structure. Increased accumulation rates in the old river channel (which followed a similar course through the reservoir) and in the new approach channel (Figure 6) further support this suggestion.

58. Organic content of sediments increased downreservoir and is positively correlated ($r = 0.84$) with percent clay (Figure 13). While similar observations in other lakes have been attributed to production of phytoplankton and their settling in deep areas coincident with small particles (e.g., Schoettle and Friedman 1973), such an explanation is not completely adequate in the case of Lake Red Rock. High inorganic turbidity restricts phytoplankton growth (Soballe 1981), suggesting that river inputs may be a more significant source of organic carbon. The association of organics with clay surfaces and the transport of these fine materials to downreservoir areas may thus contribute strongly to the observed distribution pattern of organic material.

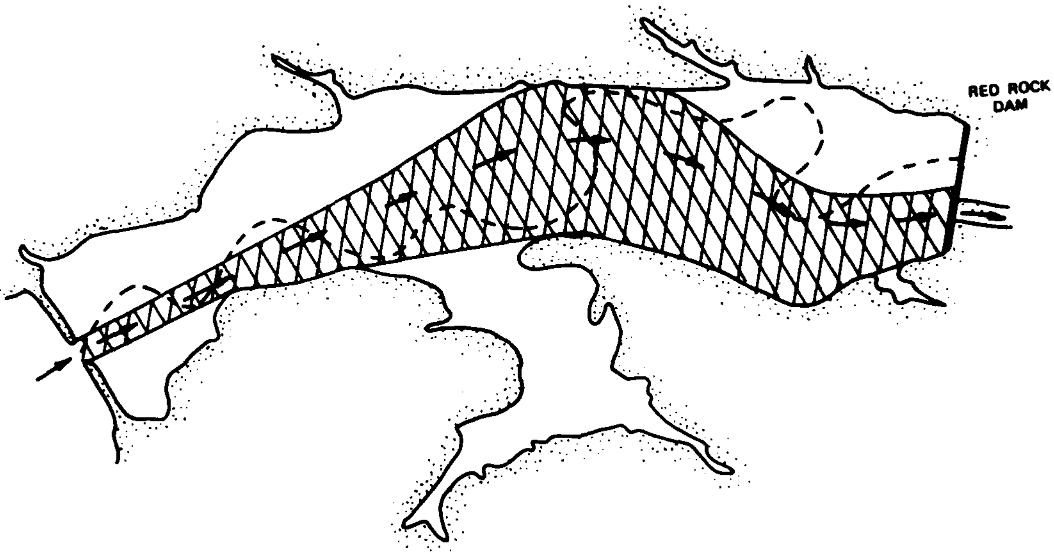

Figure 12. Generalized flow pattern observed in Lake Red Rock during an August 1979 storm event. Crosshatched area indicates the major area of conveyance. Location of the thalweg (broken line) and direction of flow (arrows) are indicated (after Kennedy et al. 1981)

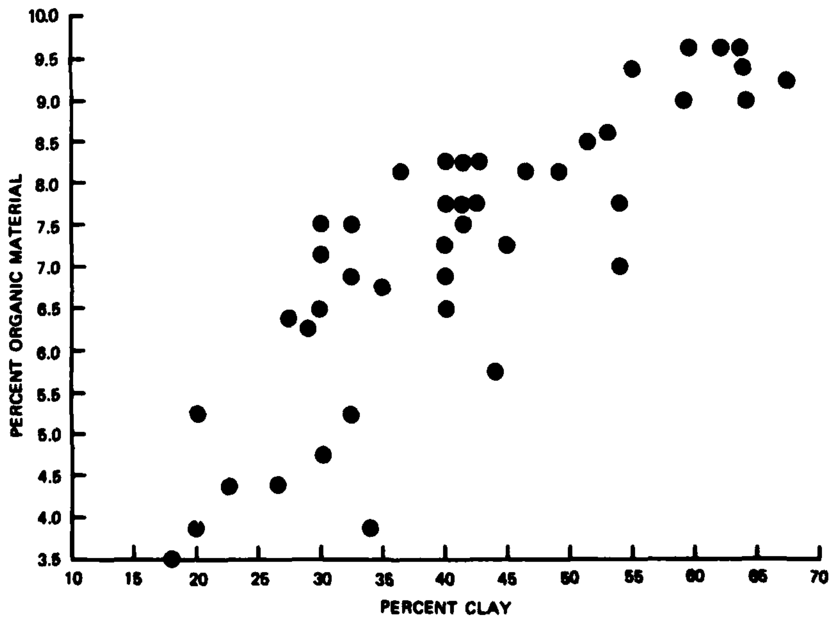

Figure 13. Relationship of percent organic material and percent clay for Lake Red Rock sediments

DeGray Lake

59. Sample collections were attempted at 57 stations in DeGray Lake and its major embayments (Figure 14). Sample collection at 12 stations located primarily in the upper reaches of the Caddo River and Big Hill Creek was prevented by the the presence of sand and gravel. Sampling at eight other stations provided only enough material for particle size analysis. A total of 37 stations provided sufficient material for both particle size and chemical analysis; however, four interstitial water and one sediment sample were lost prior to or during analysis.

60. Although reservoirs and other river-influenced systems are expected to exhibit a gradient of decreasing sediment particle size from headwater to dam (see, for example, Neel 1963), median particle size in DeGray Lake increased from headwater to dam. In addition, an abrupt change in median particle size occurred approximately 12-13 km above the dam (Figure 15). Smaller median particle sizes for sediments in the upper portion of the reservoir suggest the accumulation of riverborne material in this region of the reservoir. Sediments in the lower portion, which have larger and more variable median particle sizes, were apparently less influenced by river inputs and more representative of preimpoundment soils. This suggestion is supported by the presence of leaves, twigs, and other terrestrial debris in several cores collected in the lower portion of the reservoir.

61. The abrupt change in particle size 12-13 km above the dam was the result of hydrodynamic conditions. The capacity of the river inflow for carrying suspended loads diminished with distance from the headwater because of increases in basin width and depth. While increases in basin width and depth occurred along the entire length of the reservoir, an abrupt change in width occurred at midreservoir (see Figure 14). The portion of the reservoir below this point was therefore little affected by riverine flows and the suspended loads they transport.

62. Since several sediment chemical characteristics also

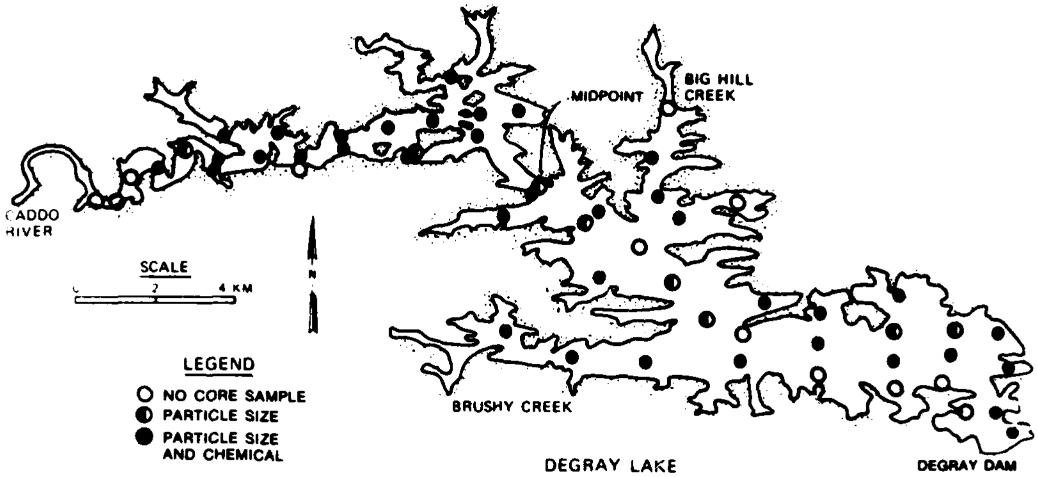

Figure 14. DeGray Lake sampling stations indicating type of sample obtained during sediment study conducted 16-21 March 1980

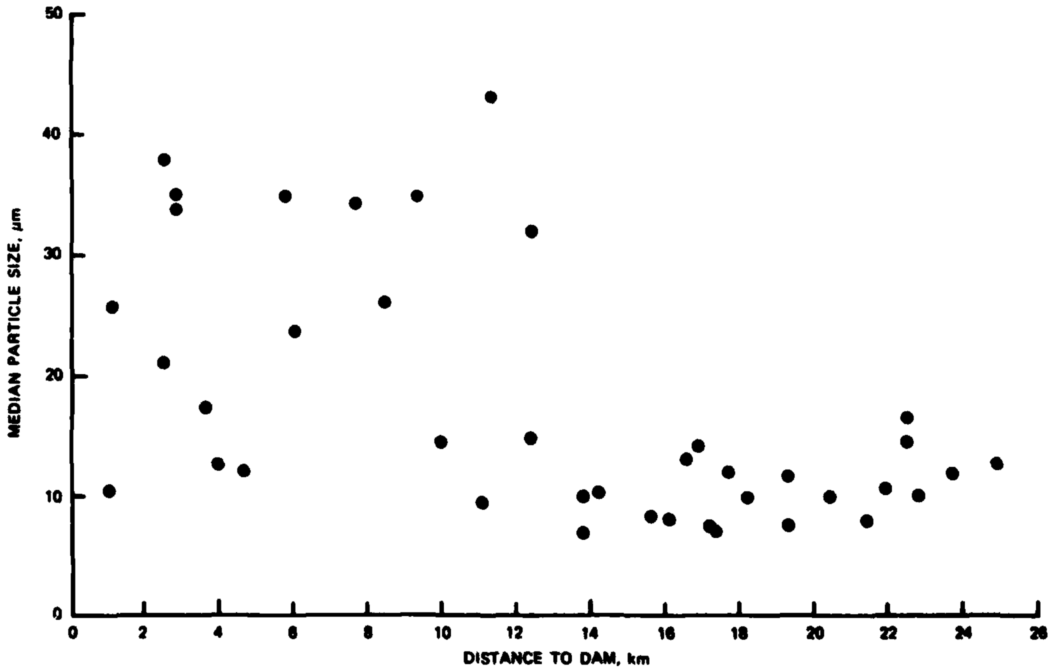

Figure 15. Relationship of sediment mean particle size and distance to dam for DeGray Lake

exhibited midreservoir changes (Figure 16), sediment data were separated into two groups: data for stations located farther than 12.5 km from the dam (upper division) and data for stations located less than 12.5 km from the dam (lower division). Sediment data from the Big Hill and Brushy Creek embayments were excluded, since these sediments were not directly affected by processes influencing the establishment of longitudinal gradients.

63. Median particle size for upper division sediments was significantly smaller than for lower division sediments (Table 5). Within each division median particle size did not correlate with distance from headwater to dam. However, when only the nine thalweg stations in the upper division were examined, median particle size decreased significantly ($r = -0.84$) from headwater to midreservoir. A significant correlation between median particle size and water column depth also existed in the upper division ($r = -0.44$). The negative correlation indicated the settling of larger particles near shore and smaller particles in deeper areas of the pool. In the lower division, however, there was no significant correlation between median particle size and depth. Preimpoundment soil conditions and the presence of terrestrial organic matter left in the reservoir may be more important factors determining characteristics of lower division sediments than are riverine and lacustrine processes.

64. Several chemical characteristics of sediments and interstitial water differed between upper and lower division samples (Table 5). In general, sediment iron, phosphorus, and inorganic carbon were higher for upper division samples than for lower division samples. Although a difference in median particle size was apparent, there was no significant difference in sediment moisture content. Interstitial manganese content, however, was higher for lower division than for upper division sediments.

65. Particle size and chemical composition of sediments in the upper and lower divisions of the reservoir, in general, did not follow expected patterns for a river-influenced reservoir. The data suggest that only the upper division was significantly affected by riverine

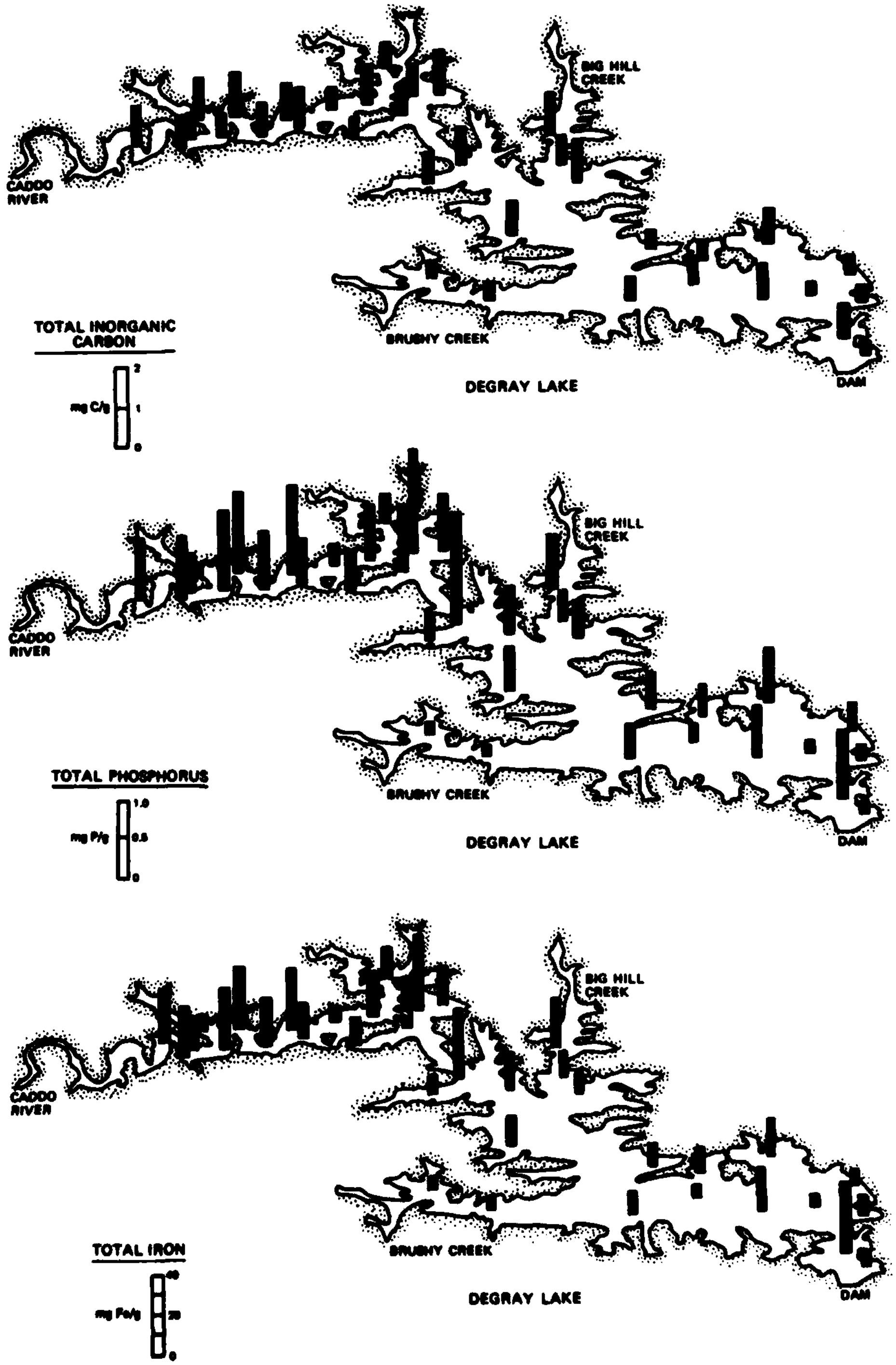

Figure 16. Sediment total inorganic carbon, phosphorus, and iron concentrations represented by bar height for DeGray Lake stations

Table 5

DeGray Lake Mean Values for Upper and Lower Divisions

Variable	Upper Division*	Lower Division*	p**
Interstitial chemical composition, mg/L			
Total manganese	2.50 (16)	7.84 (12)	<0.05
Total phosphorus	0.24 (15)	0.17 (10)	NS†
Soluble reactive phosphorus	0.22 (12)	0.14 (8)	NS
Total nitrogen	2.5 (15)	3.6 (10)	NS
Ammonium nitrogen	1.6 (15)	2.7 (10)	NS
Nitrate nitrite nitrogen	0.01 (15)	0.01 (10)	NS
Total inorganic carbon	11.7 (15)	13.7 (10)	NS
Total organic carbon	7.6 (16)	10.4 (12)	NS
Total iron	7.96 (16)	9.29 (12)	NS
Sediment chemical composition, mg/g			
Total inorganic carbon	0.86 (18)	0.68 (13)	<0.05
Total phosphorus	0.741 (18)	0.451 (14)	<0.01
Total iron	22.8 (18)	14.0 (14)	<0.01
Total nitrogen	1.795 (18)	1.743 (14)	NS
Total organic carbon	17.9 (18)	21.4 (14)	NS
Total manganese	0.761 (18)	1.360 (14)	NS
Moisture content, %	64.65 (17)	54.10 (14)	NS
Median particle size, μm	10.45 (21)	24.85 (19)	<0.001

* Values in parenthesis are the numbers of observations on which calculations are based.
** p = probability that the means are equal.
† NS = nonsignificant difference ($p > 0.05$).

influences, while the lower division sediments reflect preimpoundment conditions. Rather than comparing sediments deposited since impoundment, comparisons based on division reflect differences between postimpoundment sediments of the upper division and inundated soils of the lower division.

66. Comparisons of elemental ratios for sediments, interstitial water, and river inflows provide a means by which processes influencing sediment quality in DeGray Lake can be deduced. Elemental ratios for the Caddo River, reservoir upper and lower division sediments and interstitial water, and reservoir discharge are presented in Table 6.

Table 6

Element Ratios for DeGray Lake Inflow, Upper and Lower Divisions, and Outflow

Ratio	Flow-Weighted Caddo River Inflow	Upper Division Sediment	Upper Division Interstitial	Lower Division Sediment	Lower Division Interstitial	Outflow
Fe:Mn	17.4	40.8	2.0	15.8	1.1	--*
Fe:P	36.3	33.9	52.3	32.3	61.1	--
C:N	13.9	9.7	3.6	12.4	3.7	20.6
N:P	11.5	2.8	16.4	4.1	25.4	40.9
C:P	34.8	27.8	37.4	50.1	96.7	128.6

* Not measured.

67. The Fe:Mn ratio increased between inflowing water and upper division sediments (Table 6), indicating that proportionately more iron than manganese was being deposited and retained by these sediments. The Fe:Mn ratio for the lower division was significantly lower than the upper division ratio because most of the iron inputs from the river were deposited on upper division sediments, while manganese was transported further into the reservoir. This suggestion is supported by sediment trap data (James and Kennedy 1983). Iron deposition in traps deployed in the upper division was highest during periods of high flow and is apparently allochthonous in origin. Iron deposition also decreased from headwater to dam. Manganese deposition, on the other hand,

increased from midreservoir to the dam. Differences in depositional patterns are apparently related to differences in the rates at which iron and manganese hydrous oxides were formed and precipitated. An advective flow regime and seasonal changes in redox conditions and stratification lead to the preferential transport of manganese downstream (Kennedy et al. 1983, Gunkel et al. 1982).

68. The Fe:P ratios for sediments in the upper and lower divisions were 33.9 and 32.3, respectively, and are similar to ratios observed by Kennedy et al. (1983) for water just above the sediment. Despite the fact that sediment iron and phosphorus concentrations decreased from headwater to dam, the similarity in the Fe:P ratios for both upper and lower division sediments reflects the interrelationship between phosphorus and iron reported for most lacustrine systems (Mortimer 1971). Kennedy et al. (1983) suggest that interaction between iron and phosphorus plays an important role in the phosphorus dynamics of DeGray Lake.

69. The C:N ratio provides some indication as to the source of organic matter deposited in the reservoir. Sediments in the lower division of DeGray Lake had a slightly higher ratio than those in the upper division (Table 6). This is probably related to patterns in phytoplankton production, since higher epilimnetic chlorophyll a concentrations have been reported for DeGray's headwater area (Thornton et al. 1982). The lower division ratio was possibly influenced by the presence of preimpoundment vegetation. While C:N ratios for terrestrial material are generally three to four times higher than those observed in the lower division sediments, the exclusion of woody material from samples and the length of time elapsed since initial inundation may have resulted in the unexpectedly low ratio.

70. An increase in the N:P ratio from inflow to outflow indicates phosphorus retention by the reservoir (Table 6). This is also reflected by the increase in sediment N:P ratio from the upper to lower division (Table 6). James and Kennedy (1983) found increasing N:P ratios from headwater to the dam and concluded that this gradient was due to nutrient utilization and sedimentation. The importance of the

Fe:P relationship is indicated again, since iron precipitation provides a mechanism for retaining phosphorus in the sediments. Since there is no similar mechanism for removing nitrogen from the water column, relatively more nitrogen is exported from the reservoir. Further, the N:P ratio for lower division sediments was slightly higher than that for upper division sediments, suggesting that more of the phosphorus was retained in the sediments of the upper division than in the sediments of the lower division.

71. James and Kennedy (1983) found that water column, settling material, and sediment C:P ratios in the headwater region of DeGray were all similar and concluded that river inputs had a significant impact on the water quality of that area of the reservoir. The outflow C:P ratio was greater than the inflow ratio, which most likely was a result of carbon fixation and the retention of phosphorus by the reservoir (Table 6). The C:P ratio in lower division sediments was greater than that in upper division sediments, suggesting that upper division sediments were phosphorus-enriched compared with lower division sediments (see also Figure 16).

Eau Galle Lake

72. Sample collections were attempted at 35 stations in Eau Galle Lake (Figure 17). Gravel prevented sample collection at 10 stations, six stations provided only enough material for particle size analysis, and one is represented by only chemical data. Eighteen stations provided sufficient material for both particle size and chemical analysis.

73. Flow pattern and basin morphology strongly influenced the pattern of deposition in Eau Galle Lake. The borrow area for the earthen portion of the dam included sections of the Eau Galle River streambed. To allow for the excavation of this area, river flow was diverted to the west by connecting two knolls with a temporary earthern dam (Figure 18). This diversion still affects flow in Eau Galle Lake.

74. The pattern of flow in Eau Galle Lake was determined using a

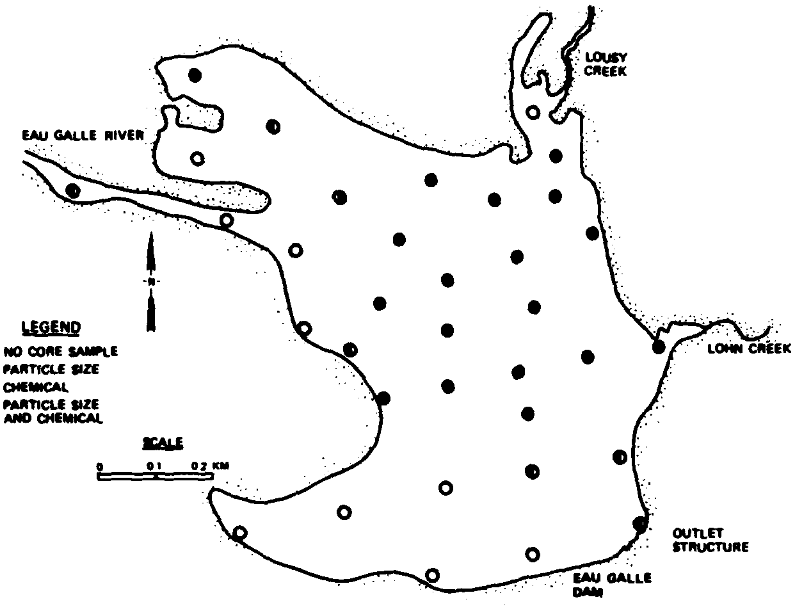

Figure 17. Eau Galle Lake sampling stations indicating type of sample obtained during sediment study conducted 1-2 February 1980

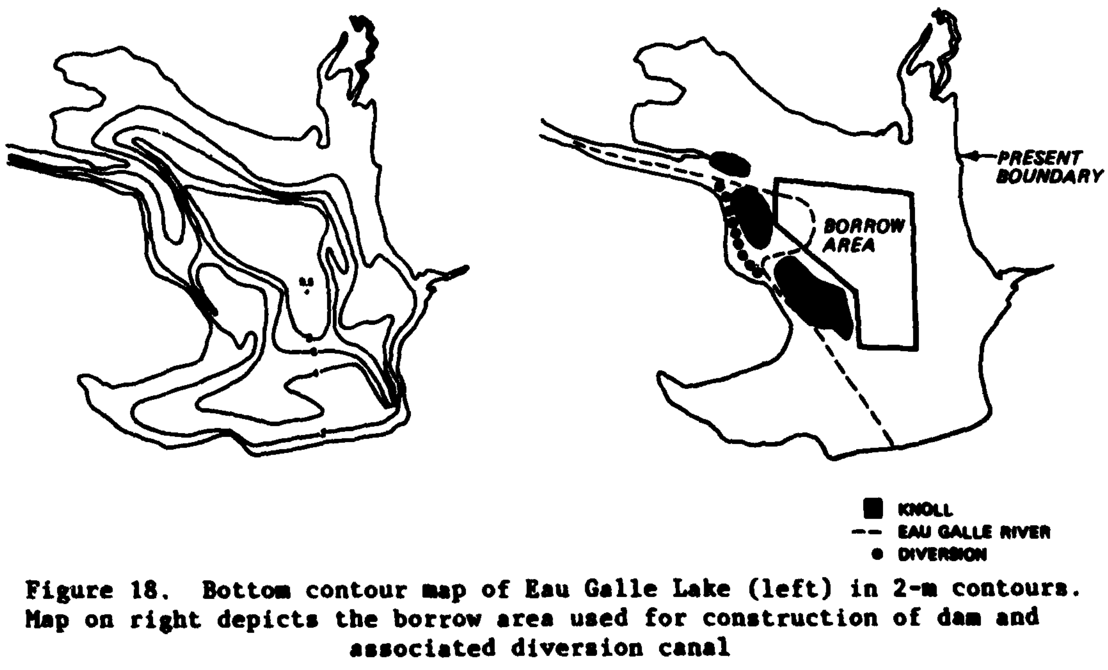

Figure 18. Bottom contour map of Eau Galle Lake (left) in 2-m contours. Map on right depicts the borrow area used for construction of dam and associated diversion canal

fluorescent dye during a 3-day study in August 1981.* The dye was injected into the Eau Galle River 1200 m upstream of the reservoir. Movement of the dye for three successive days after injection was apparently influenced to a large extent by the morphology of the basin (Figure 19). On the first day, the majority of the dye remained in a channel between the western shore and the now submerged knolls. On the second day, highest dye concentrations were located immediately above the thermocline and over the old river channel; in addition, the leading edge of the dye cloud had been deflected from the southern shore, showing the influence of wind-generated water movements and a decreasing riverine influence. Strong winds out of the north, observed during the study period, had apparently established a countercurrent directed north near the thermocline, which moved the dye in a direction opposite that of the river's flow and resulted in the observed spread of the dye in a northerly direction. The effect of wind-induced currents was more pronounced on the third day as the maximum concentration was centered over the deep basin and dye was detected in almost all of the northwestern section of the reservoir. If the observed flow pattern was consistent over time, the interaction of river-induced flow and periodic wind-generated currents may have acted to concentrate inputs of particulate matter over the deep basin. This interaction would also have tended to slow water movement over this area and to allow for considerable deposition of its sediment load. In the absence of wind-generated currents, increases in depth with distance from the river inflow would have resulted in reduced water movements and an increased potential for sedimentation.

75. Eau Galle sediment median particle size is related to depth. Since sediments at depths greater than approximately 3.5 m have a smaller median size than those at shallower depths (Figure 20) and since there is no significant correlation between median particle size and distance from the Eau Galle River, two depth-related data subsets were established for further analysis: (a) shallow sediments (at depths

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* Unpublished data from Marc C. Johnson, engineer, WES, Vicksburg, Miss.

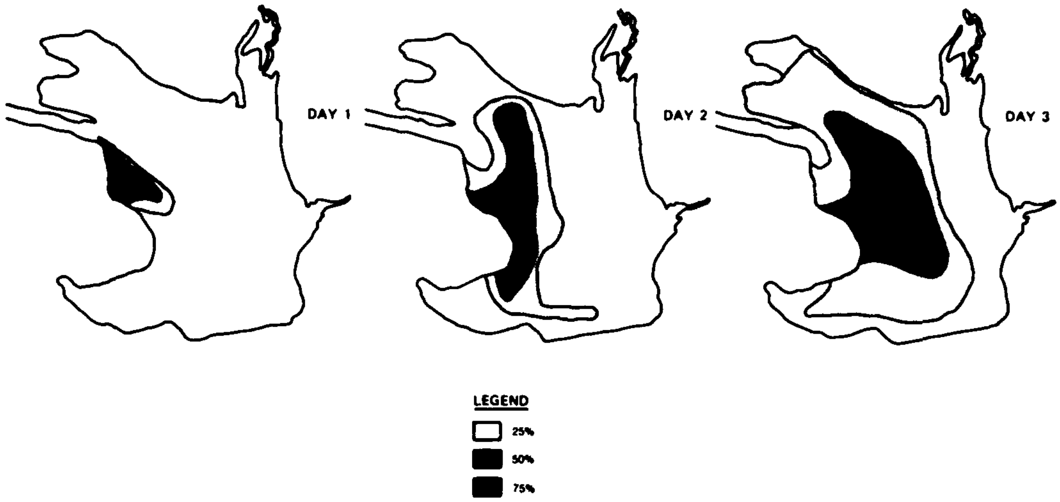


Figure 19. Distribution of fluorescent dye of Eau Galle Lake over three consecutive days. Shading indicates percentage of maximum observed dye concentration

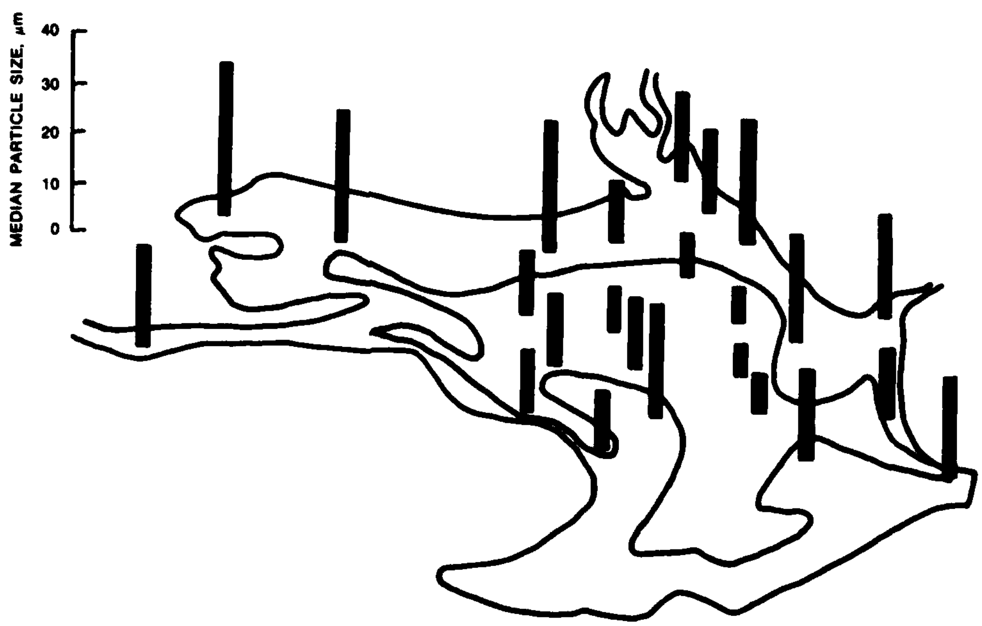


Figure 20. Sediment median particle size represented by bar height for Eau Galle Lake stations. The 3.5-m contour line is shown within the lake

≤3.5 m) and (b) deep sediments (at depths >3.5 m). Three-and-a-half meters also approximates the depth of mixing during summer stratification.

76. Particle size distribution curves for shallow and deep sediments, obtained by pooling data for each depth category, are presented in Figure 21. The turbulent or "high-energy" nature of the littoral zone is reflected in the relatively uniform distribution of particle volume among each of the 13 particle size classes for the shallow sediments. The distribution for deep sediments, however, is skewed toward

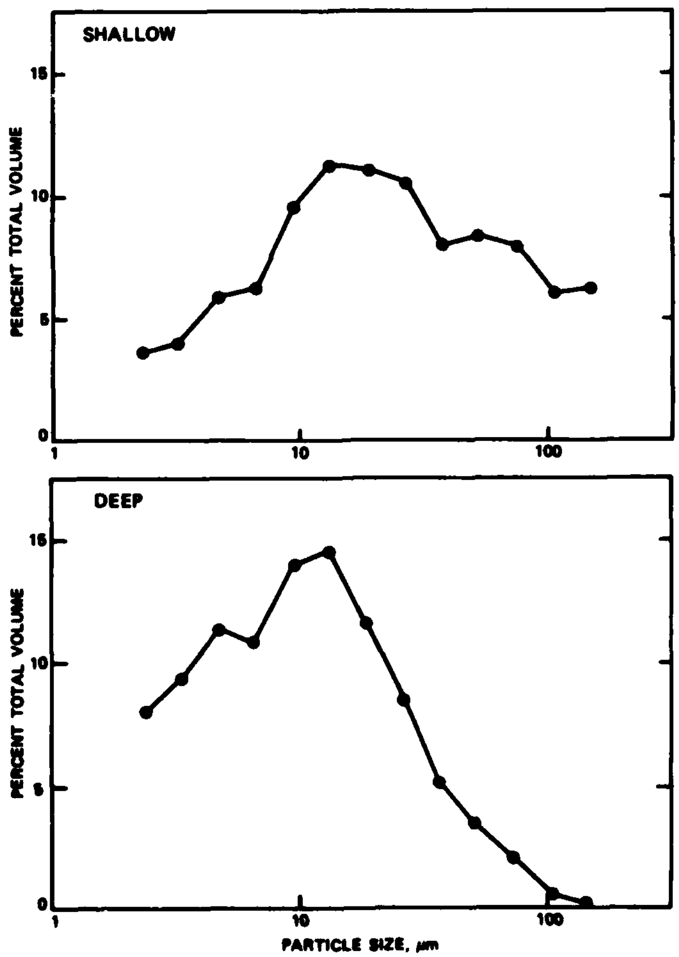


Figure 21. Relationship of percent total volume and particle size for shallow and deep sediments for Eau Galle Lake

the smaller size classes, suggesting preferential deposition of small particles in deep areas of the reservoir. This sorting of particles could be the result of differential transport of allochthonous inputs or material resuspension by mixing. The Eau Galle deep sediments also had a significantly higher moisture content than the shallow sediments (67 ± 6 percent and 44 ± 12 percent, respectively). This is consistent with Hakanson's (1977) observation that particle size is inversely related to moisture content. Differences between shallow and deep sediments in Eau Galle suggest that deep areas were zones of accumulation, while shallow sediments were constantly subjected to erosion and transport.

77. Ten of fifteen measured sediment and interstitial variables exhibit significant differences when shallow and deep stations are compared (Table 7). Differences are related either directly or indirectly to the accumulation of fine particulate matter in the deeper regions of the reservoir. Sediment concentrations of total organic carbon, nitrogen, phosphorus, iron, and manganese in the deeper sediments were approximately 1.5-2.0 times higher than those in the shallower sediments (Figure 22). Hakanson (1977) reported enrichments of 150-550 percent for organic matter, nitrogen, and phosphorus in the deep basins of Lake Vanern. The enrichment of these elements in the deep sediments is possibly due to their association with fine particulate matter and its preferential deposition in deeper areas. For instance, phytoplankton act as concentrators of epilimnetic carbon, nitrogen, and phosphorus. Since they represent a major portion of the fine particulate matter, a significant fraction of their cellular carbon, nitrogen, and phosphorus will be deposited in the deep sediments. Wetzel (1975) found that iron and manganese bound in the biomass of phytoplankton tends not to be lost in the initial stages of decomposition, but rather moves with sedimenting organic detritus. He also suggests that the fraction of $Fe(OH)_3$ not directly settled following circulation is adsorbed to fine particulate matter, which would enrich the deeper sediments with iron. Clays and other fine inorganic particulates would also serve as a mechanism for the removal of dissolved nutrients and metals from the water column.

Table 7

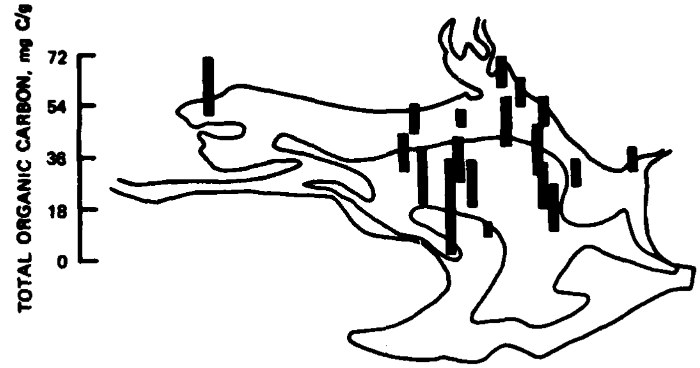
Eau Galle Lake Mean Values for Shallow and Deep Sediments

Variable	Shallow*	Deep*	p**
Interstitial chemical composition, mg/L			
Soluble reactive phosphorus	0.19	0.30	<0.05
Total phosphorus	0.19	0.33	<0.05
Total iron	8.42	20.18	<0.05
Total manganese	4.97	10.13	<0.05
Nitrate nitrite nitrogen	0.01	0.02	NS†
Ammonium nitrogen	10.92	13.43	NS
Total nitrogen	11.57	15.02	NS
Total inorganic carbon	84.4	80.56	NS
Total organic carbon	12.29	16.63	NS
Sediment chemical composition, mg/g			
Total inorganic carbon	7.54	3.33	<0.001
Total organic carbon	15.34	30.27	<0.005
Total nitrogen	2.03	3.14	<0.001
Total phosphorus	0.72	1.35	<0.001
Total iron	18.76	31.52	<0.001
Total manganese	0.76	1.09	<0.01

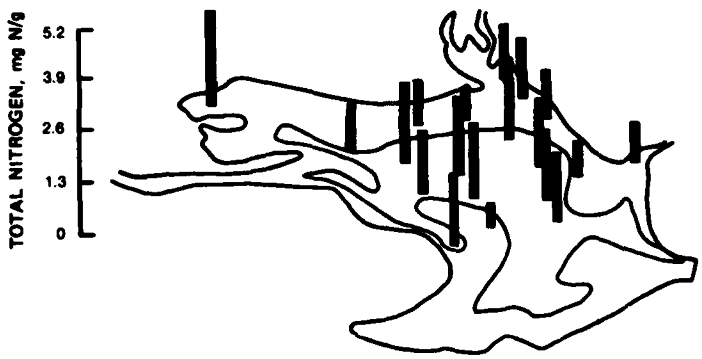
* Number of observations on which calculations are based: for shallow, $n = 10$; for deep, $n = 9$.

** Probability that means are equal.

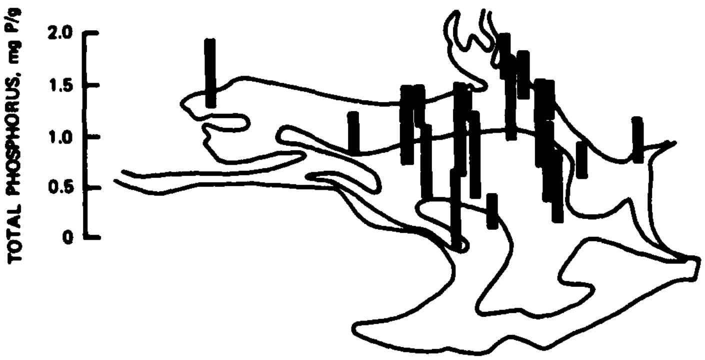
† Nonsignificant difference ($p > 0.05$).



a. Organic carbon

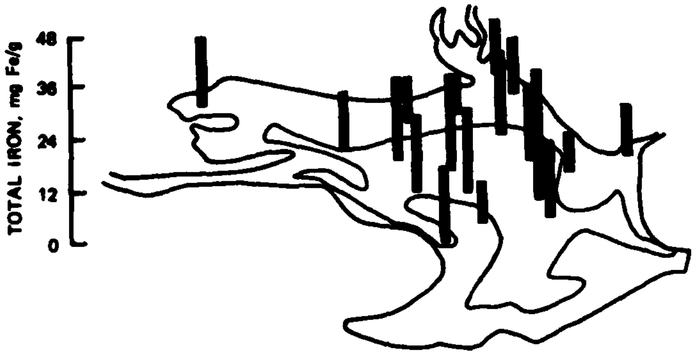


b. Nitrogen

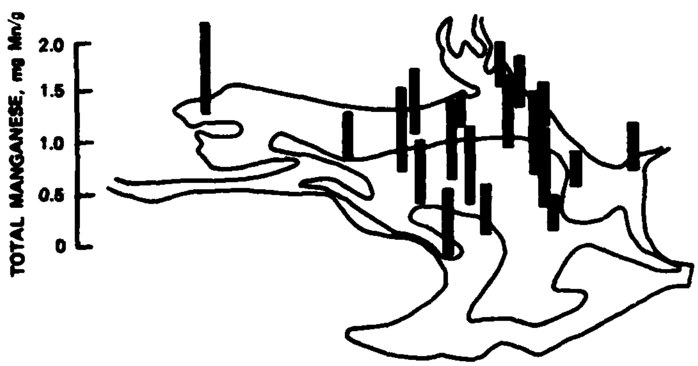


c. Phosphorus

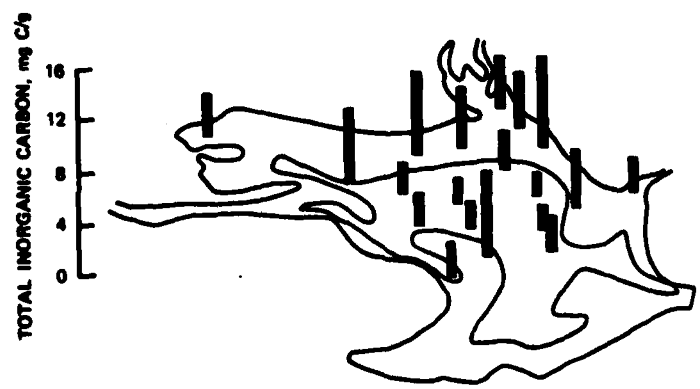
Figure 22. Sediment total concentrations represented by bar height for Eau Galle Lake. The 3.5-m contour is shown within the lake (Sheet 1 of 2)



d. Iron



e. Manganese



f. Inorganic carbon

Figure 22. (Sheet 2 of 2)

78. The distribution of sediment total inorganic carbon is not a result of sediment focusing, since inorganic carbon was approximately 1.5 times higher in the shallow sediments (Figure 22e). This was probably the result of precipitation and deposition of $CaCO_3$. When photosynthesis by phytoplankton and macrophytes removes CO_2 in excess of replacement by respiration, $CaCO_3$ can be precipitated. This precipitation can occur in the open water of the reservoir as well as the littoral region; but little, if any, $CaCO_3$ will be deposited in the deeper sediments because of chemical conditions in the hypolmnion. The CO_2 content of water increases with depth and, in the hypolimnion where CO_2 is often abundant, $CaCO_3$ is dissolved and bicarbonate content increases. This mechanism effectively prevents enrichment of deeper sediments with inorganic carbon.

79. Higher interstitial concentrations of total and soluble reactive phosphorus, iron, and manganese in deep sediments (Table 7) are thought to be an indirect result of sediment focusing for two reasons. First, since sediments showed an enrichment of phosphorus, iron, and manganese it would be expected that interstitial waters would also exhibit an enrichment through interactions between dissolved and solid phases. Second, higher total organic carbon in the sediment fraction should act to increase the rate and intensity of reduction in anaerobic systems (Gunnison and Brannon 1981) and result in higher concentrations of the soluble products. The lack of any significant enrichment of the interstitial waters of deeper sediments by any of the measured forms of nitrogen (nitrate nitrite, ammonium, and total nitrogen) may be a result of their relative ease of mobilization from the sediments (Wetzel 1975).

80. Correlations between the percents volume in individual particle size classes (Figure 21) and various chemical and physical characteristics for deep sediments are presented in Table 8. Percents volume in small size classes 2.4 through 4.7 μm show a positive correlation with all forms of nitrogen (sediment total nitrogen and interstitial nitrate nitrite, ammonium, and total nitrogen), sediment and interstitial iron and manganese, sediment total phosphorus, and interstitial carbon. Percents volume in the intermediate size classes 13 through

Table 8

Significant ($p \leq 0.05$) Correlation Coefficients for the Eau Galle Deep Stations

(Particle Size Values are Midpoints of Size Ranges)

Variable	Particle Size (µm) 150	106	75	53	38	27	19	13	9.4	6.6	4.7	3.3	2.4
Interstitial chemical composition													
Total inorganic carbon	-0.44	NS*	-0.81	-0.47	NS	-0.46	-0.44	-0.58	NS	NS	NS	0.58	0.61
Total organic carbon	NS	NS	-0.82	-0.69	NS	-0.68	-0.68	-0.53	NS	NS	0.69	0.81	0.80
Nitrate nitrite nitrogen	NS	-0.44	-0.45	-0.62	-0.45	NS	-0.70	NS	0.48	0.66	0.64	0.59	0.57
Ammonium nitrogen	NS	NS	-0.79	-0.45	NS	-0.54	-0.55	-0.59	NS	NS	0.48	0.63	0.61
Total nitrogen	NS	NS	-0.78	-0.48	NS	-0.56	-0.56	-0.57	NS	NS	0.51	0.66	0.63
Soluble reactive phosphorus	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total phosphorus	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total iron	NS	NS	-0.78	-0.52	NS	-0.67	-0.54	-0.49	0.46	NS	0.58	0.71	0.66
Total manganese	NS	NS	-0.76	NS	NS	-0.50	-0.54	-0.64	NS	NS	NS	0.59	0.56
Sediment chemical composition													
Total inorganic carbon	NS	NS	NS	NS	NS	NS	NS	0.56	NS	NS	NS	NS	NS
Total organic carbon	NS	NS	NS	NS	NS	NS	0.55	0.67	NS	NS	NS	NS	NS
Total nitrogen	NS	NS	-0.69	NS	NS	-0.68	-0.53	NS	NS	NS	0.53	0.62	0.56
Total phosphorus	NS	NS	-0.85	-0.60	NS	-0.71	-0.66	-0.67	NS	NS	0.61	0.79	0.77
Total iron	NS	NS	-0.45	NS	NS	-0.47	NS	NS	NS	NS	NS	0.46	0.45
Total manganese	NS	NS	-0.63	NS	NS	NS	NS	-0.57	NS	NS	NS	0.44	0.45
Median Particle size	NS	0.80	0.52	0.87	0.84	0.85	0.73	NS	-0.80	-0.88	-0.97	-0.91	-0.87
Column depth	NS	NS	NS	NS	NS	-0.45	-0.63	NS	0.44	0.48	0.57	0.54	0.54

* NS = correlation was not significant.

75 μm are negatively correlated with these same constituents. Percents volume in the 13- and 19-μm size classes are positively correlated with sediment organic carbon. Percents volume in the 6.6-, 9.4-, 106-, and 150-μm size classes show a general lack of correlation with the chemical data.

81. The lack of any significant correlation between chemical composition and percent volume in the 6.6-, 9.4-, 106-, and 150-μm size classes may be explained by their relative variability. Percents volume in the 6.6- and 9.4-μm size classes had the lowest coefficient of variation (CV = 12 and 8, respectively), while contributing 25 percent of the deep sediment total volume. This suggests that particles in these size classes were relatively evenly distributed across the deep sediments and therefore would show little relation to chemical composition. The absence of correlations between the chemical composition and the 106- and 150-μm particles is probably a result of the particles' high variability (CV = 149 and 316, respectively) and their small contribution (0.7 percent) to the total volume of the deep sediments.

82. The positive correlations observed for small particles (2.4 through 4.7 μm) suggest these particles dominated the chemical and biological activity of the deep sediments. This domination was probably a result of their large contribution to the total surface area of the sediments: particles in this size range constituted 29 percent of the total volume, but 61 percent of the total surface area. Sly (1977) stressed that the surface area of clay-sized particles is on the order of square meters per gram, whereas the surface area of sand grains is only on the order of square centimeters per gram. Fine-grained materials have the greatest potential for chemical and biological interaction because of the importance of surface reactions in the sediments (Jones and Bowser 1977).

83. Sediment organic carbon in Eau Galle was correlated with particles in the 13- and 19-μm size classes rather than with much smaller particles. Organic carbon is usually highly correlated with clays and is thought to form a surface film on these particles (Thomas 1969). The correlation here with larger than clay-sized particles suggests that the

organic carbon in Eau Galle was detrital in nature and represents particulate organic matter rather than organic film on inorganic particles.

84. Correlation coefficients (significant at $p \leq 0.05$) for shallow sediments are shown in Table 9. In comparison with deep sediments there is a general lack of correlation between particle size and chemical composition for the shallow sediments. Where significant correlations do occur, the sign of the coefficient is the opposite of that observed for the deep sediments. The overall absence of correlations implies that the variability of sediment chemical composition in the littoral zone may have been a function of localized influences (i.e., inflows from Eau Galle River, Lousy Creek, or Lohn Creek; macrophyte beds; direct runoff) rather than particle size, since particle size variability between stations was reduced (Figure 21) as a result of turbulence in the littoral. This reduction of variability in the distribution of particle sizes in the littoral would tend to reduce the number of correlations between particle size and chemical composition of the sediments.

85. While the concentrations of most chemical species differed significantly between shallow and deep stations, elemental ratios did not (Table 10). This indicates that although most elements were concentrated in the deeper regions of the basin, no one element was being preferentially enriched. Elemental ratios for sediment and interstitial water were significantly different ($p \leq 0.05$).

86. Interstitial elemental ratios are highly variable, as indicated by their CV's (Table 10). The CV's for interstitial ratios for all stations ranged from 46-109, while those for sediment ratios ranged from 10-33. Assuming no analysis effects, the variability of the interstitial water may be a reflection of variability in the redox potential of the sediments. Since the presence of components in the interstitial water is a result of the solubilization or decomposition of substances in the sediments, a constant redox potential across the basin should result in similar variations in both sediment and interstitial water values.

87. Sedimentary conditions in Eau Galle Lake tended to be more

Table 9

Significant ($p \leq 0.05$) Correlation Coefficients for the Eau Galle Shallow Stations

(Particle Size Values are Midpoints of Size Ranges)

Variable	Particle Size (μm) 150	106	75	53	38	27	19	13	9.4	6.6	4.7	3.3	2.4
Interstitial chemical composition													
Total inorganic carbon	NS*	NS	NS	NS	NS	0.52	NS	NS	NS	NS	NS	-0.46	NS
Total organic carbon	NS	NS	NS	0.64	NS	NS	NS	NS	-0.84	NS	NS	NS	NS
Nitrate nitrite nitrogen	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.44	NS
Ammonium nitrogen	NS	NS	NS	NS	NS	0.59	NS	NS	NS	NS	NS	-0.47	NS
Total nitrogen	NS	NS	NS	NS	NS	0.57	NS	NS	NS	NS	NS	-0.50	NS
Soluble reactive phosphorus	NS	NS	NS	0.44	NS	NS	NS	NS	NS	NS	-0.75	-0.67	NS
Total phosphorus	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.73	-0.73	NS
Total iron	NS	NS	NS	NS	0.70	NS	NS	NS	NS	NS	-0.45	-0.70	NS
Total manganese	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.46	NS
Sediment chemical composition													
Total inorganic carbon	NS	0.49	NS	NS	NS	NS	-0.46	0.46	NS	NS	NS	NS	NS
Total organic carbon	NS	NS	NS	0.54	0.46	NS	NS	NS	-0.63	NS	-0.62	-0.55	NS
Total nitrogen	NS	NS	NS	NS	0.56	NS	NS	NS	-0.50	NS	NS	-0.63	NS
Total phosphorus	NS	NS	NS	NS	0.47	NS	NS	NS	-0.47	NS	-0.59	-0.66	NS
Total iron	NS	-0.47	NS	NS	NS	NS	NS	NS	NS	NS	-0.48	-0.62	NS
Total manganese	NS	NS	0.61	NS	NS	NS	NS	NS	NS	-0.61	-0.58	NS	-0.61
Median particle size	0.58	0.72	0.69	0.57	NS	NS	-0.68	-0.81	-0.49	-0.76	-0.71	NS	-0.52
Column depth	NS	NS	NS	NS	NS	-0.64	NS	NS	NS	NS	NS	0.44	NS

* NS = correlation was not significant.

Table 10

Mean Values of Selected Elemental Ratios for Shallow, Deep, and All Stations in Eau Galle Lake

Ratio		All*		Shallow*		Deep*	
		Mean	CV,** %	Mean	CV, %	Mean	CV, %
Fe:Mn	S†	27.89	27	24.68	18	30.57	28
	I††	1.66	56	1.75	60	1.58	54
Fe:P	S‡	25.04	10	26.50	10	23.43	6
	I	53.93	89	48.69	81	58.66	96
C:N	S	8.47	32	7.50	17	9.46	34
	I	1.41	46	1.44	52	1.38	42
N:P	S‡	2.56	16	2.76	17	2.33	6
	I	62.17	109	72.13	119	53.21	95
C:P	S	21.64	33	20.81	27	22.12	37
	I	65.89	63	72.84	63	59.62	65

* Number of observations on which calculations are based: for all, n = 19 ; shallow, n = 10 ; deep, n = 9 .
** Coefficient of variation.
† Sediment.
†† Interstitial water.
‡ Means for shallow and deep sediments are significantly different ($p < 0.05$).

lakelike than expected for a "typical" reservoir. Sediment distribution was primarily a function of basin morphology (i.e., depth) rather than flow or location relative to tributary inputs. The size distribution of littoral sediments was relatively uniform, with low variability among stations as a result of resuspension by turbulence and subsequent re-deposition. Chemical composition of littoral sediments showed little relation to particle size distribution, suggesting that factors other than those influencing sediment distribution were important in determining the chemical composition. Deep sediments, because of their smaller particle size and higher nutrient and metal concentrations, may have played an important role in exchanges between sediment and overlying water.

West Point Lake

88. Sample collections were attempted at 60 locations throughout West Point Lake and its major embayments (Figure 23). With the exception of five stations located in the extreme upstream reach of the main pool near the Chattahoochee River inflow, sediments were light brown to

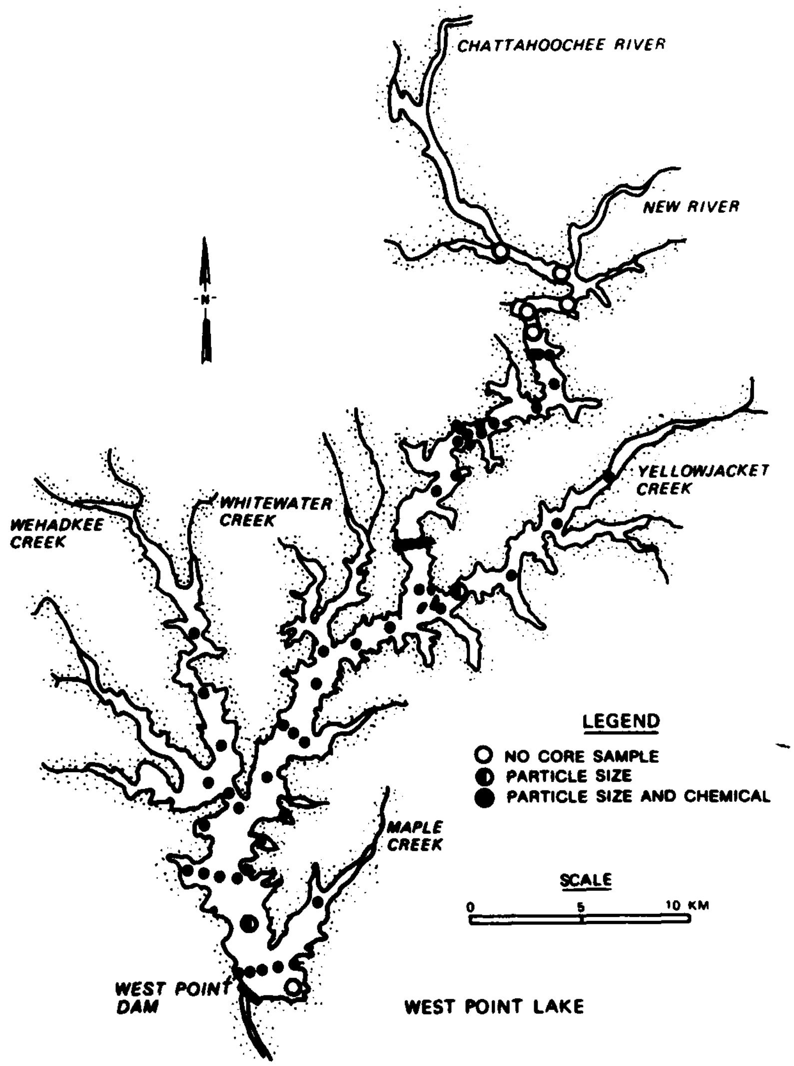


Figure 23. West Point Lake sampling stations indicating type of sample obtained during sediment study conducted 25-28 February 1980

reddish-brown in color and composed of fine, clay-like material. Attempts to sample at the five upstream locations were thwarted by the presence of gravel or by the failure of the core sampler to retain sandy sediments. Similar problems occurred at a site along the east shore near the dam. The occurrence of sands and gravel in upstream areas was not unexpected since flows are characteristically high along this narrow, riverine reach of the reservoir. The presence of sand near the dam was apparently related to preimpoundment excavation and/or nearby construction activities since impoundment. Although standing timber was not completely removed prior to impoundment, no evidence of terrestrial detritus (e.g., leaves, twigs, roots) was found in any of the core samples. Evident in several samples, however, were distinct orange masses, the origins of which are unknown. No attempt was made to determine their physical or chemical nature.

89. Another problem encountered during sampling was the failure to obtain sufficient quantities of sediment and/or interstitial water. In all, 49 complete sets of samples (i.e., particle size, sediment, and interstitial) were obtained. A majority of the samples were collected at sites located along the length of the main portion of the reservoir. Remaining samples were collected along the Yellowjacket and Wehadkee Creek embayments; one sample was obtained from the Maple Creek embayment.

90. Since both width and depth increased with distance from headwater to dam in this reservoir, longitudinal and lateral gradients were expected to be characteristic of interstitial water and sediment from the advectively dominated Chattahoochee portion of the reservoir. However, while several significant correlations were found between interstitial water chemistry and distance from headwater to dam, few correlations were found between sediment characteristics and distance (Table 11). Also, few significant correlations were found between either interstitial water chemistry or sediment characteristics and either depth or distance from shore. In general, interstitial nutrient and metal concentrations increased with distance upstream from the dam. The general lack of significant correlations between sediment variables and distance together

Table 11

Correlation Coefficients for West Point Lake

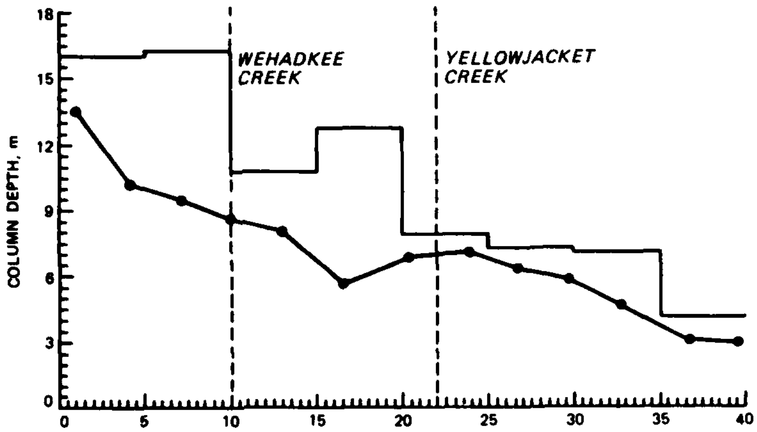
Variable	Distance to Dam	Depth	Distance to Shore	n*
Interstitial chemical characteristics				
Total inorganic carbon	0.73	-0.49	NS**	30
Total organic carbon	0.47	NS	NS	30
Nitrate nitrite nitrogen	NS	NS	NS	30
Ammonium nitrogen	0.61	NS	-0.37	30
Total nitrogen	0.60	NS	-0.37	30
Soluble reactive phosphorus	NS	NS	NS	30
Total phosphorus	NS	NS	0.34	30
Total iron	0.59	-0.39	NS	30
Total manganese	0.67	-0.43	NS	30
Sediment chemical characteristics				
Total inorganic carbon	NS	NS	NS	33
Total organic carbon	-0.41	0.60	NS	33
Total nitrogen	NS	NS	NS	33
Total phosphorus	NS	NS	NS	33
Total iron	NS	0.46	NS	33
Total manganese	NS	NS	NS	33
Moisture content	-0.37	0.52	NS	33
Median particle size	0.37	NS	NS	34

* Number of observations used to calculate the coefficient.
** Nonsignificant correlation ($p > 0.05$).

with the relatively small correlation coefficients for moisture content and median particle size suggest that factors other than distance from headwater to dam influenced sediment deposition in the Chattahoochee section.

91. Although the main pool was relatively narrow along its entire length, maximum depth increased by approximately 20-25 m from headwater to dam. Since sampling station locations were chosen to coincide with previous water quality sampling stations (Kennedy et al. 1982), it was necessary to evaluate the representativeness of these stations with respect to longitudinal changes in reservoir depth and lateral extent; nonrepresentativeness could confound evaluations of the relative importance of distance to shore, depth, and distance from the river inflow in determining sediment characteristics. Water column depth and distance to shore at sediment sampling stations were averaged over 5-km segments of the reservoir from dam to headwater and graphically compared with segment mean depth and segment mean quarter-width, respectively (Figure 24). Longitudinal patterns in segment mean depth and mean sediment sample depth are, in general, similar. However, differences are apparent at sites 5 to 10 km and 15 to 20 km above the dam; along these reaches, sediment station depths were biased toward deeper depths. Comparison of longitudinal patterns in segment quarter-width and average station-to-shore distances also indicates biases along the reach from 5 to 15 km above the dam. Stations here were, on the average, closer to shore than would be expected for a representative sampling.

92. Pooling data for stations located within 5-km segments along the length of the Chattahoochee section of the reservoir provides a means for identifying longitudinal patterns in the distribution of sediment and interstitial water characteristics. While few differences of statistical significance can be demonstrated, several patterns are apparent in the data. Interstitial concentrations of total inorganic carbon, total nitrogen, iron, and manganese decreased downstream, while interstitial total phosphorus remained relatively constant among segments (Figure 25). Elevated concentrations of total organic carbon, total nitrogen, and iron in interstitial samples collected in the segment



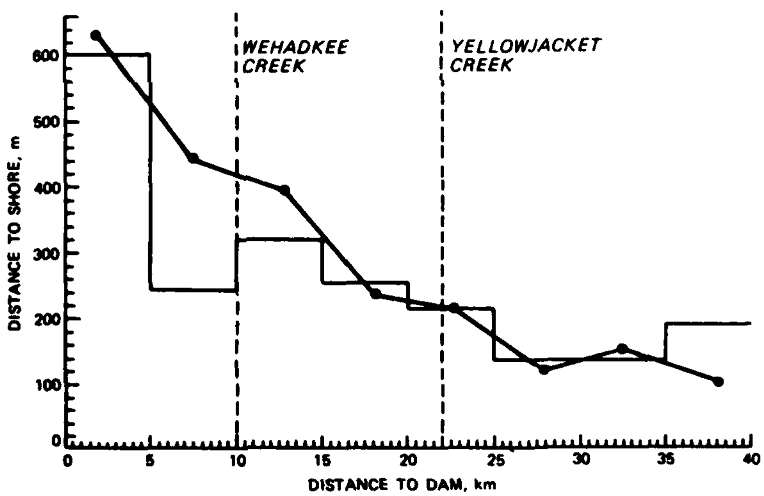
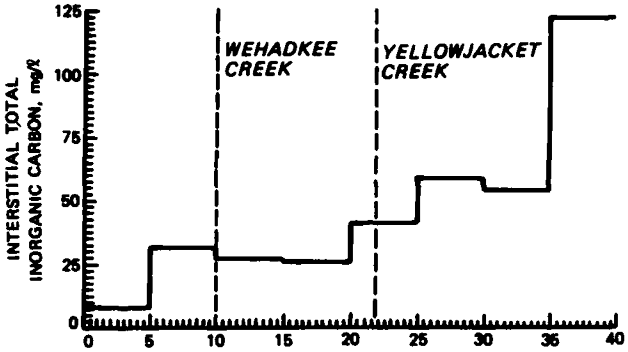
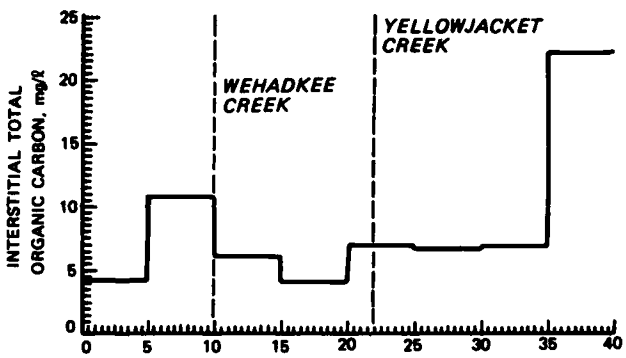


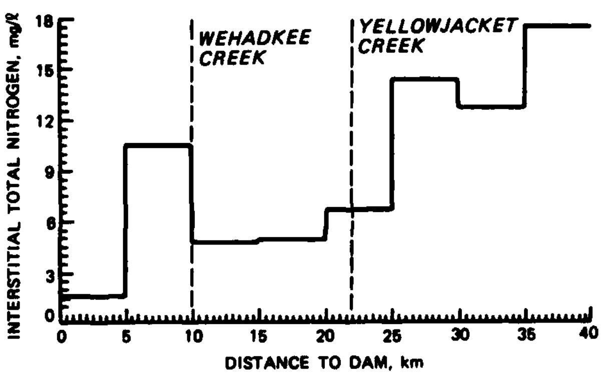
Figure 24. Relationship between mean station depth (——) and segment mean depth (—●—) (top) and relationship between mean distance to shore (——) and segment mean quarter-width (—●—) (bottom), both with respect to distance to dam for West Point Lake



a. Total inorganic carbon

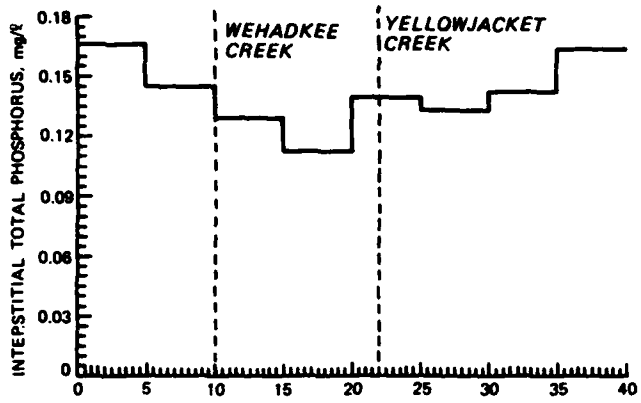


b. Total organic carbon

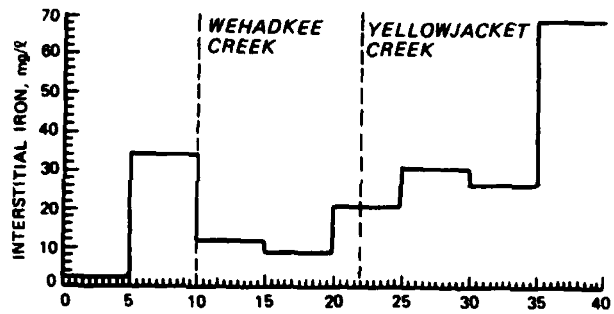


c. Total nitrogen

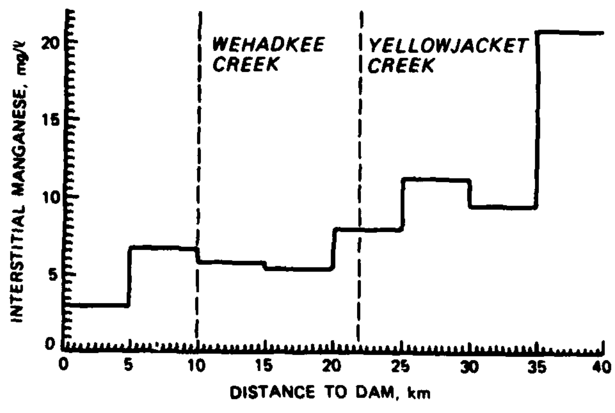
Figure 25. Relationships between distance to dam and interstitial chemical composition for West Point Lake (Sheet 1 of 2)



d. Total phosphorus



e. Iron



f. Manganese

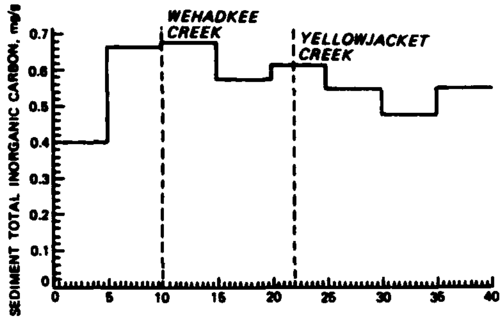
Figure 25. (Sheet 2 of 2)

5-10 km above the dam may have been due to the fact that average sample depth in this segment exceeded mean segment depth. Additionally, the characteristics of samples collected here may have been influenced by inputs from Wehadkee Creek, which enters the main portion of the lake 10 km above the dam.

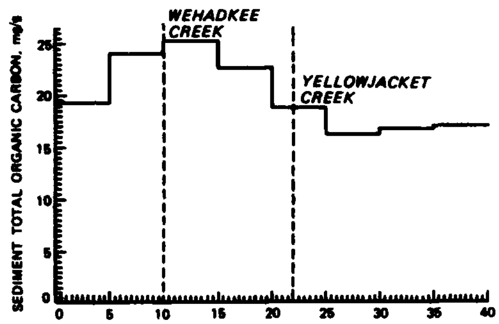
93. The longitudinal distributions of sediment organic carbon, phosphorus, iron, manganese, and moisture content exhibit similar patterns, with highest concentrations occurring approximately 10-25 km upstream from the dam (Figures 26-27). Median particle size, although variable, increased with distance above the dam (Figure 27). Total inorganic carbon and nitrogen were relatively constant along the length of the reservoir (Figure 26).

94. Longitudinal patterns for moisture content and median particle size may reflect the impact of particulate matter inputs from Wehadkee and Yellowjacket Creeks. Moisture content was highest in the area between Yellowjacket and Wehadkee, and increases in particle size are observed in the areas immediately below these two creeks. While the differences are not always statistically significant, the patterns for other sediment variables are similar to that of moisture content. Even the interstitial variables, which do show significant correlations with distance above the dam, appear to have been influenced by inputs from Wehadkee Creek. Element ratios for both sediment and interstitial variables tend to exhibit significant changes below Wehadkee Creek (Figures 28 and 29).

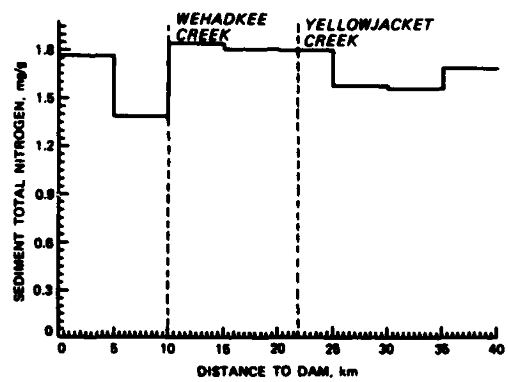
95. The consistent patterns for the variables directly associated with particulate matter (moisture content and sediment chemical composition) indicate the area between the Yellowjacket and Wehadkee Creek embayments as a site for the deposition of fine allochthonous and autochthonous particulates. Longitudinal gradients in water quality support this conclusion (Kennedy et al. 1982). During two intensive water quality surveys, turbidity decreased dramatically and chlorophyll *a* peaked and declined between 1 and 30 km above the dam (Figure 30). If sedimentation was the cause of these observed changes, maximum sedimentation should be expected to occur between 10 and 30 km above the dam. Such



a. Total inorganic carbon

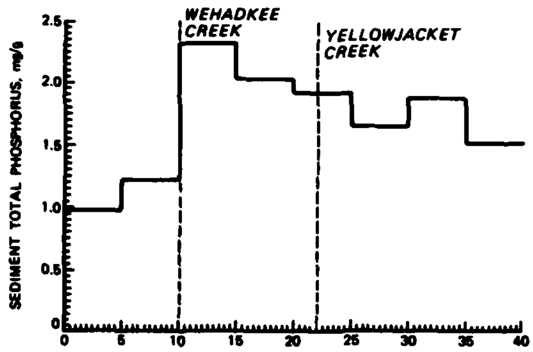


b. Total organic carbon

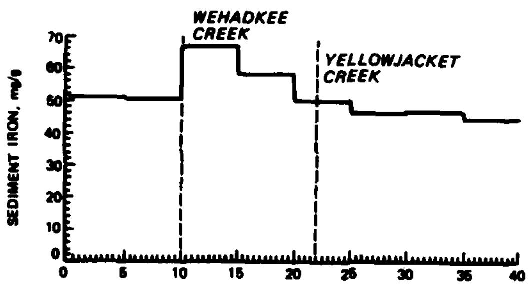


c. Total nitrogen

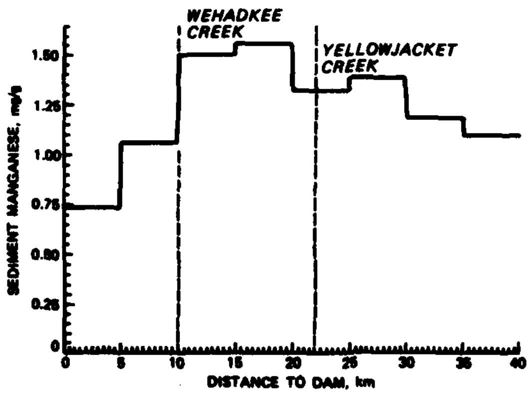
Figure 26. Relationships between distance to dam and sediment chemical composition for West Point Lake (Sheet 1 of 2)



d. Total phosphorus



e. Iron



f. Manganese

Figure 26. (Sheet 2 of 2)

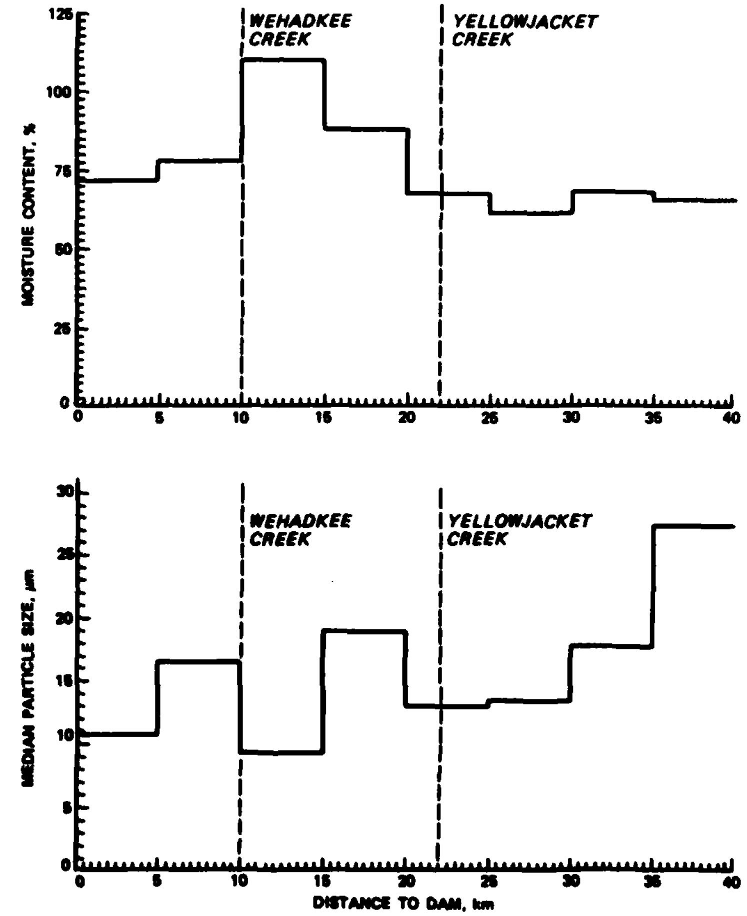


Figure 27. Relationships between distance to dam and percent moisture content (upper) and median particle size (lower) for West Point Lake

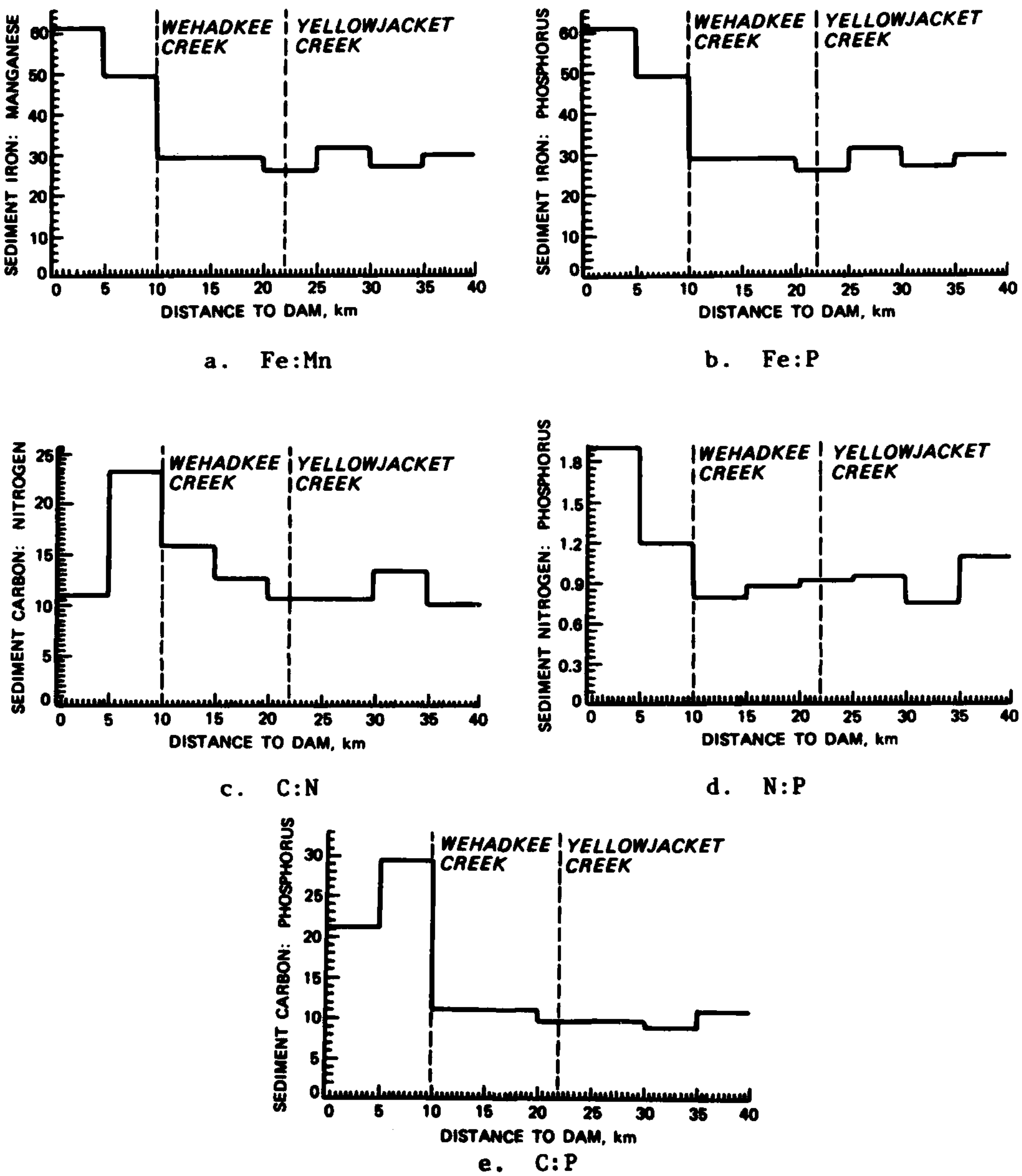


Figure 28. Relationships between sediment chemical ratios and distance to dam for West Point Lake

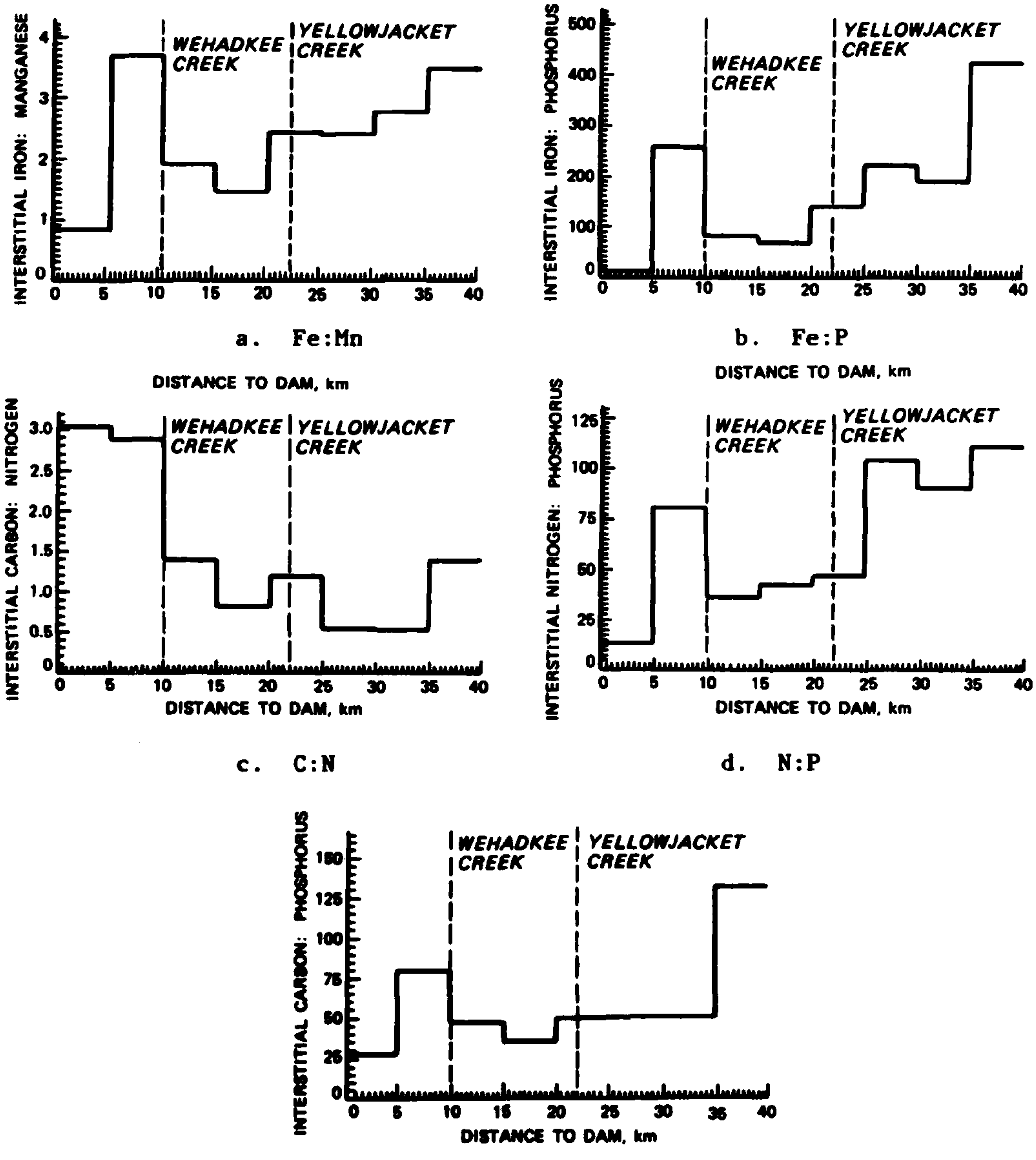


Figure 29. Relationships between interstitial water chemical ratios and distance to dam for West Point Lake

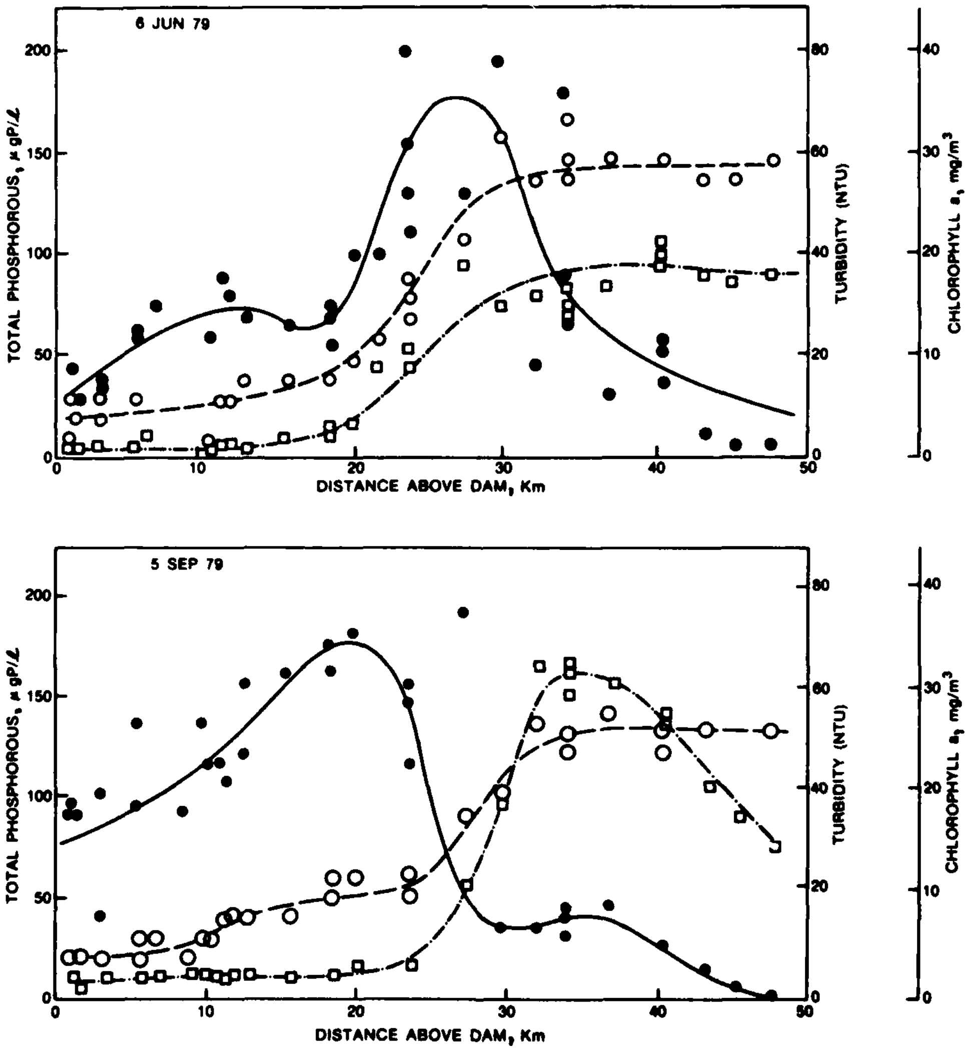


Figure 30. Relationships between surface chlorophyll *a* (● and --), total phosphorus (o and --), and turbidity (□ and -●-) with distance from dam on 6 June and 5 September 1979 for West Point Lake

patterns in water quality would be reflected in the distributional patterns for the sediment characteristics.

96. While trends in particle size, moisture content, and chemical composition are observed in the Chattahoochee section sediments of West Point Lake, the sediments of the reservoir as a whole may also be characterized by factors other than their location with respect to the dam. For instance, Hakanson (1977) indicates that sediment differences in Lake Vanern were a function of depth, moisture content, and particle size. These three factors are interrelated: deepest sediments should have (a) the smallest mean particle size as a result of sediment redistribution and (b) the highest moisture content because moisture content is inversely proportional to particle size. Hakanson also found higher concentrations of nutrients and metals in deep sediments than in shallow sediments. Thus, differentiating sediments by depth, moisture content, or particle size rather than by distance to the dam may provide a clearer picture of depositional patterns in West Point Lake.

97. Sediment data were first divided into two groups based on whether they were taken above or below the 9-m depth contour. The 9-m depth was chosen because it served to separate the data into approximately equal sample sizes (deep, $n = 30$; shallow, $n = 24$). Mean depths for deep and shallow sediments were 12.1 ± 3.4 and 5.2 ± 2.1 m, respectively. No significant differences between the sediments of these two groups were found (Student's t test $\alpha = 0.05$). The lack of depth differences suggests that depth did not influence sediment distribution in West Point Lake.

98. Hakanson (1977) reported that surficial sediments (0-1 cm) in areas characterized as "accumulation regions" had moisture contents of 75 percent or greater, while deeper sediments (9-10 cm) in the same regions had moisture contents around 65 percent. In 10-cm sediment cores from accumulation regions, moisture content should fall between the values given by Hakanson; therefore, a moisture content of 70 percent or greater was used to separate high moisture content sediments from those with low moisture content. If these high moisture content sediments were associated with areas of sediment accumulation, they

should be (a) characterized by a smaller median particle size and higher concentrations of most chemical constituents and (b) found at a relatively greater depth than sediments with a low moisture content.

99. West Point sediments with high moisture content were located at greater depths, had a smaller median particle size, and were relatively enriched with total organic carbon, nitrogen, phosphorus, and iron (Table 12). Sediment manganese and total inorganic carbon, as well as all interstitial constituents, show no significant differences between the two groups. These results suggest that high moisture content sediments may have been accumulation regions, which are sites of deposition. Because of their greater surface area and higher concentration of organic substrates, sediment particles in these areas would have been sites of increased biological and chemical activity.

Table 12

Mean Values for West Point Sediments with High (≥70%) or Low (<70%) Moisture Contents

Variable	High*	Low*	p**
Depth, m	9.98	6.66	<0.05
Median particle size, μm	13.6	20.2	<0.05
Total organic carbon, mg/g	25.8	14.7	<0.001
Total nitrogen, mg/g	1.80	1.18	<0.05
Total phosphorus, mg/g	1.70	1.01	<0.001
Total iron, mg/g	56.2	41.5	<0.001
Fe:P	36.1	53.7	<0.05

* Number of observations on which calculations are based: high moisture content, n = 33 ; low moisture content, n = 19 .
** Probability that means are equal.

100. Correlations between percent volume in each particle size class and various chemical characteristics suggest that smaller particles were associated with sediment concentrations of nutrients and metals (Table 13). Based on the correlation matrix, sediments from West Point Lake can be divided into two groups: (a) small particle size

Table 13

Significant ($p \leq 0.05$) Correlation Coefficients for All West Point Stations

(Particle Size Values are Midpoints of Size Ranges

Variable	Particle Size (µm) 150	106	75	53	38	27	19	13	9.4	6.6	4.7	3.3	2.4	Moisture Content
Interstitial chemical composition														
Total inorganic carbon	NS*	NS	NS	0.28	0.31	0.41	NS	NS	NS	NS	-0.30	NS	-0.33	NS
Total organic carbon	NS	NS	0.28	0.35	0.38	0.39	NS	-0.32	NS	-0.36	-0.38	-0.33	-0.43	NS
Nitrate nitrite nitrogen	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ammonium nitrogen	NS	NS	NS	NS	NS	0.32	NS	NS	NS	NS	NS	NS	NS	NS
Total nitrogen	NS	NS	NS	NS	NS	0.31	NS	NS	NS	NS	NS	NS	NS	NS
Soluble reactive phosphorus	NS	NS	NS	0.29	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total phosphorus	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total iron	NS	NS	0.30	0.31	0.39	0.44	NS	NS	NS	-0.29	-0.33	-0.31	-0.37	NS
Total manganese	NS	NS	NS	NS	0.30	0.42	NS	NS	NS	NS	NS	NS	-0.26	NS
Sediment chemical composition														
Total inorganic carbon	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total organic carbon	-0.34	-0.36	-0.38	NS	NS	NS	0.39	0.43	0.30	NS	NS	NS	NS	0.69
Total nitrogen	-0.41	-0.45	NS	-0.31	NS	NS	NS	0.37	0.29	0.26	0.35	0.37	0.32	0.53
Total phosphorus	-0.37	-0.47	-0.28	-0.41	-0.27	NS	NS	0.42	0.42	0.40	0.43	0.41	0.31	0.54
Total iron	-0.30	-0.33	NS	-0.44	NS	NS	NS	0.41	0.29	0.38	0.45	0.41	0.39	0.70
Total manganese	NS	NS	NS	-0.44	NS	-0.34	NS	NS	NS	NS	0.31	0.31	NS	NS
Moisture content	-0.38	-0.42	-0.30	-0.30	NS	NS	NS	0.43	0.37	0.29	0.36	0.36	NS	NS
Column depth	NS	-0.28	-0.40	-0.33	-0.33	-0.38	NS	0.35	0.32	0.43	0.46	0.38	0.36	0.37
Distance to shore	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.34
Distance to dam	NS	NS	NS	NS	NS	0.28	NS	NS	NS	NS	NS	NS	NS	NS

* NS = correlation was not significant.

(median diameter $\leq$ 13 μm) and (b) large particle size (median diameter > 13 μm). These two groups differed significantly (Student's t test $\alpha = 0.05$) in their moisture contents and in all chemical variables associated with sediment (Table 14). As was indicated by the correlation, sediments with a smaller median particle size had a higher moisture content and were relatively enriched in those variables directly associated with particulate matter.

Table 14

Mean Values for West Point Sediments with Median Particle Size ≤13 μm and >13 μm

Variable	≤13 μm*	>13 μm*	p**
Moisture content, %	79.3	58.6	<0.05
Total organic carbon, mg/g	23.8	15.7	<0.05
Total nitrogen, mg/g	1.71	1.15	<0.05
Total phosphorus, mg/g	1.56	1.11	<0.05
Total iron, mg/g	53.7	42.4	<0.05
Total manganese, mg/g	1.39	1.03	<0.05

* Number of observations on which calculations are based: median particle size ≤13 μm, n = 39 ; median particle size >13 μm, n = 13 .
** Probability that means are equal.

101. Preimpoundment conditions may affect sediment depositional patterns in many reservoirs (Batten and Hindall 1980). Areas where flow is influenced by constrictions may be intermittently scoured during periods of high flow. Sediments of these areas would therefore tend to have a larger median particle size and a lower moisture content. Sediments in West Point Lake characterized by a median particle size greater than 13 μm or a moisture content less than 70 percent are shown in Figure 31. These areas, with the exception of two cove stations and two stations below Maple Creek, were closely associated with existing bridges, submerged roads, or submerged islands (Figure 32). The presence of bridge abutments, old roadbeds, and submerged islands may, in addition to having potentially different geologic characteristics, have acted to

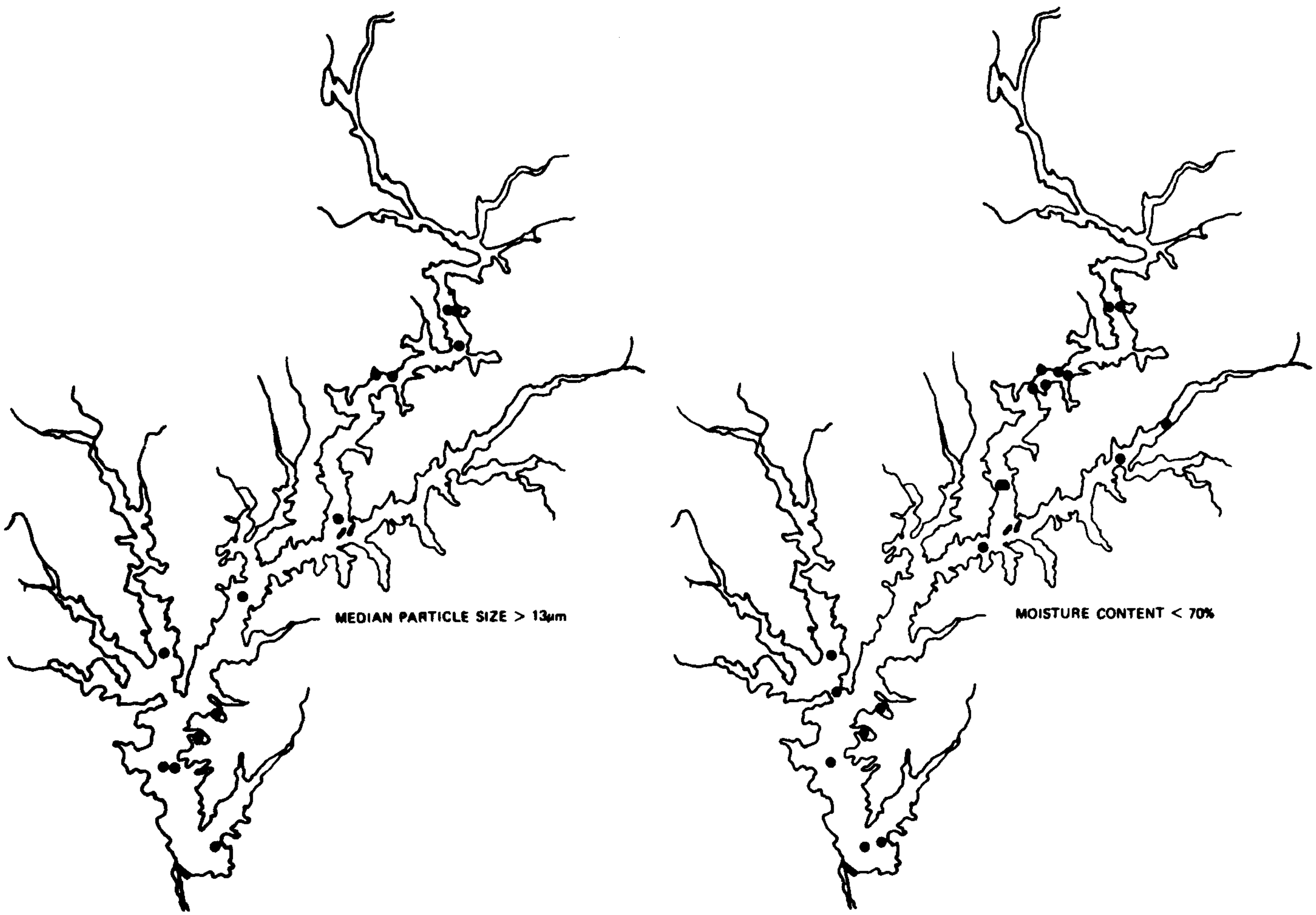


Figure 31. Stations in West Point Lake with a median particle size greater than 13 μm (left) and stations with moisture content less than 70 percent (right)

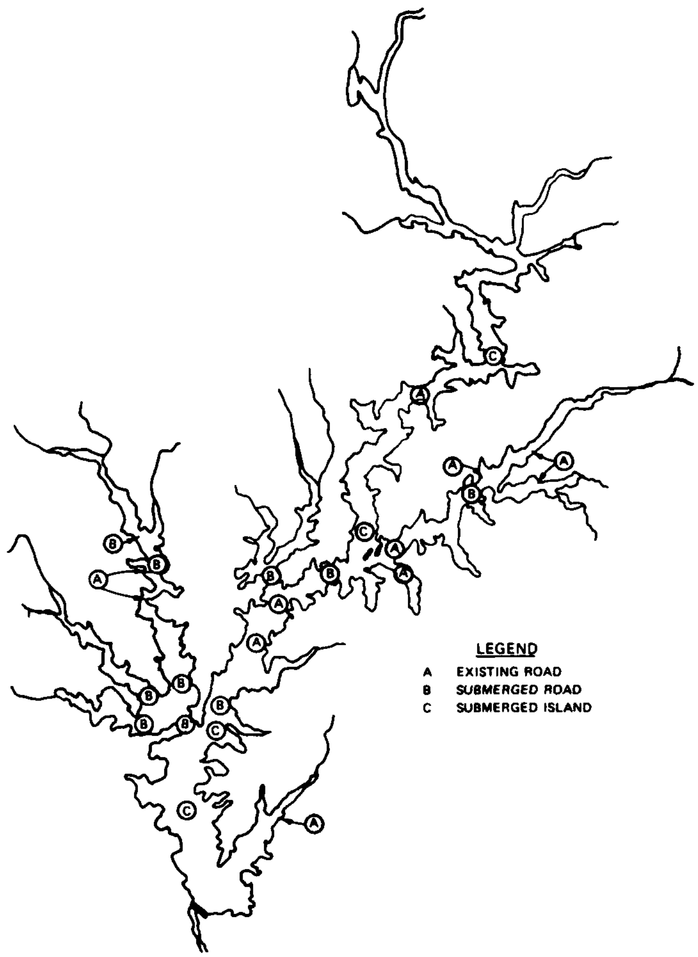


Figure 32. Locations of bridges, submerged roads and submerged islands for West Point Lake

restrict flow to certain channels thereby producing enough force to resuspend fine particulate matter deposited during periods of low flow.

102. Distribution and chemical composition of sediments in West Point Lake tended to be determined primarily by distance from headwater, but were also significantly affected by tributary inputs, patterns in water quality, and preimpoundment conditions. The reservoir section between Yellowjacket and Wehadkee Creek embayments appears to have been a major zone of accumulation. Differences between these areas and other areas of the reservoir may become more pronounced with time.

Comparative Analyses of DeGray, Eau Galle, and West Point Lakes

103. Sediment and interstitial water data for DeGray, West Point, and Eau Galle, the reservoirs for which the most complete data were available, were considered collectively to determine similarities and differences in sedimentary patterns. Since these reservoirs differed with respect to water quality, hydrology, watershed characteristics, morphology, and project operations, differences in sediment characteristics are expected. Conversely, between-reservoir similarities in the relative importance of such factors as resuspension, advective transport, and preimpoundment characteristics may allow formulation of generalizations concerning common influences on sediment depositional patterns in these and other reservoirs.

Physical analyses

104. The relative proportions of particle sizes composing sediments at any particular location reflect both the size distribution of particles originally supplied to the sediment and the occurrence of processes ultimately affecting their deposition (Friedman and Sanders 1978). Therefore, comparisons of the characteristics of particle size frequency distributions between reservoirs provide a simple means for evaluating depositional characteristics. The shape of frequency distributions for particle size, which can be described by mean, skew, and kurtosis, provides an indication of sediment sorting. Skew, which describes the relationship between the mean and median of the distribution, is an index to the symmetry of a distribution. For example, the distributions of sediments predominated by either small or large particles will have either positive or negative values of skewness, respectively. Symmetrical distributions, which have zero skewness, may also be described by kurtosis, or the degree of peakedness relative to a normal distribution. The normal distribution has a kurtosis value of 3, while a more "peaked" or leptokurtic distribution will have kurtosis value greater than 3, a more even or platykurtic distribution will have a kurtosis value less than 3; thus, kurtosis provides a measure of sorting for nonskewed

distributions. Another sorting statistic is the standard deviation of the particle size distribution based on the phi scale (phi = $\log_2$ diameter, mm). Friedman and Sanders (1978) suggest that a sorting value less than 1.4 indicates a moderately-to-well sorted particle distribution, while values greater than 1.4 represent poorly sorted sediments.

105. Moisture content has been proposed by Hakanson (1977) as a relatively consistent measure or indicator of sediment type. He reported that sediment moisture content reflects the energy environment influencing the deposition of particulate matter. High-energy environments (e.g., the littoral zone) are dominated by transport processes and are characterized by a low (<70 percent) moisture content and a dominance of large particle sizes. Low-energy environments (e.g., the deepest portions of the basin) are less susceptible to resuspension and transport by turbulence, which would act to selectively remove smaller particles; as a result, these areas are dominated by accumulation. Accumulation zones are characterized by high ($\geq$70 percent) moisture content and small particle size. The dominance by small particles in the deeper portions of the basin is the result of fine particulate matter transported from the littoral and its preferential deposition in the deeper areas (Davis and Brubaker 1973, Davis 1973).

106. Based on Hakanson's (1977) observations, the pooled sediment data were separated into high ($\geq$70 percent) and low (<70 percent) moisture content sediments. Particle size distributions for the two sediment types were significantly different ($p \leq 0.05$), with smaller size classes representing a larger proportion of the total volume in the high moisture content sediments (Figure 33). High moisture content sediments for the three lakes had a smaller mean particle size, were better sorted, and more closely approached the normal distribution (Table 15). The particle size distributions did not have significantly different values for skew. Neither of the two sediment types had a skewness that was significantly different than zero ($p \leq 0.05$), which indicates that both distributions are symmetric about their respective means. Both low and high moisture content sediments deviated from the normal distribution, and sediment particle size distributions were platykurtic. The kurtosis

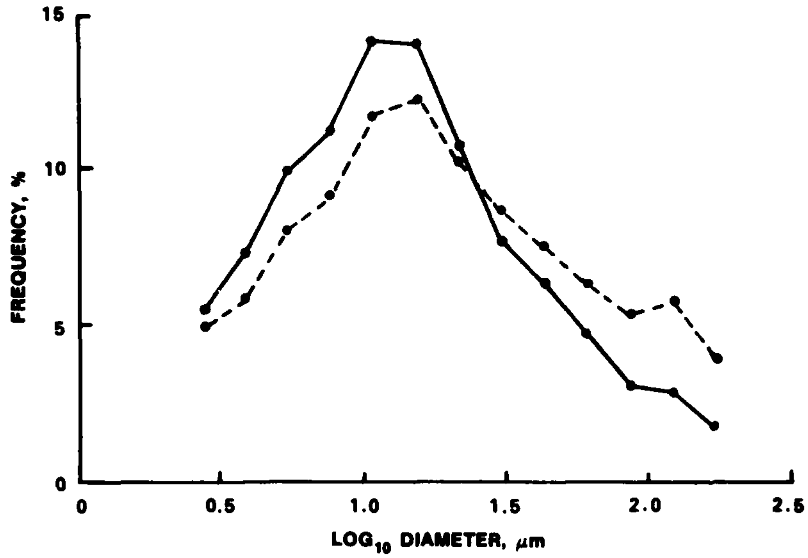


Figure 33. Particle size distribution curves of high moisture content (solid line) and low moisture content (dashed line) sediments for pooled data from DeGray, Eau Galle, and West Point Lakes

Table 15

Statistical Values for Evaluating Sediment Particle Size Distribution Relative to High (≥70%) or Low (<70%) Moisture Contents for Pooled Data from DeGray, Eau Galle, and West Point Lakes

	High*	Low*	p**
Mean particle size, μm	13.0	16.9	<0.01
Sorting statistic	1.33	1.48	<0.001
Skew	-0.032	0.049	NS†
Kurtosis	2.36	2.27	<0.05

* Number of observations on which calculations are based: high moisture content, n = 43 ; low moisture content, n = 62 .

** Probability that means are equal.

† Nonsignificant difference (p > 0.05).

value of high moisture content sediments indicates that the particle size distribution of these sediments was relatively more "peaked" than that of low moisture content sediments.

107. Differences in sediment moisture content and particle size distribution are thought to be a function of the local energy environment (Hakanson 1977); depth should be a major determinant of the energy environment of most lakes. The pooled sediment data were divided into two groups based on their depth relative to the average thermocline depth. Sediments located at depths above the thermocline should represent sediments of a high-energy environment relative to sediments found at depths below the thermocline. If the energy environments were different, the moisture content and particle size distributions should reflect these differences.

108. The particle size distribution of sediments located at depths below the thermocline in DeGray, Eau Galle, and West Point Lakes was significantly different than that of sediments located above the thermocline (Figure 34). Sediments below the thermocline had a smaller

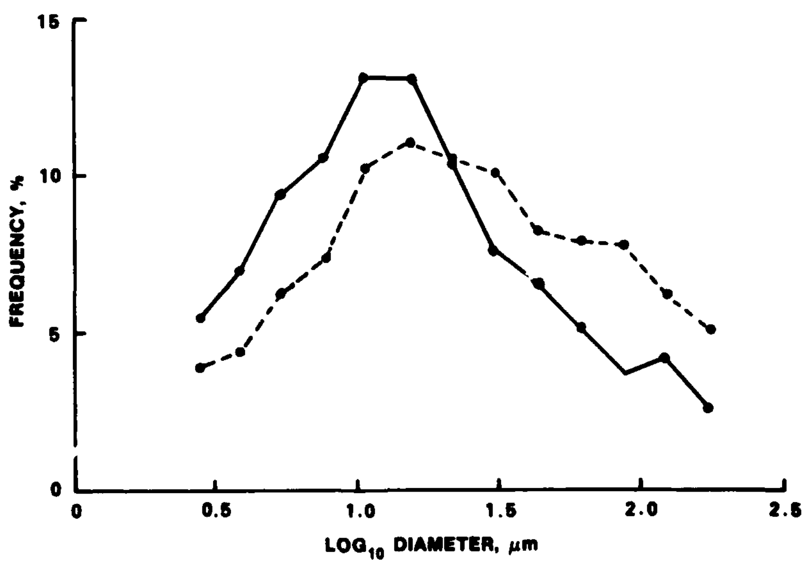


Figure 34. Particle size distribution curves of sediments below (solid line) and above (dashed line) the thermocline for pooled data from DeGray, Eau Galle, and West Point Lakes

Table 16

Statistical Values for Evaluating Sediment Particle Size Distribution Relative to Depth (Below or Above Thermocline) for Pooled Data from DeGray, Eau Galle, and West Point Lakes

	Below*	Above*	p**
Mean particle size, μm	14.2	20.5	<0.001
Sorting statistic	1.38	1.57	<0.05
Skew	-0.002	0.127	<0.05
Kurtosis	2.33	2.2	<0.05
Moisture content, %	70.0	46.3	<0.001

* Number of observations on which calculations are based: below thermocline, n = 100 ; above thermocline, n = 23 .
** Probability that means are equal.

mean size, were better sorted, and had a more peaked distribution than shallower sediments (Table 16). Particle size distribution of these deeper sediments was symmetric about the mean (i.e., skew was not significantly different from zero). Moisture content of the deeper sediments was significantly higher than for the shallow sediments. Particle size distribution and moisture content differences indicate that the average thermocline depth can serve to separate two significantly different energy environments.

109. In most natural lakes, depth is expected to be the major determinant of the local energy environment. However, depth may not be the only factor determining energy environments in man-made reservoirs. Reservoirs such as DeGray and West Point, which are long, relatively narrow, and dominated by advective transport processes, usually exhibit longitudinal gradients in sediment accumulation and particle size distribution. Sediment accumulation in this type of impoundment should be greatest near the tributary inflow, and mean particle size should decrease with distance since carrying capacity decreases as the reservoir becomes progressively wider and deeper.

110. Sediment data from DeGray and West Point were pooled to examine the effect of distance from the headwaters on particle size

distribution and moisture content. Sediments collected in the embayments of these two reservoirs were excluded from this analysis in order to consider only those sediments in the sections dominated by advective transport. Sediments from Eau Galle were excluded from the analysis because it did not appear to be an advectively dominated reservoir.

111. Significant correlations between either particle size distribution or moisture content and distance were not found. The lack of significant relationships between particle size distribution and distance may be due to the confounding influence of preimpoundment conditions and tributary inputs. This was particularly true in West Point Lake where large particle size sediments in downstream areas were associated with the presence of bridge abutments and submerged islands and roads. Also, the inputs from Yellowjacket and Wehadkee Creeks apparently influenced particle size distribution immediately downstream. Thus, while distance from the major inflow is a major factor determining energy environment along the length of a reservoir, these data suggest that more localized factors also affect the energy environment and, as a result, particle size distribution.

Chemical analysis

112. Sediment concentrations of all measured nutrients and metals exhibited significant differences between high and low moisture content sediments (Table 17). Concentrations of sediment organic carbon, nitrogen, phosphorus, iron, and manganese were 1.2-2.0 times higher in high moisture content sediments than in sediments with a low moisture content; concentration of total inorganic carbon is approximately two times higher in low moisture content sediments. Shallow sediments (low moisture content) should be enriched with inorganic carbon relative to deep sediments (high moisture content) because the deposition of carbonates in deeper regions is prevented by the presence of aggressive CO_2 in the hypolimnion.

113. These observations are consistent with those for Lake Vanern, Sweden. Hakanson (1977) found concentrations of organic matter, nitrogen, and phosphorus in high moisture content sediments that were 1.5-5.5 times higher than those of low moisture content sediments. Therefore, differences in moisture content are associated with

Table 17

Mean Values of Interstitial and Sediment Variables Relative to High (≥70%) or Low (<70%) Moisture Content for Pooled Data from DeGray, Eau Galle, and West Point Lakes

Variable	High*	Low*	p**
Interstitial chemical composition, mg/L			
Soluble reactive phosphorus	0.122 (40)	0.179 (50)	<0.05
Total phosphorus	0.138 (42)	0.201 (53)	<0.01
Total inorganic carbon	33.5 (42)	39.8 (53)	NS†
Total organic carbon	8.45 (42)	9.35 (57)	NS
Nitrate nitrite nitrogen	0.006 (42)	0.008 (53)	NS
Ammonium nitrogen	5.98 (42)	6.35 (53)	NS
Total nitrogen	6.45 (42)	7.03 (53)	NS
Total iron	18.1 (42)	11.0 (57)	NS
Total manganese	7.11 (42)	5.67 (57)	NS
Sediment chemical composition, mg/g			
Total inorganic carbon	0.85 (43)	1.92 (61)	<0.05
Total organic carbon	26.8 (43)	17.1 (62)	<0.001
Total nitrogen	1.98 (43)	1.67 (62)	<0.05
Total phosphorus	1.54 (43)	0.77 (62)	<0.001
Total iron	49.6 (43)	25.9 (62)	<0.001
Total manganese	1.34 (43)	0.98 (62)	<0.05

* Values in parenthesis are the number of observations on which calculations are based.
** Probability that means are equal.
† Nonsignificant differences ($p > 0.05$).

significant differences in the concentration of nutrients and metals. These differences are in turn related to differences in energy environment.

114. Generally, interstitial concentrations of nutrients and metals in the three lakes were not significantly different when high and low moisture content sediments were compared (Table 17). Only phosphorus (total and soluble reactive) concentration was significantly higher in the interstitial water of low moisture content sediments than in that of high moisture content sediments. The general lack of significant differences for interstitial concentrations of nutrients and metals is unexpected, given the observed differences in sediment concentrations. Differences in sediment concentrations should result in differences in interstitial concentrations, but this is not supported by the data. Correlations between sediment and interstitial concentrations were generally low or not significant (Table 18). This may have been due to the fact that sediment concentrations are the result of accumulation over a relatively long period of time, whereas interstitial concentrations reflect the conditions at the time of sampling. This suggestion is supported by the observation that concentrations of interstitial nutrients and metals were more highly correlated with interstitial inorganic carbon than with the concentrations of their sediment counterparts (Table 19). Since interstitial concentration of inorganic carbon is a function of biological and chemical activity (e.g., respiration, decomposition, and redox reactions) at the time of sampling, the relative magnitude of those activities determines interstitial concentrations of nutrients and metals rather than their concentrations in the sediment.

115. The pooled sediment data for the three lakes were separated with respect to depth relative to the thermocline. If the separation delineates two different energy environments, significant chemical differences should be apparent; i.e., sediments at depths below the thermocline should have been enriched with nutrients and metals relative to sediments located above the thermocline.

116. Generally, sediment concentrations for the two depth

Table 18

Correlation Coefficients Between Sediment and Interstitial Concentrations for Pooled Data from DeGray, Eau Galle, and West Point Lakes

	r*	n**	p†
Total inorganic carbon	0.47	95	<0.001
Total organic carbon	NS††	100	NS
Total nitrogen	0.39	96	<0.001
Total phosphorus	NS	96	NS
Total iron	0.24	100	<0.05
Total manganese	0.27	100	<0.01

* Correlation coefficient.
** Number of observations used to calculate the coefficient.
† Probability of the correlation.
†† Nonsignificant difference ($p > 0.05$).

Table 19

Correlation Coefficients Between Interstitial Total Inorganic Carbon (TIC) and Interstitial Nutrients and Metals for Pooled Data from DeGray, Eau Galle, and West Point Lakes

Variable	TIC	n*	p**
Nitrate nitrite nitrogen	0.30	99	<0.01
Ammonium nitrogen	0.90	99	<0.001
Total nitrogen	0.90	99	<0.001
Soluble reactive phosphorus	0.26	94	<0.01
Total phosphorus	0.24	99	<0.01
Total iron	0.69	98	<0.001
Total manganese	0.70	98	<0.001
Total organic carbon	0.71	99	<0.001

* Number of observations used to calculate the coefficient.
** Probability of the correlation.

Table 20

Mean Values of Interstitial and Sediment Variables Relative to Depth (Below or Above Thermocline) for Pooled Data from DeGray, Eau Galle, and West Point Lakes

Variable	Below*	Above*	p**
Interstitial chemical composition, mg/L			
Total inorganic carbon	30.6 (80)	67.7 (16)	<0.001
Total organic carbon	8.6 (83)	10.7 (17)	NS†
Nitrate nitrite nitrogen	0.007 (80)	0.006 (16)	NS
Ammonium nitrogen	5.43 (80)	9.69 (16)	NS
Total nitrogen	6.1 (80)	10.1 (16)	NS
Soluble reactive phosphorus	0.152 (75)	0.156 (16)	NS
Total phosphorus	0.173 (80)	0.17 (16)	NS
Total iron	14.0 (83)	13.5 (17)	NS
Total manganese	6.45 (83)	5.8 (17)	NS
Sediment chemical composition, mg/g			
Total inorganic carbon	0.94 (86)	3.83 (19)	<0.005
Total organic carbon	22.2 (87)	15.4 (19)	<0.01
Total phosphorus	1.16 (87)	0.75 (19)	<0.001
Total iron	37.4 (87)	26.3 (19)	<0.05
Total manganese	1.2 (87)	0.76 (19)	<0.001
Total nitrogen	1.85 (87)	1.52 (19)	NS
Moisture content, %	70.0 (86)	46.3 (19)	<0.001

* Values in parenthesis are the number of observations on which calculations are based.
** Probability that means are equal.
† Nonsignificant differences ($p > 0.05$).

categories were significantly different (Table 20); only total nitrogen was not. Concentrations of organic carbon, phosphorus, iron, and manganese were approximately 1.5 times higher in sediments below the thermocline than in those located above the thermocline. Total inorganic carbon was over four times higher in shallower sediments and is the result of the lack of inorganic carbon deposition in deeper sediments discussed in paragraph 112. As with the data partitioned with respect to moisture content (see paragraph 114), interstitial concentrations were generally not significantly different between the depth categories.

117. Although longitudinal gradients in moisture content and particle size distribution were not found in the pooled data from DeGray and West Point, longitudinal gradients in water quality characteristics are commonly observed in reservoirs and may be expected to generate similar gradients in the chemical composition of sediments and interstitial waters. Sediment chemical composition in these two lakes was generally not correlated with distance, while interstitial concentrations of most nutrients and metals decreased from headwaters to dam (Table 21). Total organic carbon was the only sediment variable significantly correlated with distance and increased from headwaters to dam. The lack of significant longitudinal gradients in sediment composition is not unexpected, given a similar lack of differences in particle size distribution and moisture content. The data suggest that depth and possibly more localized morphometric influences acted to determine sediment composition and quality. The observed longitudinal gradients for interstitial nutrients and metals may have been the result of longitudinal gradients in sediment redox potentials that existed at the time of sampling. The development of anoxia in the hypolimnion of a reservoir has been observed to proceed from headwater to dam (Hannan 1984) and would lead to the development of a redox potential gradient.

Summary

118. In the pooled sediment data from Eau Galle, DeGray, and West Point Lakes, moisture content is a relatively simple and efficient indicator of sediment composition and quality. Moisture content differences are related to significant differences in particle size distribution and

chemical composition and may serve to separate sediments from differing energy environments. Interstitial concentrations are not significantly different based on differences between high and low moisture content sediments or their energy environments. Interstitial concentrations may reflect redox conditions at the time of sampling.

Table 21

Correlation Coefficients Between Distance to Dam, and Interstitial and Sediment Variables for Pooled Data from DeGray and West Point Lakes

Variable	Distance to Dam	n*	p**
Interstitial chemical composition			
Total inorganic carbon	-0.46	52	<0.001
Total organic carbon	-0.31	54	<0.05
Ammonium nitrogen	-0.38	52	<0.01
Total nitrogen	-0.39	52	<0.05
Soluble reactive phosphorus	-0.33	48	<0.05
Total phosphorus	-0.39	52	<0.01
Total iron	-0.39	54	<0.01
Total manganese	-0.38	54	<0.01
Nitrate nitrite nitrogen	NS†	52	NS
Sediment chemical composition			
Total organic carbon	0.29	58	<0.05
Total inorganic carbon	NS	58	NS
Total phosphorus	NS	58	NS
Total nitrogen	NS	58	NS
Total iron	NS	58	NS
Total manganese	NS	58	NS

* Number of observations used to calculate the coefficient.
** Probability of the correlation.
† Nonsignificant difference ($p > 0.05$).

PART V: CONCLUSIONS

119. Sediment transport, distribution, and deposition adversely impacts reservoir operation. Not only does the physical accumulation of sediments affect reservoir longevity, the quality and quantity of the sediments also influence reservoir water quality. This report has characterized the physical and chemical condition of sediments in four CE reservoirs and identified factors that influence sediment distribution and quality. These include reservoir morphological and hydrological characteristics, preimpoundment conditions, and water quality.

120. Lakes Red Rock, DeGray, and West Point are classified as flow-dominated systems. Typically, these types of reservoirs have an upper riverine zone exhibiting high-flow velocities and turbulence. Velocity and turbulence decrease as the reservoir widens and deepens, resulting in a decreased carrying capacity for particulate matter. This decreased carrying capacity results in the establishment of longitudinal gradients in sediment accumulation. Particle sorting can also occur along the length of the reservoir. This expected longitudinal gradient in sediment particle size and accumulation was best exhibited in Lake Red Rock. In DeGray and West Point Lakes, longitudinal gradients were confounded by preimpoundment conditions and the entrance of secondary tributaries. Also important were bridge abutments, submerged roads, and islands which apparently constricted flow enough to produce sufficient force to resuspend and transport fine particulate matter. Although less pronounced, gradients in sediment quality in DeGray and West Point Lakes corresponded with those observed for water quality.

121. Unlike the three other reservoirs considered, sediment depositional patterns in Eau Galle Lake appear to have been most influenced by morphometry. A circular shape, multiple inflows, and a deep, central basin had the combined effect of promoting sediment focusing. As a result, depositional patterns and sediment quality in this reservoir were depth related.

122. In general, two sedimentary zones can be distinguished within a reservoir: (a) a transport zone, which is characterized as a

AD-A140 750 A COMPARATIVE STUDY OF SEDIMENT QUALITY IN FOUR RESERVOIRS(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIRONMENTAL LAB 2/2

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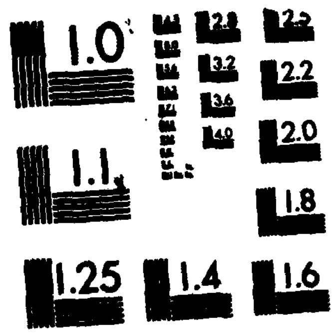

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high-energy environment dominated by turbulent processes (e.g., flow, pool fluctuation, wind), and (b) an accumulation zone, which is characterized as a low-energy environment. For reservoirs receiving a majority of their water and material loads from a single, large tributary, upstream sediments are continually perturbed by high flows and changes in flow. The high energy or turbulent nature of these areas discourages the permanent deposition of fine particulates. As a result, sediments in these areas are characterized as having relatively larger median particle sizes and low moisture contents. Similar conditions exist in shallow, littoral areas and/or near constrictions of the reservoir basin.

123. Conditions in deeper, less turbulent areas of the reservoir provide a different sedimentary environment. These are areas of accumulation. Since larger suspended particles are often deposited in shallower upstream areas, sediments in areas of accumulation are characteristically higher in moisture content and are composed of relatively smaller particles.

124. Coincident with differences in moisture content and particle size are differences in sediment chemical characteristics. In general, sediments in accumulation areas are higher in nutrients, metals, and organic matter. These sediments may therefore be more likely to influence water quality through exchanges at the sediment/water interface. Patterns in interstitial water quality are less obvious and appear to be more influnced by local redox conditions than by sediment quality.

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APPENDIX A: PARTICLE SIZE AND CHEMISTRY DATA FOR RED ROCK, DEGRAY, EAU GALLE, AND WEST POINT LAKES

Glossary of SAS Variable Names Used in Tables A1-A7

CH__2__4 through CH__150. Center of the channel range in micrometers (i.e., 2.4 through 150 μm); values within each range are percents of total volume

CLAY. Percent clay

COLDEPTH. Depth of water column at time of sampling, m

CSURAREA. Calculated mean specific surface area, m^2/cm^3

DISTDAM. Distance to dam, km; DeGray and Eau Galle are linear measurements, and West Point was measured along the thalweg

IFE. Interstitial total iron, mg/L

IMN. Interstitial total manganese, mg/L

INH4N. Interstitial ammonium nitrogen, mg/L

INO3NO2N. Interstitial nitrate nitrite nitrogen, mg/L

ISRP. Interstitial soluble reactive phosphorus, mg/L

ITIC. Interstitial total inorganic carbon, mg/L

ITN. Interstitial total nitrogen, mg/L

ITOC. Interstitial total organic carbon, mg/L

ITP. Interstitial total phosphorus, mg/L

MC. Sediment moisture content, %

MTPCT__90, MTPCT__50, and MTPCT__10. Value in micrometers at 90th, 50th, and 10th percentiles of the volume distribution

ORGANIC. Percent organic matter

SAMNO. Number of replicate sample taken in the field

SAND. Percent sand

SFE. Sediment total iron, mg/g

SILT. Percent silt

SMN. Sediment total manganese, mg/g

STATION. Station identification

STIC. Sediment total inorganic carbon, mg/g

STN. Sediment total nitrogen, mg/g

STOC. Sediment total organic carbon, mg/g

STP. Sediment total phosphorus, mg/g

SUBSAMNO. Number of split sample analyzed in laboratory

TRANS. Transect identification

UCSAMVOL. Uncalibrated sample volume

VOLMEAND. Mean diameter of the volume distribution, micrometers

Table A1

Sediment Data, Red Rock

TRANS	STATION	SAMNO	SUBSAMNO	SAND	SILT	CLAY	ORGANIC
1	A	1	1	7.5	32.5	60.0	7.7
1	A	1	2	15.0	25.0	60.0	.
1	A	2	1	5.0	32.5	62.5	8.3
1	A	2	2	5.0	32.5	62.5	.
1	A	3	1	42.5	17.5	40.0	4.9
1	A	3	2	47.5	15.0	37.5	.
1	B	1	1	7.5	30.0	62.5	9.6
1	B	1	2	7.5	27.5	65.0	.
1	C	1	1	17.5	27.5	55.0	7.8
1	C	1	2	17.5	30.0	52.5	.
1	D	1	1	12.5	30.0	57.5	9.0
1	D	1	2	17.5	22.5	60.0	.
1	E	1	1	7.5	25.0	67.5	9.0
1	E	1	2	12.5	27.5	60.0	.
1	F	1	1	10.0	25.0	65.0	9.4
1	F	1	2	15.0	22.5	62.5	.
2	A	1	1	27.5	42.5	30.0	7.1
2	A	1	2	37.5	32.5	30.0	.
2	B	1	1	47.5	35.0	17.5	3.6
2	B	1	2	50.0	32.5	17.5	.
2	B	2	1	52.5	27.5	20.0	3.4
2	B	2	2	52.5	30.0	17.5	.
2	B	3	1	50.0	32.5	17.5	3.5
2	B	3	2	52.5	30.0	17.5	.
2	C	1	1	32.5	37.5	30.0	4.8
2	C	1	2	32.5	37.5	30.0	.
2	D	1	1	22.5	12.5	65.0	9.6
2	D	1	2	17.5	22.5	60.0	.
2	E	1	1	15.0	37.5	47.5	7.3
2	E	1	2	20.0	37.5	42.5	.
3	A	1	1	10.0	32.5	57.5	9.4
3	A	1	2	20.0	27.5	52.5	.
3	B	1	1	0.0	32.5	67.5	9.3
3	B	1	2	0.0	32.5	67.5	.
3	C	1	1	10.0	37.5	52.5	8.9
3	C	1	2	12.5	37.5	50.0	.
3	C	2	1	7.5	40.0	52.5	8.6
3	C	2	2	17.5	32.5	50.0	.
3	C	3	1	2.5	37.5	60.0	8.5
3	C	3	2	15.0	32.5	52.5	.
3	D	1	1	22.5	45.0	32.5	3.9
3	D	1	2	22.5	42.5	35.0	.
3	E	1	1	17.5	40.0	42.5	7.8
3	E	1	2	22.5	40.0	37.5	.
4	A	1	1	12.5	40.0	47.5	7.9
4	A	1	2	7.5	45.0	47.5	.
4	A	2	1	5.0	45.0	50.0	8.1
4	A	2	2	15.0	37.5	47.5	.
4	A	3	1	17.5	37.5	45.0	8.3
4	A	3	2	22.5	35.0	42.5	.
4	B	1	1	15.0	57.5	27.5	6.2
4	B	1	2	15.0	55.0	30.0	.
4	C	1	1	15.0	42.5	42.5	7.2
4	C	1	2	20.0	42.5	37.5	.
4	D	1	1	27.5	32.5	40.0	6.9
4	D	1	2	32.5	27.5	40.0	.
4	E	1	1	5.0	35.0	60.0	9.6
4	E	1	2	7.5	32.5	60.0	.
5	A	1	1	7.5	50.0	42.5	7.7
5	A	1	2	10.0	50.0	40.0	.
5	B	1	1	10.0	50.0	40.0	6.5
5	B	1	2	10.0	50.0	40.0	.
5	C	1	1	12.5	47.5	40.0	7.6
5	C	1	2	10.0	50.0	40.0	

(Continued)

Table A1 (Concluded)

TRANS	STATION	SAMNO	SUBSAMNO	SAND	SILT	CLAY	ORGANIC
5	C	2	1	2.5	37.5	60.0	8.6
5	C	2	2	5.0	40.0	55.0	
5	D	1	1	0.0	57.5	42.5	5.7
5	D	1	2	0.0	55.0	45.0	
5	E	1	1	0.0	47.5	52.5	8.5
5	E	1	2	2.5	47.5	50.0	
6	A	1	1	15.0	42.5	42.5	8.2
6	A	1	2	20.0	40.0	40.0	
6	B	1	1	5.0	50.0	45.0	7.8
6	B	1	2	7.5	52.5	40.0	
6	C	1	1	12.5	50.0	37.5	8.1
6	C	1	2	17.5	47.5	35.0	
6	D	1	1	30.0	40.0	30.0	7.5
6	D	1	2	30.0	40.0	30.0	
6	E	1	1	5.0	55.0	40.0	8.2
6	E	1	2	10.0	50.0	40.0	
7	A	1	1	10.0	47.5	42.5	8.2
7	A	1	2	12.5	45.0	42.5	
7	B	1	1	7.5	52.5	40.0	7.3
7	B	1	2	7.5	50.0	42.5	
8	A	1	1	12.5	60.0	27.5	6.4
8	A	1	2	12.5	60.0	27.5	
8	B	1	1	10.0	57.5	32.5	[illegible]
8	B	1	2	10.0	57.5	32.5	
8	D	1	1	15.0	52.5	32.5	5.3
8	D	1	2	15.0	52.5	32.5	
9	A	1	1	17.5	60.0	22.5	4.4
9	A	1	2	20.0	57.5	22.5	
9	B	1	1	35.0	45.0	20.0	3.9
9	B	1	2	32.5	47.5	20.0	
9	C	1	1	20.0	55.0	25.0	4.4
9	C	1	2	12.5	60.0	27.5	
66	A	1	1	10.0	57.5	32.5	5.9
66	A	1	2	10.0	57.5	32.5	
66	B	1	1	10.0	30.0	60.0	8.9
66	B	1	2	10.0	30.0	60.0	
66	C	1	1	7.5	37.5	55.0	7.8
66	C	1	2	7.5	37.5	55.0	
66	D	1	1	0.0	42.5	57.5	8.5
66	D	1	2	2.5	42.5	55.0	
67	A	1	1	5.0	42.5	52.5	8.5
67	A	1	2	5.0	40.0	55.0	
67	B	1	1	5.0	37.5	57.5	8.2
67	B	1	2	5.0	37.5	57.5	
67	C	1	1	10.0	62.5	27.5	3.7
67	C	1	2	12.5	60.0	27.5	
67	D	1	1	0.0	35.0	65.0	8.1
67	D	1	2	0.0	42.5	57.5	
[illegible]	J1	1	1	17.5	57.5	25.0	5.2
[illegible]	J1	1	2	20.0	65.0	15.0	
[illegible]	J2	1	1	10.0	60.0	30.0	6.3
[illegible]	J2	1	2	10.0	60.0	30.0	
[illegible]	J3	1	1	7.5	60.0	32.5	6.9
[illegible]	J3	1	2	7.5	60.0	32.5	
[illegible]	J4	1	1	7.5	60.0	32.5	7.5
[illegible]	J4	1	2	7.5	60.0	32.5	
[illegible]	J5	1	1	7.5	57.5	35.0	6.8
[illegible]	J5	1	2	10.0	55.0	35.0	
[illegible]	J6	1	1	[illegible]	60.0	[illegible]	6.4
[illegible]	J6	1	2	7.5	57.5	35.0	
[illegible]	J7	1	1	10.0	57.5	32.5	4.8
[illegible]	J7	1	2	10.0	60.0	30.0	
[illegible]	[illegible]	1	1	[illegible]	[illegible]	[illegible]	7.9
[illegible]	[illegible]	1	2	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	1	1	[illegible]	[illegible]	[illegible]	6.6
[illegible]	[illegible]	1	2	[illegible]	[illegible]	[illegible]	

Table A2

Sediment Data, DeGray, Particle Size

STATION	CH150	CH106	CH75	CH53	CH38	CH27	CH19	CH13	CH94	CH66	CH47	CH33	CH24	MTPCT90	MTPCT50	MTPCT10	CSURAREA	VOLMEAND	UCSAMVOL
BH2C	0.0	2.6	1.5	5.7	3.9	3.9	10.5	14.9	15.6	12.6	12.6	9.1	6.7	43.7	9.45	3.11	0.837	16.80	0.438
B2B	10.5	15.1	4.0	10.2	4.7	3.7	10.3	11.4	7.3	7.2	7.0	4.1	3.8	126.0	20.80	4.26	0.506	48.30	0.396
B3B	14.6	15.2	12.0	11.5	6.0	6.5	4.7	6.8	6.9	1.1	5.3	5.9	2.9	138.0	48.70	4.14	0.415	60.30	0.493
1B	0.0	0.0	3.2	1.4	5.3	6.4	13.7	17.5	16.0	13.9	10.4	6.8	4.7	31.1	10.40	3.56	0.760	15.10	0.208
10B	1.3	5.0	5.8	6.9	10.2	9.5	9.6	11.1	13.0	9.3	6.9	5.1	5.7	71.2	14.80	3.66	0.630	27.60	0.304
10C	9.3	12.2	9.7	8.9	10.5	9.1	7.2	6.7	8.9	7.0	3.3	3.1	3.5	121.0	31.90	5.46	0.431	49.40	0.222
11C	0.0	0.0	0.0	1.1	2.8	3.6	6.6	13.2	17.4	15.4	16.1	12.8	10.6	19.3	6.94	2.69	1.050	9.73	0.375
12B	0.0	0.0	0.0	0.6	3.4	4.8	7.9	16.2	18.7	15.6	13.7	10.1	8.5	20.9	8.03	2.88	0.956	10.50	0.325
13	0.0	0.0	0.0	0.7	3.2	4.7	8.0	15.1	18.7	15.6	14.1	10.7	8.8	20.7	7.86	2.85	0.974	10.30	0.559
13A	0.0	0.0	0.0	0.7	2.2	4.4	7.7	14.6	19.0	16.0	14.7	11.3	8.9	19.6	7.56	2.82	0.996	9.95	0.424
14C	0.0	1.5	2.4	2.7	6.0	7.8	10.2	14.8	15.6	12.1	11.0	8.3	6.9	36.3	9.97	3.11	0.815	16.40	0.571
15A	0.0	3.4	4.6	4.8	6.4	10.0	11.8	14.9	14.1	9.3	9.0	6.6	4.6	54.0	12.60	3.62	0.680	21.60	0.578
17	0.0	2.9	3.9	3.9	6.0	8.3	12.3	15.6	14.7	10.3	9.4	7.1	5.0	47.4	11.80	3.48	0.715	19.90	0.525
18	1.4	5.2	7.3	7.3	8.2	10.6	11.5	13.6	11.6	8.8	6.3	3.8	3.8	75.2	16.40	4.40	0.557	29.20	0.576
2B	8.1	19.7	2.9	9.1	13.1	7.6	9.0	7.4	8.3	5.7	3.4	3.0	2.0	120.0	33.70	5.99	0.385	51.30	0.292
2C	11.7	18.2	9.3	6.1	10.4	8.1	6.9	7.1	8.0	5.4	2.8	2.8	2.6	130.0	37.80	6.09	0.376	56.90	0.446
20	3.0	3.2	5.6	5.3	8.7	8.7	9.0	11.7	9.6	9.8	10.1	7.0	7.4	70.0	13.00	3.09	0.731	26.50	0.312
21	5.3	7.5	3.3	5.2	6.0	6.8	8.0	10.2	14.1	11.5	8.2	6.3	7.1	100.0	11.90	3.21	0.709	31.00	0.445
22	1.6	3.6	4.2	6.4	11.4	9.2	10.3	11.5	11.2	9.5	8.1	6.0	6.4	60.5	14.10	3.35	0.674	25.50	0.304
23	0.0	1.3	4.1	3.3	4.9	7.5	10.3	13.7	14.2	12.4	11.6	8.3	7.9	40.5	9.81	2.98	0.834	17.10	0.450
24	0.8	3.1	4.2	4.3	7.6	7.9	10.5	13.5	13.8	11.3	9.2	6.7	6.5	53.7	11.60	3.28	0.734	21.70	0.492
25	0.0	0.0	2.3	2.5	7.5	9.3	11.9	14.7	14.8	12.1	10.2	7.4	6.5	35.0	10.60	3.21	0.782	15.80	0.498
26	0.0	1.7	2.9	5.0	11.1	13.1	12.7	15.1	11.5	7.8	8.0	6.0	4.5	43.5	14.40	3.74	0.641	21.00	0.498
27	0.0	0.0	0.0	1.1	5.7	9.3	12.7	16.1	15.9	12.1	11.1	8.5	6.9	27.6	9.86	3.09	0.834	13.00	0.442
28	0.0	0.0	0.0	0.3	3.9	5.7	8.0	13.5	17.0	14.2	14.7	12.1	10.1	22.0	7.52	2.73	1.010	10.30	0.416
29	0.0	0.0	0.0	1.4	3.5	4.9	7.2	12.3	16.2	14.2	15.3	12.7	11.8	21.8	7.01	2.60	1.060	10.30	0.656
30	0.0	0.0	1.2	1.9	4.8	5.9	9.0	14.4	15.5	14.7	13.4	9.7	8.9	27.6	8.29	2.84	0.930	12.50	0.414
32	0.0	0.0	1.3	2.7	6.9	7.8	10.7	16.0	15.6	12.1	11.5	8.2	6.6	32.6	9.97	3.16	0.817	14.50	0.409
33	0.0	0.0	0.3	5.2	4.0	7.2	14.0	16.1	17.1	13.3	10.0	6.8	5.5	30.6	10.30	3.43	0.771	14.50	0.358
34	0.0	1.7	0.8	4.5	3.8	4.6	12.9	15.4	15.8	14.2	11.2	7.9	6.7	33.9	9.60	3.16	0.824	15.40	0.340
39	10.6	15.6	9.2	10.5	7.7	5.1	8.2	4.6	8.6	5.1	5.2	5.3	3.8	126.0	36.90	4.10	0.467	53.10	0.479
41	0.1	1.2	2.8	3.8	4.0	5.9	9.9	13.7	18.0	13.1	11.2	9.2	6.4	37.4	9.40	3.14	0.831	16.00	0.185
43	9.0	14.7	12.1	13.6	8.9	8.3	6.8	6.1	7.1	4.1	3.7	2.4	2.7	121.0	43.00	5.99	0.365	54.40	0.552
45	9.8	15.5	12.7	7.2	6.9	5.9	6.3	8.2	6.3	6.4	5.6	3.6	5.0	123.0	34.60	4.19	0.480	52.60	0.550
5C	14.3	13.7	7.9	11.0	4.3	5.6	8.8	9.2	4.9	4.9	6.5	4.6	3.6	137.0	34.80	4.24	0.460	55.30	0.428
51	4.2	7.4	10.2	10.7	9.3	10.2	11.6	12.5	7.8	4.9	5.2	3.0	2.6	94.9	23.60	5.18	0.442	39.10	0.416
52	0.0	0.3	5.5	4.5	4.5	7.3	15.8	16.4	15.8	11.9	8.2	5.1	4.2	45.2	12.00	3.97	0.677	18.60	0.262
53	0.0	0.0	1.1	3.5	4.6	11.2	17.7	19.8	15.5	11.1	7.2	4.0	3.7	30.4	12.60	4.31	0.646	16.20	0.193
55	6.3	17.6	12.8	2.3	16.5	11.0	4.8	8.8	7.5	2.7	3.8	3.4	1.9	115.0	35.00	6.03	0.366	51.60	0.434
56	3.3	9.6	6.8	5.0	11.0	12.3	13.1	11.9	9.1	7.1	4.6	2.3	3.1	98.0	21.00	5.41	0.466	36.30	0.468
58	6.3	10.9	11.3	5.6	8.8	12.6	10.1	10.8	8.9	6.9	3.6	1.4	2.2	110.0	25.70	6.26	0.398	44.20	0.400
6B	10.7	16.6	6.8	10.0	8.1	7.7	7.7	6.2	10.2	4.9	4.1	3.8	2.6	127.0	34.20	5.15	0.416	53.20	0.386
62	0.9	2.9	4.7	6.3	11.6	12.6	15.6	16.3	10.7	7.6	5.1	2.6	2.4	57.6	17.30	5.38	0.498	26.20	0.417
7C	5.4	10.4	12.6	11.3	7.2	5.5	7.8	8.5	8.5	3.4	7.6	7.1	4.0	106.0	26.00	3.66	0.535	43.30	0.551
8C	0.0	0.0	6.3	8.7	4.7	8.6	18.1	16.8	13.7	8.6	6.4	5.0	2.4	53.7	14.40	4.42	0.579	21.50	0.362

Table A3

Sediment Data, DeGray, Chemistry

STATION	DISTDAM	COLDEPTH	SFE	SMN	STP	STN	STIC	STOC	IFE	IMN	ITP	ISRP	ITN	INH4N	INO3NO2N	ITIC	ITOC	MC
DH2C	12.7	17.0	25.0	0.880	0.701	2.252	1.06	26.2	1.21	2.78	0.06	0.06	1.2	0.9	0.00	6	2.5	74.03
B2B	11.8	16.8	7.3	0.134	0.104	0.532	0.46	9.0	9.00	3.14	.	.	.	.	.	.	8.0	28.14
B3B	13.7	7.5	6.9	0.167	0.151	0.565	0.43	4.2	0.56	1.98	0.06	0.06	1.9	1.3	0.00	7	4.6	29.22
1B	1.1	57.5	35.8	2.830	0.887	2.251	0.91	22.6	42.40	12.10	0.16	.	7.7	6.1	0.00	32	19.2	87.53
10B	12.4	9.5	19.3	0.930	0.591	2.521	.	24.8	0.94	1.98	0.51	0.46	0.7	0.4	0.01	5	3.2	60.21
10C	12.4	25.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11C	13.8	8.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12B	16.1	14.9	38.2	0.880	1.340	2.840	0.76	24.6	.	.	.	.	.	.	.	.	.	105.47
13	21.4	12.5	32.2	0.640	1.031	2.138	1.18	19.9	7.80	2.28	0.34	.	2.5	1.8	0.00	12	9.5	66.14
13A	19.3	16.5	31.7	0.640	1.131	2.304	0.93	20.3	7.50	2.32	0.76	0.72	3.2	2.0	0.00	10	13.9	69.14
14C	22.8	9.0	26.3	0.500	0.831	1.963	0.83	17.5	3.53	1.84	0.32	0.27	2.0	1.1	0.02	11	6.8	51.15
15A	24.9	6.8	27.0	0.610	0.781	1.984	1.04	18.1	1.80	2.54	0.36	0.32	2.6	1.7	0.00	16	7.2	50.78
17	23.7	7.9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	22.5	4.3	15.1	0.214	0.502	1.340	0.67	15.4	1.93	1.27	0.18	0.16	1.1	0.6	0.00	9	3.1	36.49
2B	2.9	25.7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2C	2.6	21.0	5.6	0.194	0.138	0.812	0.34	8.4	1.06	0.87	0.17	0.12	1.6	0.6	0.01	8	6.0	24.11
20	16.6	11.9	21.0	1.250	0.718	2.339	1.13	36.9	0.21	0.79	0.15	0.14	0.5	0.2	0.02	3	3.9	46.35
21	17.7	15.0	16.2	0.236	0.380	1.004	0.63	8.8	4.40	2.32	0.12	0.13	1.1	0.6	0.01	13	4.0	40.86
22	16.9	16.0	23.3	1.160	0.684	2.344	1.07	25.1	0.10	0.91	0.12	0.10	0.5	0.2	0.02	3	3.9	44.72
23	18.2	16.0	8.5	0.275	0.294	0.658	0.60	3.5	1.84	1.19	0.28	0.26	1.2	0.8	0.02	3	5.0	29.24
24	19.3	9.5	18.8	0.490	0.575	1.461	1.06	13.6	1.56	1.70	0.16	0.10	1.1	0.7	0.01	8	2.5	49.41
25	21.9	10.8	30.2	0.670	1.049	2.152	0.56	18.2	1.13	2.00	0.20	0.17	2.5	1.7	0.01	11	5.5	63.41
26	22.5	5.0	8.6	0.193	0.111	0.805	1.09	7.7	5.60	1.86	.	.	.	.	.	.	15.9	30.29
27	20.4	14.2	24.8	0.520	0.797	1.633	0.81	15.8	4.10	1.92	0.18	0.17	1.6	1.1	0.00	9	4.3	50.83
28	17.2	17.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29	17.4	8.3	15.1	0.368	0.507	1.317	0.43	11.0	.	.	.	.	.	.	.	.	.	.
30	15.6	14.4	26.8	0.730	0.862	2.097	0.84	23.1	12.90	2.82	0.18	.	4.1	3.0	0.01	14	10.9	47.65
32	13.8	9.5	35.8	1.170	1.428	2.507	1.03	27.1	72.00	13.20	0.13	.	9.6	7.7	0.05	51	22.5	266.23
33	14.2	8.6	11.0	3.160	0.315	1.417	0.75	15.6	0.98	0.98	0.06	0.05	4.2	0.5	0.00	3	2.8	50.96
34	11.9	16.5	13.2	0.490	0.393	1.363	0.74	16.8	3.63	1.29	0.09	0.09	2.1	1.6	0.00	5	6.8	58.83
39	9.8	17.5	.	.	.	.	.	.	3.85	12.10	0.12	0.11	2.7	2.0	0.00	12	5.7	.
41	11.1	20.1	11.1	0.490	0.481	1.672	1.07	16.6	33.30	11.20	0.20	.	8.5	6.7	0.01	27	20.5	57.61
43	11.3	26.8	14.5	0.670	0.535	1.596	0.88	22.1	11.50	6.80	0.17	0.17	4.5	3.6	0.01	14	8.5	70.17
45	9.3	17.1	10.3	0.560	0.480	1.763	0.56	28.4	1.40	1.70	0.06	0.05	0.9	0.5	0.01	5	2.6	72.18
5C	5.8	18.4	5.6	0.600	0.234	0.944	0.78	12.1	2.15	9.68	0.07	0.06	1.9	1.5	0.00	9	7.0	41.60
51	6.1	9.5	12.4	1.460	0.422	1.490	0.47	17.5	0.64	3.56	.	.	.	.	.	.	4.0	27.27
52	4.7	17.1	20.5	2.220	0.705	3.026	0.90	40.6	4.85	11.00	0.11	0.11	2.2	1.5	0.00	9	8.3	103.80
53	4.0	24.6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
55	2.9	20.9	8.9	1.310	0.392	1.813	0.51	23.0	6.95	14.20	0.09	0.07	4.1	2.8	0.00	11	29.5	41.29
56	2.6	17.1	10.6	0.300	0.212	0.936	0.47	7.7	2.55	0.95	.	.	.	.	.	.	3.2	33.55
58	1.2	17.1	6.9	0.321	0.164	0.634	0.36	10.1	.	.	.	.	.	.	.	.	.	25.62
6B	7.7	25.7	11.1	1.240	0.424	1.515	0.64	17.4	3.70	20.00	0.11	0.11	3.9	2.9	0.00	17	12.3	46.00
62	3.7	17.7	22.7	5.920	0.652	3.423	0.90	48.4	.	.	.	.	.	.	.	.	.	66.43
7C	8.5	17.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8C	10.0	22.6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

* No. measurement.

Table A4

Sediment Data, Eau Galle, Particle Size

STATION	CH150	CH106	CH75	CH53	CH38	CH27	CH19	CH13	CH94	CH66	CH47	CH33	CH24	MTPCT90	MTPCT50	MTPCT10	CSURAREA	VOLMEAND	UCSAMVOL
01	6.0	0.0	4.9	8.1	9.5	12.4	12.7	15.5	11.1	7.7	5.0	0.0	5.6	70.4	17.70	5.23	0.521	31.60	0.192
02	1.0	5.6	2.6	5.1	10.0	10.4	11.6	13.7	12.1	8.6	8.7	5.8	4.3	59.5	14.20	3.82	0.634	25.30	0.282
03	0.0	0.6	0.5	3.0	9.2	8.2	14.7	18.6	14.0	9.0	9.2	8.5	3.9	35.4	12.00	3.50	0.715	16.30	0.229
04	0.0	0.0	3.1	3.0	1.8	8.8	9.8	14.9	15.2	12.3	12.9	9.6	9.2	28.8	9.09	2.91	0.886	14.20	0.570
05	0.0	0.0	0.0	1.7	4.5	7.3	7.9	11.8	15.2	12.1	14.3	12.7	11.8	26.0	7.52	2.59	1.030	11.20	0.633
06	1.0	2.4	3.5	6.1	8.4	10.4	11.7	13.3	12.6	9.4	8.5	7.0	5.1	52.6	13.20	3.47	0.681	22.60	0.494
07	0.0	4.0	5.2	3.2	9.9	9.1	11.2	12.8	11.9	11.4	8.8	6.0	6.1	57.3	12.80	3.43	0.699	22.50	0.462
1C	6.2	4.4	8.9	10.3	7.7	10.5	11.6	11.4	8.0	4.9	6.0	5.2	4.0	92.3	20.90	4.01	0.523	37.40	0.403
2D	5.2	3.5	12.2	8.9	3.6	8.5	12.1	10.7	10.8	8.4	6.6	4.3	4.6	84.7	17.50	4.08	0.565	35.00	0.439
2E	0.0	1.6	5.9	6.3	7.5	12.0	12.7	15.3	12.7	7.3	8.1	6.3	3.7	54.3	14.20	3.84	0.626	22.30	0.396
3A	0.0	0.0	3.6	3.9	3.4	9.9	14.1	16.6	14.1	10.8	10.1	7.2	5.8	34.2	11.30	3.34	0.755	16.50	0.673
3B	7.7	8.1	11.1	7.3	6.7	10.0	8.4	9.7	10.9	5.5	5.9	5.1	2.8	112.0	22.80	4.35	0.493	42.50	0.535
3C	0.0	0.0	0.7	0.0	0.9	6.3	9.4	13.8	14.2	11.9	15.3	13.5	13.5	20.3	6.82	2.50	1.090	9.83	0.662
3D	9.2	7.2	7.9	12.6	6.0	6.8	11.6	8.9	6.9	6.9	5.9	4.3	5.1	119.0	22.00	3.99	0.526	43.30	0.472
3D	9.2	7.2	7.9	12.6	6.0	6.8	11.6	8.9	6.9	6.9	5.9	4.3	5.1	119.0	22.00	3.99	0.526	43.30	0.472
3E	6.0	5.7	6.9	9.5	8.2	12.6	11.0	11.3	8.7	5.2	6.0	4.6	3.7	98.0	21.40	4.26	0.510	37.20	0.540
4B	0.0	1.3	3.7	5.3	7.6	11.8	13.9	14.9	12.5	9.6	8.1	5.6	5.1	44.9	13.40	3.68	0.667	20.10	0.441
4C	0.0	0.0	2.0	3.6	3.1	7.1	11.6	14.7	15.4	11.0	12.3	10.3	8.4	29.3	9.24	2.88	0.891	13.90	0.471
4D	0.0	0.0	1.8	3.0	3.4	6.6	11.0	14.4	14.2	12.2	13.0	10.3	9.6	28.5	8.71	2.77	0.929	13.40	0.416
4E	4.5	7.4	9.8	9.9	11.5	10.3	11.1	9.0	8.5	6.5	4.4	2.9	3.5	96.4	24.70	5.07	0.459	39.30	0.521
5A	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5B	9.0	10.5	9.2	8.1	8.0	11.0	6.9	6.4	10.1	5.0	5.9	5.3	3.9	119.0	26.50	4.03	0.500	45.90	0.473
6B	6.7	6.8	11.9	11.1	10.7	11.0	10.1	10.2	6.8	5.0	4.1	2.7	2.2	105.0	28.60	5.83	0.398	43.90	0.427
6C	10.2	9.5	12.1	7.9	3.4	12.2	10.2	8.6	11.6	5.5	3.9	2.8	1.6	125.0	25.60	6.03	0.403	48.10	0.302
7A	11.8	7.3	3.1	5.1	8.1	8.7	13.3	12.5	10.7	8.8	4.1	3.4	2.5	131.0	19.00	5.43	0.478	42.20	0.185
8D	3.5	3.8	6.0	8.0	9.6	14.1	11.7	13.7	8.6	7.1	6.3	2.6	4.4	75.2	19.10	4.54	0.527	31.30	0.467

* No measurement.

Table A5

Sediment Data, Eau Galle, Chemistry

STATION	DISTDAM	COLDEPTH	SFE	SMN	STP	STN	STIC	STOC	IFE	IMN	ITP	ISRP	ITN	INH4N	INO3NO2N	ITIC	ITOC	MC
01	0.63	1.5	22.4	0.77	0.879	2.637	6.5	18.5	13.80	5.40	0.33	0.32	16.1	14.9	0.00	92	7.5	57.00
02	0.66	1.5	15.5	0.57	0.521	1.350	7.9	8.5	3.83	3.57	0.11	0.11	5.4	4.9	0.01	54	5.3	36.10
03	0.59	6.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
04	0.28	8.2	29.2	0.54	1.215	3.080	4.2	26.5	7.70	6.90	0.18	0.19	11.2	9.3	0.05	53	15.6	61.93
05	0.46	8.5	30.4	1.28	1.458	3.218	2.6	29.5	36.20	14.40	0.34	0.39	20.5	19.0	0.03	105	20.0	65.19
06	0.49	7.0	32.1	1.21	1.367	3.047	2.6	24.4	5.40	6.38	0.26	0.26	6.8	5.9	0.00	51	11.0	66.29
07	0.68	5.0	32.7	1.23	1.423	3.435	3.3	24.1	27.90	17.70	0.15	0.16	28.2	26.5	0.03	112	23.4	64.89
1C	0.03	3.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2D	0.20	2.9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2E	0.16	1.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3A	0.51	3.7	30.6	0.97	1.256	3.079	3.7	55.3	1.86	2.28	0.27	0.28	3.0	2.2	0.01	51	8.6	72.17
3B	0.42	2.8	15.3	0.75	0.485	0.962	10.3	4.4	0.51	2.43	0.15	0.14	2.3	1.8	0.01	57	6.2	28.66
3C	0.35	8.4	34.8	1.37	1.524	3.193	2.8	27.5	32.10	13.20	0.45	0.21	22.4	19.3	0.03	101	27.1	75.86
3D	0.33	2.0	14.8	0.55	0.581	1.623	7.2	14.5	3.63	3.90	0.15	0.16	9.9	8.3	0.01	74	19.0	30.47
3D	0.33	2.0	14.8	0.55	0.581	1.623	7.2	14.5	3.63	3.90	0.15	0.16	9.9	8.3	0.01	74	19.0	30.47
3E	0.36	0.2	20.5	0.66	0.802	1.900	4.5	15.1	5.60	3.61	0.23	0.23	4.8	4.1	0.02	42	9.9	47.64
4B	0.62	7.4	29.8	0.94	1.166	2.719	3.7	31.5	8.05	6.37	0.42	0.42	7.2	6.2	0.00	78	9.1	58.76
4C	0.56	8.1	33.2	1.21	1.383	3.218	2.7	26.3	47.60	17.00	0.54	0.36	25.6	23.1	0.01	104	22.0	62.52
4D	0.54	7.6	30.9	1.09	1.357	3.286	4.4	27.3	14.80	6.90	0.40	0.41	10.3	9.4	0.01	70	12.9	72.12
4E	0.55	0.2	15.7	0.68	0.643	2.063	10.6	14.9	17.40	5.00	0.21	0.24	11.3	10.5	0.01	91	13.0	52.36
5A	0.80	3.5	20.6	0.68	0.803	1.814	8.5	13.0	0.56	1.80	0.07	0.07	3.1	3.0	0.02	47	4.6	49.45
5B	0.73	0.8	17.2	0.95	0.609	1.912	9.5	15.8	9.20	3.12	0.15	0.14	10.2	8.9	0.01	77	12.9	32.35
6B	1.13	0.2	25.5	1.29	1.105	3.897	4.5	31.3	10.90	6.20	0.35	0.34	11.3	10.0	0.00	93	21.5	60.13
6C	0.99	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7A	1.22	1.6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8B	0.69	0.5	20.1	0.70	0.780	2.138	5.9	17.4	18.80	14.70	0.14	0.10	41.3	42.8	0.02	217	23.0	53.43

* No measurement.

Table A6

Sediment Data, West Point, Particle Size

STATION	CN150	CN106	CN75	CN53	CN38	CN27	CN19	CN13	CN94	CN66	CN47	CN33	CN24	MTPCT90	MTPCT50	MTPCT10	CSURAREA	VOLMEAND	UCSAMVOL
AC1	0.0	0.0	0.5	2.9	4.6	7.6	8.7	13.6	16.7	14.2	12.9	9.3	7.7	29.6	8.71	2.98	0.887	13.60	0.520
C4	0.0	0.0	1.6	2.7	6.1	8.4	12.0	15.7	16.8	12.7	10.6	8.0	4.8	31.9	10.20	3.41	0.773	14.80	0.638
IC1	0.0	3.7	1.4	6.2	9.8	9.4	11.5	14.0	13.8	9.8	9.0	6.4	4.5	47.2	12.80	3.68	0.674	21.20	0.293
IC2	0.0	1.7	4.7	8.3	7.1	11.5	12.9	14.2	12.9	8.3	8.0	6.1	3.8	53.4	14.10	3.88	0.628	22.30	0.588
MC11	3.2	5.6	4.5	6.2	9.4	8.2	10.6	12.5	11.8	8.2	7.8	7.2	4.0	81.1	14.70	3.64	0.626	29.40	0.418
MC2	2.1	2.6	4.1	5.7	6.9	8.6	10.7	14.6	13.8	10.4	9.1	6.0	4.7	58.3	12.50	3.70	0.675	23.80	0.556
WEC26	2.8	4.9	4.0	7.6	9.3	8.4	11.0	12.3	10.3	9.7	8.1	5.9	5.1	72.4	14.80	3.62	0.639	28.30	0.643
WES10	21.4	22.0	6.3	5.0	6.7	3.6	7.1	8.1	3.5	5.3	5.4	2.9	2.0	149.0	61.20	5.35	0.356	70.00	0.368
WES11	6.0	6.8	0.0	6.6	7.1	6.9	7.7	13.4	12.4	9.9	9.7	7.0	5.2	101.0	12.60	3.47	0.682	30.80	0.426
WES12	0.0	0.0	0.0	0.5	2.5	3.5	9.8	17.3	18.9	16.2	14.0	9.9	7.0	19.4	8.16	3.03	0.930	10.30	0.512
WES15	2.1	4.8	5.1	5.0	8.4	8.2	8.1	13.5	12.5	9.8	9.3	7.2	5.3	71.2	12.60	3.41	0.692	26.10	0.479
WES20	1.1	3.1	5.4	8.7	9.3	9.2	11.7	12.9	10.4	8.6	8.6	6.2	4.2	61.5	15.00	3.78	0.626	26.00	0.647
WES21	3.8	5.5	3.4	8.9	8.9	9.5	10.4	11.0	12.8	9.4	6.6	5.1	4.0	82.4	15.90	4.06	0.585	30.70	0.592
WES27	0.0	0.0	1.6	5.3	8.6	8.9	11.3	12.4	12.9	10.1	10.8	9.7	7.7	39.0	10.50	2.96	0.823	16.40	0.422
WES3	4.1	12.1	9.0	9.3	7.7	8.1	9.1	10.7	8.8	6.1	5.7	3.5	3.2	111.0	24.50	4.72	0.468	43.80	0.487
WES30	1.6	5.9	7.8	9.1	12.9	12.4	11.0	11.5	9.4	5.8	5.6	4.2	2.1	78.9	22.00	4.82	0.475	33.00	0.692
WES37	0.0	0.0	0.6	3.3	5.9	8.7	12.1	15.4	16.7	12.9	10.6	8.1	5.0	30.9	10.10	3.39	0.780	14.40	0.583
WES38	6.2	11.4	13.0	12.8	10.8	8.9	8.7	7.2	8.1	4.8	3.1	2.5	1.9	110.0	35.60	6.43	0.366	48.40	0.620
WES39	0.0	2.3	3.4	6.2	11.4	10.5	12.4	13.4	11.7	9.2	8.2	6.2	4.4	49.2	14.10	3.72	0.646	22.00	0.797
WES4	1.0	4.2	5.4	6.7	10.0	9.0	8.4	10.7	11.4	9.2	9.5	7.6	6.2	64.9	13.20	3.25	0.706	25.50	0.592
WES40	9.1	13.5	13.8	11.3	6.2	7.1	8.0	5.9	6.6	6.3	4.4	4.0	3.3	121.0	38.80	4.72	0.430	52.40	0.564
WES42	0.0	0.3	2.3	5.8	6.1	9.0	13.2	15.5	14.0	11.9	9.7	6.9	4.8	40.3	11.60	3.54	0.722	17.30	0.562
WES43	1.9	3.9	7.5	6.8	8.6	9.8	10.1	11.5	12.2	10.6	7.1	4.7	4.7	72.7	15.00	3.97	0.611	28.10	0.692
WES430	0.0	0.0	0.5	1.8	2.5	6.5	12.0	15.8	18.0	15.4	12.2	8.6	6.2	23.8	8.95	3.18	0.859	12.10	0.497
WES450	0.0	0.0	0.0	0.8	4.8	6.1	7.8	14.9	18.4	15.7	13.7	10.3	7.0	24.3	8.21	3.03	0.919	11.30	0.522
WES47	11.7	14.7	13.6	8.2	6.3	5.6	7.2	8.9	5.0	6.5	5.6	2.9	3.0	130.0	40.30	4.93	0.416	55.60	0.519
WES5	0.0	0.0	0.0	0.6	2.5	2.7	6.5	13.2	18.3	17.6	16.1	12.4	9.5	17.7	6.90	2.77	1.040	9.32	0.550
WES50	0.0	0.0	0.0	0.0	1.3	3.0	9.1	16.2	19.4	17.1	14.9	10.9	7.7	17.7	7.61	2.93	0.980	9.37	0.463
WES51	0.0	0.7	0.9	3.8	8.2	10.0	13.0	16.9	15.3	12.1	8.4	5.4	4.6	36.3	11.80	3.84	0.694	16.90	0.278
WES54	3.9	6.1	0.0	6.8	8.8	8.0	12.4	12.8	12.8	8.1	8.1	7.8	3.8	88.0	14.00	3.60	0.644	28.00	0.448
WES55	7.1	10.8	6.1	5.6	9.0	7.3	8.0	7.8	12.3	9.1	6.3	6.0	4.0	112.0	18.50	3.84	0.569	39.90	0.569
WES60	4.5	6.4	9.7	9.4	9.1	8.7	10.2	11.0	7.8	8.1	6.1	4.2	4.0	92.3	20.50	4.26	0.526	36.90	0.578
WES62	6.4	10.2	8.2	9.6	7.4	8.5	9.2	11.3	9.5	6.5	6.2	3.3	3.1	110.0	22.40	4.72	0.478	42.00	0.528
WES7	3.7	6.3	6.8	9.7	8.7	7.8	10.1	11.4	9.4	8.0	7.9	5.3	4.1	88.4	17.50	3.95	0.577	33.50	0.584
WES9	0.4	1.8	2.1	3.6	5.7	7.9	12.3	15.0	16.7	12.2	9.5	7.6	4.6	39.0	10.70	3.50	0.738	17.90	0.416
YC13JC	2.0	4.4	0.0	6.6	7.8	5.8	12.2	14.6	11.8	11.4	9.9	6.6	6.5	51.4	11.90	3.28	0.736	22.60	0.201
YC27BMC	6.2	9.1	3.1	4.0	8.9	5.1	9.3	12.0	10.8	8.8	9.6	7.7	4.9	107.0	13.80	3.43	0.663	34.00	0.419
YC32	2.4	4.3	4.6	4.8	7.3	8.7	7.9	11.0	11.4	9.6	10.5	8.4	8.5	68.9	11.40	2.90	0.787	25.00	0.564
YC5	0.0	0.0	0.0	1.1	2.8	5.5	10.2	16.1	18.3	16.4	13.4	9.2	6.5	21.5	8.38	3.11	0.899	11.00	0.486
1	0.9	1.7	4.5	7.3	9.0	9.4	11.8	13.4	12.3	9.7	8.3	6.3	4.6	54.6	13.60	3.66	0.656	23.10	0.575
100	17.2	11.6	5.3	12.5	7.8	12.0	4.1	5.4	11.8	3.2	3.0	3.8	1.8	143.0	38.00	6.29	0.369	58.10	0.392
151C	6.2	4.7	0.0	15.0	9.9	8.8	12.1	11.5	9.4	10.2	5.9	2.2	3.4	94.4	19.00	4.96	0.508	34.30	0.206
29WEC	2.2	5.6	3.4	3.8	8.4	8.3	11.1	15.0	12.5	11.1	8.6	5.2	4.0	71.2	13.20	3.97	0.640	26.00	0.328
36AMC	0.0	0.0	0.0	1.2	4.7	6.7	11.2	17.9	18.5	13.7	11.6	8.1	5.8	25.1	9.45	3.27	0.832	12.30	0.368
4	0.0	0.3	3.4	5.1	3.4	5.2	10.9	15.4	14.8	13.9	11.8	8.4	6.6	39.4	9.55	3.14	0.828	15.80	0.524
45AMMC	0.0	0.0	0.0	0.8	1.8	4.6	10.7	17.9	19.4	15.8	13.1	9.1	6.3	20.1	8.57	3.14	0.893	10.70	0.444
46	0.0	0.0	0.0	0.9	2.4	5.3	9.4	16.2	18.6	15.6	14.0	10.2	7.0	20.9	8.21	3.03	0.926	10.70	0.401
65	0.0	0.0	0.6	2.3	5.3	6.0	10.0	15.0	17.2	14.6	12.4	9.5	6.4	28.3	8.90	3.11	0.867	12.90	0.559
66	0.0	0.0	0.7	3.3	6.0	9.1	12.3	15.3	16.6	12.6	10.4	7.8	5.4	31.2	10.30	3.35	0.779	14.60	0.615
78	0.0	0.0	3.3	2.7	6.6	8.0	9.3	13.9	15.2	12.6	12.1	9.1	6.6	35.8	9.60	3.11	0.831	15.50	0.608
86	0.0	0.0	1.3	3.5	6.3	7.4	13.4	17.1	14.8	12.4	10.8	7.4	5.0	33.1	10.80	3.45	0.763	15.10	0.634
87	5.3	9.9	12.5	8.7	8.1	8.5	9.1	9.8	7.1	5.9	6.5	4.7	3.4	105.0	25.00	4.26	0.490	42.40	0.687
88A	0.0	0.0	0.0	3.3	6.4	9.3	14.3	16.3	16.7	12.6	9.6	6.5	4.6	30.7	10.90	3.64	0.736	14.70	0.324
89	0.0	0.0	0.1	3.8	7.2	9.6	12.7	15.4	15.6	12.1	10.2	7.5	5.3	32.8	10.70	3.37	0.764	15.00	0.635

Table A7

Sediment Data, West Point, Chemistry

STATION	DISTDAM	COLDEPTH	SFE	SMN	STP	STN	STIC	STOC	IFE	IMN	ITP	ISRP	ITN	INH4N	INO3NO2N	ITIC	ITOC	MC
AC1	9.1	8.9	70.6	1.44	1.469	1.373	0.56	30.7	2.900	2.28	0.10	0.11	1.5	1.1	0.00	8	4.0	85.18
C4	23.8	6.5	60.3	1.28	2.215	1.968	0.54	21.3	16.100	7.26	0.16	0.17	5.7	5.5	0.01	39	5.7	78.25
IC1	5.8	14.0	56.5	1.27	1.112	1.669	0.87	45.4	4.950	1.85	0.11	0.10	1.3	0.9	0.01	7	6.9	104.19
IC2	5.9	7.2	59.7	1.19	1.101	1.419	0.50	34.5	2.800	3.24	0.07	0.07	1.3	1.0	0.00	7	3.1	156.00
MC11	5.0	9.0	62.9	1.30	0.950	1.524	0.36	31.3	0.700	0.87	0.06	0.05	0.3	0.1	0.00	4	1.5	102.71
MC2	1.6	3.6	57.4	1.06	1.160	1.459	0.70	41.8	2.080	1.73	0.08	0.07	0.8	0.7	0.00	5	3.5	90.85
WEC26	18.6	5.8	46.7	1.36	0.979	1.343	0.48	27.4	2.220	3.33	0.08	0.07	1.7	1.3	0.00	8	5.0	72.11
WE310	12.2	10.5	51.2	1.07	0.506	0.573	0.34	16.0	2.180	3.04	0.08	0.09	1.3	1.0	0.00	7	6.0	45.39
WE311	9.8	13.5	22.9	0.84	0.422	0.749	0.51	6.2	3.340	2.20	0.21	0.20	2.2	1.8	0.00	5	4.6	30.72
WE312	12.7	11.1	71.4	1.53	2.399	2.373	0.55	23.5	10.000	6.68	0.13	0.10	5.5	5.2	0.01	34	6.0	104.67
WE313	12.7	9.8	70.1	1.43	2.344	2.579	0.85	24.2	23.000	5.92	0.16	0.10	5.5	5.1	0.00	33	6.2	109.14
WE320	23.6	6.3	44.0	1.12	1.996	1.996	0.68	18.7	38.700	9.90	0.16	0.17	9.0	8.9	0.01	59	9.1	64.94
WE321	23.6	7.3	44.5	1.05	1.557	1.636	0.65	16.6	28.600	7.72	0.16	0.13	8.2	8.0	0.01	49	10.4	59.42
WE327	33.0	8.5	56.3	1.60	2.386	2.060	0.54	20.8	18.200	6.63	0.16	0.16	9.4	9.3	0.01	38	5.3	89.67
WE33	2.0	4.5	51.4	0.79	0.449	1.054	0.37	13.8	0.050	1.00	0.11	0.06	0.8	0.7	0.00	3	3.6	41.19
WE330	37.0	4.5	48.7	1.43	1.482	2.064	0.68	20.1	99.400	35.30	0.18	0.30	12.7	12.0	0.01	156	37.9	73.97
WE337	29.6	10.0	62.6	1.70	2.311	1.967	0.66	22.9	9.560	8.05	0.12	0.08	6.4	4.8	0.01	34	6.2	84.52
WE338	37.0	2.9	38.2	0.91	1.188	1.257	0.48	12.8	75.100	14.40	0.14	0.13	20.2	20.6	0.01	142	18.8	53.50
WE339	37.0	2.9	52.7	1.10	1.871	1.885	0.54	20.7	44.400	14.40	0.13	0.08	17.8	18.5	0.00	81	8.6	65.79
WE34	1.3	21.0	50.6	1.04	1.482	2.439	0.46	26.7	1.630	4.40	0.09	0.12	2.5	2.2	0.00	9	3.5	94.08
WE340	30.4	2.0	26.5	0.49	0.711	0.314	0.24	7.4	*	*	*	*	*	*	*	*	*	45.93
WE342	30.5	9.0	54.1	1.35	2.083	1.927	0.54	19.3	29.900	11.40	0.13	0.10	14.3	14.4	0.00	68	8.1	61.94
WE343	29.9	1.4	30.4	0.90	0.625	0.889	0.32	7.3	10.100	6.04	0.13	0.09	4.1	4.0	0.00	23	2.3	30.83
WE3430	21.7	9.7	41.6	0.98	1.032	2.172	0.40	24.1	1.350	2.36	0.09	0.08	1.4	1.1	0.01	8	4.1	75.75
WE3450	20.0	12.0	38.6	1.30	1.456	1.079	0.44	13.6	7.870	7.92	0.12	0.08	5.3	5.1	0.00	38	3.4	49.07
WE347	15.2	10.0	65.2	1.61	2.494	2.191	0.65	23.5	14.500	7.75	0.13	0.10	6.0	5.8	0.01	35	4.8	94.65
WE35	3.0	20.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
WE350	10.7	13.0	70.0	1.80	2.729	1.253	0.73	24.6	15.400	9.12	0.13	0.07	6.6	6.1	0.00	36	9.2	120.23
WE351	10.7	12.9	42.8	0.81	1.116	1.724	0.24	53.2	2.560	1.65	0.08	0.06	1.1	0.7	0.00	5	5.1	84.29
WE354	5.6	10.0	31.0	0.93	0.924	0.919	0.54	26.1	0.168	1.58	0.06	0.06	1.1	0.8	0.00	6	3.5	70.95
WE355	6.7	3.0	20.5	0.87	0.365	0.383	0.35	11.6	2.340	2.42	0.12	0.09	1.0	1.3	0.00	8	6.5	28.26
WE360	21.7	9.0	50.4	1.49	2.060	1.841	0.82	22.9	36.400	9.44	0.14	0.10	10.1	10.4	0.01	55	8.2	73.46
WE362	7.7	6.0	34.8	1.16	0.741	0.429	0.33	5.3	10.600	3.32	0.07	0.06	3.4	3.2	0.00	22	4.2	41.01
WE37	5.4	20.0	62.3	0.83	1.818	2.336	0.55	25.2	3.800	2.20	0.16	0.13	1.1	0.8	0.00	6	5.5	95.38
WE39	16.9	7.5	44.0	1.74	0.874	1.361	0.66	32.3	3.960	2.87	0.09	0.06	2.5	2.1	0.00	8	8.6	72.26
YC13JC	25.8	5.7	56.9	1.66	1.362	1.866	0.58	19.0	5.800	3.72	0.14	0.15	2.1	1.6	0.01	5	6.0	78.54
YC27DBC	29.9	5.0	65.6	4.28	0.811	2.392	1.88	23.4	4.960	4.50	0.13	0.09	3.4	3.0	0.00	14	7.0	61.91
YC32	33.4	2.3	62.1	1.32	0.661	1.750	1.26	22.9	3.900	8.52	0.12	0.10	3.2	3.1	0.00	18	4.4	61.35
YC5	23.0	12.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	1.3	9.5	60.0	0.43	0.997	1.764	0.41	18.6	2.070	2.48	0.15	0.13	0.9	0.6	0.00	8	3.4	70.99
100	35.3	6.5	42.4	0.97	1.592	1.574	0.48	15.1	59.300	20.00	0.21	0.21	19.2	19.2	0.01	112	23.8	72.05
191C	5.7	12.0	30.1	0.50	0.419	0.614	0.61	24.8	*	*	*	*	*	*	*	*	*	58.53
29MEC	8.9	16.8	60.1	1.87	1.413	1.217	0.84	22.2	65.200	11.40	0.13	0.12	20.0	19.0	0.00	58	16.2	80.83
36AMC	12.7	9.2	57.7	1.25	1.813	1.174	0.58	28.9	1.290	1.86	0.10	0.10	1.7	1.5	0.00	7	3.5	104.97
4	1.4	13.5	42.4	0.75	0.473	1.093	0.34	12.7	3.450	2.46	0.26	0.21	1.5	1.1	0.01	7	6.0	51.14
45AMMC	16.8	14.0	50.5	1.47	1.900	1.831	0.48	26.7	1.710	3.09	0.08	0.08	2.5	2.3	0.00	13	2.3	99.84
48	18.2	14.2	60.2	1.61	1.706	1.402	0.59	17.8	12.100	5.91	0.13	0.09	6.5	6.3	0.01	32	5.4	70.38
65	23.6	7.0	58.4	1.41	2.265	2.151	0.57	20.3	4.300	5.48	0.12	0.13	2.5	1.9	0.02	12	6.6	83.89
66	23.7	6.0	58.7	1.57	2.227	2.111	0.51	21.0	12.600	8.24	0.14	0.15	5.3	5.1	0.01	37	4.8	77.48
78	27.3	10.5	58.6	1.67	2.003	2.168	0.79	20.6	70.800	16.30	0.15	0.11	30.8	31.0	0.00	113	12.5	76.28
86	29.6	9.5	56.0	1.72	2.315	2.029	0.57	22.1	26.900	11.80	0.14	0.09	11.8	11.8	0.01	51	6.3	64.17
87	29.8	3.0	22.3	0.50	0.592	0.356	0.27	5.0	*	*	*	*	*	*	*	*	*	38.52
88A	29.9	9.5	50.9	1.84	2.132	2.039	0.65	20.1	39.600	14.80	0.13	0.08	18.7	19.7	0.00	75	6.8	76.69
89	30.3	9.0	52.7	1.32	2.360	1.953	0.57	19.9	33.100	10.80	0.14	0.09	14.3	14.6	0.00	57	7.7	77.28

* No measurement.