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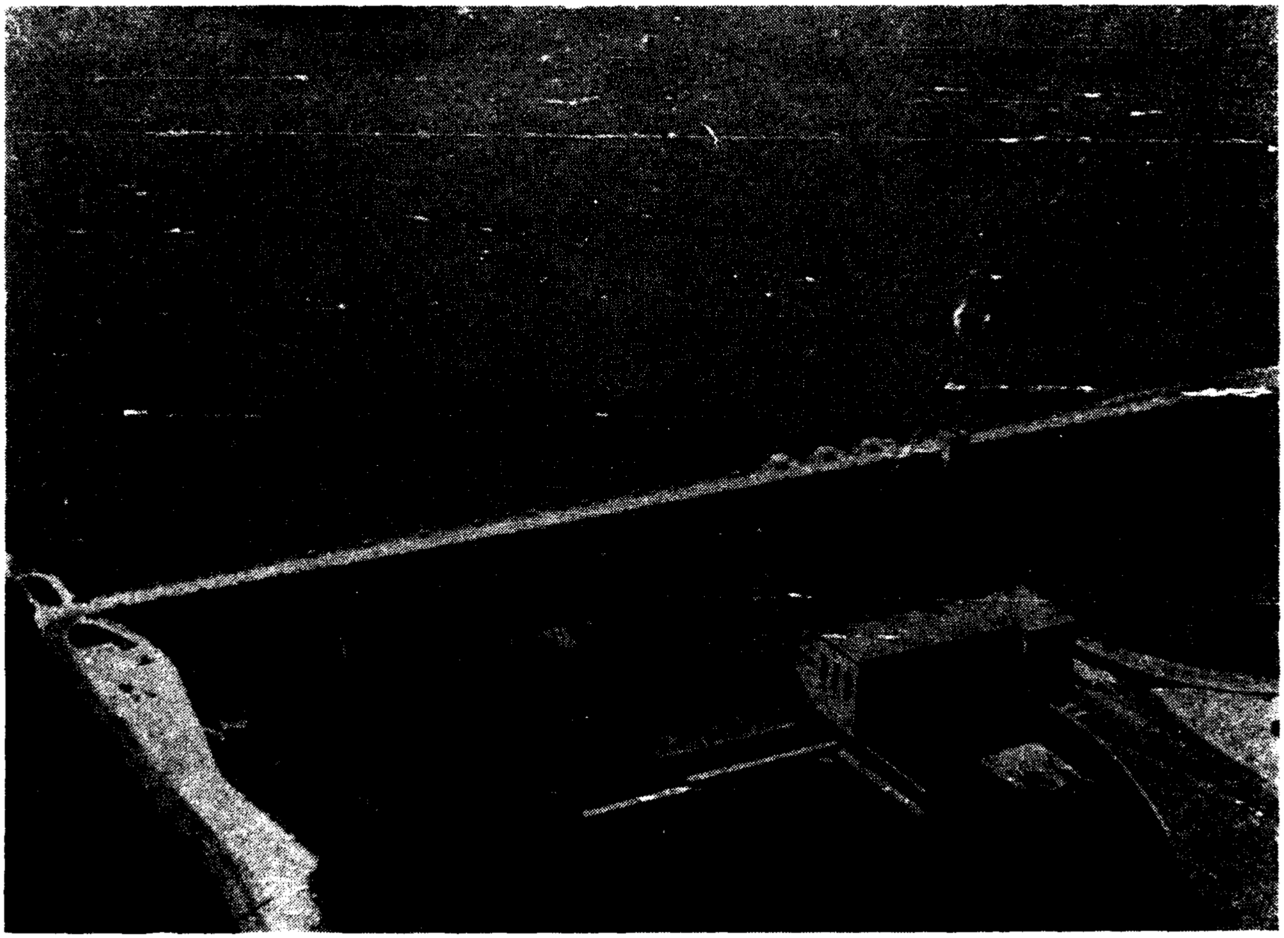
A Water Quality Survey of Nutrient Loadings to Center Hill Lake from the Caney Fork River Basin



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The U.S. Army Corps of Engineers contracted with Tennessee Technological University for a comprehensive survey of water quality conditions in Center Hill Lake and the Caney Fork River Basin. Primary purposes of the survey were to evaluate nutrient loadings of major inflows and wastewater treatment plants in the basin by bi-weekly grab-sampling and to determine effects of nutrients on water quality conditions in both embayments and the main-channel of the lake. The report presents a thorough analysis of those water quality parameters measured in the survey period and compares the data with previous data from the lake and similar reservoirs. Trophic levels for the survey period are estimated based on collected lake information. In addition, one storm event was surveyed in detail at two stream locations to evaluate the relationship between runoff and nutrient levels.

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A Water Quality Survey of Nutrient Loadings to Center Hill Lake from the Caney Fork River Basin

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Tennessee Technological University

Executive Summary

In recent years, concerns have been raised by various state and federal agencies over water quality changes in Center Hill Lake. During the period of March, 1988 to January, 1989, sampling of Center Hill Lake and its inflows and outflows was conducted on a regular basis in order to determine the water quality of the lake, its embayments, and its trophic state. Major inflows and wastewater treatment plants were sampled at two week intervals for water quality in order to perform a meaningful nutrient analysis for the lake.

The results of the study are specific for the data collection period, but none-the-less- are quite meaningful for lake managers and standards-setters. (It is possible that grab sampling missed peaks in flow and/or quality. The mass balances may not, therefore, present an exact picture of nutrient flux.) The study led to the following conclusions:

1. The main lake portion of Center Hill Lake is low in essential nutrients and is phosphorus limited. The mean orthophosphorus concentration was less than 10 micrograms per liter.

2. Embayments had more of the essential nutrients and phosphorus was more abundant in the metalimnion and hypolimnion.

3. Dissolved oxygen values are much lower in the embayments and are well below life sustaining concentrations below the epilimnion.

4. The main lake portion of Center Hill Lake had good dissolved oxygen concentrations except for a pronounced zone of low D.O. termed the metalimnetic minimum.

5. This new information supports the conclusions of Hunter (1987) who noted that Center Hill Lake is lower in nitrogen and phosphorus than it was in the early 1970s.

6. Based upon 1988 concentrations of total phosphorus and chlorophyll a and 1988 Secchi disk measurements, the main-channel of Center Hill Lake has been identified as mesotrophic through criteria set forth by three different

methods. The lake's classification using 1973 data indicated that the lake was strongly eutrophic (Gordon, 1976). It is believed that land-use changes and more efficient domestic wastewater treatment within the basin are the cause of an improved trophic classification.

7. Identical analyses performed for two of Center Hill's embayments, Falling Water and Mine Lick, indicate that the embayments are eutrophic. Higher nutrient loads and low flushing rates are believed to be significant factors in the trophic state of Center Hill's embayments.

8. The Caney Fork River which leaves Great Falls Lake contributed 71 percent of flow, 59 percent of orthophosphorus, and 56 percent of the total nitrogen to Center Hill Lake. The McMinnville and Sparta wastewater treatment plants contributed 15 percent of this ortho-phosphate phosphorus but only 3 percent of the total nitrogen.

9. The Falling Water River contributed 4.7 percent of flow, 23 percent of orthophosphorus, and 7.2 percent of total nitrogen to Center Hill Lake. The Cookeville wastewater treatment plant contributed most of the orthophosphorus and half of the nitrogen.

10. Direct precipitation contributed 4.8 percent of total nitrogen to the lake.

11. Ungaged, unmeasured runoff contributed 15 percent of flow during the study period.

12. Center Hill Lake trapped 78 percent of incoming phosphorus and 52 percent of total nitrogen during this study period.

13. A storm event sampling showed a non-uniform relationship between flow and water quality. Most parameters showed a first-flush pattern although nitrate increased as flows tailed off. This means that it is possible that grab samples do not adequately reflect the exact nutrient flux of Center Hill Lake.

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INTRODUCTION

1. Center Hill Lake is a tributary storage project created by a dam at mile 26.6 on the Caney Fork River in Middle Tennessee and operated by the Nashville District, U.S. Army Corps of Engineers. In recent years, concerns have been raised by various state agencies over water quality changes in the lake and its major embayments. Possible causes indicated were management of land use and/or point source discharges [Sansing, 1987]. Due to these concerns, a lake management coordination group was formed on April 28, 1987, with members from the Corps; the U.S. Soil Conservation Service; the Tennessee Wildlife Resources Agency (TWRA); and the Tennessee Divisions of Agriculture, Forestry, and Water Pollution Control [Sansing, 1987].

2. A major water quality concern of these state and federal agencies is a zone of dissolved oxygen depletion that has been observed in the metalimnion. This phenomena is believed to be caused by natural physical processes and a unique phytoplankton relationship that involves a combination of biological fallout and competition through shading [Morris, 1978; Sansing, 1987]. TWRA believes this layer of depleted dissolved oxygen represents a barrier to coolwater species of fish such as walleye and smallmouth bass [Sansing, 1987].

3. To better understand and quantify the cause(s) of this zone of oxygen depletion as well as its impact on fisheries and to gain much needed data concerning the nutrient load of streams entering Center Hill Lake, the Corps entered into a contract with Tennessee Technological University (TTU), Center for the Management, Utilization, and Protection of Water Resources (Water Center). The resulting research program was designed to survey the water quality of Center Hill Lake and its watershed and to collect water samples and field data from inflows, wastewater treatment plants (WWTP's), worse-case embayments, selected reservoir stations, and the tailwater.

4. The overall objective of this study was to estimate a nutrient budget for Center Hill Lake. The specific objectives are listed below:

1. Document and analyze the physical and chemical water quality patterns with respect to stream flow and time.
2. Document nutrient loadings of streams entering Center Hill Lake.
3. Document the contribution of WWTP effluent to the nutrient load of streams entering the lake.
4. Estimate the sources of nutrients with respect to point and non-point pollution.
5. Examine the effects of high nutrient loadings on localized water quality conditions in the lake by sampling worse-case embayments.

6. Determine the trophic status of the lake during the survey period.

7. Compare water quality in the embayments to that in the main portion of the lake.

STUDY AREA DESCRIPTION

5. The purpose of this chapter is to describe Center Hill Lake, including inflows and drainage basin. Descriptions of the lake's purposes, general features, hydrology, and major inflows are given in the following paragraphs.

Center Hill Lake

6. Center Hill Lake is a U.S. Army Corps of Engineers reservoir impounded by a concrete gravity and earthfill dam 250 feet high and 2160 feet long. It is located at mile 26.6 on the Caney Fork River in Middle Tennessee. In addition to authorized benefits of flood control and hydroelectric power generation, the lake provides for recreation, water supply, and fish and wildlife conservation.

7. The Center Hill Lake drainage basin covers 2,195 square miles. The lake has a maximum surface area of 23,060 acres, shoreline length of 415 miles, and a total storage capacity of 2,092,000 acre-feet. The lake is 64 miles in length, but averages only 2000 feet in width. The maximum water depth is 160 feet and the average depth is 71 feet with shallow depths located in the upstream reaches and relatively deep depths in the lower reaches. Center Hill Lake is located in DeKalb, Putnam, Warren, and White Counties about 20 miles southwest of Cookeville.

Statistical data on the physical dimensions of the lake are listed in Table 1. A map of Center Hill Lake is shown by Figure 1.

8. Project purposes. Center Hill Lake is one of the multipurpose projects included in the Corps' plan for the development of the Cumberland River Basin's water resources. This lake system controls the floodwaters of the Caney Fork River and contributes to the reduction of flood heights downstream along the Cumberland, Lower Ohio, and Mississippi Rivers. It provides a flood storage capacity of 762,000 acre-feet during the winter and spring months when the probability of heavy rainfall and flooding is greatest.

9. The Center Hill Project contributes an average of 351,000,000 kW hours of annual energy output to the surrounding Upper Cumberland power users. This electric power supply is produced by three 45,000 kW electric power generators using an allotted water volume of 492,000 acre-feet (plus inflows). This corresponds to a drawdown of 30 feet from El. 648 to El. 618.

10. Additional benefits realized from the lake are recreation, water supply, and fish and wildlife conservation. The U.S. Army Corps of Engineers was authorized by the enactment of the Flood Control Act of 1944 to construct, maintain, and operate public parks and recreational facilities on Corps projects [USACOE, 1948]. In addition, lands owned by the Corps were permitted to

Table 1

Statistical Data for Center Hill

Dam	
Type:	Concrete-gravity and earthfill
Dimensions:	
Max height, feet	250
Length, feet	2,160
Elevations (above mean sea level):	
Top of Dam	696
Top of gates	685
Spillway crest	648
Quantities	
Concrete, cubic yards	993,800
Earthfill, cubic yards	2,541,000
Hydropower	
Installation	135,000 kw. in 3 units
Rating each generator, kw.	45,000
Estimated energy output, average yearly, kwh.	351,000,000
Reservoir	
Drainage area, square miles	2,195
Areas, acres:	
Top of flood-control pool(El. 685)	23,060
Maximum power pool(El. 648)	18,220
Minimum power pool(El. 618)	14,590
Storage capacities, acre-feet	
Flood control(El. 685-648)	762,000
Power drawdown(El. 648-618)	492,000
Dead(below El. 618)	838,000
Total(below El. 685)	2,092,000
Length of pool at El. 685, river miles	64
Shoreline, pool at El. 685, miles	415

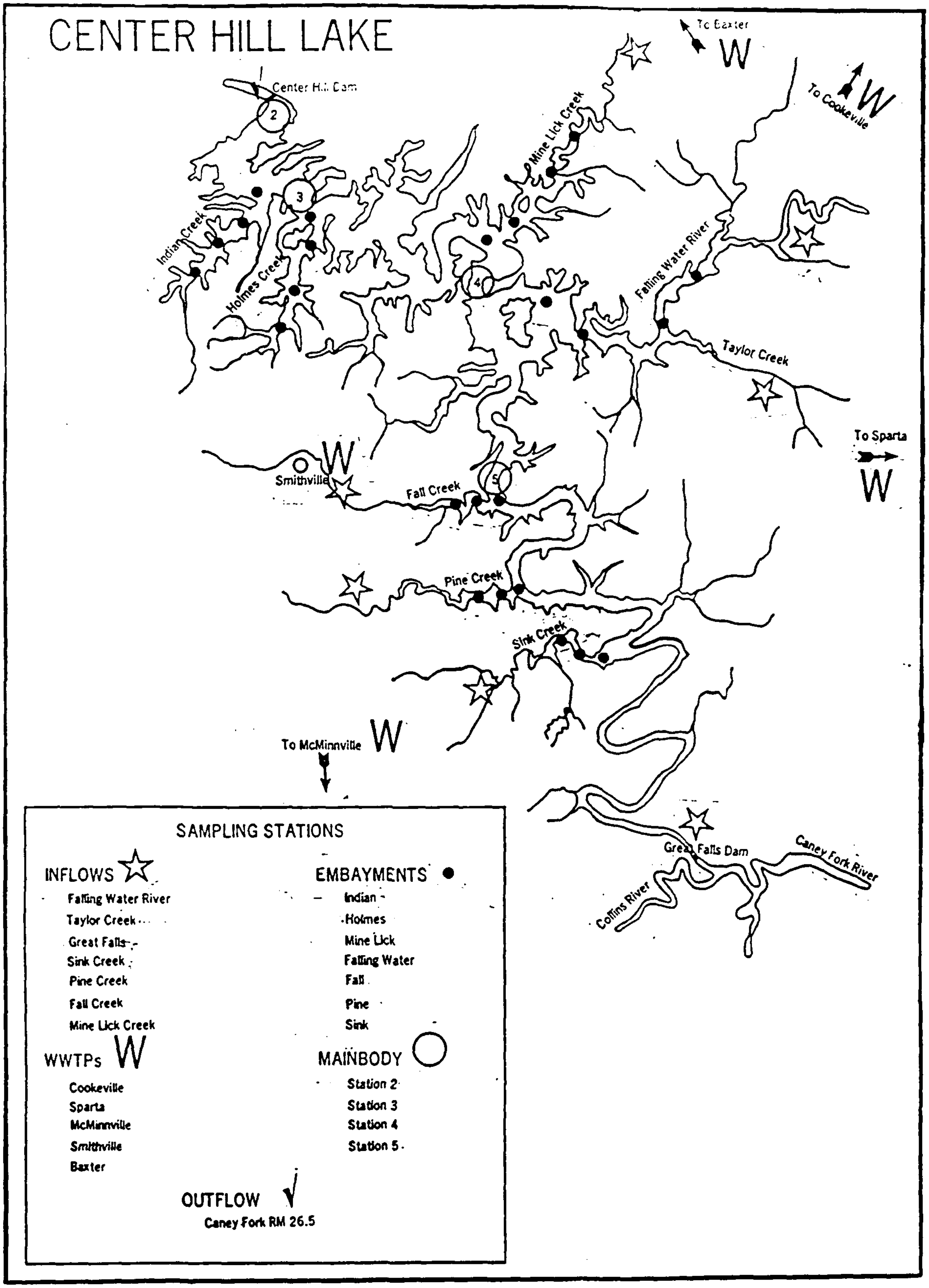

Figure 1. Schematic of Center Hill Lake Sampling Stations

be leased for recreational development. Currently, seven commercial boatdocks, two Tennessee State Parks, and nine major Corps' recreation areas are in operation for lake-related recreation which bring five million annual visitors to the project [Sansing,1987]. It should be noted that the present sanitary waste pumping facilities located at the commercial marinas are not adequate for handling the wastes from the current population of houseboats and cruisers. Currently, only three docks, Cookeville, Cove Hollow and Hurricane, have waste handling facilities and these are used primarily for their own rental houseboats. There seems to be a general reluctance of the boating public to use the few pump out facilities which are available. However, any possible effects caused by sanitary waste discharges from the boating population (possibly only localized impacts near marinas) are unknown at this time [Sansing, 1987].

11. The lake is a source of water for the cities of Smithville and Cookeville and their utility districts serving a combined population of 55,000 in the distribution area [Census, 1980]. The Smithville water supply intake is located on the reservoir's mainstream near Sligo Bridge and the Cookeville intake is on the Mine Lick Creek Embayment. These withdrawals are authorized by the Water Supply Act of 1956 [COE, 1975].

12. Fish and Wildlife management in and surrounding the lake falls under the jurisdiction of the State of Tennessee and has been assumed by TWRA. For this purpose, the Corps

has outgranted about 18,000 land acres to various state agencies of Tennessee and maintains a stable water level during fish spawning, when possible [COE, 1977]. TWRA is currently concerned with water quality in the reservoir as it affects various fish species.

13. Project features. Center Hill Lake is located in both the Central Basin and the Highland Rim, two physiographic regions of Tennessee. The Central Basin occupies the northwestern part of the reservoir downstream of Fall Creek and its surface is characterized by many rounded hills which rise a few hundred feet above the level of the surrounding lowlands. Slopes ranging from five to thirty percent are common in the rounded hills area and from three to twenty percent in the lowlands. The Highland Rim occupies the southeast portion of the reservoir upstream of Fall Creek and includes the FWR embayment area and the Mine Lick Creek Embayment area. It averages approximately 1,000 feet in altitude and has slopes ranging from three to eighteen percent [May, et al., 1981].

14. The geology of Center Hill Lake consists of Ordovician limestones underlying the Central Basin and Mississippian carbonate rocks underlying the Highland Rim. The two groups of Ordovician limestones which underlie the Central Basin are the Nashville and Stones River Groups. The Nashville Group is a resistant clay-rich phosphatic combination of limestone, mudstone, and dolomite. The

Stones River Group which underlies the Nashville Group is a more soluble limestone. The Mississippian rocks which underlie the Highland Rim are a combination of relatively insoluble silicates and highly soluble carbonates that form a thick cherty regolith [May, et al., 1981].

15. The soils of the Center Hill Lake watershed are defined with respect to its physiography. Within the watershed, the soils of the Central Basin (Dellrose-Mimosa-Bodine association) are cherty and clayey derived from colluvium, phosphatic limestone, cherty limestone, and shale. The potential for erosion in this soil region is moderate to high. The soils of the Highland Rim within the lake's basin (Bodine-Mountview-Dickson association) were formed from both thin loess and carbonate rocks and shale. The erosion potential in this soil region is also moderate to high. Soil erosion in the Caney Fork River Basin is not as severe as in other parts of the state [May, et al., 1981; Tennessee Department of Public Health, 1978].

16. The climate of Middle Tennessee has pronounced seasonal variations. The average annual temperature is about 60°F, with temperatures usually ranging from -5°F to 100°F. Temperatures are above 90°F about 75 days per year from April to October, the "frost-free" season [May, et al., 1981].

17. The land cover and land use characteristics surrounding Center Hill Lake consist of forestry, agriculture, and urban, industrial, and recreational uses.

The land immediately surrounding the lake is mostly forested while land surrounding the lake's major tributaries is mostly agricultural with some industrial use and urbanization. The shoreline population of Center Hill Lake is not known, but is probably on the order of 1,500 recreational residences with approximately 9,000 to 10,000 more residential sites available. The majority of the present shoreline population utilize septic tank/drain field systems for their wastewater disposal [May, et al., 1981; Gordon, 1976].

18. Project hydrology. The Caney Fork River drainage area above Center Hill Dam is 2,195 square miles of mostly forested and agricultural land. The average annual precipitation is about 54 inches with extremes seldom above 70 inches in wet years or below 35 inches in dry years. Precipitation measured at the Cooekville WWTP during this survey, March 1988 to January 1989, was approximately 52.25 inches [Personal communication with Tom Graham, 1989]. During the four years prior to this survey, precipitation in the Cumberland River Basin ranged from 35 to 39 inches or about 12 inches per year below normal. Rainfall was low in the lake basin for the first 8 months of this study, while November, December, and January were fairly rainy. Thunderstorms which often produce locally heavy rainfall occur about 56 days per year with the heaviest storms

occurring December through April [May, et al., 1981; Gordon, 1976].

19. The flow in Center Hill Lake is controlled by the Great Falls and Center Hill releases. Consequently, the water quality of the lake's main-channel is expected to be a function of the hydraulic retention time (HRT) of the water in the lake, not rainfall or runoff within the watershed. The long-term average HRT for Center Hill Lake is about 240 days [Gordon, 1976]. In contrast, the water quality of the lake's embayments is expected to be a strong function of runoff in the upper reaches because water flowing through the embayments is more controlled by stream inflows than by the releases from Great Falls and Center Hill. The average annual runoff is approximately 22 inches for the basin [May, et al., 1981; Gordon, 1976].

Center Hill Inflows

20. Center Hill Lake is a long, narrow, tributary storage project with several large inflows located in the upper end of the reservoir and several small inflows located along the lower reaches of the reservoir. The largest inflow, the Caney Fork River (Great Falls Power House), controls 76.4 percent of the reservoir's drainage area. Five major tributaries drain 58.4 percent of the watershed between the two dams of which Falling Water River accounts for 34.7 percent. All tributaries/embayments with

significant drainage area and inflow to the reservoir were sampled and are described below.

Sink Creek

21. The Sink Creek tributary/embayment is located at CFRM 74.7, has a length of 21.8 river miles, and a drainage area of 44.4 square miles. Its stream use is classified as providing for fish and aquatic life, recreation, irrigaton, livestock watering, and wildlife [Tennessee Department of Public Health, 1978]. Pates Ford Marina is located at the mouth of Sink Creek on Center Hill's mainstream. Sink Creek is a put-and-take trout stream stocked by TWRA. Land use is agriculture and tree/ornamental nursery proaduction.

Pine Creek

22. The Pine Creek tributary/embayment is located at CFRM 68.8, has a length of 14.5 river miles, and a drainage area of 27.0 square miles. Its stream use is classified as providing for fish and aquatic life, recreation, irrigation, livestock watering, and wildlife [Tennessee Department of Public Health, 1978]. Pine Creek is also a put-and-take trout stream. Predominant land use is agriculture similar to Sink Creek.

Fall Creek

23. The Fall Creek tributary/embayment is located at CFRM 62.3, has a length of 11.2 river miles, and drainage area of 16.0 square miles. Its stream use is classified as

providing for fish and aquatic life, irrigation, livestock watering, and wildlife. Recreation also is included in the lower 3.2 miles of the stream [Tennessee Department of Public Health, 1978]. At mile 4.6, Fall Creek receives the effluent from the Smithville WWTP, a contact stabilization activated sludge process. The plant's effluent has a biological oxygen demand (BOD) limit of 10 mg/l and a suspended solids (SS) limit of 15 mg/l [Personal communication with Barry Turner, 1989]. The creek also receives approximately 0.008 million gallons of seepage per day from the Hibdon Hosiery Mill at river mile 4.3. The BOD of this seepage is reported to 4.6 mg/l [Tennesse Department of Public Health, 1978]. Land use is a combination of agriculture and urban development.

Falling Water River

24. The Falling Water River tributary/embayment is located at CFRM 53.4, has a length of 47.9 river miles, and a drainage area of 208 square miles. Its stream use is classified as providing for fish and aquatic life, recreation, irrigation, livestock watering, wildlife, and domestic water supply (mile 0.0 to 39.0) [Tennessee Department of Public Health, 1978]. The Johnson Chapel recreation area, Cookeville Marina, and Burgess Falls State Natural Area are located in the Falling Water River Basin.

25. Falling Water River receives the flows of several small streams of which only two, Pigeon Roost Creek and Cane

Creek, are known to have an appreciable waste load. Pigeon Roost Creek, which receives the effluent from the Cookeville WWTP, an oxidation ditch/activated sludge process, at river mile 2.3, flows into Falling Water River at mile 25.22. Cookeville's treated effluent has a BOD limit of 15 mg/l and a SS limit of 30 mg/l [Personal communication with Barry Turner, 1989]. Cane Creek enters Falling Water River at mile 9.1 carrying Husky Industry's treated wastewater. It is reported to contain unknown amounts of phenols, oil and grease, and suspended solids [Tennessee Department of Public Health, 1978]. Land use is a combination of agriculture and urban/industrial development.

Mine Lick Creek

26. The Mine Lick Creek tributary/embayment is located at CFRM 42.5, has a length of 17.4 river miles, and a drainage area of 35.6 square miles. Its stream use is classified as providing for fish and aquatic life, recreation, irrigation, livestock watering, wildlife, and Cookeville's domestic water supply [Tennessee Department of Public Health, 1978]. Prior to December 30, 1988, Mine Lick Creek received the effluent from the Baxter WWTP, a packaged activated sludge plant, at river mile 15.8. This plant has a long history of operational problems and probably has done little to protect Mine Lick Creek. Currently, the Creek receives Baxter's treated wastewater at river mile 15.4. The new plant, an extended air activated sludge process

plant, currently has the same SS limit as the old plant, set at 30 mg/l, and a lower BOD limit, reduced from 30 to 25 mg/l [Personal communication with Barry Turner, 1989]. Basin land use is predominantly agricultural.

Holmes Creek

27. The Holmes Creek tributary/embayment is located at CFRM 32.5 and has a length of 6.4 river miles. Although the stream's drainage area and its flow are insignificant, the embayment is of sampling importance due to its size, and location in relation to Center Hill Dam, and the fact that it is widely used for recreation. Located within the Holmes Creek embayment are the Corps' Holmes Creek Recreation Area and the Holmes Creek Marina. The drainage is largely forested.

Indian Creek

28. The Indian Creek tributary/embayment is located at CFRM 30.3 and has a length of approximately 6.2 river miles. Like Holmes Creek, it has an insignificant drainage area and flow, but due to its location, size, and recreational use, it was chosen as a sampling site. The land surrounding the Indian Creek embayment is part of the Edgar Evins State Park. The drainage area is largely forested or wooded.

Caney Fork River (including Great Falls Lake)

29. The Tennessee Valley Authority (TVA) Great Falls Dam and its hydroelectric power generation facility, located

nearly two river miles downstream of Great Falls Dam (CFRM 86.4) provides for the largest inflow to Center Hill Lake. Flows are generally made via the powerhouse but very significant spillage often occurs at the dam. Associated with this inflow are the effluents from both the Sparta and McMinville WWTPs as well as treated industrial effluents. The Caney Fork Basin above Great Falls Dam includes inflow from Calfkiller, Rocky, Collins and Barren Fork Rivers, and Cane Creek. Most of the watershed is forested, but agriculture and urban development are important.

30. Prior to June 14, 1988, the Sparta WWTP, a trickling filter system, discharged into Calfkiller River at mile 14.1. Currently, Calfkiller River receives Sparta's treated wastewater at river mile 10.6. The new plant, an oxidation ditch, has the same BOD and SS limits as the old plant, both set at 30 mg/l [Personal communication with Barry Turner, 1989]. The Calfkiller River flows into the Caney Fork at CFRM 104.63. This new plant will, hopefully, prevent the wastewater and sludge problems experienced by Sparta in the past.

31. Currently, the McMinnville WWTP, an activated sludge and anaerobic digestion system, is designed for a maximum flow capacity of 2.0 mgd. Current expansions, an oxidation runway system, will allow the plant to treat a larger flow by early Spring 1989 [Personal communication with Barry Turner, 1989]. The plant's effluent will continue to have BOD and SS limits of 30 mg/l [Personal communication with

Barry Turner, 1989]. The McMinnville WWTP discharges into the Barren Fork River at mile 4.5 which in turn flows into the Collins River at CRM 21.49. The Collins River flows into the Caney Fork River at CFRM 91.18.

32. In the Caney Fork River Basin above Center Hill Dam there are 26 industries which have been recorded as maintaining wastewater discharges into surface streams [Tennessee Department of Public Health, 1978]. Of these, the treated effluents of Avalon Dairies, Duromatic, Oster Corporation, Benjamin Electric (Thomas Industry), and Doyle Launderette may impact the quality of water immediately downstream of Great Falls Lake [Tennessee Department of Public Health, 1978]. Recent industrial development around Cookeville, McMinnville, Smithville, and Sparta has been considerable and could be quantified if water quality problems are noted.

LITERATURE REVIEW

33. The purpose of this literature review was to gain background information on the physical, chemical, and biological water quality parameters that affect a lake's characteristics and to determine the current techniques of data analyses, applicable to this study's database, that would best represent water quality changes and nutrient loadings within the Center Hill watershed.

Physical Water Quality Parameters

34. The water quality of a lake is determined by the quality of the inflow water and by physical, chemical, and biological processes occurring within the lake. The following discussion describes the parameters that were monitored for technical analyses and future use in the management of Center Hill Lake and its watershed.

35. Physical parameters measured in this study were temperature, dissolved oxygen, pH, conductivity, ORP, Secchi disk transparency, turbidity, and stream flow. The importance of each of these parameters, with respect to Center Hill Lake, is discussed below.

Temperature

36. The thermal property of a body of water is an important factor in biological production, dissolved oxygen

variations, pollutant toxicity, and hydrodynamics. Most of these processes are significantly affected by the phenomena of thermal stratification which reduces reaeration due to the reduction in vertical circulation of the water [Kittrell, 1965].

37. Lakes become stratified due to low thermal conductivity of water, limited penetration of radient heat and light, and/or warmer inflows during late spring and early summer than the lake surface waters [Wells, 1980; Hutchinson, 1957]. Due to thermal density differences, the body of water divides into layers: the epilimnion, hypolimnion, and metalimnion or thermocline which is defined as the plane of maximum rate of decrease in temperature. The metalimnion is a term widely used to designate the whole of the region in which the temprature gradient is steep, from the upper plane of maximum curvature to the lower plane of maximum (inverse) curvature [Hutchinson, 1957].

38. From previous studies it is clear that the main body of Center Hill Lake is strongly stratified from early May until the middle of Fall [Gordon, 1976]. The reservoir is classified as monomictic since it does not cool down below 4°C in the winter and, therefore, does not experience winter stratification [Gordon, 1976; Hutchinson, 1957]. Similar thermal regimes are expected for Center Hill's embayments.

Dissolved Oxygen

39. The presence of dissolved oxygen in a body of water is of great importance in determining its nature and has been studied extensively over the years. The amount of dissolved oxygen (DO) in a simple solution is dependent on four factors: (1) the temperature of the water, (2) the partial pressure of the gas in the atmosphere above the water, (3) the concentration of dissolved salts in the water, and (4) the biological activity within the water body [Reid and Wood, 1976].

40. Oxygen depletion in the hypolimnetic waters of deep, thermally stratified lakes is a well-documented phenomena. During the 4 to 6 months of summer stratification, the hypolimnion is unable to replenish its dissolved oxygen by reaeration. Furthermore, decomposition of organic matter present in the water, bottom deposits, and dead plankton which settle from the top strata continuously, further deplete the available oxygen [Kittrell, 1965]. The biological/chemical and physical mechanisms that deplete oxygen in the isolated, deep water of stratified lakes are given in Table 2 [Gordon and Nicholas, 1977].

41. The observed oxygen deficit in the metalimnion of Center Hill Lake has been studied extensively [Gordon, 1976; Morris, 1978; Wells, 1980; Hunter, 1987]. The conclusions made by Morris [1978] as to the causes of oxygen depletion in Center Hill Lake, as taken from his report, are:

Table 2

Mechanisms of Oxygen Depletion that Occur in the Hypolimnia of Thermally Stratified Lakes (from Gordon and Nicholas, 1977)

Biological Processes

Biochemical Oxygen Demand

1. Long-term effects caused by organic carbon present in the lake water at the onset of stratification.

2. Continuous effects caused by autochthonous carbon supplies.

3. Nitrification of ammonia present at the onset of stratification.

Phytoplankton respiration

Zooplankton respiration

Fish respiration

Benthic respiration

1. Diffusion of dissolved oxygen into bottom muds.

2. Diffusion of dissolved organics from bottom muds into the overlying water.

3. Gas-stripping of dissolved oxygen by gas bubbles arising from the bottom muds.

4. Chemical oxygen demand by oxidizable metals and gases released from the anaerobic water and bottom muds.

Physical Processes

Groundwater

1. Inflow of a layer of ground water with low dissolved oxygen content.

"(1) The mechanism having the greatest impact on DO levels in the metalimnion is phytoplankton and zooplankton respiration with a minor but significant contribution exerted by 28-day biological oxygen demand.

(2) The relationship of phytoplankton concentrations to the position of the photic zone is directly related to whether high levels of production or severe depletions of DO occur within the metalimnion. If the waters of Center Hill were not so very clear, this relationship would cause more drastic dissolved oxygen depletion to occur.

(3) Bacterial and nutrient levels never reached a level high enough to exert a significant DO demand."

The analyses of DO data from 1971 to 1981 by Hunter [1987] showed that no long-term changes in dissolved oxygen have occurred within Center Hill Lake.

pH

42. The pH of a body of water is principally related to the carbon dioxide-bicarbonate system. Carbon dioxide is a normal component of all natural waters through absorption from the atmosphere and/or through biological oxidation of organic matter. The majority of natural waters have a somewhat alkaline pH due to the presence of carbonates and bicarbonates, inputs to natural waters from the ubiquitous supply of limestone and from the equilibrium of carbon dioxide in water [Stumm and Morgan, 1970].

43. Waters from the hypolimnion of stratified lakes often contain considerable amounts of carbon dioxide [Sawyer and McCarty, 1978]. This increased concentration results from bacterial oxidation of organic matter with which the

water has been in contact thereby increasing pH. Carbon dioxide is an end product of both aerobic and anaerobic bacterial oxidation; consequently, dissolved oxygen does not limit its concentration [Sawyer and McCarty, 1978].

44. Previous studies of Center Hill Lake revealed that its general range of pH is 7.2 to 7.5 [Gordon, 1976; Hunter 1987]. This range is subject to two mechanisms which alter pH. The first mechanism is photosynthesis, which involves the uptake of carbon dioxide by phytoplankton, thereby raising the pH. The second mechanism is respiration, which causes the release of carbon dioxide by heterotrophic bacteria and algae, resulting in a reduction of pH. High pH values in the photic zone of Center Hill Lake indicate fairly high photosynthetic rates [Gordon, 1976]. The analysis of pH data gathered from 1971 to 1981 showed no long-term pH changes within the reservoir [Hunter, 1987].

Secchi Disk

45. A Secchi disk is a simple round disk, painted with black and white quadrants, used to measure transparency or light penetration in lakes or reservoirs. Where low Secchi disk readings are caused by algae, the Secchi disk indirectly provides some measure of a lake or reservoir's fertility [Cooke, et al., 1986]. In other cases it provides an indirect measure of suspended solids concentrations.

46. Although there are more elaborate methods to study light transmission in reservoirs, the Secchi disk still

retains its value [Hutchinson, 1957]. The procedure is simply to observe the points of disappearance and reappearance while the disk is lowered and raised, respectively. These observations must be made through a shaded area of surface water; and their mean value is taken as the Secchi disk transparency. It was concluded by Yoshimura [1938], using the data of Birge and Juday, that the Secchi disk transparency is approximately equivalent to the level of penetration of five percent solar radiation [Hutchinson, 1957].

47. Except for occasional periods of high turbidity following major inflow events during the winter and spring seasons, the waters of Center Hill Lake have been found to be very clear [Gordon, 1976]. Secchi disk readings taken between May 27, 1971, and September 17, 1974, were analyzed statistically resulting in a mean value of 8 feet with a standard deviation of 3.2 feet [Gordon, 1976].

Turbidity

48. Turbidity is a term used to describe the degree of opaqueness, the optical property of water that causes the scattering and absorption of light rays instead of transmittance in straight lines, produced in water by suspended particulate matter [Reid and Wood, 1976; Mackenthun and Ingram, 1967]. The concentrations of these particulates determine the transparency of the water by limiting light transmission.

49. The matter creating turbid conditions in a given body of water are as varied as the composition of the surrounding watershed and inflowing streams. Such matter may be humus, silt and clay, living or dead phytoplankton or zooplankton cells, or other finely divided inorganic and organic waste materials. Substances produced outside and brought into a lake are termed allochthonous; and turbidity-creating matter produced within the lake are termed autochthonous.

50. Turbidity limits aquatic growth, interrupts food chains, and reduces animal life. Turbidity varies within a lake in response to seasonal increases in stream discharge, land uses, and particulate settling within the lake.

Stream Flow

51. Flow is the volumetric discharge or transport of water in a stream or channel cross-section. Stream flow may be laminar, low flow parallel to the sides of the channel, or turbulent, rough flow above a certain critical velocity. Most streams have turbulent flow.

52. Stream velocity is the distance a mass of water moves per unit time. The movement of dissolved and suspended materials, rate of discharge, erosion, distribution cf plant and animal life, and other aspects of stream ecology are dependent on stream velocity [Reid and Wood, 1976]. The velocity of a stream is determined by the

flow, the cross-section and gradient, and the bottom roughness of the stream.

53. Stream discharge is the total volume of stream water passing a point in a given period of time and its measurement is termed "gaging" [Reid and Wood, 1976]. Discharge varies with season and with the contribution of tributaries because it is proportional to rate of flow and volume of water.

54. Electrical parameters monitored for this study were specific conductivity and oxidation-reduction potential. A discussion of the importance of these parameters, with respect to Center Hill Lake, follows.

Conductivity

55. Conductivity is a measure of a water's ability to carry an electrical current, and varies with both the number and type of ions in solution and the temperature during the time of measurement [Sawyer and McCarty, 1978; Gordon, 1976]. By definition, specific conductance is the reciprocal of the resistance measured between two electrodes separated by 1 cm and having a cross-sectional area of 1 sq. cm [Stumm and Morgan, 1970]. If a solution has many electrolytes dissociated within it, the conductance will be high; on the other hand, if the solution has few ions present, the conductance will be low because the resistance to the flow of electrons will be high. The most common anions and cations in natural waters have generally been

found to be CO_3^{--}, SO_4^{--}, Cl^-, Ca^{++}, Mg^{++}, Na^+, and K^+ [Cole, 197556.].

56. Two of the most beneficial uses of the specific conductance measurement in aquatic systems have been to clarify the relationship between dissolved ion concentrations and water productivity or photosynthetic activity and to provide a check for total water quality alterations due to pollution inputs [Lind, 1979].

Oxidation-Reduction Potential

57. The measurement of the oxidation-reduction potential (ORP) for a natural water reflects the "proportion of oxidized to reduced components of a particular system in relation to other systems" [Reid, 1961]. In other words, it can help to indicate whether a particular reaction is possible under given environmental conditions. The ORP measurement will not tell whether the reaction will in fact occur, but it is helpful in evaluating how conditions might best be changed to encourage desirable transformations or to prevent undesirable ones [Sawyer and McCarty, 1978]. The predominant participants in aquatic redox processes are N, O, C, S, Fe, and Mn [Stumm and Morgan, 1970].

58. Many redox reactions are biologically mediated. The "chemical reaction sequence is paralled by an ecological succession of microorganisms: aerobic heterotrophs, denitrifiers, fermentators, sulfate reducers, to methane bacteria" [Stumm and Morgan, 1970]. Therefore, the balance

between the photosynthetic and the oxygen-conserving processes is important for establishing the ORP of a natural water.

59. In a natural body of water, ORP measurements decrease as the oxygen concentration decreases because of the "depletion of successively less-easily reduced chemical species" [Varga and Falls, 1972]. Lower ORP values suggest that reducing agents are present which would utilize free dissolved oxygen if it were available [Reid, 1961].

Nutrients

60. The life cycle of a lake or reservoir is referred to as eutrophication, the process of "excessive addition of inorganic nutrients, organic matter, and/or silt to lakes and reservoirs, leading to increased biological production and a decrease in volume" [Cooke, et al., 1986]. Of the nutrients available in waterbodies, phosphorus and nitrogen have emerged as the nutrients responsible for eutrophication. Sawyer [1947] suggested that a lake may be expected to produce excessive growths of algae if, during the time of spring overturn, concentrations of inorganic phosphorus and inorganic nitrogen exceeded 0.01 mg/l and 0.3 mg/l, respectively. His criteria are still valid and accepted today.

61. The following paragraphs will focus on phosphorus and nitrogen species in lakes, their effects, and their potential sources and corresponding concentrations.

Historical nutrient data will be referenced for Center Hill Lake as developed and summmarized by Gordon [1976] and Hunter [1987].

Phosphorus

62. Of all elements, phosphorus is likely to be the most ecologically important because the ratio of phosphorus to other elements in organisms tends to be significantly greater than the ratio of phosphorus to other elements in the mineral sources of the essential elements [Gordon, 1976]. Comprehensive studies of phosphorus experiments by Bartsch [1972] and Cooke et al. [1986] concluded that the limiting nutrient in eutrophication and productivity of freshwaters is often phosphorus. Furthermore, among a wide spectrum of major and minor nutrients which are needed for algal growth, phosphorus is the most controllable major nutrient required by algae [Cooke, et al., 1986]. Sawyer [1962] indicated that the removal of phosphorus from a waterbody would first, decrease the phosphorus-to-nitrogen ratio and allow phosphorus to become a limiting factor in the growth of green algae and second, allow for growth of green algae thereby further reducing the concentration of phosphorus such that the growth of nitrogen-fixing blue green algae might be curtailed.

63. Figure 2 illustrates the phosphorus cycle in water [AWWA Task Group, 1970]. Soluble inorganic phosphorus in natural waters results from the weathering and solution of

crystalline and/or amorphous particulate phosphate minerals contained in the water or soils. In addition, soluble orthophosphates in excessive quantities may precipitate to form poorly soluble particulate phosphates. Complex phosphates, which are manmade as well as generated by all living organisms, are unstable in water and slowly hydrolyze to the orthophosphate form. Soluble orthophosphates are the most available for biological growth while refractory phosphorus is relatively unavailable and may settle to form part of the sludge deposits and organic muds of rivers and lakes.

64. Gordon's [1976] conclusions, drawn from phosphorus data collected on Center Hill Lake, stated that the major form of phosphorus in the waterbody is particulate. His analyses of data also showed that there appeared to be additions of total phosphorus from Sink, Pine, and Fall Creeks. Approximately ten years of phosphorus data for Center Hill were analyzed by Hunter [1987] and revealed long-term reductions of total phosphorus in the reservoir between 1971 and 1981. However, some of the data used by Hunter have recently been retracted by the Nashville District, U. S. Corps of Engineers.

Nitrogen

65. With the exception of carbon and oxygen, nitrogen is the most prevalent element in algal cells. However, in most cases, it is not practical or feasible to consider it as a

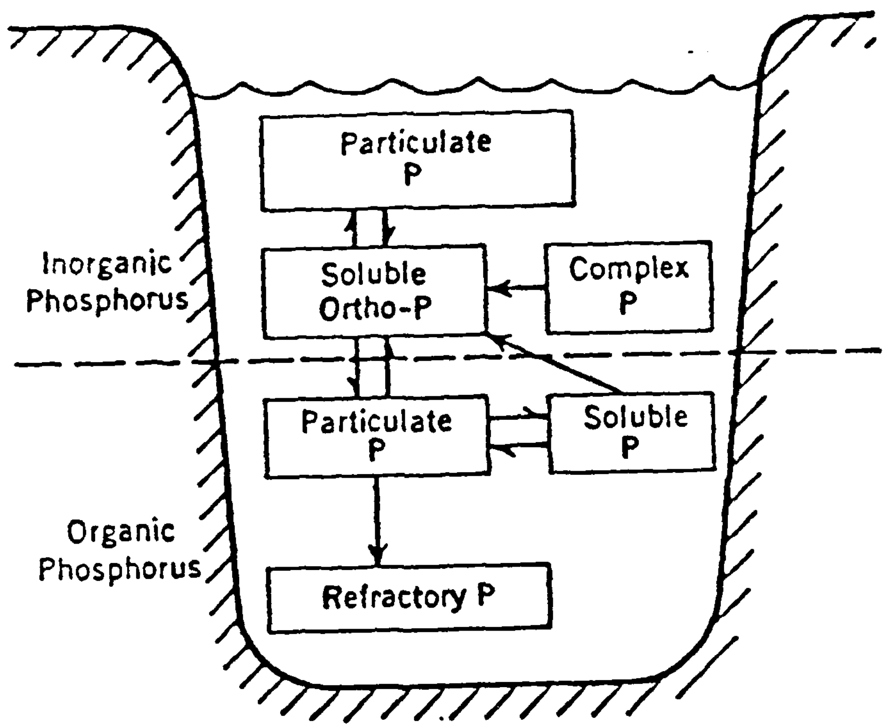

Figure 2: Phosphorus Cycle in Water (from AWWA Journal)

key to limiting algal growth for the following reasons as summarized by Tsai and Huang [1979]:

> "(1) Nitrogen in most wastewaters is present in the forms of ammonium ion and organic nitrogen, which may be converted to nitrate in the process of biological treatment. The removal of all different forms of nitrogen cannot be accomplished by a single treatment method.
>
> (2) In land application of wastewaters, although organic nitrogen generally does not penetrate through soil and the ammonium ion is also retained effectively by soil through adsorption and ion exchange, these compounds are gradually converted to nitrate under aerobic conditions. Since nitrate is not fixed in soil by any special mechanism, it will eventually leach through soil and reach groundwater unless it is removed by growing crops.
>
> (3) In the absence of adequate sources of inorganic and organic nitrogen, certain blue green algae are capable of fixing atmospheric nitrogen. As such, there is no assurance that the reduction of nitrogen input into natural waters can effectively limit the growth of the nitrogen-fixing blue greens, such as Anabaena, Gloeotrichia and Nostoc, etc."

66. The average nitrogen-to-phosphorus ratio in plankton is about 15 to 1 [Tsai and Huang, 1979]. Therefore, waters which contain nitrogen and phosphorus in ratios greater than 15 to 1 will probably have their productivities limited by phosphorus. On the other hand, productivities will be limited by nitrogen for waters having a N:P ratio less than 15 to 1. The key determinant with respect to a limiting nutrient, whether nitrogen or phosphorus, lies on the relative quantities of these two nutrients in an aquatic ecosystem.

67. The relationships between the various nitrogen species of major interest are indicated in Figure 3 [AWWA Task Group, 1970]. Molecular nitrogen, derived from the atmosphere, may be reduced and converted to organic nitrogen by certain nitrogen-fixing bacteria and algae. In natural waters, there is dissolved N_2, ammonia, and salts of the nitrate and nitrite ions. In addition, waters contain organic-nitrogen compounds which are attributable to the presence of aquatic life and insoluble organic-nitrogen compounds which do not readily undergo degradation by microorganisms [AWWA Task Group, 1970].

68. Gordon's [1976] analyses of Center Hill Lake data indicated that nitrogen concentrations were high in the reservoir when compared to trophic danger levels cited in literature. The predominant nitrogen forms found in the reservoir were organic nitrogen and nitrate. Furthermore, their concentrations substantiated the phosphorus-concentration-based classification of Center Hill Lake as an early-stage eutrophic waterbody. The analyses of nitrogen data over a ten-year period by Hunter [1987] showed long-term reductions in total inorganic nitrogen concentrations over the period of 1971 to 1981.

Nutrient Sources

69. The potential of a waterbody to become eutrophic is greatly influenced by the nature of its drainage basin because it is usually the land and its uses that govern the

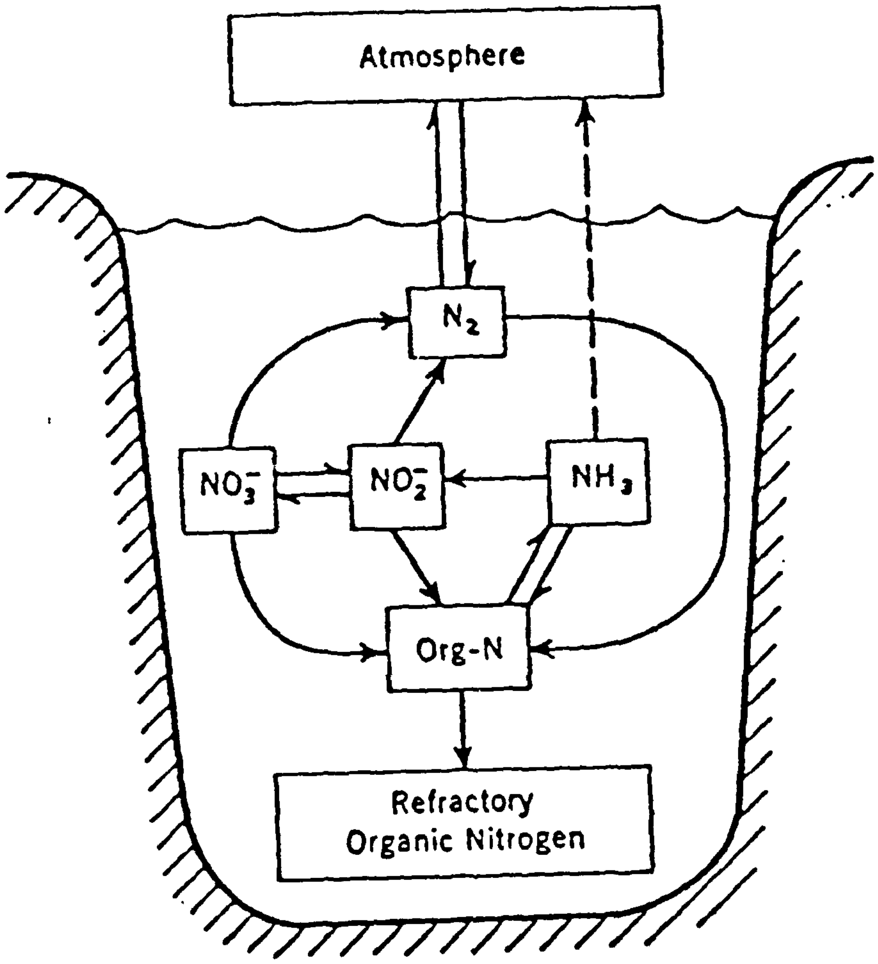

Figure 3: Nitrogen Cycle in Water (from AWWA Journal)

sources and pathways along which nutrients, organic matter, and silt are transported. Sources of these materials are classified as "point" or "nonpoint." Point sources are cultural locations at which nutrients are released in measurable quantities and concentrations, usually through pipes from domestic and/or industrial sewage treatment plants [Uttormark, et al., 1974; Cooke, et al., 1986]. Non-point sources, which are more difficult to quantify and control, include soil erosion, animal wastes, urban runoff, septic systems, acid mine drainage, groundwater, and fertilizers [Cooke, et al., 1986]. Materials from any of these sources may enter a waterbody through biological, meteorological (rain), or hydrological (runoff, groundwater) pathways.

70. Cultural sources. Concentration data for both nitrogen and phosphorus have been gathered and analyzed over the years for various water bodies and wastewater streams [Hutchinson, 1957; AWWA Task Group, 1970]. Nitrogen data from these studies show total nitrogen concentrations present in domestic wastewater effluents ranging from about 18 to 28 mg/l with ammonia nitrogen being the most predominant species in effluents from primary and high-rate treatment plants and nitrites/nitrates most predominant in aerobic biological treatment plants. Nitrogen species are highly variable depending on degree of operational control of factors such as aeration time and sludge age.

Agricultural drainage waters are highly variable with respect to nitrogen concentrations with values ranging from 1 to more than 100 mg/l, mostly in the form of nitrate. Relatively large concentrations of organic nitrogen and some ammonia nitrogen are also found in surface runoff; however, even higher concentrations are associated with subsurface drainage waters as they percolate through soil. Groundwater contributions to the nutrient load of a lake are difficult to determine but should not be ignored because in many cases low dissolved oxygen and high nutrient concentrations are associated with ground water inflows [Cooke, et al., 1986]. Due to the karst nature of the Center Hill watershed whereby groundwater recharge occurs rapidly via sinkholes, groundwater was assumed to have the same seasonal qualities as surface water. Feth [1966] indicated that nitrate concentrations in rivers throughout the United States averaged about 0.8 mg/l for rivers receiving low areal discharge to about 0.5 mg/l in rivers with a relatively high areal discharge. Hutchinson's [1957] summary of data indicated organic nitrogen as the predominant combined-nitrogen species in lakes followed by nitrate nitrogen.

71. Definitive statements about typical phosphorus concentrations are difficult due to limited and possibly erroneous data collected over the years [Cooke, et al., 1986]. Total phosphorus in sewage treatment plant effluents, not specifically treated for phosphorus removal, ranges from about 3.5 to 9 mg/l [AWWA Task Group, 1970]. In

secondary sewage effluents, about 70 to 90 percent of the total phosphorus is orthophosphate [AWWA Task Group, 1970]. Some phosphorus is removed by sewage sludges if the sludge is kept aerobic. Agricultural drainage waters contain phosphorus in concentrations ranging from 0.05 to 1.0 mg/l, and the phosphorus may be present in many dissolved and particulate forms. The AWWA Task Group [1970] reported that total phosphorus concentrations in U.S. rivers ranged from 0.01 to 1.0 mg/l and concentrations in U.S. lakes varied widely from 0.001 mg/l to 100 mg/l depending on the waters they receive.

72. <u>Bulk precipitation</u>. Bulk precipitation is defined to include rainfall, snowfall, and dry fallout (dust fall). Of these types of precipitation, dry fallout is believed to be the largest contributor of nutrients [Uttormark, et al., 1974]. In many studies, it was found that nitrogen contributions from dry fallout ranged from 40 to 70 percent of atmospheric nitrogen [Uttormark, et al., 1974]. The contribution of phosphorus through bulk precipitation has been studied less than nitrogen because it is believed that other sources of phosphorus are likely to be more important in lake management. Furthermore, not only are phosphorus data limited for atmospheric bulk precipitation, but sampling problems and regional variations also complicate data interpretation [Uttormark, et al., 1974].

73. Agriculture and industrial development tend to increase atmospheric nutrient contributions [Uttormark, et al., 1974]. As these activities are certain to increase in the future, it appears that the atmospheric contributions of nitrogen and phosphorus are becoming more significant with respect to the control of lake eutrophication.

Biological Water Quality Parameters

74. Biological parameters monitored for this study were chlorophyll a, pheophytin a, and phytoplankton. The importance of these parameters, with respect to Center Hill Lake, is discussed in the following paragraphs. No quantitative biological data were reported for Center Hill Lake although it is known that the Nashville District has taken some data.

Phytoplankton

75. The term "phytoplankton" refers to planktonic plants, "microscopic aquatic forms having little or no resistance to currents and living free-floating and suspended in open or pelagic waters" [Standard Methods, 1985]. They occur in unicellular, colonial, and/or filamentous forms. The phytoplankton population of lakes and reservoirs is made up mainly of diatoms, blue green algae, green algae, and photosynthetic flagellates, but no truely "typical" community exists [Reid and Wood, 1976]. Diatoms affect water quality by shortening filter runs

during raw water treatment; blue-greens have demonstrated toxicity to fish and domestic mammals as well as taste and odors to drinking water; and greens and flagellates increase turbidity and can increase the overall productivity of an aquatic community [Lorenzen, et al., 1981]. Blue-green algae contribute to major nuisance problems (floating mats and scums) in lakes and reservoirs.

76. Plankton, especially phytoplankton, have long been used as water quality indicators and have been correlated with trophic stages of lakes [Reid and Wood, 1976]. Because of their short life cycles, plankters respond quickly to environmental changes. Phytoplankton biomass tends to be high in the spring and early summer due to increasing water temperature and to light availability, and to low losses to plankton grazing. The biomass declines from early to mid-summer due to increased grazing and decreased nutrient concentration, but increases again with the fall overturn. Algal biomass is generally low in winter because of low water temperatures and low light availability although diatom species can grow abundantly. As water quality indicators, some species flourish in eutrophic waters while others are very sensitive to organic and/or chemical wastes. Plankters can also be initiators of certain changes in water quality such as pH, taste, color, and odor. Correlations of phytoplankton with trophic states of lakes have been used to characterize oligotrophic lakes as having a relatively low quantity of total plankton with few population pulses and

eutrophic lakes as supporting a large quantity of phytoplankton composed of few species with frequent population pulses [Reid and Wood, 1976]. Phytoplankton productivity may be limited by high turbidity in inflowing water and/or if the retention time in the euphotic zone is low [Hunter, 1987].

Chlorophyll a

77. Chlorophyll is an enzyme present in green plants and a common indicator of phytoplankton biomass. Most green plants contain the pigments chlorophyll a, b, and c; and, chlorophyll a constitutes about 1 to 2 percent of the dry weight of planktonic algae [Standard Methods, 1985]. As chlorophyll increases in lakes, the phytoplankton population generally increases causing the lake to become more eutrophic. However, since chlorophyll is directly related to light levels and primary production capacity, it may not correlate directly to a large quantity of algae that are not growing nor directly relate to a small population of algae with a substantial growth rate [Mackenthun and Ingram, 1967].

Pheophytin a

78. Pheophytin a is the most common degradation product of chlorophyll a. It can interfere with the determination of chlorophyll a because it absorbs light and fluoresces in the same region of the spectrum as chlorophyll a [Standard

Methods, 1985]. Therefore, pheophytin a is measured to reduce errors in effective chlorophyll a values.

Data Analyses Techniques

79. Data analyses techniques were required to summarize water quality conditions and to provide for simple nutrient budgets using biweekly nutrient, flow, and physical water quality data obtained by grab sampling. The most common techniques used to analyze water quality data on a broad scale are basic statistics and water quality indicies. Time series analyses and modeling are applicable to a more detailed database for a specific water quality problem. A nutrient budget may be developed from estimated source loadings to determine problem areas in a reservoir and aid in lake management.

80. Analyses techniques which can be applied to water quality data can be grouped into two categories, graphical techniques and statistical techniques. Obviously, the size of the data base is an important factor in the applicability of various analytical techniques. The techniques that apply to this study are lake profile plots, streamflow and time-series plots, basic summary statistics, correlations and regressions, and loadings and eutrophication estimates.

Graphical Techniques

81. Graphs are used to display data patterns and as a check for data errors. By plotting one variable versus

another, any correlation between the values may be more readily identified for further statistical analyses.

82. Water quality profiles. Water quality profiles depict the changes of water quality parameters with increasing depth at a specific location in a lake or reservoir. The most common water quality profiles developed for lakes and reservoirs are those for temperature, dissolved oxygen, and pH during stratification.

83. Stratified temperature curves are useful for displaying a lake or reservoir's epilimnion, hypolimnion, and thermocline patterns. The depth of each layer as well as multiple layers can also be exhibited by profile plots.

84. Dissolved oxygen profiles are useful for depicting dissolved oxygen maximas and minima in a lake or reservoir. Two dissolved oxygen minima commonly found in deep stratified reservoirs are the metalimnetic minimum and the hypolimnetic minimum. The metalimnetic minimum is the depletion of oxygen from a restricted layer in the middle depths of a reservoir that occurs when river inflow, BOD, and nutrients do not immediately mix with the reservoir water [Lorenzen, et al., 1981]. The hypolimnetic minimum is the depletion of oxygen throughout the hypolimnion; or in some cases, a more pronounced depletion at the bottom of the lake caused by organic-rich sediments and the settling of organic particles [Hutchinson, 1957].

85. The vertical distribution of pH in a reservoir is determined by the utilization and liberation of CO_2 [Hutchinson, 1957]. The profile curves of pH can show slight decreases in pH in the hypolimnion of a reservoir which often correspond to a decrease in dissolved oxygen concentrations during summer stratificaton. A minimum pH value in the upper hypolimnion may be caused by the liberation of ferrous and manganous bicarbonate [Hutchinson, 1957]. Maximum values in the pH curve are often the result of photosynthesis in the photic zone near the lake surface.

86. Streamflow and time-series plots. Plots used to illustrate the patterns of streamflow within a basin are termed "hydrographs." Used in conjunction with time-series plots of water quality data, hydrographs are effective graphical techniques for describing water quality variations due to streamflow fluctuations [Young, 1988]. Many different methods of plotting can be used depending on the purpose of the graph and the detail of the data base [Knapton, 1978]. Significant flow variations depicted by these plots include total runoff from year to year, variations due to storm events and dry periods throughout the year, and seasonal variations in runoff [Young, 1988].

87. With sufficient streamflow data, stormflow (surface runoff) and baseflow (groundwater that enters a stream through seeps and springs) can be mathematically separated and used to determine the relative contribution of direct

runoff and groundwater discharge on a sample date. Water quality data can then be analyzed with respect to both baseflow and stormflow. A simple equation commonly used to describe baseflow is the recession curve:

$$Q_t = Q_o * K^t \quad (1)$$

where Q_o is the discharge at some initial time, Q_t is the discharge at some time (t) after Q_o, K is the recession constant ($time^{-1}$), and t is the time interval between Q_o and Q_t [ASCE, 1949]. A large recession coefficient (K) represents the high-rate release of groundwater to the stream; and a small recession coefficent represents the slow release of water from a large-capacity aquifer to the stream [Young, 1988].

88. Several studies referenced by Young (1988) revealed that baseflow is characterized by higher dissolved solutes and lower concentrations of suspended sediments as compared to stormflow. These observations can be explained by the long residence time of the baseflow beneath the land surface and its pathway to the stream.

Statistical Techniques

89. Statistical techniques are frequently used to derive summary information (i.e. means, medians, standard deviations) from water quality data that can be used to compare data from different sampling sites. Basic statistics commonly computed for water quality data are the

arithmetic mean, median, range, distribution quartiles, standard deviation, variance, coefficient of variation, and coefficient of skewness [Young, 1988]. In addition, correlation and regression analyses are often used to describe relationships between water quality variables. Furthermore, the graphic display of data, scatterplots and time-series plots, may be used as an indicator of the validity of any statistical assumptions [Sanders, et al., 1983].

90. Basic statistics. The central tendency of a data set is measured by the mean, the arithmetic average of the data, and by the median, the middle value of the ranked data for which there is 50 percent probability of exceedance. Other measures of central tendency are the range, the difference between the maximum and minimum observation, and quartiles, values which divide the cumulative distribution of data into four quartiles including the minimum, median, and maximum [Meyers, 1975].

91. Quantities that describe variation, how an individual variable differs from another and how they vary from the average values, are measures of dispersion [Meyers, 1975]. Measures of dispersion are the standard deviation, variance, and coefficient of variation.

92. For a symmetrical distribution, the mean, median, and mode (most probable measured value) coincide. Skewness is the "deviation from symmetry" or noncoincidence of these values [Meyers, 1975]. A negative coefficient of skewness

means that the mean of a set of data is less than its mode whereas a positive coefficient represents data that has a mean greater than its mode [Young, 1988]. A skewness coefficient of zero not only means that the data set has equal mean and mode values; but more importantly, it means that the data are also normally distributed. The type of distribution a water quality parameter exhibits is important for many statistical analyses techniques; most of which are based on the assumption that the data are normally distributed. Nonparametric tests, distribution free tests, such as the Wilcox and Seasonal Kendall Tests, are applied to data sets which do not exhibit a normal distribution [Young, 1988].

93. Correlations and regressions. Correlation and regression analyses are used to estimate the relationship that may exist between water quality variables [Young, 1988; Knapton, 1978; Steele, 1973; Frost, 1974]. The degree of (linear) correlation between two quantities is described by the correlation coefficient (r). If the two quantities are uncorrelated, the coefficient is expected to be close to zero. For a perfect correlation (anticorrelation) the coefficient is expected to be close to 1 (-1) [Meyers, 1975]. A scatter diagram is commonly used to visually display correlations between two variables.

94. Once the degree of correlation has been verified between two variables, regression models can be developed

that describe the desired water quality variable as a function of one or more other variables. Regression models developed for lake management studies may be useful in providing predictive capabilities that could lead to reduced sampling thereby reducing laboratory analyses and data storage and processing. Regression models can also be used to estimate instream constituent loads, predict phytoplankton productivity in lakes, and quantify the effects of large-scale land use changes on upstream drainage [Knapton, 1978].

95. Water quality variations are often due to variations in streamflow [Knapton, 1978; Daniel,et al., 1979]. The most common regression model developed for streamflow variations is the logarithmic model:

$$C = a * Q^{b} \qquad (2)$$

where Q is stream discharge and a and b are regression coefficients [Steele, 1976]. The disadvantage of this model is that unrealistically high concentrations are estimated at low flows for negative values of b because the concentration (C) approaches infinity as the flow (Q) approaches zero. Therefore, the model may overestimate concentrations under flow dilution conditions.

96. The linear regression model:

$$C = a + b * Cond \qquad (3)$$

is commonly used to express solute concentration as a function of conductivity, where C is the concentration of a major inorganic solute (mg/l), Cond is the specific conductance (micromhos per centimeter at 25 degrees Celsius), and a and b are regression coefficients. These coefficients are assumed to be constant for each sampling site when no significant changes in upstream land use or discharges are observed. Although a calibration period of 3 to 5 years is recommended for the regression analysis, a single year may be used [Steele, 1973]. Young's [1988] review of several studies revealed successful results in explaining cause and effect relationships due to streamflow and conductivity [Steele, 1971; Blakley, 1972; Dyer, 1973; Frost, 1974; Knapton, 1978; Daniel, et al., 1979].

Transport Loading Estimates and Nutrient Budgets

97. In order to develop a nutrient budget of a lake or reservoir, loading estimates are required to quantify the nutrient, particulate, and/or chemical transport in rivers and streams [Verhoff, et al., 1980]. The mass load of a specific substance transported by a river is defined as the product of the stream's discharge and the concentration of that substance in the river [Walling and Webb, 1985].

98. Daily flow and concentration data are required for accurate load calculations since most water quality variables fluctuate with flow. Although daily flows may be available, daily concentrations are usually not due to the

cost of analyses. For this reason, various loading models have been employed to estimate chemical and nutrient loads on the basis of limited data. The most common loading methods are given in Table 3 as taken from Yaksich and Verhoff [1983] and Walling and Webb [1985]. Of these, only the product of the means (Method 1) and the means of the products (Method 2) are applicable where discrete measurements of flow and nutient concentration are available [Yaksich and Verhoff, 1983]. For Method 1, the average flux is calculated by multiplying the mean flow times the mean concentration times a constant to correct for units. This method should not be used to calculate fluxes for parameters which are flow-dependent because it underestimates the flux for parameters which increase with increasing flow and overestimates the flux for parameters which decrease with increasing flow. For averages calculated by the means of the individual products (Method 2), fluxes are calculated and then averaged.

99. Cooke, et al., [1986] have also summarized methods for the calculation of stream discharge and nutrient input where only discrete measurements of discharge and nutrient concentration are available. These methods are listed in Table 4 [Cooke, et al., 1986]. They have found that Method 7 best estimates stream nutrient input.

100. Nutrient budgets are based on estimated nutrient loads and are performed to determine the rate of

Table 3

Load Estimation Models

METHODS

1. Total Load = $SUM(C_i/n) * Sum(Q_i/n) * K$
2. Total Load = $SUM(C_i * Q_i/n) * K$
3. Total Load = $SUM(C_i * Q_p) * K$
4. Total Load = $(KQ_r) * SUM(C_i/n)$
5. Total Load = $SUM(C_i * Q_i/Q_i)(Q_r) * K$

VARIABLES

K = conversion factor to take account for period of record and units

C_i = instantaneous concentration of individual sample (mg/l)

Q_i = instantaneous discharge at sampling time (cfs/sq. mi.)

Q_r = mean discharge of period of record (cfs/sq. mi.)

Q_p = mean discharge for interval between samples (cfs/sq. mi.)

n = number of samples

Table 4

Hydraulic and Nutrient Calculations

Calculation Method	Mean Absolute Percent Error	Range in Percent Error
STREAM DISCHARGE		
1. Integration of discrete discharge vrs. time plot	12	-19 to +35
2. Three-point running mean of discrete discharge	35	-15 to +130
NUTRIENT LOAD		
3. Product of integrated discharge vrs. time plot and [N] at midpoint of time interval ([N] = nutrient conc.)	11	-19 to +11
4. Product of integrated discharge vrs. time plot and [N] at endpoints of time interval	14	-25 to +16
5. Product of discharge calculated by three-point running mean and [N] at midpoint of time interval	30	-19 to +92
6. Integration of the plot of the product of discharge and [P] vrs. time	10	-19 to +8
7. Three-point running mean of product of discharge and [N]	27	-14 to +57

eutrophication in a water system [Smith and Stewart, 1977]. Often examined are the weekly differences between the changes in mass content of individual nutrients in the reservoir (M) and the net loading (mass inflow - mass outflow). Redshaw, et al., [1987] found that a large net reduction in the inorganic nitrogen content of the reservoir occurred durding most of the year in Ardleigh Reservoir, England, suggesting that the reservoir was acting as a sink. In contrast, positive values for the net loading suggest the release of nutrients from the sediments.

Empirical Models for Trophic State

101. Trophic state models are mathematical formulations which represent natural water systems. They are used to increase the level of understanding of cross-sectional associations among variables; and when used in conjunction with a detailed lake study, can aid in the evaluation of lake management options.

102. For most basins, available data consist of only routine monitoring data. Although these data can be used for model verification and calibration, they have the following limitations as described in a literature review by Young [1988]:

> "(1) Hydrology data are seldom available for interpreting the water quality data. Thus, effects rather that causes are known.
>
> (2) Monitoring networks usually collect a limited number of grab samples at only a few sites under a wide variety of conditions. Quantitative knowledge

of reach-to-reach, cross-sectional, and daily variations are not provided by such data.

(3) The inherent sampling and analysis errors for river water quality variables are quite large. Thus to develop an applied model, a number of sample sets are required."

103. Models provide a method for integrating and interpreting available monitored data for a reservoir system and may be helpful in redesigning monitoring networks to provide more useful data. The empirical phosphorus loading-mean depth relationship developed by Vollenweider [1968] has been widely accepted and used as a guide to the degree of eutrophy of lakes, as well as a guide to the permissible and dangerous loading levels of phosphorus in lakes. Vollenweider's original work on phosphorus loading-mean depth relationships was modified by Dillon [1975] to include flushing rate and retention rate. Dillon's relationship expresses the effects of both flushing rate and retention rate on phosphorus loading and is dimensionally consistent [Dillon, 1975]. His relationship is as follows:

$$L(1-R)/p \qquad (4)$$

where L is defined as the areal phosphorus loading, R is defined as the retention coefficient, and p is defined as the flushing rate.

104. Vollenweider [1969] described a model for predicting the concentration of nutrients, particularly total

phosphorus, in lakes. His simplest steady state solution was equivalent to:

$$[P] = L/\langle z \rangle * (p+r) \qquad (5)$$

where <z> was defined as the mean depth and r was defined as the sedimentation rate coefficent. Based on Vollenweilder's assumptions that the waterbody is well-mixed, has a constant volume, has an outflow phosphorus concentration equal to the in-lake phosphorus concentration, has equivalent inflow and outflow rates, has no net loading from the sediments, and neglect that its phosphorus sedimentation is proportional to its in-lake phosphorus concentration rather than to its phosphorus load. Dillon [1975] similarly showed that the retention coefficient, R, and sedimentation rate coefficent, r, could be related by the equation:

$$r = Rp/(1-R). \qquad (6)$$

Thus, when the lake is at steady state,

$$[P] = L(1-R)/\langle z \rangle * p. \qquad (7)$$

Lines can therefore be drawn on a plot of L(1-R)/p versus <z> representing equal predicted concentrations. Lines representing predicted concentrations of 10 and 20 mg m^{-3} have been determined to be good divisions of lake trophic state; lakes represented by points below the 10 mg m^{-3} are generally oligotrophic, between the 10 and 20 mg m^{-3} are generally mesotrophic, and those above the 20 mg m^{-3} are generally eutrophic. The Dillon phosphorus loading for Center Hill in 1973 (a wet year) was 1.33 gm/m^2 (based upon total phosphorus concentration of 73 mg m^{-3}) which placed the lake in the eutrophic classification [Gordon, 1976].

105. Trophic state empirical models, based on Vollenweider's and Dillon's work, have recently been developed for Southeastern U.S. lakes and reservoirs [Reckhow, 1988]. The models were calibrated and verified based upon a cross-sectional data set from 80 lakes and reservoirs in nine southeastern states (Alabama, Georgia, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) and are based on a mechanistic description of a lake as a continuously-stirred-tank-reactor [Reckhow, 1988]. These models are given in Table 5 and may be used as planning tools. At the same time, it must be recognized that these models simply express cross-section associations among variables, and a more detailed lake-specific study if often necessary for a thorough evaluation of lake management options [Reckhow, 1988].

Table 5

Empirical Models for Trophic State in Southeastern U.S. Lakes and Reservoirs

Model	Model Statistics
$\log P = \log (P_{in}/(1+kT_w))$;	$R^2 = 0.752$
$k = 3.0(P_{in})^{0.53}(T_w)^{-0.75}(z)^{0.58}$	$S_{y/x} = 0.174$
$\log N = \log (N_{in}/(1+kT_w))$;	$R^2 = 0.643$
$k = 0.67(T_w)^{-0.75}$	$S_{y/x} = 0.113$
$\log(\text{chl a}) = 1.314+0.321\log(P)+$	$R^2 = 0.391$
$0.384\log(N)+0.450\log(n_{CA})+$	$S_{y/x} = 0.220$
$0.136\log(T_w)$	
$\log(SD) = -0.470-0.364(P)+0.102\log$	$R^2 = 0.689$
$(T_w)+0.137\log(z)$	$S_{y/x} = 0.124$

Where:
- P = median summer total phosphorus concentration (mg/l).
- P_{in} = mean annual influent total phosphorus concentration (mg/l).
- T_w = hydraulic detention time (yr).
- z = mean depth (m).
- $S_{y/x}$ = model error.
- N = meadian summer total nitrogen concentration (mg/l).
- N_{in} = mean annual influent total nitrogen concentration (mg/l).
- chla = median summer chlorophyll a concentration (ug/l).
- n_{CA} = total number of chlorophyll a samples for each lake.
- SD = median summer Secchi disk depth (m)

MATERIALS AND METHODS

106. The purpose of this chapter is to describe the methods and materials used for data collection, sample collection, laboratory analyses, and data analyses.

Methods and Materials for Field Analyses

107. A series of 42 sampling stations was established within the Center Hill watershed in order to measure the gradient of various water quality properties. The stations were located at major inflows, wastewater treatment plants discharging into the watershed, major embayments, four main reservoir stations, and the tailwater. At each station, except those located at the WWTPs, water quality data (temperature, dissolved oxygen, pH, conductivity, and oxidation-reduction potential) were obtained in the field using a Hydrolab Surveyor II (Model SVR2-SU). The hydrolab was calibrated prior to and after each day of sampling, as specified by the manufacturer to reduce equipment-induced errors. Discharge was calculated for each inflow except Great Falls from stream velocities, measured by a portable water current meter (Marsh McBirney Model 201D), and cross-sectional areas. During extremely high-flow conditions, flows were estimated by noting the water surface elevation, velocity, and the cross-sectional area of the stream channel (estimated flows are noted in Appendix III by an asterisk).

The inflow values at Great Falls and outflow values at Center Hill Dam were obtained from the U.S. Army Corps of Engineers for each sampling date and specific time of day. Flows for the Caney Fork River at Great Falls were obtained from USGS based on gage readings. Turbidity was measured at the inflow and outflow stations using a portable turbidimeter (Hach Model No. 16800-00). Secchi disk depths were recorded for reservoir stations using a 20 centimeter disk.

108. In-situ water quality parameters obtained at the inflows, WWTPs, and tailwater were measured biweekly from March 1988 through January 1989 in a part of the stream having an obvious current. Embayment water quality parameters were measured monthly from July 1988 through September 1988. Water quality parameters were also measured monthly at each main-channel station from June 1988 through October 1988. Mainbody water quality data were also measured prior to the onset of stratification in March 1988.

109. Water samples were collected at all inflows, the outflow, four main-channel stations, and in two "worse-case" embayments with respect to nutrient loadings. The embayments were sampled at a location influenced by stream inflow rather than the main body of the reservoir. Inflow samples were collected from a portion of the stream having an obvious current. Inflows receiving WWTP effluent were sampled a sufficient distance downstream of the discharge point to allow mixing of the streamflow and WWTP effluent.

An exception was made for Fall Creek in which case samples were collected upstream of the WWTP's discharge due to limited stream access. Tailwater samples were collected during power generation, but not during the first 30 minutes of generation. Effluent water samples were "grabbed" prior to chlorination from each WWTP; 24-hour composite samples were collected when possible. Water samples collected at each of the lake stations were pumped up from three depths (approximately 2, 10, and 20 meters) at each main-channel station and from six depths at each embayment station. Depths from which embayment samples were pumped included 0.5 meters below the surface, 1.0 meter above the thermocline, 1.0 meter below the thermocline, 0.5 meters above the bottom, halfway between the thermocline and surface, and halfway between the thermocline and bottom. All samples were packed in ice and held in a 4°C room until their analyses were complete. Sample collection coincided with in-situ water quality data collection.

110. Special storm event sampling was performed at two inflow stations to characterize the relationship between streamflow and nutrient levels. These stations were Falling Water River, impacted by Cookeville's WWTP discharge, and Taylor Creek, impacted by agricultural drainage. A minimum of four samples were collected before and during the peak flow, with one sample collected before the rain event began (base conditions). A minimum of four samples were also collected after the peak flow, with the final sample

collected when the streamflow had decreased to less than 50 percent of the peak flow.

111. Information concerning the nutrient loadings from atmospheric dust-fall and precipitation was obtained from the Tennessee Division of Air Pollution Control's monitoring site near the Joe L. Evans Craft Center. Monthly and yearly summaries were acquired for nitrates, nitrites, ammonium, and phosphates and were examined to determine the relative significance of the atmospheric sources.

Materials and Methods for Laboratory Analyses

112. All water samples were chemically and biologically analyzed by TTU Water Center staff using Corps and/or EPA approved methods. Chemical parameters analyzed included total phosphorus, ortho-phosphate phosphorus, nitrite/nitrate, ammonia, total nitrogen, and organic nitrogen. Biological parameters analyzed included total chlorophyll *a*, pheophytin *a*, and the five most prevalent genera of phytoplankton.

Chemical Parameters

113. Samples were analyzed for nitrite/nitrate using a Technicon Auto Analyzer II cadmium-reduction procedure with ammonium chloride and color reagents. Total nitrogen analyses followed the same procedure as that for nitrite/nitrate, but samples were first digested with persulfate. An automated process, using the Technicon Auto Analyzer II, was also used to determine ammonia

concentrations. The three reagents used in each analysis were sodium hypochorite, alkaline phenol, and potassium sodium tartrate. Organic nitrogen concentrations were calculated by subtracting both the ammonia and nitrate concentrations from the total nitrogen concentration.

114. Total phosphorus concentrations were obtained using a persulfate digestion/ascorbic acid technique. The samples were digested oxidatively with ammonium persulfate and hydrolyzed with sulfuric acid to release phosphorus as ortho-phosphate which formed a complex that was reduced to an intensely blue-colored complex by ascorbic acid. The intensity of the color, measured on a spectrophotometer at 885 nanometers, is proportional to the ortho-phosphate, and to the total phosphorus concentration. Phosphates that respond to colorimetric tests without preliminary hydrolysis or oxidative digestion of a sample are termed "reactive phosphorus" which is largely a measure of ortho-phosphate or inorganic phosphorus. Ortho-phosphate concentrations were measured with a method based on a reaction that is specific for the orthophosphate ion. Ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form a complex which is then reduced to an intensely blue-colored complex by ascorbic acid. The intensity of the color is proportional to the orthophosphate concentration.

115. A quality control program was conducted by the Water Center Laboratory throughout the study to ensure validity of the results. The program ensured the following:

1. Standardization of instruments as specified by the manufacturer;

2. Duplicate analyses of each tenth sample;

3. Spiked tenth-sample analyses where applicable;

4. Analysis of EPA reference samples as needed; and

5. Calibration of field equipment prior to and after each day's use with any differences in calibrated values recorded.

Biological Parameters

116. Chlorophyll a and Pheophytin a analyses were performed by the Water Center Laboratory by approved methods. The analyses were carried out using the spectrophotometric method as given in Standard Methods.

117. Field plankton collections were taken with a 2 L Kemmerer bottle at the surface and at depths of 2 m, 3 m, 4 m, and 5m. A sample of approximately 500 mL was placed in an ice chest and returned to the laboratory for microscopic analyses.

118. A 100 mL sample of the field collection was placed in a 100 mL cylinder and preserved with 1.0 mL Lugol's solution. The 100 mL sample was allowed to settle at least 10 days before 90 mL of the supernatant were removed with a

volumetric pipet. The remaining 10 mL concentrate was stored in a capped test tube.

119. Microscopic examinations were made with a Nikon inverted microscope at magnifications of 100x and 400x; and with Zeiss RA Standard microscope at magnifications of 160x and 400x, with bright-field, phase contrast, and Nomarski interference optics.

120. Preparations for the Nikon inverted microscope were made by futher concentrating the 10 mL sample to a volume of 3-4 mL. The 3-4 mL concentrates were allowed to settle overnight in 10 mL settling chambers before counts were taken.

121. Preparations for the Zeiss standard microscope were made by concentrating the 10 mL sample to a volume of 2 mL by pipetting the supernatant. A 0.1 mL aliquot of the 2 mL concentrate was placed in a Palmer counting cell for microscopic examination.

122. In samples with little debris, detritus, and gel, the inverted microscope is a convenient instrument with which to make planktonic counts. Where there is either debris or extracellular gel, the thick accumulation in the settling chamber is extremely difficult to analyze.

123. The Palmer Cell is so thin that examination with 40x objectives is possible and the entire thickness can be seen with clarity. A disadvantage of the Palmer Cell is that an aliquot is used rather than the entire settled sample.

124. In subjective analysis of the two counting methods, the optics of the Zeiss microscope are far superior to the optics of the Nikon. Phase contrast and Nomarski options on the Zeiss microscope greatly facilitate the work.

125. To prepare Lugol's solution dissolve 20 g potassium iodide and 10 g iodine crystals in 200 mL distilled water cointaining 20 mL glacial acetic acid.

Methods and Materials for Mathematical and Graphical Analyses

126. The methodology succeeding the acquisition of field and laboratory data can be summarized as (1) data reliability checking, (2) statistical analyses, and (3) display techniques.

127. The data obtained from the field and from the TTU Water Center Laboratory were compiled into one data base using the computerized data base system, ENABLE. This system was also used to format the data for convenient transfer onto TTU's VAX 8800. STORET codes used in the database are listed in Table 6.

128. Potential typographical errors in field data were checked by comparing computer printouts with the original field sheets and by plotting time series of data. Outlier points on the plots were checked and corrected. Potential errors in chemical data were checked with the original laboratory work sheets and were also checked in relation to other parameters for consistancy.

129. Once the reliability of the data was confirmed, basic statistics, correlations, regressions, and loadings were calculated and displayed. Basic statistics were computed for each set of parameters utilizing TTU's version of the statistical software package SAS (univariate procedure). Although some parameters were not assumed to be normally distributed, common statistical measures were calculated. The statistical summaries provided information about the distribution of the parameters in terms of quartiles (0, 25, 50, 75, and 100 percent) to help judge the normality of the data. Correlation and regression analyses were performed to estimate the strength of the relationships between the water quality and flow data. The analyses were carried out utilizing the SAS statistical software package's correlation and regression procedures. Phosphorus and nitrogen loadings were estimated for the inflows and the outflow in order to develop a nutrient budget for Center Hill Lake and to identify potential problem areas. Inflow loadings were estimated for each major tributary and WWTP as well as for bulk precipitation. Loading contributions from groundwater were assumed to be nearly the same as loadings from surface water. Tennessee Tech's version of TECHPLOT was used to graphically portray the numerical data.

130. The objectives of these mathematical and graphical analyses were to convert the raw data, collected from the field and laboratory, into meaningful information for use

in lake classification, problem identification, and future watershed management.

Table 6

Database Storet/Station Codes

STORET/Station Code	Location/Parameter
3CEN10001	Caney Fork RM 26.5
3CEN10023	Fall Creek RM 4.6
3CEN10024	Pine Creek RM 5.7
3CEN10026	Falling Water RM 10.7
3CEN10027	Sink Creek RM 6.3
3CEN10028	Taylor Creek RM 2.2
3CEN10029	Mine Lick Creek RM 12.5
3CEN10030	Caney Fork RM 90.2
3CEN40031	Baxter WWTP
3CEN40032	Cookeville WWTP
3CEN40033	McMinnville WWTP
3CEN40034	Smithville WWTP
3CEN40035	Sparta WWTP
3CEN20002	Caney Fork RM 27.2
3CEN20003	Caney Fork RM 31.9
3CEN20004	Caney Fork RM 48.8
3CEN20005	Caney Fork RM 61.1
3CEN20008	FWR Mile 5.1
3CEN20015	MLC Mile 2.0
00010	Temperature
00299	Dissolved Oxygen
00094	Specific Conductance
00400	pH
00078	Secchi Disk
00076	Turbidity
00061	Flow
00610	Total Ammonia Nitrogen
00630	Total Nitrite/Nitrate Nitrogen
00600	Total Nitrogen
00605	Total Organic Nitrogen
00665	Total Phosphorus
00671	Ortho-Phosphorus
32210	Chlorophyll a
32218	Pheophytin a

RESULTS

131. The purpose of this chapter is to present and discuss the measured and calculated data obtained for this study. The results are presented in five sections: (1) embayment results, (2) main channel results, (3) inflow/outflow results, 4) water and nutrient budget estimates, and (5) the determination of the trophic status of the lake.

Embayment Results

132. Water quality data were obtained at several locations in Indian, Holmes, Mine Lick, Falling Water, Fall, Pine, and Sink Embayments in order to compare the water quality of Center Hill's major embayments to the water quality of the lake's main channel. In addition to these measurements, samples from Falling Water and Mine Lick Embayments were chemically and biologically analyzed in an attempt to characterize the nutrient-algae-water quality relationships in two embayments.

133. Figures 4 through 10 show the changes in dissolved oxygen (DO), temperature, pH, and oxidation-reduction potential (ORP) with depth at several stations in each embayment. Station I is located furthest upstream from each embayment's mouth; Stations II, III, and IV are located downstream of Station I with Station III or IV, depending on

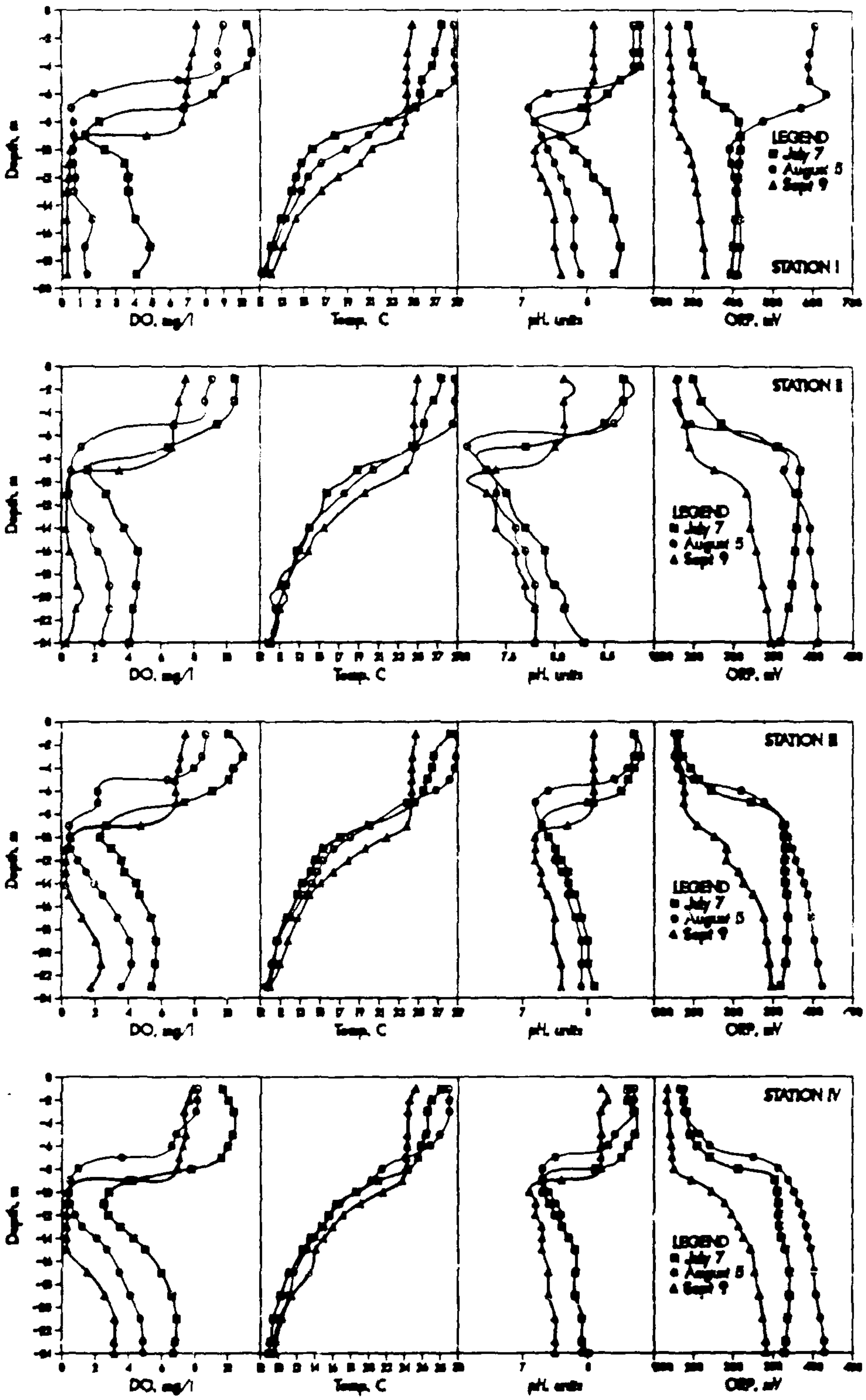

Figure 4: Indian Creek Embayment Water Quality Profiles

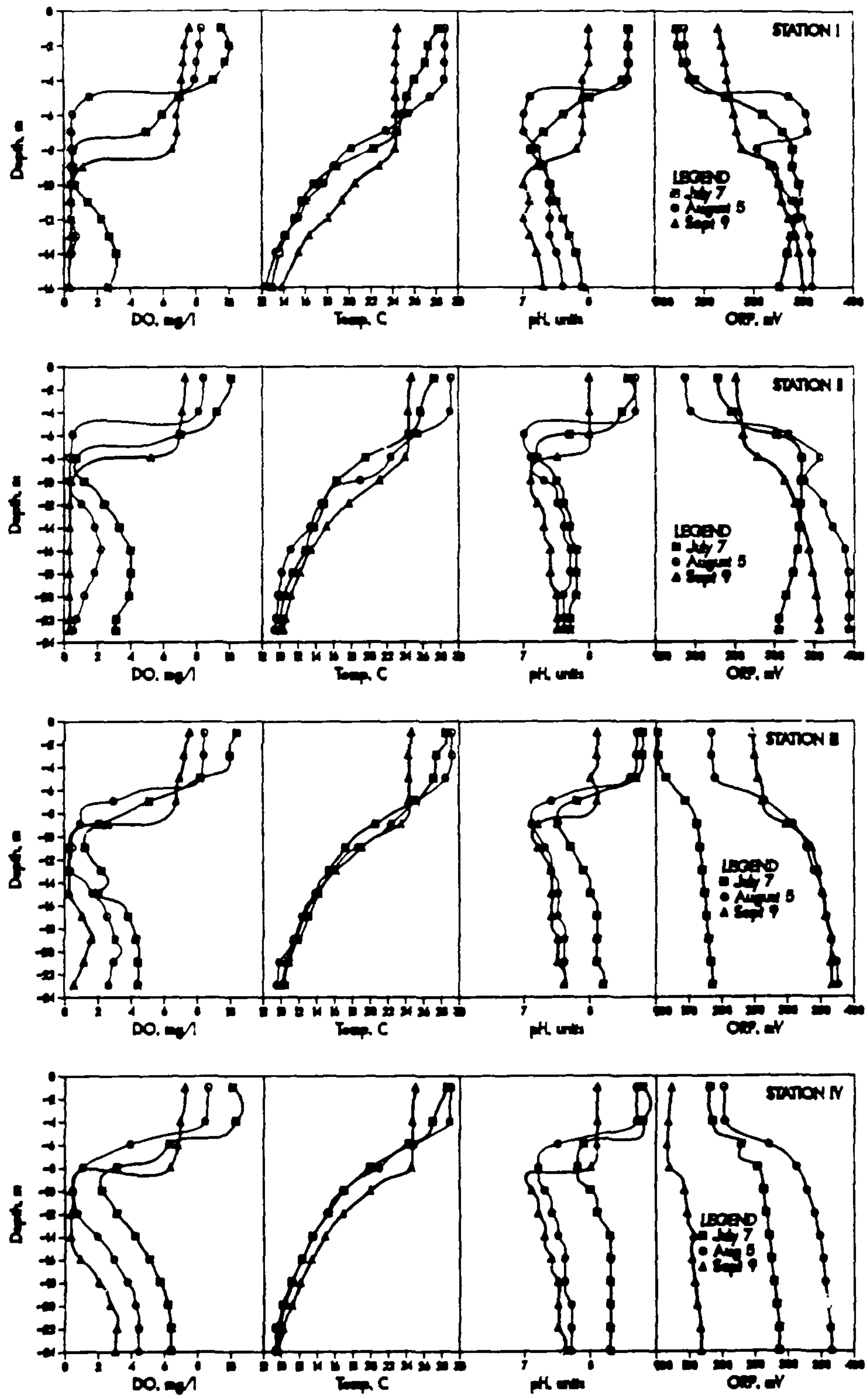

Figure 5: Holmes Creek Embayment Water Quality Profiles

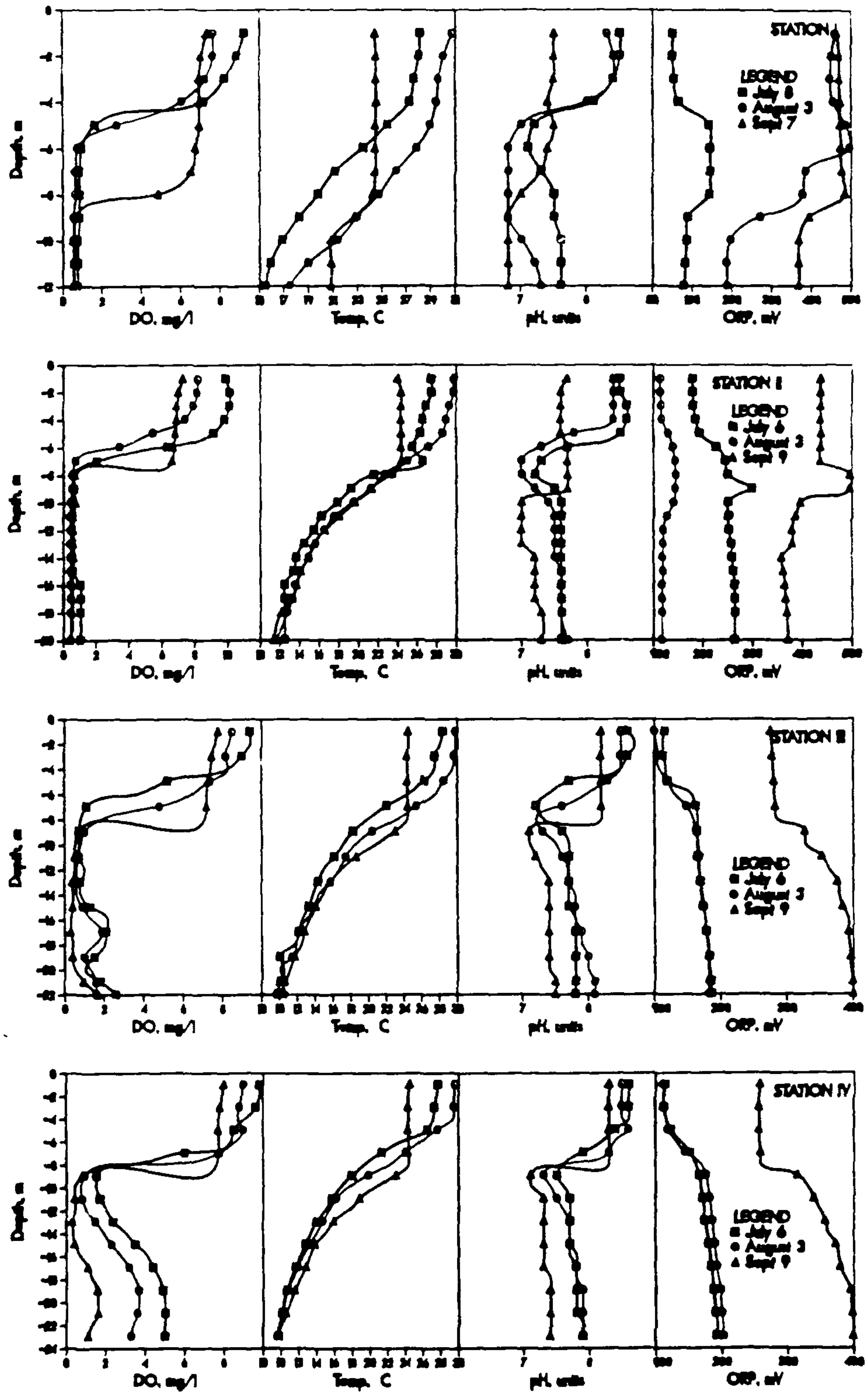

Figure 6: Mine Lick Creek Embayment Water Quality Profiles

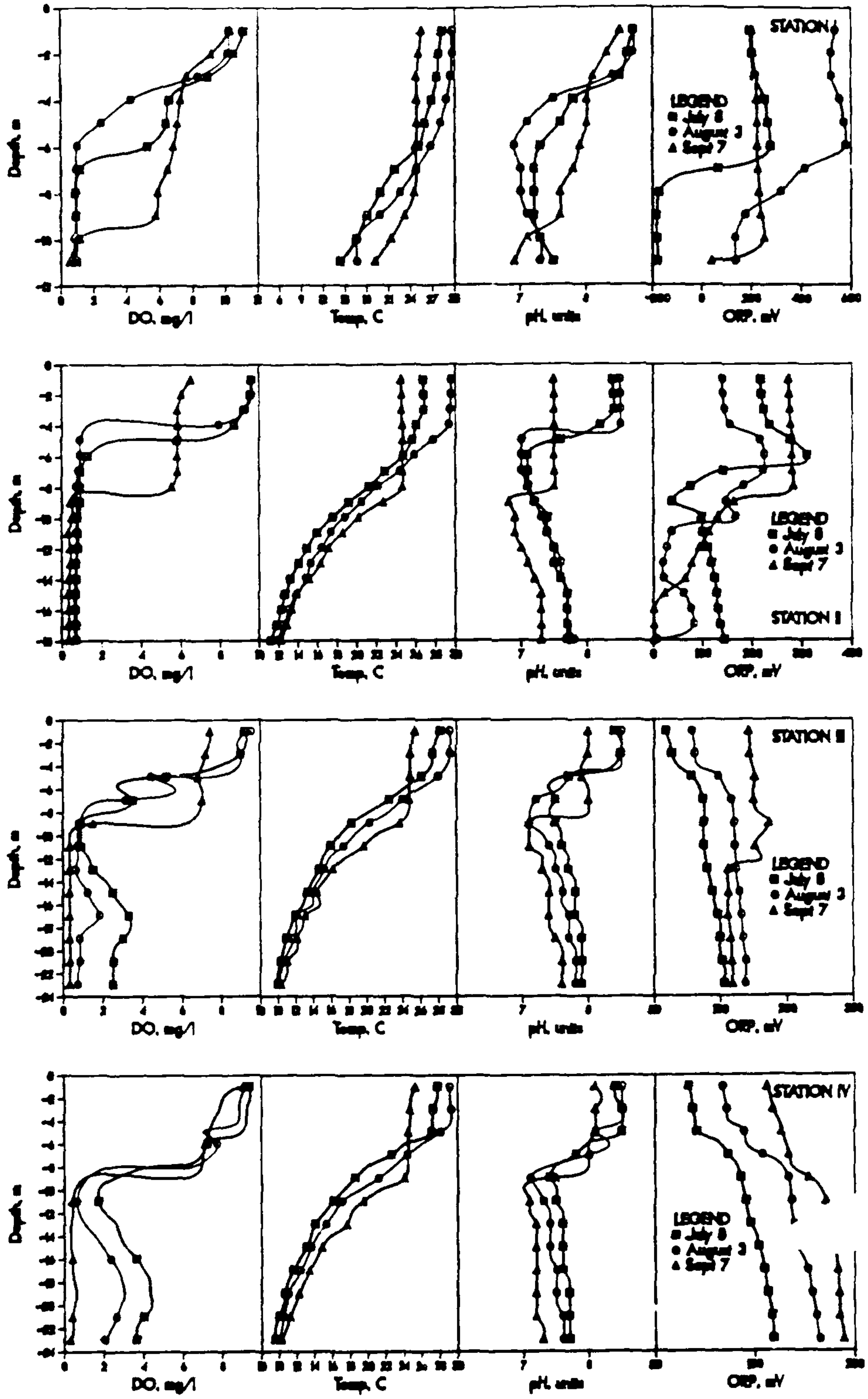

Figure 7: Falling Water River Embayment Water Quality Profiles

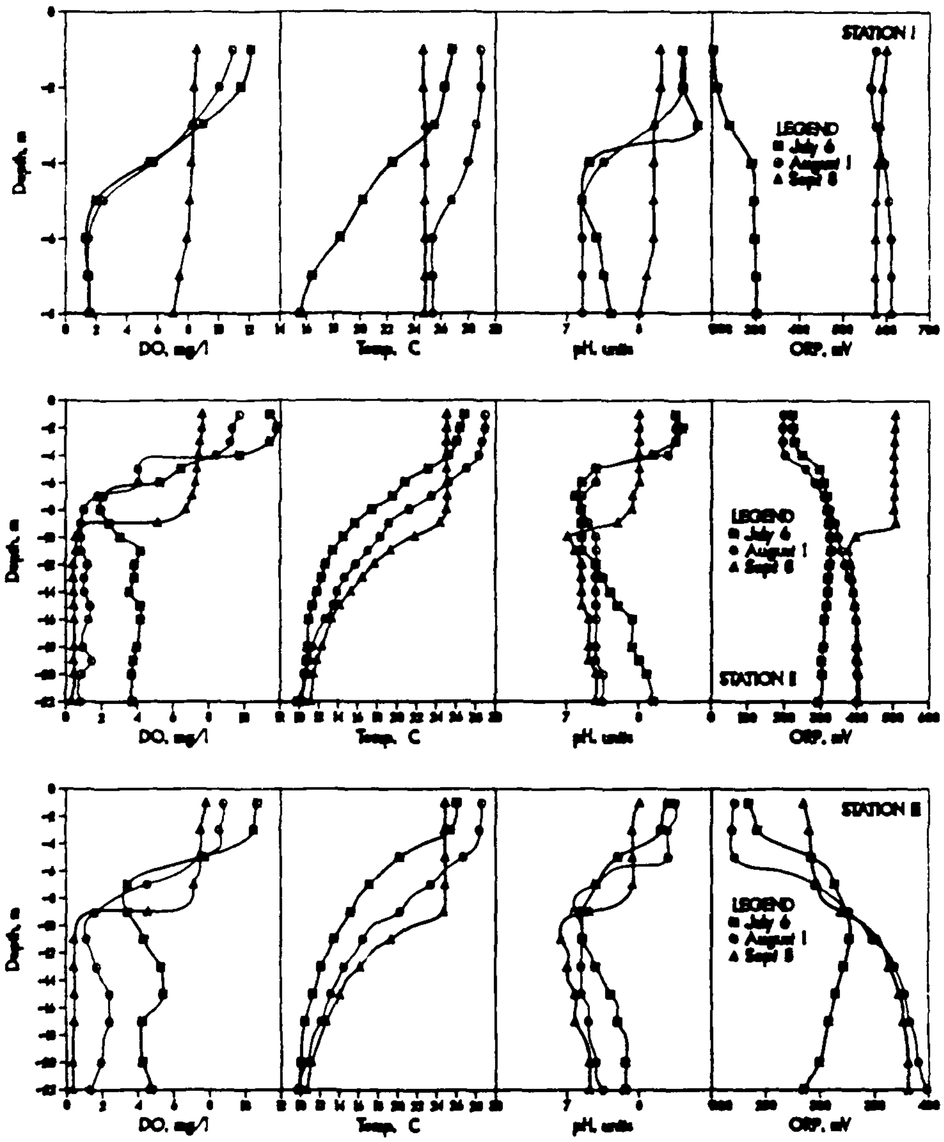

Figure 8: Fall Creek Embayment Water Quality Profiles

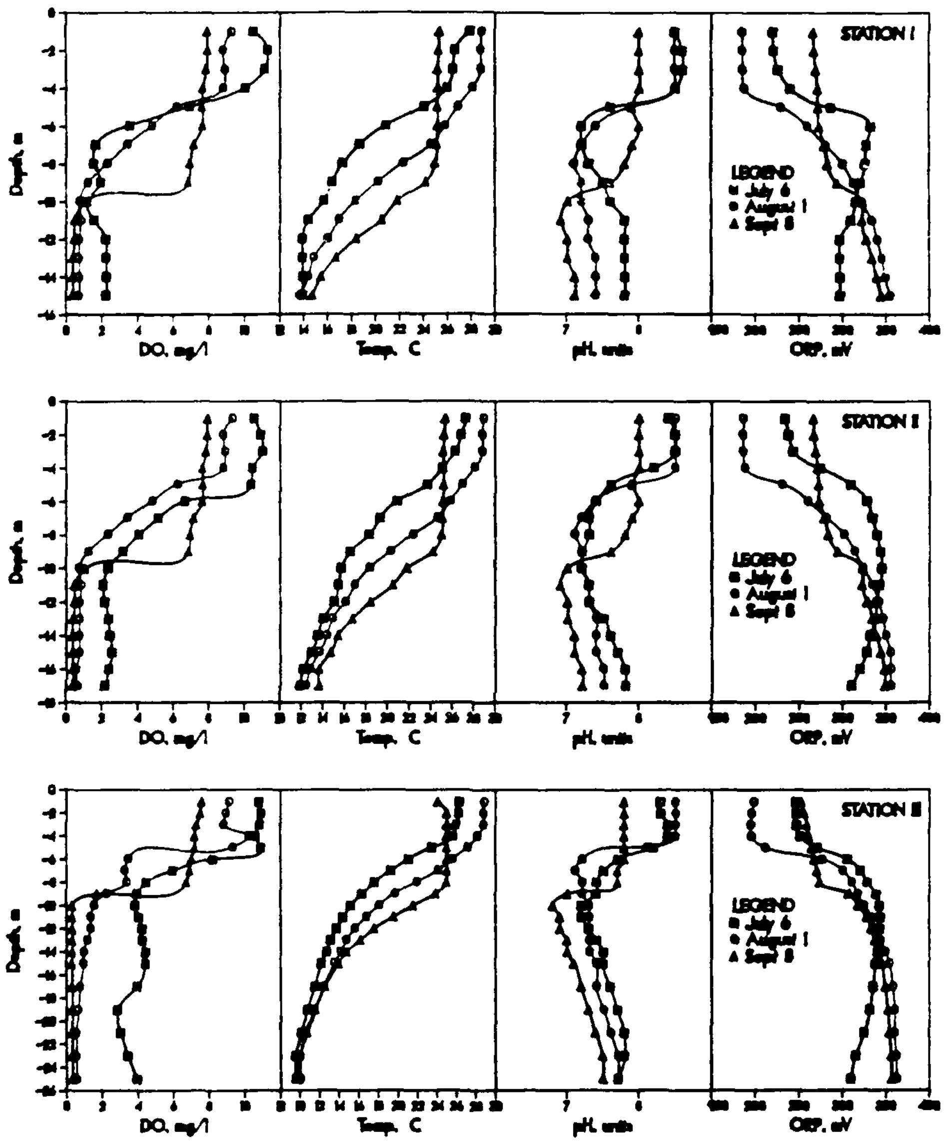

Figure 9: Pine Creek Embayment Water Quality Profiles

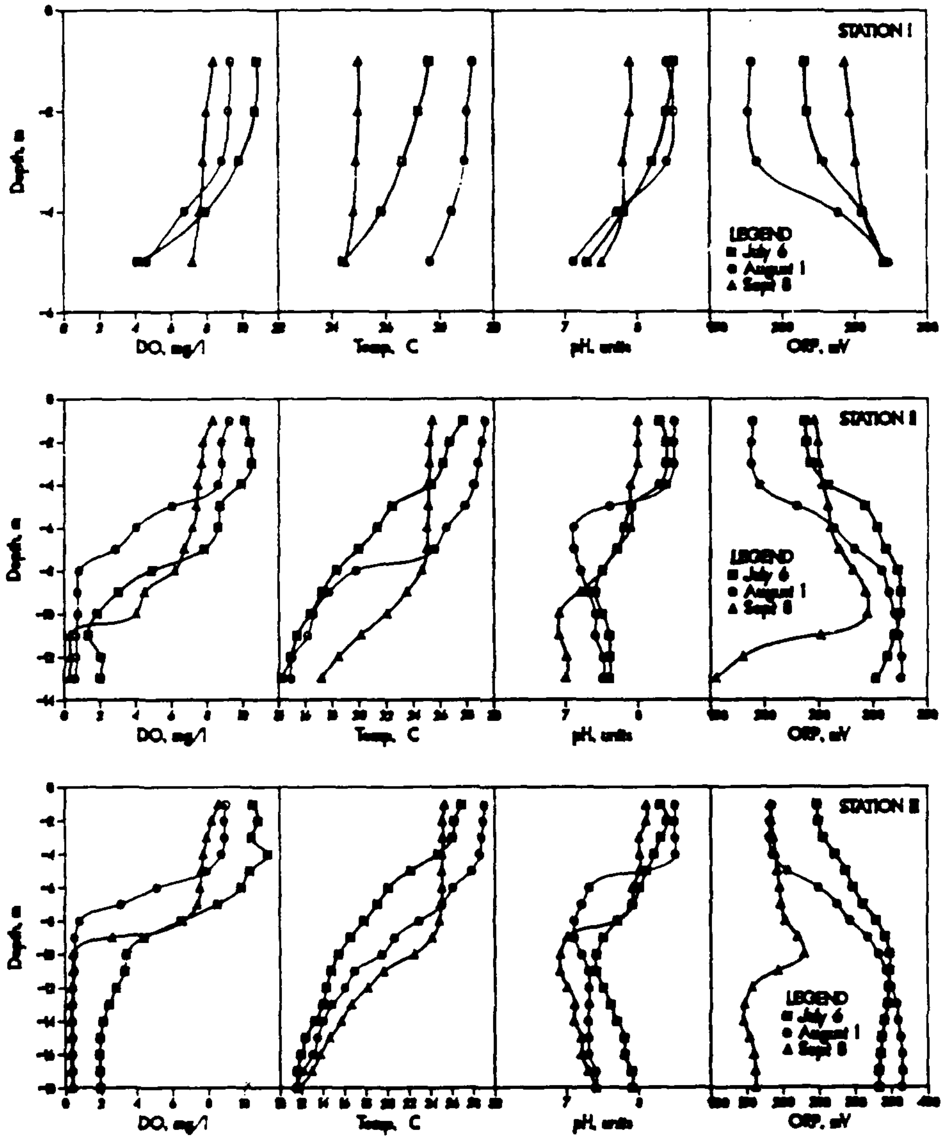

Figure 10: Sink Creek Embayment Water Quality Profiles

the embayment's size, located at the embayment's mouth in the main channel of the reservoir. Locations of all sampling stations are shown on Figure 1 on page 7 of this report.

134. In general, all the embayments had developed a minimum dissolved oxygen concentration between a depth of 6 to 12 meters by July 1988. The depletion of oxygen in the embayments was observed to occur within a depth of 1 meter and to correspond to a sharp decrease in temperature and pH measurements and an increase in ORP values. In most cases, the DO concentration increased noticably in the deeper hypolimnetic waters, just below the thermocline, before depleting again a few meters above the lake's floor due to sediment oxygen demand. An increase in hypolimnetic DO concentrations was not observed at most of the embayments' upstream station which indicates that inflow flushing was not enough to balance the DO demands.

135. The depth at which the metalimnetic minima formed fluctuated through the summer months within the thermocline as did the changes in pH and ORP measurements. The development of a metalimnetic minima has been observed in numerous lakes and is usually attributed to the settling of organic matter from overlying water followed by accelerated DO consumption within the restricted layer [Hutchinson, 1957; Nix, 1981]. Through the use of turbidity and dyes as interflow tracers, density currents have also been proven to cause a metalimnetic minimum in lakes [Carmack, et al.,

1979; Elder and Wunderlich, 1968]. Inflows resulting from storm events have been noted to have lower specific conductance, lower calcium, and higher coliform bacteria levels [Thornton, et al., 1980]. In addition, it is likely that the introduction of organic matter and bacteria into the metalimnion of an embayment or lake following storm events may contribute significantly to subsequent oxygen depletion. Nix [1981] observed the interflow phenomenom even during low inflow conditions during his study of DeGray Reservoir. This phenomena may contribute to the DO depletion in Center Hill Lake.

136. Further examination of the water quality profiles shows that DO concentrations decrease not only with depth but also with time throughout the summer. July concentrations averaged 2 mg/l higher than those in September. Comparatively, pH and ORP values decreased each month. Surface temperatures had cooled slightly in September causing a deeper epilimnion.

137. The results of chemical analyses for the embayments' are listed in Tables 7 and 8. Significant differences between Falling Water and Mine Lick Embayments predominantly involve ammonia nitrogen, total nitrogen, and orthophosphate phosphorus concentrations. Ammonia nitrogen concentrations were nearly the same in both embayments during June 1988. However, low DO concentrations developed in both embayments causing anoxic conditions and

Table 7

Nitrogen and Phosphorus Concentrations in Mine Lick Embayment

DEPTH (m)	DO (mg/l)	NO2/NO3 (mg/l)	NH3 (mg/l)	Total N (mg/l)	Organic N (mg/l)	Total P (ug/l)	Ortho P (ug/l)
6/15/88							
0.6	13.0	0.01	0.15	0.38	0.23	51	<10
3	15.3	0.62	0.15	0.77	0.01	29	<10
5	5.8	0.01	0.18	0.42	0.23	67	<10
7	0.6	0.01	0.18	0.47	0.29	44	<10
15	1.5	0.66	0.20	0.86	0.01	55	23
23	1.4	0.01	0.03	0.46	0.43	40	<10
7/8/88							
2	9.5	0.01	0.10	0.23	0.13	21	<10
3	9.2	0.01	0.20	0.24	0.03	21	<10
6	1.3	0.27	0.08	0.44	0.09	10	<10
8	0.9	0.01	0.08	0.22	0.13	16	<10
12	0.8	0.61	0.33	0.94	0.01	10	<10
16	0.7	0.59	0.09	0.68	0.01	10	<10
8/9/88							
1	10.3	0.01	0.03	0.31	0.27	25	<10
3	8.9	0.24	0.18	0.42	0.01	20	13
5	2.7	0.01	0.06	0.36	0.3	19	<10
12	0.5	0.07	0.15	0.41	0.19	29	24
15	0.5	0.01	0.06	0.62	0.56	36	24
20	0.5	0.06	0.22	0.61	0.33	71	57
9/8/88							
1	6.1	0.04	0.01	0.18	0.14	11	<10
4	5.8	0.02	0.01	0.18	0.15	10	<10
8	5.5	0.02	0.01	0.15	0.13	10	<10
14	0.3	0.02	0.15	0.31	0.14	29	27
17	0.3	0.04	0.27	0.45	0.14	59	57
21	0.3	0.11	0.33	0.60	0.16	47	22
10/13/88							
1	8.0	0.01	0.02	0.34	0.32	17	<10
6	7.3	0.01	0.01	0.36	0.36	17	<10
11	7.2	0.01	0.01	0.32	0.32	16	<10
15	0.5	0.01	0.29	0.53	0.24	44	39
18	0.3	0.01	0.34	0.65	0.31	245	211
20	0.3	0.01	0.47	0.78	0.31	240	42

Table 8

Nitrogen and Phosphorus Concentrations
in Falling Water Embayment

DEPTH (m)	DO (mg/l)	NO2/NO3 (mg/l)	NH3 (mg/l)	Total N (mg/l)	Organic N (mg/l)	Total P (ug/l)	Ortho P (ug/l)
6/15/88							
0.5	13.9	0.01	0.15	0.42	0.27	44	<10
2	16.2	0.02	0.09	0.51	0.40	55	11
6	2.3	0.49	0.18	0.74	0.07	40	<10
8	1.5	0.89	0.12	1.00	0.01	45	<10
14	3.0	0.82	0.16	0.99	0.01	68	32
18	3.3	0.84	0.16	1.00	0.01	68	34
7/8/88							
2	9.9	0.01	0.08	0.28	0.20	22	<10
4	9.8	0.01	0.09	0.28	0.19	23	<10
6	6.3	0.01	0.10	1.50	1.40	30	<10
8	0.6	0.07	0.15	0.38	0.16	35	22
14	0.5	0.06	0.27	0.42	0.09	64	43
18	1.0	0.41	0.27	0.78	0.10	104	83
8/10/88							
1	8.2	0.01	0.04	0.39	0.35	40	11
3	7.9	0.01	0.09	0.41	0.32	32	<10
5	5.4	0.02	0.20	0.71	0.49	71	28
11	0.4	0.01	0.57	0.88	0.31	223	200
14	0.4	0.01	0.42	0.67	0.25	116	97
17	0.4	0.01	0.69	0.96	0.27	10	<10
9/7/88							
1	7.3	0.03	0.09	0.35	0.23	22	<10
4	6.9	0.03	0.06	0.36	0.27	21	<10
8	0.7	0.03	0.05	0.28	0.20	20	11
13	0.6	0.02	0.59	0.77	0.16	177	188
15	0.5	0.21	0.84	1.08	0.03	243	231
18	0.5	0.06	1.17	1.43	0.20	327	295
10/13/88							
1	7.8	0.01	0.21	0.38	0.17	26	12
7	7.0	0.01	0.05	0.60	0.55	29	12
12	4.4	0.01	0.07	0.52	0.45	10	18
14	0.4	0.01	1.10	1.35	0.25	378	46
15	0.4	0.01	1.23	1.55	0.32	456	62
16	0.4	0.01	1.39	1.78	0.39	521	81

significant increases in ammonia concentrations. Increases in ammonia concentrations were pronounced in the Falling Water Embayment. Anaerobic activity in the Mine Lick Embayment, confirmed by near zero DO concentrations and negative ORP values, was also the cause of increased ortho-phosphate phosphorus concentrations. Under anaerobic conditions, decomposition of proteins gives rise to ammonia, and dissolved phosphorus arises from other catabolites. These forms of nitrogen and phosphorus are chemically stable and accumulate during anaerobic conditions. They are typically diluted and oxidized during fall overturn.

Main-Channel Results

138. Physical water quality parameters were measured at four main-channel stations in Center Hill Lake; and at the same time, samples were collected at three depths for chemical analysis. Figures 11 through 14 show the changes in dissolved oxygen, temperature, pH, and oxidation-reduction potential with depth at each station. Station 2 is located at the dam (CFRM 27.2); Station 3 is located at Raccoon Hollow (CFRM 31.9); Station 4 is located at Tech Aqua (CFRM 48.8); and Station 5 is located upstream of Sligo Marina (CFRM 61.1).

139. The physical water quality of Center Hill Lake is longitudinally stable as shown by the main channel stations' nearly-identical water quality profiles. In March 1988, the lake was completely mixed with a constant

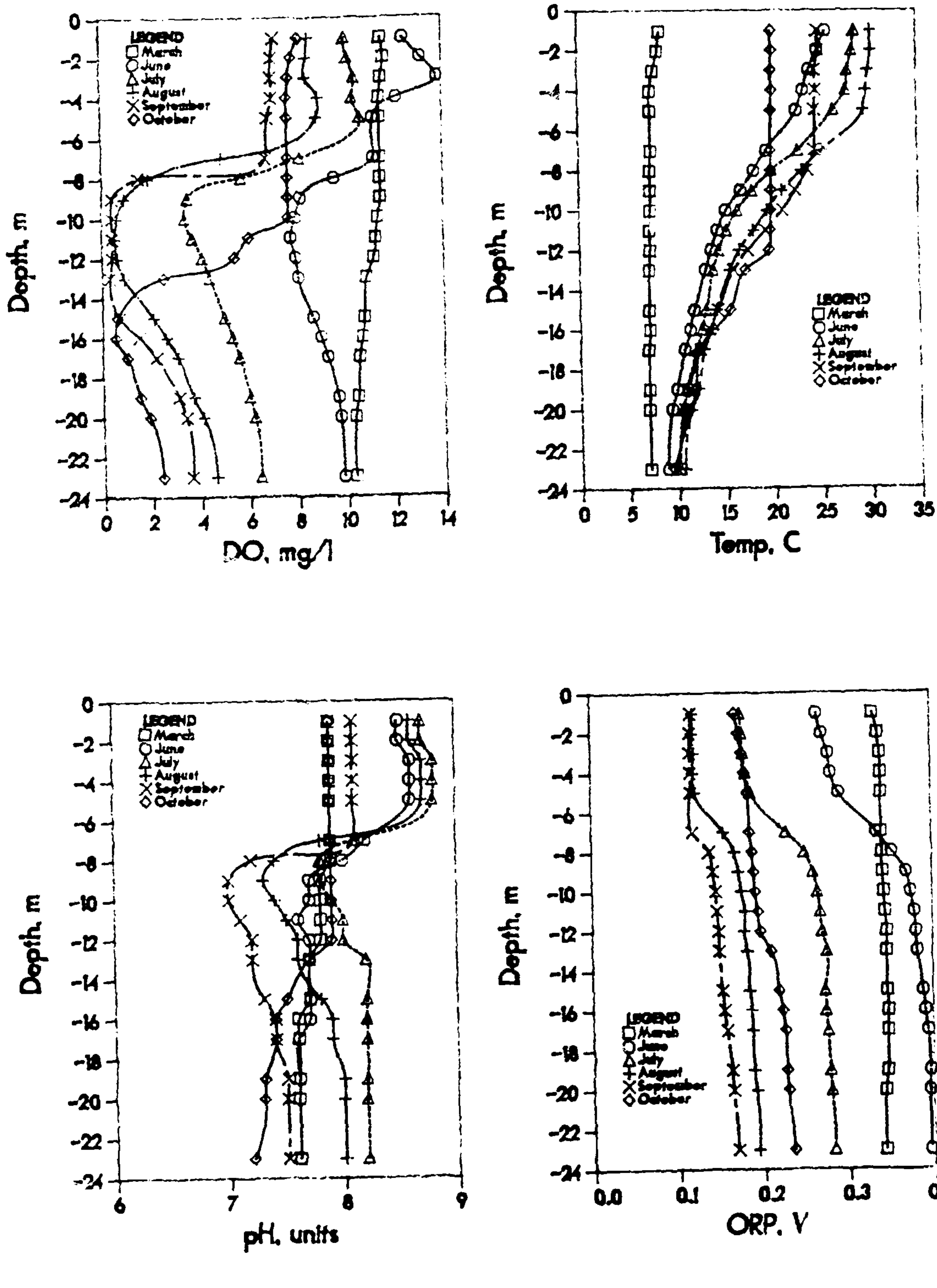

Figure 11: Station 2 Water Quality Profiles

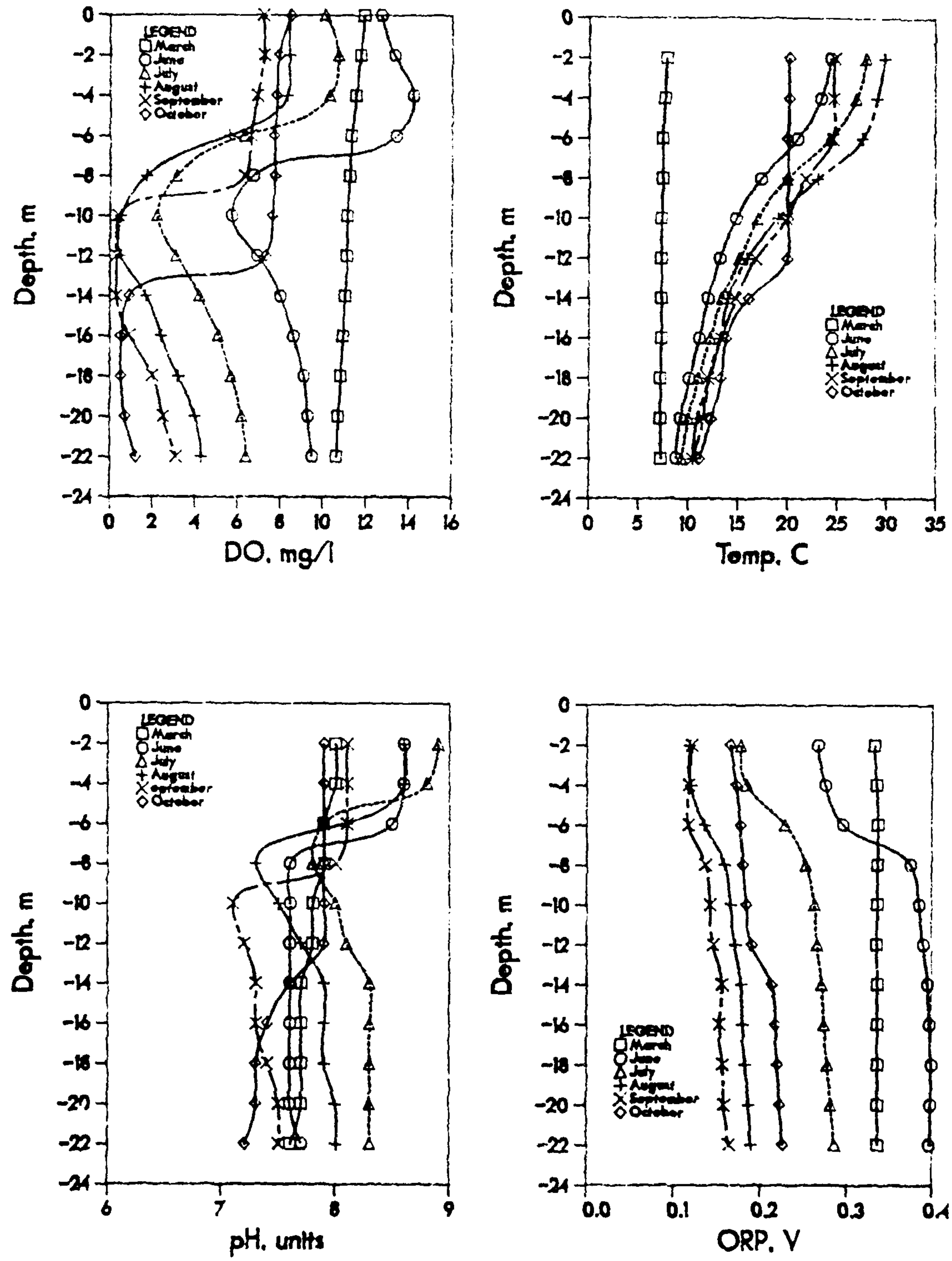

Figure 12: Station 3 Water Quality Profiles

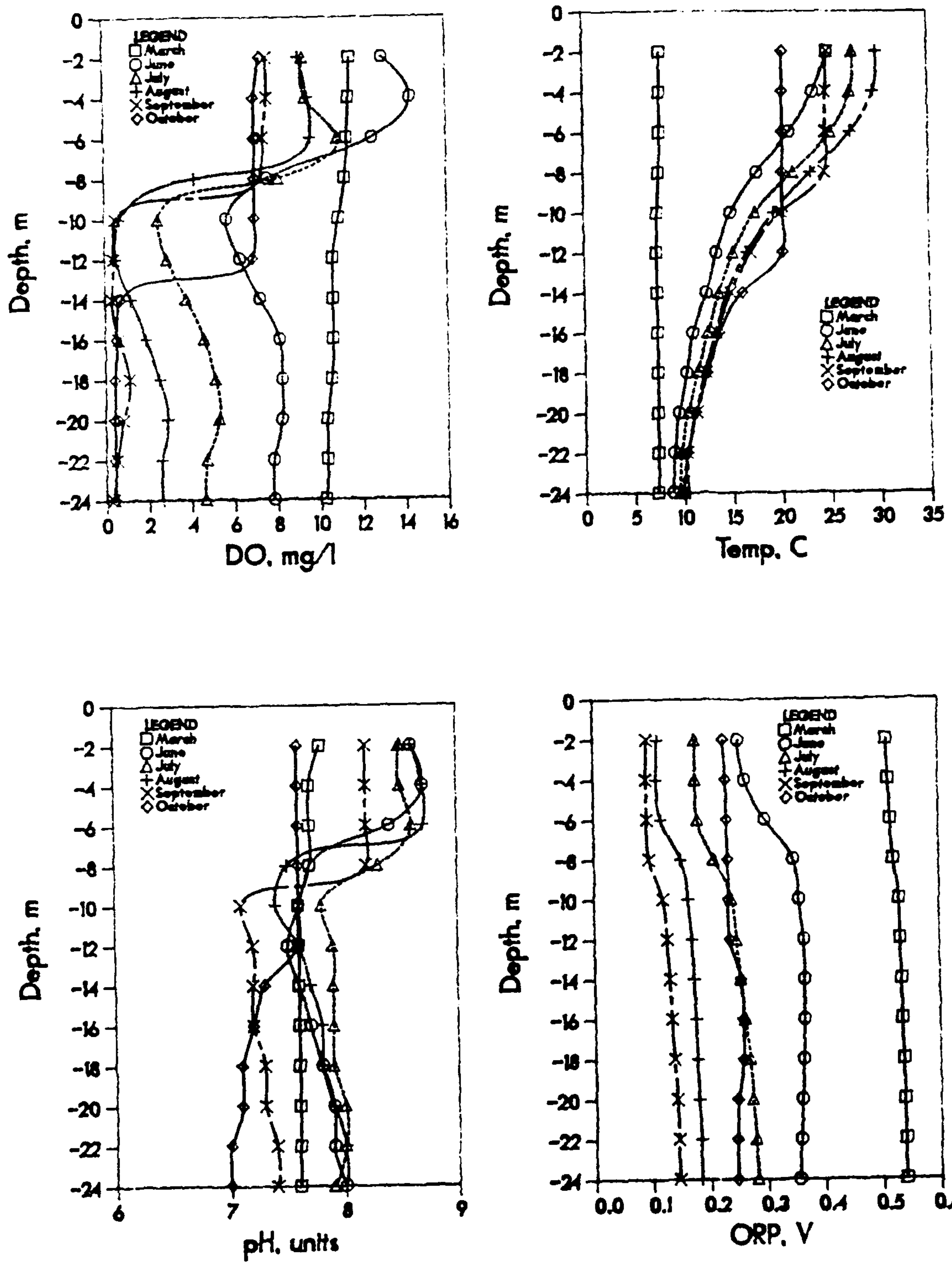

Figure 13: Station 4 Water Quality Profiles

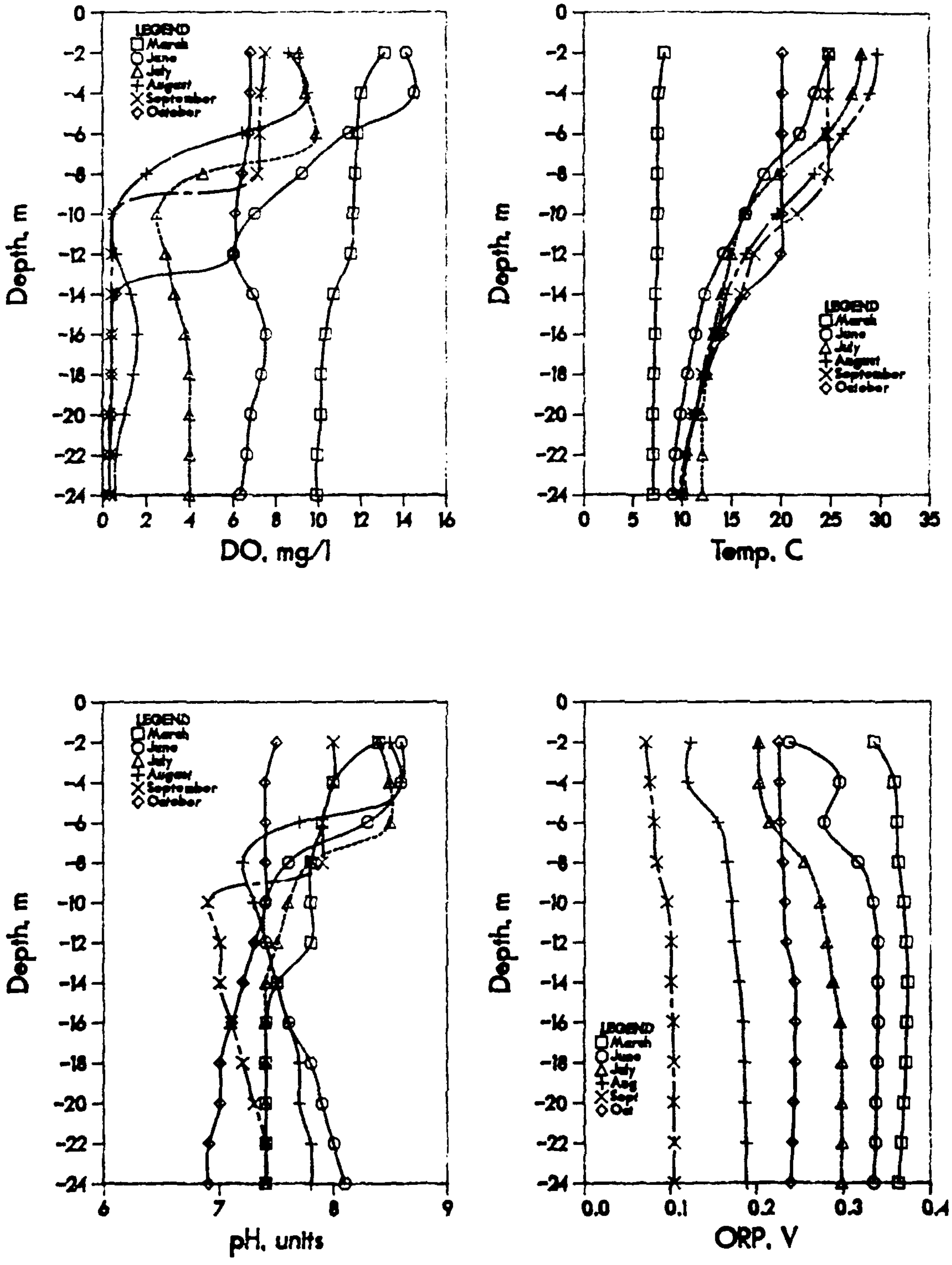

Figure 14: Station 5 Water Quality Profiles

temperature of approximately 7°C and a DO concentration of approximately 10.0 mg/l. By June 1988 the lake had thermally stratified and had a metalimnetic DO minima of approximately 5.0 mg/l from 8 to 12 meters. The hypolimnetic DO had declined to about 8 mg/l. At this time, D.O. supersaturation was occuring throughout the epilimnion due to photosynthesis. By July 1988 superstaturation had ceased and the metalimnetic minima had decreased to a concentration of 4.0 mg/l and the hypolimnetic DO demand had declined to 4-6 mg/l. By August, the DO concentration in the metalimnion was nearly 0.0 mg/l at a depth of 8.0 meters. This lake condition persisted through the last sampling period in mid-October during the Fall overturn process. (Overturn was in progress but not yet complete.)

140. Similar profile patterns were established by pH and ORP. Oxidation-reduction potential and pH values corresponded well with temperature and DO measurements; pH decreased sharply with decreases in temperature and DO concentration while ORP values increased slightly with a decrease in temperature and DO. The pH was highest in the epilimnion during supersaturation due to photosynthesis, and it dropped sharply with decreases in temperature, DO concentrations, and depth due to algal respiration and organic decay. Throughout the summer, the lake's hypolimnetic pH decreased from approximately 8.0 units to approximately 7.0 units. Oxidation-reduction values increased slightly with decreasing DO concentrations and

decreasing pH; the values also decreased throughout the summer by approximately 300 mV.

141. The nutrient data, evaluated for each main channel station, are listed in Tables 9 through 12. Significant trends in the nutrient data occur with depth, time, and length. Depth trends are insignificant in relation to all the nutrient species except for the nitrite/nitrate nitrogen specie concentration; at each station these concentrations increased significantly with depth throughout the summer months.

142. Time trends were significant for each nitrogen specie. Inorganic nitrogen concentrations (NO3 and NH3) in the epilimnion and metalimnion were dominant in late Spring and peaked in July 1988. By mid-August, organic nitrogen in the epilimnion and metalimnion had become the dominant specie and its concentration continued to increase during the Fall overturn process in October 1988. No significant time trends were observed for phosphorus with the exception that total phosphorus concentrations peaked in June 1988, decreased during the summer, and increased slightly during the Fall overturn process. Ortho-phosphate phosphorus concentrations were generally reported as less than 10 mg/l.

Table 9

Nitrogen and Phosphorus Concentrations in Station 2

DEPTH (m)	DO (mg/l)	NO2/NO3 (mg/l)	NH3 (mg/l)	Total N (mg/l)	Organic N (mg/l)	Total P (ug/l)	Ortho P (ug/l)
3/17/88							
2	11.6	0.20	0.10	0.68	0.30	13	<10
10	11.3	0.22	0.05	0.73	0.51	10	<10
36	10.5	0.30	0.05	0.86	0.56	10	<10
6/15/88							
3	13.8	0.01	0.12	0.36	0.24	37	<10
11	7.7	0.45	0.12	0.57	0.01	16	<10
45	8.5	0.65	0.09	0.74	0.01	36	<10
7/8/88							
3	10.4	0.20	0.17	0.43	0.06	10	<10
12	4.1	0.49	0.08	0.62	0.05	10	<10
21	6.4	0.71	0.09	0.80	0.01	10	<10
8/10/88							
2	8.4	0.01	0.05	0.38	0.33	17	<10
10	0.6	0.01	0.03	0.23	0.19	10	<10
22	4.6	0.60	0.04	0.80	0.16	10	<10
9/7/88							
2	7.0	0.03	0.01	0.24	0.21	10	<10
10	0.4	0.02	0.01	0.17	0.15	10	<10
28	3.7	0.77	0.01	0.85	0.08	10	<10
10/13/88							
2	7.8	0.01	0.02	0.46	0.44	13	<10
10	7.6	0.01	0.01	0.28	0.28	13	<10
24	2.4	0.69	0.01	0.82	0.13	13	<10

Table 10

Nitrogen and Phosphorus Concentrations in Station 3

DEPTH (m)	DO (mg/l)	NO2/NO3 (mg/l)	NH3 (mg/l)	Total N (mg/l)	Organic N (mg/l)	Total P (ug/l)	Ortho P (ug/l)
3/17/88							
2	11.7	0.30	0.05	0.95	0.65	17	<10
10	11.1	0.32	0.05	0.99	0.67	18	<10
36	10.2	0.45	0.05	1.10	0.65	23	17
6/15/88							
2	13.3	0.01	0.07	0.44	0.37	47	<10
10	5.7	0.55	0.11	0.69	0.03	31	<10
36	8.4	0.64	0.16	0.80	0.01	34	<10
7/8/88							
4	10.3	0.13	0.28	0.41	0.01	16	<10
12	3.1	0.54	0.59	1.10	0.01	13	<10
22	6.4	0.82	0.11	0.93	0.01	14	<10
8/10/88							
2	8.4	0.01	0.06	0.36	0.29	17	<10
10	0.5	0.01	0.05	0.30	0.25	12	<10
22	4.3	0.69	0.02	0.86	0.15	10	<10
9/7/88							
2	7.2	0.04	0.01	0.26	0.22	10	<10
10	0.4	0.02	0.01	0.15	0.13	10	<10
27	3.0	0.79	0.01	0.79	0.01	10	<10
10/13/88							
3	7.9	0.01	0.01	0.37	0.37	14	<10
10	7.6	0.01	0.02	0.37	0.35	36	<10
24	1.2	0.65	0.16	0.83	0.02	12	<10

Table 11

Nitrogen and Phosphorus Concentrations
in Station 4

DEPTH (m)	DO (mg/l)	NO2/NO3 (mg/l)	NH3 (mg/l)	Total N (mg/l)	Organic N (mg/l)	Total P (ug/l)	Ortho P (ug/l)
3/17/88							
2	11.5	0.61	0.05	1.70	1.09	39	<10
10	10.9	0.65	0.05	1.50	0.85	27	<10
32	9.7	0.73	0.07	1.60	0.80	36	19
6/15/88							
2	13.0	0.28	0.15	0.51	0.08	56	12
10	5.7	0.70	0.19	0.89	0.01	24	<10
38	7.3	0.21	0.14	0.78	0.43	39	<10
7/8/88							
1	9.2	0.01	0.08	0.29	0.21	20	<10
9	3.3	0.63	0.10	0.73	0.01	18	<10
20	5.3	0.89	0.29	1.50	0.30	18	<10
8/10/88							
2	9.1	0.01	0.05	0.32	0.26	12	<10
10	0.7	0.26	0.03	0.44	0.15	11	<10
22	2.6	0.71	0.05	0.88	0.12	10	<10
9/7/88							
2	7.6	0.02	0.01	0.21	0.19	10	<10
10	0.5	0.05	0.01	0.19	0.14	10	<10
26	0.3	0.82	0.01	0.19	0.14	10	<10
10/13/88							
2	7.3	0.01	0.01	0.24	0.24	12	<10
10	7.0	0.01	0.01	0.26	0.26	12	<10
22	0.4	0.01	0.01	0.26	0.26	12	<10

Table 12

Nitrogen and Phosphorus Concentrations
in Station 5

DEPTH (m)	DO (mg/l)	NO2/NO3 (mg/l)	NH3 (mg/l)	Total N (mg/l)	Organic N (mg/l)	Total P (ug/l)	Ortho P (ug/l)
3/17/88							
2	13.1	0.66	0.05	1.80	1.14	27	<10
10	11.6	0.71	0.05	1.60	0.89	15	<10
30	10.2	0.81	0.07	1.7	0.82	25	<10
6/15/88							
2	14.1	0.07	0.15	0.37	0.15	46	<10
10	7.0	0.86	0.08	0.94	0.01	31	<10
28	6.1	0.81	0.02	0.94	0.11	31	<10
7/8/88							
2	9.1	0.01	0.09	0.26	0.17	16	<10
8	4.6	0.25	0.09	0.40	0.06	15	<10
17	4.0	0.91	0.08	0.99	0.01	16	<10
8/10/88							
2	8.6	0.01	0.04	0.28	0.23	16	<10
10	0.5	0.25	0.03	0.49	0.21	10	<10
22	0.6	0.44	0.12	0.61	0.05	10	<10
10/13/88							
2	7.5	0.01	0.01	0.33	0.33	13	<10
10	0.5	0.01	0.01	0.39	0.39	14	11
24	0.3	0.02	0.38	0.68	0.28	36	33

Nutrient trends in relation to the length of Center Hill were significant for both nitrogen species and for total phosphorus. In March and June 1988, total nitrogen and total phosphorus concentrations decreased with the length of the lake; the lowest concentrations were at the dam, Station 2. In July, the total nitrogen and phosphorus concentrations were nearly constant throughout the lake. By mid-August, both nitrogen and total phosphorus concentrations were increasing with length and concentrations were highest at the dam. Concentrations remained highest at the dam through September and October. These nutrient/length trends indicate that nutrients enter Center Hill through its tributaries during the spring and early summer when rain events are more frequent. During the summer, inflows are considerably lower and nutrients are not flushed into the main channel of the lake.

143. Literature has indicated that nitrogen to phosphorus ratios above 20:1 represent phosphorus-limited lakes [Tsai and Huang, 1979; EPA, 1988]. Based upon mean total nitrogen and total phosphorus concentrations, Center Hill Lake has a nitrogen to phosphorus ratio of 35:1 and is phosphorus-limited.

Comparison of Lake and Embayment Water Quality Data

144. In order to compare the water quality in the embayments to that of the main channel, means and standard deviations were calculated for each chemical parameter in

relation to each station's epilimnion, thermocline, and hypolimnion. These analyses were based on data gathered from the two worse-case embayments (with respect to nutrient loadings), Falling Water and Mine Lick, and the four main channel stations. The results are listed in Table 13.

145. On average, the embayments contained higher concentrations of total and ortho-phosphate phosphorus and lower concentrations of dissolved oxygen. Ortho-phosphate phosphorus concentrations were high in the embayments due to anaerobic activity after complete D.O. depletion. Anaerobic activity was not observed to occur within the main channel of Center Hill. Additional evidence that oxygen was limiting in the embayments was the observation that nitrite/nitrate concentrations were low in comparison to their corresponding ammonia concentrations. At a pH of 8.5 and a temperature of 25°C, the concentration of total ammonia which causes free ammonia to exceed 0.02 mg/l is 0.13 mg/l. Ammonia concentrations often exceeded this value in the epilimnion of the lake. However, the toxic level for fish is in the range of 0.2 to 2 mg/l free ammonia.

Trophic State Determination

146. The trophic state of Center Hill Lake using 1973 data was determined to be eutrophic based upon criteria set forth by Gakstatter, et al., [1975] and Dillon [1975] [Gordon, 1976]. The trophic state of Center Hill Lake and

Table 13

Statistics for the Embayments and the Lake

Parameter	Lake Statistics Mean	Lake Statistics Std. Dev.	Embayment Statistics Mean	Embayment Statistics Std. Dev.
NO2/NO3 (mg/l as N)				
Epilimnion	0.112	0.180	0.056	0.138
Metalimnion	0.293	0.278	0.100	0.214
Hypolimnion	0.615	0.247	0.227	0.294
NH3 (mg/l as N)				
Epilimnion	0.068	0.060	0.090	0.063
Metalimnion	0.074	0.116	0.216	0.253
Hypolimnion	0.086	0.089	0.447	0.393
Total Nitrogen (mg/l as N)				
Epilimnion	0.494	0.410	0.365	0.137
Metalimnion	0.590	0.400	0.588	0.354
Hypolimnion	0.880	0.334	0.865	0.359
Organic Nitrogen (mg/l as N)				
Epilimnion	0.323	0.271	0.227	0.131
Metalimnion	0.238	0.252	0.278	0.282
Hypolimnion	0.219	0.246	0.197	0.160
Total Phosphorus (mg/l as P)				
Epilimnion	20.75	13.30	26.55	12.10
Metalimnion	16.08	10.53	65.65	89.48
Hypolimnion	18.54	10.53	139.5	146.3
Ortho Phosphorus (mg/l as P)				
Epilimnion	<10	NA	10.45	0 086
Metalimnion	<10	NA	35.15	53.98
Hypolimnion	<10	NA	71.70	78.44

its embayments was reevaluated using 1988 data based upon criteria set forth by Gakstatter, Dillon, and Carlson.

147. Gakstatter [1975] assessed parameters associated with lake trophic conditions in order to develop criteria by which the trophic state of a lake could be judged. Table 14 lists Gakstatter's trophic state criteria [Gakstatter, et al., 1975].

148. According to these criteria, the main-channel of the lake can be classified as mesotrophic in view of a total phosphorus average of 18.4 ug/l, an average Secchi transparency of 2.3 meters and an average chlorophyll a value of 7.4 ug/l (average values from Table 13). Based upon Secchi transparency, chlorophyll a and total phosphorus, both embayments can be classified as eutrophic; Secchi transparency means for the two embayments (Falling Water and Mine Lick) were 1.7 and 1.9 meters, chlorophyll a was 5.0 and 4.1 ug/l and total phosphorus was 44 and 111, respectively.

149. The classification of Center Hill Lake using Gakstatter's criteria did not consider the hydraulics of the lake, the areal total phosphorus loading or the phosphorus retention in the lake [Gordon, 1976]. Dillon [1975] used these factors to derive a relationship between mean depth and a factor which accounts for net annual total phosphorus loads and hydraulic flushing time. Dillon's loading factor is as follows:

Table 14

Key Parameter Values Associated with Three
Lake Trophic Conditions
Gakstatter (1975)

Parameter	Oligotrophic	Mesotrophic	Eutrophic
Total Phosphorus (ug/l)	<10	10-20	>20-25
Chlorophyll a (ug/l)	<4	4-10	>10
Secchi Disk (meters)	>3.7	2.0-3.7	<2.0

$$\text{Effective Loading} = L(1-R)/p \qquad (8)$$

where p, the annual flushing rate, is the annual discharge to lake volume ratio, L is the areal loading expressed in terms of grams total phosphorus per square mile per year and R, the total phosphorus retention in the lake, is that fraction of the input phosphorus not lost through the outflow. The Dillon relationship and data points accumulated by Gatskatter are shown in Figure 15.

150. An attempt to assess Dillon's Model for Center Hill Lake in 1988 resulted in the following values:

$p = 1.016$ year^{-1} (1988 was a dry year)
L = 0.408 gms TP/sq. mile/yr
1-R = 0.2432
Mean Depth = 71 feet (22 meters).

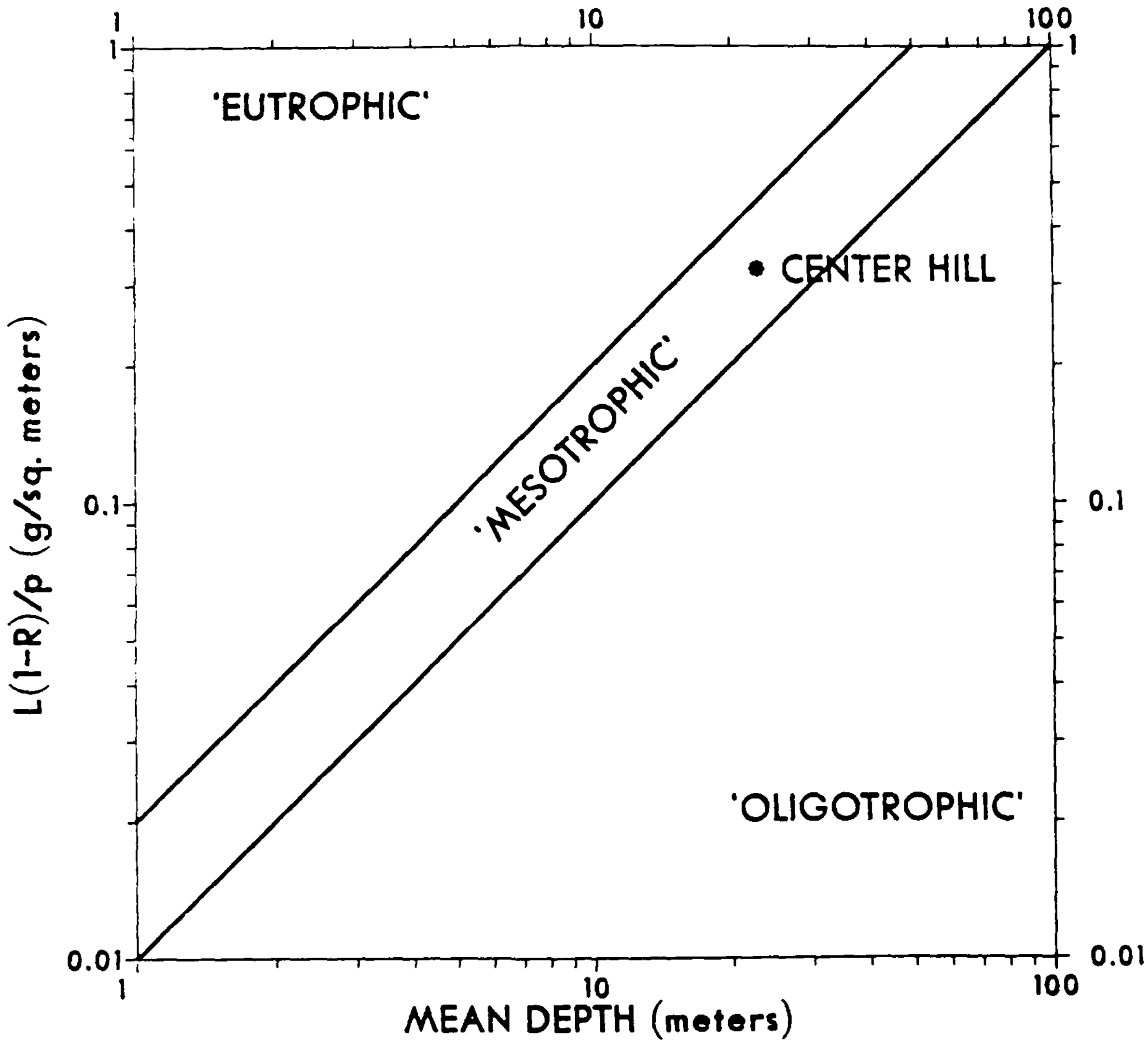

Figure 15. Dillon Relationship (from Gordon's 1976 Report)

The Dillon relationship for Center Hill in 1988 was 0.305 which places the reservoir in the mesotrophic classification.

151. The Carlson [1977] Trophic State Index (TSI) is the most widely used index to rate measured in-lake variables on a scale so that the severity of lake problems can be compared to other lakes in the area [NALMS, 1988]. The index was developed to compare determinations of chlorophyll a, Secchi transparency, and total phosphorus concentration. Higher index numbers indicate a degree of eutrophy while low numbers indicate a degree of oligotrophy. Carlson's trophic state equations are as follows:[Carlson, 1977]

$$TSI = 60 - 14.41 \ln(\text{Secchi Transparency, meters}); \quad (9)$$
$$TSI = 9.81 \ln(\text{Chloro } \underline{a}\text{, ug/l}) + 30.6; \quad (10)$$
$$TSI = 14.42 \ln(\text{Total Phosphorus, ug/l}) + 4.15. \quad (11)$$

Index values above 50 indicate a degree of eutrophy, between 35 and 50 a degree of mesotrophy, and below 35 a degree of oligotrophy. Trophic state indicies are listed in Table 15 for two embayments, Falling Water and Mine Lick, and the main-channel of the reservoir based upon average Secchi transparencies, chlorophyll a values, and total phosphorus concentrations.

152. Indicies calculated for chlorophyll a are lower than the other indicies while total phosphorus indicies are generally higher. An explanation might be the presence of suspended materials that reduce light attenuation and therefore algal productivity [NALMS, 1988]. The trophic

state indicies imply that the main-channel of the lake is slightly mesotrophic while the embayments are slightly eutrophic.

Inflow and Tailwater Results

153. Center Hill's major inflows and tailwater were measured for water quality field parameters and sampled biweekly for chemical analysis from March 1988 through January 1989. Instantaneous flow and turbidity measurements were also made during each sampling period.

Table 15

Carlson's Trophic State Indicies for Center Hill's Main-Channel and Two Embayments

Station	Sechhi Disk TSI	Chloro a TSI	Total-P TSI
Falling Water Embayment	53	46	58
Mine Lick Embayment	53	44	72
Main-Channel	48	50	46

Streamflow analysis

154. Daily flow data, within the time frame of this study, were obtained for the Collins River near McMinnville from the U.S. Geological Survey. The Collin's daily flow data were utilized to reveal storm events within the Caney Fork River Basin that were not measured by biweekly sampling trips. The Collin's hydrograph for March 1988 through

January 1989 is shown in Figure 16. Figure 17 displays the hydrographs for Center Hill's inflows based upon biweekly instantaneous flow measurements. A comparative analysis of the hydrographs indicates that the instantaneous flow measurements made at two week intervals were sufficient in describing the year's flow patterns, especially during the period between days 140 - 300.

155. These flow patterns are typical of unregulated streams in which numerous isolated runoff events normally occur. Precipitation accounts for sharp rises in streamflow during early spring and late fall/early winter. During summer dry periods, few runoff events occur, and the majority of streamflow is contributed by groundwater discharge. Rainfall at the Cookeville gage was quite low after mid-May, non-existant during June and moderate during the July to September period. October rainfall was very low while November, December, and January, 1989, were wetter. The low soil moisture during the May to October period resulted in negligible direct runoff and sustained low flows. However, with the return of rainfall in November, flows became more flashy.

Time-Series Analysis for Water Quality Parameters

156. Time-series plots used in conjunction with hydrographs effectively describe water quality variations due to streamflow. A combination of these graphical techniques was used to depict variations in streamflow and

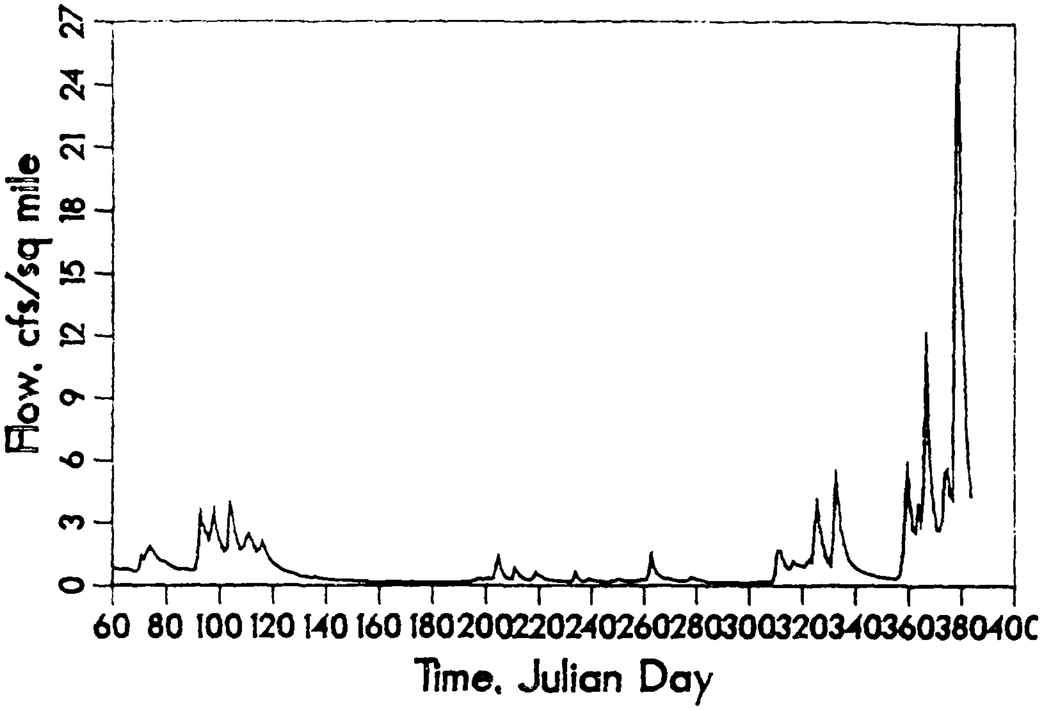

Figure 16: Collins River Hydrograph

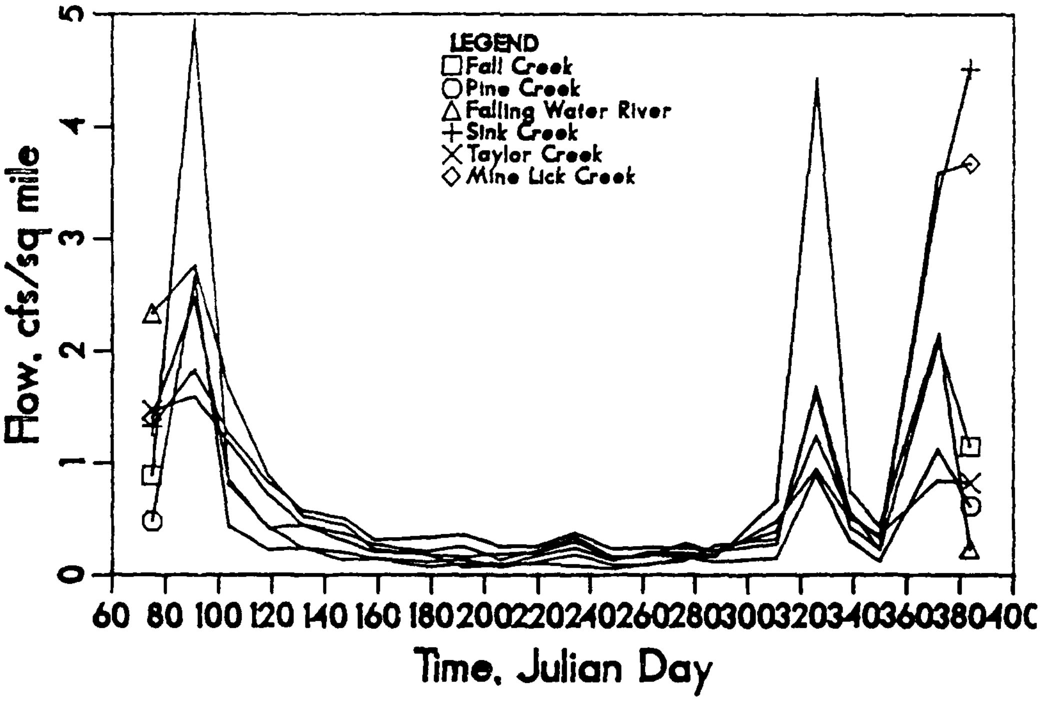

Figure 17: Center Hill's Inflow Hydrographs

water quality parameters during a fall runoff event. Time-series plots were also used to describe nutrient-concentration fluctuations in the biweekly inflow measurements.

157. Falling Water River, impacted by Cookeville's sewage treatment plant, and Taylor Creek, impacted primarily by agriculture, were sampled before, during, and after a 4-inch rain event during November 19-22 in order to characterize the relationship between streamflow and nutrient levels in response to a runoff event. The precendent flow at Falling Water River was about 90 cfs and rainfall during the previous ten days was just over 1 inch. A minimum of four samples were obtained before and after the peak flow with the first sample collected before the rain event began and the last sample collected two days after the peak flow. Table 16 lists the field measurements of each inflow during the runoff event, and Figures 18 through 21 graphically depict the variations in streamflow and nutrient levels with time. The storm event nutrient data are listed in Appendix II.

158. No significant trends with respect to flow were observed for the majority of the physical parameters with the exception of turbidity and conductivity. However, significant trends with respect to flow were observed for conductivity and chemical water quality. Turbidity was the only physical parameter that showed a significant response to an increase in streamflow. Turbidity increased with flow

Table 16

Water Quality Field Data From a Runoff Event from Falling Water River and Taylor Creek

Time hour	Flow cfs	Temp °C	DO mg/l	Cond mmho/cm	pH units	ORP mV	Turb NTU
Falling Water River							
0.0	85	11.2	10.3	350	7.2	440	15
4.5	197	11.5	9.8	285	7.3	306	83
7.5	395*	11.8	9.8	235	7.3	325	490
22.5	939*	13.3	9.2	211	7.2	286	230
26.5	970*	13.8	9.6	214	7.3	332	175
31.0	997*	13.7	9.9	217	7.3	332	115
46.5	549*	12.9	10.0	192	7.5	450	64
52.0	412*	12.7	9.5	215	7.5	356	48
69.5	231*	11.1	9.7	233	7.4	244	40
77.5	200*	12.3	10.3	213	7.6	253	**
Taylor Creek							
0.0	16	11.9	10.1	241	7.4	386	8
4.5	45	11.9	10.3	132	7.1	321	600
8.5	42	12.2	10.1	115	7.2	317	270
23.0	51*	13.7	10.0	104	7.1	296	235
29.0	41*	14.3	9.9	127	7.3	297	110
33.0	39*	13.7	10.0	135	7.4	295	75
48.5	32*	11.8	10.2	138	7.2	334	29
54.5	29*	12.5	10.0	145	7.3	338	26
80.5	25*	12.7	9.9	160	7.4	254	**

* Streamflows estimated from staff gage and velocity measurements

** missing data

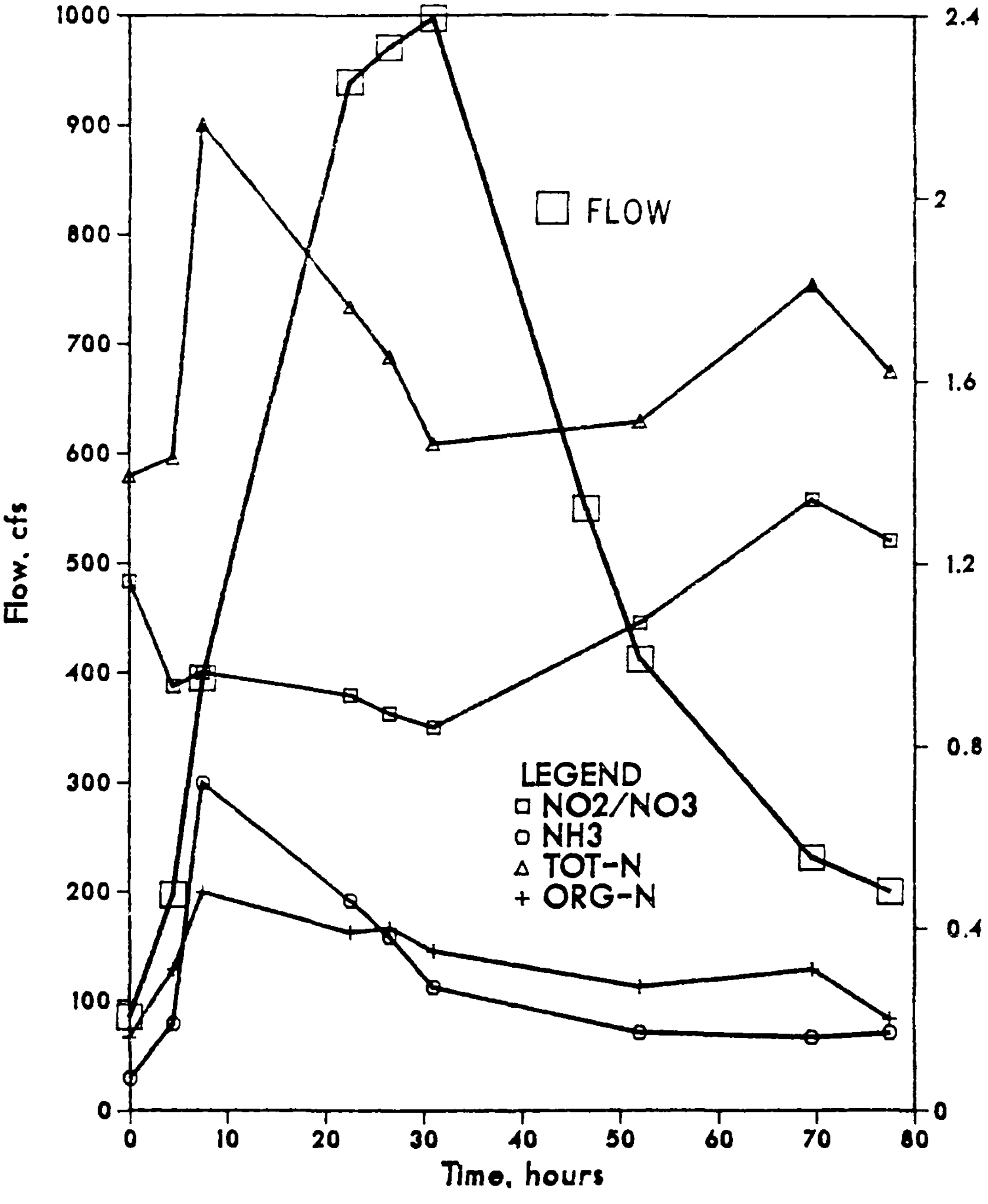

Figure 18: Falling Water River Nitrogen
Fluctuations during Runoff Event

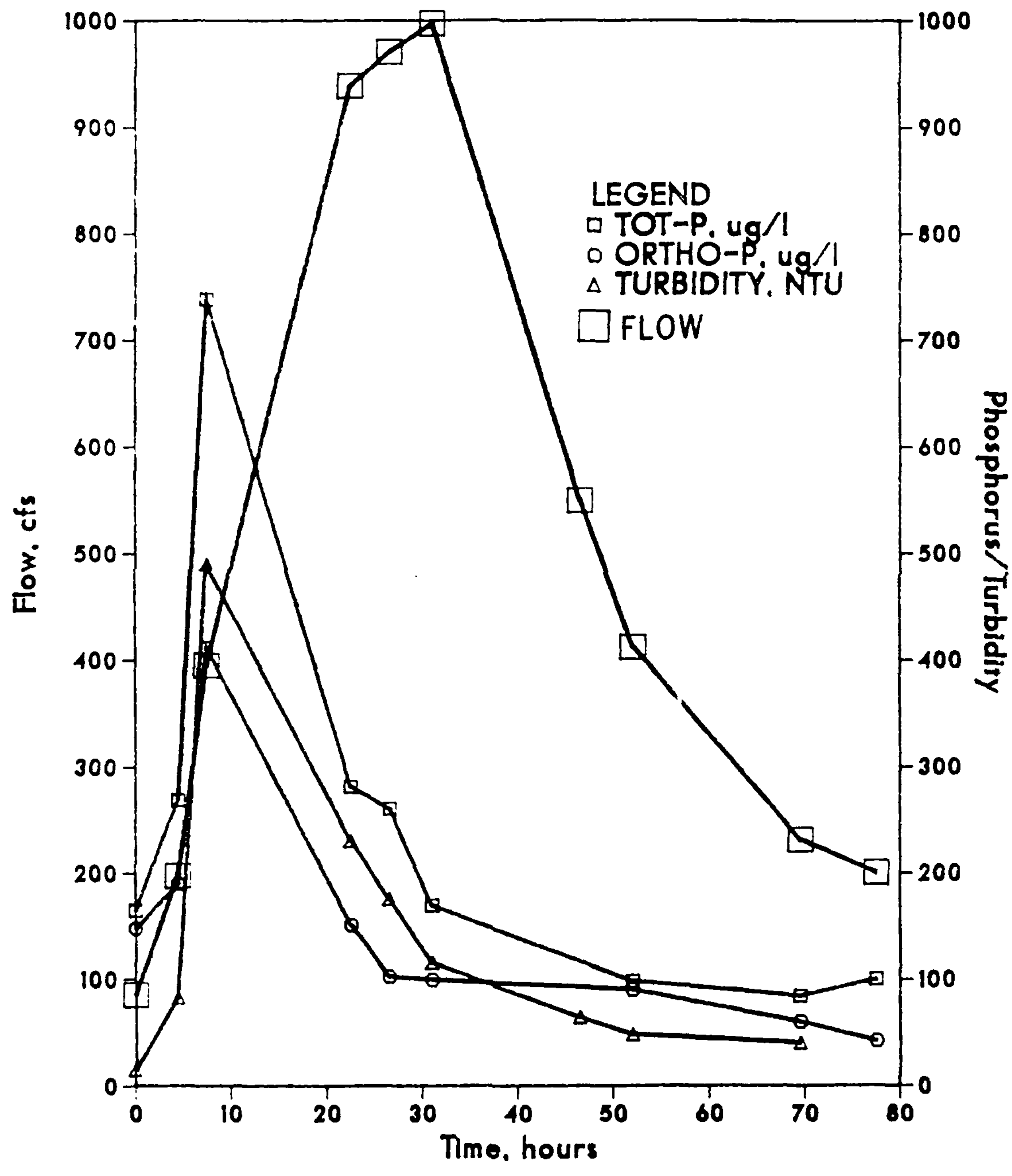

Figure 19: Falling Water River Phosphorus Fluctuations during Runoff Event

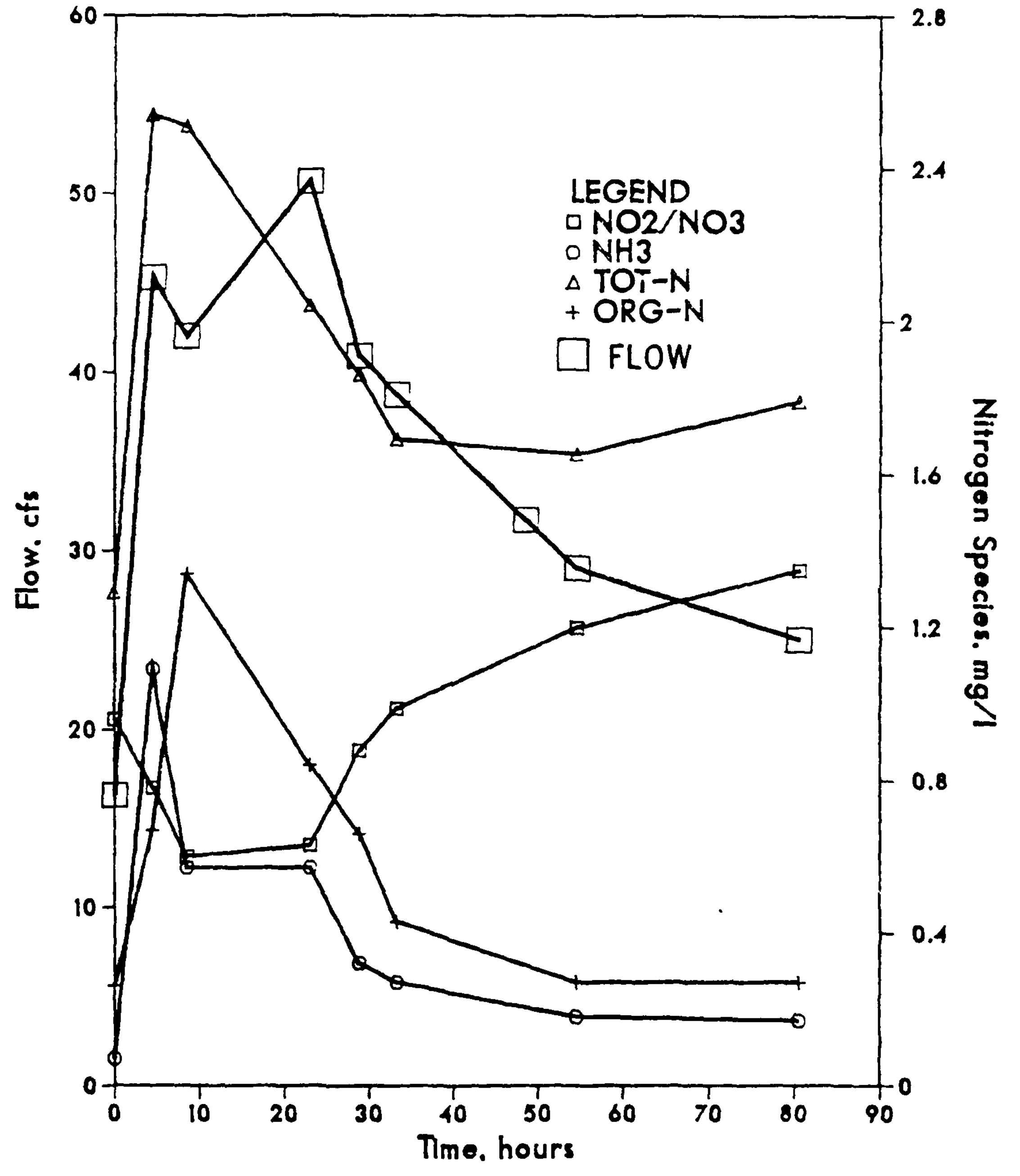

Figure 20: Taylor Creek Nitrogen Fluctuations during Runoff Event

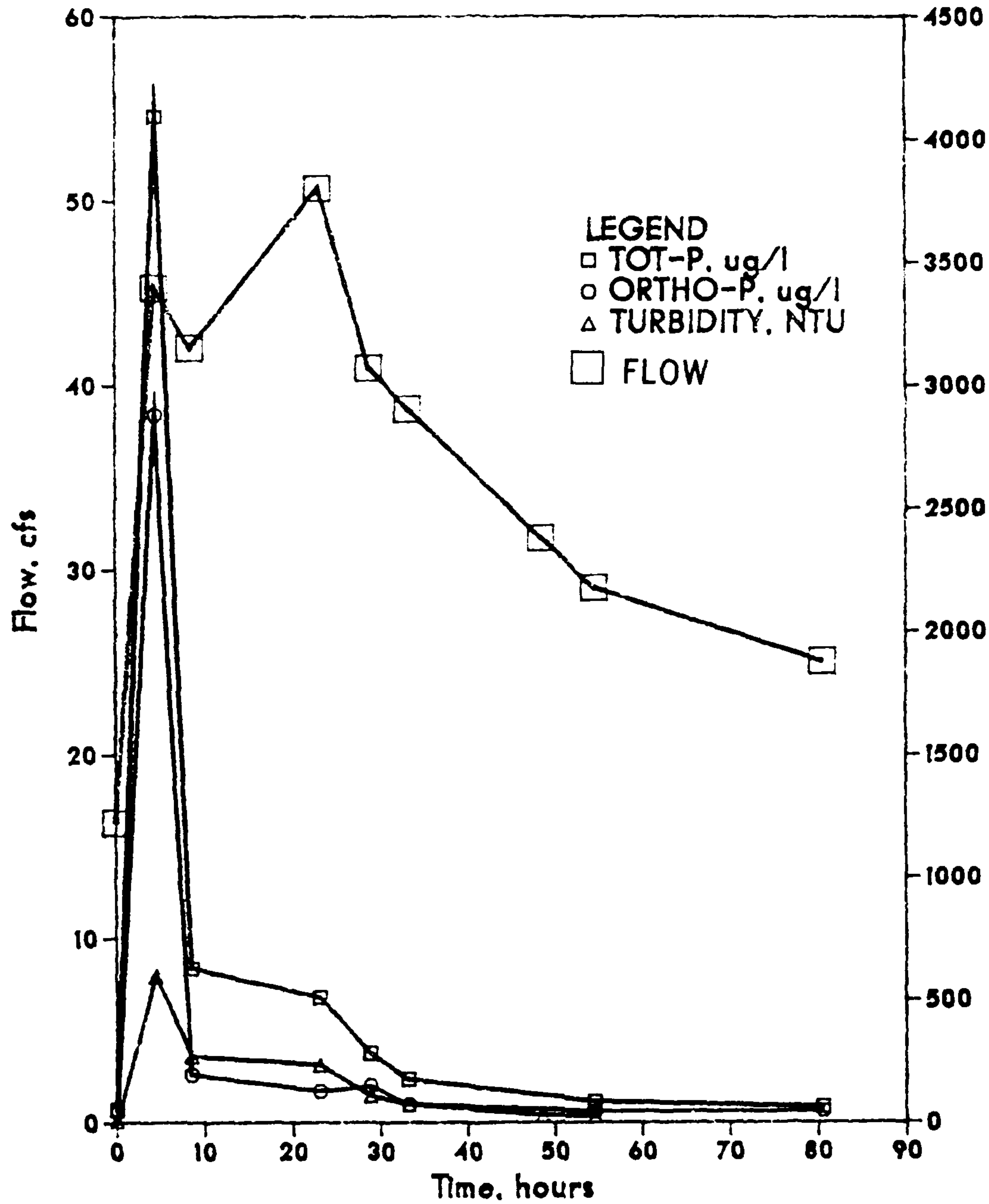

Figure 21: Taylor Creek Phosphorus Fluctuations
during Runoff Event

and reached its peak value approximately six hours before the streamflow reached its peak. Taylor Creek had a large initial increase in turbidity, from 8 NTUs to 600 NTUs (the peak value) over a 4.5 hour time span, presumably due to direct runoff from adjacent agricultural lands. Falling Water River was observed to have a large increase in turbidity, from 15 NTUs to 490 NTUs (the peak value) over a 7.5 hour time span. Conductivity and ORP generally decreased with an increase in streamflow, but increased slightly at the time of peak flow, decreased and then increased again several hours after the peak flow which clearly illustrates a combination of the dilutional effect an increase in streamflow has on ions and demonstrates the difference between the quality of the first flush of surface runoff and that of ground water recharge of the stream. Nutrient levels at first increased with flow reaching their maximum concentration just before the streamflow reached its peak. This observation is referred to as "the first flush" or "washoff"" effect. Total nitrogen and nitrate/nitrite concentrations in Falling Water River were observed to decline and then have a second smaller peak several hours after peak flow which corresponded with the peak in conductivity values. Total and nitrite/nitrate nitrogen in Taylor Creek also increased later in the rain event, but unlike Falling Water River, their concentrations did not reach a second peak within the time span of the study. Total phosphorus concentrations increased with flow, probably due to the suspension of bottom sediments, which during low-flow conditions may adsorb particulate phosphorus. No significant differences were observed between the two streams' nutrient concentrations or their relationships with flow.

159. Seasonal time-series plots were constructed for Falling Water River and Taylor Creek to display long-term fluctuations in nutrient concentrations and to compare the fluctuations with streamflow trends. Figures 22 through 27 display nutrient concentration and streamflow fluctuations from March 1988 through January 1989 for Falling Water River and Taylor Creek. No obvious relationship exists between flow and nitrogen species in either stream. Total and orthophosphate phosphorus concentrations in both streams were greatest during the summer months when streamflows were lowest. Phosphorus concentrations were highest in the Falling Water River. During periods of high flows, early spring and late fall, phosphorus concentrations were lower.

Basic statistical summaries

160. Basic statistics were computed for each inflows' data set utilizing the SAS statistical software package (SAS program in Appendix). Although the parameters were not assumed to approximate the normal distribution, common

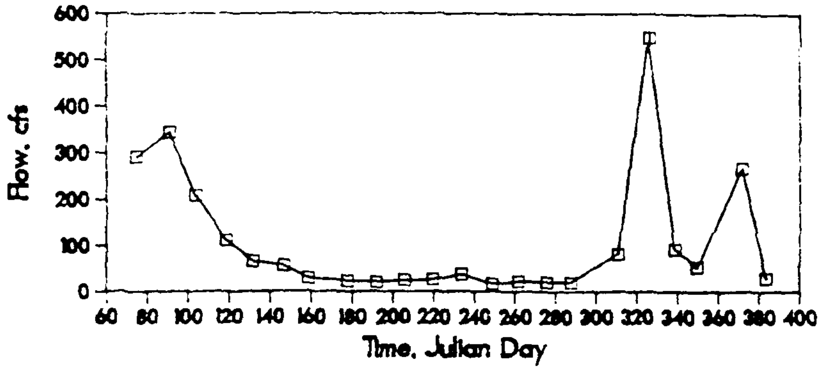

Figure 22: Falling Water River Hydrograph

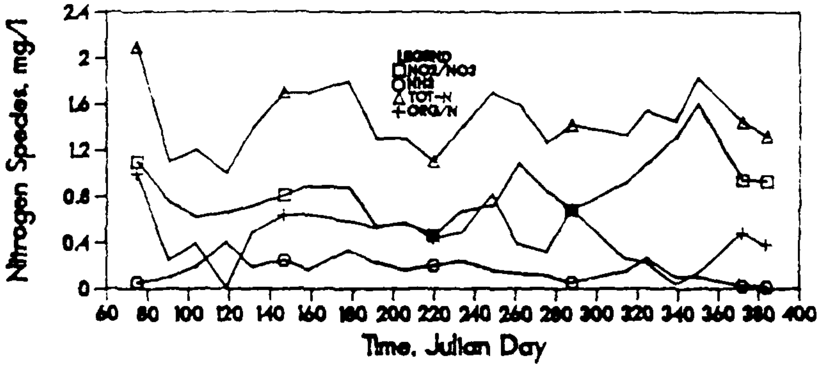

Figure 23: FWR Nitrogen Specie Time-series

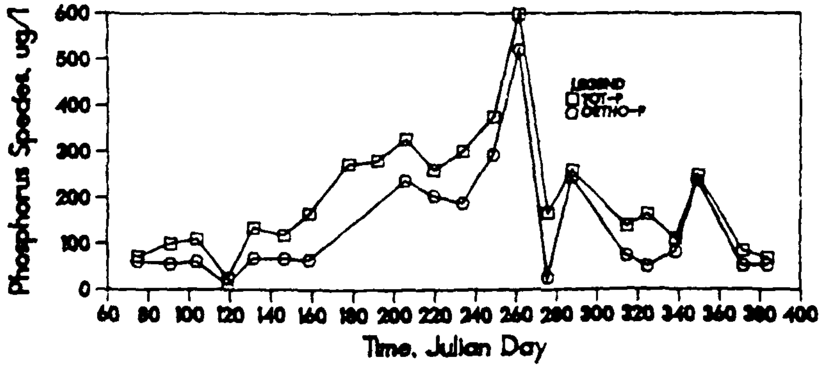

Figure 24: FWR Phosphorus Specie Time-series

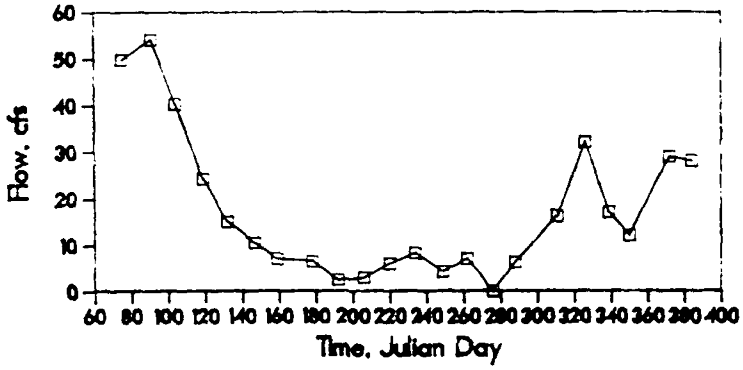

Figure 25: Taylor Creek Hydrograph

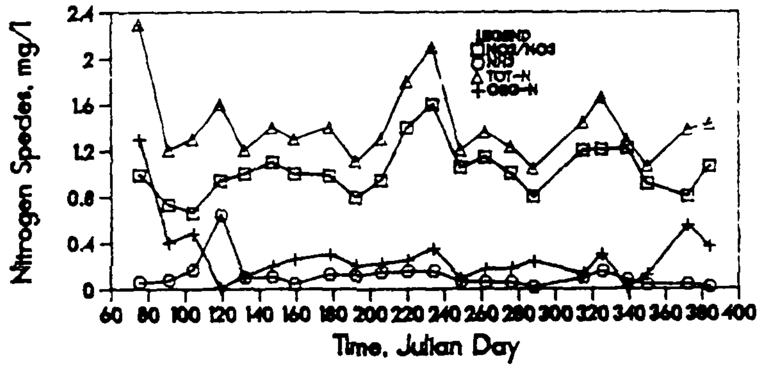

Figure 26: Taylor Creek Nitrogen Specie Time-series

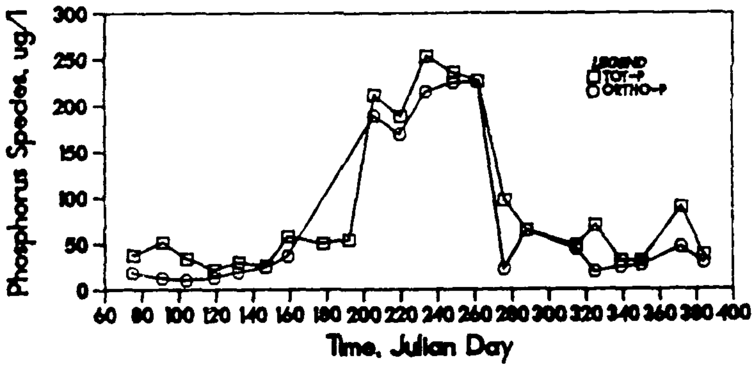

Figure 27: Taylor Creek Phosphorus Specie Time-series

statistical measures such as the mean and standard deviation were calculated. The statistical summaries provide information about the distribution of the constituents in terms of quartiles (0, 25, 50, 75, and 100 percent) to help judge the normality of the data. Table 17 summarizes the basic statistics and quartiles calculated for each inflow and the tailwater from biweekly data collected from March 1988, through January 1989.

161. The means for most physical parameters were quite close for all inflows including streams receiving sewage treatment plant effluents and streams impacted primarily by agricultural runoff. The means for most nutrient species were considerably different for each inflow. Specific causes of these nutrient concentration differences cannot be determined from the data. Means for both physical parameters and nutrient concentrations were quite low in the tailwater due to its release from the lower hypolimnion of Center Hill.

Correlation and Regression Analyses

162. Correlation and regression analyses were performed to estimate the strength of the relationships that existed between the water quality and flow data. The analyses were carried out utilizing the SAS Statistical Software package correlation and regression procedures (SAS program in Appendix).

Table 17

Basic Statistics for Center Hill Lake's
Inflows and Tailwater

Variable	N	Mean	S.D.	0%	25%	50%	75%	100%
GREAT FALLS								
Temp, °C	21	17.5	6.4	6	11	18	23	29
D.O., mg/l	21	9.9	1.9	5	9	10	12	13
Turb, NTU	21	7.7	3.3	4	5	6	10	17
NO3, mg/l	21	0.40	0.17	0.08	0.3	0.4	0.5	0.9
NH3, mg/l	21	0.18	0.31	0.01	0.06	0.09	0.1	1.5
TOT-N, mg/l	21	0.75	0.26	0.42	0.61	0.65	0.9	1.7
ORG-N, mg/l	21	0.20	0.12	0.01	0.08	0.20	0.3	0.4
TOT-P, ug/l	21	40.5	44.6	10	21	29	33	194
O-P, ug/l	19	22.8	25.8	10	10	15	25	124
Flow, cfs	322	1797	-	-	-	-	-	-
SINK CREEK								
Temp, °C	22	16.0	5.9	5	11	17	21	23
D.O., mg/l	22	11.2	2.0	9	10	11	12	17
Turb, NTU	22	7.7	10.0	2	2	4	5	33
NO3, mg/l	22	0.20	0.22	0.33	0.90	1.0	1.1	1.5
NH3, mg/l	22	0.09	0.08	0.01	0.03	0.08	0.1	0.3
TOT-N, mg/l	22	1.28	0.24	0.97	1.1	1.2	1.5	1.9
ORG-N, mg/l	22	0.23	0.24	0.01	0.09	0.18	0.2	0.9
TOT-P, ug/l	22	30.4	37.5	10	10	14	40	157
O-P, ug/l	20	10.8	4.2	6	10	10	11	58
Flow, cfs	21	26.6	28.3	8	9	14	38	126
PINE CREEK								
Temp, °C	22	15.5	4.8	6	12	17	20	21
D.O., mg/l	22	10.8	1.4	9	10	11	11	15
Turb, NTU	22	9.0	14.2	2	2	3	10	62
NO3, mg/l	22	1.5	0.26	0.87	1.5	1.6	1.7	1.8
NH3, mg/l	22	0.09	0.11	0.01	0.02	0.06	0.1	0.6
TOT-N, mg/l	22	1.8	0.40	1.4	1.6	1.7	1.8	3.0
ORG-N, mg/l	22	0.22	0.36	0.01	0.01	0.05	0.34	1.2
TOT-P, ug/l	22	29.6	27.6	10	15	19	28	129
O-P, ug/l	20	19.0	14.0	5	10	16	22	69
Flow, cfs	22	22.6	18.4	9	11	15	27	81
FALL CREEK *								
Temp, °C	22	16.7	5.9	6	12	19	22	24
D.O., mg/l	22	10.2	2.1	7	8	10	11	16
Turb, NTU	22	6.4	8.0	1	2	3	8	30
NO3, mg/l	22	0.77	0.34	0.34	0.46	0.64	1.1	1.4
NH3, mg/l	22	0.13	0.14	0.01	0.04	0.08	0.17	0.5
TOT-N, mg/l	22	1.19	0.49	0.51	0.90	1.0	1.4	2.8

Table 17. Continued

ORG-N, mg/l	22	0.29	0.32	0.01	0.08	0.24	0.35	1.4
TOT-P, ug/l	22	32.9	27.4	11	16	22	33	113
O-P, ug/l	22	17.1	10.6	10	10	13	19	54
Flow, cfs	22	9.1	13.3	2	3	4	10	61
FWR								
Temp, °C	22	16.9	6.5	6	11	18	23	27
D.O., mg/l	22	9.9	2.9	6	7	10	11	18
Turb, NTU	22	18.0	14.2	2	12	14	19	64
NO3, mg/l	22	0.85	0.27	0.5	0.7	0.8	1.0	1.6
NH3, mg/l	22	0.16	0.10	0.01	0.1	0.2	0.2	0.4
TOT-N, mg/l	22	1.45	0.27	1.00	1.3	1.4	1.7	2.1
ORG-N, mg/l	22	0.44	0.24	0.01	0.3	0.5	0.6	1.0
TOT-P, ug/l	22	200	131	25	108	165	276	599
O-P, ug/l	20	133	125	11	55	68	230	522
Flow, cfs	22	108	139	16	22	46	134	549
TAYLOR								
Temp, °C	22	14.8	5.0	6	11	15	19	22
D.O., mg/l	22	10.3	1.7	8	9	11	12	14
Turb, NTU	22	11.0	9.4	3	5	7	14	41
NO3, mg/l	22	1.02	0.78	0.66	0.88	1.0	1.2	1.6
NH3, mg/l	22	0.11	0.13	0.01	0.05	0.08	0.1	0.6
TOT-N, mg/l	22	1.41	0.31	1.0	1.2	1.3	1.5	2.3
ORG-N, mg/l	22	0.23	0.14	0.01	0.13	0.23	0.3	0.6
TOT-P, ug/l	20	87.8	77.9	21	32	53	119	253
O-P, ug/l	20	71.5	80.8	10	19	28	143	226
Flow, cfs	21	18.0	15.5	2	6	12	28	54
MLC								
Temp, °C	21	18.1	9.1	3	10	17	26	32
D.O., mg/l	21	12.4	1.3	10	11	12	13	16
Turb, NTU	22	6.0	5.6	2	2	4	8	22
NO3, mg/l	22	0.59	0.30	0.06	0.38	0.54	0.82	1.3
NH3, mg/l	22	0.10	0.08	0.01	0.05	0.08	0.10	0.3
TOT-N, mg/l	22	0.97	0.36	0.39	0.84	0.88	1.11	2.1
ORG-N, mg/l	22	0.24	0.14	0.01	0.17	0.24	0.34	0.5
TOT-P, ug/l	22	189	96	14	103	181	271	354
O-P, ug/l	20	144	98	10	45	144	213	354
Flow, mg/l	22	14.5	21.6	1	2	5	19	71
TAILWATER								
Temp, °C	21	10.7	1.2	8	10	11	12	12
D.O., mg/l	21	8.58	2.8	4	7	9	10	13
Turb, NTU	22	3.28	2.0	0.5	1.6	2.8	4.3	9
NO3, mg/l	22	0.41	0.17	0.11	0.22	0.45	0.6	0.6
NH3, mg/l	22	0.14	0.20	0.01	0.04	0.08	0.1	0.7
TOT-N, mg/l	22	0.72	0.23	0.4	0.5	0.7	0.8	1.3
ORG-N, mg/l	22	0.17	0.13	0.01	0.09	0.15	0.2	0.6
TOT-P, ug/l	22	14.0	4.8	10	10	12	16	25
O-P, ug/l	20	10.0	2.0	6	10	10	10	15
Flow, cfs	322	2281	-	-	-	-	-	-

163. Linear and logarithmic transformed correlations were performed for each inflow and the tailwaters. The results for two inflows, Falling Water River and Taylor Creek, and the tailwater are given in Tables 18 through 20. Falling Water River is representative of inflows receiving WWTP effluents and Taylor Creek is representative of inflows receiving primarily agricultural runoff. The correlations were computed from 22 biweekly observations. A correlation coefficient of +1 represents a perfect positive relationship whereas a coefficient of -1 represents a perfect inverse relationship. No relationship is indicated by a correlation coefficent near zero.

164. Correlations at all sites, shown in ranked order, were generally low. Nutrient species were both negatively and positively correlated with each other as well as with flow. Furthermore, the correlations and their ranking varied from stream to stream. Therefore, no simple relationships were found to occur between most of the variables based on the biweekly data base.

165. Flow regression analyses were performed to determine if variations in the water quality data were due to streamflow. The logarithmic regression model of the form:

$$C = aQ^b \qquad (12)$$

was used [Steele, 1976; Young, 1988] where Q is stream discharge (cfs) and a and b are regression coefficients. Table 21 lists the regression equation results for Falling

Table 18

Falling Water River Correlations

PEARSON CORRELATION COEFFICIENTS / NUMBER OF OBSERVATIONS

TEMP

TEMP	PH	COND	NO3	DO	NH3	TOTP	FLOW	OP	ORGN	TOTN	ORP	TURB
1.00000	-0.87760	0.73652	-0.68232	-0.55736	0.54253	0.51492	-0.44212	0.31886	0.30823	-0.18346	-0.18235	0.01074
22	22	22	22	22	22	22	22	20	22	22	22	22

DO

DO	PH	TEMP	COND	TOTP	OP	NO3	NH3	FLOW	TOTN	TURB	ORP	ORGN
1.00000	0.59781	-0.55736	-0.53020	-0.53018	-0.43407	0.41774	-0.33078	0.27590	0.23668	-0.16383	-0.15658	-0.04106
22	22	22	22	22	20	22	22	22	22	22	22	22

COND

COND	TOTP	TEMP	OP	FLOW	PH	DO	NO3	ORGN	NH3	TURB	TOTN	ORP
1.00000	0.74573	0.73652	0.69787	-0.69698	-0.57351	-0.53020	-0.38602	0.38275	0.27561	-0.24519	0.08074	0.02562
22	22	22	20	22	22	22	22	22	22	22	22	22

PH

PH	TEMP	DO	COND	NO3	NH3	TOTP	ORGN	FLOW	OP	TURB	ORP	TOTN
1.00000	-0.87760	0.59781	-0.57351	0.51860	-0.48897	-0.48568	-0.32225	0.29111	-0.25252	-0.24445	0.04400	0.03790
22	22	22	22	22	22	22	22	22	20	22	22	22

ORP

ORP	NH3	FLOW	TURB	TEMP	DO	ORGN	NO3	TOTN	PH	OP	COND	TOTP
1.00000	-0.30851	-0.28350	0.26484	-0.18235	-0.15658	-0.12683	0.12237	-0.08135	0.04400	-0.02807	0.02562	0.00247
22	22	22	22	22	22	22	22	22	22	20	22	22

TURB

TURB	FLOW	NH3	ORGN	ORP	COND	PH	DO	TOTN	TOTP	OP	NO3	TEMP
1.00000	0.44403	0.28356	-0.27142	0.26484	-0.24519	-0.24445	-0.16383	-0.10044	0.07025	-0.05627	0.04780	0.01074
22	22	22	22	22	22	22	22	22	22	20	22	22

NO3

NO3	TEMP	TOTN	PH	DO	COND	NH3	ORGN	FLOW	ORP	OP	TOTP	TURB
1.00000	-0.68232	0.58711	0.51860	0.41774	-0.38602	-0.34983	-0.30142	0.21233	0.12237	0.06022	-0.05309	0.04780
22	22	22	22	22	22	22	22	22	22	20	22	22

NH3

NH3	TEMP	PH	NO3	DO	ORP	TURB	COND	ORGN	TOTN	OP	TOTP	FLOW
1.00000	0.54253	-0.48897	-0.34983	-0.33078	-0.30851	0.28356	0.27561	-0.18935	-0.17798	-0.11601	0.04956	-0.04238
22	22	22	22	22	22	22	22	22	22	20	22	22

TOTN

TOTN	NO3	ORGN	DO	OP	TOTP	TEMP	NH3	TURB	ORP	COND	PH	FLOW
1.00000	0.58711	0.53983	0.23668	0.22428	0.19473	-0.18346	-0.17798	-0.10044	-0.08135	0.08074	0.03790	0.02808
22	22	22	22	20	22	22	22	22	22	22	22	22

ORGN

ORGN	TOTN	COND	PH	TEMP	NO3	TURB	TOTP	OP	NH3	FLOW	ORP	DO
1.00000	0.53983	0.38275	-0.32225	0.30823	-0.30142	-0.27142	0.22554	0.19526	-0.18935	-0.15921	-0.12683	-0.04106
22	22	22	22	22	22	22	22	20	22	22	22	22

TOTP

TOTP	OP	COND	DO	TEMP	PH	FLOW	ORGN	TOTN	TURB	NO3	NH3	ORP
1.00000	0.95827	0.74573	-0.53018	0.51492	-0.48568	-0.41691	0.22554	0.19473	0.07025	-0.05309	0.04956	0.00247
22	20	22	22	22	22	22	22	22	22	22	22	22

OP

OP	TOTP	COND	DO	FLOW	TEMP	PH	TOTN	ORGN	NH3	NO3	TURB	ORP
1.00000	0.95827	0.69787	-0.43407	-0.41182	0.31886	-0.25252	0.22428	0.19526	-0.11601	0.06022	-0.05627	-0.02807
20	20	20	20	20	20	20	20	20	20	20	20	20

FLOW

FLOW	COND	TURB	TEMP	TOTP	OP	PH	ORP	DO	NO3	ORGN	NH3	TOTN
1.00000	-0.69698	0.44403	-0.44212	-0.41691	-0.41182	0.29111	-0.28350	0.27590	0.21233	-0.15921	-0.04238	0.02808
22	22	22	22	22	20	22	22	22	22	22	22	22

Table 19

Taylor Creek Correlations

PEARSON CORRELATION COEFFICIENTS / NUMBER OF OBSERVATIONS

TEMP

TEMP	DO	COND	OP	FLOW	PH	TOTP	ORP	NO3	TURB	NH3	ORGN	TOTN
1.00000	-0.76592	0.72375	0.63715	-0.47537	-0.35117	-0.30118	-0.26696	0.16071	-0.15398	0.08447	0.06982	0.02449
22	22	22	20	21	22	19	22	22	21	22	22	22

DO

DO	TEMP	OP	PH	COND	FLOW	NO3	TURB	TOTP	TOTN	NH3	ORP	ORGN
1.00000	-0.76592	-0.64296	0.60951	-0.60281	0.55948	-0.30476	-0.11383	-0.10710	0.10561	0.06520	-0.04996	0.01699
22	22	20	22	22	21	22	21	19	22	22	22	22

COND

COND	FLOW	TEMP	OP	DO	TURB	ORGN	TOTP	TOTN	NO3	PH	NH3	ORP
1.00000	-0.84566	0.72375	0.62006	-0.60281	-0.51346	-0.41707	-0.24834	-0.21119	0.18119	-0.08925	0.00725	-0.00417
22	21	22	20	22	21	22	19	22	22	22	22	22

PH

PH	DO	TURB	TEMP	OP	NO3	ORP	ORGN	TOTP	FLOW	NH3	COND	TOTN
1.00000	0.60951	-0.49025	-0.35117	-0.34901	-0.32463	-0.32369	-0.26610	-0.22144	0.15508	0.13105	-0.08925	-0.03656
22	22	21	22	20	22	22	22	19	21	22	22	22

ORP

ORP	TURB	TOTP	TOTN	PH	NH3	TEMP	FLOW	OP	ORGN	DO	NO3	COND
1.00000	0.35275	0.33233	-0.32858	-0.32369	-0.32187	-0.26696	-0.23163	-0.14322	0.06288	-0.04996	-0.01040	-0.00417
22	21	19	22	22	22	22	21	20	22	22	22	22

TURB

TURB	ORGN	COND	TOTP	PH	ORP	FLOW	TOTN	NO3	TEMP	NH3	DO	OP
1.00000	0.59632	-0.51346	0.50027	-0.49025	0.35275	0.34191	0.33420	0.17857	-0.15398	-0.15012	-0.11383	0.02277
21	21	21	18	21	21	20	21	21	21	21	21	19

NO3

NO3	TOTN	OP	FLOW	PH	DO	TOTP	ORGN	COND	TURB	TEMP	NH3	ORP
1.00000	0.57941	0.48166	-0.33942	-0.32463	-0.30476	0.28022	-0.24661	0.18119	0.17857	0.16071	0.03858	-0.01040
22	22	20	21	22	22	19	22	22	21	22	22	22

NH3

NH3	TOTP	ORP	ORGN	TOTN	TURB	PH	TEMP	OP	DO	FLOW	NO3	COND
1.00000	-0.44342	-0.32187	-0.30246	0.24269	-0.15012	0.13105	0.08447	-0.06928	0.06520	0.05486	0.03858	0.00725
22	19	22	22	22	21	22	22	20	22	21	22	22

TOTN

TOTN	NO3	TURB	ORP	FLOW	NH3	COND	ORGN	OP	TOTP	DO	PH	TEMP
1.00000	0.57941	0.33420	-0.32858	0.30105	0.24269	-0.21119	0.20621	0.15957	0.14950	0.10561	-0.03656	0.02449
22	22	21	22	21	22	22	22	20	19	22	22	22

ORGN

ORGN	TURB	FLOW	COND	NH3	PH	NO3	TOTN	TOTP	OP	TEMP	ORP	DO
1.00000	0.59632	0.47054	-0.41707	-0.30246	-0.26610	-0.24661	0.20621	0.10319	-0.08539	0.06982	0.06288	0.01699
22	21	21	22	22	22	22	22	19	20	22	22	22

TOTP

TOTP	TURB	NH3	ORP	TEMP	NO3	COND	PH	OP	TOTN	DO	ORGN	FLOW
1.00000	0.50027	-0.44342	0.33233	-0.30118	0.28022	-0.24834	-0.22144	-0.16478	0.14950	-0.10710	0.10319	-0.02475
19	19	19	19	19	19	19	19	18	19	19	19	18

OP

OP	DO	TEMP	COND	FLOW	NO3	PH	TOTP	TOTN	ORP	ORGN	NH3	TURB
1.00000	-0.64296	0.63715	0.62006	-0.60295	0.48166	-0.34901	-0.16478	0.15957	-0.14322	-0.08839	-0.06928	0.02277
20	20	20	20	19	20	20	18	20	20	20	20	19

FLOW

FLOW	COND	OP	DO	TEMP	ORGN	TURB	NO3	TOTN	ORP	PH	NH3	TOTP
1.00000	-0.84566	-0.60295	0.55948	-0.47537	0.47054	0.34191	-0.33942	0.30105	-0.23163	0.15508	0.05486	-0.02475
21	21	19	21	21	21	20	21	21	21	21	21	16

Table 20

Tailwater Correlations

PEARSON CORRELATION COEFFICIENTS / NUMBER OF OBSERVATIONS

TEMP												
TEMP	DO	ORGN	NO3	TOTP	OP	FLOW	COND	TOTN	TURB	NH3	PH	ORP
1.00000	-0.50229	-0.48418	0.46645	0.38440	0.33316	0.17937	-0.14581	0.11080	-0.06035	-0.03701	0.02706	0.02245
21	21	21	21	21	19	13	21	21	21	21	21	21
DO												
DO	PH	TEMP	ORGN	TURB	ORP	NO3	TOTP	NH3	COND	TOTN	OP	FLOW
1.00000	0.68020	-0.50229	0.40335	0.37842	-0.28295	-0.19345	0.17522	0.16493	0.15266	0.14035	-0.11110	0.04404
21	21	21	21	21	21	21	21	21	21	21	19	13
COND												
COND	ORP	TOTN	TURB	TOTP	DO	TEMP	OP	NH3	ORGN	PH	FLOW	NO3
1.00000	-0.69965	0.23481	-0.20458	0.15341	0.15266	-0.14581	-0.13054	0.12620	0.10984	-0.03997	0.01232	0.00453
21	21	21	21	21	21	21	19	21	21	21	13	21
PH												
PH	DO	TURB	FLOW	NO3	TOTN	NH3	TOTP	ORGN	ORP	COND	TEMP	OP
1.00000	0.68020	0.44917	0.36860	0.33887	0.28919	0.21812	0.20257	-0.11177	-0.05776	-0.03997	0.02706	0.00035
21	21	21	13	21	21	21	21	21	21	21	21	19
ORP												
ORP	COND	DO	TOTN	FLOW	ORGN	NH3	TOTP	OP	TURB	PH	NO3	TEMP
1.00000	-0.69965	-0.28295	-0.23734	-0.19096	-0.17009	-0.16239	-0.15910	-0.12649	-0.11374	-0.05776	0.03611	0.02245
21	21	21	21	13	21	21	21	19	21	21	21	21
TURB												
TURB	PH	DO	ORGN	FLOW	COND	NO3	TOTP	NH3	ORP	TOTN	OP	TEMP
1.00000	0.44917	0.37842	0.30012	-0.22263	-0.20456	-0.18183	0.17535	-0.11679	-0.11374	-0.10677	0.05727	-0.06035
22	21	21	22	13	21	22	22	22	21	22	20	21
NO3												
NO3	TOTN	FLOW	ORGN	TEMP	PH	NH3	DO	TURB	OP	TOTP	ORP	COND
1.00000	0.68396	0.67783	-0.51328	0.46645	0.33887	0.24697	-0.19345	-0.18183	0.13937	-0.12731	0.03611	0.00453
22	22	13	22	21	21	22	21	22	20	22	21	21
NH3												
NH3	TOTN	ORGN	TOTP	NO3	PH	OP	FLOW	DO	ORP	COND	TURB	TEMP
1.00000	0.72383	-0.47091	-0.25130	0.24697	0.21812	0.21452	0.19186	0.16493	-0.16239	0.12620	-0.11679	-0.03701
22	22	22	22	22	21	20	13	21	21	21	22	21
TOTN												
TOTN	NH3	NO3	FLOW	PH	ORP	COND	ORGN	TOTP	DO	OP	TEMP	TURB
1.00000	0.72383	0.68396	0.35966	0.28919	-0.23734	0.23481	-0.23113	-0.17027	0.14035	0.13507	0.11080	-0.10677
22	22	22	13	21	21	21	22	22	21	20	21	22
ORGN												
ORGN	NO3	TEMP	NH3	FLOW	DO	TURB	TOTN	TOTP	ORP	OP	PH	COND
1.00000	-0.51328	-0.48418	-0.47091	-0.43155	0.40335	0.30012	-0.23113	0.19691	-0.17009	0.15324	-0.11177	0.10984
22	22	21	22	13	21	22	22	22	21	20	21	21
TOTP												
TOTP	TEMP	OP	NH3	FLOW	PH	ORGN	TURB	DO	TOTN	ORP	COND	NO3
1.00000	0.38440	0.25319	-0.25130	-0.23541	0.20257	0.19691	0.17535	0.17522	-0.17027	-0.15910	0.15341	-0.12731
22	21	20	22	13	21	22	22	21	22	21	21	22
OP												
OP	FLOW	TEMP	TOTP	NH3	ORGN	NO3	TOTN	COND	ORP	DO	TURB	PH
1.00000	0.51333	0.33316	0.25319	0.21452	-0.15324	0.13937	0.13507	-0.13054	-0.12648	-0.11110	0.05727	0.00035
20	11	19	20	20	20	20	20	19	19	19	20	19
FLOW												
FLOW	NO3	OP	ORGN	PH	TOTN	TOTP	TURB	NH3	ORP	TEMP	DO	COND
1.00000	0.67783	0.51333	-0.43155	0.36860	0.35966	-0.23541	-0.22263	0.19186	-0.19096	0.17937	0.04404	0.01232
13	13	11	13	13	13	13	13	13	13	13	13	13

Water River, Taylor Creek, and the tailwater. All regressions were based upon the 22 biweekly observations made during this study.

166. Parameters that increase with increased flow are represented by positive exponents while parameters that decrease with flow are represented by negative exponents. Furthermore, r-square values represent the decimal percent of parameter variability due to flow. Most of the r-square values listed in Table 21 for both physical parameters and nutrient species are less than 0.30 which implies that less than 30 percent of the variability in the dependant parameters cannot be explained by these simple flow regressions. However, studies have shown that materials associated with suspended solids tend to increase with flow [Frost, 1974; Daniel, et al., 1979]. The weak regressions could be due to a low erosion potential in a drainage basin and/or lack of storm event sampling [Young, 1988].

Loading and Nutrient Budget Estimates

167. Loading estimates were required to quantify the nutrient transport in Center Hill's inflows and tailwater in order to estimate a nutrient budget for the lake. Other loading estimates were calculated for wastewater treatment plants and precipitation. Nutrient loadings with respect to groundwater and sediments were not calculated.

Table 21

Flow Regression Results for Falling Water River,
Taylor Creek, and Center Hill's Tailwater

Dependant Variables	N	Independant Variables a	b	r-sq
FWR				
Temperature	21	37.2	-0.216	0.2724
Dissolved Oxygen	21	5.69	0.128	0.2480
Turbidity	21	10.4	0.084	0.0197
NO2/NO3	21	0.59	0.082	0.0899
NH3	21	0.17	-0.079	0.0097
Total Nitrogen	21	1.49	-0.009	0.0032
Organic Nitrogen	21	0.97	-0.265	0.0771
Total Phosphorus	21	783.0	-0.389	0.3620
Ortho-phosphorus	21	551.0	-0.434	0.2657
TAYLOR CREEK				
Temperature	20	25.1	-0.243	0.3282
Dissolved Oxygen	20	0.52	-0.330	0.3546
Turbidity	20	3.92	0.303	0.1613
NO2/NO3	20	1.13	-0.046	0.0398
NH3	20	0.08	-0.030	0.0008
Total Nitrogen	20	1.17	0.070	0.0989
Organic Nitrogen	20	0.15	0.634	0.0030
Total Phosphorus	20	4.09	0.024	0.0010
Ortho-phosphorus	20	619.2	-1.020	0.6672
TAILWATER				
Temperature	12	9.55	0.011	0.0185
Dissolved Oxygen	12	8.78	0.012	0.0048
Turbidity	12	5.09	-0.111	0.0674
NO2/NO3	12	0.06	0.332	0.7035
NH3	12	0.05	0.141	0.0350
Total Nitrogen	12	0.34	0.142	0.3689
Organic Nitrogen	12	0.60	0.266	0.1705
Total Phosphorus	12	17.2	-0.064	0.1139
Ortho-phosphorus	12	6.61	0.071	0.4085

Loading Estimates

168. The load of a specific substance transported by a stream is defined as the product of water discharge and the concentration of that substance in the stream [Walling and Webb, 1985]. Since both flow and nutrient concentrations vary on a daily time scale, the most accurate loading estimates are calculated using daily values. However, this study's data base is comprised of only biweekly flow and concentration measurements. Therefore, the calculated nutrient loads are approximations and may underestimate true storm event loadings. Methods utilized to estimate loadings for Center Hill's inflows and tailwat ~ were: (1) the product of the integrated discharge versus time plot and nutrient concentration at the midpoint of the time intervals; (2) the product of the integrated discharge versus time plot, as modified in relation to the Collin's daily discharge, and nutrient concentration at the midpoint of the time intervals; and (3) the product of three-point running means for both discharge and nutrient concentration over time (raw data are provided in Appendix III).

169. Method 1 can be represented by a simple bar graph as shown in Figure 28. This method estimates loads by the following equation:

$$\text{Annual Load} = \text{SUM}(Ci * Qi * Ti * K) \qquad (13)$$

where Ci = measured instantaneous concentration, Qi = measured instantaneous flow, Ti = time interval, and K is a

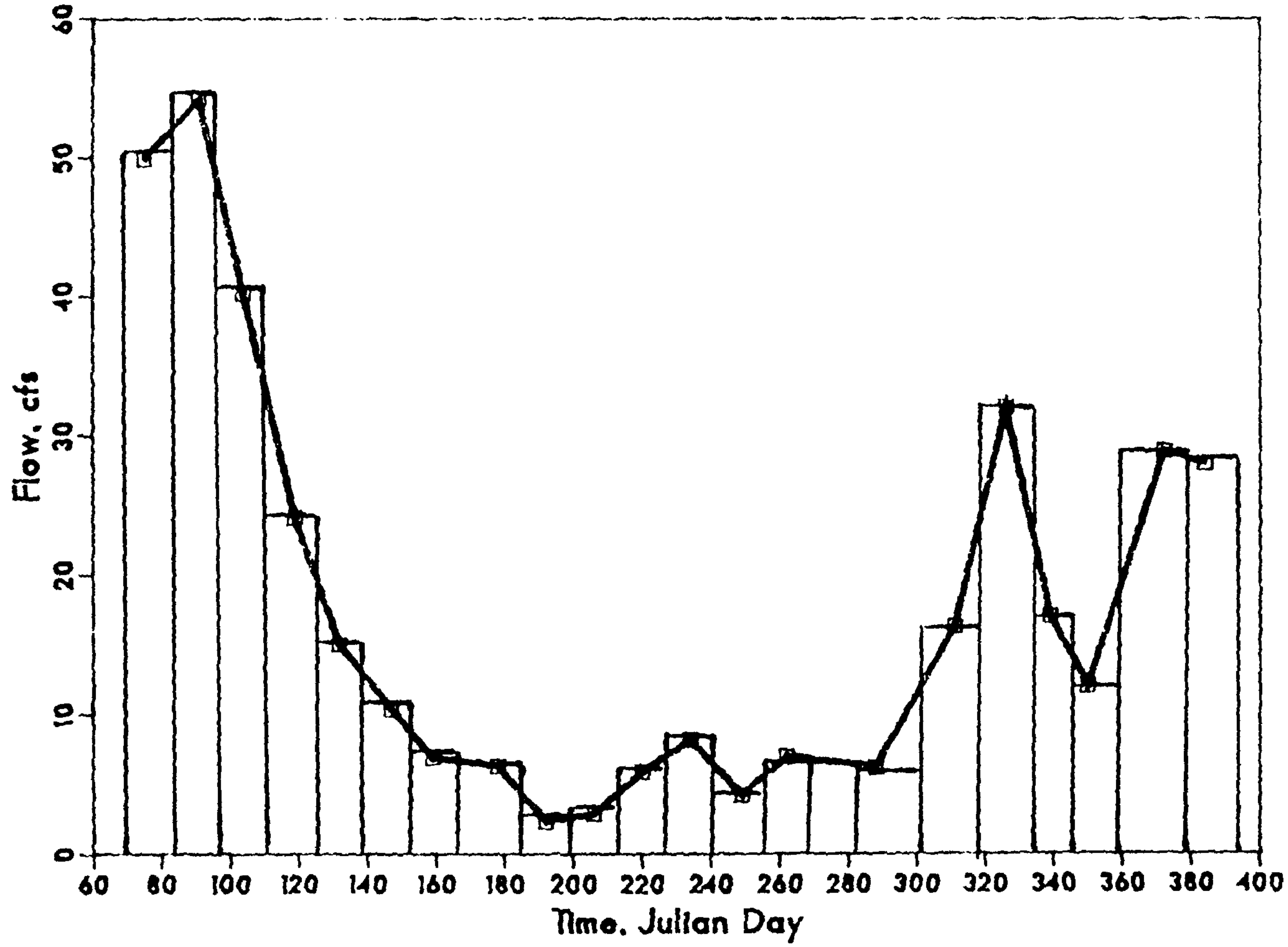

Figure 28: Method 1 Bar Graph for Taylor Creek

conversion factor. Table 22 lists the loading results for each inflow and the tailwater.

170. The second method's calculations were dependent upon the comparison of instantaneous biweekly stream flows to daily Collins River flows. Unexpectedly there were no significant differences between the Collins' daily and streams' instantaneous hydrographs in terms of bi-weekly volume estimates as previously displayed in Figures 16 and

171. Because 1988 was a dry year, biweekly instantaneous flow measurements were adequate in describing the summer portion of the year's inflow patterns. Therefore, Method 2 was not used to approximate annual nutrient loads because no method was available for converting from the Collins Gage to sample point flows.

172. Method 3 was recommended by Cooke, et al., [1986] as the best nutrient load estimate where only discrete measurements of flow and nutrient concentrations are available. The following equation was used to estimate annual nutrient loads by the three-point running mean method as listed in Table 23:

$$\begin{aligned}\text{Annual Load} = \text{SUM}[&\text{AVG}([N_i]+[N_{i+1}]+[N_{i+2}]) \\ &*\text{AVG}(Q_i+Q_{i+1}+Q_{i+2})]*T_i*K\end{aligned} \tag{14}$$

where [N] is the nutrient concentration, Q is the stream discharge, T is the time interval, and K is the conversion constant.

173. Effluent nutrient loadings were calculated for each WWTP using the three-point running mean method based on

Table 22

Method 1 Loading Estimates
From March 1988 through January 1989

Inflow/ Outflow	NO2/NO3 lb	NH3 lb	TOT-N lb	ORG-N lb	TOT-P lb	O-P lb
Fall Creek*	19301	18197	67657	30274	7536	4413
Pine Creek	48460	4804	62860	9532	1754	808
FWR	165865	28415	263317	71515	23886	12888
Sink Creek	54848	4268	77023	18272	1510	596
Taylor Creek	27443	3318	42808	12193	1674	1001
Mine Lick	16671	2072	28029	9443	2793	1816
Great Falls	1753596	342406	2759504	684036	92747	59101
Tailwater	1126356	456774	2417161	846748	57273	29218

* Note Fall Creek station above Smithville WWTP

biweekly sampling using grab samples and daily flows recorded by the plant operators. The loads are listed in Table 24.

174. Precipitation nutrient loadings were calculated from data received from Global Geochemistry Corporation, a contractor for Tennessee Division of Air Pollution Control, (raw data are provided in Appendix IV). Loadings for phosporus, nitrate, and ammonia nitrogen were calculated to be the product of rainfall volume over the lake surface area and their respective concentrations. Nitrite concentrations were also measured, but were consistantly found to be below detection limits. The loadings for phosphorus, nitrate, and ammonia nitrogen from January 1988 through November 1988 were 2572, 149711, and 27162 lb, respectively. These loads are comparable to the loads of Center Hill's smaller tributaries.

175. Figures 29 and 30 display annual WWTP loads along with the loads of their receiving streams as calculated by Method 3. Each WWTP introduces a significant nutrient load to its receiving stream. The Cookeville WWTP introduces more phosphorus than measured downstream in Falling Water River, suggesting some loss of phosphorus between the WWTP and inflow station located several miles downstream. No other inflow appears to have a strong assimilative capacity for either nitrogen or phosphorus. Most inflow streams, especially Mine Lick Creek, had attached algal growth which

Table 23

Method 3 Loading Estimates
From March 1988 through January 1989

Inflow/ Outflow	NO2/NO3 lb	NH3 lb	TOT-N lb	ORG-N lb	TOT-P lb	O-P lb
Fall Creek	20468	17832	69356	31277	7289	4353
Pine Creek	52208	4429	67979	11365	1446	707
FWR	171683	26215	265522	69997	25212	15992
Sink Creek	54079	4475	76107	17987	1433	543
Taylor Creek	27096	3371	41490	11145	1632	982
Mine Lick	16704	2019	27186	8591	3060	2154
Great Falls	1893334	364173	2949206	714213	112597	70757
Tailwater	1120191	458272	2369681	796786	57317	29733

Table 24

WWTP Loading Estimates
From March 1988 through January 1989

WWTP	NO2/NO3 lb	NH3 lb	TOT-N lb	ORG-N lb	TOT-P lb	O-P lb
Baxter	1369	3324	6993	2636	2010	1378
Cookeville	61415	52727	196726	86586	36390	24412
McMinnville	11638	18637	44889	16509	6006	3769
Smithville	4201	15476	45026	25369	6554	4100
Sparta	1776	23173	34180	11714	9209	6499

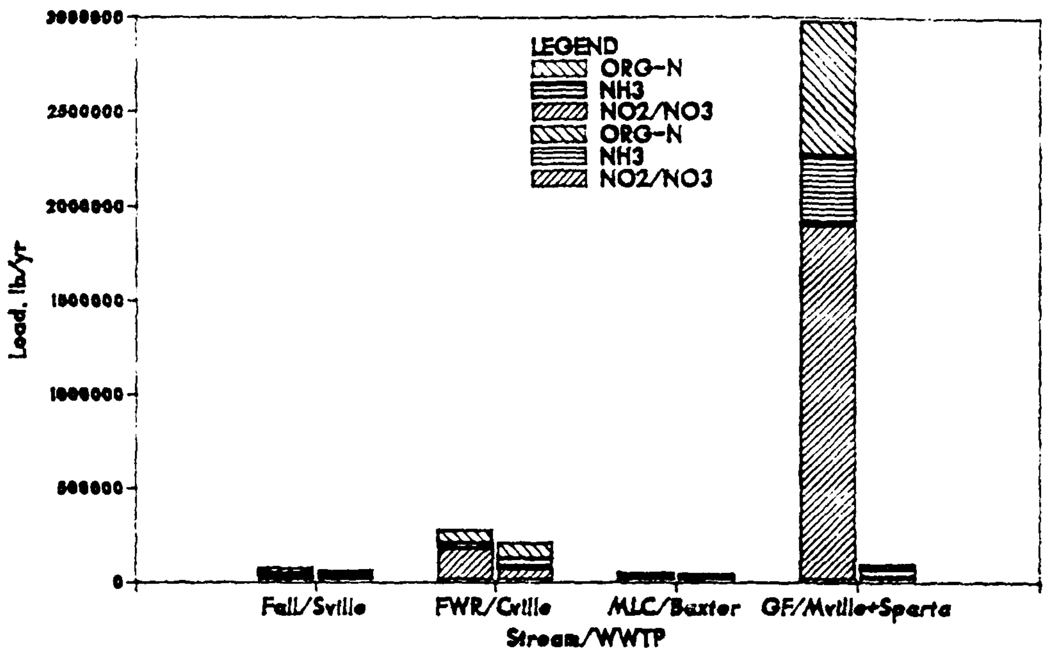

Figure 29: Nitrogen Loadings for WWTPs and their Receiving Streams

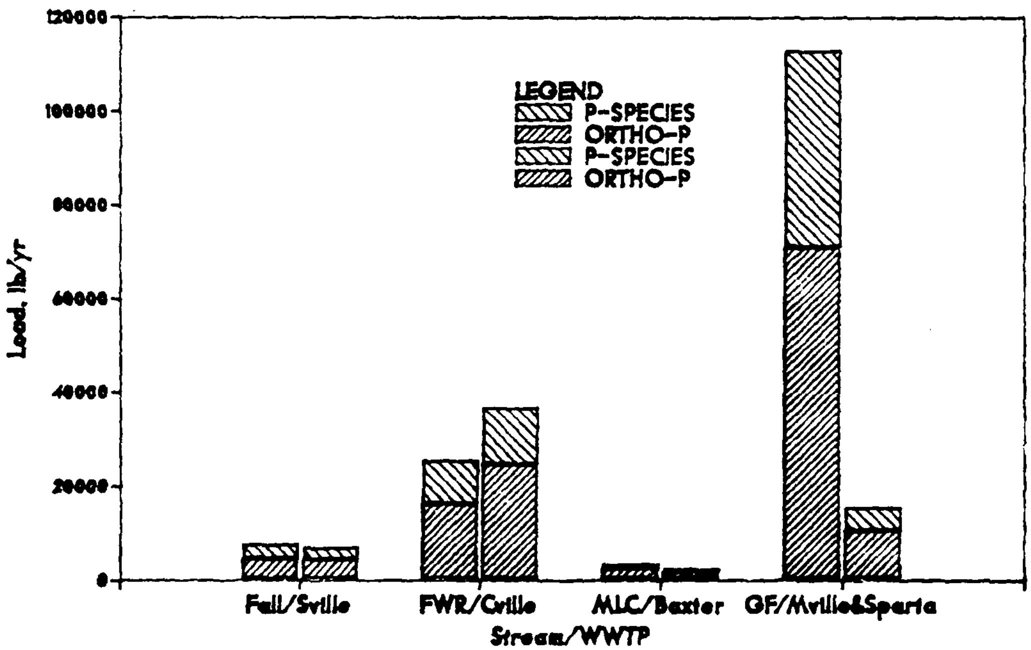

Figure 30: Phosphorus Loadings for WWTPs and their Receiving Streams

should have removed inorganic nitrogen and phosphorus. This removal was evidently overshadowed by non-point sources of nutrients.

176. Figures 31 and 32 display Center Hill's inflow loads. Great Falls and Falling Water River have the highest nitrogen and phosphorus loads. Furthermore, streams receiving WWTP effluent generally have higher nutrient loads than streams not receiving treated effluent, but this is not proof of a WWTP problem as non-point loads were not enumerated.

Water and Nutrient Budget Estimates

177. Flows carry pollutants into and out of lakes; therefore, in order to analyze lake eutrophication and estimate nutrient budgets, a quantitative understanding of the lake's basic hydrology must be known [NALMS, 1988]. The basic water budget of a lake is shown by the following equation:

$$\begin{array}{c}\text{Inflows + Precipitation =}\\ \text{Outflow + Evaporation + Change in Storage.}\end{array} \qquad (15)$$

Table 25 lists the inflows and outflows of Center Hill Lake. Fifteen percent of the lake's inflow consisted of ungaged direct runoff during 1988-89.

178. Nutrient budgets are the cornerstone for evaluating many eutrophication problems in a lake [NALMS, 1988]. The

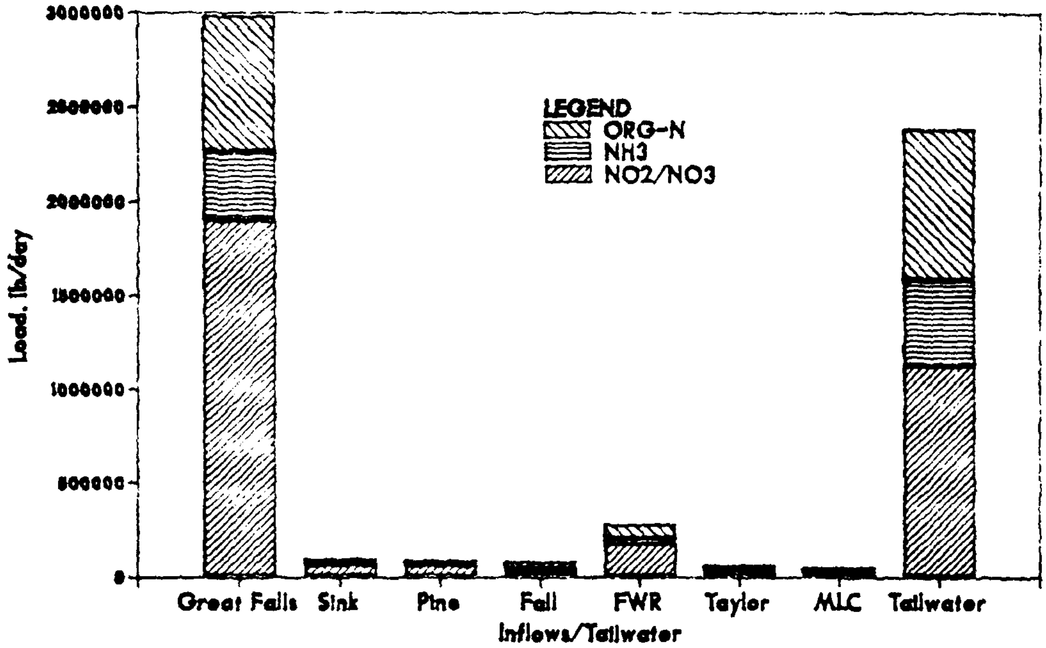

Figure 31: Center Hill's Inflow Nitrogen Loadings

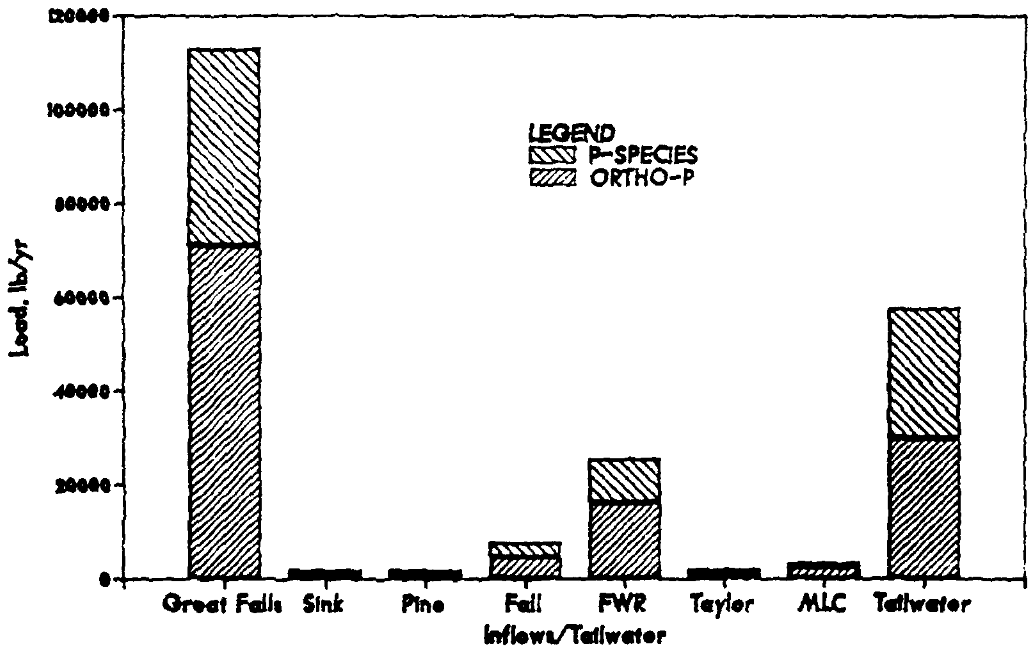

Figure 32: Center Hill's Inflow Phosphorus Loadings

Table 25

Water Budget for Center Hill Lake
from March 1988 through January 1989

Item	Drainage Area (acre)	Mean Flow (ac-ft/yr)	Runoff (ac-ft/ac)	Water Inflow (%)
Mine Lick	12352	10500	0.85	0.636
FWR	80000	78200	0.98	4.740
Pine	14848	16400	1.10	0.994
Sink	23808	19300	0.81	1.170
Fall	8000	6590	0.82	0.399
Taylor	21760	13000	0.60	0.788
Great Falls	1073280	1174000	1.20	71.200
Precipitation[1]	18220	79000	4.40	4.790
Ungaged Direct Runoff[2]	152532	253000	3.20	15.300
Total Inflow	1404800	1650000	1.2	100.0
Evaporation[3]	18220	45550	2.5	2.7
Outflow	1404800	1333000		80.8
Change in Storage		317000		

[1] Precipitation of 52.25 at Cookeville WWTP.
[2] Calculated value includes seepage, change in storage, and errors.
[3] Assumed evaporation of 30 inches.

basic nutrient budget of a lake is shown by the following equation:

$$\text{Inflow Load} = \text{Outflow Load} + \text{Net Sedimentatioan} + \text{Changes in Storage.} \qquad (16)$$

Tables 26 and 27 list the results of these budget calculations.

179. Phosphorus loadings correspond almost directly with mean flow. The largest phosphorus loadings are from ungaged direct runoff, Great Falls and Falling Water River. Eighty-three percent of total phosphorus was captured within the reservoir; and 78 percent of ortho-phosphate phosporus was captured. Nitrogen loadings also directly corresponded with mean flow. Fifty-two percent of the total nitrogen entering the reservoir was captured. Of the nitrogen species, the reservoir captured 50 percent of the inflowing nitrate, 44 percent of the inflowing ammonia, and 56 percent of the inflowing organic nitrogen.

Long-Term Dissolved Oxygen Analysis

180. The depletion of DO in the Center Hill metalimnion was noted by the Corps of Engineers in 1976 [Corps, 1976]. The metalimnetic minimum zone was shown to extend fairly uniformly from the dam for about 40 miles upstream. Depletion began in May and continued until all DO was gone by September.

Table 26

Phosphorus Budgets for Center Hill Lake
From March 1988 through January 1989

Item	TOT-P Loading (lb)	P Inflow (%)	ORTHO-P Loading (lb)	ORTHO-P Inflow (%)
Mine Lick	5400	2.60	4110	3.30
FWR	42500	20.10	28300	23.00
Pine	1320	0.64	847	0.69
Sink	1600	0.76	567	0.46
Fall	590	0.30	306	0.25
Taylor	3104	1.50	2528	2.00
Great Falls	128000	60.60	72800	59.00
Precipitation	4530	2.10	-	-
Ungaged Direct Runoff	24100[1]	11.40	13800[2]	11.20
Total Inflow	211144	100.0	123258	100.0
Outflow	50800	24.0	36255	29.4
Increase in Storage	15500[3]	7.3	8622[4]	7.0
Captured Phosphorus	175844	83.3	95625	77.6

[1] Calculation based on phosphorus concentration of 35 ug/l.
[2] Calculation based on ortho-phosphate concentration of 20 ug/l.
[3] Calculation based on phosphorus concentration of 18 ug/l.
[4] Calculation based on ortho-phosphate concentration of 10 ug/l.

Table 27

Nitrogen Budgets for Center Hill Lake
From March 1988 through January 1989

Item	TOT-N Load lb	TOT-N In %	NO3 Load lb	NO3 In %	NH3 Load lb	NH3 In %	ORG-N Load lb	ORG-N In %
MLC	27700	0.60	11700	0.50	2860	0.37	6850	0.72
FWR	308000	7.20	181000	7.60	34000	4.50	93600	9.90
Pine	80300	1.90	66900	2.80	4010	0.53	9810	1.00
Sink	67200	1.60	10500	0.40	4720	0.62	12100	1.30
Fall	21300	0.50	13800	0.60	2330	0.31	5200	0.54
Taylor	49800	1.20	36100	1.50	3890	0.51	8130	0.85
G.F.	2390000	56.00	1280000	53.60	575000	75.70	639000	66.80
Rain	312000	7.30	264000	11.00	47900	6.30	-	-
R.O.	1000000[1]	23.00	523000[2]	21.90	84600[3]	11.10	182000[4]	19.00
Inflow	4266300	100	2387000	100	759310	100	956690	100
Outflow	2610355	61.2	1490000	62.4	508000	66.9	616000	64.4
Storage	560000	13.1	284000	11.9	86200	11.3	198000	20.7
Captured	2215945	51.9	1181000	49.5	337510	44.4	538690	56.3

1 Based on total nitrogen concentration of 1.46 mg/l.
2 Based on nitrate concentration of 0.76 mg/l.
3 Based on ammonia concentration of 0.123 mg/l.
4 Based on organic nitrogen concentration of 0.264 mg/l.

181. Morris (1978) studied the oxygen depletion process in the Center Hill metalimnion and concluded that the most active utilization processes were phytoplankton and zooplankton respiration. These plankters accumulated in the metalimnion because of temperature-density-viscosity gradients. High concentrations of chlorophyll a were observed in the metalimnion and oxygen was either produced or consumed depending upon the photic zone. Morris (1978) also noted BOD_{28} values between 0.5 and 3.0 mg/l in the metalimnion which correspond to high chlorophyll a concentrations. The metalimnetic DO depletion rate during 1977 was reported to be only 0.09 mg/l*day.

182. Gordon (1981) reported that a computer model showed that flows through Center Hill traveled as shallow interflows through the metalimnetic zone. Thus, nutrients and organics brought into the system would exert their effects in the metaliminion.

183. Hunter (1987) made a long-term analysis of DO trends in Center Hill Lake and found no pronounced trends between 1971 and 1983.

184. Since DO data were available to make another long-term DO study, an analysis of metalimnetic DO trends was conducted. Tables 28 through 33 show all DO data that could be located at Stations 2 and 4 (near the dam and near Tech Aqua) between 1971 and 1988. The zone of the metalimnetic minimum is boxed for each year for each sampling period.

Table 29. CENTER HILL LAKE D.O. @ CANEY FORK RM 27.2 (STATION 1) DURING LATE JULY

YEAR	1971	1972	1974	1977	1977	1979	1979	1981	1982	1983	1984	1985
DATE	7/28	8/09	7/16	7/20	8/02	7/17	8/01	7/14	8/03	7/26	8/01	7/24
DEPTH	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.
0	9.0	8.8	8.2	8.1	8.1	9.0	8.6	9.7	11.4	8.6	10.0	9.3
-5	8.7	8.8	8.3	8.1	8.1	-1	-1	10.3	11.2	8.7	9.8	9.4
-10	8.7	8.8	9.3	8.1	8.1	9.5	8.7	13.8	10.8	13.2	9.7	9.3
-15	8.7	-1	9.4	9.3	8.1	-1	-1	14.0	10.2	10.2	9.9	9.7
-20	8.7	9.1	8.7	11.1	7.6	8.1	6.9	15.5	9.1	4.9	9.5	7.3
-25	10.4	10.8	7.7	8.4	6.4	-1	-1	12.4	6.2	1.2	5.8	3.3
-30	9.6	7.7	6.6	2.0	0.4	3.0	1.8	8.6	3.8	0.4	2.0	1.0
-35	6.0	-1	-1	0.3	0.1	-1	-1	6.0	1.8	0.9	0.0	1.3
-40	1.8	0.9	3.2	0.9	0.7	1.7	0.9	4.5	1.3	3.0	0.0	2.2
-45	2.2	-1	-1	2.2	2.1	-1	-1	-1	2.1	3.9	0.7	3.2
-50	3.2	1.1	3.1	3.6	3.5	2.6	0.9	3.4	2.8	4.5	2.4	4.0
-55	3.9	-1	-1	4.8	5.1	-1	-1	-1	3.8	-1	3.7	4.6
-60	4.6	3.0	4.4	5.9	5.8	3.7	1.9	5.3	4.9	5.1	4.8	4.9
-65	5.2	-1	-1	6.4	6.5	-1	-1	-1	5.5	-1	5.3	5.3
-70	5.4	3.9	5.5	6.7	6.6	5.3	3.5	7.7	5.8	5.2	5.6	5.4
-75	5.6	-1	-1	6.7	6.5	-1	-1	-1	6.1	-1	5.6	5.6
-80	5.8	4.5	6.0	6.8	6.4	6.1	4.6	8.2	6.1	5.2	5.6	5.5
-85	6.0	-1	-1	-1	-1	-1	-1	-1	6.0	-1	5.5	5.5
-90	6.2	5.2	5.9	-1	-1	6.5	5.7	7.8	5.7	5.2	5.4	5.5
-95	6.3	-1	-1	-1	-1	-1	-1	-1	5.5	-1	5.1	5.5
-100	6.4	5.5	5.5	-1	-1	6.3	5.9	7.6	5.4	5.1	4.8	6.0
-105	6.5	-1	-1	-1	-1	-1	-1	-1	-1	-1	4.0	5.6
-110	6.3	5.3	4.8	-1	-1	5.6	5.3	7.2	5.2	4.7	3.7	5.5
-115	6.3	-1	-1	-1	-1	-1	-1	-1	-1	-1	3.7	5.0
-120	6.2	4.5	3.9	-1	-1	5.2	4.5	6.9	4.5	4.3	3.5	4.4
-125	6.0	-1	-1	-1	-1	-1	-1	-1	-1	-1	3.0	4.2
-130	5.8	4.4	3.1	-1	-1	4.3	3.8	6.3	3.5	3.6	3.0	4.2
-135	5.6	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.3	4.0
-140	-1	3.7	2.6	-1	-1	4.2	3.4	6.0	-1	2.4	2.0	3.7
-145	-1	-1	2.0	-1	-1	-1	-1	-1	-1	-1	1.6	3.5
-150	-1	3.0	-1	-1	-1	4.0	3.2	5.5	-1	1.8	1.2	3.2
-155	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1.0	2.7
-160	-1	2.8	-1	-1	-1	-1	-1	4.8	-1	1.2	1.0	-1
-165	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.7	-1
-170	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.6	-1

Note: -1 indicates missing data

Table 29. CENTER HILL LAKE D.O. @ CANEY FORK RM 27.2 (STATION 2) DURING EARLY AUGUST

YEAR	1971	1972	1973	1976	1977	1979	1988
DATE	8/19	8/09	8/15	8/22	8/02	8/15	8/10
DEPTH	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.
0	10.0	8.8	8.7	9.7	8.1	8.7	8.5
-5	10.0	8.8	8.9	9.6	8.1	-1	8.4
-10	10.0	8.8	8.9	9.6	8.1	8.7	8.4
-15	10.0	-1	8.8	11.6	8.1	-1	8.8
-20	9.9	9.1	7.0	10.8	7.6	6.8	8.0
-25	8.2	10.8	5.3	8.1	6.4	-1	2.5
-30	7.7	7.7	3.8	7.2	0.4	0.5	0.9
-35	6.5	-1	2.1	5.9	0.1	-1	0.5
-40	5.3	0.9	1.0	3.7	0.7	0.5	0.6
-45	1.6	-1	0.5	1.9	2.1	-1	1.6
-50	0.8	1.1	0.7	1.6	3.5	0.6	2.2
-55	1.6	-1	1.9	1.8	5.1	-1	3.0
-60	3.0	3.0	3.8	1.8	5.8	1.2	3.7
-65	3.9	-1	-1	1.9	6.5	-1	4.1
-70	4.4	3.9	5.0	2.1	6.6	2.7	4.3
-75	4.8	-1	-1	2.5	6.5	-1	4.6
-80	5.0	4.5	5.1	3.3	6.4	4.0	-1
-85	5.2	-1	-1	-1	-1	-1	-1
-90	5.3	5.2	4.9	-1	-1	4.9	-1
-95	5.6	-1	-1	-1	-1	-1	-1
-100	5.8	5.5	4.5	-1	-1	5.0	-1
-105	-1	-1	-1	-1	-1	-1	-1
-110	5.8	5.3	3.9	-1	-1	4.4	-1
-115	-1	-1	-1	-1	-1	-1	-1
-120	5.6	4.5	3.1	-1	-1	3.3	-1
-125	-1	-1	-1	-1	-1	-1	-1
-130	5.2	4.4	2.4	-1	-1	2.8	-1
-135	5.0	-1	-1	-1	-1	-1	-1
-140	4.8	3.7	1.4	-1	-1	2.4	-1
-145	4.6	-1	-1	-1	-1	-1	-1
-150	4.4	3.0	0.9	-1	-1	1.9	-1
-155	3.8	-1	-1	-1	-1	-1	-1
-160	3.7	2.8	0.7	-1	-1	-1	-1
-165	3.6	-1	-1	-1	-1	-1	-1
-170	3.1	-1	0.3	-1	-1	-1	-1

Note: -1 indicates missing data

Table 30. CENTER HILL LAKE D.O. @ CANEY FORK RM 27.2 (STATION 2) DURING MID-SEPTEMBER

YEAR	1971	1972	1974	1976	1979	1982	1983	1987	1988
DATE	9/15	9/27	9/17	9/16	9/22	9/14	9/13	9/29	9/22
DEPTH	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.
0	8.4	8.3	8.6	8.2	6.5	9.1	9.3	9.0	8.1
-5	8.6	8.3	8.2	-1	-1	9.6	9.2	8.7	8.3
-10	8.7	8.3	9.1	7.9	6.5	9.6	9.2	8.3	8.1
-15	8.6	8.2	8.2	-1	-1	9.1	8.1	8.1	8.1
-20	8.5	8.1	8.4	7.9	6.5	8.7	1.5	7.7	8.2
-25	8.2	8.0	8.4	-1	-1	6.5	0.1	7.0	7.9
-30	7.1	7.4	8.3	7.3	6.2	0.8	0.0	6.4	3.4
-35	5.7	4.9	3.4	-1	-1	0.3	0.0	2.3	0.1
-40	4.3	1.1	3.0	0.1	0.1	0.0	0.0	2.0	0.1
-45	1.8	0.3	2.8	-1	-1	0.0	0.4	1.8	0.1
-50	0.3	0.2	2.7	0.2	0.1	0.1	1.5	1.5	0.0
-55	0.2	0.2	2.9	-1	-1	1.1	2.6	1.5	0.9
-60	0.8	0.5	2.7	1.0	0.1	1.9	3.3	1.7	1.7
-65	1.9	1.8	2.3	-1	-1	2.9	3.6	1.8	2.5
-70	3.2	2.3	2.6	1.4	0.5	3.4	3.8	1.7	2.8
-75	4.0	2.7	3.0	-1	-1	4.0	3.3	1.3	2.9
-80	4.3	3.1	3.3	1.4	1.6	4.2	2.8	1.1	3.1
-85	4.5	3.3	3.5	-1	-1	4.2	2.8	0.6	3.1
-90	4.6	3.3	3.6	-1	2.5	4.0	2.3	0.5	3.1
-95	4.6	-1	3.4	-1	-1	3.5	1.9	0.2	2.8
-100	4.6	3.0	3.1	-1	2.7	3.1	1.7	0.2	2.8
-105	4.7	-1	3.0	-1	-1	2.6	-1	0.2	2.3
-110	4.3	1.9	2.6	-1	1.8	2.6	0.8	0.2	1.7
-115	4.4	-1	2.3	-1	-1	2.4	-1	0.2	1.5
-120	4.0	0.9	2.0	-1	0.7	1.6	0.1	0.2	0.7
-125	-1	-1	1.3	-1	-1	1.2	-1	0.2	0.4
-130	3.6	0.3	1.1	-1	0.6	0.9	0.0	0.1	0.1
-135	-1	-1	0.8	-1	-1	0.8	-1	0.1	0.1
-140	2.7	0.2	0.5	-1	0.7	0.3	0.0	0.1	0.1
-145	-1	-1	0.2	-1	-1	0.1	-1	0.0	0.1
-150	2.2	0.2	-1	-1	0.8	0.1	0.0	0.0	0.1
-155	-1	-1	-1	-1	-1	0.1	-1	0.0	0.1
-160	2.0	0.2	-1	-1	-1	0.0	-1	0.0	-1
-165	-1	-1	-1	-1	-1	0.0	-1	0.0	-1
-170	1.5	-1	-1	-1	-1	-1	-1	-1	-1

Note: -1 indicates missing data

Table 31. CENTER HILL LAKE D.O. @ CANEY FORK RM 49.1 (STATION 4) DURING LATE JULY

YEAR	1971	1974	1977	1977	1979	1981	1982	1983	1984	1988
DATE	7/27	7/16	7/20	8/02	7/17	7/14	8/03	7/26	8/01	7/22
DEPTH	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.
-0	9.1	8.4	7.7	8.2	9.7	10.2	9.6	8.8	9.9	8.6
-5	9.2	8.6	7.7	8.2	-1	10.2	9.4	9.1	9.7	8.6
-10	9.4	8.7	8.1	8.2	11.6	14.2	9.2	9.1	9.6	8.6
-15	9.3	11.0	10.7	8.3	-1	12.7	9.5	10.2	9.2	8.5
-20	9.1	7.6	8.4	8.2	6.1	9.8	9.6	4.1	5.4	10.4
-25	8.6	4.3	5.4	5.3	-1	4.2	6.3	1.7	3.6	6.9
-30	11.2	2.9	3.1	1.9	3.2	1.6	2.5	1.5	2.7	1.0
-35	6.2	2.5	1.3	0.5	-1	1.4	1.9	2.2	0.9	1.0
-40	2.3	2.8	1.5	0.9	3.7	1.3	2.1	3.1	1.4	1.3
-45	3.2	3.1	2.2	1.6	-1	-1	2.5	3.6	2.1	2.2
-50	4.0	3.5	2.2	2.7	4.5	1.8	3.0	4.4	3.7	3.0
-55	4.8	-1	4.2	3.9	-1	-1	3.5	-1	4.5	3.6
-60	5.3	4.0	5.2	4.9	4.7	4.1	4.3	4.6	4.7	3.7
-65	5.4	-1	6.0	5.3	-1	-1	4.5	-1	4.9	3.6
-70	5.6	4.4	6.0	5.3	4.8	5.6	4.6	4.6	5.2	3.3
-75	5.5	-1	5.6	4.8	-1	-1	4.1	-1	5.2	3.0
-80	4.9	3.8	4.6	4.0	4.3	5.3	3.0	3.6	4.4	2.8
-85	4.1	-1	-1	-1	-1	-1	1.8	-1	4.5	2.7
-90	3.3	2.5	-1	-1	3.3	4.4	1.1	2.3	3.5	2.8
-95	3.1	-1	-1	-1	-1	-1	1.0	-1	2.5	3.1
-100	2.9	1.6	-1	-1	1.9	4.1	1.1	0.8	1.4	3.1
-105	3.1	-1	-1	-1	-1	-1	-1	-1	0.7	2.7
-110	3.0	1.2	-1	-1	0.8	4.0	0.8	0.3	0.0	2.4
-115	2.6	-1	-1	-1	-1	-1	-1	-1	0.0	-1
-120	2.2	0.3	-1	-1	-1	-1	0.2	0.0	0.0	-1
-125	1.8	-1	-1	-1	-1	-1	-1	-1	0.0	-1
-130	1.6	-1	-1	-1	-1	-1	0.0	0.0	-1	-1

Note: -1 indicates missing data

Table 32. CENTER HILL LAKE D.O. @ CANEY FORK RM 49.1 (STATION 4) DURING EARLY AUGUST

YEAR	1971	1972	1973	1976	1977	1979	1988
DATE	8/19	8/09	8/15	8/22	8/02	8/15	8/10
DEPTH	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.
-0	8.8	8.9	8.6	9.2	8.2	9.3	9.1
-5	8.9	8.9	8.6	8.9	8.2	-1	9.1
-10	9.0	8.9	8.6	8.7	8.2	9.3	9.0
-15	8.9	8.9	8.5	9.3	8.3	-1	9.1
-20	8.5	8.8	5.2	7.1	8.2	7.4	9.6
-25	4.9	7.7	3.2	3.4	5.3	-1	4.5
-30	2.8	3.9	3.0	2.0	1.9	5.0	1.7
-35	1.8	1.8	1.4	2.5	0.5	-1	0.5
-40	0.9	0.7	0.6	1.8	0.9	5.0	0.5
-45	0.6	1.1	0.9	1.9	1.6	-1	1.2
-50	1.0	1.8	1.8	2.3	2.7	2.0	1.5
-55	2.1	-1	-1	2.8	3.9	-1	2.0
-60	3.0	2.8	4.1	2.8	4.9	2.6	2.5
-65	3.6	-1	-1	2.5	5.3	-1	2.9
-70	4.2	4.0	4.3	2.1	5.3	2.7	-1
-75	4.5	-1	-1	2.0	4.8	-1	-1
-80	4.3	4.1	3.1	1.8	4.0	1.5	-1
-85	3.8	-1	-1	-1	-1	-1	-1
-90	3.2	3.2	0.7	-1	-1	0.8	-1
-95	2.3	-1	-1	-1	-1	-1	-1
-100	2.0	1.9	0.2	-1	-1	0.7	-1
-105	1.9	-1	-1	-1	-1	-1	-1
-110	1.8	1.2	0.1	-1	-1	0.7	-1
-115	1.6	-1	-1	-1	-1	-1	-1
-120	1.3	0.4	0.1	-1	-1	-1	-1
-125	1.2	-1	-1	-1	-1	-1	-1
-130	0.8	-1	-1	-1	-1	-1	-1
-135	0.3	-1	-1	-1	-1	-1	-1

Note: -1 indicates missing data

Table 33. CENTER HILL LAKE D.O. @ CANEY FORK RM 49.1 (STATION 4) DURING MID-SEPTEMBER

YEAR	1971	1972	1974	1976	1979	1982	1983	1987	1988
DATE	9/16	9/27	9/17	9/16	9/22	9/14	9/13	9/30	9/21
DEPTH	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.	D.O.
-0	8.5	8.6	7.8	8.2	7.3	8.8	9.4	8.0	8.3
-5	8.4	8.7	7.8	8.2	-1	8.9	9.5	7.4	8.3
-10	8.4	8.7	7.6	8.2	7.3	8.8	8.8	7.2	8.3
-15	8.3	8.7	7.5	-1	-1	8.7	8.5	7.0	8.1
-20	8.2	8.7	7.4	8.1	7.2	7.7	5.1	6.7	7.9
-25	7.6	8.7	7.2	-1	-1	0.7	0.1	4.2	7.0
-30	2.4	1.1	5.2	7.8	5.6	1.5	0.0	2.0	0.2
-35	0.2	0.3	1.3	-1	-1	0.8	0.0	0.5	0.2
-40	0.1	0.3	1.1	0.1	1.7	0.1	0.0	0.5	0.1
-45	0.1	0.3	1.0	-1	-1	0.1	0.6	0.6	0.1
-50	0.1	0.3	0.9	0.1	1.6	0.1	1.3	0.9	0.1
-55	0.5	-1	1.0	-1	-1	0.4	2.1	1.3	0.1
-60	1.2	0.5	1.4	0.7	0.6	0.9	2.4	1.5	0.0
-65	2.4	-1	1.8	-1	-1	1.3	2.1	1.4	0.0
-70	3.1	1.1	1.7	0.6	0.5	1.6	1.2	0.6	0.0
-75	-1	-1	1.2	-1	-1	1.4	0.1	0.4	0.0
-80	3.2	0.3	0.7	0.2	0.5	0.9	0.0	0.3	0.0
-85	-1	-1	0.3	-1	-1	0.2	0.0	0.0	0.0
-90	1.9	0.3	0.3	-1	0.6	0.0	0.0	0.0	0.0
-95	-1	-1	0.2	-1	-1	0.0	0.0	0.0	0.1
-100	0.2	0.3	0.2	-1	0.6	0.0	0.0	0.0	0.1
-105	-1	-1	0.2	-1	-1	0.0	0.0	0.0	0.1
-110	0.1	-1	0.2	-1	0.8	0.0	0.0	0.0	0.1
-115	-1	-1	0.1	-1	-1	0.0	0.0	-1	0.1
-120	0.1	-1	-1	-1	-1	0.0	-1	-1	-1
-125	-1	-1	0.1	-1	-1	0.0	-1	-1	-1
-130	-1	-1	0.1	-1	-1	0.0	-1	-1	-1

Note: -1 indicates missing data

The zone is delineated at the top by DO concentrations of 5 or less and at the bottom by either DO increases to 5 or more or by an increase prior to a decrease as depths increase into the benthic zone.

185. Table 28 shows DO concentrations during mid-July to early-August at Station 2. The thickness of the zone is a yearly variable and no obvious trends are noted. Table 31 shows similar data at Station 4. Table 29 shows the DO during mid-August, 1971-1988 at Station 2 while Table 32 shows similar data for Station 4. Again, no obvious trends are apparent. Tables 30 and 33 show DO values during late-September at Stations 2 and 4, respectively. The data are more erratic during September but no obvious trends are noted.

186. If Morris (1978) was correct in his statement that phytoplankton were major users of metalimnetic DO and if nutrient levels have decreased with time Hunter (1987), one would expect that less phosphorus and nitrogen would lead to lesser amounts of phytoplankton which would lead to better DO conditions in the metalimnion. According to this subjective analysis, better DO levels were not present in 1988. However, the metalimnetic DO picture is not noticeably worse now either.

Phytoplankton Analysis/Numerical Analysis and Descriptive Results

187. The depletion of oxygen in the Center Hill has been blamed upon respiration and decay of algae produced in the epilimnion. Thus, this study included analysis for chlorophyll a, pheophytin a, and plankton in Mine Lick Creek and Falling Water River Embayments. Phytoplankton were enumerated by genus as cells per liter on five monthly lake visits with samples being taken at depths of 0, 2, 3, 4, and 5 meters. These data are presented in Appendix VI.

188. Similiar data were collected by Gordon (1972) on South Holston and Watauga Reservoirs and by Morris (1978) on Center Hill Reservoir. Table 34 shows the comparison of these three reservoirs which are all affected by the metalimnetic minimum of dissolved oxygen. The similarities in the data sets are profound. The DO depletion rates in the metalimnions were 0.06 mg/l*day in both Watauga and South Holston during 1971, 0.09 mg/l*day for Center Hill during 1977, and 0.06 mg/l*day for Center Hill during 1988.

189. June chlorophyll a values (uncorrected) ranged from 1 to 7 ug/l at South Holston, from 1 to 9 at a similiar station on Center Hill during 1977 and from 0.5 to 5 during 1988. June cell counts on South Holston during 1971 ranged from 600 to 2200 cells/ml while those in the Falling Water and Mine Lick Embayments during June 1988 ranged from 500 to 4300 cells/ml.

Table 34

A Comparison of Phytoplankton Related Data for Three Tennessee Reservoirs

Reservoir Station	Date (M/D/YR)	Metalimnion D.O.D.R.[1] (mg/l*day)	Upper 15 ft Chl a Range (ug/l)	Upper 20 ft Tot-Phytoplankton Range (cells/l)
Center Hill Station 2	6/22/77	0.09	1-9	*
Center Hill Station 4	6/22/77	0.09	5-20	*
Center Hill Station 2&3	6/15/88	0.06	0.5-5	*
Center Hill Stations 2,3,4, 5,FWR[2],& MLC[3]	6/15/88	0.06	0.5-15	500-4300
Center Hill Stations 2,3,4, 5,FWR,& MLC	9/7/88	0.06	1-13	200-400
Center Hill Stations 2,3, 4,& 5	10/13/88	0.06	1-15	120-400
South Holston Station 2	6/29/71	0.06	1-7	600-2200
South Holston Station 2	9/15/71	0.06	1.5-2.5	400-1000
Watauga Station 2	9/28/71	0.06	1-2	600-700

1 D.O. depletion rate
2 FWR = Falling Water River
3 MLC = Mine Lick Creek
* no available data

190. September chlorophyll a levels for South Holston were 1.5 to 2.5 ug/l in 1971; for Watauga were 1 to 2 ug/l in 1971; and for Center Hill were 1 to 7 ug/l in 1988. September cell counts were 400 to 1000 cells/ml in South Holston (1971), 600 to 700 cells/ml in Watauga (1971), and 200 to 400 cells/ml in Center Hill (1988).

191. Based upon this comparison, one can conclude that Center Hill Lake is slightly more productive than South Holston and Watauga were in 1971. This slightly more productive aspect is matched by a slightly higher DO depletion rate in the metalimnion.

192. Table 35 shows a comparison of 1977 chlorophyll a data with 1988 data. Values are similar with 1988 data tending to be slightly lower in most cases. Morris (1978) measured total phosphorus, dissolved phosphorus, ammonia, and nitrate levels in Center Hill Lake during 1977 and these values are 35.5 ug/l (n = 91, S.D. = 19.6), 23.8 ug/l (n = 87, S.D. = 17.6), 0.048 mg/l (n = 89, S.D. = 0.054), and 0.261 mg/l (n = 91, S.D. = 0.181), respectively. The phosphorus values are all higher than the 1988 means of 18.1 ug/l (n = 71, S.D. = 10.9) and 10.2 ug/l (n = 71, S.D. = 3.31). Nitrogen values were higher in 1988 as ammonia had a mean of 0.07 mg/l (n = 71, S.D. = 0.093) and the nitrate mean was 0.345 mg/l (n = 71, S.D. = 0.316).

193. In summary, the numerical analysis showed that there are profound chemical and algal similarities among Center Hill, South Holston, and Watauga Lakes. All three are high-

Table 35

Comparison of 1977 and 1988 Chlorophyll a Data for Center Hill Stations 2 and 4

Reservoir Station	Date (M/D/YR)	Depth (ft)	Chl a (ug/l)
2	6/22/77	1	1
2	6/22/77	5	2.7
2	6/22/77	10	4.7
2	6/15/88	10	2.1
4	6/22/77	1	4.5
4	6/22/77	5	6.0
4	6/22/77	10	8.6
4	6/15/88	5	5.3
2	7/6/77	1	1.9
2	7/6/77	5	3.8
2	7/6/77	10	6.8
2	7/8/88	10	0.5
4	7/6/77	1	5.1
4	7/6/77	5	5.9
4	7/6/77	10	6.6
4	7/8/88	3	1.3
2	7/20/77	1	7.6
2	7/20/77	5	8.5
2	7/20/77	10	8.0
2	8/10/88	5	1.6
4	7/20/77	1	3.6
4	7/20/77	5	3.5
4	7/20/77	10	5.6
4	8/10/88	5	3.2

quality resources having a distinct DO metalimnetic minimum which only slightly reduces the overall usefulness of the project.

194. All of the algal counts at each location and on each of the collecting dates were relatively low, and they were not indicative of "bloom" conditions. The algal populations were not so great as to discolor the water or to impart a distinctive taste to the water. Even in the filtered and concentrated samples there was not an algal-associated odor. From an aesthetic view, the algal populations in Center Hill Reservoir during the period June to October, 1988, could not be considered a problem either to recreation or to a drinking water supply. From a biological standpoint, the algal population during this period would be a small autochthonous energy source for the reservoir.

195. The diatoms (Class Bacillariophyceae) were the dominant organisms throughout most of the sampling period. Their numbers were greatest at depths of 2 to 4 meters. Mixed with the diatoms were species of green (Chlorophyceae), dinoflagellate (Pyrrhophyceae), blue-green (Cyanobacteria), and euglenoid (Euglenophyceae) algae. Several incidents were noted by dominance or co-dominance of greens and dinoflagellates. The wax and wane of green algal populations throughout the warmer months, and the persistence of diatoms and dinoflagellates throughout the year are well-known phenomena.

196. All of the dominant algae are tolerant of organic enrichment. The algal assemblage in Center Hill Reservoir is not characteristic of "clean water," but the concentrations of cells are not indicative of a highly enriched situation. The algal populations show that there may be organic enrichment in the two embayments, but that there may also be a factor limiting growth.

197. From the writer's experience (Dr. Andrews), algal populations in the summer months have been low in Center Hill Reservoir for nearly twenty years. Algal activity has been much greater during the winter and early spring. Dominance in this period is by golden-browns (Chrysophyceae) and diatoms.

CONCLUSIONS

198. The overall objective of this study was to collect and present water quality data and estimate nutrient loads for the Caney Fork River Basin. Sites studied within the basin included (1) embayments, (2) the main-channel, (3) wastewater treatment plant discharges, and (4) the tailwater. This report summarized and analyzed the water quality data collected from March 1988 through January 1989 and resulted in the following conclusions and recommendations:

Embayment and Main-Channel

1. Falling Water River and Mine Lick Creek Embayments have similar physical and chemical water quality characteristics. In general, they are poorer than the water quality characteristics in the lake's main-channel.

2. During the summer months, high ammmonia nitrogen and ortho-phosphate phosphorus concentrations, and low dissolved oxygen concentrations developed in the Mine Lick Creek Embayment due to low inflows. Falling Water River which received a significant inflow had similar yet not as poor summer water quality characteristics.

3. Holmes and Indian Creek Embayments which have insignificant inflows had nearly the same physical water quality characteristics as the main-channel of the lake.

4. Of the lake's smaller embayments, Fall Creek Embayment had the worst dissolved oxygen profiles with near complete DO depletion occurring below the epilimnion throughout the summer months.

5. Although the physical water quality characteristics of the Pine and Sink Creek Embayments were better than those in the Fall Creek Embayment, they too had significant dissolved oxygen depletion below the epilimnion. All three of the smaller embayments had slightly worse dissolved oxygen characteristics than those found in the main-channel of the reservoir.

6. The physical water quality of Center Hill's main-channel is longitudally homogeneous with the metalimnetic minima occurring from depths of 8.0 to 14.0 meters throughout the summer months.

7. Nutrient trends in the lake are significant. Various nutrient species increase with lake depth, length, and hydraulic residence time.

8. Based on data taken during this year, Center Hill Lake appears to be phosphorus limited and slightly mesotrophic while its embayments are eutrophic. Trophic status may vary from year to year depending on runoff events, etc.

Inflows and the Tailwater

9. Due to a dry year (1988), biweekly instantaneous flow measurements were adequate in describing the summer

(dry period) flow patterns of streams within the Caney Fork River Basin, as compared to daily flows obtained for the Collins River. After November, increased rainfall may have led to runoff events which were not sampled by the study.

10. Storm runoff event sampling on Falling Water River and Taylor Creek showed that there are significant increases in turbidity, total nitrogen, and both total and ortho-phosphate phosphorus with increases in streamflow. The nutrients followed a washoff pattern, returning to lower concentrations following the peak flows.

11. Increases in turbidity, total nitrogen, and phosphorus concentrations during the rain event were significantly larger in Taylor Creek as compared to Falling Water River.

12. Time-series plots of stream nutrient data show high phosphorus concentrations during summer months when flows were minimal and low concentrations during high flow months due to dilutional effects. Nitrogen concentrations did not show a strong correlation with flow.

13. Stream physical parameter means were similar for each inflow; but nutrient concentrations were quite different for each inflow as are their drainage area characteristics.

Nutrient Loadings and Budgets

14. Nutrient concentrations/loads were generally larger for inflows receiving WWTP effluent.

15. Wastewater treatment plants contributed a significant nutrient load to their receiving streams. Of these receiving streams, only Falling Water River appeared to have some assimilative capacity for phosphorus. None of the streams appeared to have a significant assimilative capacity for nitrogen.

16. Center Hill's water budget showed that approximately 71 percent of Center Hill's inflow was attributable to Great Falls; 5 percent to Falling Water River; and 4 percent to rainfall. Approximately 15 percent of Center Hill's inflow was ungaged during this study.

17. Approximately 83 percent of inflowing phosphorus was captured in the lake; 78 percent of inflowing ortho-phosphate phosphorus was captured. Fifty-two percent of inflowing total nitrogen was captured within the reservoir. Of the nitrogen species, 50 percent of inflowing nitrate, 44 percent of inflowing ammonia, and 56 percent of organic nitrogen were captured.

Biological Conditions

18. The levels of plankton and chlorophyll a were low in the lake during the summer months. This produces a small amount of autochthonous energy for the reservoir.

19. Summer plankton were those species tolerant of organic enrichment rather than clean water types. This may indicate a link to the low dissolved oxygen levels in the metalimnion.

REFERENCES

APHA, AWWA, and WPCF. Standard Methods for the Examination of Water and Wastewater, 16th Ed., 1980.

ASCE. Hydrology Handbook, Manual of Engineering Practice, No. 28: American Society of Civil Engineers, 1949.

AWWA Task Group. "Chemistry of Nitrogen and Phosphorus in Water," AWWA Journal, 62, February 1970, 127-31.

Blakely, J.F., R.O. Hawkinson, and T.D. Steele. "An Evaluation of Water Quality Records for Texas Streams," U. S. Geological Survey Open File Report, March 1973.

Carlson, R. E. "A Trophic State Index for Lakes," Limnol. Oceanogr., 22(2): 361-369, 1977.

Carmack, E. C., C. B. J. Gray, C. H. Pharo, and R. J. Daley "Importance of lake-river interaction on seasonal patterns in the general circulation of Kamloops Lake, British Columbia," Limnol. Oceanogr., 24(4), 634-644, 1979.

Cole, G.A. Textbook of Limnology. St. Louis: C.V. Mosby Co., 1975.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R Newroth. Lake and Reservoir Restoration, Butterworth Publishers, Massachusetts, 1986.

Daniel, C.C., H.B. Wilder, and M.S. Weiner. "Water Quality of the French Broad River, North Carolina - An Analysis of Data Collected at Marshall 1958-1977," Geological Survey, Raleigh, North Carolina, Water Resources Division, 1979.

Dillion, P.J. The Phosphorus Budget of Cameren Lake, Ontario: The Importance of Flushing Rate to the Degree of Eutrophy of Lakes, Journal of Limnology and Oceanography, Vol. 20, 1975.

Dyer, K.L. "An Evaluation of Water Quality Data Obtained at Four Streamflow Daily-records for Texas Streams," U.S. Geological Survey Water Resources Investigations 30-73, August 1973.

Elder, R. A., and Wunderlich. "Evaluation of Fontana Reservoir field measurements, current research into the effects of reservoirs on water quality," Tech. Rep. 17, Dep. of Environ. and Water Resour. Eng., Vanderbilt Univ., Nashville, Tennessee, 1968.

Frost, L.R. "Evaluation and Simulation of Chemical Quality Data for five Montana Sampling Stations," Geological Survey, Helena, Montana, 1974.

Gakstatter, J. H., M. O. Allum, and J. M. Omernik. "Lake Eutrophication: Results from the National Eutrophication Survey," presented at the Twenty-sixth Annual AIBS Meeting, OSU, Curvallis, Oregon, August 1975.

Gordon, J.A. "Effects of Impoundments on Water Quality: Report of Research Conducted at South Holston and Watauga Reservoirs During 1970-1971," TVA Report I-WQ-87-7, 1972.

Gordon, J.A. "Water Quality Conditions in Center Hill Reservoir," Department of Civil Engineering, Tennessee Technological University, Cookeville, Tennessee, January 1976.

Gordon, J.A. and W.R. Nicholas. "Effects of Impoundments on Water Quality: Mechanisms of Dissolved Oxygen Depletion," Division of Environmental Planning, TVA, 1977.

Gordon, J.A. "LARM Two-Dimensional Model: An Evaluation," Journal of the Environmental Engineering Division, ASCE, Vol. 107, No. EE5, p. 877, 1981.

Graham, T. Personal Communication, Cookeville Wastewater Treatment Plant, Cookeville, Tennessee, 1989.

Hem, J.D. "Study and Interpretation of the Chemical Characteristic of Natural Water," U.S. Geological Survey, Water Supply Paper 1473, 1959.

Hunter, M.A. "Effects of Stage Fluctuations on Water Quality of Center Hill Reservoir," Department of Civil Engineering, Tennessee Technological University, Cookeville, Tennessee, 1987.

Hutchinson, G.E. A Treatise on Limnology: Geography, Physics, and Chemistry. New York: John Wiley and Sons, Inc., 1957.

Kittrell, F.W. "Thermal Stratification in Reservoirs," Symposium on Streamflow Regulation for Quality Control, Public Health Service Publication No. 999-WP-30, June 1965.

Knapton, J.R. Evaluation and Correlation of Water Quality Data for the North Fork Flat Head River, Northwestern Montana, U.S. Geological Survey Water Resurces Investigations, 78-111, 1978.

Lorenzen, M.W., D.B. Porcella, and T.M. Grieb. Phytoplankton - Environmental interactions in Reservoirs, Bellevue, Washington: Technical Report E-81-13, September 1981.

Lind, O.T. Handbook of Common Methods in Limnology, St. Louis: C.V. Mosby Co., 1979.

Mackenthun, K.M. and W.M. Ingram. Biological Associated Problems in Freshwater Environments: Their Identification, Investigation, and Control, Washington D.C.: U.S. Government Printing Office, 1967.

May, V.J., et al. "Hydrology of Area 18, Eastern Coal Province, Tennessee," U.S. Geological Survey Water Resources Investigations 81-492, Nashville, Tennessee, August 1981.

Morris, J.W. "Dissolved Oxygen Depletion Mechanisms Operating in the Metalimnion of a Deep Impoundment," Department of Civil Engineering, Tennessee Technological University, Cookeville, Tennessee, June 1978.

NALMS, The Lake and Reservoir Restoration Guidance Manual, 1st ed., EPA 440/5-88-022, 1988.

Nix, J. "Contribution of Hypolimnetic Water on Metalimnetic Dissolved Oxygen Minima in a Reservoir," Water Resources Research, 17(2), 329-332, 1981.

Omernik, J.M. Nonpoint Source - Stream Nutrient Level Relationships: A Nationwide Study, Corvallis, Oregon: EPA-600/3-77-105, September 1977.

Reckhow, K.H. "Empirical Models for Trophic State in Southeastern U.S. Lakes and Reservoirs," Water Resource Bulletin, Vol. 24, No. 4, 1988.

Reid, G.K. Ecology of Inland Waters, New York: Reinhold Publishing Co., 1961.

Reid, G.K. and R.D. Wood. Ecology of Inland Waters and Estuaries, 2nd., New York: D. Van Nostrand Company, 1976.

Sanders, T.G., et al. "Design of Networks for Monitoring Water Quality," Colorado: Water Resources Publications, 1983.

Sansing, H." Discussion Paper: Meeting of Professional Managers of Natural Resources," Nashville Division, Corps of Engineers, Nashville, Tennessee, April 1987.

Sawyer, C.N. and P.L. McCarty. Chemistry for Environmental Engineers. 3rd ed., New York: McGraw Hill, Inc., 1978.

Smith, R.V. and D.A. Stewart. 'Statistical Models of River Loadings of Nitrogen and Phosphorus in the Lough Neagh System," Water Research, Vol. 11, 1977.

Steele, T.D. "A Study of the Chemical Quality of Streamflow in Arkansas," U.S. Geological Survey Open File Report, Washington, D.C., October 1971.

Steele, T.G. "Computer Simulation of Solute Concentrations and Loads in Streams, River and Estuary Model Analysis," Vol. 3 of Proceedings of the International Association of Hydraulics Research, International Symposium on River Mechanics, January 1973.

Steele, T.D. "A Bivariate Regression Model for Estimating Chemical Composition of Streamflow and Groundwater," Hydrological Sciences Bulletin, Vol. 21, No. 1, 1976.

Stumm, W. and J.J. Morgan. Aquatic Chemistry, New York: John Wiley and Sons, Inc., 1970.

Tennessee Department of Public Health, Division of Water Quality Control, "Water Quality Management Plan for the Upper Cumberland River Basin," November 1978.

Thornton, K., J. Nix, and J. Bragg. "Coliforms and water quality: Use of data in project design and operation," Water Resour. Bull., 16, 1980.

Tsai, K. and J. Huang. "P, N & C head the critical list," Water and Wastewater Engineering, 25, 45-47, 1979.

Turner, B. Personal Communication, Tennessee Department of Health and Environment, Cookeville, Tennessee, 1989.

U.S. Army Corps of Engineers, Nashville District. "Master Plan for Recreational Development - - Center Hill Reservoir," June 1948.

U.S. Army Corps of Engineers, Nashville District. "Project Resource Management Plan - - Center Hill Lake," July 1975.

U.S. Census, 1980.

Uttormark, P.D., J.D. Chaphin, and K.M. Green. Estimating Nutrient Loadings of Lakes from Non-Point Sources, Corvallis, Oregon: EPA-660/3-74-020, August 1974.

Varga, L.P. and C.P. Falls. "Continuous System Models of Oxygen Depletion in a Eutrophic Reservoir," Environmental Science and Technology, Vol. 6, No. 2, February, 1972.

Verhoff, F.M., S.M. Yaksich, and D.A. Melif. "River Nutrient and Chemical Transport Estimation," The Journal of the Environmental Engineering Division, Proceeding of ASCE, Vol. 106, No. EE3, 1980.

Walling, D.E. and B.W. Webb. "Estimating the Discharge of Contaminants to Coastal Waters by Rivers," Marine Pollution Bulletin, Vol. 16, No. 12, 1985.

Wang, W.C. and R.C. Evans. "Dynamics of Nutrient Concentrations in the Illinois River," Journal of Water Pollution Control Federation, Vol. 42, 1970.

Wells, S.A. "A Three-Dimensional Field Evaluation and Analysis of Water Quality in Two Reservoirs," Department of Civil Engineering, Tennessee Technological University, Cookeville, Tennessee, June 1980.

Yaksich, S.M. and F.H. Verhoff. "Sampling Strategy for River Pollutant Transport," Journal of Environmental Engineering, ASCE, Vol. 109, No. 1, 1983.

Young, J.L. "Hydrologic Interpretation of Water Quality Data for the Emory and French Broad Rivers," Department of Civil Engineering, Tennessee Technological University, Cookeville, Tennessee, December 1988.

APPENDIX I

Chlorophyll a Values

Date	Station	Depth (m)	Chloro a (ug/l)	Pheophytin (ug/l)	Secchi Disk (m)
880615	3CEN20002	3	2.1	1.3	2.1
	3CEN20002	11	1.5	2.8	
	3CEN20002	45	0.5	8.9	
880708	3CEN20002	3	0.5	9.6	1.5
	3CEN20002	12	0.9	7.5	
	3CEN20002	21	1.8	3.8	
880810	3CEN20002	2	1.6	2.1	2.1
	3CEN20002	10	1.6	2.5	
	3CEN20002	22	1	3.05	
880907	3CEN20002	2	3.5	0.67	2.3
	3CEN20002	10	4	-2.1	
	3CEN20002	28	1.6	-0.1	
881013	3CEN20002	2	7.7	1	4.4
	3CEN20002	10	25.1	1	
	3CEN20002	24	62.1	1	
880615	3CEN20003	2	5.3	5.4	2
	3CEN20003	10	1.3	6.5	
	3CEN20003	36	1.3	1.3	
880708	3CEN20003	4	2.8	4.4	1.8
	3CEN20003	12	6.1	19.9	
	3CEN20003	22	0.5	8.5	
880810	3CEN20003	2	1.1	0.47	2
	3CEN20003	10	3.6	7.1	
	3CEN20003	22	1	6.15	
880907	3CEN20003	2	7	-9.93	2.1
	3CEN20003	10	2.2	32.8	
	3CEN20003	27	0.8	-0.45	
881013	3CEN20003	3	65.8	1	4.3
	3CEN20003	10	8.7	1	
	3CEN20003	24	23.9	1	
880615	3CEN20004	2	5.3	5.1	2
	3CEN20004	10	1.7	1	
	3CEN20004	38	3.6	5.6	
880708	3CEN20004	1	1.3	7.4	2.3
	3CEN20004	9	0.5	7	
	3CEN20004	20	1.4	17.8	
880810	3CEN20004	2	3.2	4.25	1.8
	3CEN20004	10	2.7	6.95	
	3CEN20004	22	1	45.5	
880907	3CEN20004	2	7.8	-3.7	1.8
	3CEN20004	10	3.4	1.1	
	3CEN20004	26	1	2.3	

881013	3CEN20004	2	8.2	1	3.4
	3CEN20004	10	4.8	1	
880615	3CEN20005	2	5.8	11.32	2
	3CEN20005	10	1.3	4.3	
	3CEN20005	28	0.5	4	
880708	3CEN20005	2	1.7	11.2	1.5
	3CEN20005	8	1.3	11.5	
	3CEN20005	17	0.5	3.2	
880810	3CEN20005	2	3.9	0.57	2
	3CEN20005	10	3.4	2.05	
	3CEN20005	22	1.2	1.4	
880907	3CEN20005	2	3.8	1.03	1.7
	3CEN20005	10	10	-2.95	
	3CEN20005	22	1.8	-1.45	
881013	3CEN20005	2	12	1	3.5
	3CEN20005	10	14.8	1	
	3CEN20005	24	1	9.1	
880615	3CEN20008	0.5	7.9	6.9	1.7
	3CEN20008	2	9.4	8.1	
	3CEN20008	6	4.5	3.9	
	3CEN20008	8	0.9	2.9	
	3CEN20008	14	2.4	1.2	
	3CEN20008	18	1.5	2.9	
880708	3CEN20008	2	1.3	7.7	1.8
	3CEN20008	4	0.5	17.5	
	3CEN20008	6	1.3	16.7	
	3CEN20008	8	0.5	7.7	
	3CEN20008	14	0.8	6	
	3CEN20008	18	0.5	5.2	
880810	3CEN20008	1	3.7	2.55	1.4
	3CEN20008	3	5.6	13.25	
	3CEN20008	5	6.2	9.1	
	3CEN20008	11	3.8	8.5	
	3CEN20008	14	2.7	6.37	
	3CEN20008	17	2.7	3.45	
880907	3CEN20008	1	2.5	13.63	1.5
	3CEN20008	4	12.7	1.05	
	3CEN20008	8	5.2	4.27	
	3CEN20008	13	7.1	2.85	
	3CEN20008	15	5.6	7.05	
	3CEN20008	18	10.8	4.9	
881013	3CEN20008	1	11.9	1	2
	3CEN20008	7	1.4	8.7	
	3CEN20008	12	8.5	1	
	3CEN20008	14	9	2.9	
	3CEN20008	15	9.9	1	
	3CEN20008	16	9.2	5.2	
880615	3CEN20015	0.6	4.7	1.3	1.7
	3CEN20015	3	0.5	5.3	
	3CEN20015	5	4.7	6.1	

	3CEN20015	7	11.1	3.5	
	3CEN20015	15	14.1	0.5	
	3CEN20015	23	9.4	1.4	
880708	3CEN20015	2	2.1	6.5	1.5
	3CEN20015	3	0.5	9.9	
	3CEN20015	6	0.5	5.2	
	3CEN20015	8	0.8	14.4	
	3CEN20015	12	0.5	2.1	
	3CEN20015	16	0.8	4.8	
880809	3CEN20015	1	3		1.4
	3CEN20015	3	3.5	3.95	
	3CEN20015	5	3.7		
	3CEN20015	12	2.2	0.85	
	3CEN20015	15	1.6	5.47	
	3CEN20015	20	1.5	4.25	
880908	3CEN20015	1	5.1	-1.1	2.1
	3CEN20015	4	6.6	7.6	
	3CEN20015	8	4.3	-0.9	
	3CEN20015	14	3.3	-0.65	
	3CEN20015	17	1.2	2.2	
	3CEN20015	21	1.1	1.5	
881013	3CEN20015	1	4.8	1	3
	3CEN20015	6	9.1	1	
	3CEN20015	11	4.4	1.7	
	3CEN20015	15	5.8	1.1	
	3CEN20015	18	7.4	4.6	
	3CEN20015	20	5.9	7.7	

APPENDIX II

RAIN EVENT NUTRIENT DATA FOR TAYLOR CREEK

November 19-22, 1989

Time (hrs)	Flow (cfs)	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P (ug/l)
0	16.3	0.96	0.07	1.29	0.25	50	42
4.5	45.3	0.78	1.09	2.54	0.67	4095	2881
8.5	42	0.6	0.57	2.51	1.34	624	193
23	50.7*	0.63	0.57	2.04	0.847	506	125
28.8	40.9 *	0.88	0.32	1.86	0.66	279	147
33.2	38.7 *	0.99	0.27	1.69	0.43	173	73
48.5	31.7 *	-	-	-	-	-	-
54.5	29 *	1.2	0.18	1.65	0.27	82	41
80.5	25 *	1.35	0.17	1.79	0.27	60	45

* *Streamflows estimated from staff gage and velocity measurements.*

RAIN EVENT NUTRIENT DATA
FOR FALLING WATER RIVER
November 19-22, 1989

Time (hrs)	Flow (cfs)	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P (ug/l)
0	85	1.16	0.07	1.39	0.16	165	148
4.5	197.5	0.93	0.19	1.43	0.31	269	190
7.5	395*	0.96	0.72	2.16	0.48	738	412
22.5	939*	0.91	0.46	1.76	0.39	281	151
26.5	971*	0.87	0.38	1.65	0.4	260	102
31	997*	0.84	0.27	1.46	0.35	169	99
46.5	549*	-	-	-	-	-	-
52	412*	1.07	0.17	1.51	0.27	98	90
69.5	231*	1.34	0.16	1.81	0.31	84	60
77.5	200*	1.25	0.17	1.62	0.2	42	42

* Streamflows estimated from staff gage and velocity measurements.

APPENDIX III

TAILWATER FIELD DATA

Julian Day	NO3 mg/l	NH3 mg/l	TOT-N mg/l	ORG-N mg/l	TOT-P ug/l	O-P* ug/l	Flow dsf
75	0.21	0.05	0.8	0.59	11	5	37944
91	0.22	0.05	0.52	0.3	10	6	23982
104	0.34	0.13	0.68	0.21	17	5	27315
119	0.39	0.38	0.77	0.01	10	7	30872
132	0.41	0.04	0.54	0.09	11	7	17022
147	0.5	0.07	0.74	0.17	10	4	12660
159	0.47	0.04	0.64	0.13	16.4	6.7	11857
178	0.52	0.05	.73	.16	10	-	14134
192	0.59	0.7	1.3	0.01	10	-	23737
206	0.52	0.1	0.82	0.2	24	10	15151
220	0.62	0.08	0.82	0.12	14	14	18601
234	0.56	0.06	0.73	0.11	19	8	11593
249	0.48	0.05	0.62	0.09	10	5	20637
262	0.58	0.02	0.6	0.01	10	7	18955
276	0.54	0.02	0.89	0.33	21	5	4677
292	0.56	0.01	0.93	0.16	14	5	6177
311	0.43	0.1	0.75	0.22	10	7	6906
326	0.37	0.08	0.57	0.12	10	5	44856
339	0.17	0.13	0.49	0.19	25	15	70914
350	0.11	0.15	0.4	0.14	16	11	26517
6	0.12	0.09	0.45	0.24	16	7	132462
18	0.19	0.02	0.52	0.31	13	6	157646

* Reportable detection limit is 10 μg/l

FALL CREEK FIELD DATA*

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P** (µg/l)	Flow (csf)
75	1.4	0.05	2.8	1.4	24	10	11.1
91	1.1	0.31	1.7	0.29	113	19	61.3
104	1.4	0.11	1.5	0.01	32	0.4	10
119	0.74	0.39	1.1	0.01	17	7	5.2
132	0.6	0.08	1	0.32	23	12	5.6
147	0.65	0.07	0.92	0.22	10.8	12	4.6
159	0.55	0.03	0.85	0.27	29.5	15.3	3.4
178	0.49	0.21	.82	.12	28	-	2.6
192	0.44	0.46	0.9	0.01	22	-	3.2
206	0.34	0.09	0.8	0.37	30	15	1.7
220	0.47	0.16	1.5	0.87	22	18	2.7
234	0.55	0.02	1	0.43	58	28	4.2
249	0.39	0.04	0.51	0.08	13	12	2
262	0.39	0.01	0.56	0.17	13	5	2
276	0.64	0.01	0.94	0.3	14	5	3.5
288	0.56	0.01	0.88	0.32	22	5	2.7
315	1.1	0.11	1.38	0.19	23	14	3.5
325	1.02	0.19	1.39	0.18	103	54	20.9
339	1.16	0.08	1.37	0.13	22	16	6.9
350	1.08	0.05	1.2	0.07	14	12	2.8
6	1.1	0.13	1.62	0.39	59	25	26
18	0.99	0.04	1.37	0.34	37	30	14.4

* upstream of Smithville WWTP

** reportable detection limit is 10 µg/l

PINE CREEK FIELD DATA

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P* (ug/l)	Flow (cfs)
75.0	1.7	0.05	2.9	1.2	15.0	5.0	2.60
91.0	0.9	0.2	1.4	0.3	86.0	23.0	80.6
104.0	0.9	0.1	1.8	0.8	28.0	4.0	27.0
119.0	1.5	0.6	2.1	0.0	25.0	11.0	23.5
132.0	1.5	0.1	1.6	0.0	25.0	16.0	15.6
147.0	1.7	0.1	1.8	0.0	10.7	17.0	17.7
159.0	1.6	0.0	1.7	0.1	37.0	21.3	12.0
178.0	1.6	0.0	1.6	0.0	17.0	-	12.2
192.0	1.7	0.1	1.8	0.0	19.0	-	13.9
206.0	1.5	0.1	1.6	0.0	23.0	17.0	10.0
220.0	1.7	0.1	3.0	1.2	25.0	25.0	10.2
234.0	1.7	0.1	1.8	0.0	49.0	42.0	14.8
249.0	1.6	0.0	1.6	0.0	20.0	14.0	21.7
262.0	1.5	0.0	1.6	0.1	16.0	16.0	9.3
276.0	1.6	0.0	1.6	0.1	14.0	5.0	10.1
288.0	1.4	0.01	1.5	0.1	14.0	9.0	9.6
315.0	1.4	0.1	1.5	0.1	11.0	5.0	14.9
325.0	1.8	0.1	2.1	0.2	52.0	24.0	42.0
339.0	1.7	0.1	1.8	0.1	19.0	16.0	15.7
350.0	1.5	0.1	1.5	0.01	19.0	15.0	10.8
6.0	0.9	0.3	1.7	0.5	129.0	69.0	62.8
18.0	1.5	0.0	1.9	0.4	10.0	5.0	41.6

* reportable detection limit is 10 μg/l

FALLING WATER RIVER FIELD DATA

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P* (ug/l)	Flow (cfs)
75	1.1	0.05	2.1	1	72	61	291.9
91	0.75	0.1	1.1	0.25	101	56	344.4
104	0.62	0.19	1.2	0.39	111	61	207.2
119	0.66	0.4	1	0.01	25	11	110
132	0.72	0.19	1.4	0.49	135	69	65.1
147	0.81	0.25	1.7	0.64	119.2	68	55.8
159	0.89	0.16	1.7	0.65	166.5	65.3	28.4
178	0.88	0.33	1.8	0.59	274	-	22.1
192	0.54	0.23	1.3	0.53	282	-	20
206	0.56	0.16	1.3	0.58	328	238	23.8
220	0.46	0.2	1.1	0.44	260	204	25.4
234	0.67	0.24	1.4	0.49	302	189	37.2
249	0.72	0.16	1.7	0.82	377	295	16.5
262	1.08	0.13	1.6	0.39	599	522	22
276	0.84	0.11	1.27	0.32	167	27	20
288	0.68	0.05	1.42	0.69	260	245	20
315	0.92	0.15	1.33	0.26	138	74	82.1
325	1.08	0.26	1.54	0.22	164	51	549.3
339	1.31	0.1	1.45	0.04	111	83	91.5
350	1.6	0.1	1.83	0.13	249	238	54
6	0.94	0.02	1.44	0.48	84	52	268.1
18	0.93	0.011	1.32	0.38	69	54	29

* reportable limit is 10 μg/l

SINK CREEK FIELD DATA

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P * (ug/l)	Flow (cfs)
75	1	0.05	1.9	0.9	10	5	49.3
91	0.59	0.22	1	0.19	45	6	68
104	0.33	0.11	1.3	0.86	17	6	46.8
119	0.99	0.22	1.3	0.09	10	5	30.5
132	1	0.06	1.2	0.14	13	6	21.3
147	1.1	0.07	1.3	0.14	15.3	5	18.8
159	0.97	0.31	1.2	0.01	100	8.4	11.6
178	0.93	0.09	1.2	0.18	10	-	12.5
192	0.96	0.27	1.2	0.01	10	-	13.5
206	0.88	0.08	1.1	0.14	16	6	9.5
220	0.92	0.07	1.2	0.21	10	10	9.4
234	1.1	0.1	1.4	0.2	86	58	13.9
249	0.96	0.03	1	0.01	12	5	8.5
262	0.88	0.01	0.97	0.09	14	10	9.2
276	0.92	0.01	1.12	0.2	157	5	8.7
288	0.79	0.01	1	0.21	12	5	8
315	0.9	0.08	1.11	0.13	13	11	14.6
325	1.24	0.12	1.53	0.17	40	15	46
339	1.47	0.08	1.64	0.09	12	10	19.7
350	1.05	0.05	1.53	0.43	10	6	12
6	1.12	0.03	1.53	0.38	41	16	126
18	1.18	0.01	1.53	0.35	16	13	168

* reportable limit is 10 μg/l

TAYLOR CREEK FIELD DATA

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P* (ug/l)	Flow (cfs)
75	0.99	0.05	2.3	1.3	37	18	49.9
91	0.73	0.07	1.2	0.4	51	12	54.2
104	0.66	0.16	1.3	0.48	33	5	40.2
119	0.94	0.64	1.6	0.01	21	13	24.1
132	1	0.09	1.2	0.11	29	19	15
147	1.1	0.1	1.4	0.2	24.8	24	10.4
159	1	0.04	1.3	0.26	57.6	36.7	6.9
178	0.98	0.12	1.4	0.3	50	-	6.3
192	0.79	0.11	1.1	0.2	54	-	2.3
206	0.94	0.14	1.3	0.22	211	189	2.9
220	1.4	0.15	1.8	0.25	188	169	5.9
234	1.6	0.15	2.1	0.35	253	215	8.2
249	1.05	0.06	1.2	0.09	235	225	4.2
262	1.14	0.05	1.36	0.17	226	226	7
276	1	0.05	1.23	0.18	96	22	0
288	0.8	0.01	1.04	0.24	64	64	6.2
315	1.2	0.09	1.44	0.13	47	44	16.3
325	1.21	0.15	1.66	0.3	69	19	32
339	1.22	0.07	1.29	0.01	30	24	17
350	0.91	0.03	1.06	0.12	30	26	12
372	0.8	0.03	1.38	0.55	89	46	28.9
384	1.06	0.01	1.43	0.37	37	29	28

* reportable limit is 10 µg/l

MINE LICK CREEK FIELD DATA

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P* (ug/l)	Flow (cfs)
75	0.82	0.05	2.1	1.3	127	97	26.9
91	0.39	0.23	0.92	0.3	182	124	47.6
104	0.57	0.1	0.86	0.19	94	1	16.3
119	0.25	0.29	0.67	0.06	14	7	8
132	0.56	0.08	0.87	0.23	258	205	4.6
147	0.8	0.08	1.1	0.22	272.6	206	2.5
159	0.49	0.1	0.84	0.25	270.9	220.2	2.8
178	0.16	0.11	0.58	0.31	197	-	1.4
192	0.06	0.32	0.39	0.01	149	-	1.9
206	0.33	0.1	0.85	0.42	180	150	2
220	0.51	0.12	0.88	0.25	205	170	2
234	0.42	0.04	1	0.54	353	281	1.5
249	0.25	0.06	0.52	0.21	226	215	1
262	0.56	0.05	0.83	0.22	277	270	1.9
276	0.53	0.02	0.88	0.33	327	31	2.4
288	0.71	0.01	1.09	0.38	354	354	5.2
315	0.98	0.07	1.17	0.12	150	138	6.3
325	1.28	0.09	1.57	0.2	100	45	31.3
339	1.07	0.08	1.17	0.02	104	97	7.9
350	0.83	0.02	0.86	0.01	176	172	4.5
6	0.53	0.06	1.04	0.45	85	45	69.4
18	0.83	0.01	1.19	0.36	54	39	71

* reportable limit is 10 μg/l

GREAT FALLS FIELD DATA

Julian Day	NO3 (mg/l)	NH3 (mg/l)	TOT-N (mg/l)	ORG-N (mg/l)	TOT-P (ug/l)	O-P* (ug/l)	Flow (cfs)
75	0.55	0.05	1.2	0.65	24	10	21691
91	0.31	0.34	0.65	0.05	20	10	34310
104	0.33	0.15	0.92	0.44	31	10	51260
119	0.3	0.31	0.67	0.06	12	10	34350
132	0.41	0.09	0.6	0.1	25	10	7157
147	0.43	0.11	0.75	0.21	17.7	17	3036
159	0.37	0.08	0.65	0.2	32.4	15.5	1079
178	0.33	0.08	0.57	0.16	29	-	700
192	0.21	1.5	1.7	0.01	23	-	2321
206	0.38	0.08	0.65	0.34	42	25	3060
220	0.45	0.09	0.64	0.1	32	32	5155
234	0.41	0.09	0.84	0.34	40	35	3563
249	0.08	0.16	0.42	0.24	18	10	8247
262	0.42	0.1	0.62	0.1	22	16	1489
276	0.24	0.06	0.6	0.3	147	10	1411
288	0.25	0.01	0.52	0.27	194	124	913
315	0.22	0.07	0.62	0.33	10	10	19943
325	0.56	0.1	0.76	0.1	33	13	64410
339	0.56	0.13	0.75	0.06	29	11	10352
350	0.87	0.03	0.96	0.06	26	24	91094
372	0.61	0.06	0.94	0.27	34	24	202650
394	0.61	0.05	0.89	0.23	33	26	23410

* reportable limit is 10 μg/l

APPENDIX IV

PRECIPITATION DATA
(From Global Geochemistry)

Julian Day	Rain (in)	PO4 (mg/l)	NO3 (mg/l)	NH4 (mg/l)
364-5	0.65	0.016	2.658	0.246
5-12	0.25	0.017	2.122	0.035
12-19	2.41	0.027	0.503	0.085
19-26	1.04	-	2.458	0.325
26-33	0.64	-	0.45	0.08
33-47	0.34	0.049	0.925	0.161
47-60	0.5	0.048	1.389	0.262
60-67	1.22	0.024	0.579	0.211
67-74	1.27	0.017	1.156	0.318
74-88	0.13	-	6.214	0.659
88-102	1.8	0.022	1.63	0.249
102-123	1.32	0.053	1.266	0.495
123-137	0.58	0.036	3.113	0.711
137-179	0.31	-	1.123	0.226
179-186	0.3	-	15.72	3.025
186-193	0.98	0.029	1.118	0.145
193-200	1.96	-	0.6	0.09
200-207	0.37	-	1.832	0.096
207-214	1.04	0.043	1.72	0.406
214-242	1.55	0.031	1.354	0.243
242-255	0.6	0.035	1.086	0.16
255-263	1.49	0.044	0.407	-
263-270	1.72	0.05	0.812	0.13
270-305	0.5	0.056	0.585	0.112
305-312	2.08	-	0.842	0.143
312-319	0.4	-	1.422	0.221
319-324	3.85	-	0.451	0.075

SAS Programs

```
DATA CHR;
       INFILE SAS30;
       INPUT YEAR YYMMDD6. TEMP 11-17 .1 DO 21-26 .1 COND 31-35 .3 PH 41-44 .1 ORP 47-50 TURB 56-61 .1
            NO3 62-67 .2 NH3 71-77 .2 TOTN 81-86 .2 ORGN 91-95 .2 TOTP 98-102 .1 OP 107-111 .1
            FLOW 119-125 .1;
            RETAIN;
              IF TEMP = 0.0 THEN TEMP = .;
              IF DO = 0.0 THEN DO = .;
              IF COND = 0.0 THEN COND = .;
              IF PH = 0.0 THEN PH = .;
              IF ORP = 0.0 THEN ORP = .;
              IF TURB = 0.0 THEN TURB = .;
              IF NO3 = 0.0 THEN NO3 = .;
              IF NH3 = 0.0 THEN NH3 = .;
              IF TOTN = 0.0 THEN TOTN = .;
              IF ORGN = 0.0 THEN ORGN = .;
              IF TOTP = 0.0 THEN TOTP = .;
              IF OP = 0.0 THEN OP = .;
              IF FLOW = 0.0 THEN FLOW = .;
DATA STAT;
       SET CHR ;
       PROC MEANS N NMISS MEAN STD MIN MAX VAR MAXDEC = 3;
              VAR TEMP DO COND PH ORP TURB NO3 NH3 TOTN
                     ORGN TOTP OP FLOW;
              TITLE1 'FIELD DATA';
              TITLE2 'GREAT FALLS  CANEY FORK RM 90';
PROC UNIVARIATE;
       VAR TEMP DO COND PH ORP TURB NO3 NH3
                     TOTN ORGN TOTP OP FLOW;
       TITLE1 'FIELD DATA';
       TITLE2 'CANEY FORK RM 90';
PROC CORR NOPROB RANK NOSIMPLE ;
       VAR TEMP DO COND PH ORP TURB NO3 NH3
                     TOTN ORGN TOTP OP FLOW;
       TITLE1 'FIELD DATA';
       TITLE2 'CANEY FORK RM 90';
DATA NEW;
       SET STAT;
       RETAIN;
       IF TEMP > 0.0 THEN TEMP = LOG10(TEMP);
       IF DO > 0.0 THEN DO = LOG10(DO);
       IF COND > 0.0 THEN COND = LOG10(COND);
       IF PH > 0.0 THEN PH = LOG10(PH);
       IF ORP > 0.0 THEN ORP = LOG10(ORP);
       IF TURB > 0.0 THEN TURB = LOG10(TURB);
       IF NO3 > 0.0 THEN NO3 = LOG10(NO3);
       IF NH3 > 0.0 THEN NH3 = LOG10(NH3);
       IF TOTN > 0.0 THEN TOTN = LOG10(TOTN);
       IF ORGN > 0.0 THEN ORGN = LOG10(ORGN);
       IF TOTP > 0.0 THEN TOTP = LOG10(TOTP);
       IF OP > 0.0 THEN OP = LOG10(OP);
       IF FLOW > 0.0 THEN FLOW = LOG10(FLOW);
```

```
DATA NEWA;
        SET NEW;
        PROC CORR NOPROB RANK NOSIMPLE ;
        VAR TEMP DO COND PH ORP TURB NO3 NH3 TOTN ORGN TOTP
                OP FLOW;
DATA NEWB;
        SET NEWA;
        TITLE1 'FIELD DATA';
        TITLE2 'GREAT FALLS CANEY FORK RM 90';
        TITLE3 'LOGRITHMIC REGRESSION ANALYSIS';
PROC REG;
        MODEL TEMP = FLOW;
PROC REG;
        MODEL DO = FLOW;
PROC REG;
        MODEL COND = FLOW;
PROC REG;
        MODEL PH = FLOW;
PROC REG;
        MODEL ORP = FLOW;
PROC REG;
        MODEL TURB = FLOW;
PROC REG;
        MODEL NO3 = FLOW;
PROC REG;
        MODEL NH3 = FLOW;
PROC REG;
        MODEL TOTN = FLOW;
PROC REG;
        MODEL ORGN = FLOW;
PROC REG;
        MODEL TOTP = FLOW;
PROC REG;
        MODEL OP = FLOW;
```

Phytoplankton Counts at Falling Water River and Mine Lick Creek Embayments

6/15/8[illegible] Depth = 0 m

Falling Water R.

GENUS	CELLS/ML	ALGAL CLASS
Achnanthes	1600	Bacillariophyceae
Synedra	500	Bacillariophyceae
Ankistrodesmus	160	Chlorophyceae
Glenodinium	100	Dinophyceae
Trachelomonas	100	Euglenophyceae
Tetraedron	40	
TOTAL	2500	

Depth = 2 m

GENUS	CELLS/ML	ALGAL CLASS
Achnanthes	3500	Bacillariophyceae
Synedra	460	Bacillariophyceae
Glenodinium	150	Dinophyceae
Pandorina	80	Chlorophyceae
Ankistrodesmus	50	Chlorophyceae
Cosmarium	20	
Cymbella	20	
Tetraedron	20	
TOTAL	4300	

Depth = 3 m

GENUS	CELLS/ML	ALGAL CLASS
Achnanthes	2900	Bacillariophyceae
Pandorina	400	Chlorophyceae
Glenodinium	290	Dinophyceae
Ceratium	170	Dinophyceae
Scenedesmus	60	Chlorophyceae
Synedra	60	
Ankistrodesmus	60	
Cymbella	20	
Tetraedron	20	
Trachelomonas	20	
TOTAL	4000	

Depth = 4 m

GENUS	CELLS/ML	ALGAL CLASS
Achnanthes	600	Bacillariophyceae
Pandorina	500	Chlorophyceae
Ankistrodesmus	180	Chlorophyceae
Synedra	140	Bacillariophyceae
Glenodinium	100	Dinophyceae
Ceratium	100	
Tetraedron	40	
Trachelomonas	40	
TOTAL	1700	

Depth = 5 m

N.A.

6/15/99 Depth = 0 m

Mine Lick Creek	GENUS	CELLS/ML	ALGAL CLASS
	Glenodinium	280	Dinophyceae
	Synedra	120	Bacillariophyceae
	Ceratium	80	Dinophyceae
	Trachelomonas	50	Euglenophyceae
	Tetraedron	30	Chlorophyceae
	Gymnodinium	20	
	Micractinium	15	
	Mallomonas	10	
	Chlamydomonas	10	
	Achnanthes	10	
	Nitzschia	5	
	Golenkinia	5	
	Fragilaria	5	
	Cosmarium	5	
	Phacotus	5	
	TOTAL	650	
Depth = 2 m			
	Synedra	200	Bacillariophyceae
	Glenodinium	140	Dinophyceae
	Ceratium	90	Dinophyceae
	Achnanthes	60	Bacillariophyceae
	Trachelomonas	50	Euglenophyceae
	Dinobryon	50	
	Tetraedron	40	
	Micractinium	20	
	Scenedesmus	20	
	Gymnodinium	10	
	Mallomonas	10	
	Pandorina	5	
	Treubaria	5	
	TOTAL	700	
Depth = 3 m			
	Synedra	230	Bacillariophyceae
	Glenodinium	230	Dinophyceae
	Ceratium	150	Dinophyceae
	Golenkinia	120	Chlorophyceae
	Tetraedron	70	Chlorophyceae
	Achnanthes	60	
	Trachelomonas	30	
	Dictyosphaerium	20	
	Gymnodinium	20	
	Phacus	20	
	Scenedesmus	10	
	Phacotus	10	
	TOTAL	970	

Depth = 4 m

Synedra	265	Bacillariophyceae
Ceratium	150	Dinophyceae
Glenodinium	120	Dinophyceae
Trachelomonas	75	Euglenophyceae
Melosira	50	Bacillariophyceae
Achnanthes	30	
Golenkinia	20	
Tetraedron	15	
Pandorina	15	
Gymnodinium	15	
Scenedesmus	10	
Cryptomonas	5	
Dinobryon	5	
Coelastrum	5	
TOTAL	780	

Depth = 5 m

Synedra	170	Bacillariophyceae
Ceratium	90	Dinophyceae
Glenodinium	70	Dinophyceae
Melosira	55	Bacillariophyceae
Achnanthes	30	Bacillariophyceae
Trachelomonas	20	
Golenkinia	20	
Tetraedron	10	
Pandorina	10	
Gymnodinium	10	
Scenedesmus	10	
Dictyosphaerium	5	
TOTAL	500	

7/8/88 Depth = 0 m

Falling Water R.

GENUS	CELLS/ML	ALGAL CLASS
Anabaenopsis	4700	Cyanobacteria
Achnanthes	1600	Bacillariophyceae
Synedra	900	Bacillariophyceae
Tetraedron	300	Chlorophyceae
Oscillatoria	300	Cyanobacteria
Pandorina	100	
Trachelomonas	100	
TOTAL	8000	

Depth = 2 m

Anabaenopsis	4600	Cyanobacteria
Achnanthes	1800	Bacillariophyceae
Synedra	1400	Bacillariophyceae
Scenedesmus	320	Chlorophyceae
Tetraedron	240	Chlorophyceae
Pandorina	160	
Glenodinium	80	
TOTAL	8600	

Depth = 3 m

Pandorina	3500	Chlorophyceae
Synedra	1000	Bacillariophyceae
Tetraedron	300	Chlorophyceae
Ankistrodesmus	70	Chlorophyceae
Achnanthes	70	Bacillariophyceae
Anabaenopsis	60	
TOTAL	5000	

Depth = 4 m

Synedra	1900	Bacillariophyceae
Pandorina	1400	Chlorophyceae
Anabaenopsis	1400	Cyanobacteria
Achnanthes	1400	Bacillariophyceae
Tetraedron	450	Chlorophyceae
Coelastrum	450	
TOTAL	7000	

Depth = 5 m

Achnanthes	1500	Bacillariophyceae
Synedra	1000	Bacillariophyceae
Ankistrodesmus	390	Chlorophyceae
Pandorina	220	Chlorophyceae
Tetraedron	220	Chlorophyceae
Anabaenopsis	170	
TOTAL	3500	

	GENUS	CELLS/ML	ALGAL CLASS
[illegible] Depth = 1 m			
Mine Lick Creek			
	Synedra	3400	Bacillariophyceae
	Ankistrodesmus	3000	Chlorophyceae
	Tetraedron	460	Chlorophyceae
	Trachelomonas	170	Euglenophyceae
	Glenodinium	85	Dinophyceae
	Cosmarium	85	
	TOTAL	7200	
Depth = 2 m			
	Ankistrodesmus	3500	Chlorophyceae
	Synedra	2400	Bacillariophyceae
	Trachelomonas	170	Euglenophyceae
	Tetraedron	110	Chlorophyceae
	Achnanthes	100	Bacillariophyceae
	Gymnodinium	60	
	Anabaena	60	
	TOTAL	6400	
Depth = 3 m			
	Ankistrodesmus	4300	Chlorophyceae
	Synedra	1900	Bacillariophyceae
	Tetraedron	200	Chlorophyceae
	TOTAL	6400	
Depth = 4 m			
	Synedra	3800	Bacillariophyceae
	Ankistrodesmus	3500	Chlorophyceae
	Tetraedron	300	Chlorophyceae
	Glenodinium	200	Dinophyceae
	Achnanthes	200	Bacillariophyceae
	TOTAL	8000	
Depth = 5 m			
	Synedra	1600	Bacillariophyceae
	Ankistrodesmus	3100	Chlorophyceae
	Tetraedron	70	Chlorophyceae
	Achnanthes	130	Bacillariophyceae
	Anabaenopsis	130	Cyanobacteria
	Anabaena	70	
	TOTAL	5100	

8/10/89 Depth = 0 m

Falling Water R.

GENUS	CELLS/ML	ALGAL CLASS
Achnanthes	1100	Bacillariophyceae
Pandorina	1000	Chlorophyceae
Synedra	400	Bacillariophyceae
Glenodinium	100	Glenodinium
Scenedesmus	100	Chlorophyceae
Trachelomonas	50	
Gonium	50	
Gymnodinium	50	
Ceratium	50	
TOTAL	2900	

Depth = 2 m

GENUS	CELLS/ML	ALGAL CLASS
Pandorina	1400	Chlorophyceae
Achnanthes	700	Bacillariophyceae
Synedra	250	Bacillariophyceae
Anabaenopsis	60	Cyanobacteria
Glenodinium	30	Dinophyceae
Euglena	30	
Ceratium	30	
TOTAL	2500	

Depth = 3 m

GENUS	CELLS/ML	ALGAL CLASS
Pandorina	1700	Chlorophyceae
Achnanthes	200	Bacillariophyceae
Ceratium	80	Dinophyceae
Platydorina	60	Chlorophyceae
Synedra	20	Bacillariophyceae
Euglena	20	
Phacotus	20	
TOTAL	2100	

Depth = 4 m

GENUS	CELLS/ML	ALGAL CLASS
Pandorina	1800	Chlorophyceae
Achnanthes	470	Bacillariophyceae
Synedra	95	Bacillariophyceae
Phacus	25	Euglenophyceae
Ceratium	10	Dinophyceae
TOTAL	2400	

Depth = 5 m

GENUS	CELLS/ML	ALGAL CLASS
Pandorina	2500	Chlorophyceae
Achnanthes	850	Bacillariophyceae
Synedra	100	Bacillariophyceae
Phacus	25	Euglenophyceae
Euglena	25	Euglenophyceae
TOTAL	3500	

8/10/89 Depth = 0 m			
Mine Lick Creek	GENUS	CELLS/ML	ALGAL CLASS
	Pandorina	310	Chlorophyceae
	Synedra	20	Bacillariophyceae
	Ceratium	16	Dinophyceae
	Anabaenopsis	9	Cyanobacteria
	Euglena	5	Euglenophyceae
	TOTAL	360	
Depth = 2 m			
	Pandorina	250	Chlorophyceae
	Synedra	170	Bacillariophyceae
	Glenodinium	24	Dinophyceae
	Tetraedron	8	Chlorophyceae
	Ceratium	8	Dinophyceae
		460	
Depth = 3 m			
	Synedra	230	Bacillariophyceae
	Pandorina	30	Chlorophyceae
	Ceratium	30	Dinophyceae
	Chlamydomonas	30	Chlorophyceae
	Achnanthes	15	Bacillariophyceae
	Phacus	15	
	Polycystis	10	
	TOTAL	130	
Depth = 4 m			
	Synedra	390	Bacillariophyceae
	Phacus	5	Euglenophyceae
	Cosmarium	5	Chlorophyceae
	TOTAL	400	
Depth = 5 m			
	Synedra	230	Bacillariophyceae
	Anabaenopsis	40	Cyanobacteria
	Achnanthes	8	Bacillariophyceae
	Euglena	5	Euglenophyceae
	Tetraedron	5	Chlorophyceae
	Trachelomonas	3	
	Ceratium	3	
	Chlamydomonas	3	
	Cosmarium	3	
	TOTAL	300	

9/7/93 Depth = 0 m

Falling Water R.

	GENUS	CELLS/ML	ALGAL CLASS
	Euglena	100	Euglenophyceae
	Synedra	50	Bacillariophyceae
	Achnanthes	50	Bacillariophyceae
	Ceratium	50	Dinophyceae
	TOTAL	250	
Depth = 2 m			
	Achnanthes	50	Bacillariophyceae
	Anabaena	40	Cyanobacteria
	Melosira	40	Bacillariophyceae
	Gloeocystis	20	Chlorophyceae
	Cyclotella	20	Bacillariophyceae
	Schroederia	10	
	Chroococcus	10	
	Mallomonas	10	
	Pandorina	10	
	Chlamydomonas	10	
	Mougeotia	10	
	Platydorina	10	
	TOTAL	240	
Depth = 3 m			
	Ceratium	180	Dinophyceae
	Synedra	20	Bacillariophyceae
	TOTAL	200	
Depth = 4 m			
	Ceratium	100	Dinophyceae
	Achnanthes	50	Bacillariophyceae
	Melosira	20	Bacillariophyceae
	Mougeotia	10	Chlorophyceae
	Micractinium	10	Chlorophyceae
	Chlamydomonas	10	
	Synedra	10	
	Chroococcus	10	
	Anabaenopsis	10	
	Anabaena	5	
	Schroederia	5	
	Trachelomonas	5	
	Dictyosphaerium	5	
	TOTAL	250	

Depth = 5 m

Melosira	60	Bacillariophyceae
Micractinium	50	Chlorophyceae
Ceratium	15	Dinophyceae
Gomphosphaeria	15	Cyanobacteria
Chroococcus	15	Cyanobacteria
Synedra	15	
Achnanthes	15	
Coelastrum	15	
TOTAL	200	

9/7/83 Depth = 0 m

Mine Lick Creek

GENUS	CELLS/ML	ALGAL CLASS
Achnanthes	60	Bacillariophyceae
Chlamydomonas	25	Chlorophyceae
Cryptomonas	25	Cryptophyceae
Euglena	25	Euglenophyceae
Golenkinia	25	Chlorophyceae
TOTAL	160	

Depth = 2 m

Cryptomonas	90	Cryptophyceae
Chlamydomonas	40	Chlorophyceae
Euglena	40	Euglenophyceae
Golenkinia	40	Chlorophyceae
Achnanthes	40	Bacillariophyceae
TOTAL	250	

Depth = 3 m

Achnanthes	200	Bacillariophyceae
Synedra	130	Bacillariophyceae
Euglena	70	Euglenophyceae
TOTAL	400	

Depth = 4 m

Achnanthes	220	Bacillariophyceae
Synedra	20	Bacillariophyceae
Tetraedron	10	Chlorophyceae
TOTAL	250	

Depth = 5 m

Achnanthes	210	Bacillariophyceae
Synedra	20	Bacillariophyceae
Staurastrum	20	Chlorophyceae
TOTAL	250	

[illegible] Depth = [illegible]

Falling Water R.

GENUS	CELLS/ML	ALGAL CLASS
Melosira	100	Bacillariophyceae
Ceratium	60	Dinophyceae
Scenedesmus	20	Chlorophyceae
Gymnodinium	10	Dinophyceae
Anabaenopsis	10	Cyanobacteria
TOTAL	200	

Depth = 2 m

GENUS	CELLS/ML	ALGAL CLASS
Melosira	85	Bacillariophyceae
Synedra	50	Bacillariophyceae
Cyclotella	20	Bacillariophyceae
Glenodinium	15	Dinophyceae
Cryptomonas	15	Cryptophyceae
Ceratium	10	
Scenedesmus	10	
Dictyosphaerium	5	
Nitzschia	5	
Tetraedron	5	
TOTAL	220	

Depth = 3 m

GENUS	CELLS/ML	ALGAL CLASS
Ceratium	100	Dinophyceae
Melosira	70	Bacillariophyceae
Synedra	70	Bacillariophyceae
Cryptomonas	60	Cryptophyceae
Scenedesmus	40	Chlorophyceae
Cyclotella	30	
Euglena	15	
Glenodinium	5	
Dictyosphaerium	5	
Navicula	5	
TOTAL	400	

Depth = 4 m

GENUS	CELLS/ML	ALGAL CLASS
Synedra	100	Bacillariophyceae
Ceratium	30	Dinophyceae
Melosira	15	Bacillariophyceae
Euglena	15	Euglenophyceae
Tetradinium	10	Xanothophyceae
Cryptomonas	5	
Ankistrodesmus	5	
Tetraedron	5	
Phacus	5	
Scenedesmus	5	
Dictyosphaerium	5	
TOTAL	200	

Depth = 5 m

Synedra	60	Bacillariophyceae
Cyclotella	30	Bacillariophyceae
Cryptomonas	20	Cryptophyceae
Ceratium	20	Dinophyceae
Glenodinium	15	Dinophyceae
Euglena	10	
Tetraedron	5	
Pandorina	5	
Dictyosphaerium	5	
TOTAL	170	

10/13/89 Depth = 0 m

Mine Lick Creek	GENUS	CELLS/ML	ALGAL CLASS
	Melosira	100	Bacillariophyceae
	Synedra	30	Bacillariophyceae
	TOTAL	130	
Depth = 2 m			
	Melosira	110	Bacillariophyceae
	Synedra	50	Bacillariophyceae
	Pandorina	10	Chlorophyceae
	Surirella	10	Bacillariophyceae
	TOTAL	180	
Depth 3 m			
	Melosira	80	Bacillariophyceae
	Mougeotia	45	Chlorophyceae
	Synedra	20	Bacillariophyceae
	Cryptomonas	5	Cryptophyceae
	Glenodinium	5	Dinophyceae
	Pandorina	5	
	TOTAL	160	
Depth = 4 m			
	Melosira	80	Bacillariophyceae
	Mougeotia	20	Chlorohyceae
	Synedra	20	Bacillariophyceae
			Bacillariophyceae
	TOTAL	120	
Depth = 5 m			
	Melosira	130	Bacillariophyceae
	Synedra	50	Bacillariophyceae
	TOTAL	180	

APPENDIX VIII

Quality Control Data for the Center Hill Lake Project

$NO_3 + NO_2$

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards EPA 486-1(2X) True	Certified Standards EPA 486-1(2X) Measured
1750-6	0.97	102.5		
1750-7	1.22	112.6		
1750-9	0.0	112.6		
(13)*				
1751-1	0.5		1.0	1.07
1751-4	1.03	107.9		
1751-6	1.57	84.6		
1751-7	0.33	105.7		
(12)*				
1766-1	0.76		1.0	1.07
1766-5	0.96	114.2		
1766-9	0.57	107.9		
(13)*				
1780-7	No Data	No Data	1.0	1.28
(13)*				
1798-1	0.68	100.5	1.0	1.06
1798-5	0.34	108.9		
(13)*				
1820-1	0.0	100.5	1.0	1.07
1820-5	1.71	109.9		
1820-8	1.33	110.6		
(13)*				
1832-1	0.60	98.5	1.0	1.10
1832-5	0.93	108.5		
(10)*				
1845-1	1.26	92.5	1.0	1.02
1845-6	1.30	103.1		
(11)*				
1847-1	0.0	114.2	1.0	1.10
1847-7	0.0	126.6		
1847-8	.93			
1847-20	.22	132.1		
(24)*				

$NO_3 + NO_2$

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards EPA 486-1(2X) True	Certified Standards EPA 486-1(2X) Measured
1858-1	0.64	104.5	1.0	1.08
1858-6	0.19	112.6		
(13)*				
1872-4	1.54	113.2	1.0	1.06
1872-8		116.8		
(13)*				
1873-8	0.75	88.2	1.0	1.06
1873-19	2.76	120.6		
(24)*				
1903-1	2.3	109.4	1.0	1.04
1903-8	0.8	101.0		
(13)*				
1920-1	3.0		1.0	1.04
1920-8	0.85			
(13)*				
1924-1	0.0	93.9	1.0	1.03
1924-10	0.0	100.5		
1924-20	0.0	110.4		
(24)*				
1937-1	1.59		1.0	1.10
1937-8	0.0	69.8		
(13)*				
1951-1	4.21	95.5	1.0	.98
1951-8	1.25	107.2		
(13)*				
1952-1	27.62	107.9	1.0	.98
1952-11	7.78	115.4		
1952-21	6.03	113.0		
(24)*				
1964-1	2.41	110.6	1.0	1.10
1964-8	.24	113.1		
1964-10	.38	107.3		
(13)*				
1983-1	1.01	99.5	1.0	1.08
1983-8	0.0	110.8		
(13)*				

$NO_3 + NO_2$

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards EPA 486-1(2X) True	Certified Standards EPA 486-1(2X) Measured
1995-1	0.0	106.1	1.0	1.07
1995-11	0.0	104.1		
1995-21	0.0	105.1		
(24)*				
1997-1	1.98	105.5	1.0	1.06
1997-8	1.22	102.7		
(13)*				
2021-1	11.38	97.5	1.0	.98
2021-8	34.48	94.9		
(13)*				
2031-1	10.55	101.9	1.0	1.03
(13)*				
2032-1	7.79	96.5	1.0	1.04
2032-8	2.99	94.5		
2032-16	2.51	90.5		
2032-17	0.0	92.5		
(17)*				
2046-1	8.65	91.7	1.0	.98
2046-8	10.53	90.5		
(13)*				
2068-1	3.51	91.5	1.0	.96
2068-8	1.04	97.5		
(13)*				
2075-1	18.03	99.1	1.0	.997
1075-8	2.30	94.5		
(13)*				
2085-1	7.79	87.4	2.0	1.82
2085-8	0.328	94.5		
(13)*				
	$n = 67$	$n = 62$		
	$\bar{x} = 3.10\%$	$\bar{x} = 103.45$		

* Number of samples

Total N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards EPA 486-2(2X) True	Certified Standards EPA 486-2(2X) Measured
1750-3	1.99	No Data	2.5	2.7
1750-6	10.28			
1750-7	1.77			
(13)*				
1751-2	.54	No Data	2.5	2.6
1751-3	5.93			
1751-5	2.55			
1751-7	1.63			
1751-8	1.16			
1751-9	1.09			
(12)*				
1766-1	3.29		2.5	1.6
1766-5	16.10	111.4		
1766-8	7.89	94.0		
1766-12		102.0		
(13)*				
1780-2	8.24	2.96	2.5	1.5
1780-11		107.6		
(13)*				
1798-1	1.0	90.0	2.5	2.4
1798-5	19.87	92.0		
1798-7		95.4		
(13)*				
1820-1	0.0	110.0	2.5	1.2
1820-5	.40	104.4		
1820-8	3.54	86.0		
(13)*				
1832-1	2.19	96.0	2.5	2.4
1832-5	3.53	114.8		
1832-8		99.6		
(10)*				
1845-1	1.18	98.0	2.5	2.4
1845-5	.31	101.6		
1845-8	1.66	97.6		
(11)*				
1847-1	42.48	78.8	2.5	2.3
1847-8	1.11	118.2		
1847-20	1.35	121.0		
(24)*				

Total N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards EPA 486-2(2X) True	Certified Standards EPA 486-2(2X) Measured
1858-1	1.23	128.0	2.5	1.3
1858-6	6.12	99.8		
(13)*				
1872-1	3.02	136.0	2.5	1.3
1872-7		104.4		
(13)*				
1873-1	2.13	98.8	2.5	1.3
1873-8	.92	103.2		
1873-20	6.57	113.6		
(24)*				
1903-9	1.80	96.0	2.5	2.45
(13)*				
1920-1	2.69		2.5	2.42
1920-8		100.0		
(13)*				
1924-1	2.76	108.0	2.5	2.45
1924-11	4.41	109.4		
1924-21	.74	116.2		
(24)*				
1937-2	15.93	99.2	2.5	2.47
1937-9	9.48			
(13)*				
1951-1	1.56	106.9	2.5	2.4
1951-8	1.40	111.8		
(13)*				
1952-1	1.86	112.4	2.5	2.4
1952-11	.85	106.8		
1952-21	6.90	106.8		
(24)*				
1964-1	.99	114.8	2.5	2.5
1964-8	.68	119.6		
(13)*				
1983-1	.82	84.0	2.5	2.32
1983-9	.32	80.2		
(13)*				

Total N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards EPA 486-2(2X) True	Certified Standards EPA 486-2(2X) Measured
1995-1	7.87	100.6	2.5	2.4
1995-12	4.35	102.6		
1995-24	8.35	104.6		
(24)*				
1997-2	5.22	97.8	2.5	2.4
1997-8	5.24	102.8		
(13)*				
2021-1	12.99	94.6	2.5	2.4
2021-8	3.74	88.8		
(13)*				
2031-1	10.79	102.8	2.5	2.10
2031-8	12.12	86.2		
(13)*				
2032-1	12.27	102.0	2.5	2.42
2032-10	0.0	94.0		
2032-11		114.34		
2032-12	0.0			
(17)*				
2046-8	2.27	101.6	No EPA Data	
(13)*				
2068-1	1.50		.50	.507
2068-8	3.32	93.2		
(13)*				
2075-8	1.28	90.6	.50	.53
(13)*				
2085-1	10.24	100.4	.50	.53
2085-8	0.56	98.4		
(13)*				
	$n = 67$	$n = 58$		
	$\bar{x} = 4.77\%$	$\bar{x} = 102.27\%$		

* Number of samples

Total NH_3N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
			EPA 486-1(1X)	
1750-1	2.63		2.0	1.92
1750-6	0.0	98.3		
1750-7	0.0	111.6		
1750-13		103.7		
(13)*				
			No EPA Data	
1751-4	0.0	101.6		
1751-6		105.4		
1751-7		110.6		
(12)*				
			EPA 486-2(2X)	
1766-5	4.78	No Spikes	2.2	1.89
1766-8	9.68			
(13)*				
			EPA 486-1(1X)	
1780-1	8.76	92.5	2.0	1.95
1780-2	7.79			
1780-5	8.12	97.9		
1780-6	2.37			
1780-7	8.49	92.5		
(13)*				
			EPA 486-2(2X)	
1798-1		110.8	2.2	2.5
1798-5	11.0			
1798-7	2.43			
(13)*				
			EPA 486-1(2X)	
1820-1	6.36	92.9	1.0	1.2
1820-8	9.13	93.1		
(13)*				
			EPA 486-1(2X)	
1832-1	9.21	100.9	1.0	1.05
1832-5	1.82	102.1		
1832-[illegible]		99.1		
(10)*				
			EPA 486-1(2X)	
1845-6	20.39	89.4	1.0	1.1
(11)*				

Total NH_3N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Measured
1847-1	48.31	80.6	No EPA Run	
1847-7	9.29	80.2		
1847-20	1.30	98.3		
(24)*				
			EPA 486-1(2X)	
1858-1	28.76	90.1	1.0	1.03
1858-5	9.34	85.4		
(13)*				
			EPA 486-1(2X)	
1872-1	1.60	73.2	1.0	.95
1872-6	2.69	119.4		
(13)*				
			EPA 486-1(2X)	
1873-1	8.17		1.0	.95
1873-12	1.49			
1873-19	2.11	72.8		
(13)*				
			EPA 486-1(2X)	
1903-1	49.0	97.1	1.0	1.05
1903-8	29.16	107.7		
(13)*				
			EPA 486-1(2X)	
1920-1	6.24	99.7	1.0	1.02
1920-8	.62	108.9		
(13)*				
			EPA 486-1(2X)	
1924-11	19.74	107.5	1.0	1.03
1924-21	7.14	115.4		
(24)*				
			EPA 486-1(2X)	
1937-8	10.67	No Data	1.0	.99
(13)*				
			EPA 486-1(2X)	
1951-9	3.03	108.1	1.0	1.1
1951-10	1.26	97.3		
(13)*				

Total NH_3N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
			EPA 486-1(2X)	
1952-1		106.3	1.0	1.1
1952-11	0.0	99.1		
1952-21	5.37	105.5		
(24)*				
			EPA 486-1(2X)	
1964-8	14.53	97.7	1.0	1.02
(13)*				
			EPA 486-1(2X)	
1983-1	77.99	95.3	1.0	1.1
1983-8	33.66	98.0		
1983-9	25.45	96.7		
1983-13	2.61	99.1		
(13)*				
			EPA 486-1(2X)	
1995-1		82.4	1.0	1.08
1995-11	8.82	98.9		
1995-24	2.82	105.3		
(24)*				
			EPA 486-1(2X)	
1997-1	27.64	97.9	1.0	1.08
1997-8	12.85	88.4		
(13)*				
			EPA 486-1(2X)	
2021-1	11.51	107.9	1.0	.97
2021-8	90.30	87.0		
(13)*				
			EPA 486-1(2X)	
2031-1	11.81	153.0	1.0	.98
(13)*				
			EPA 486-1(2X)	
2032-1	12.08	82.4	1.0	.98
2032-9	2.31			
2032-11	0.0	160.8		
2032-16	3.99	85.2		
2032-17	2.93			
(17)*				

Total NH_3N

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
			EPA 486-1(2X)	
2046-1	12.05	90.1	1.0	.96
2046-8	16.92	83.4		
2046-9	5.33			
2046-10	.77			
2046-12	7.56			
2046-13	4.85	111.4		
(13)*				
			EPA 486-1(2X)	
2068-8	6.37	90.1	1.0	.99
(13)*				
			EPA 486-1(1X)	
2075-8	81.35	97.1	2.0	2.1
(13)*				
			EPA 486-1(1X)	
2085-8		107.5	2.0	2.1
(13)*				
	n = 64 $\bar{x}$ = 13.04%	n = 57 $\bar{x}$ = 99.57%		

* Number of Samples

Total Phosphorus

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
1750 (13)*	12.55	96.2	125.0	155.2
1751 (12)*	0.0	95.0 110.8	125.0	155.2
1766 (13)*	3.02	88.0 32.3	150.0	152.1
1780 (13)*	6.83	96.67	150.0	156.0
1798 (13)*	0.50	120.1	150.0	1[illegible].3
1820 (13)*	8.0	90.7 96.2	150.0	154.6
1832 (10)*	2.8	93.67	150.0	155.3
1845 (11)*	2.06	95.5 107.0	750.0	369.5
1847 (24)*	27.16	49.3	150.0	157.9
1859 (13)*	7.0 0.0		-	-
1872 (13)*	3.19	94.7	-	-
1873 (24)*	5.87	102.4	-	-
1903 (13)*	15.64 7.4	84.7 95.3	250.0	251.4

Total Phosphorus

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
1920 (13)*	2.9	106.0	150.0	148.1
1924 (24)*	1.49	114.0	50.0	51.2
1937 (13)*	3.12	93.7	50.0	54.9
1951 (13)*	0.0	92.0	50.0	43.4
1952 (24)*	0.0 10.8	101.0 105.0	50.0	43.4
1964 (13)*	33.0	142.66	250.0	248.8
1983 (13)*	1.14	97.33	75.0**	50.6**
1995 (24)*	1.94	101.0	75.0	63.28
1997 (13)*	0.0	111.0	75.0	60.2
2021 (13)*	0.0	96.45	75.0	67.94
2031 (13)*	6.0	103.0	150.0	86.0
2032 (17)*	6.0	103.0	150.0	86.0
2046 (13)*	4.4	103.0	50.0	47.6
2068 (13)*	4.0	100.0	50.0	52.0
2075 (13)*	0.0	106.0	50.0	42.3

Total Phosphorus

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
2085 (13)*	0.0	106.0	50.0	49.5
	n = 32 x = 5.53%	n = 34 x = 97.93%		

* Number of samples

** Reference out of tolerance

Orthophosphorus

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
1750 (13)*	9.0	98.7	125.0	125.1
1751 (12)*	27.5	94.0 103.0	125.0	125.1
1766 (13)*	5.4	107.5	50.0	51.7
1780 (13)*	19.4	100.0 92.5	50.0	50.9
1798 (13)*		102.9	50.0	55.7
1820 (13)*	8.0	92.7 95.3	150.0	152.2
1832 (10)*			50.0	44.4
1845 (11)*			50.0	48.0
1847 (24)*	25.0	58.3 67.0	50.0	48.4
1858 (13)*			-	-
1872 (13)*			-	-
1873 (24)*			50.0	46.4
1903 (13)*	6.25	107.0	-	-

Orthophosphorus

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Measured
1920 (13)*	3.54	101.0	250.0	254.8
1924 (24)*	8.41 0.0	92.33 93.67	250.0	248.9
1937 (13)*	3.83	99.2	50.0	51.4
1951 (13)*	8.33	98.33	50.0	48.3
1952 (24)*	0.0 3.51	134.0 100.0	50.0	48.3
1964 (13)*	22.5	98.33	50.0	51.8
1983 (13)*	2.01	81.83	250.0	241.8
1995 (24)*	2.57 0.0	102.5 99.0	50.0	51.5
1997 (13)*	0.0	111.0	-	-
2021 (13)*	3.05	93.0	50.0	35.7
2031 (13)*	5.0	98.0	50.0	41.2
2032 (17)*	0.0	111.0	50.0	41.2
2046 (13)*	7.0	100.0	50.0	42.0
2068 (13)*	0.0	117.0	50.0	49.1
2075 (13)*	0.0	97.0	50.0	45.6

Orthophosphorus

Log No.	Duplicates (Ave % Rel Error)	Spikes (Ave % Recovery)	Certified Standards True	Certified Standards Measured
2095 (13)*	0.0	103.0	50.0	49.0
	$n = 26$ $\bar{x} = 6.55\%$	$n = 31$ $\bar{x} = 98.36\%$		

* Number of samples

Chlorophyll a

Date	Sample	Triplicate Mean $\bar{x}$ (μg/l)	Triplicate Standard Deviation (μg/l)
8/10/88	MLC-3	2.2	.71
	MLC-4	1.4	.35
	MLC-5	3.4	.64
	MLC-6	1.6	1.28
	STA2-2m	1.6	.31
	STA2-10m	1.6	.42
	STA2-22m	.1	.63
	STA3-2m	1.1	1.27
	STA3-10m	3.6	.00
	STA3-22m	- .2	.35
	STA4-2m	3.2	.60
	STA4-10m	2.6	.21
	STA4-22m	.3	.35
	STA5-2m	3.9	1.66
	STA5-10m	3.4	2.12
	STA5-22m	1.2	.99
	FWR-1	3.6	4.31
	FWR-2	6.2	1.75
	FWR-3	3.8	.85
	FWR-4	2.6	.07
	FWR-5	5.6	1.55
	FWR-6	2.7	2.25
9/7/88	FWR-1	2.5	11.60
	FWR-2	5.2	2.94
	FWR-3	7.0	2.47
	FWR-4	10.7	1.48
	FWR-5	12.6	2.05
	FWR-6	5.6	2.54
	MLC-1	5.1	2.85
	MLC-2	4.3	3.07
	MLC-3	3.3	.85

Date	Sample	Triplicate Mean $\bar{x}$ (µg/l)	Triplicate Standard Deviation (µg/l)
	MLC-4	1.1	.71
	MLC-5	6.6	1.55
	MLC-6	1.2	.85
	STA2-2m	3.5	1.86
	STA2-10m	4.0	1.13
	STA2-30m	1.6	1.55
	STA3-2m	11.0	7.09
	STA3-10m	2.2	.78
	STA3-30m	.8	.42
	STA4-2m	7.8	1.62
	STA4-10m	3.4	16.05
	STA4-30m	0.0	0.00
	STA5-2m	3.8	2.36
	STA5-10m	9.9	3.32
	STA5-30m	1.8	1.84

Reference Material:

	Found	T.V.	
EPA 885-2	1.90	1.99	mg/l
EPA 885-1	6.44	7.94	mg/l