

NUTRIENT DYNAMICS IN THE LAKE MANASSAS (VIRGINIA) WATERSHED

by

Susan Marie Laufer

Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University in
partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in

ENVIRONMENTAL SCIENCES AND ENGINEERING

APPROVED:

~~Dr. Barron L. Weand, Chairman~~

~~Dr. Robert C. Hoehn~~

~~Dr. Clifford W. Randall~~

~~Dr. Andrew Evans~~

November, 1986
Blacksburg, Virginia

NUTRIENT DYNAMICS
IN THE LAKE MANASSAS (VIRGINIA) WATERSHED

by

Susan Marie Laufer

Committee Chairman: Barron L. Weand

(ABSTRACT)

Lake Manassas is a 706-acre public water supply reservoir for the City of Manassas, formed by the impoundment of Broad Run. It is located in western Prince William County at the periphery of the metropolitan Washington, D. C. area. Its watershed drains approximately 46,500 acres of rural land that is expected to undergo rapid development in the next 25 years.

The objective of this study was to provide a comprehensive report of the quality of water in Lake Manassas and its tributary streams, analyzing data that had been collected from October, 1984 through April, 1986, as part of a monitoring program funded by the City of Manassas.

The capacity of Lake Manassas at full pool was determined to be 4.2 billion gallons (15.8 million cubic meters)

and its mean depth 25 feet (7.7 meters). The calculated volume was considerably less than had been previously thought. Trophic state indices indicated that Lake Manassas is eutrophic, and water column chemistry suggested phosphorus to be the limiting nutrient. The Vollenweider model was applied to elucidate the relative impacts of South Run and Broad Run on the lake.

While Broad Run contributed the vast majority of flow to the reservoir, higher concentrations of algal nutrients, nitrogen and phosphorus, were transported to the lake by South Run, which receives effluent from the treatment plant at Vint Hill Station, a U.S. Army reservation. Phosphorus loadings from South Run were higher than from Broad Run under baseflow conditions. On an annual basis, stormflow runoff contributed as much as twelve times the tributary baseflow loading of phosphorus.

ACKNOWLEDGEMENTS

The author wishes to thank her thesis advisor, Dr. Barron L. Weand for his support and encouragement during the writing of this thesis. His lively lectures, genuine interest in environmental problems, and dedicated concern for the students in the Northern Virginia program are to be commended.

The author also wishes to thank Dr. Hoehn, Dr. Randall, and Dr. Evans for contributing thoughtful and expert constructive criticism. For that, and for their interest in the contents of this thesis, I am appreciative. Special thanks are extended to Dr. Hoehn for chairing the examining committee.

Dr. Thomas J. Grizzard is to be thanked for providing the author the opportunity to work at Occoquan Watershed Monitoring Laboratory and encouraging her to develop her skill in using the personal computer which has proved invaluable for accomplishing this research.

Many thanks are due the laboratory technicians at OWML for their sincere effort to produce high-quality data and for putting up with the author during her tenure as lab supervisor. The entire field crew are to be thanked for collecting the samples used in this study.

Thanks are also to be extended to Wade Whetzel, Chief Operator of the Manassas Water Treatment Plant, for answering numerous questions and for the tour of the treatment facility. His interest in this work was appreciated.

The author wishes to sincerely thank her father, Jerry Laufer. Without his support, financial and otherwise, this thesis would not have been written. Thanks and appreciation go especially to her brother, Dave, who has accommodated without protest the many changes that have occurred as a result of this thesis. Thanks are also due Joanne Laufer, the author's mother, for her assistance and support, and Kathy Laufer, the author's sister, for her empathy and understanding.

Special thanks go to Cynthia Sale, who first informed the author of the ESEN program in Northern Virginia. Her friendship as a colleague and fellow graduate student has been refreshing. She has always been encouraging and quick to offer and give assistance.

The author also wishes to thank her good friends, Marilyn and Sid, for making this experience much more than an academic exercise.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iv
LIST OF FIGURES	viii
LIST OF TABLES	xii
 CHAPTER	
I. INTRODUCTION.	1
II. LITERATURE REVIEW	5
Lake Manassas	5
Historical Aspects	5
Water Treatment.	5
Watershed Management	7
Limnological Principles	12
Morphology	12
Thermal Stratification	13
Eutrophication	15
Nutrients.	17
Lake Classification	25
Trophic Levels	25
Nutrient Loading	31
Internal Loading and Bioavailability.	34
Watershed Management.	38
Water Quality Standards.	38
Stream Characterization.	39
Protection of Water Supply	44
III. METHODS AND MATERIALS	48
Sampling.	48
Analytical Techniques	51

TABLE OF CONTENTS (continued)

Chapter	Page
IV. RESULTS	54
Lake Manassas	54
Lake Morpholgy	55
Thermal Regime	57
Dissolved Oxygen Variation	63
Algal Activity	78
Nutrient Variation	89
Nitrogen	90
Phosphorus	97
Trophic State Indices.	99
Nitrogen to Phosphorus Ratios.	106
Tributary Streams	107
Field Measurements	110
Nutrients and Suspended Solids	112
Stream Flows and Loading Estimates	125
V. DISCUSSION.	134
Physical Characteristics.	134
Lake Productivity and Nutrient Dynamics	138
Algal Productivity	138
Nutrients.	144
Lake Models	155
Trophic State.	155
Trophic State Index.	156
The Vollenweider Model	160
Future Outlook.	163
VI. CONCLUSIONS	169
VII. RECOMMENDATIONS	171
REFERENCES	173
APPENDIX TABLES	180
VITA	243

LIST OF FIGURES

Figure		Page
1	The Lake Manassas watershed in relation to the larger Occoquan Watershed	2
2	Temperature and dissolved oxygen variations in oligotrophic and eutrophic lakes	18
3	The Vollenweider relationship	32
4	Causal pathways for eutrophication effects on water supplies.	45
5	Sampling sites on Lake Manassas and its tributaries	49
6	Hypsographic (volume-depth) curve for Lake Manassas.	58
7	Thermocline development at Station LM01, Lake Manassas, February through July, 1985	59
8	Thermocline development in Lake Manassas at Stations LM01-LM06, Spring and Summer, 1985	61
9	Dissolved oxygen and temperature profiles at Lake Manassas Station LM01 on December 11, 1984.	64
10	Dissolved oxygen and temperature profiles at Lake Manassas Station LM01 on July 25, 1985	65
11	Dissolved oxygen variations at the surface and bottom of Station LM01, Lake Manassas	66
12	Dissolved oxygen variations at the surface and bottom of Station LM02, Lake Manassas	67
13	Dissolved oxygen variations at the surface and bottom of Station LM03, Lake Manassas	68
14	Dissolved oxygen variations at the surface and bottom of Station LM04, Lake Manassas	69

Figure		Page
15	Dissolved oxygen variations at the surface and bottom of Station LM05, Lake Manassas . . .	70
16	Dissolved oxygen variations at the surface and bottom of Station LM06, Lake Manassas . . .	71
17	Isopleth of dissolved oxygen saturation, Lake Manassas Station LM01	73
18	Dissolved oxygen saturation profiles in Lake Manassas, Stations LM01-LM06, Spring and Summer, 1985	74
19	Isopleths of dissolved oxygen saturation in Lake Manassas at Stations LM06 and LM03 . . .	77
20	Chlorophyll <u>a</u> variation in surface samples from Lake Manassas.	79
21	Chlorophyll <u>a</u> variation at Station LM01, Lake Manassas.	82
22	Chlorophyll <u>a</u> variation at Station LM02, Lake Manassas.	83
23	Chlorophyll <u>a</u> variation at Station LM03, Lake Manassas.	84
24	Chlorophyll <u>a</u> variation at Station LM04, Lake Manassas.	85
25	Chlorophyll <u>a</u> variation at Station LM05, Lake Manassas.	86
26	Chlorophyll <u>a</u> variation at Station LM06, Lake Manassas.	87
27	Composition of mean nitrogen concentrations in the surface waters of Lake Manassas, October, 1984 - April, 1986	93
28	Composition of mean nitrogen concentrations in the bottom waters of Lake Manassas, October, 1984 - April, 1986	94

Figure		Page
29	Ammonia variation in the surface and bottom waters of Lake Manassas at Station LM01 . . .	96
30	Oxidized nitrogen variation in the surface and bottom waters of Lake Manassas at Station LM01.	98
31	Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM01.	100
32	Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM02.	101
33	Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM03.	102
34	Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM04.	103
35	Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM05.	104
36	Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM06.	105
37	Mean nitrogen distribution in Broad Run during baseflow and runoff conditions, November, 1984 - May, 1986.	118
38	Mean nitrogen distribution in South Run during baseflow and runoff conditions, November, 1984 - May, 1986.	119
39	Mean nitrogen distribution in North Fork during baseflow and runoff conditions, November, 1984 - May, 1986.	120
40	Mean phosphorus distribution in Broad Run during baseflow and runoff conditions, November, 1984 - May, 1986	122

Figure		Page
41	Mean phosphorus distribution in South Run during baseflow and runoff conditions, November, 1984 - May, 1986	123
42	Mean phosphorus distribution in North Fork during baseflow and runoff conditions, November, 1984 - May, 1986	124
43	Probability plot of phosphorus storm loads, Broad Run at Buckland (ST70).	133
44	Relationship of chlorophyll <u>a</u> and dissolved oxygen in Lake Manassas at Station LM01 . . .	139
45	Mean chlorophyll <u>a</u> concentration, mean secchi depth, and mean station depth for each sampling site on Lake Manassas.	142
46	Dissolved oxygen variation and oxidized and ammonia nitrogen variation in the bottom waters of Lake Manassas at Station LM01 . . .	150
47	Soluble and total phosphorus variations and alkalinity and conductivity variations in bottom waters of Lake Manassas at Station LM01.	151
48	Comparison of baseflow and stormflow loadings of phosphorus from Broad Run and South Run with the Vollenweider loading guidelines. . .	162

LIST OF TABLES

Table		Page
I	Potential nitrogen and phosphorus sources and sinks for lakes	20
II	Forsberg's limiting nutrients and chlorophyll <u>a</u> values.	24
III	Carlson's Trophic State Indices	27
IV	Equations for calculating Carlson's Trophic State Indices	27
V	Trophic state vs chlorophyll <u>a</u>	29
VI	EPA - NES trophic state delineations.	29
VII	Estimated magnitudes of pollutant contributions to surface waters from selected non-point sources	41
VIII	Ranges and mean values for export of total phosphorus from 31 southern Ontario watersheds	42
IX	A summary of nutrient export rates reported in the literature	43
X	Morphometric parameters of Lake Manassas.	56
XI	Copper sulfate applications to Lake Manassas and subsequent sampling dates	81
XII	Mean chlorophyll and pheophytin concentrations in Lake Manassas, October, 1984 - April, 1986	88
XIII	Nutrient levels in surface waters of Lake Manassas.	91
XIV	Nutrient levels in bottom waters of Lake Manassas.	92

Table	Page
XV	Carlson's Trophic State Indices for Lake Lake Manassas 107
XVI	N:P ratios in Lake Manassas based on surface concentrations at spring overturn 108
XVII	Lake Manassas tributary stream baseflow characteristics 111
XVIII	Lake Manassas tributary stream baseflow characteristics: nutrients and suspended solids. 113
XIX	Lake Manassas tributary stream runoff characteristics: nutrients and suspended solids. 114
XX	Estimates of baseflow loadings from Broad Run and South Run onto Lake Manassas. 128
XXI	Composite storm data for Broad Run at Buckland (ST70) 130
XXII	Estimates of stormflow phosphorus loadings from Broad Run onto Lake Manassas 131
XXIII	Monthly precipitation at Lake Manassas for 1985 and 1986 as compared to average precipi- tation at Washington, D.C.. 135
XXIV	Mean summer chlorophyll <u>a</u> concentrations and secchi disk depth in Lake Manassas, June - September, 1985 141
XXV	N:P ratios in Lake Manassas based on overall mean concentrations and mean summer concen- trations of surface samples 148
XXVI	Trophic State Indices for Lake Manassas based on mean summer values, June - September, 1985 159
A-1	Surface water standards for surface public water supplies promulgated by the Virginia State Water Control Board in 1981 181

Table	Page
A-2	Analytical methods used at the Occoquan Watershed Monitoring Laboratory for the analysis of chlorophyll, suspended solids, and nutrients 182
A-3	Planimetered areas of the contours of Lake Manassas from USGS quadrangle maps. 185
A-4	Vint Hill Farms Station's average monthly discharge of total phosphorus and total suspended solids, October, 1984 - April, 1986. . 186
A-5	Field data from Lake Manassas, October, 1984 - July, 1986 187
A-6	Analyses of surface and bottom samples from Lake Manassas, October, 1984 - April, 1986. . 215
A-7	Lake Manassas tributary stream analyses, November, 1984 - April, 1986. 227
A-8	Broad Run at Buckland (ST70): Baseflow concentrations of total P, total N, and TSS, November, 1984 - April, 1986 243

I. INTRODUCTION

Lake Manassas is a man-made impoundment located in Prince William County, Virginia, about sixteen miles west of the City of Manassas, for which the reservoir serves as a drinking water supply. The watershed for this 706-acre reservoir is located on Broad Run in the upper reaches of the Occoquan Watershed, a much-studied area in the Northern Virginia Region which is tributary to the Potomac River (Figure 1).

As a surface drinking water supply at the periphery of the metropolitan Washington, D.C. area, Lake Manassas is a valuable resource. The population of the area that is served by Lake Manassas is expected to increase rapidly in the next twenty-five years. After completion of the expansion of the water treatment facility, now underway, Lake Manassas will provide eight million gallons per day (MGD) of potable water, twice the current capacity. The original treatment plant was placed in operation in 1970. Additionally, in recent drought years, Lake Manassas has provided water, through controlled releases downstream, to the Occoquan Reservoir, an impoundment that serves as the water supply for a large portion of the Northern Virginia area.

As the surrounding area are developed, the demand for water-based recreational activities will increase as well

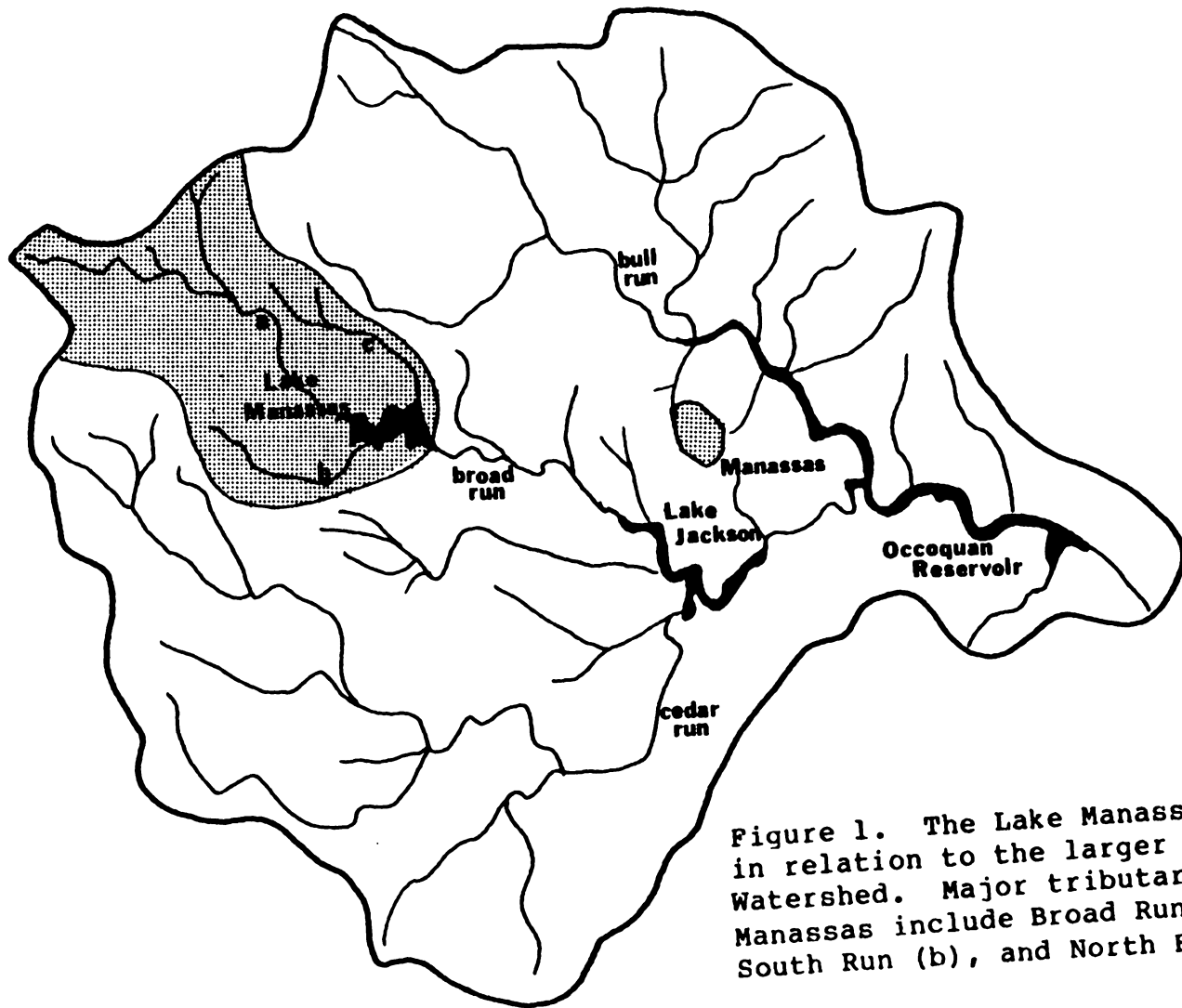


Figure 1. The Lake Manassas watershed in relation to the larger Occoquan Watershed. Major tributaries to Lake Manassas include Broad Run (a), South Run (b), and North Fork (c).

as the demand for drinking water. Lake Manassas is a popular fishing spot, and users enjoy the rural environment reflective of its location in a relatively undeveloped watershed. Recently, Lake Manassas was chosen as the scenic site where a large recreational golf course resort, planned residential area, and conference center is to be built. Maintenance of the lake for its aesthetic appeal is therefore important, as is the need to preserve it as a pollutant-free water supply for potable water.

Land development and urbanization have often been followed by the deterioration, usually noted as increased or prolific algal growth, of nearby lakes and streams. Increased availability of nutrients causes the increase in algal growth, or lake productivity, which, in turn, leads to further changes in lake dynamics and deteriorating water quality conditions. Specifically designed land-use practices can minimize these detrimental effects.

It is important to provide a report of the quality of water in Lake Manassas prior to further development of its watershed so that any changes in the quality of the water can be evaluated. The objective of this study, therefore, was to provide such a comprehensive report that characterizes the current quality of water in Lake Manassas and its major tributary streams with data that has been collected since 1984.

Specific objectives were (1) to investigate limnological factors of Lake Manassas with regard to lake morphology, oxygen and thermal stratification, seasonal turnover, nitrogen and phosphorus concentrations, and lake productivity as determined by chlorophyll a concentrations and Secchi disk transparency; (2) to determine the trophic state, or level of eutrophication, of Lake Manassas; (3) to characterize the input of major tributary streams to the lake according to nutrient and suspended solids concentrations and the relative loadings they contribute to the reservoir; and (4) to assess the relative impact of stream baseflow and storm runoff on the quality of the water in the reservoir.

II. LITERATURE REVIEW

LAKE MANASSAS

Historical Aspects

In 1962, the Town Council of Manassas requested that the Northern Virginia Soil Conservation District make a survey of possible sites for a water impoundment that would alleviate the increasing demand for potable water by a rapidly developing community. Ultimately, the Council procured options to purchase the land adjacent to Broad Run near Greenwich. In 1966, a bond referendum provided funds to construct dam, 85 feet high, to impound the waters of Broad Run where North Fork tributary enters the stream. Construction began in November, 1968 and was completed in 1970. A treatment plant at the base of the spillway was designed to process the water that would be transported seven miles to the City through a 24-inch main (1).

Water Treatment

The water treatment plant was designed to produce four MGD. Currently, it is producing finished water at its maximum rate, serving a population of 21,000 in the City of Manassas and also providing 0.5 MGD to the Prince William Service Authority. The treatment facility is presently

undergoing an expansion which will double its capacity. Plans for increasing the height of the spillway by five feet are under consideration. In addition, a hydroelectric plant is under construction that will also draw water from the reservoir.

Raw water is withdrawn from one of six intake ports located in the spillway structure, at five, 15, 25, 35, 45, and 55 feet below the top of the dam. After mixing with alum, the water is flocculated and then allowed to settle in two settling tanks. The water then passes through dual media filters. An unusual feature of this facility is that it uses granular activated carbon (GAC) in its four filter beds, rather than the more typical anthracite. Taste and odor problems encountered in treating the water apparently were severe enough to warrant the use of GAC, a costly commodity, as filter media. The GAC was installed after several years of initial operation.

Finished water is held in a 205,000 gallon clearwell below the plant. A 24-inch service main carries the finished water to a 2.5 MG ground-level tank, and two elevated tanks in the City of Manassas, one 300,000 gallon and one 75,000 gallon capacity. An additional 24-inch main will carry water to the Gainesville area once the plant begins treating more water.

Filter operation occasionally is impaired by filter-

clogging algae. Other algae, specifically bluegreen algae, are responsible for the taste and odor problems at the treatment plant. To minimize these problems, Lake Manassas is treated with copper sulfate, an algicide commonly used to kill algae. Turbidity removal does not appear to be a significant problem since the average raw water turbidity is in the range of 2.5 to 3.5 nephelometric turbidity units (NTU). The treatment facility does not require water softening processes to produce an effluent with a total hardness concentration of 40 mg/L as CaCO_3 , which is considered a soft water in the water treatment field (2).

Watershed Management

Lake Manassas lies in a triassic basin area of sedimentary and igneous rock that has formed by a downfall of the Piedmont physiographic province (3). The reservoir is part of the upper watershed of the Occoquan Reservoir, which serves as a major source of drinking water for the Northern Virginia suburbs of Washington, D.C. (Figure 1). The drainage basin tributary to Lake Manassas reservoir is 188 km^2 (46,500 acres), which is 13 percent of the total drainage area of the whole Occoquan basin (1476 km^2) and 21 percent of the Occoquan Creek sub-basin (888 km^2) (4).

Most of the Lake Manassas watershed is either forested, pastureland, or used for agricultural purposes. A portion

of Gainesville, an urbanizing area, drains into North Fork, which begins as a spring near Antioch, at the base of Bull Run Mountain. Broad Run begins in the Watery Mountains and, although it does not drain any urban areas, it does provide the flood plain upon which Route 55 and Interstate Route 66 were built. Mill Run and Trapp Brook are tributaries of Broad Run upstream of Lake Manassas. South Run, another tributary to Lake Manassas, begins in the Pond Mountains and is first impounded at Lake Brittle near Broken Hill. Below Lake Brittle, South Run receives effluent from Vint Hill Farms Military Reservation. This discharge is permitted by Virginia State Water Control Board, under the National Pollutant Discharge Elimination System (NPDES).

The larger Occoquan Watershed has been the subject of much study. A study commissioned by the Commonwealth of Virginia State Water Control Board determined that the quality of the water in the Occoquan Reservoir was rapidly deteriorating. In 1971, the "Policy for Waste Treatment and Water Quality Management in the Occoquan Watershed" was adopted by the Water Control Board. In addition to mandating that regional high-performance treatment facilities replace eleven major point sources of pollution in the basin, the Policy established the Occoquan Watershed Monitoring Program to gather information on water quality in

the reservoir and its major tributaries (5). Two of the major stream-sampling sites eventually established to monitor water quality were on Broad Run, one just above Lake Manassas at Buckland and another several miles below the spillway at Linton Hall, which is designated Broad Run at Bristow.

A cooperative study between the Northern Virginia Planning District Commission (NVPDC) and the Occoquan Watershed Monitoring Laboratory (OWML) known as the "208 Study", was completed in 1978. The Occoquan River Basin was found to be contributing much higher levels of nonpoint pollution loadings to its receiving waters than previously assumed. From the data collected, NVPDC was able to develop a sophisticated water-quality model to assess the impact of nonpoint pollution from different land use patterns in the Occoquan watershed (6).

In June 1980, the Prince William County Planning Office requested NVPDC to perform a model study comparing five future land-use scenarios for the Lake Manassas planning area. The resulting Lake Manassas Plan designates the County's portion of the Lake Manassas Watershed (53 km²) as a "resource management" area. Lower density residential development was ultimately designated for this area in the Comprehensive Plan of 1982. Further action to protect the Occoquan Watershed, which included Lake Manassas drainage,

was taken by Prince William County; the use of "Best Management Practices (BMPs) was required in the Occoquan Watershed effective January 1, 1983 (6).

Current Interest

In the Spring of 1986, Lake Manassas attracted considerable public attention. A large tract of land, 803 acres, was purchased adjacent to the reservoir by Robert Trent Jones International, which intends to develop the area as a planned resort/community featuring several golf courses (7). Because most of the land would drain directly into the Reservoir, the potential impact of this development has raised concern. The Prince William County Planning Office requested NVPDC to analyze the water quality impact of the Robert Trent Jones International proposed development plans. Their final report was issued in April, 1986 and several recommendations were made with respect to the design and management of stormwater runoff within the community (8). A significant assumption made in the model used by NVPDC is that the lake dynamics within the North Fork arm of the reservoir are the same for that in the rest of the reservoir. That assumption will be addressed later in this work.

Lake Manassas apparently has been the subject of only one other research paper. McLaughlin (9) studied sediment

release and uptake of nitrogen and phosphorus in the Occoquan and Lake Manassas Reservoirs. It was found that total phosphorus, orthophosphate-phosphorus, and ammonia moved from the sediment to the water column under anaerobic conditions. Sediment samples were collected and analyzed from two sites from Lake Manassas, one near the spillway and the other one near the Lake Manassas Marina located in an arm on the southern shore of the reservoir, about two miles from the dam. This research confirmed that the phenomenon of sediment release of certain nutrient forms, which researchers have observed in other lake sediments, could in fact occur in Lake Manassas given the appropriate conditions.

In the Summer of 1984, the Occoquan Watershed Monitoring Laboratory (OWML), a research laboratory associated with Virginia Polytechnic Institute and State University, contracted with the City of Manassas to design and implement a monitoring program for Lake Manassas and its watershed. The work plan included routine sampling the lake at six locations, and the tributaries at seven locations. A regular sampling program was in effect by late October 1984. Sampling at the Broad Run station, just above Lake Manassas, was operated as part of the Occoquan Watershed Monitoring Program, and was coordinated with the Lake Manassas Monitoring.

LIMNOLOGICAL PRINCIPLES

Morphology

Both natural and man-made lakes vary tremendously in size and shape. Common morphological characteristics used to describe a lake are maximum length, surface area, storage volume, maximum depth, mean depth, length of shoreline, and shoreline development. The development of shoreline is the ratio of shoreline length to the circumference of a circle whose area is equal to the lake's surface area. A circular body of water would have a shoreline development value of unity. Crater Lake, which is nearly circular, has a shoreline development value of 1.33 (10). Generally, natural lakes have a lower value for shoreline development, in the range of 2.0-3.0, than do man-made reservoirs. Impounded waters flooding a river valley tend to be dendritic, having a shoreline development ratio of about five (11).

The storage volume of a lake or reservoir is an important consideration in the management of a water supply. Water surface elevation of a reservoir is directly related to the storage volume. Hydrographic data of a lake are often presented as depth-area and depth-volume curves and can be useful in the design and operation of a multi-purpose reservoir.

Another important characteristic of lakes is the renewal time or hydraulic retention time, which is calculated by dividing the total water volume by the rate of outflow. Natural lakes tend to have longer hydraulic retention times (2-10 years) than man-made impoundments (1-12 months) (11).

Thermal Stratification

Solar radiation is most often the greatest source of heat to lakes. The amount of solar energy reaching a lake depends on its geographical position (latitude and altitude) and the seasons. Because most of the solar energy is absorbed by the upper few meters of water, depth is an important consideration in the thermal response of a lake. Water has its maximum density at 4°C. Warmer, less dense, water tends to stay on top of the deeper cooler water that is not warmed by the sun. Heat is vertically distributed mainly by wind action that mixes upper and lower waters.

When wind is not sufficient to break the high surface tension of water which resists its action, a lake will stratify into upper and lower layers, called the epilimnion and hypolimnion, respectively. These strata are separated by a metalimnion, generally referred to as the thermocline, in which temperature and density change rapidly with depth. This stratum serves as a barrier, preventing the epilimnion

and hypolimnion from mixing while the upper layer continues to be heated by the sun. This stratification is typical of temperate zone lakes in the summertime.

As the air cools in the autumn the heat gained from solar radiation is less than the heat lost to the atmosphere. The thickness of the thermocline is reduced by surface waters becoming more dense as they cool and move downward. Eventually the surface and bottom waters become totally mixed. This event can occur over a period of either several days or weeks, depending on how fast conditions change. Known as fall overturn, the lake becomes a uniform temperature, surface to bottom, and is characterized by vertical mixing.

In winter, the densest, cold water sinks to the bottom and ice forms at the surface wherever climatic air temperature becomes cold enough to permit freezing. The coldest water is then found at the surface of the lake. When ice coverage prevents the wind from mixing the surface and bottom, an inverse stratification can develop. A minor density gradient from 0°C to 4°C occurs just below the ice.

Increasing air temperatures and warm rains melt the ice cover and warm up the lake in spring. As the solar radiation continues to heat the surface waters, wind action serves to mix the entire water column. Because the difference in temperature, from surface to bottom, is relatively

small compared to summer stratification, there is less thermal resistance to vertical mixing and relatively light winds can produce a spring turnover. As the surface water receives greater heat input and spring winds subside, stratification again occurs, trapping cooler waters below the thermocline.

The thermal effects described above are typical of temperate zone lakes, with contrasting summer stratifications and spring and fall overturns. With two periods of mixing, this pattern is termed dimictic. Other lakes categorized by their mixing regimes are designated amictic, monomictic, polymictic, or meromictic (10, 12).

Eutrophication

All lakes are subject to the gradual accumulation of silt and organic matter that has been washed off the soils that border the lake and its streams. The lake fills in slowly to become a marsh and ultimately to become a field (13). This natural aging process, called eutrophication, is defined as the enrichment of nutrients or organic material, or both, and results in high biological productivity and decreasing lake volume (14). A lake that is low in nutrient content and has low plant productivity, which generally results in high transparency, is called an oligotrophic lake. As the lake acquires more nutrients through

stream inputs it becomes more productive and is considered a mesotrophic lake. Highly enriched lakes -- characterized by algae blooms of predominantly bluegreen algal species, low transparency, and hypolimnetic oxygen depletion in the summer season -- are considered eutrophic.

Cultural eutrophication refers to the vast acceleration of the aging process resulting from mans' activities. In 1947, Sawyer (15) studied several lakes near Madison, Wisconsin, and determined that erosion and soil runoff from agricultural practices, in addition to sewage discharge, were the causes for the severe algal growth problems in these lakes. He speculated that while phosphorus was the key element enriching the lakes, both nitrogen and phosphorus should be below 0.3 mg/L and 0.01 mg/L, respectively, to prevent algal blooms, which are often the most conspicuous effect of cultural eutrophication.

Due to the availability of nutrients, an eutrophic lake has a high rate of productivity. Algal populations can increase rapidly, forming mats of growth just below the surface of the water. When the phytoplankton photosynthesize during the daytime, large amounts of oxygen are produced that can result in dissolved oxygen supersaturation near the surface. Generally, the presence of dissolved oxygen saturation values greater than 100 percent is indicative of excessive algal growth. Due to the thermocline

barrier, the oxygen at the surface cannot reach the lower depths, where oxygen is rapidly depleted by the decomposition of the organic carbon, which in turn is contributed by the phytoplankton settling into the bottom waters (12). Figure 2 illustrates the variation in temperature and dissolved oxygen content for both oligotrophic and eutrophic lakes as they change with depth and season.

The absence of oxygen in the hypolimnion precludes the presence of aerobic aquatic species, including fish. The depletion of oxygen at the bottom sediment surface is concomitant with a reducing redox potential. This in turn encourages the release of reduced forms of iron (Fe^{2+}) and manganese (Mn^{2+}) and of sulfide into the water column above the sediment interface (16). The thermocline usually prevents these reduced forms from circulating into the epilimnion. But during overturn a dramatic change in water quality generally becomes evident in the upper lake waters as these chemical species become fully dispersed in the lake.

Nutrients

The many elements and dissolved salts which are essential for life may be divided into two groups: macronutrients and micronutrients. The former includes elements and their compounds that have important roles in protoplasm

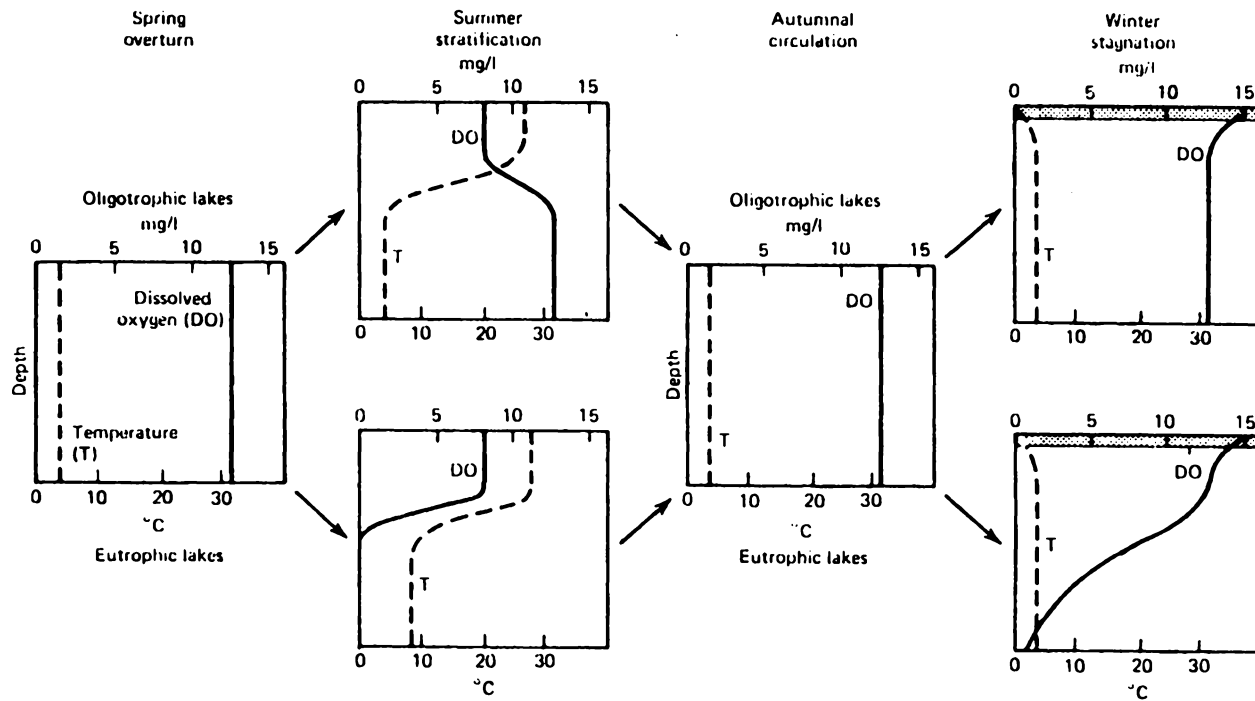


Figure 2. Temperature and dissolved oxygen variations in oligotrophic and eutrophic lakes (after Wetzel, reference 10).

and are needed in relatively large quantities. These are carbon, hydrogen, oxygen, nitrogen, potassium, calcium, magnesium, sulfur, and phosphorus. The micronutrients are also needed to sustain life but are required only in minute quantities. These include iron, manganese, copper, zinc, boron, sodium, molybdenum, chlorine, vanadium, and cobalt (12).

Oxygen is needed by organisms that possess strict aerobic respiratory systems. The solubility of oxygen in water is a function of temperature: the lower the temperature, the greater the amount of oxygen that can be dissolved in it. During summer stratification aerobic activity can drastically reduce the dissolved oxygen concentration in the hypolimnion. In addition, oxygen demanding substances, often quantified as BOD (biochemical oxygen demand) and COD (chemical oxygen demand), may enter a lake and reduce its oxygen concentration.

Nitrogen is present in the environment in many available forms. In fresh water, nitrogen exists as dissolved molecular nitrogen (N_2), organic nitrogen, ammonia (NH_3), nitrate (NO_3^-), and nitrite (NO_2^-). Sources of nitrogen include precipitation, nitrogen fixation both in the water and the sediment, and inputs from surface and groundwater (10). Table I describes, in general, the potential sources for nitrogen and phosphorus.

TABLE I. POTENTIAL NITROGEN AND PHOSPHORUS SOURCES AND SINKS FOR LAKES (After Shannon and Brezonik, reference 17)

NATURAL	CULTURAL
Sources	
Precipitation on lake surface	Domestic and industrial waste waters
Swamp runoff	Agricultural runoff
Virginal meadowland runoff	Managed forest runoff
Forest runoff	Urban runoff
Soil erosion	Septic tanks
Aquatic bird and animal wastes	Landfill drainage
Leaf and pollen deposition	
Groundwater influxes	
Nitrogen fixation *	
Sediment recycling	
Sinks	
Outlet losses	Denitrification *
Fish catches	Volatilization *
Aquatic plant removal	Groundwater recharge
	Sediment losses
* Applies to nitrogen alone.	

Ammonia is the major nitrogenous end product of the bacterial decomposition of organic matter. It is also an excretory product of invertebrate animals (12). In the presence of oxygen, ammonia is rapidly oxidized to nitrite then to nitrate through the process known as nitrification (18). Nitrate is an important water quality parameter not only because it is an algal nutrient, but also because it is a potential health hazard to infants. The U.S. Environmental Protection Agency sets the criterion for nitrate at 10 mg $\text{NO}_3\text{-N/L}$ maximum concentration for drinking water. Ammonia is another important water quality constituent. In its unionized form, NH_3 , it is toxic to living organisms in low concentrations. At high pH levels, the equilibrium of ionized ammonium (NH_4^+) and unionized ammonia in water can shift to produce a predominance of the toxic chemical species (18).

Phosphorus is the least abundant required nutrient in relation to its requirements, and its concentration in fresh waters is generally very low. The most significant form in terms of bioavailability is the inorganic form, orthophosphate. Usually 90 percent or more of the phosphorus in lakes is organically bound. Orthophosphate, which is the most readily bioavailable form, and polyphosphates, which are polymers of phosphoric acid, are the non-organic forms of phosphorus found in lakes. Water is commonly ana-

lyzed for total phosphorus, total soluble phosphorus, and orthophosphorus (also known as soluble reactive P). Inorganic phosphate entering a lake is rapidly assimilated by phytoplankton and bacteria. Particulate phosphorus may enter the lake as such and settle to the bottom. Phosphates may also form insoluble compounds with metallic ions, especially with iron, manganese, and calcium. Phosphates will also strongly sorb to clay particles that settle. Organic phosphorus from dying phytoplankton also will eventually end up in the sediments (11). Sediment release of phosphorus will be discussed later.

In 1840, Justus Leibig, while studying inorganic chemical fertilizers, found that crop growth was limited by whatever essential element was in shortest supply, regardless of whether the total amount required was large or small. Leibig's "Law of the Minimum" has come to mean that growth is limited by the nutrient that is available to the least extent relative to the plant's need (12).

The structural elements of algal protoplasm are C, H, O, N, and P. They exist in algae in an atomic ratio of 106:263:110:16:1, in that respective order (19). By weight the ratios become approximately 40C:7N:1P (ignoring hydrogen and oxygen because they are so abundant in the environment). Vallentyne (20), during a panel discussion at a special American Society of Limnology and Oceanography

symposia that addressed the issue of limiting nutrients, cited that nutrients were available from natural sources in the ratio 600C:20N:1P, and that C and N could not be limiting nutrients since they were available in excess of need. Carbon is considered readily available as carbonates, bicarbonates, and carbon dioxide. Moreover, the vast reservoir of molecular nitrogen, existing at saturation in dissolved form in surface waters of lakes, has been shown to be fixed by some species of bluegreen algae, for example Anabaena (10). It was the consensus, at the conclusion of the special symposia noted, that phosphorus was the most important factor in controlling eutrophication of fresh water lakes (14).

Odum (21) emphasized that a growing algal population is a system in flux, and as it changes so may its nutrient requirements. Thus, a nutrient that appears to be in ample supply could become limiting, as the demand for it, caused by a rapid growth phase, exceeds the immediate supply. Generally, lakes with an N:P mass ratio greater than 12 are considered phosphorus limited. Most fresh waters have been found to be phosphorus limited and most marine waters are nitrogen limited. Forsberg (22) suggested the use of biomass, quantified as summer average chlorophyll a concentrations, to determine the limiting factor for a lake (Table II).

Table II. FORSBERG'S LIMITING NUTRIENTS AND
CHLOROPHYLL a VALUES (Reference 22).

Total N: Total P	Limiting Nutrient	Chlorophyll <u>a</u> Level, ug/L
>17	P	<20
10 - 17	N and/or P	20 - 70
<10	N	>70

LAKE CLASSIFICATION

Two approaches to lake classification are (1) Trophic State Indices (TSI), which utilize water quality data in-lake samples and (2) Loading Concepts, which use nutrient (phosphorus) loading criteria to predict the trophic status of a lake. The latter scheme can be used to forecast the effect of changes in phosphorus loading on a lake, and to estimate its carrying capacity, thus providing a management tool for predicting the impacts of activities on lakes (23, 24).

Trophic Levels

The original trophic state index is the classic oligotrophic - mesotrophic - eutrophic continuum. Hypereutrophic and ultra-oligotrophic are terms more recently coined to describe the extremes of the continuum. Almost all classification schemes ultimately refer back to these few categories because their simple approach can easily be understood by the public. This approach is also useful because it can be applied to a wide variety of lakes throughout the world. Much has been written delineating the limitations of such an approach (24,25,26). The most common criticism is that it is a subjective index and does not relate to specific water quality criteria.

Carlson (26) addressed the fact that one could use different criterion to come up with different classifications for the same lake or impoundment. In 1977 he published a scheme to classify lakes using three different Trophic State Indices (TSI). While emphasizing that a TSI was not a water quality index, Carlson stated that the TSI could be a valuable tool in comparing lakes in a region, and as a management tool for predicting changes when used in conjunction with nutrient loading concepts.

Because of the importance of algal blooms to the public, Carlson used algal biomass as the key descriptor for trophic state. For phosphorus limited lakes, as the concentration of total phosphorus (P) increases, algal growth (determined as chlorophyll a concentration) increases, and the transparency (determined as Secchi disk depth) decreases. Carlson used each doubling of the biomass (algal) as a trophic state division (Table III) for each parameter. Table IV presents the equations used to calculate the TSIs. Carlson suggests using data obtained from epilimnetic samples taken during summer stratification.

Indices for total P, chlorophyll a, and Secchi disk transparency should be approximately the same for a particular lake. If one or two indices differ significantly, there should be an investigation to explain the divergence. Seasonal changes can affect the index calculation and Sec-

TABLE III. CARLSON'S TROPHIC STATE INDICES (reference 26).

TSI	Secchi Disk Depth (m)	Surface Total Phosphorus (ug/L)	Surface Chlorophyll a (ug/L)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1183

TABLE IV. EQUATIONS FOR CALCULATING CARLSON'S TROPHIC STATE INDICES (reference 26).

$$TSI (SD) = 10 \left(6 - \frac{\ln SD}{\ln 2} \right)$$

$$TSI (Chl) = 10 \left(6 - \frac{2.04 - 0.68 \ln Chl}{\ln 2} \right)$$

$$TSI (TP) = 10 \left(6 - \frac{\ln(48/TP)}{\ln 2} \right)$$

chi depth values may be affected by highly colored or turbid waters. In addition, man-made impoundments show different relationships among the indices than natural lakes (27). Chlorophyll a and Secchi depth did not correlate as well to Total P in impoundments as they did in natural lakes. Carlson speculated that impoundments may be muddier than natural lakes to account for this difference.

In Carlson's approach, field measurements are used to develop TSIs on a scale of 0 - 100, a more defined system than the eutrophic - mesotrophic - oligotrophic scheme. Tables V and VI present other commonly used trophic level indicators as developed by Sakamoto, the National Academy of Sciences, Dobson, and EPA's National Eutrophication Survey (24). The individual parameters chlorophyll a, total P, and Secchi disk depth again relate back to the original trophic level designations.

Walker (25) suggested the use of hypolimnetic oxygen depletion rate as a trophic state index because it corresponds to a water quality criteria for minimum oxygen concentrations. Water Quality Standards for streams and surface drinking water supply designate the lower limit of dissolved oxygen concentrations at 4 mg/L in Virginia (28). Walker suggested relating the epilimnetic standing crop (algal biomass) to the rate at which oxygen depletes in the hypolimnion as the summer stratification develops.

TABLE V. TROPHIC STATE VS. CHLOROPHYLL a (reference 24).

Trophic Condition	Chlorophyll <u>a</u> (ug/L)			
	Sakamoto	Academy	Dobson	EPA-NES
Oligotrophic	0.3-2.5	0-4	0-4.3	<7
Mesotrophic	1-15	4-10	4.3-8.8	7-12
Eutrophic	5-140	>10	>8.8	>12

TABLE VI. EPA-NES TROPHIC STATE DELINEATION (reference 24).

Trophic State	Chl <u>a</u> (ug/L)	Total P. (ug/L)	Secchi Disk Depth (m)
Oligotrophic	<7	<10	>3.7
Mesotrophic	7-12	10-20	2.0-3.7
Eutrophic	>12	>20	<2.0

Dillon and Rigler (29) suggested the use of phosphorus levels in a lake at spring overturn to predict summer chlorophyll a values. They developed a formula for phosphorus-limited lakes that can be used to calculate the average chlorophyll a in the trophogenic zone in North American Lakes. This approach is useful where lake sampling is minimal.

In order to determine the natural condition of a lake, where anthropogenic, or human-caused, nutrient inputs are excluded, Vighi and Chiaudani (30) studied 53 lakes that had negligible nutrient input from human activities. They developed a morphological index (MEI) that is a ratio between mean depth and alkalinity or conductivity and related it to in-lake mean total phosphorus concentrations. It was found that the relationship between the phosphorus concentrations and the MEI was significant for a wide variety of lakes and was independent of geographical location. It was suggested that just as phosphorus is more easily leached from sedimentary rocks than from igneous rocks (31), the export of ions, which contribute to the alkalinity and conductivity values, follows a similar leaching mechanism. In polluted waters, the MEI can be used to predict the natural trophic level a lake would reach were anthropogenic nutrient inputs removed, the lake water quality then reflecting only its morphology and other fac-

tors that depend upon the natural characteristics of the drainage basin.

Nutrient Loading

As the population of the world increases, lakes that are not affected by human activities will become fewer and fewer. Predicting the impact of an increasing population on water quality has become an important task for lake managers. A second approach to classify lakes is based on the nutrient loading concept.

Vollenweider developed the concept that one can start with the amount of total phosphorus being added to a lake and then infer the degree of eutrophication is being experienced by that lake. The "Input-Output Model" (32) developed by Vollenweider is based on the mass balance equation:

$$\text{Change in total P} = \text{inflow} - \text{sedimentation} - \text{outflow}$$

Phosphorus input, or loading, (expressed as $\text{g/m}^2/\text{yr}$) is inversely related to the mean depth of the lake, H , and annual flushing rate, p , which is equal to annual inflow divided by lake volume. Figure 3 presents this relationship and how it relates to trophic conditions. Vollenweider designated "admissible" and "dangerous" loading levels, which are depicted on the axis by the two curves.

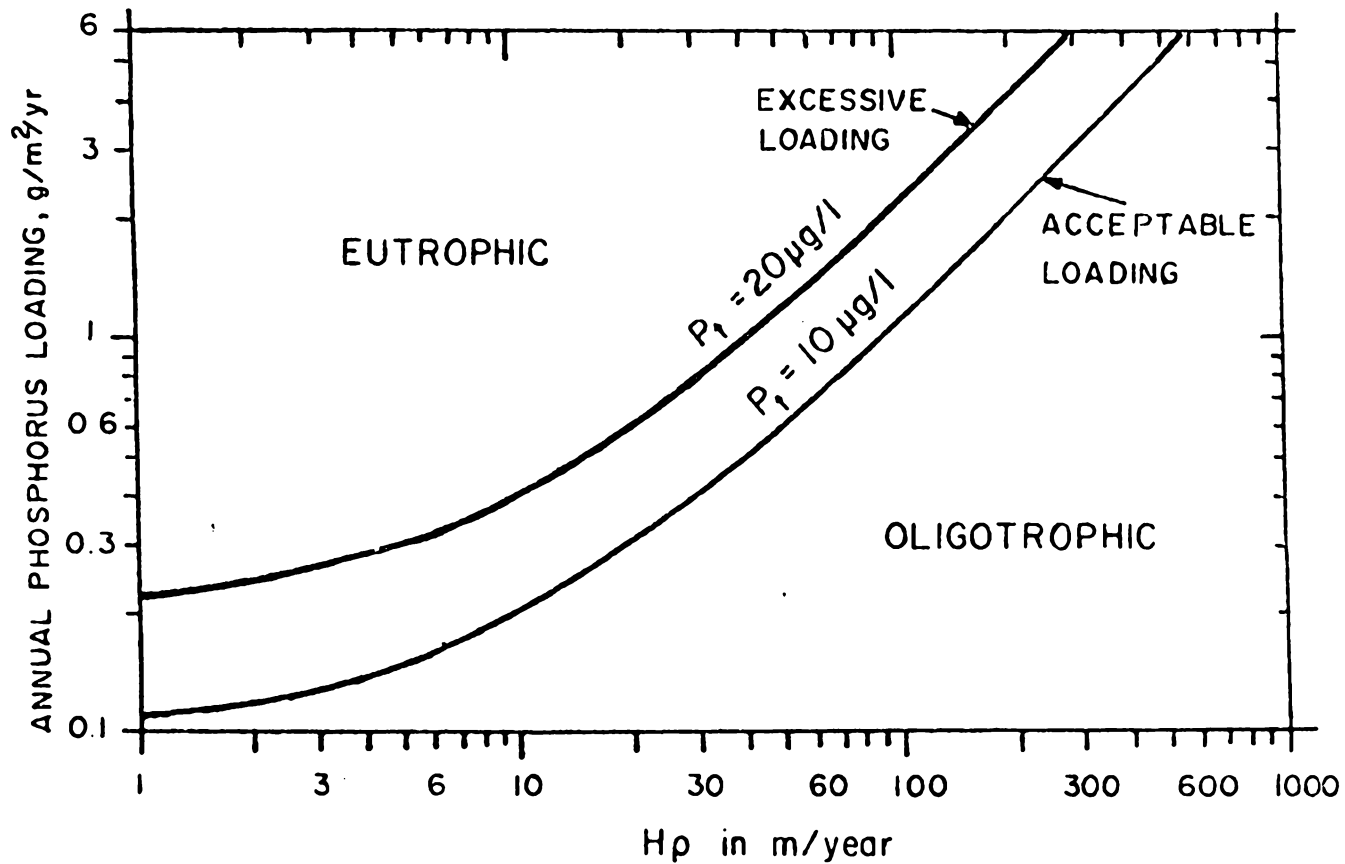


Figure 3. The Vollenweider relationship (adapted from Novotny and Chesters, reference 33).

Dillon (34) pointed out some important limitations in Vollenweider's model: (1) a completely mixed lake is assumed, thus ignoring stratification effects which would affect the flushing rate, (2) loading, flushing, and sedimentation rates are assumed to be constant, (3) outflow concentration is equal to the mean concentration in the lake, and (4) the sedimentation process is a first order reaction dependent on the amount of phosphorus in the lake. Vollenweider's model also does not account for any internal loading of phosphorus onto the lake.

While any model attempts to describe the infinitely complex nature of lake nutrient budgets in relatively simple terms, it can serve as a useful tool in lake management. Vollenweider's concepts have been expanded, modified, and applied to other trophic state indicators. Imboden (35), relating mean oxygen depletion in the hypolimnion as a function of phosphorus loading, calculated critical phosphorus loading figures above which lakes can become eutrophic. The figures agreed with Vollenweider's. Kirchner and Dillon (36) developed an equation to determine phosphorus retention, the percentage of phosphorus supplied but not leaving a lake via outflow. Phosphorus retention is needed to determine phosphorus loadings to lakes in the input-output model. Shannon and Brezonik (17) developed graphical relationships between Trophic State Indices and

phosphorus loading rates for lakes in north-central Florida. Lee, *et al.* (37) related chlorophyll *a*, Secchi disk, and hypolimnetic oxygen depletion to Vollenweider's phosphorus loading concept.

INTERNAL LOADING AND BIOAVAILABILITY

Any phosphorus entering a lake that is not transported downstream nor withdrawn in some manner ultimately ends up in the sediment as settled particulate phosphorus, organic phosphorus in living or decaying organisms, precipitated apatite, or as orthophosphate covalently bonded to hydrated iron oxides (10, 12). Lake sediment could be a significant source of phosphorus. This potential internal loading is a major current issue in lake management.

During summer stratification the hypolimnetic oxygen concentration decreases due to the decomposition of settled organic matter. When oxygen is dissolved in water a redox potential is generated according to the equilibrium reaction of water and oxygen. When the oxygen concentration approaches zero and anoxic conditions appear, the redox potential decreases very rapidly, and ferric hydroxides and other complexes are reduced, releasing the soluble ferrous iron and phosphorus into the water column (10, 12).

Mortimer (38) documented the release of phosphate,

ammonia, ferrous iron, and manganese from sediments into the anaerobic hypolimnion of an eutrophic lake in England. Holdren and Armstrong (39) found that reduction of ferric iron released phosphorus from sediments even when oxygen was present. They surmised that the rate of oxygen utilization at the interface is high enough to create an anoxic zone at the sediment surface.

Initially, phosphorus released from the sediment was not considered a significant phosphorus source for algal growth (37). However, subsequent research has shown the complexity of the issue. Grobler and Davies (40) experimented with sediment cores from shallow impoundments and found that the amount of phosphate consumed by an algal species correlated significantly with the inorganic phosphate content of the sediment. Larsen, et al. (41) found that in spite of external phosphorus loading being eliminated by tertiary treatment of wastewater discharges, Shagawa Lake, Minnesota, continued to be highly productive. Increases in phosphorus in summer came from within the lake as sediments released phosphorus under anaerobic conditions. Mayer, et al. (42) found that internal cycling of phosphorus was responsible for the present hyper-eutrophic status of Lake Sebasticook in Maine. Mawson, et al. (43) studied Liberty Lake, Washington. It had a mean depth of 7 m and an N:P ratio of 17:1. Internal loading was found to

be important in this lake and that some of the sediments studied released soluble reactive phosphorus (orthophosphate) in preference to total soluble phosphorus.

Orthophosphate-phosphorus, generally analyzed as soluble reactive phosphorus, is the form most readily available for algal uptake (44). Young, et al. (45) found that all soluble forms of phosphorus as well as 63% of particulate phosphorus in wastewater were ultimately available to the alga Scenedesmus.

Most researchers agree that sediment phosphorus is available for algal growth in shallow waters but may not be available in deep lakes. Sonzogni, et al. (44), using data primarily from Great Lakes studies, determined that generally only 60% of total phosphorus in tributaries is potentially bioavailable. Whether particulate phosphorus becomes available depends on the soluble reactive phosphorus concentration in the receiving waters, and the position or location of the particle in the water. It was noted that large particulate phosphorous loadings may be an important factor in lake productivity of shallow waters. DePinto, et al. (46) noted that the western basin of Lake Erie and Saginaw Bay of Lake Huron, both relatively shallow waters, have not experienced the decline in phosphorus concentrations that would otherwise have been expected from the comparatively rapid decrease in external phosphorus

loadings. Resuspended sediment phosphorus was considered the reason higher concentrations of phosphorus have been maintained. It was noted, however, that chlorophyll a values were much lower, and that the phosphorus from internal loading was not very bioavailable.

Sediment release of phosphorus has been attributed to the low redox potential at the sediment interface due to the absence or low concentration of dissolved oxygen. Recent studies have indicated that the presence of oxidized forms of nitrogen, usually absent in an anoxic hypolimnion, may inhibit the reduction of iron and manganese which releases phosphorus into the water column. Davison (16) suggested that this may be due to the sinking of certain forms of phytoplankton to create a layer that serves as a physical barrier that resists decomposition. Andersen (47) suggested that oxidized nitrogen prevents the release of phosphorus by buffering the redox potential of the sediment surface at a level high enough to prevent the release of phosphorus. Grizzard, et al. (48), working with sediments from the Occoquan Reservoir, obtained results that indicate that nitrate may act as an alternate terminal electron acceptor following the disappearance of oxygen from the system, thereby inhibiting the release of phosphorus to the water column.

WATERSHED MANAGEMENT

Water Quality Standards

Most man-made lakes, as is Lake Manassas, pass through an initial first fill eutrophic stage produced by leaching soil and decaying vegetation (49). After this internal source of nutrients becomes depleted, the lake is more directly affected by what its tributary streams carry into the impoundment. Stream quality in Virginia is protected by State Water Control Law (28) that mandates the protection of existing high quality waters. Permits to discharge into a stream delineate the quantities of specific pollutants that are allowable. These permits, known as NPDES (National Pollutant Discharge Elimination System) permits, are designed to prevent violations of water quality standards. Stream standards are based on conditions that would occur in the stream whenever flows are equal to, or greater than, the minimum mean 7-consecutive day drought flow with a 10-year return frequency. The standards for Broad Run and other tributaries to Lake Manassas to a point 5 miles above the dam are as follows:

Minimum dissolved oxygen:	4.0 mg/L
Daily average dissolved oxygen:	5.0 mg/L
pH	6.0 - 8.5
Maximum temperature:	32°C

These waters must also meet special requirements of the "Surface Water Standards for Surface Public Water Supplies" (Appendix Table A-1), Potomac Embayment Standards, and Thermal Discharge Standards, and conform to the Occoquan Watershed Policy.

Stream Characterization

Stream water quality reflects the drainage area of the watershed as well as the way in which the land has been altered by man's activities.

Streams carry sediments, nutrients, and any other material that will be carried by the flow in dissolved or particulate form. Of particular significance are material of an organic nature that will exert an oxygen demand on the water, pathogens that may be harmful to aquatic organisms and humans, and any toxic substances which often may go undetected. Nutrients carried downstream may serve to enhance aquatic growth which can result in eutrophication (11, 33).

Ambient streamflow is generally referred to as baseflow. Storm water and runoff contribute what has been termed nonpoint source pollutant loads. Whereas point source discharges, generally from wastewater treatment facilities for sewage or industrial wastes, can be easy to identify and control, nonpoint source pollution is diffuse

and can be controlled only by land use practices. Best Management Practices (BMPs) are practices that have been determined to be effective means of preventing or reducing the amount of pollution generated by nonpoint sources (50).

Nonpoint pollutant loadings can be a significant source of contaminants. Table VII delineates pollutant contributions to surface waters that have been determined from selected nonpoint sources. Dillon and Kirchner (31) published data that suggested a strong effect of geology on phosphorus loads in streams. Table VIII presents their results comparing igneous and sedimentary rock, for both forested watersheds and forest and pasture watersheds in Southern Ontario. However, the National Eutrophication Survey (NES), conducted in 1973 - 1974, found that there did not appear to be any significant effect of geology on stream nutrient loads (51).

The NES was a major project undertaken by the USEPA to study the relationship between drainage area characteristics (particularly land use) and stream nutrient levels. In recent years research has become more focused on nonpoint source pollution. Table IX presents a summary of nutrient export rates associated with different land use categories. Mean nutrient levels were found to be much higher in streams draining agricultural watersheds than in forested watersheds and the concentrations were generally

TABLE VII. ESTIMATED MAGNITUDES OF POLLUTANT CONTRIBUTIONS TO SURFACE WATERS FROM SELECTED NONPOINT SOURCES IN THE CONTERMINOUS UNITED STATES (After Novotny and Chesters, reference 33).

Nonpoint Source Category	Sediment	BOD5	Nitrogen	Phosphorus
	(million tonnes/yr)			
Cropland	1700	8.2	3.9	1.42
Pasture & range	1190	4.5	2.3	0.98
Forest	232	0.73	0.35	0.08
Construction	179			
Mining	54			
Urban Runoff	18	0.45	0.13	0.017
Rural Roadways	2	0.004	0.0005	0.001
Small feedlots	2	0.05	0.15	0.032
Land fills		0.27	0.024	
Subtotal	3377	14.2	6.9	2.5
Background Loading	1150	4.6	2.3	1.0
Total	4527	18.8	9.2	3.5

TABLE VIII. RANGES AND MEAN VALUES FOR EXPORT OF TOTAL PHOSPHORUS FROM 31 SOUTHERN ONTARIO WATERSHEDS (kg/km²/yr) (After Dillon and Kirchner, reference 31).

Land Use	Geological Classification	
	Igneous	Sedimentary
Forest		
Range	2.5 - 7.7	6.7 - 14.5
Mean	4.8	10.7
Forest & Pasture		
Range	8.1 - 16.0	20.5 - 37.0
Mean	11.7	28.8

TABLE IX. A SUMMARY OF NUTRIENT EXPORT RATES REPORTED IN THE LITERATURE (After Brown and Grizzard, reference 52).

Land use	Ortho P	TSP	TP	(NO ₂ + NO ₃) - N	NH ₃ - N	TKN	TN	Source
kg/ha/yr								
Single Family			0.21				1.46	Matraw and Sherwood
Large Lot Single Family			0.17-0.67				1.8-7.1	Hartigan <i>et al.</i>
Single Family			0.77-1.44				4.9-7.1	
Multi-Family			1.29-1.61				6.7-8.4	
High-Rise Residential			1.96-2.18				8.7-9.7	
Shopping Center			2.09-2.14				29.8-30.5	
Central Business District			2.78-2.85				18.9-19.4	
Agriculture	0.01-0.06		0.1-9.1				0.6-42	Pluang
Cropland	0.05-0.4		0.2-4.6				4.3-31	
Improved Pasture	0.02-0.2		0.1-0.5				3.2-14	
Forest	0.01-0.1		0.02-0.67				1-6.3	
Idle	0.01-0.07		0.02-0.67				0.5-6.0	
General Urban	0.05-0.3		0.3-2.1				6.2-10.0	
Residential	0.2		0.4-1.3				5-7.3	
Commercial	0.02-0.08		0.1-0.9				1.9-11	
Industrial	0.3		0.9-4.1				1.9-14	
Developing Urban	0.1		23				63.0	
Urban			2.0				8.5	Wanielista
Residential			1.8				6.6	
Commercial			2.7				14.5	
Pasture			0.50				6.2	
Cultivated			1.05				26.0	
Citrus			0.95				23.0	
Woodland			0.10				3.0	
Contour Corn		0.16	1.65	1.62	0.84		59.3	Alberts <i>et al.</i>
Terrace Corn		0.08	0.23	0.90	0.21		6.35	
Pine Forest		0.06-0.11	0.22-0.37					Duffy <i>et al.</i>
Cultivated Muckland	0.6-30.7			39.2-87.5	1.0-1.9			Duxbury and Peverly
Fallow	0.1-1.2		0.4-2.9	0.1-0.3		0.4-4.1		Nicholaichuk and Read
Prairie	0.02	0.03	0.11	0.12	0.14	0.71		Timmons and Holt
Forest			0.21	0.06				Bedient <i>et al.</i>
Cotton		1.1	6.7				11.6	Menzel <i>et al.</i>
Wheat		0.3	2.2				7.2	
Rangeland		0.04-0.06	0.54-1.86				1.7-6.3	

proportional to the percent of land in agriculture.

In the Occoquan Watershed, studies have quantified the serious nature of nonpoint source pollution problems. Randall, et al. (4) found that point source discharges from upstream wastewater treatment facilities could not alone explain nutrient concentrations in the reservoir. The water quality in the reservoir had continued to deteriorate despite strict control measures taken at the treatment facilities to dramatically reduce pollutant loads. Stormwater runoff was determined to be the greatest source of nutrients and other pollutants. In fact, in 1975, a relatively rainy summer, nearly 90 percent of the phosphorus and 85 percent of the nitrogen entering the reservoir were transported in stormwater flow. The largest pollutant loads had originated in the urbanized portion of the watershed as compared to the agricultural portion, even though the agricultural area was much larger in size.

Protection of Water Supply

Figure 4 illustrates how reservoir eutrophication can affect a water supply, impacting both the user and the purveyor. Walker (53) predicted that more and more stringent standards will be applied to drinking water as our monitoring technology and understanding of the relationships between water quality and health improve. We have already

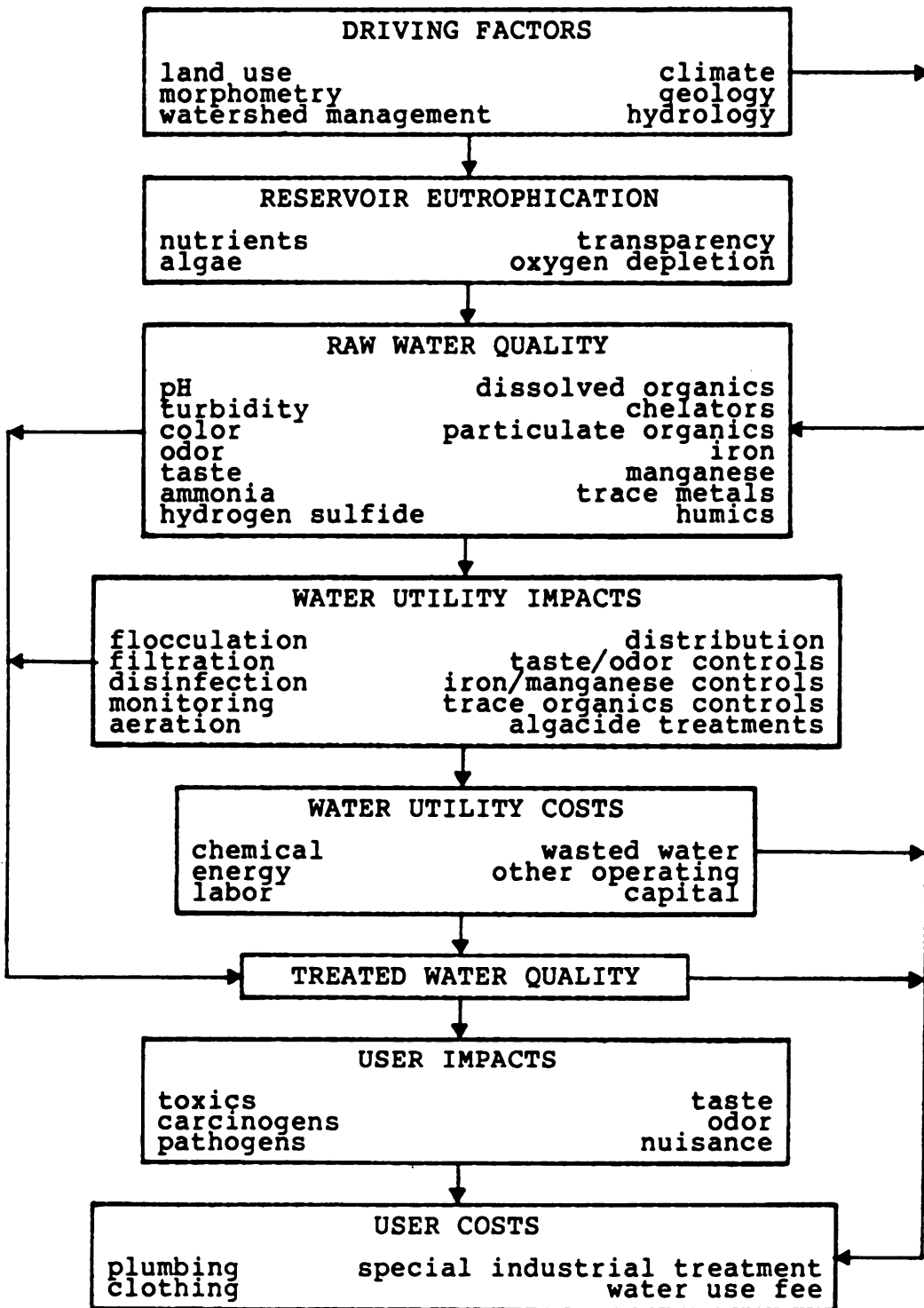


Figure 4. Causal pathways for eutrophication effects on water supply (after Walker, reference 53).

seen the great impact of meeting the standard for trihalomethanes (THMs), not to exceed 1 ug/L, has had on water utilities in terms of process changes and in cost to the industry. There is some indication that the reduction and control of phosphorus through watershed management may ultimately be cost effective for organics-related treatment problems. It is interesting to note that the Lake Manassas Treatment plant is operated with activated carbon in its filter beds to solve periodic taste and odor problems. While the installation of GAC occurred prior to promulgation of THM regulations, it can probably be expected to help in effectively managing any potential trace organics problems that might occur.

Bernhardt (54) delineates the impact of eutrophication on human health: (1) penetration of algae through the treatment plant into finished water inducing bacterial growth from decay in distribution systems, holding reservoirs, and end points; (2) chlorination may be impaired due to algal growth by-products, organic substances; (3) algal organic substances can act as precursors to form THMs when oxidized by chlorination; (4) oxygen reduction in the hypolimnion leads to reductive release of iron and manganese ions which can be difficult problem to remove if found in excess of standards; and (5) increased ammonia resulting from an anoxic hypolimnion can interfere with the dis-

infection process. In addition to these health-related issues, operational problems occur with algae that clog filters and impart an undesirable taste and odor to the finished water.

The watershed is considered a basic ecosystem in water resource management. All management programs within the watershed are likely to impact the lake. The ever-increasing demand for recreational and other uses of lakes makes management imperative. Overuse of lakes detracts from recreational experiences, degrades the environment, and threatens public health (23).

Because Lake Manassas is in a rapidly developing area, its maintenance as a water supply and a recreational resource is of particular importance at this time. Its location in the Occoquan Watershed is opportune for the sake of comparison as well as control. The Occoquan Basin Nonpoint Pollution Management Program (6) may serve the public well in protecting this natural resource and preventing the problems that have plagued the Occoquan Reservoir.

III. METHODS AND MATERIALS

In order to determine the factors affecting water quality in Lake Manassas, the City of Manassas contracted with the Occoquan Watershed Monitoring Laboratory (OWML), located in Manassas, Virginia, to design and implement a sampling program for the lake and its tributaries. Sampling and analysis, which began in October, 1984, was carried out on a regular basis by laboratory personnel according to established procedures. The data generated were subject to quality control testing and stored on the mainframe computer at VPI & SU.

Sampling

Six sampling stations, designated LM01 - LM06, were established on the lake (Figure 5). Station LM01 was near the dam and the raw water intake for the treatment plant. Sampling was done at three-week intervals during warmer months (April through October) and once monthly during colder months (November through March).

At each lake station field measurements were taken at the one-foot depth, the five-foot depth, and then at increments of five feet (10,15,20, etc.) until the bottom was reached. Field measurements included temperature, pH, and dissolved oxygen (DO) concentrations. Alkalinity and spe-

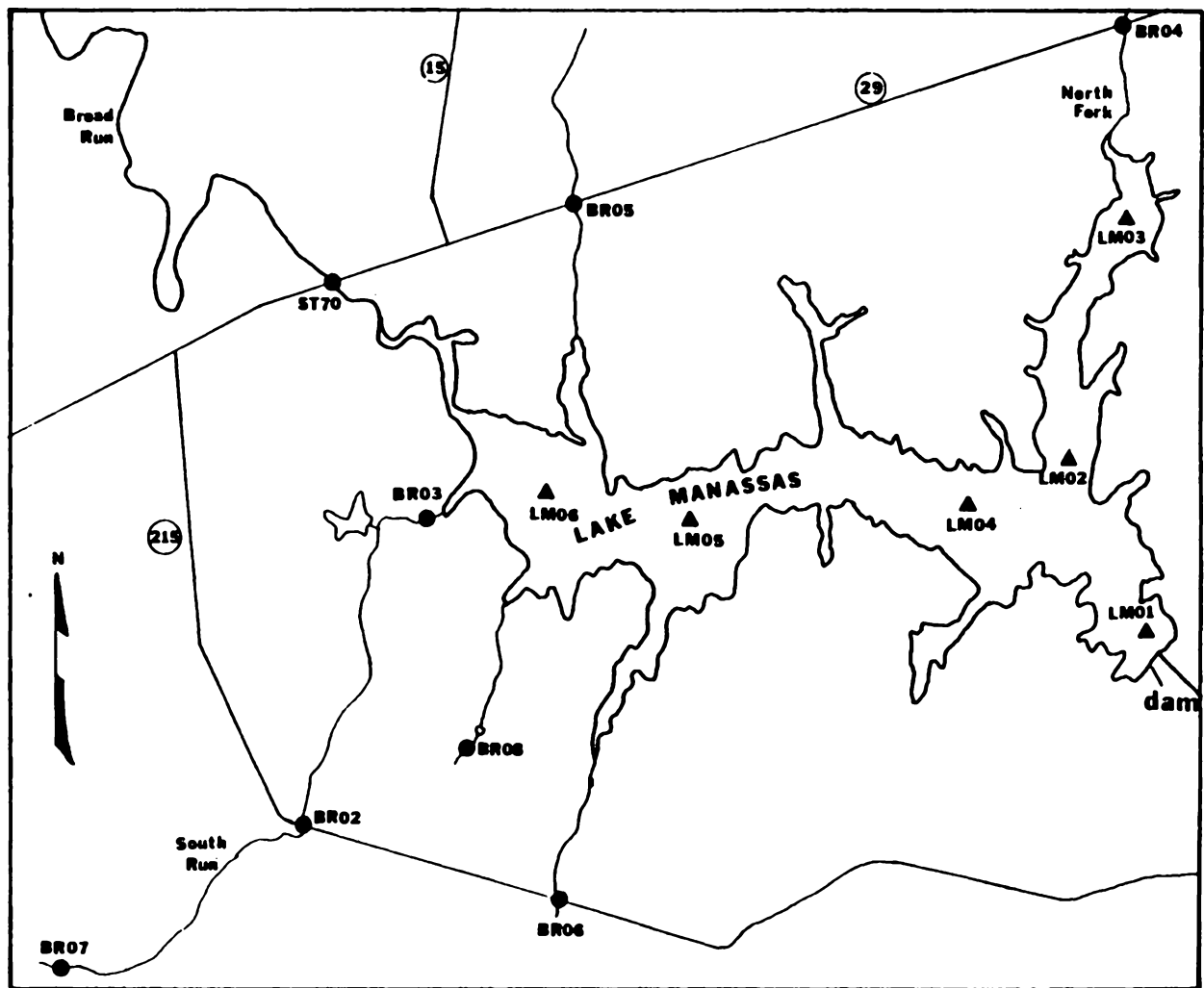


Figure 5. Sampling sites on Lake Manassas and its tributaries.

cific conductivity measurements were taken at the one-foot depth (surface) and the last multiple-of-five-foot depth (bottom). The Secchi disk depth was also determined at each station.

Surface and bottom samples were collected at each lake station to be later analyzed in the laboratory. These analyses included nutrients (nitrogen and phosphorus forms), total suspended solids, chlorophyll a, and pheophytin a.

The OWML maintains a sampling station on Broad Run at Buckland, immediately upstream of Lake Manassas, at Route 29. This sampling location is part of the Occoquan Watershed Monitoring Program (OWMP) and is designated ST70 (Figure 4). It has automatic sampling and gaging capabilities which provide flow-weighted composite samples for water-quality analyses during runoff events and a continuous record of stream-discharge measurements.

The other stream sampling stations, BR02 - BR08, were located on ungaged tributaries. Station ST70 was initially designated as BR01, but the former name was maintained for the sake of data continuity for the OWMP. Samples from BR02 - BR08 were grab samples, taken just below the surface of freely flowing water in midstream. Three sampling sites were located along South Run: one above Vint Hill Farm Station, a U.S. Army Military Reservation (BR07); one immediately below it (BR02); and one where South Run

enters the reservoir (BR03). Vint Hill Farms discharges treated sewage effluent into South Run, so the sampling sites were specifically located to determine the effects of this discharge.

Data from the streams were collected once a month during baseflow conditions and approximately once a month during stormflow conditions, when the streams were flowing higher after rain had fallen. Rainfall did not always generate sufficient runoff to be collected as stormflow in the streams, hence the number of storms represented in the data is less than the number of baseflow samples.

Under baseflow conditions, field measurements were taken of pH, temperature, alkalinity, DO, and specific conductivity at each sample site at a single depth near the surface. Analyses for nutrients and total suspended solids were performed on baseflow and runoff grab samples from the smaller tributaries and on the composite samples from Broad Run.

Analytical Techniques

Dissolved oxygen concentrations and temperature measurements were taken on-site using a YSI Dissolved Oxygen Meter (Yellow Springs Instrument Co., Yellow Springs, Ohio) Model 57. The air calibration technique was used to calibrate the meter in the field. Specific conductivity

was determined with the YSI SCT Meter, Model 33. Measurements for pH were taken with a hand-held "pH-Stick" (Haake Buchler Instruments, Saddle Brook, New Jersey) Model 445-0000, which was also calibrated in the field. Total alkalinity analysis was done with a field kit (Hach Chemical Co., Loveland, Colorado) using the method described in Standard Methods (55). Phenolphthalein alkalinity was also determined for the samples.

Samples were collected with a Kemmerer water sampler and were placed in one-liter plastic containers that had been acid-washed to prevent sample contamination. The samples were put on ice immediately after collection and transported to the lab. They were received within eight hours of collection. Total suspended solids were determined according to Standard Methods using glass-fiber filters. Chlorophyll a and pheophytin a samples, collected in opaque bottles, were also determined according to Standard Methods.

Nutrient analysis consisted of several parameters: total Kjeldahl nitrogen, soluble Kjeldahl nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, soluble orthophosphorus, total soluble phosphorus, and total phosphorus. The analyses made with a Technicon Auto-Analyzer (Technicon Instrument Co., Tarrytown, N.Y.) by techniques described by Technicon Instrument Company and the U.S. Environmental

Protection Agency. The complete citation of analytical methodology for each nutrient form, chlorophyll a, pheophytin a, and total suspended solids can be found in the appendix (Table A-2).

IV. RESULTS

As originally designed, there were two distinct elements to the monitoring program for Lake Manassas. The first was a regular survey of six locations within the lake itself, which included both water-column profile measurements, and the collection of water samples for chemical analyses. In addition, the monitoring effort also included field measurements and water sample collection from several streams, that are tributary to the lake. Both baseflow and storm runoff samples were collected. Because a considerable amount of data are available for both the reservoir itself and its tributaries, they will be presented separately.

LAKE MANASSAS

Samples were collected from Lake Manassas approximately every three weeks during the spring, summer, and fall, and once per month during the winter, providing there was no ice coverage. Figures in this section that represent temporal variations denote the sampling dates by month, which are listed along the abscissa in the order in which they were collected. Specific sampling dates can be found listed in the appendix containing the complete analytical

data (Table A-6). Note that samples were collected twice during the months of July and October, 1985.

Lake Morphology

United States Geological Survey (USGS) maps, 1:24,000 scale, were used to determine the morphometric parameters of Lake Manassas (Table X). The "Thoroughfare Gap" and "Gainesville" quadrangles delineate the original topography of the area that was flooded when Broad Run was impounded. An accurate outline of the lake, based on aerial photographs, was superimposed on the scale map that was originally drawn in 1966. In the absence of more complete bathymetric data, the contour lines shown on these maps were used in estimating areas by a planimeter, and for calculating other parameters shown in Table X.

The shoreline development ratio was calculated as 4.4 which indicates that Lake Manassas is a relatively dendritic body of water, a common feature of river impoundments. The total volume was estimated to be 15.8 million cubic meters (4.2 billion gallons). The volume of the lake has been previously reported as 22 million cubic meters (9), which is significantly larger than that found here. A hypsographic curve showing the relationship between volume and depth has been developed from calculations of the areas and volumes at each elevation delineated by contour lines

TABLE X. MORPHOMETRIC PARAMETERS OF LAKE MANASSAS

PARAMETER	METRIC UNITS	U.S. CUSTOMARY UNITS
Area	$2.86 \times 10^6 \text{ m}^2$	706 acres
Volume	$1.58 \times 10^7 \text{ m}^3$	4.2×10^9 gal
Mean Depth	7.7 m	25 ft
Maximum Depth	16.8 m	55 ft
Shore Line	26.5 km	42.6 mi
Length	3.7 km	2.3 mi
Shoreline Development	4.4	4.4

(Figure 6). Planimetered areas of each contour can be found in the appendix (Table A-3).

The water-renewal time, or hydraulic detention time, in an impoundment, is determined by dividing the water volume by the rate of outflow. Because there is no gaging of discharge over the spillway at Lake Manassas, this parameter is difficult to ascertain. However, if one assumes the inflow equals outflow and that all the inflow is from Broad Run (which averages 52.8 cfs), the calculated detention time would be 123 days. The calculation also can be made by using the minimum gaged outflow when 6.2 cfs (4 MGD) is diverted to the treatment plant and about 12 cfs (2) is released downstream. In this instance, the calculated detention time would be 210 days. Both these calculations are only gross estimates because accurate outflow data are lacking.

Thermal Regime

Station LM01 is the deepest of the reservoir sampling stations. Because it is also the station closest to the raw water intake for the water treatment plant, emphasis has been placed on these results.

Thermal stratification at Station LM01 was noticeable by the end of April, and Figure 7 illustrates the development of the thermocline between February and July of 1985.

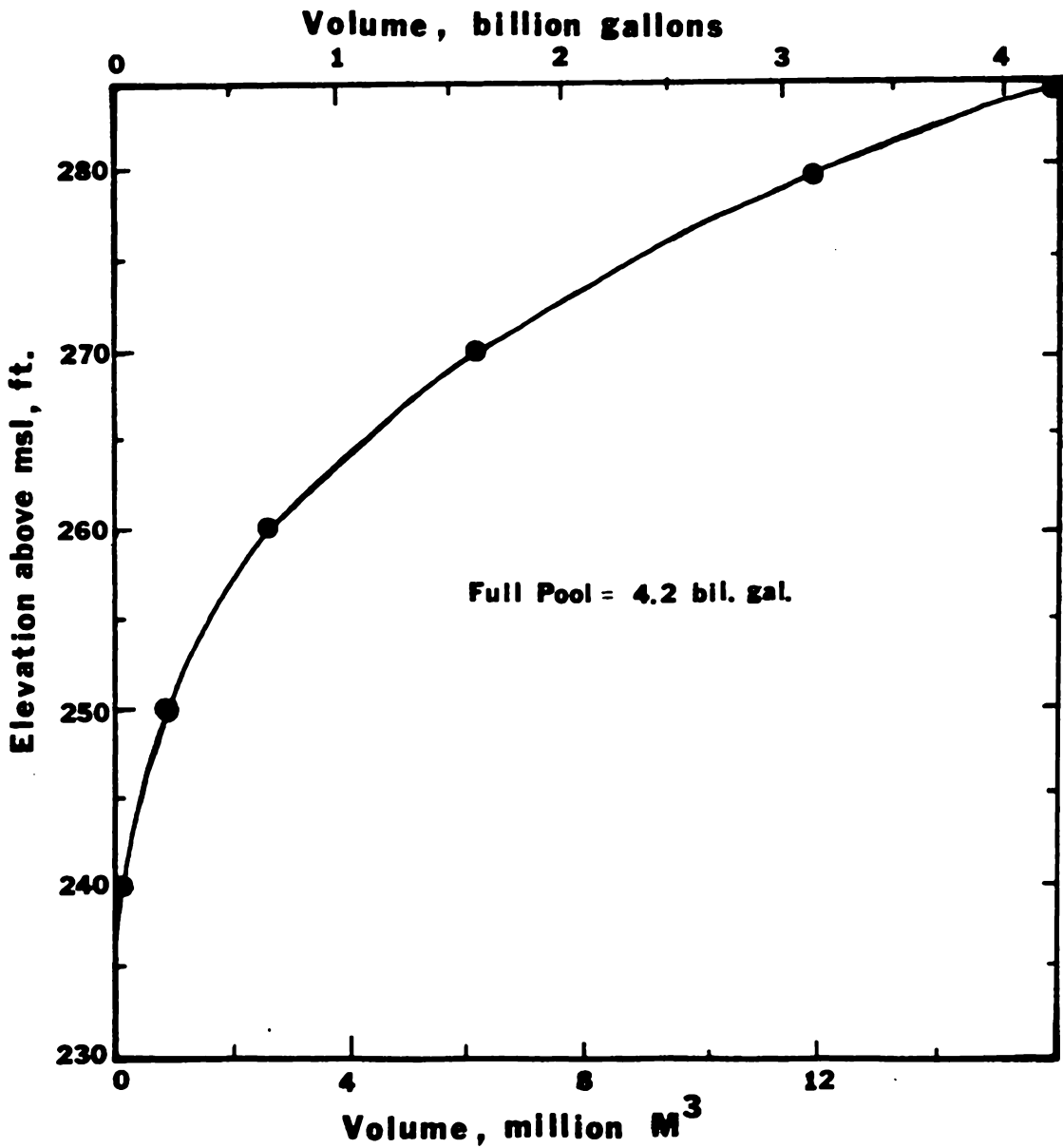


Figure 6. Hypsographic (volume-depth) curve for Lake Manassas derived from planimetered areas formed by contour lines on USGS maps, 1:24,000 scale.

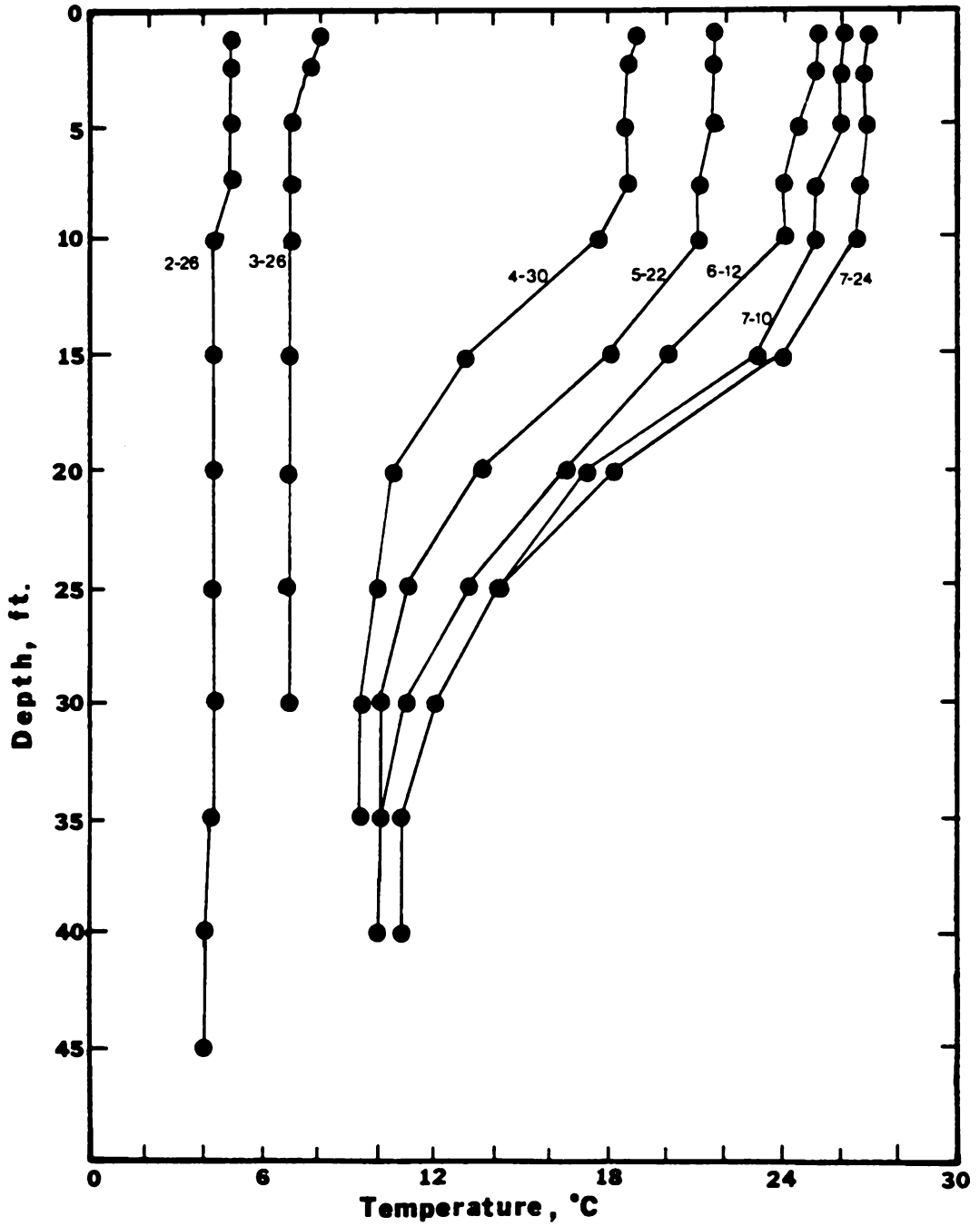


Figure 7. Thermocline development at Station LM01, Lake Manassas, February through July, 1985.

Temperatures at the one-foot depth increased 11°C (from 8°C to 19°C) between March 26 and April 30, 1985. In contrast, the temperature increased only 2.5°C , from 7°C to 9.5°C , at the 30-foot depth. Similar changes occurred during the spring of 1986.

While the lake remained stratified, the difference in temperature between the near-surface and the bottom waters was 10°C or greater. On July 9, 1986 the difference in surface and bottom temperatures was the greatest recorded to that date: 28°C at the surface, but only 10.5°C at 45 feet.

Stratification of the main body of the reservoir followed a pattern similar to that described for Station LM01. Figure 8 illustrates the development of the thermocline in 1985 for Stations LM01 through LM06. The extent to which the thermocline developed and remained stable was dependent on the depth of the reservoir at that point. The temperatures at each station became uniform to a depth of 10 ft. as the surface waters warmed during the spring. As the summer progresses the epilimnion at Stations LM01, LM02, and LM04 extended to a depth of 15 ft. The thermoclines at Stations LM03, LM05, and LM06, however, while evident in early surveys, disappeared by July 10. The depth of the reservoir at these shallower stations did not extend below the depth of the epilimnion.

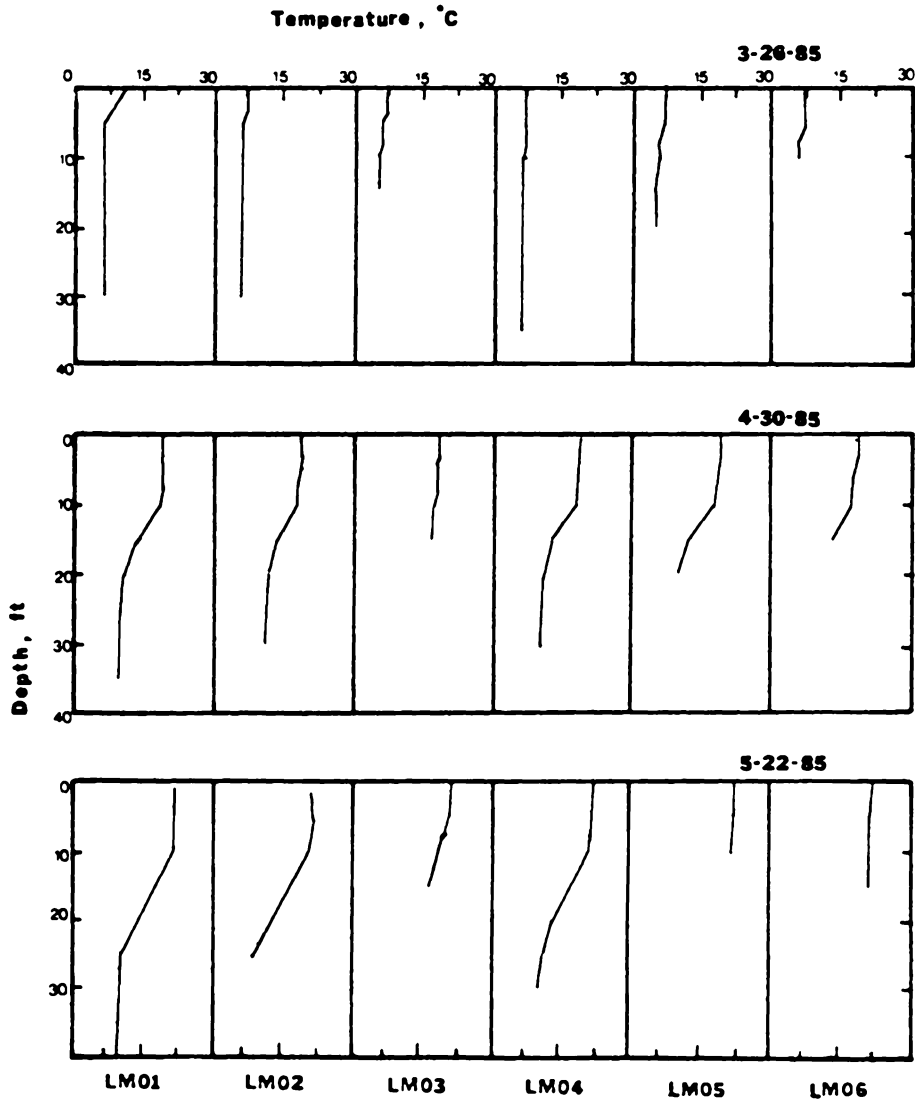


Figure 8. Thermocline development in Lake Manassas at Stations LM01-LM06, Spring and Summer, 1985.

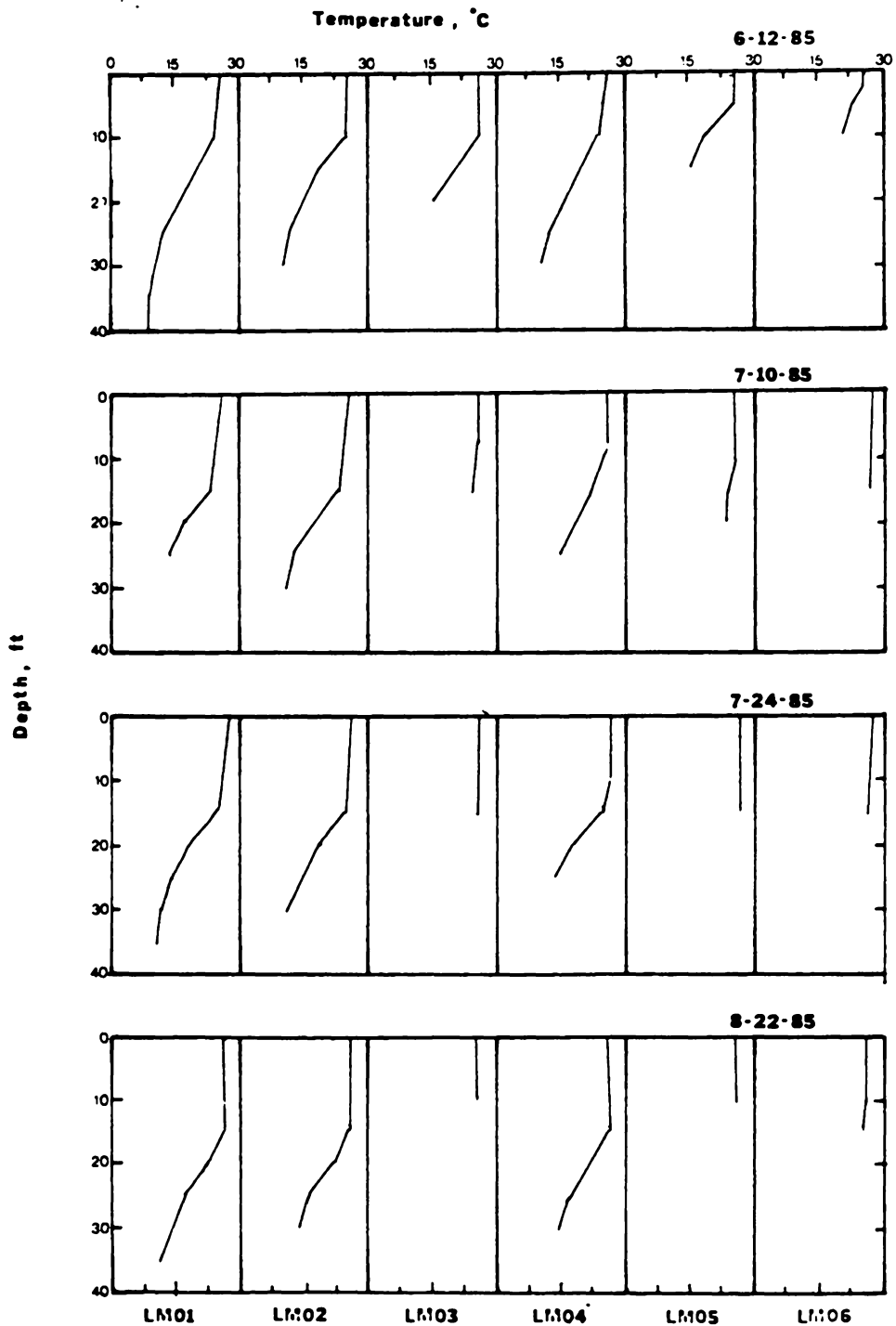


Figure 8 (continued). Thermocline development in Lake Manassas at Stations LM01-LM06, Spring and Summer, 1985.

Dissolved Oxygen Variation

As is typical of temperate lake dynamics, the concentration of dissolved oxygen changed seasonally. The dissolved oxygen (DO) concentrations expressed as mg/L and as a percentage of a saturated DO concentration (percent saturation), along with the temperature data collected at Station LM01 are illustrated in Figures 9 and 10. These relationships are typical of winter (Figure 9) and summer (Figure 10) distributions of oxygen content and temperature.

At Station LM01, on July 24, 1985 (Figure 10), the epilimnion extended to approximately 10 ft., the metalimnion from 10 to 15 ft., and the hypolimnion from 15 ft. to the bottom. Oxygen levels at the bottom remained below 0.5 mg/L from June 12 through October 16, 1985, with the exception of October 4 (Figure 11).

Temporal variations in oxygen concentrations at the other reservoir stations, at surface and bottom, are presented in Figures 12-16. Stations LM02 and LM04 follow the same pattern of sustained bottom-level oxygen depletion as Station LM01, which occurred during the summer months, except that on October 4 the bottom depths remained low in oxygen content. Stations LM03, LM05, and LM06 did become oxygen deficient on several occasions despite the absence of a measured thermocline barrier. This might have been caused by an oxygen depletion rate that was greater than

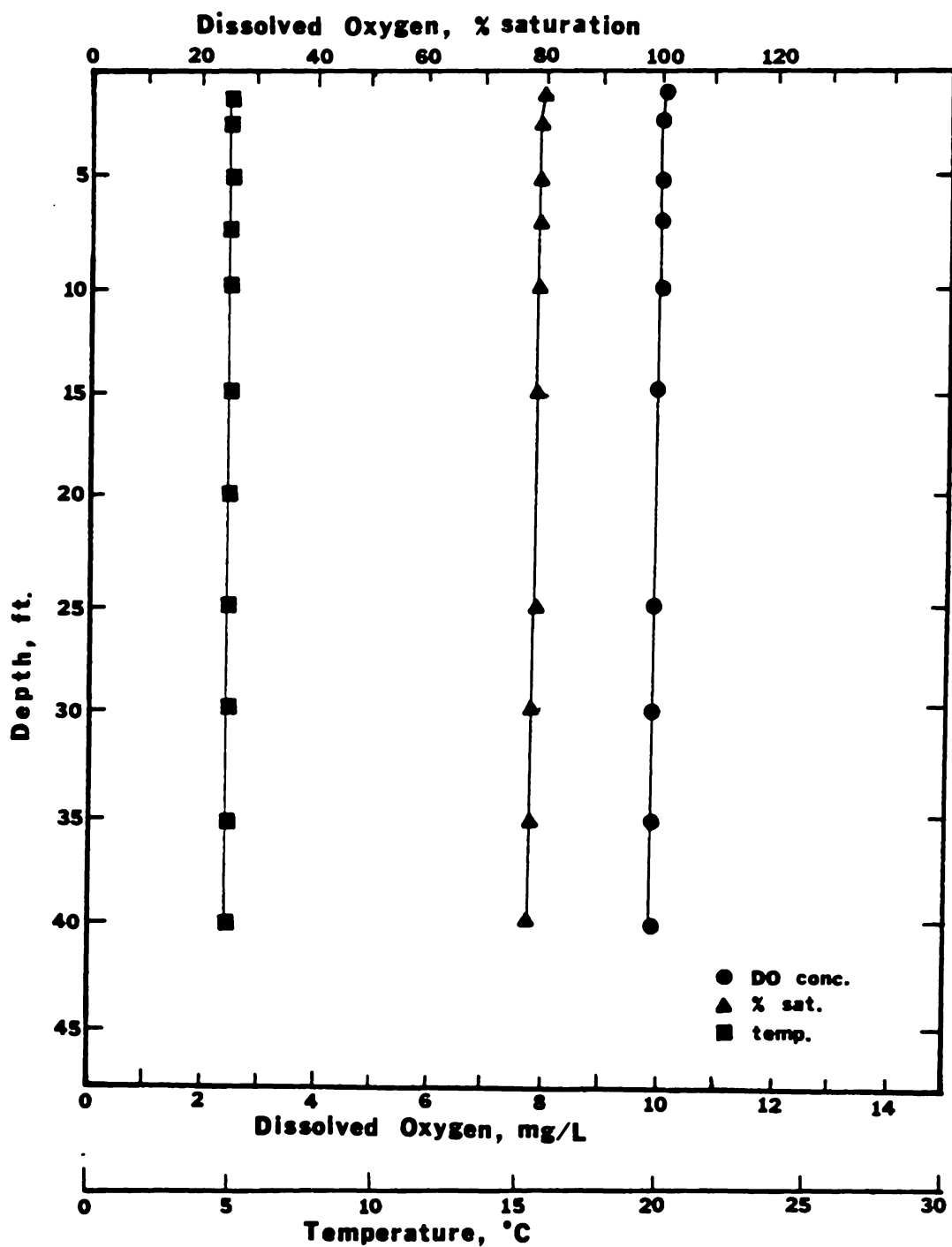


Figure 9. Dissolved oxygen and temperature profiles at Lake Manassas Station LM01 on December 11, 1984.

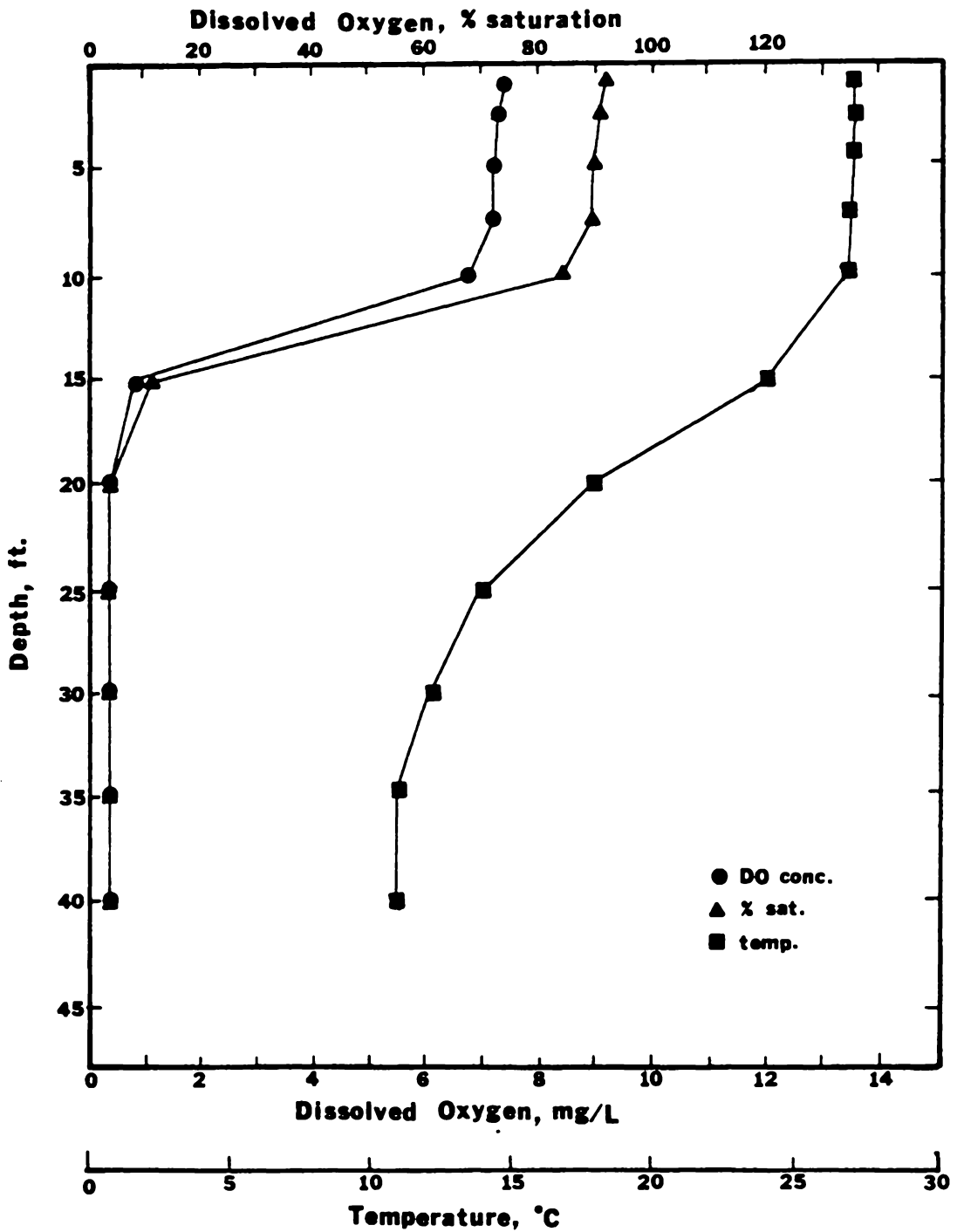


Figure 10. Dissolved oxygen and temperature profiles at Lake Manassas Station LM01 on July 25, 1985.

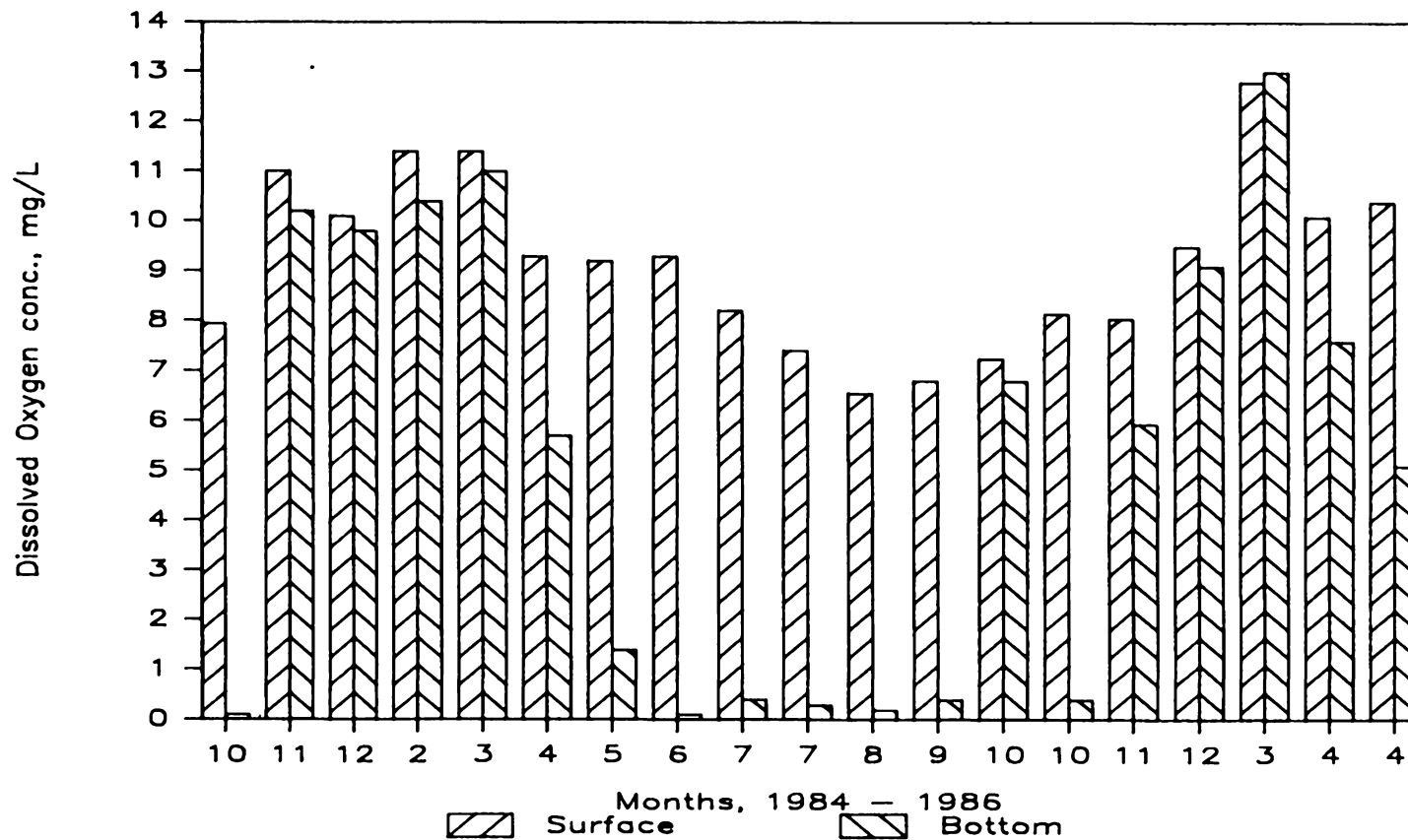


Figure 11. Dissolved oxygen variations at the surface and bottom of Station LM01, Lake Manassas.

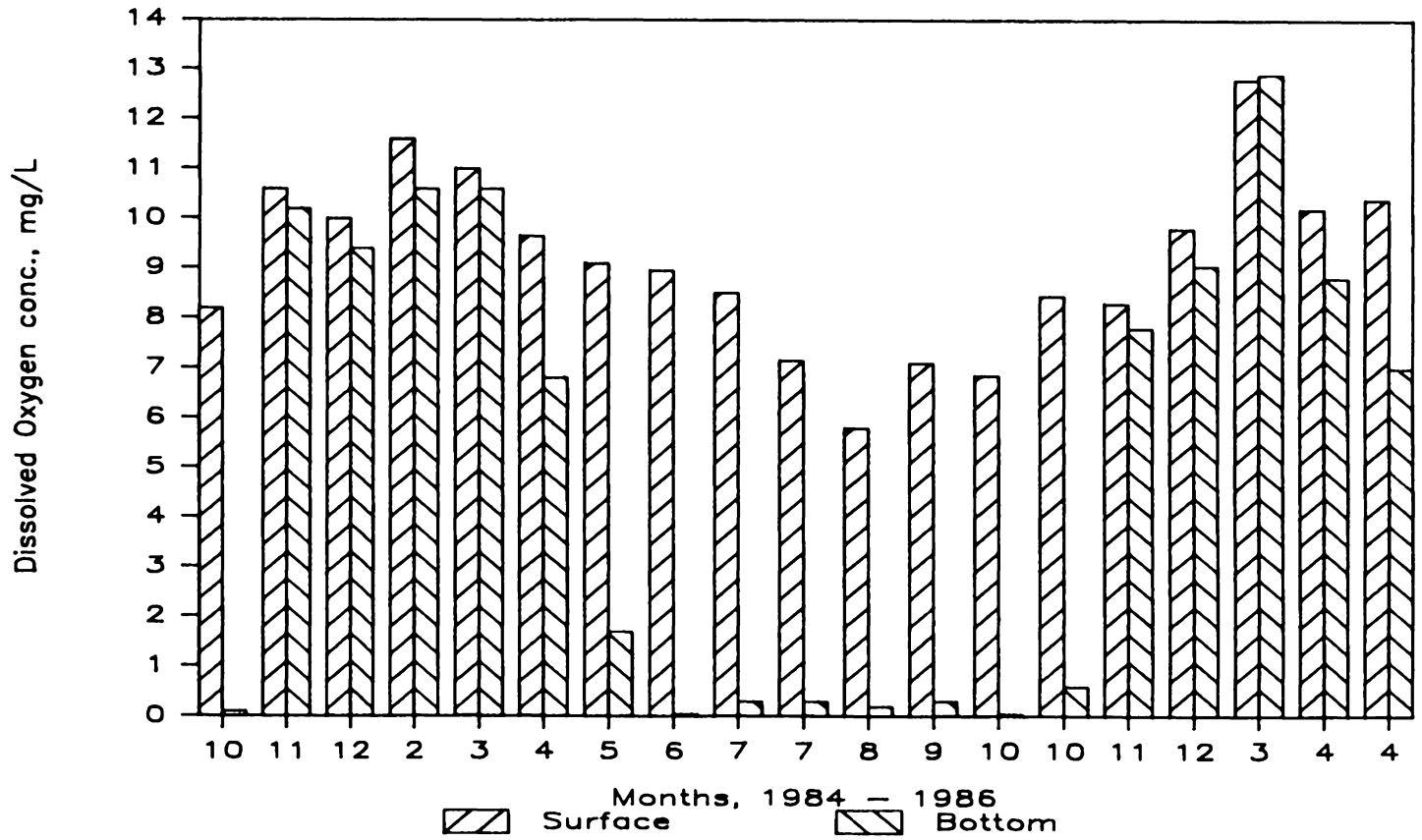


Figure 12. Dissolved oxygen variations at the surface and bottom of Station LM02, Lake Manassas.

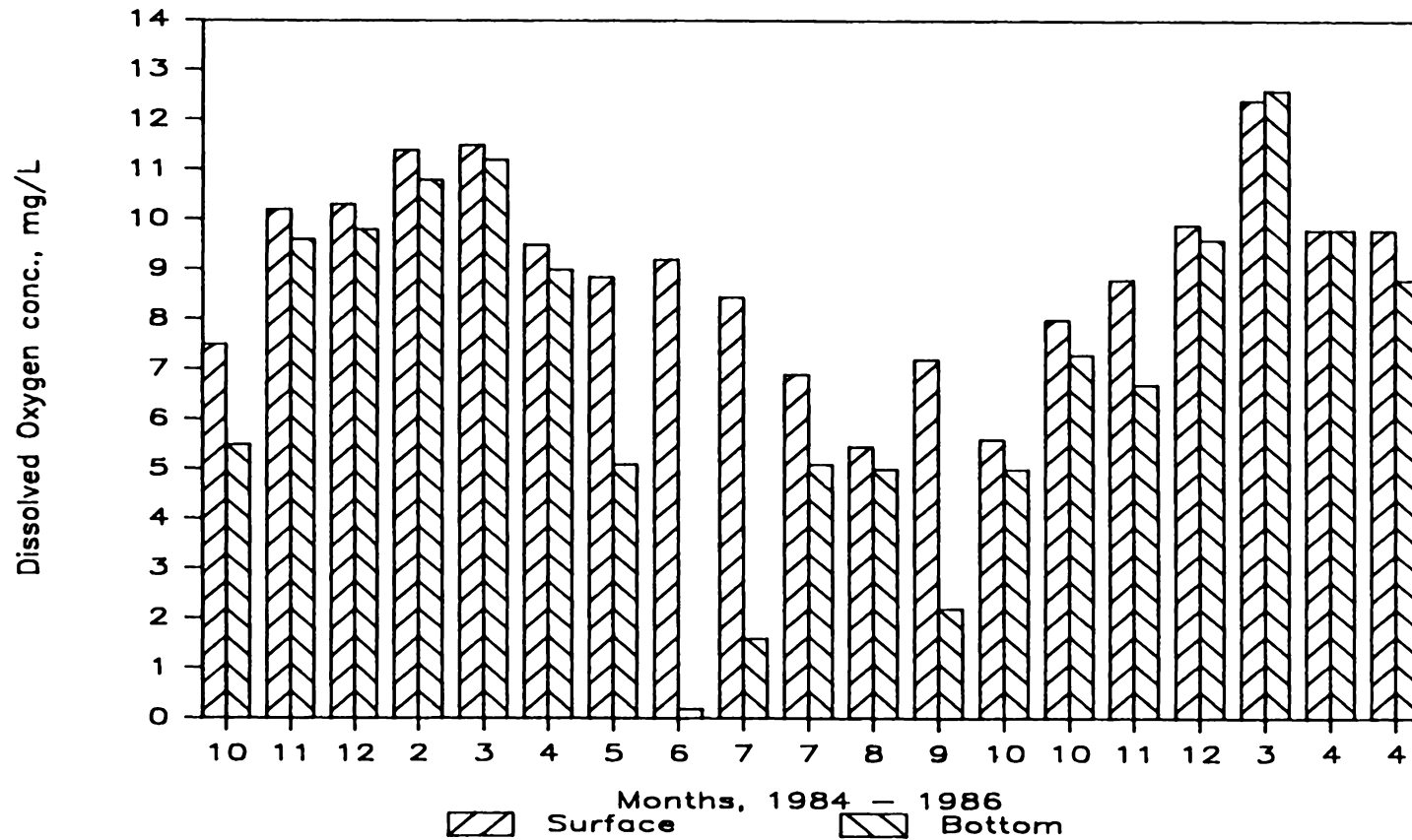


Figure 13. Dissolved oxygen variations at the surface and bottom of Station LM03, Lake Manassas.

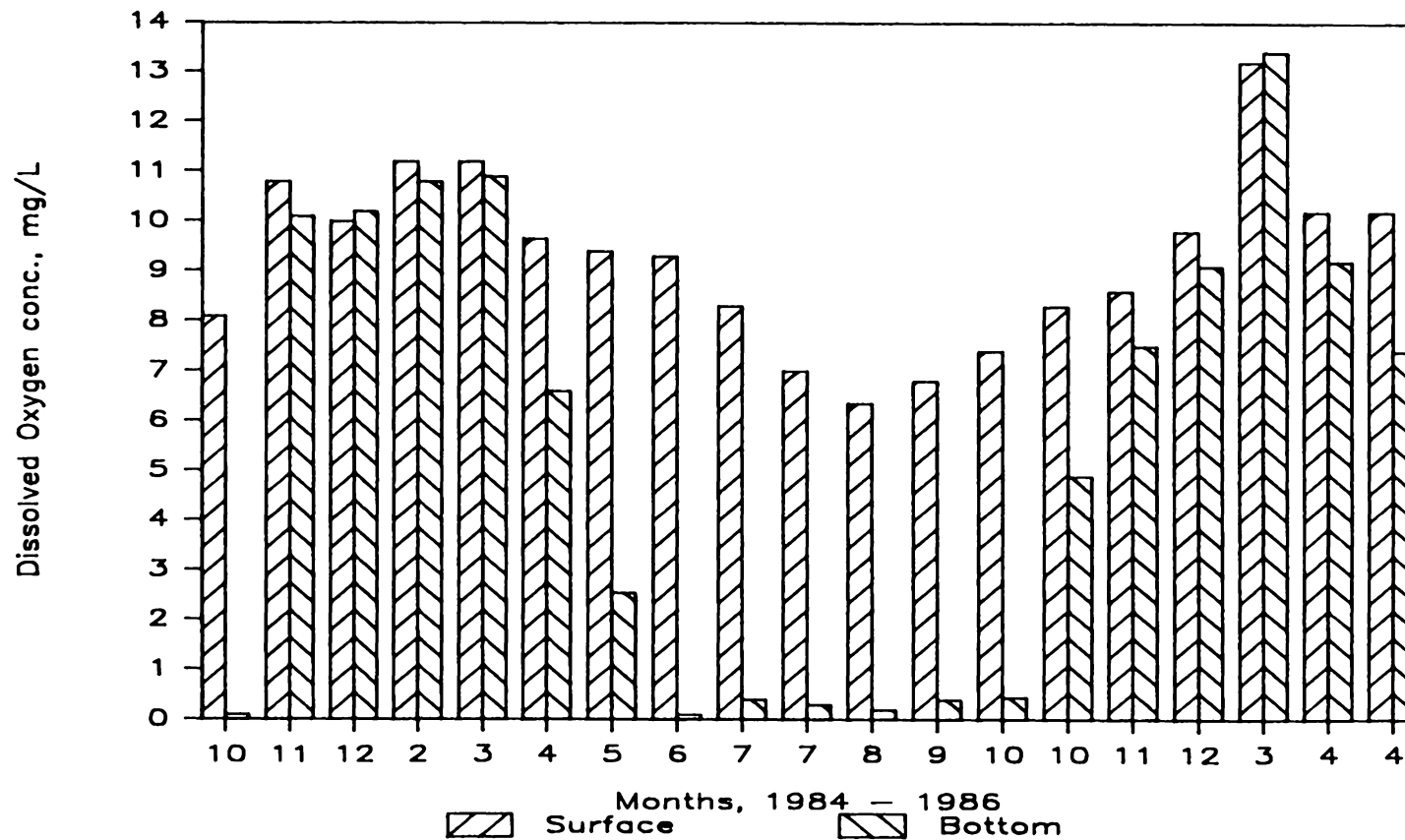


Figure 14. Dissolved oxygen variations at the surface and bottom of Station LM04, Lake Manassas.

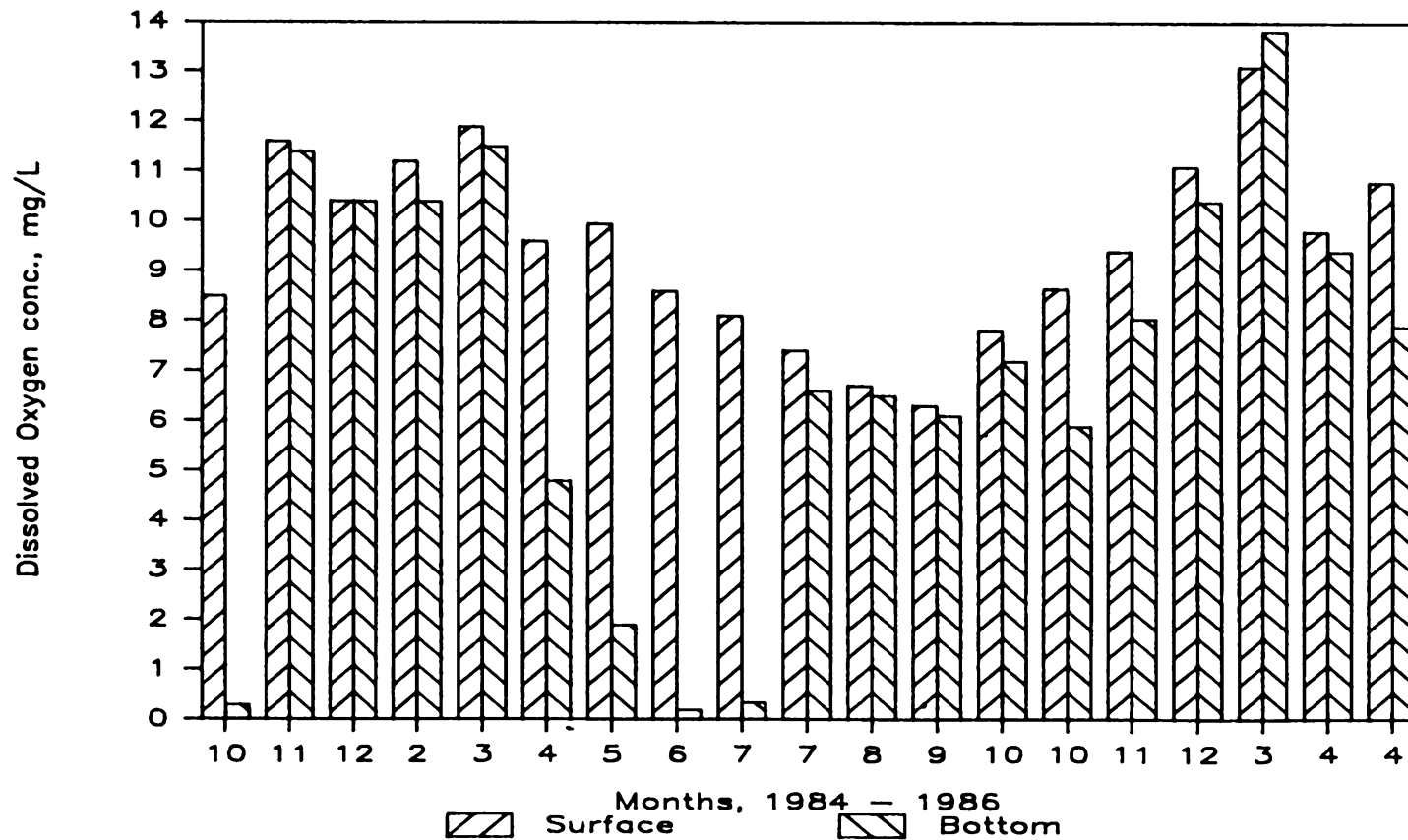


Figure 15. Dissolved oxygen variations at the surface and bottom of Station LM05, Lake Manassas.

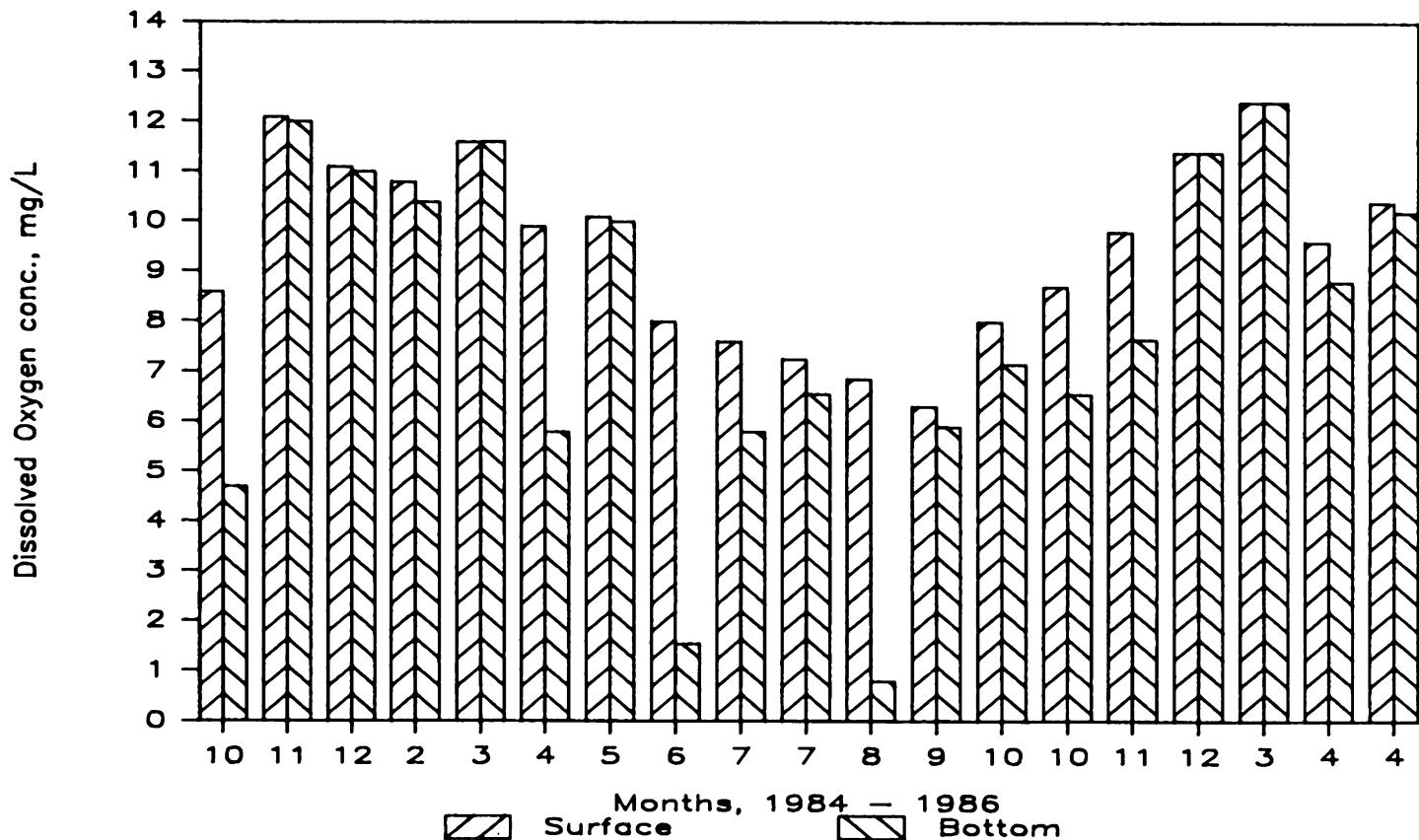


Figure 16. Dissolved oxygen variations at the surface and bottom of Station LM06, Lake Manassas.

the reaeration rate from epilimnetic circulation.

Percent DO saturation was calculated from equations given in Standard Methods (55). Figure 17 is an isopleth illustrating variations in DO saturation at Station LM01. Because the measured depth at the actual sampling location varied between 25 and 45 feet, the isopleths for lower depths are incomplete. The vertical lines during the winter months indicate a relatively high concentration of dissolved oxygen in deep waters. As the thermocline develops in April, the lower depths become depleted of dissolved oxygen. The isopleth representing the five percent DO saturation extended as far as 20 feet from the surface during June through August, 1985.

Figure 17 also indicates the presence of supersaturated dissolved oxygen concentrations, which typically indicate intense algal activity. From the end of April to the middle of July, 1985, and for most of April through July, 1986, the surface waters remain at or above 100 percent DO saturation concentrations. On May 19, 1985, full saturation extended to a depth of 10 ft. The highest saturation recorded at LM01 occurred on June 12, 1985, when the surface water was at 112 percent DO saturation.

All stations exhibited fairly uniform dissolved oxygen saturation profiles in March of each year (Figure 18). As the surface temperatures increased, however, saturation

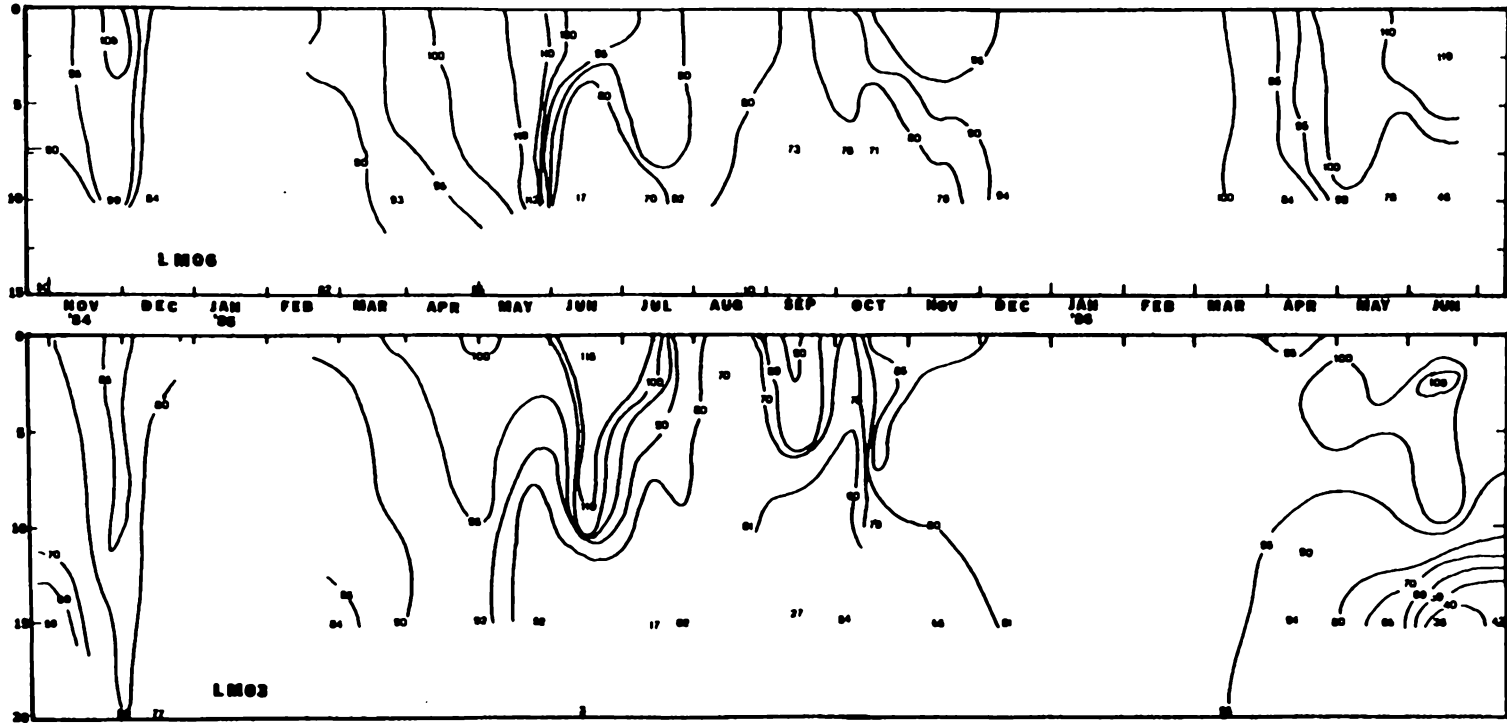


Figure 17. Isopleth of dissolved oxygen saturation, Lake Manassas Station LM01.

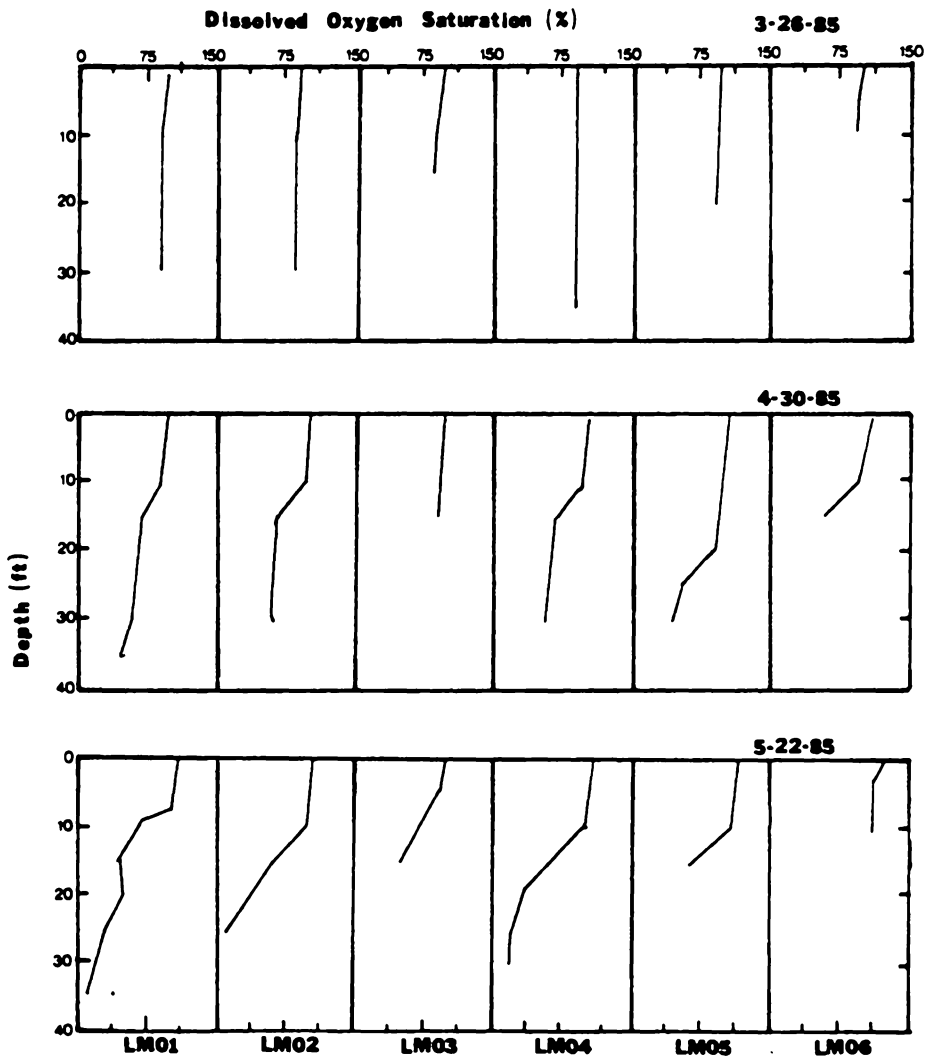


Figure 18. Dissolved oxygen saturation profiles in Lake Manassas, Stations LM01-LM06, Spring and Summer, 1985.

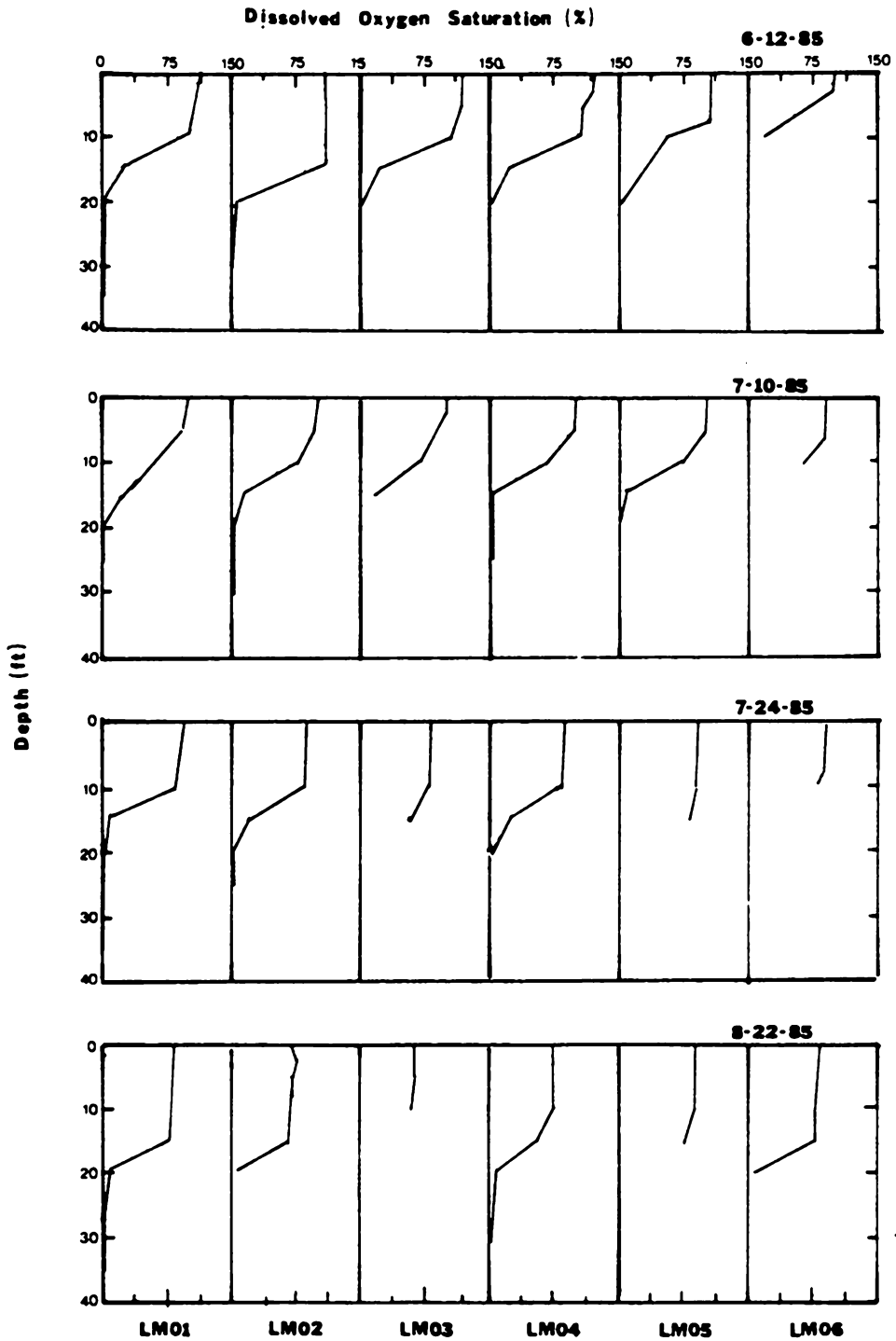


Figure 18 (continued). Dissolved oxygen saturation profiles in Lake Manassas, Stations LM01-LM06, Spring and Summer, 1985.

levels began to decline below a depth of 10 ft. at all stations except for Station LM03. Stations LM01, LM02, and LM04 were similar, developing the same profiles of oxygen saturation decreasing significantly below 20 ft. The profiles at the remaining stations were similar though the lake was generally not deep enough at each station to permit near anaerobic conditions to develop at their deepest point. Station LM03 appeared to be the most variable with respect to oxygen concentrations, possibly because the lake received water from the North Fork tributary at this point.

The dissolved oxygen concentrations were above saturation at each station one-third of the time (Appendix Table A-5). The majority of these supersaturated conditions occurred from April to July during 1985 and 1986. The average depth of the zone of supersaturation was 7.5 feet, but it often extended as far as 10 feet. While the highest degree of DO saturation was generally found near the surface, on several occasions the highest levels occurred at 2.5 or 5 feet below the surface of the water. Circular subsurface isopleth lines at stations LM01 and LM03 illustrate this phenomenon (Figures 17 & 19). Station LM06 showed the highest degree of supersaturation (Figure 19). These effects extended throughout the water column at this location during some periods.

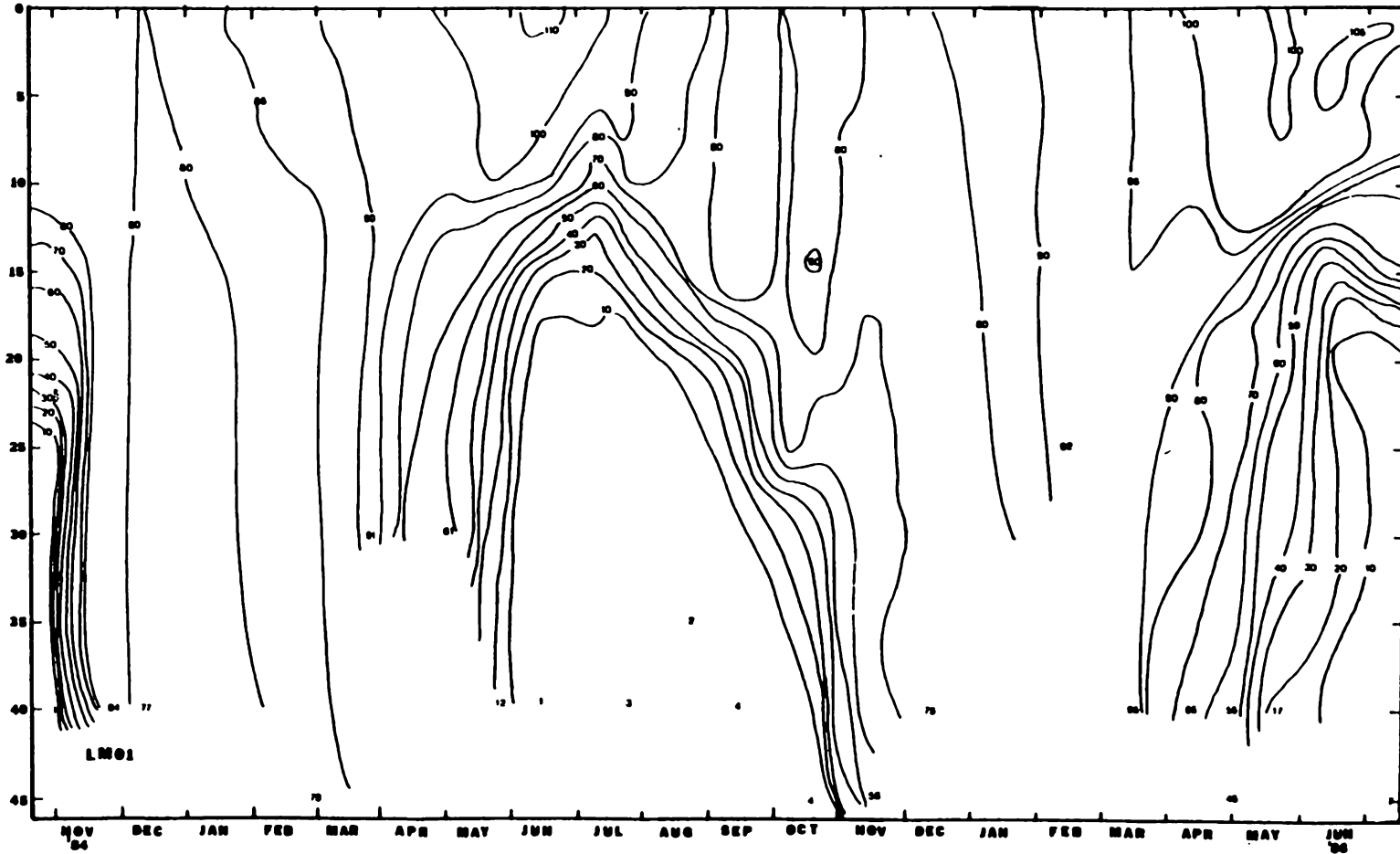


Figure 19. Isopleths of dissolved oxygen saturation in Lake Manassas at Stations LM06 and LM03.

Algal Activity

Chlorophyll a concentrations provide an estimate of algal biomass. Figure 20 illustrates the variation with time of chlorophyll a concentrations in the reservoir over the period of time samples were collected. Each point represents the mean concentration of all stations for each date sampled during the month indicated on the abscissa. Samples were collected at a depth of one foot (0.3 m).

The lowest value of 4.6 ug/L occurred on October 31, 1984. From April to December, the overall chlorophyll a concentration increased to the highest value of 13.3 ug/L on December 10, 1985. An increase in the mean concentration occurred on March 26, 1985. This could be attributed to the occurrence of spring turnover, whereby nutrients trapped at lower depths, due to stratification, become available to algae at the surface. An increase in algal growth because of this increase in available nutrients is reflected in the high chlorophyll a concentrations. The highest mean chlorophyll concentrations, measured during November and December, 1985, were due to the extremely high concentrations at LM05 and LM06. These will be discussed later.

On occasion, copper sulfate has been applied as an algicide to Lake Manassas. It was generally added in the spring of each year to the main body of the reservoir.

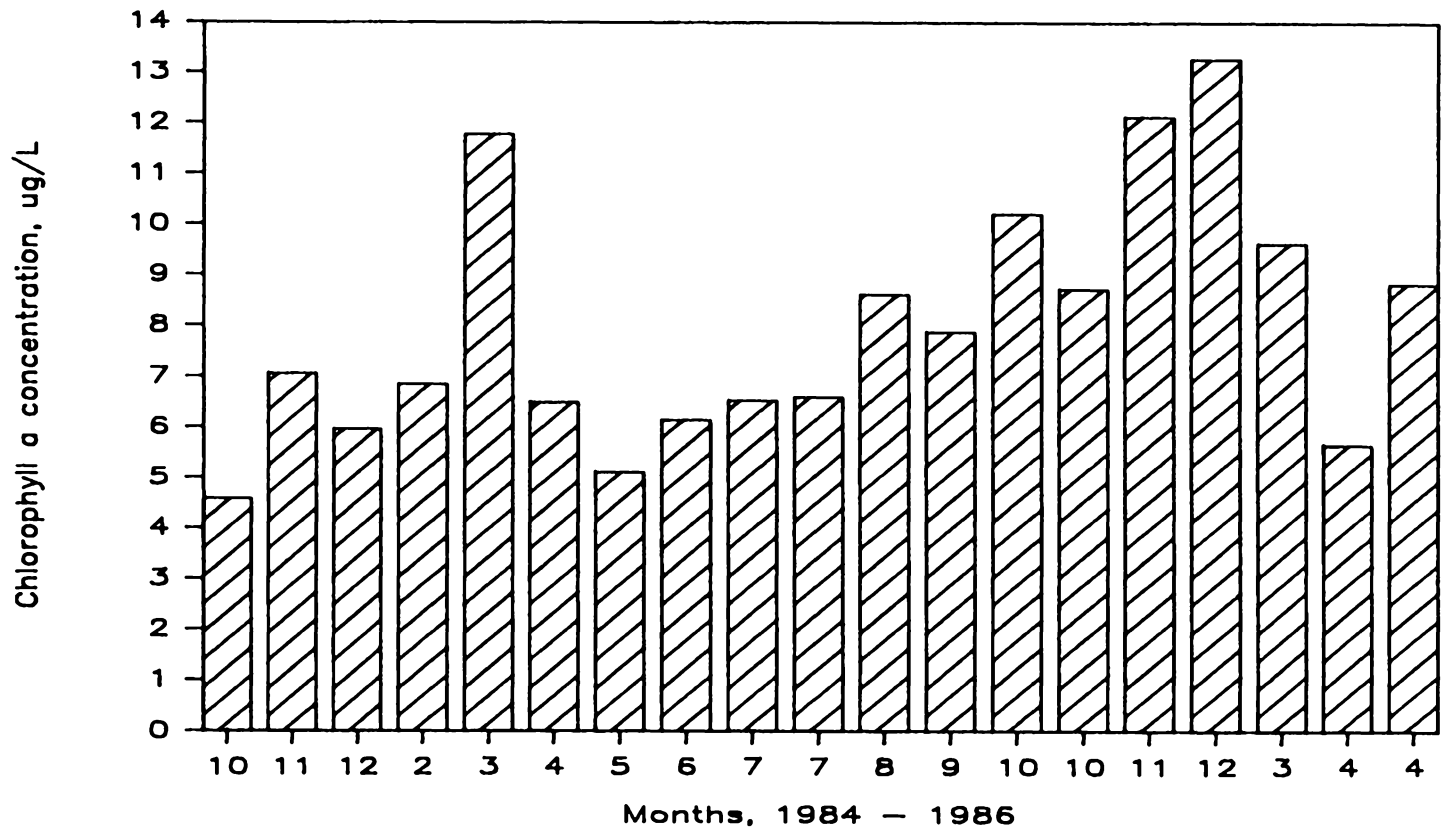


Figure 20. Chlorophyll a variation in surface samples from Lake Manassas.

Additional applications were made when the water treatment plant operators perceived a potential problem with taste and odor producing algae. The dates of application and the sampling dates following each application are presented in Table XI. The effect of the copper sulfate may explain the decrease in chlorophyll a concentrations observed in April and May, 1985 and in April, 1986. Copper sulfate is not applied to the North Fork arm of the reservoir (2).

Individual profiles of each station for chlorophyll a concentrations are illustrated in Figures 21 - 26. The same peak in concentration during March, 1985 was noted at all stations except for LM03, which is located far up the North Fork arm of the reservoir. Chlorophyll a concentrations also peaked at Stations LM01, LM02, and LM04 in March, 1986. Chlorophyll a concentrations fluctuated at Stations LM05 and LM06 more than at the other stations, and overall was significantly greater than at the other stations. The maximum value determined for Station LM05 was 25 ug/L and for Station LM06 26 ug/l. The maximum values observed at other stations was 14 ug/L.

Table XII contains mean concentrations of chlorophyll a and pheophytin a for the entire sampling period from October, 1984 through April, 1986. Station LM06 had the highest mean concentration of chlorophyll a (11.4 ug/L). Station LM05 had the next highest mean concentration with 9.1

TABLE XI. COPPER SULFATE APPLICATIONS TO LAKE MANASSAS
AND SUBSEQUENT SAMPLING DATES

CuSO ₄ APPLICATIONS		SAMPLING	
Date applied	Quantity applied	Date sampled	No. days after sampling
April 10, 1985	5200 lbs.	April 30, 1985	20 days
May 15, 1985	5200 lbs.	May 22, 1985	7 days
April 2, 1986	5200 lbs.	April 9, 1986	5 days

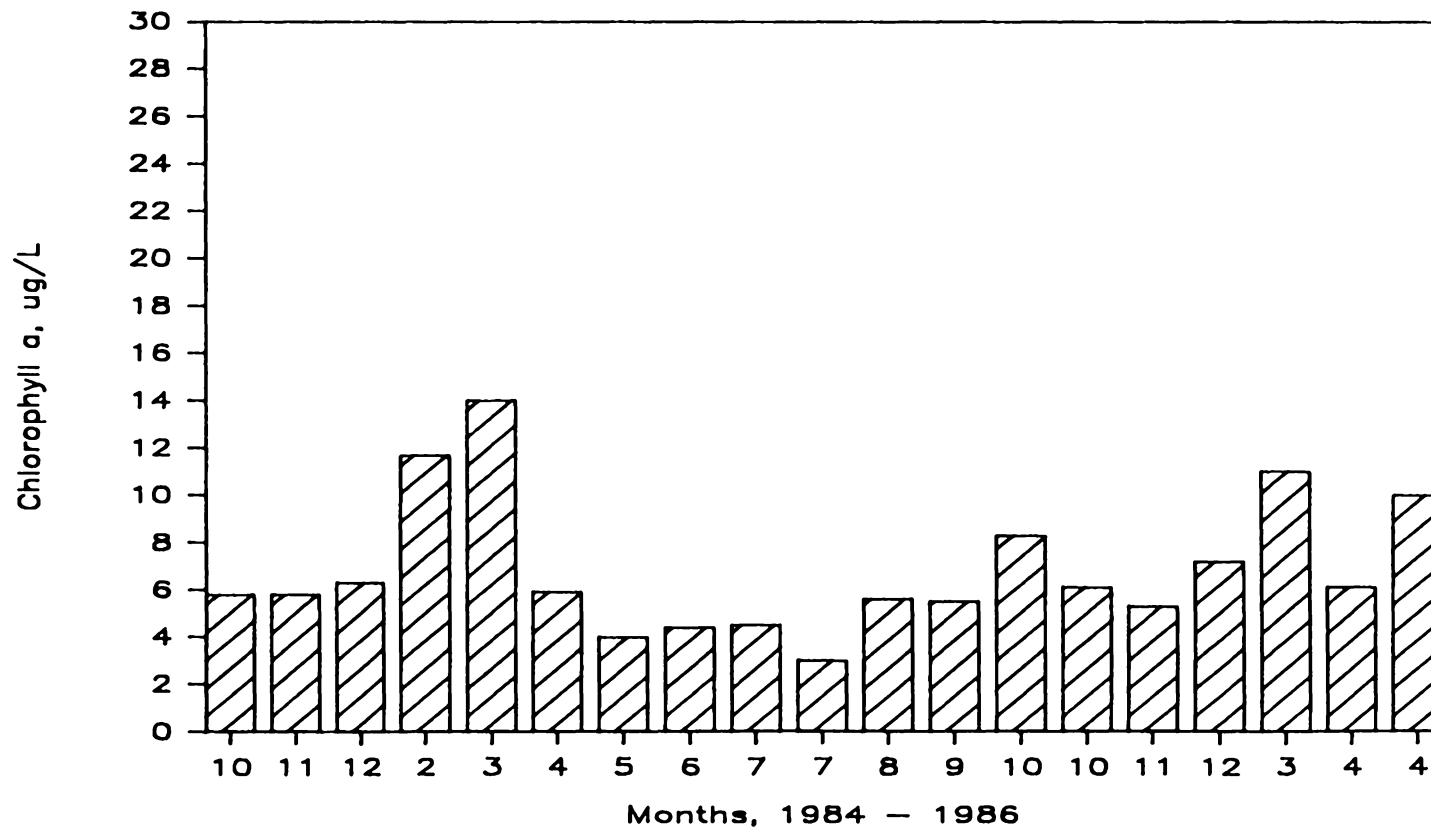


Figure 21. Chlorophyll a variation at Station LM01, Lake Manassas.

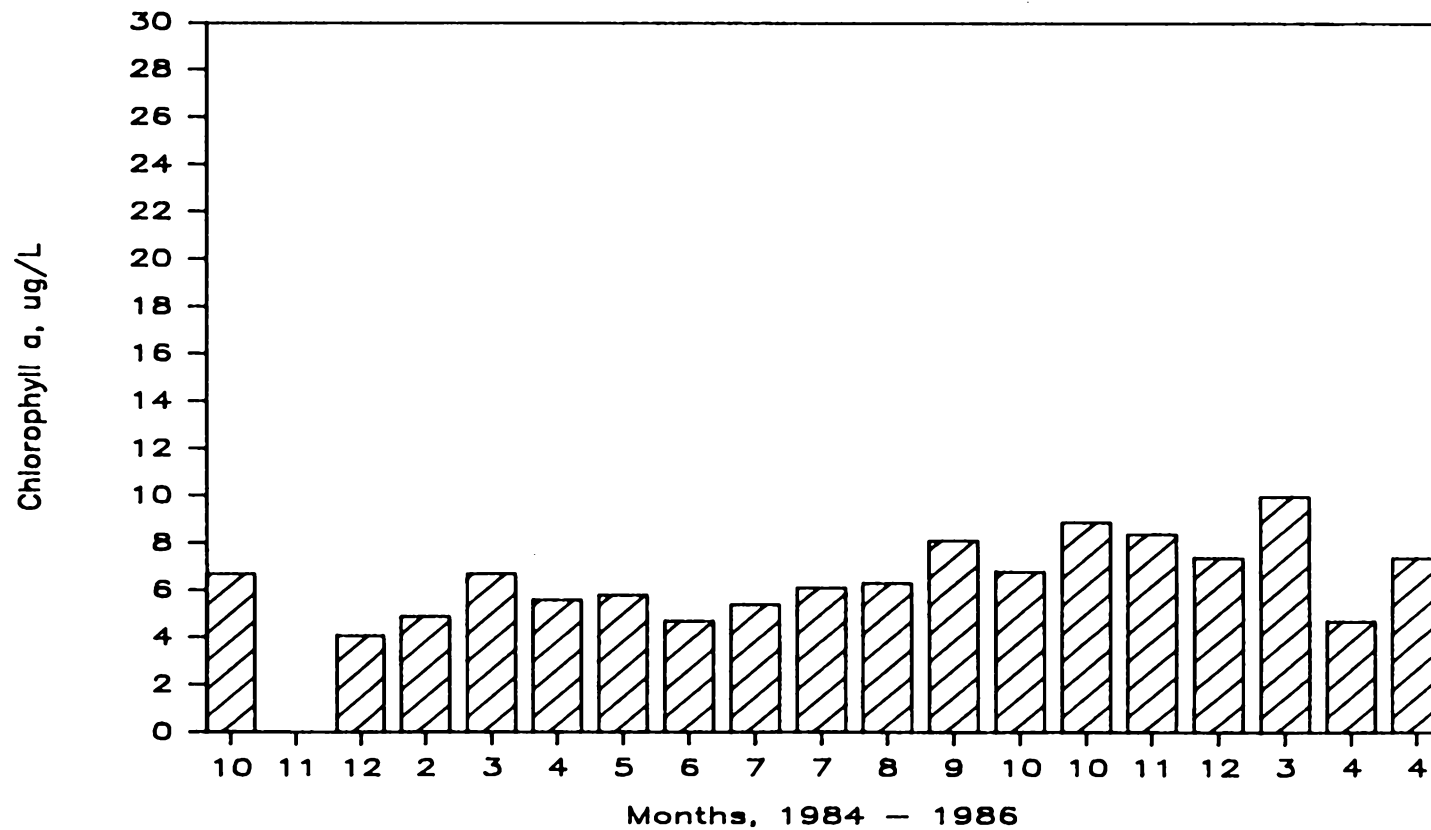


Figure 22. Chlorophyll a variation at Station LM02, Lake Manassas.

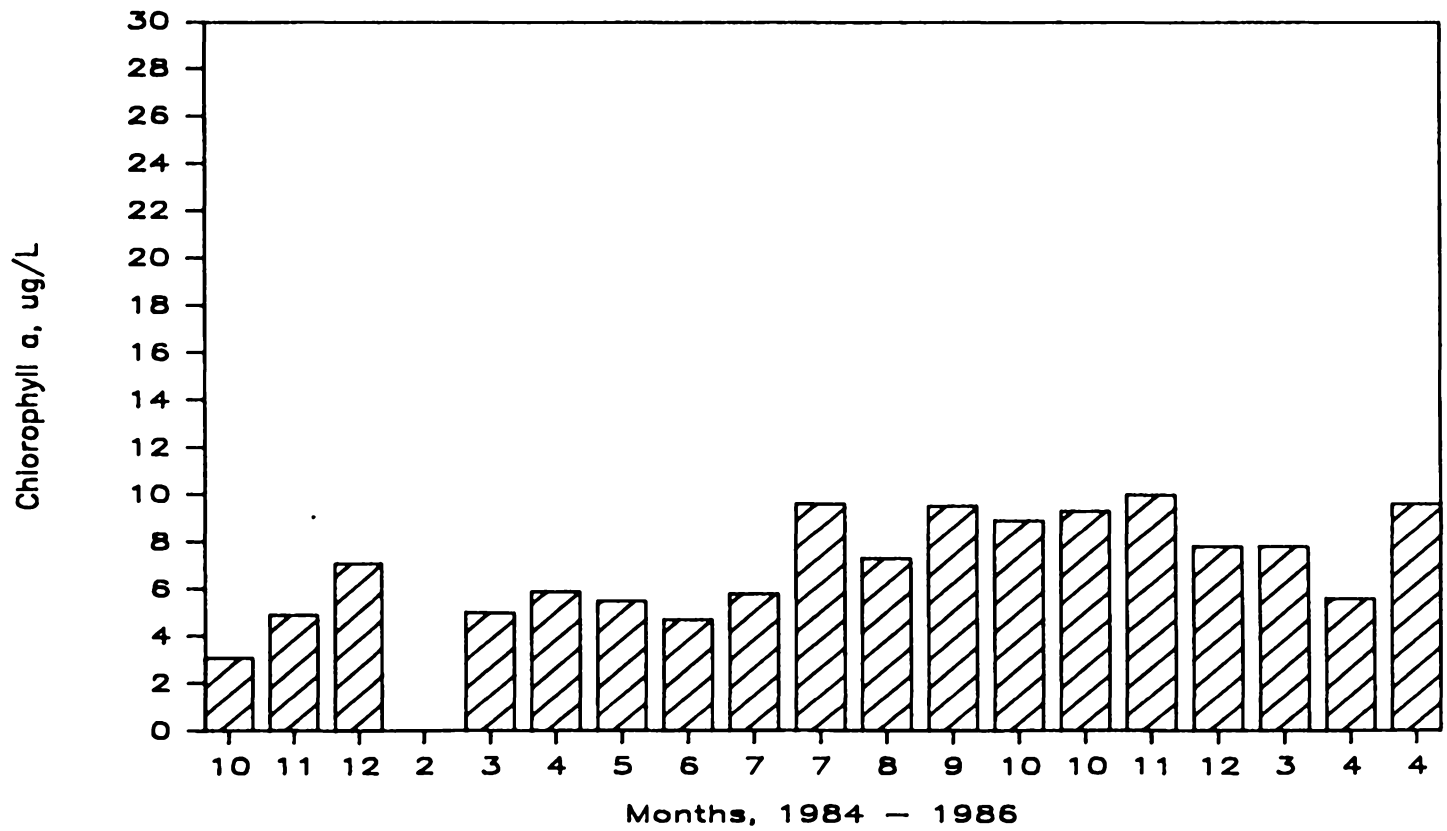


Figure 23. Chlorophyll a variation at Station LM03, Lake Manassas.

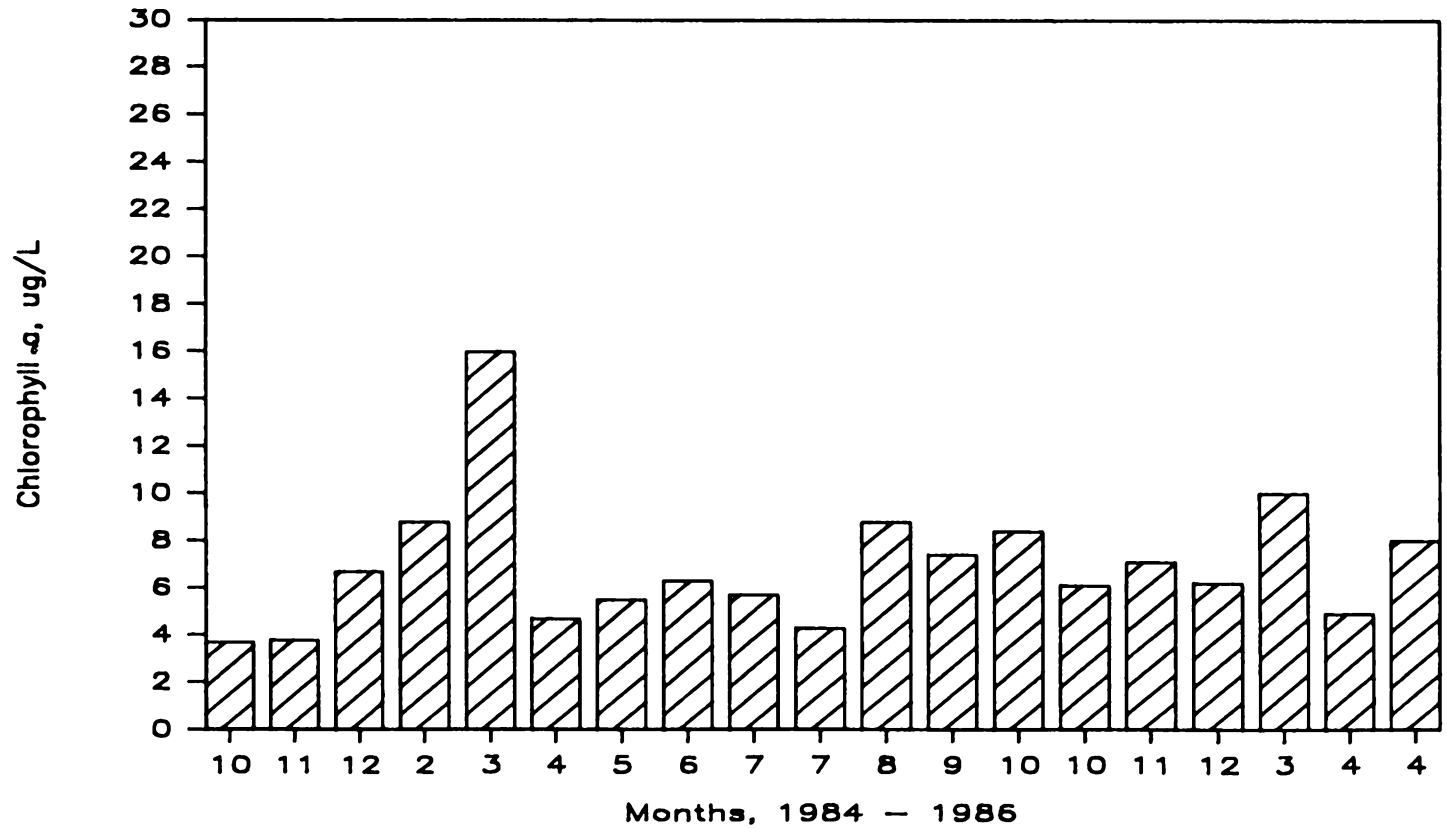


Figure 24. Chlorophyll a variation at Station LM04, Lake Manassas.

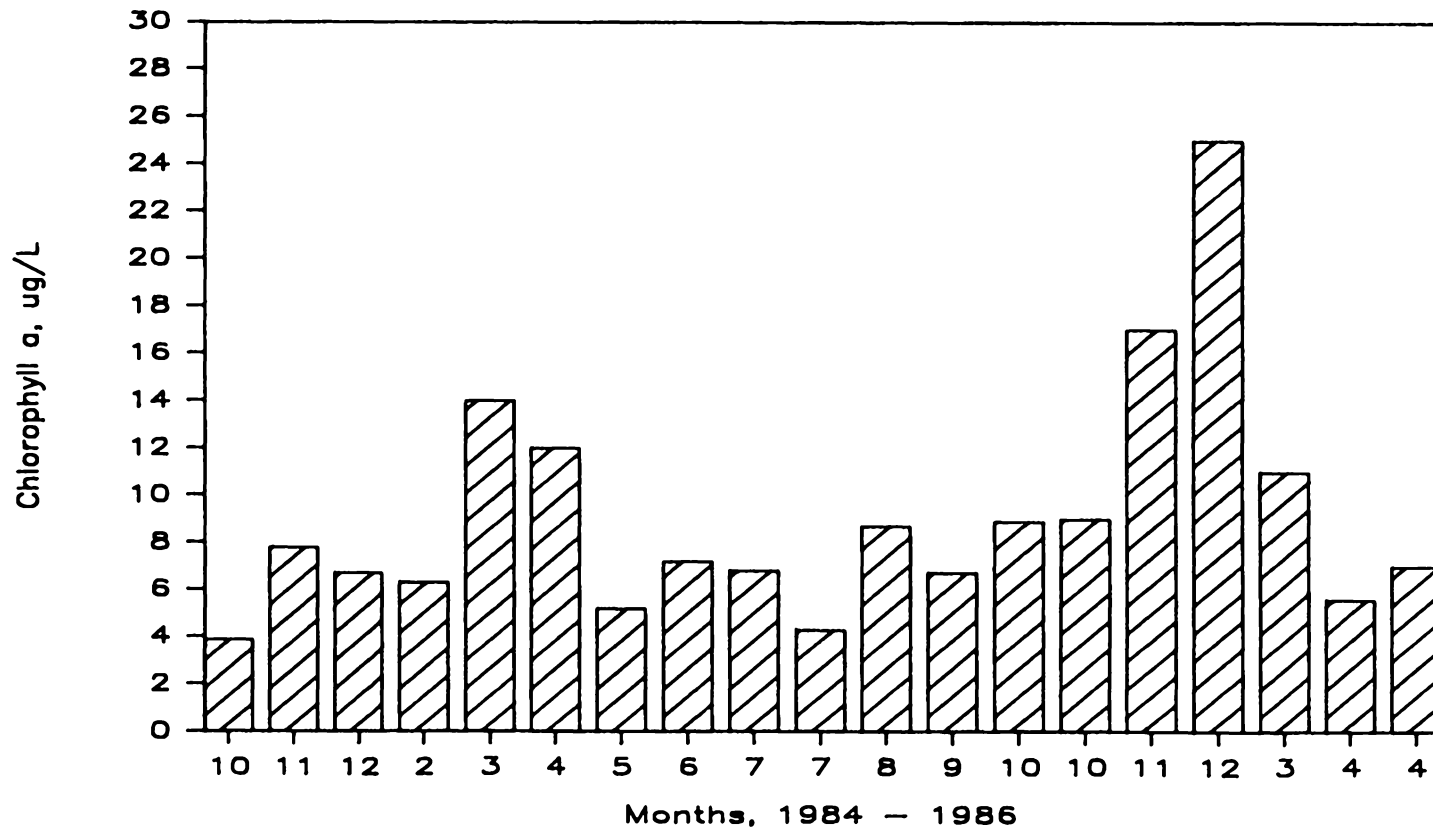


Figure 25. Chlorophyll a variation at Station LM05, Lake Manassas.

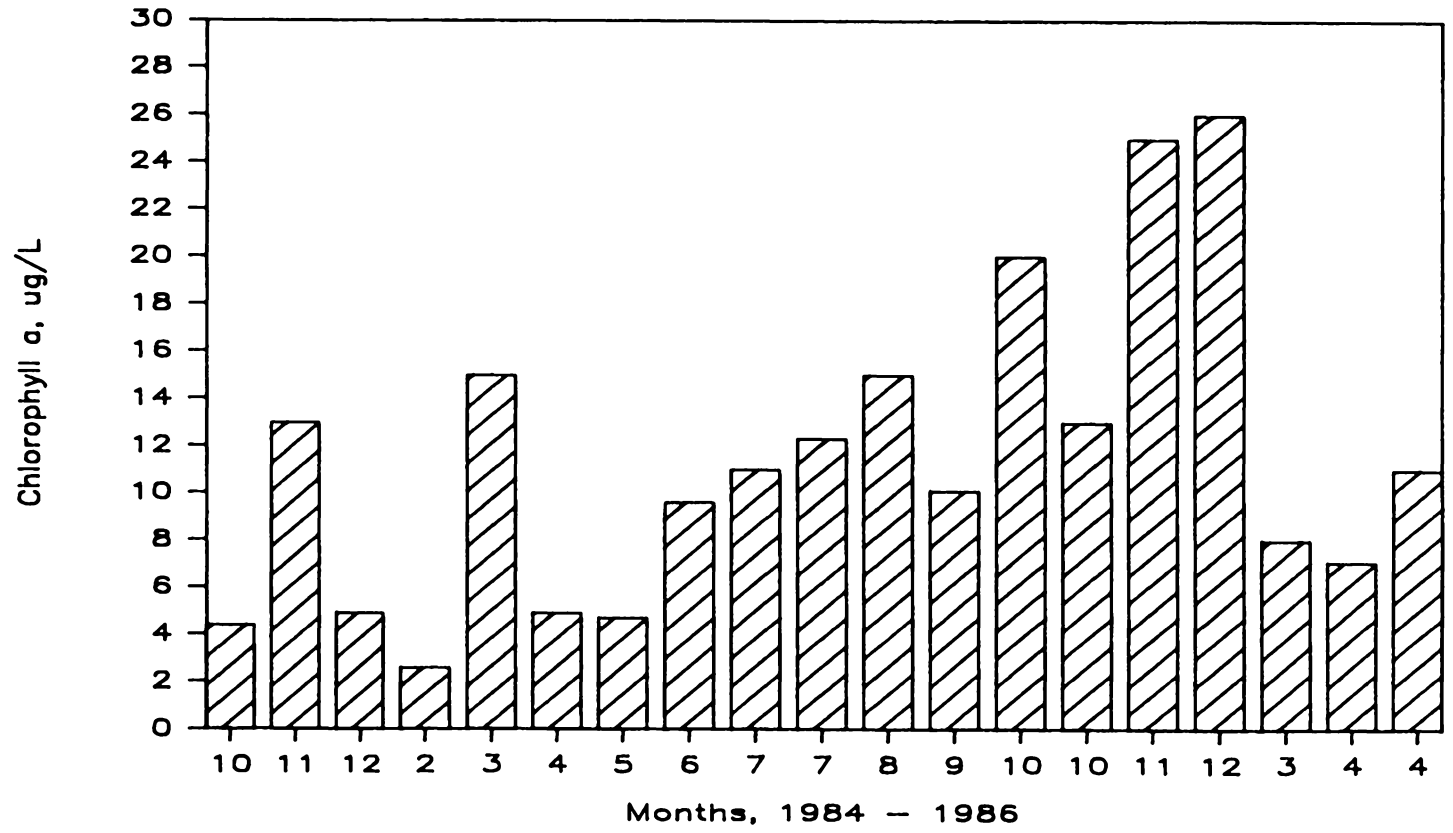


Figure 26. Chlorophyll a variation at Station LM06, Lake Manassas.

TABLE XII. MEAN CHLOROPHYLL AND PHEOPHYTIN
CONCENTRATIONS IN LAKE MANASSAS
OCTOBER, 1984 - APRIL, 1986.

STATION:	LM01	LM02	LM03	LM04	LM05	LM06
Chlorophyll <u>a</u>	6.9	6.6	7.1	7.0	9.1	11.4
Pheophytin <u>a</u>	1.3	1.9	1.6	1.1	1.2	2.3
Ratio of Chl:Phe	5.2	3.5	4.4	6.6	7.6	5.2

ug/L. The other stations had lower mean concentrations, and were very similar. Pheophytin a is a degradation product of chlorophyll a. The ratio of chlorophyll a to pheophytin a is described in Standard Methods as an indicator of the physiological condition of algae. The higher the ratio the better the physiological condition of the algae. This ratio fell in the range of 3.5 - 7.6, with the highest value at Station LM05, and the lowest at station LM02.

Nutrient Variations

Surface and bottom samples collected during the sampling period were analyzed for the following nutrient species which will henceforth be referred to by their abbreviated designations:

OP	Soluble orthophosphorus (mg/L as P)
TP	Total phosphorus (mg/L as P)
TSP	Total soluble phosphorus (mg/L as P)
NH ₃ -N	Soluble ammonia nitrogen (mg/L as N)
SKN	Soluble Kjeldahl nitrogen (mg/L as N)
TKN	Total Kjeldahl nitrogen (mg/L as N)
Ox-N	Oxidized nitrogen: nitrate plus nitrite, (mg/L as N)

Tables XIII and XIV present the mean, maximum, minimum, and median values for each parameter by station, surface and bottom, respectively. In all but a few instances, these values were determined from a total of 19 samples analyzed over a span of 18 months. One complete summer season (1985) and two complete winter periods (1985 and 1986) are represented by these values. The complete analytical results for each sample collected may be found in the appendix (Table A-6).

Nitrogen

At the reservoir surface, there was little variation in average nitrogen concentrations from station to station, with the exception of higher concentrations of Ox-N at Station LM06. Figure 27 depicts the forms of nitrogen that comprised the average nitrogen concentration at each station. $\text{NH}_3\text{-N}$ represented a small fraction of inorganic nitrogen throughout the reservoir. Most of the nitrogen was in the organic fraction. Total nitrogen (TN) did not average above 1 mg/L in the surface waters at any sample location.

The bottom TN concentrations (Figure 28) were more variable across the reservoir than at the surface. The average concentration of all forms of nitrogen were higher at the bottom than at the surface. The most significant

TABLE XIII. NUTRIENT LEVELS IN SURFACE WATERS
OF LAKE MANASSAS

STATION	OP	TSP	TP	NH ₃ -N	SKN	TKN	OX-N
	.....milligram per liter.....						
LM01							
mean	0.00	0.02	0.03	0.05	0.45	0.54	0.23
max	0.01	0.03	0.05	0.19	0.71	0.82	0.62
min	0.00	0.00	0.02	0.00	0.29	0.38	0.00
median	0.00	0.02	0.03	0.04	0.42	0.48	0.13

LM02							
mean	0.00	0.01	0.03	0.04	0.43	0.52	0.22
max	0.01	0.02	0.05	0.17	0.66	0.80	0.58
min	0.00	0.00	0.02	0.00	0.25	0.36	0.00
median	0.00	0.01	0.03	0.03	0.40	0.49	0.15

LM03							
mean	0.00	0.02	0.03	0.05	0.45	0.55	0.23
max	0.01	0.03	0.07	0.18	0.73	0.78	0.72
min	0.00	0.00	0.02	0.00	0.29	0.40	0.00
median	0.00	0.02	0.03	0.02	0.41	0.50	0.11

LM04							
mean	0.00	0.01	0.03	0.04	0.41	0.50	0.23
max	0.01	0.04	0.06	0.16	0.69	0.95	0.67
min	0.00	0.00	0.02	0.00	0.29	0.36	0.00
median	0.00	0.01	0.03	0.03	0.37	0.45	0.13

LM05							
mean	0.00	0.02	0.03	0.04	0.42	0.55	0.24
max	0.03	0.04	0.07	0.13	0.61	0.83	0.73
min	0.00	0.00	0.02	0.00	0.28	0.36	0.00
median	0.00	0.02	0.03	0.03	0.42	0.52	0.12

LM06							
mean	0.00	0.02	0.04	0.03	0.43	0.55	0.40
max	0.01	0.03	0.06	0.12	0.60	0.85	2.67
min	0.00	0.00	0.02	0.00	0.33	0.38	0.00
median	0.00	0.02	0.04	0.02	0.42	0.54	0.26

TABLE XIV. NUTRIENT LEVELS IN BOTTOM WATERS
OF LAKE MANASSAS

STATION	OP	TSP	TP	NH3-N	SKN	TKN	OX-N
	.....milligram per liter.....						
LM01							
mean	0.02	0.04	0.09	0.42	0.88	1.06	0.29
max	0.14	0.16	0.26	1.73	2.36	3.02	0.63
min	0.00	0.00	0.02	0.01	0.30	0.43	0.00
median	0.00	0.02	0.06	0.17	0.57	0.83	0.37

LM02							
mean	0.02	0.03	0.06	0.35	0.72	0.87	0.28
max	0.11	0.13	0.24	1.44	1.59	1.84	0.58
min	0.00	0.00	0.02	0.01	0.36	0.39	0.00
median	0.01	0.02	0.05	0.15	0.60	0.81	0.37

LM03							
mean	0.00	0.02	0.04	0.07	0.43	0.55	0.25
max	0.01	0.03	0.07	0.19	0.65	0.86	0.80
min	0.00	0.00	0.02	0.00	0.27	0.34	0.00
median	0.00	0.02	0.04	0.06	0.42	0.54	0.15

LM04							
mean	0.01	0.03	0.06	0.31	0.66	0.81	0.28
max	0.07	0.09	0.21	1.20	1.46	1.88	0.63
min	0.00	0.00	0.02	0.00	0.28	0.36	0.00
median	0.01	0.02	0.05	0.12	0.55	0.63	0.38

LM05							
mean	0.00	0.02	0.05	0.10	0.51	0.62	0.29
max	0.02	0.05	0.08	0.30	0.78	0.87	0.74
min	0.00	0.00	0.02	0.01	0.30	0.40	0.00
median	0.00	0.02	0.05	0.09	0.52	0.64	0.32

LM06							
mean	0.00	0.02	0.05	0.06	0.50	0.62	0.28
max	0.02	0.04	0.18	0.19	0.73	1.05	0.82
min	0.00	0.00	0.02	0.01	0.31	0.37	0.00
median	0.00	0.02	0.04	0.04	0.46	0.60	0.29

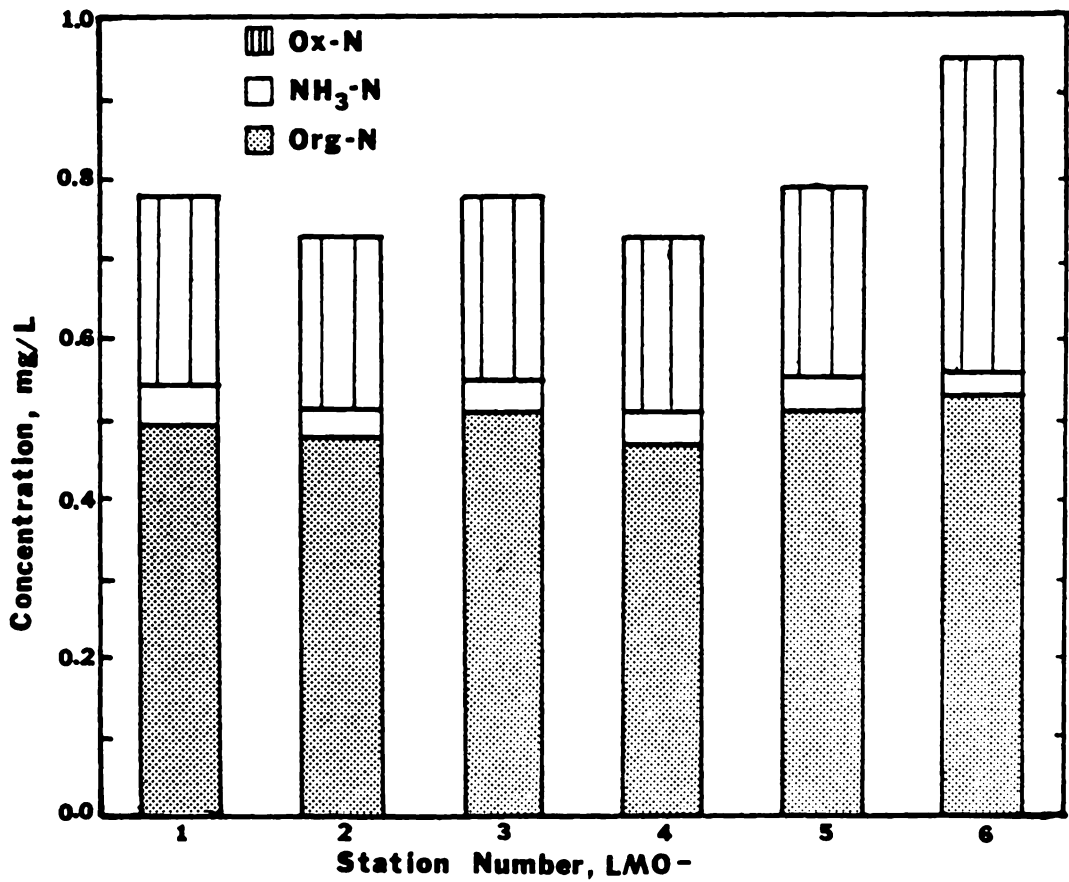


Figure 27. Composition of mean nitrogen concentrations in the surface waters of Lake Manassas.

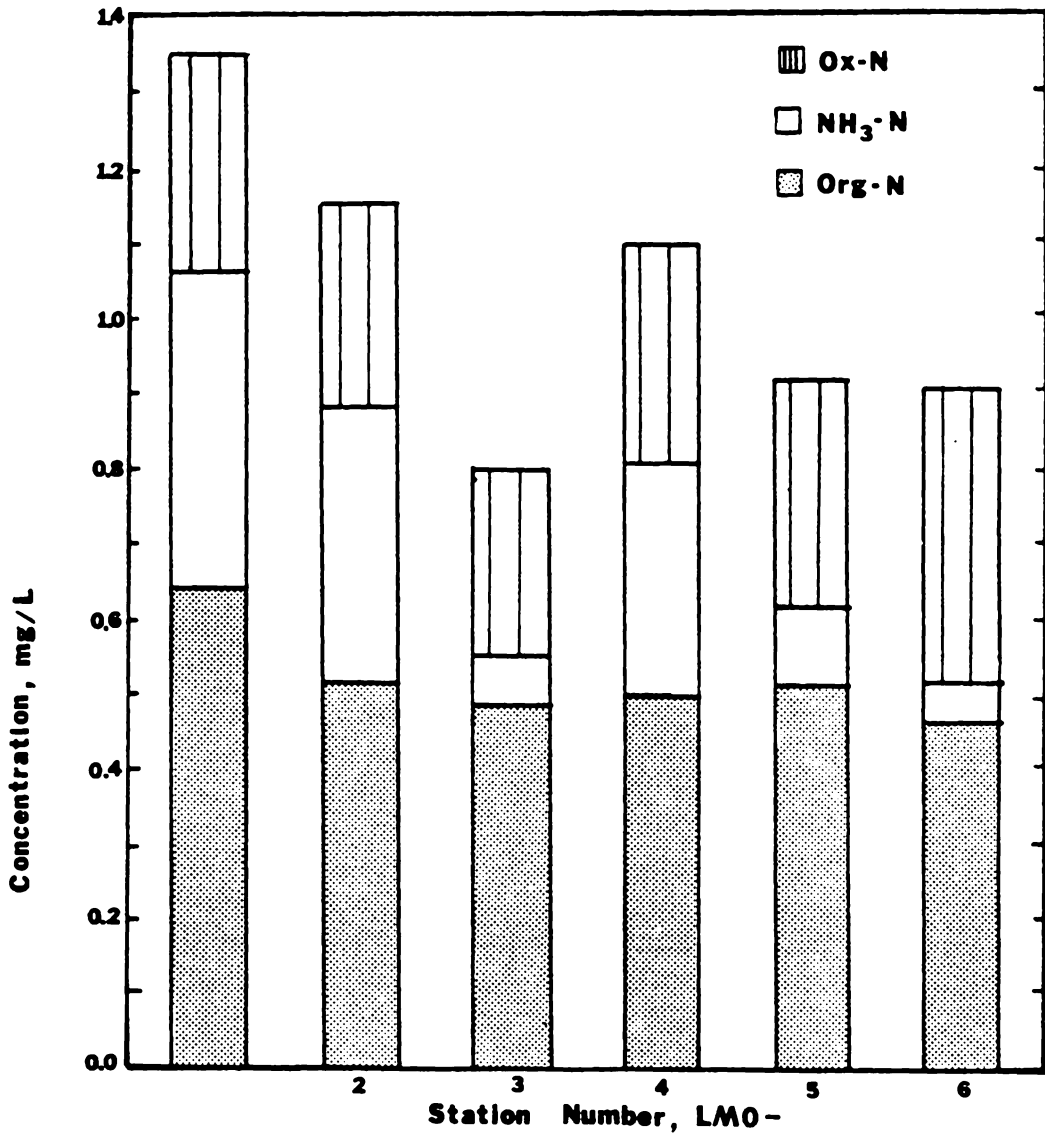


Figure 28. Composition of mean nitrogen concentrations in the bottom waters of Lake Manassas.

differences are in the greater concentrations and variability of $\text{NH}_3\text{-N}$. At the surface $\text{NH}_3\text{-N}$ comprised less than 10 percent of the TKN for all stations. The bottom samples of Stations LM01, LM02, and LM04, the deepest stations, displayed an eight-fold increase in average $\text{NH}_3\text{-N}$ concentration over the surface water, and comprised approximately 40 percent of the measured TKN. Median values for bottom $\text{NH}_3\text{-N}$ concentrations were about three times higher than found at the surface for these stations.

Both longitudinal and seasonal changes in concentrations of the different forms of nitrogen were related to the stratification of the reservoir and the extent to which the hypolimnion remains devoid of dissolved oxygen. In the presence of oxygen, nitrification occurs: ammonia is transformed into nitrite and then nitrate. In the absence of oxygen this process does not occur. Reduced forms of nitrogen predominate under anaerobic conditions.

Figure 11 illustrates the loss of DO at the bottom level of Station LM01, as thermal stratification became established in the spring. This depletion of oxygen was accompanied by an increase in $\text{NH}_3\text{-N}$ concentrations, as shown in Figure 29. At the the surface, concentrations of $\text{NH}_3\text{-N}$ remained at a fairly low level where DO was still prevalent.

Ox-N was depleted at the bottom of the reservoir at

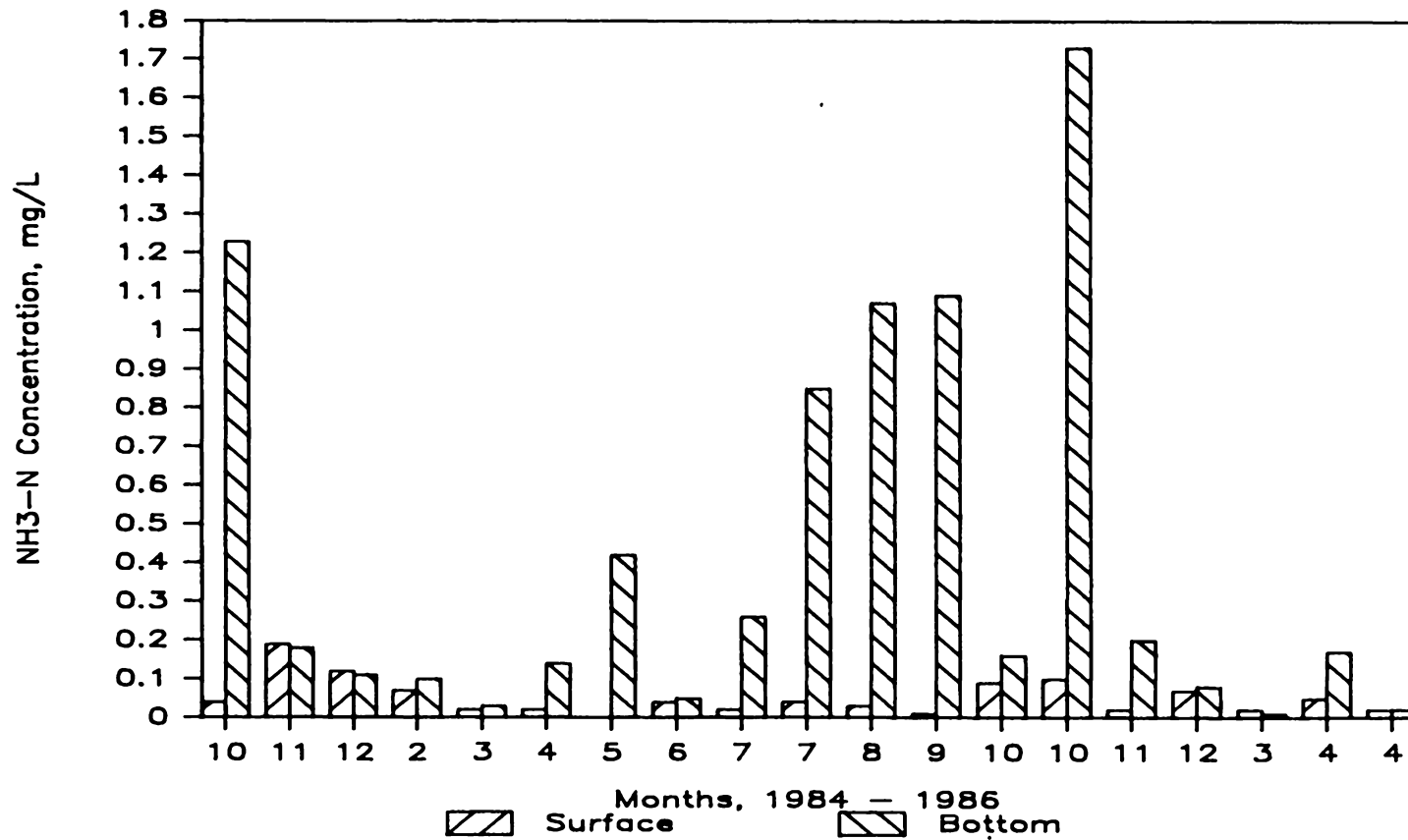


Figure 29. Ammonia variation in the surface and bottom waters of Lake Manassas at Station LM01.

Station LM01 after the second month of low oxygen levels (Figure 30). This phenomenon occurred at all the stations. Figure 30 also indicates that Ox-N was depleted at the surface of Station LM01, from July through October, 1985. In fact, no oxidized nitrogen was detected in any of the lake samples collected during that time.

Phosphorus

As was true of nitrogen concentrations, the average phosphorus concentrations at the surface of the reservoir varied little from station to station (Table XIII). The mean and the median concentrations for total phosphorus were both 0.03 mg/L at the surface for Stations LM01 -LM05. The mean and median surface TP concentrations at Station LM06 were only slightly higher, 0.04 mg/L.

Orthophosphorus was generally not detectable at the surface. Only in the bottom samples from Stations LM01, LM02, and LM03 were the average concentrations for OP greater than zero. The OP concentrations was found to be greatest (0.14 mg/L) at the bottom of Station LM01. This occurred during summer stratification when anaerobic conditions existed at the bottom depths. The bottom samples from Stations LM02 and LM04 also had high OP concentrations, at 0.11 and 0.07 mg/L, respectively, during summer stratification.

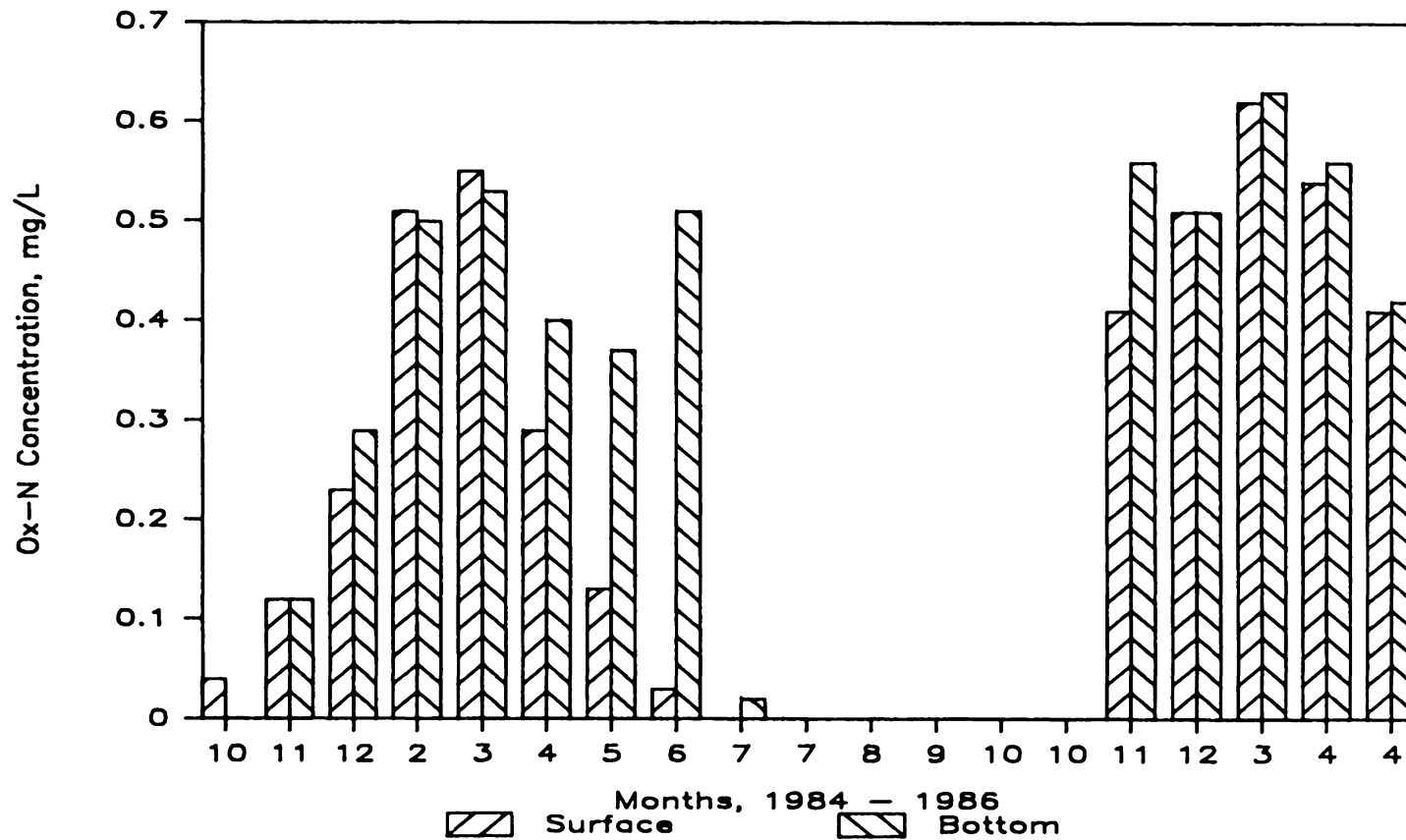


Figure 30. Oxidized nitrogen variation in the surface and bottom waters of Lake Manassas at Station LM01.

The mean value for TP at the bottom of the reservoir was the highest at Station LM01, 0.09 mg/L. Figure 31 illustrates how the bottom concentrations at LM01 increased rapidly at the end of July, 1985. They remained elevated until December of that year. Seasonal variations at the bottom depths of Stations LM02 and LM04 were similar (Figures 32 & 34). Concentrations of TP in bottom samples from the other stations were generally lower and fluctuated less than at Station LM01, LM02, and LM04 (Figures 33, 35, & 36).

Trophic State Indices

Samples collected from the reservoir in March of 1985 and 1986 represent the state of the reservoir just prior to stratification. Some of the figures already presented show that during March of each year many of the surface and bottom samples have similar concentrations of nutrients. During this period of spring turnover, surface concentrations of total phosphorus can increase to their highest level for the year. Increases in algal growth, responding to the higher level of phosphorus, may result in higher chlorophyll *a* values and lower Secchi disc depths.

Trophic State Indices have been calculated according to Carlson (Table IV), and are based on TP values at spring turnover. Calculated TSI values for each station are pre-

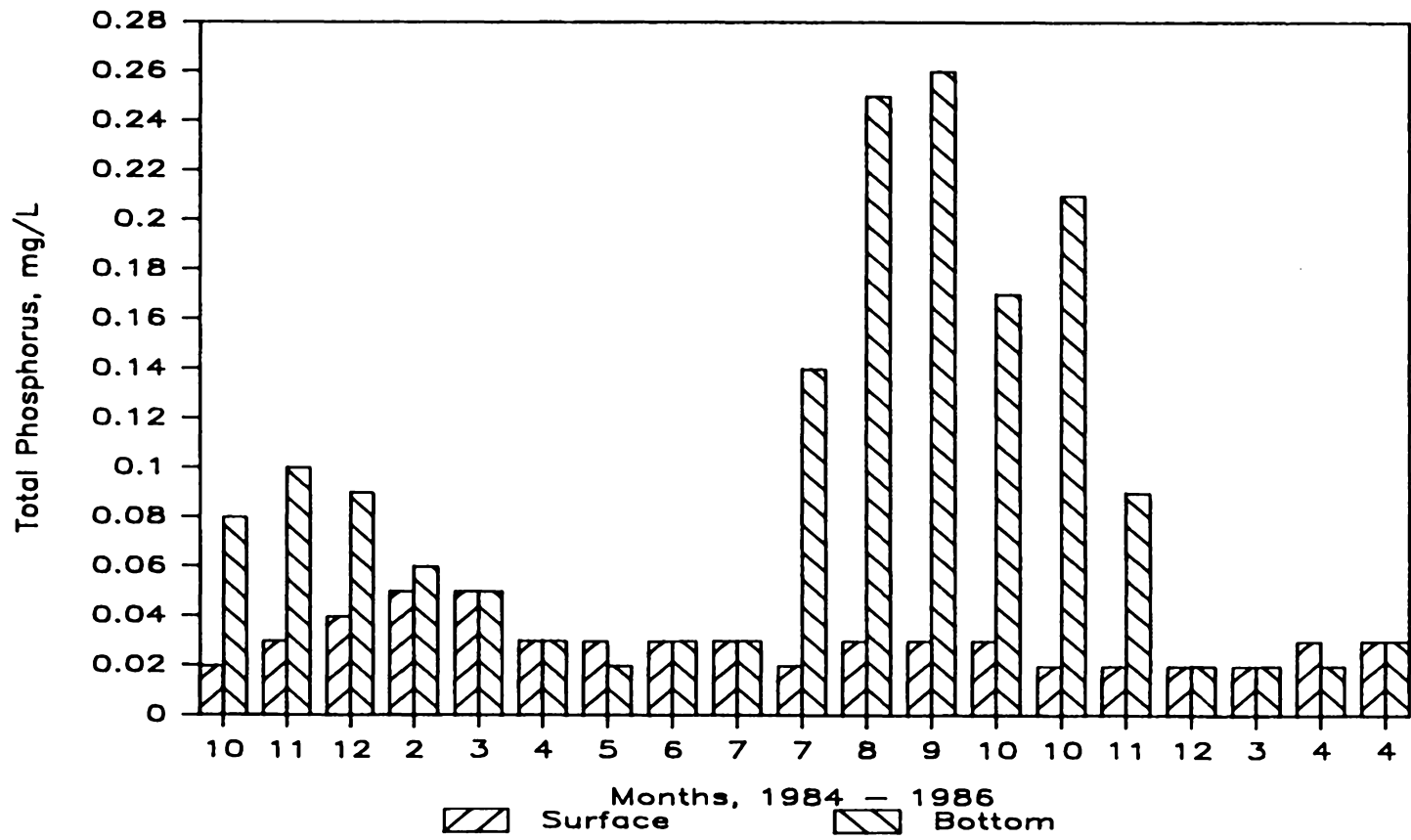


Figure 31. Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM01.

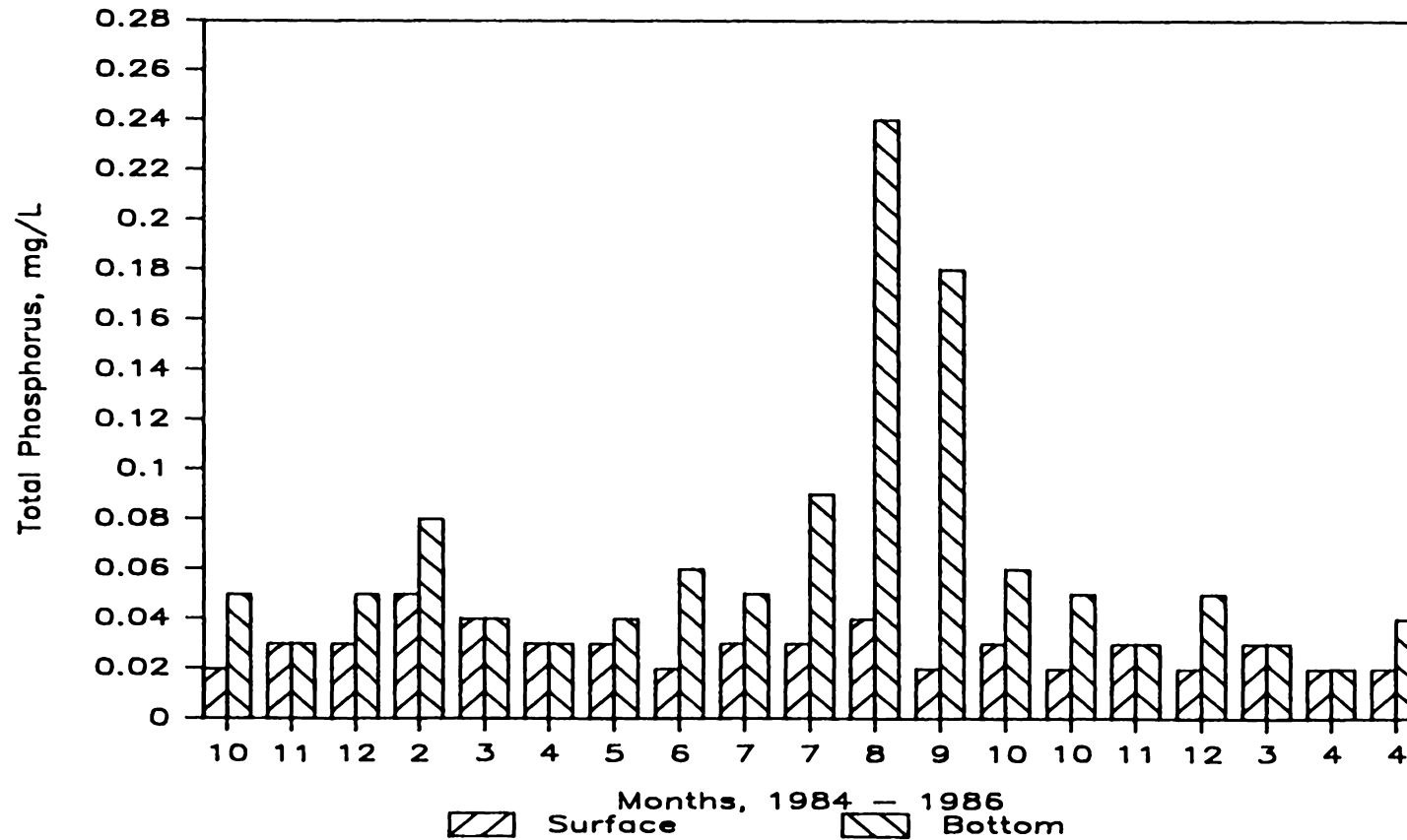


Figure 32. Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM02.

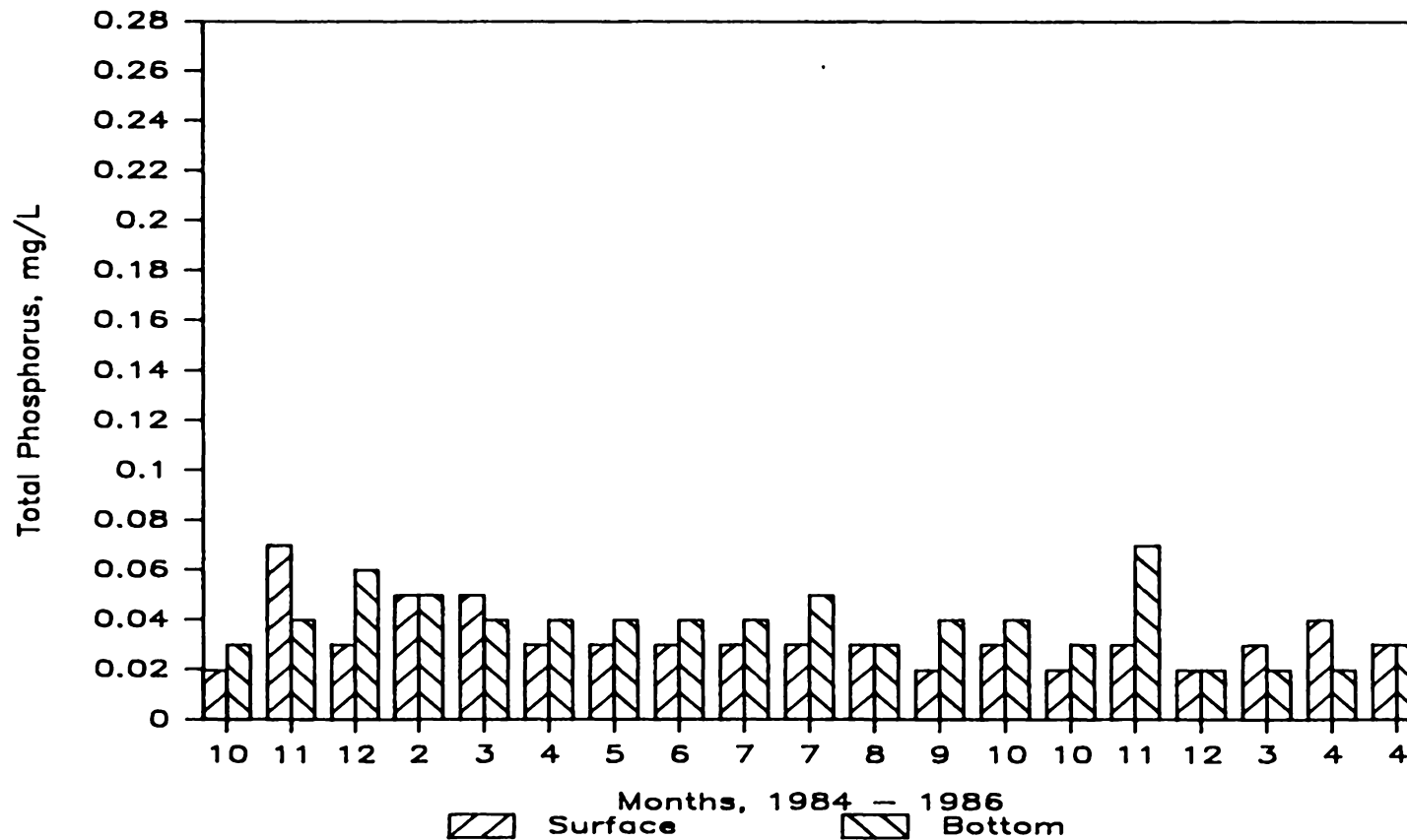


Figure 33. Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM03.

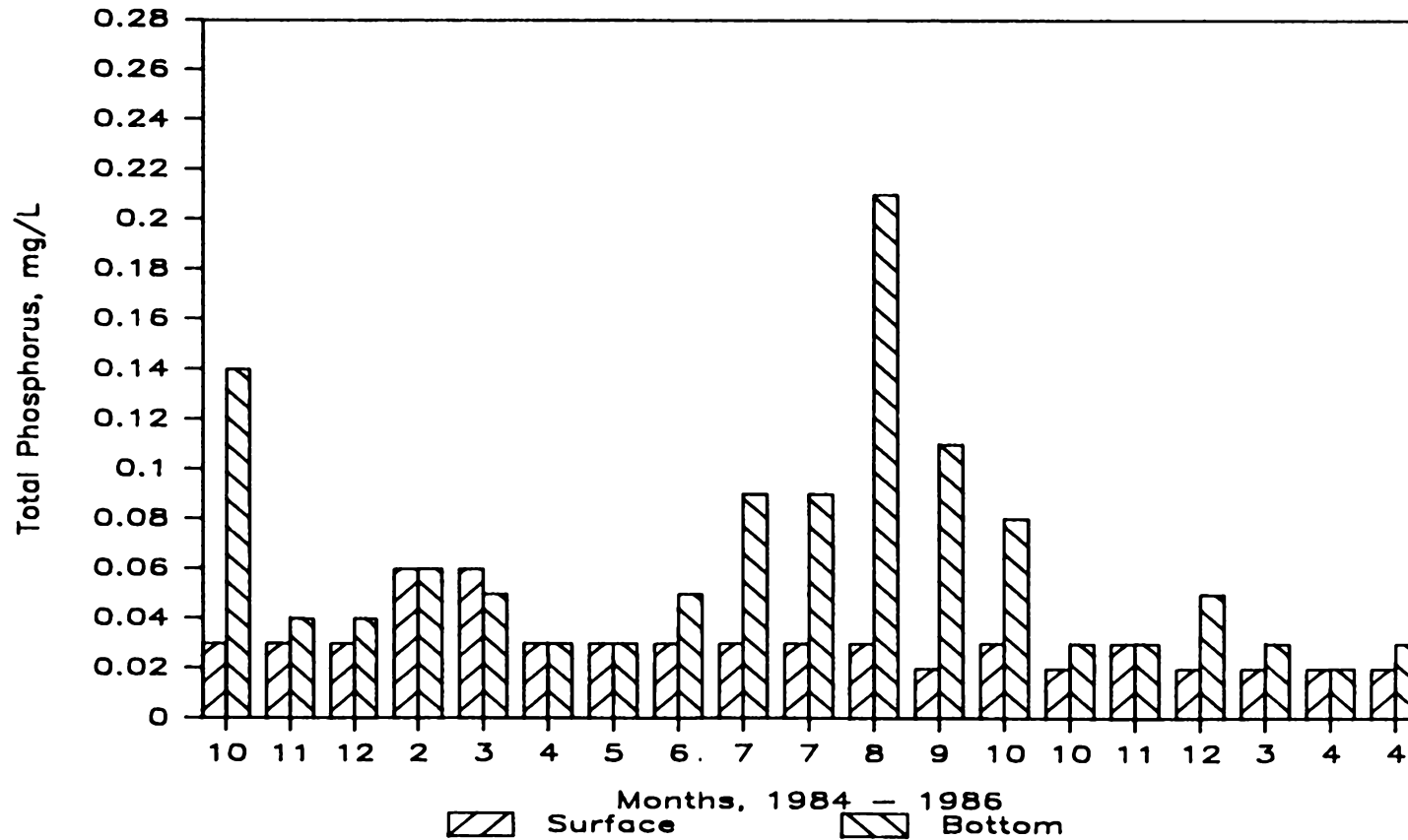


Figure 34. Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM04.

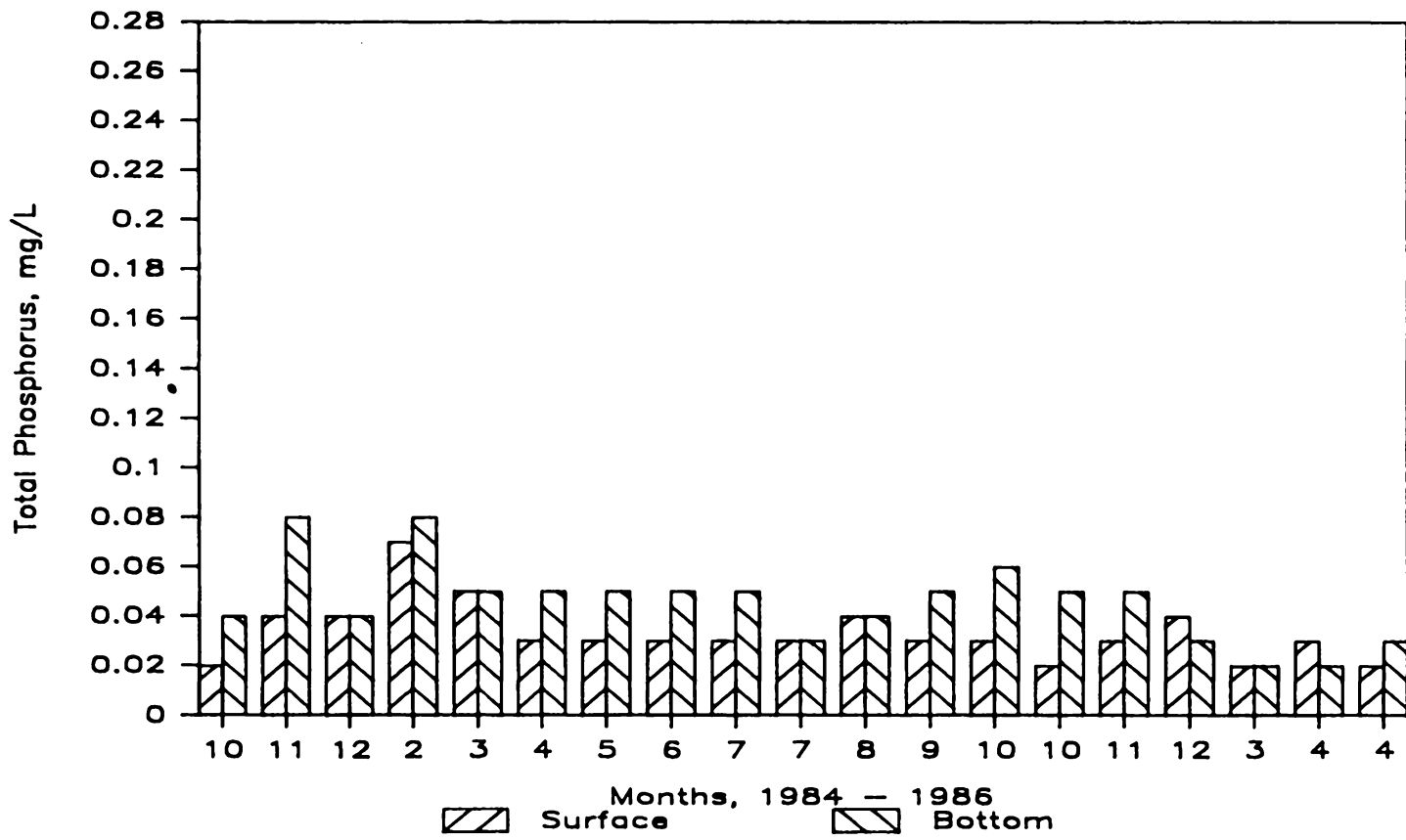


Figure 35. Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM05.

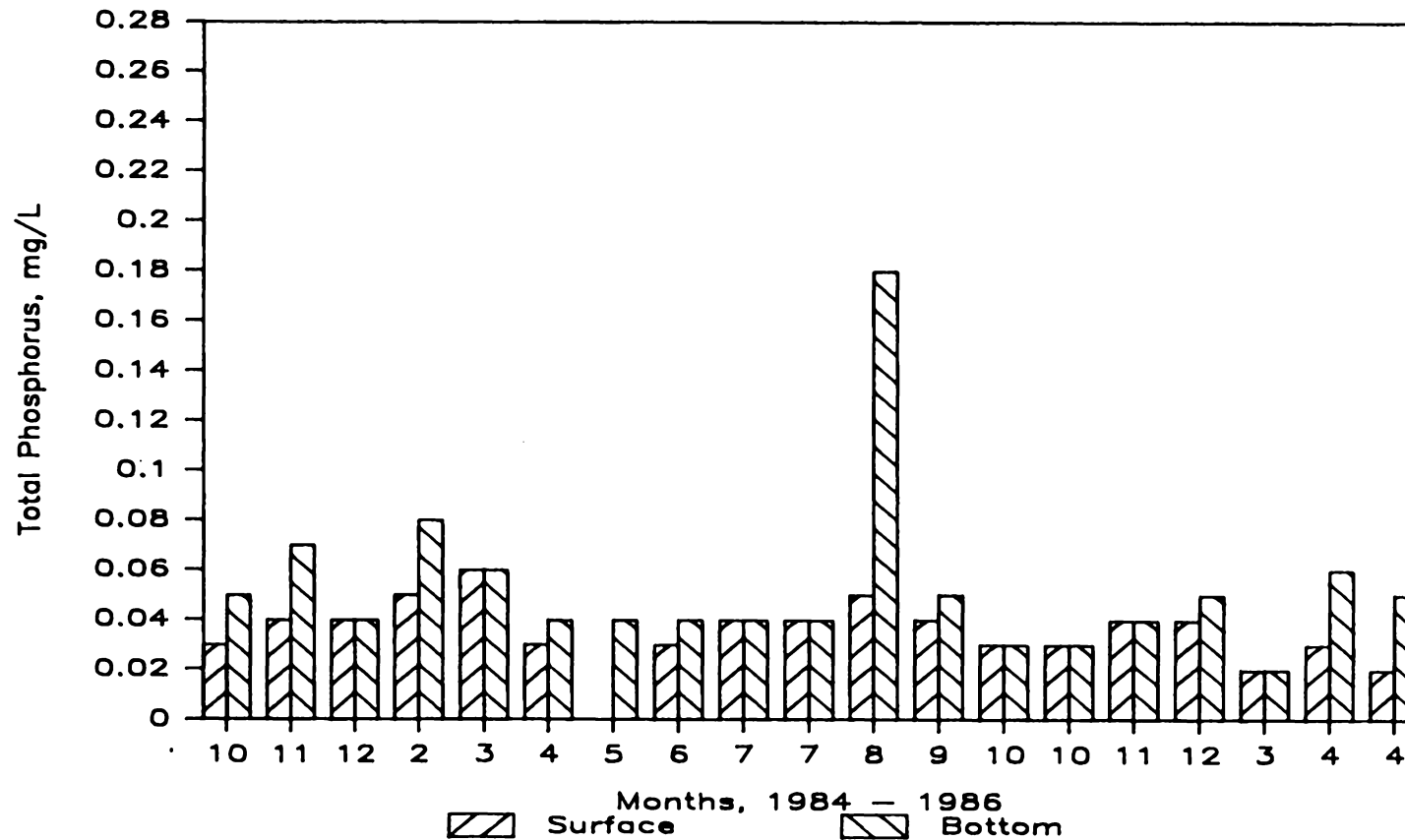


Figure 36. Total phosphorus variation in the surface and bottom waters of Lake Manassas at Station LM06.

sented for each year (Table XV). The resulting TSIs are lower for 1986 than for 1985. However, for both years, the calculated TSI values are indicative of eutrophic conditions.

Nitrogen to Phosphorus Ratios

The ratio of total nitrogen to total phosphorus concentrations has been used as an indication of the limiting nutrient in particular lake or impoundment. This ratio has been calculated at the several reservoir stations using values at turnover (Table XVI). The calculated N:P ratios ranged from 22.7 to 62.0. The ratios were all higher in 1985 than in 1986, which appears to result from decreased TP concentrations. These ratios suggest that the lake is phosphorus limited.

TRIBUTARY STREAMS

A stream sampling program was devised to provide preliminary information to evaluate the relative importance of various inputs to the reservoir. Both baseflow and storm runoff samples were collected from seven monitoring stations. Most of the monitored streams were small and samples collected were taken as grab samples. The Broad Run at Buckland station is operated as part of the Occoquan

TABLE XV. CARLSON'S TROPHIC STATE INDICES FOR
LAKE MANASSAS

A. BASED ON VALUES FOR MARCH 22, 1985

Station	Total P		Chlorophyll <u>a</u>		Secchi Disk	
	ug/L	TSI	ug/L	TSI	meters	TSI
LM01	50	61	14	56	0.89	62
LM02	40	57	6.7	49	0.79	63
LM03	50	61	5	46	0.94	61
LM04	60	63	16	58	0.79	63
LM05	50	61	14	56	0.71	65
LM06	60	63	15	57	0.74	64
Total Reservoir:		61		55		63

B. BASED ON VALUES FOR MARCH 11, 1986

Station	Total P		Chlorophyll <u>a</u>		Secchi Disk	
	ug/L	TSI	ug/L	TSI	meters	TSI
LM01	20	47	11	54	0.96	61
LM02	30	53	10	53	1.24	57
LM03	30	53	7.8	51	1.22	57
LM04	20	47	10	53	1.42	55
LM05	20	47	11	54	1.24	57
LM06	20	47	8	51	1.42	55
Total Reservoir:		49		53		57

TABLE XVI. N:P RATIOS IN LAKE MANASSAS BASED ON SURFACE CONCENTRATIONS AT SPRING OVERTURN

STATION	MARCH 22, 1985			MARCH 11, 1986		
	TN	(mg/L) TP	N:P Ratio	TN	(mg/L) TP	N:P Ratio
LM01	1.37	0.05	27	1.00	0.02	50
LM02	1.21	0.04	30	0.95	0.03	32
LM03	1.28	0.05	26	0.84	0.03	28
LM04	1.47	0.06	24	1.14	0.02	57
LM05	1.34	0.05	27	1.18	0.02	59
LM06	1.36	0.06	23	1.24	0.02	62

Watershed Monitoring Program (OWMP). Data from this large tributary included composited storm sample analyses.

North Fork enters Broad Run just above the dam structure which forms Lake Manassas. Its drainage area composes approximately eleven percent of the Lake Manassas Watershed. About six miles upstream, South Run enters the reservoir; its drainage area is about nine percent of the Lake Manassas Watershed. Several small tributaries, some permanent and some intermittent, also contribute to the lake. The vast majority of the flow, however, is contributed by Broad Run, which drains about 75 percent of the total watershed area. The OWMP station, located on Broad Run, just above the impoundment, has been in operation since 1978. It has a continuous flow monitor and an associated sampling apparatus which allows for flow-related water samples.

The Broad Run at Buckland station, designated as ST70, and the other tributaries to the reservoir, designated BR02 - BR08, were shown in Figure 5. Three sampling sites were located on South Run: one upstream of Vint Hill Farms discharge (BR07), one below the discharge point (BR02), and one at a point close to where South Run enters the Lake (BR03). This last Station, BR03, was described several times by field technicians during sampling, as being flooded, or "backed up", by the high water in the reser-

voir. Some stations dried up completely in the late summer of 1985, and thus are represented by fewer samples.

Field Measurements

During baseflow conditions, the various streams were analyzed on site for dissolved oxygen content, temperature, pH, alkalinity and specific conductivity. Mean, minima, and maxima values for these data are presented in Table XVII. The conductivity measurements have been corrected to 25°C. Alkalinity values are total alkalinity as CaCO₃. (Phenolphthalein alkalinity was measured but never detected). A complete listing of these field data can be found in the appendix (Table A-7).

Although dissolved oxygen concentrations averaged about 10 mg/L at most sampling stations, values were below the minimum Virginia water quality standard of 4.0 mg/L on a few occasions at Stations BR04 and BR05. The North Fork station (BR04) had the lowest average DO concentration. At that station during June and July, 1985, field analysis determined only 2.5 and 3.5 mg/L DO, respectively. BR05 had a DO level of only 3.6 mg/L in July 1985. The water level was very low at both stations when these low DO concentrations were measured, which undoubtedly resulted in stagnant conditions.

Except on one occasion, at Station BR06, pH values were

TABLE XVII. LAKE MANASSAS TRIBUTARY STREAM
BASEFLOW CHARACTERISTICS

STATION		DO mg/L	TEMP oC	pH	ALK mg/L	COND umho/cm
ST70	(N = 17)					
	mean	10.2	10.8	6.8	40.1	123
	min	5.8	0.0	6.1	25.2	100
	max	13.3	27.0	7.6	60.8	175
BR02	(N = 17)					
	mean	9.6	10.7	6.8	45.4	311
	min	5.2	1.0	6.0	28.3	115
	max	13.2	24.5	7.2	87.6	715
BR03	(N = 14)					
	mean	9.7	12.2	7.0	47.7	291
	min	5.0	1.5	6.3	29.4	100
	max	12.8	25.0	7.5	86.1	665
BR04	(N = 15)					
	mean	9.2	8.3	6.7	64.9	213
	min	2.5	0.0	6.1	25.8	105
	max	13.2	24.0	7.2	195.6	510
BR05	(N = 14)					
	mean	10.0	7.6	6.8	74.6	376
	min	3.6	0.0	6.1	19.1	115
	max	12.9	26.0	7.5	186.7	1030
BR06	(N = 13)					
	mean	10.0	8.2	6.6	54.3	153
	min	5.6	0.0	5.9	23.7	40
	max	13.2	19.0	7.4	126.6	310
BR07	(N = 17)					
	mean	9.6	11.4	6.8	40.6	125
	min	4.8	2.5	6.1	27.2	95
	max	13.2	24.5	7.3	70.4	260
BR08	(N = 3)					
	mean	11.0	3.7	6.6	46.2	198
	min	10.1	0.5	6.0	39.5	145
	max	12.0	7.0	7.2	55.8	290

within the water quality standard range of 6.0 - 8.5. Minimum measured values, however, were at or within 0.1 pH units from the lower acceptable range limit of 6.0 at all stations except BR03.

Exceptionally high values for alkalinity were found at times at Stations BR04 and BR05 (both just downstream from State Highway 29) on the same day in July, 1985. Specific conductivities were unusually high on several dates at station BR05: values were above 600 umho/cm in May, June, and July, 1985 and was 585 umho/cm in November, 1984. Broad Run (ST70) showed the least variability in either alkalinity or conductivity of all the streams monitored.

Nutrients and Suspended Solids

Baseflow and stormflow runoff samples were analyzed for nitrogen and phosphorus forms and total suspended solids. Average values and the range of concentrations found at each station are presented in Tables XVIII and XIX, for baseflow and runoff samples, respectively.

South Run, below Vint Hill Farms (BR02 and BR03), had significantly higher concentrations for all parameters except suspended solids. Baseflow concentrations of total phosphorus at BR02 averaged over 10 times higher than those at the Broad Run station, ST70. While the downstream station on South Run (BR03) had lower concentrations than

TABLE XVIII. LAKE MANASSAS TRIBUTARY STREAM
BASEFLOW CHARACTERISTICS: NUTRIENTS
AND SUSPENDED SOLIDS

STATION	NH ₃ -N	TKN	SKN	OX-N	OP	TSP	TP	TSS
.....milligram per liter.....								
ST70 (N = 17)								
mean	0.02	0.39	0.34	0.61	0.00	0.02	0.03	3.7
min	0.00	0.20	0.13	0.00	0.00	0.01	0.02	0.2
max	0.08	0.79	0.66	1.25	0.03	0.06	0.08	11.5
BR02 (N = 17)								
mean	0.17	0.76	0.65	2.03	0.26	0.30	0.33	2.7
min	0.02	0.44	0.42	0.38	0.05	0.06	0.09	0.5
max	1.31	1.55	0.79	6.71	0.77	0.79	0.82	6.5
BR03 (N = 14)								
mean	0.07	0.61	0.55	1.37	0.14	0.16	0.19	3.6
min	0.01	0.46	0.35	0.27	0.04	0.07	0.09	0.5
max	0.54	0.96	0.94	3.13	0.32	0.42	0.43	12.0
BR04 (N = 15)								
mean	0.05	0.59	0.52	0.09	0.01	0.03	0.06	5.9
min	0.01	0.24	0.23	0.00	0.00	0.01	0.03	0.5
max	0.46	1.27	1.20	0.35	0.06	0.08	0.16	16.0
BR05 (N = 14)								
mean	0.03	0.43	0.37	0.13	0.00	0.02	0.03	4.4
min	0.01	0.21	0.14	0.00	0.00	0.01	0.02	1.0
max	0.26	1.16	0.94	0.41	0.03	0.04	0.06	12.5
BR06 (N = 13)								
mean	0.03	0.69	0.47	0.12	0.01	0.04	0.07	13.0
min	0.00	0.23	0.23	0.00	0.00	0.02	0.02	0.8
max	0.10	1.34	0.78	0.81	0.05	0.08	0.16	65.5
BR07 (N = 17)								
mean	0.15	0.82	0.66	0.26	0.00	0.02	0.05	6.2
min	0.00	0.42	0.36	0.00	0.00	0.00	0.03	0.5
max	0.44	1.99	0.99	0.61	0.02	0.05	0.08	16.5
BR08 (N = 3)								
mean	0.03	0.48	0.40	0.47	0.02	0.03	0.06	15.7
min	0.02	0.39	0.30	0.40	0.01	0.03	0.04	4.0
max	0.04	0.54	0.47	0.56	0.03	0.04	0.08	25.5

TABLE XIX. LAKE MANASSAS TRIBUTARY STREAM
 RUNOFF CHARACTERISTICS: NUTRIENTS
 AND SUSPENDED SOLIDS

STATION	NH3-N	TKN	SKN	OX-N	OP	TSP	TP	TSS
.....milligram per liter.....								
ST70 (N = 9)								
mean	0.03	0.57	0.36	0.53	0.00	0.03	0.10	41.4
min	0.01	0.17	0.17	0.00	0.00	0.02	0.02	2.0
max	0.07	1.99	0.57	0.91	0.03	0.05	0.57	308.0
BR02 (N = 10)								
mean	0.36	1.18	0.99	1.90	0.24	0.28	0.35	15.4
min	0.07	0.77	0.70	0.35	0.05	0.08	0.11	4.0
max	0.99	1.88	1.76	5.90	0.54	0.54	0.56	70.0
BR03 (N = 9)								
mean	0.07	0.86	0.70	1.93	0.18	0.20	0.27	16.0
min	0.00	0.58	0.51	0.53	0.06	0.09	0.11	1.0
max	0.19	1.61	0.93	4.04	0.42	0.42	0.47	88.0
BR04 (N = 10)								
mean	0.03	0.67	0.59	0.27	0.04	0.06	0.10	17.2
min	0.00	0.37	0.36	0.03	0.01	0.02	0.03	5.0
max	0.09	0.81	0.79	0.40	0.09	0.11	0.20	33.0
BR05 (N = 10)								
mean	0.04	1.03	0.69	0.37	0.09	0.12	0.19	40.8
min	0.00	0.28	0.23	0.05	0.00	0.02	0.03	5.0
max	0.12	3.69	1.52	1.00	0.59	0.65	1.09	177.0
BR06 (N = 9)								
mean	0.06	1.15	0.70	0.38	0.06	0.08	0.19	56.0
min	0.00	0.66	0.55	0.01	0.01	0.04	0.08	6.0
max	0.27	2.42	0.91	1.27	0.20	0.22	0.50	325.0
BR07 (N = 10)								
mean	0.25	0.76	0.61	0.15	0.00	0.02	0.05	14.3
min	0.03	0.52	0.38	0.01	0.00	0.02	0.03	4.4
max	0.69	1.18	0.97	0.27	0.02	0.05	0.12	45.0
BR08 (N = 1)								
value	0.03	2.66	1.67	0.68	0.29	-	-	62.0

BR02, which is just below Vint Hill's discharge point, it should be noted that the reservoir level was often high during sampling and could account for some dilution. Measured concentrations at BR03 appeared to be more similar to those at BR02 under storm conditions than under baseflow conditions, except for ammonia. Phosphorus concentrations in Broad Run were the lowest of all the stations except for upper South Run (BR07).

In lower South Run a significant portion of the total phosphorus was in soluble forms. The average TSP comprised 91 percent of total phosphorus at BR02, and OP accounted for 79 percent of the TP under baseflow conditions. Orthophosphorus is considered readily available for algal uptake.

Under baseflow conditions, Station BR02 had the highest observed concentrations for TP, $\text{NH}_3\text{-N}$, and Ox-N of all the stations. Mean concentrations of TP were relatively the same for the tributaries except for the greater value at BR02, and to a lesser extent, BR03. In runoff samples the highest observed concentrations for $\text{NH}_3\text{-N}$ and Ox-N were again found at BR02. However, the highest concentration for TP during stormflow conditions was observed at BR05. Mean TP concentrations increase significantly during runoff conditions at Stations BR05, BR06, and ST70, but do not change much at BR02.

The highest concentrations of TKN was observed at BR07, under baseflow conditions, and at BR05, under stormflow conditions. The mean baseflow concentration of $\text{NH}_3\text{-N}$ at the upstream South Run station (BR07) was nearly as great as that observed below Vint Hill Farms (BR02) and remained relatively high during runoff periods. Oxidized nitrogen, on the other hand, was observed in its lowest concentrations at BR07 during baseflow, while the observed mean Ox-N concentrations at BR02 were triple the values found at the Broad Run station (ST70), which had the next highest mean concentration.

It is interesting to note that while Broad Run contributes the vast majority of flow to Lake Manassas, it did not have the highest observed concentration for any of the nutrient forms for which it was analyzed. Under runoff conditions, however, total suspended solids were found to be much higher in Broad Run (ST70) than in North Fork (BR04), and in all of South Run's stations. Yet Broad Run's mean runoff suspended solid concentration was almost the same as one of the smallest tributaries monitored, BR05. The highest mean concentration of suspended solids was observed in another relatively small stream, BR06, during runoff conditions. This mean value mostly likely reflects the single highest concentration observed for suspended solids in the watershed, 325 mg/L.

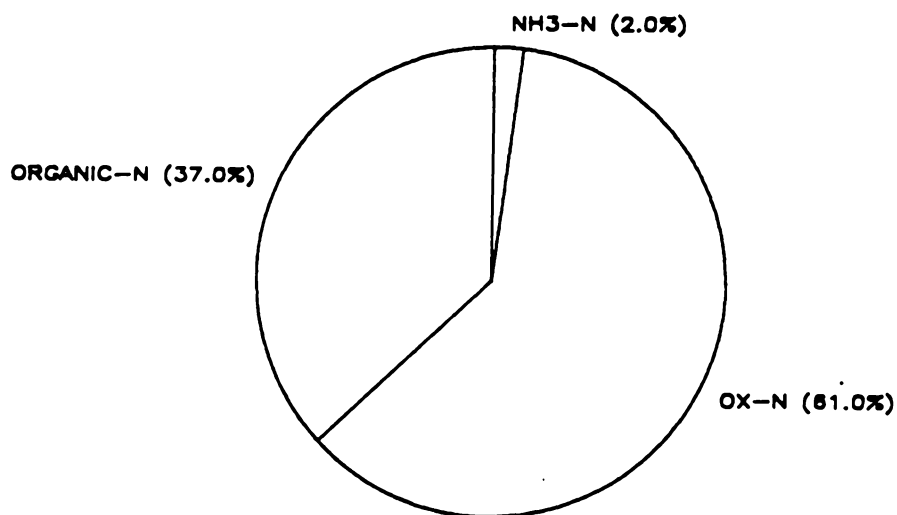
Distribution of Nutrient Species

Broad Run, South Run, and North Fork contribute the vast majority of flow into Lake Manassas. While there are some interesting aspects to water quality in the other tributaries surveyed, their overall impact on the lake is minimal. It is notable that only South Run and Broad Run exhibited continuous flow throughout the dry summer of 1985. The South Run station at BR02 is probably more representative than BR03 of what is going into the reservoir, due to the influence of high lake level at the latter station. In light of the above, Stations BR02, BR04, and ST70 will be given primary consideration in the following.

Mean nitrogen distributions during baseflow and runoff conditions are presented in Figures 37-39. A relatively high percentage of organic nitrogen was found in North Fork as compared to Broad Run and South Run, during baseflow and runoff conditions. South Run showed the least differences in its nitrogen profile between baseflow and runoff and had the highest percentage of ammonia of the three tributaries under both conditions. Oxidized nitrogen predominated in South Run.

Broad Run was observed to have the lowest percentage of ammonia of these tributaries. The greater percentage of organic nitrogen in Broad Run during runoff was probably caused by the great increase in sediment that occurred dur-

BROAD RUN (ST70)
BASEFLOW N DISTRIBUTION TN = 1.0 mg/L



BROAD RUN (ST70)
RUNOFF N DISTRIBUTION TN = 1.10 mg/L

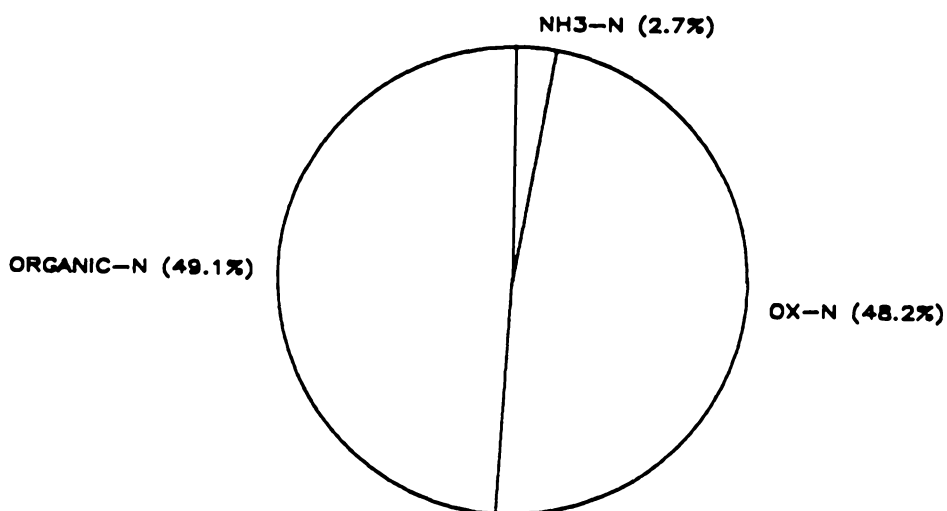
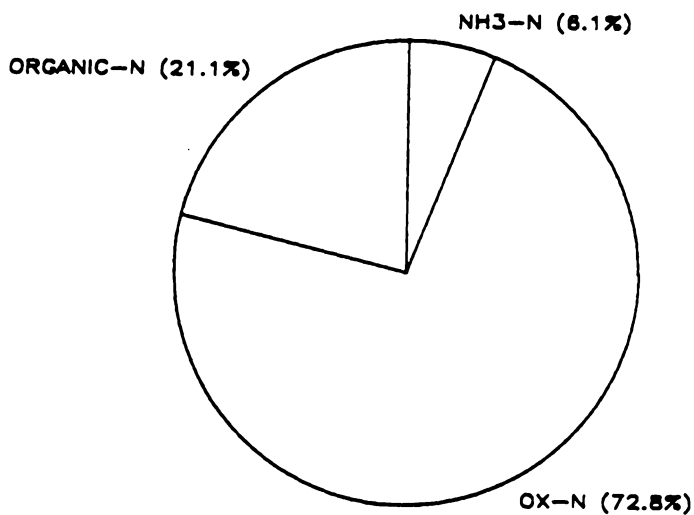


Figure 37. Mean nitrogen distribution in Broad Run during baseflow (top) and runoff (bottom) conditions, November, 1984 - May, 1986.

SOUTH RUN (BR02)
BASEFLOW N DISTRIBUTION TN = 2.79 mg/L



SOUTH RUN (BR02)
RUNOFF N DISTRIBUTION TN = 3.08 mg/L

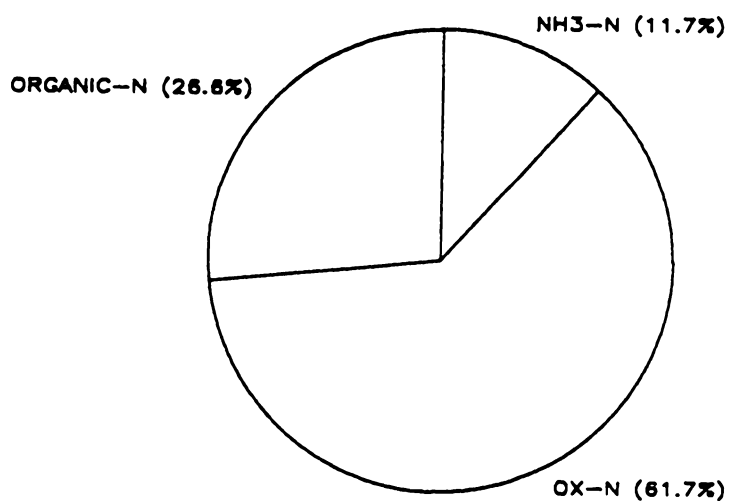
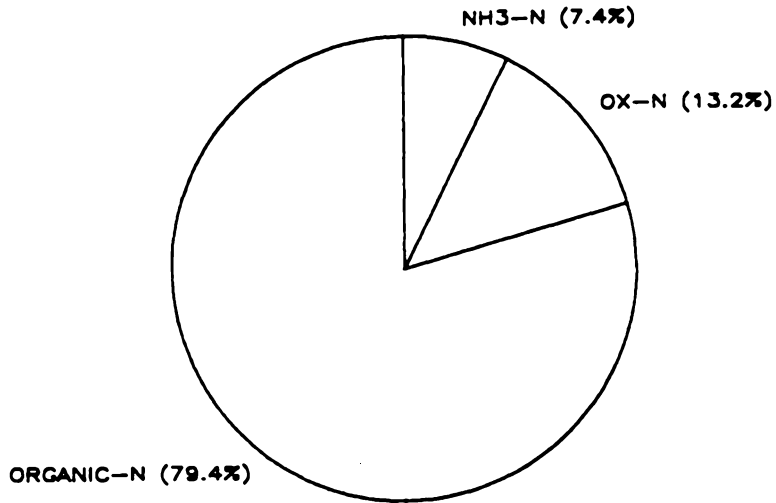


Figure 38. Mean nitrogen distribution in South Run during baseflow (top) and runoff (bottom) conditions, November, 1984 - May, 1986.

NORTH FORK (BR04)
BASEFLOW N DISTRIBUTION TN = 0.68 mg/L



NORTH FORK (BR04)
RUNOFF N DISTRIBUTION TN = 0.94 mg/L

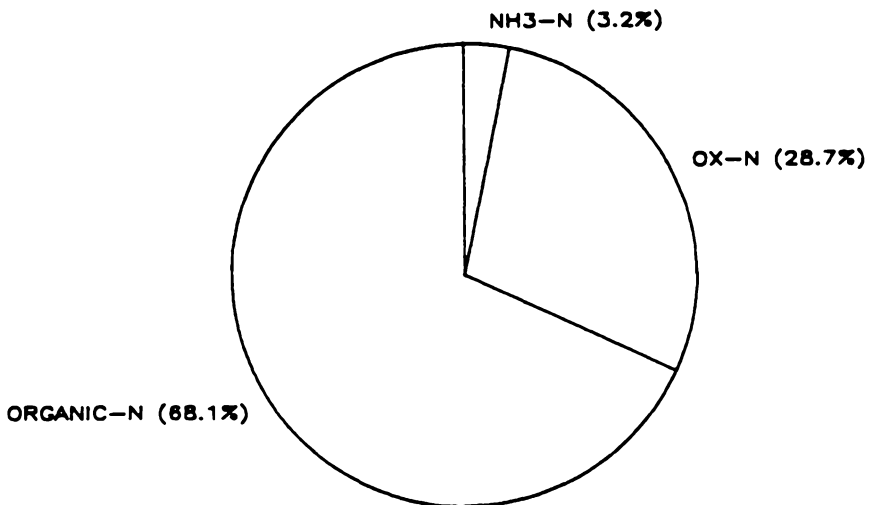


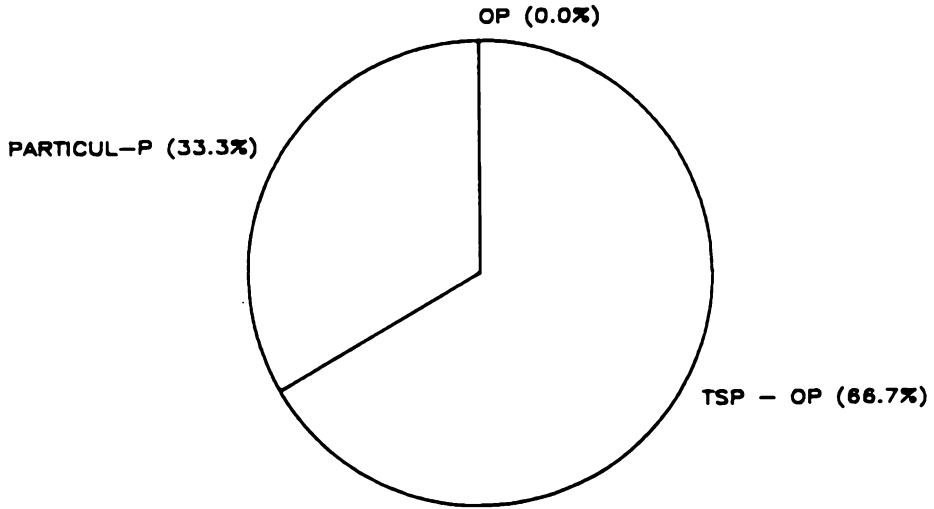
Figure 39. Mean nitrogen distribution in North Fork during baseflow (top) and runoff (bottom) conditions, November, 1984 - May, 1986.

ing stormflow in that stream. In North Fork the percentage of ammonia concentration decreased and oxidized nitrogen increased during runoff conditions as one might expect. In South Run, on the other hand, ammonia concentrations increased during stormflow.

Mean phosphorus distributions (Figures 40-42) are developed from TP, TSP, and OP analyses of baseflow and runoff samples. While they do not represent the specific species, as do the nitrogen pie charts, they are useful for comparative purposes. Orthophosphorus, "OP" is considered here as a fraction of total soluble P. The slice designated "TSP-OP" is that portion of TP which is soluble, but not orthophosphorus. "Particulate-P" is that portion of P that can be removed from the sample by filtration. It has been calculated by subtracting TSP from TP values.

The distribution pattern for phosphorus was diverse among the three tributaries. The overall mean concentrations found in South Run was ten times the concentration found in Broad Run, which, in turn, was half as great as the North Fork concentration, during baseflow conditions. Mean OP concentrations in Broad Run was zero, for baseflow and runoff samples. In contrast, in South Run, OP comprised a major portion of TP for both types of samples. In North Fork, OP concentrations were greater in runoff than in baseflow samples, increasing from 19 to 40 percent, a

BROAD RUN (ST70)
BASEFLOW P DISTRIBUTION TP = 0.03 mg/L



BROAD RUN (ST70)
RUNOFF P DISTRIBUTION TP = 0.10 mg/L

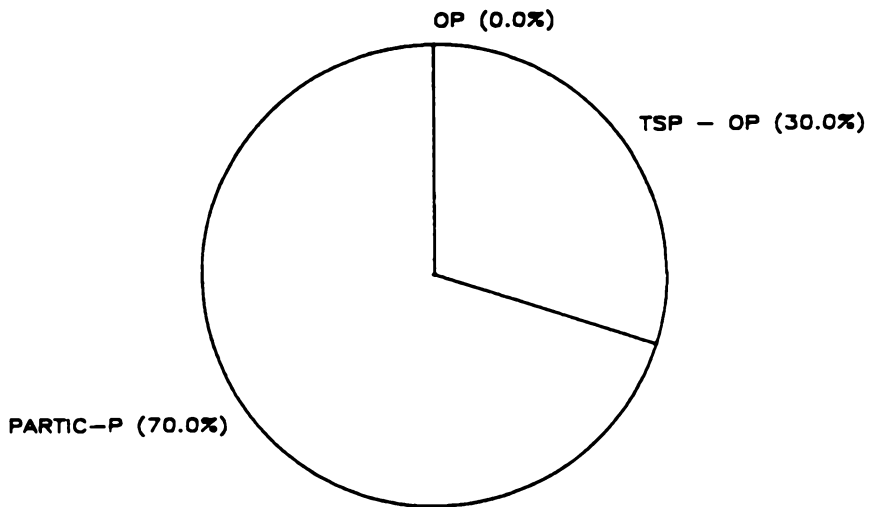
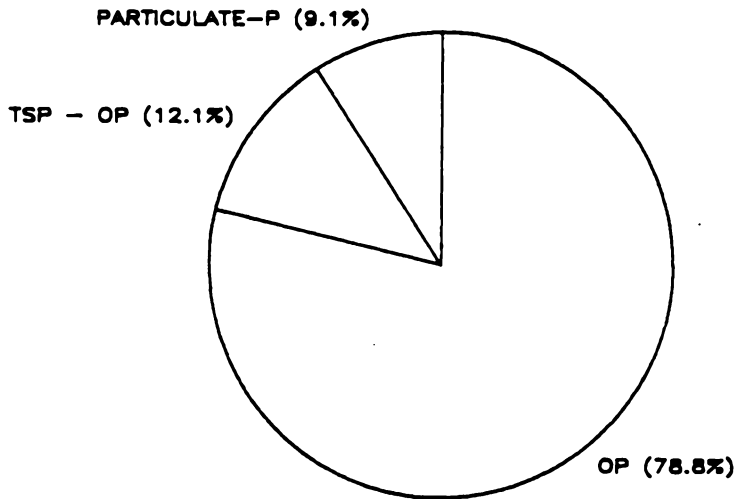


Figure 40. Mean phosphorus distribution in Broad Run during baseflow (top) and runoff (bottom) conditions, November, 1984 - May, 1986.

SOUTH RUN (BR02)
BASEFLOW P DISTRIBUTION TP = 0.33 mg/L



SOUTH RUN (BR02)
RUNOFF P DISTRIBUTION TP = 0.35 mg/L

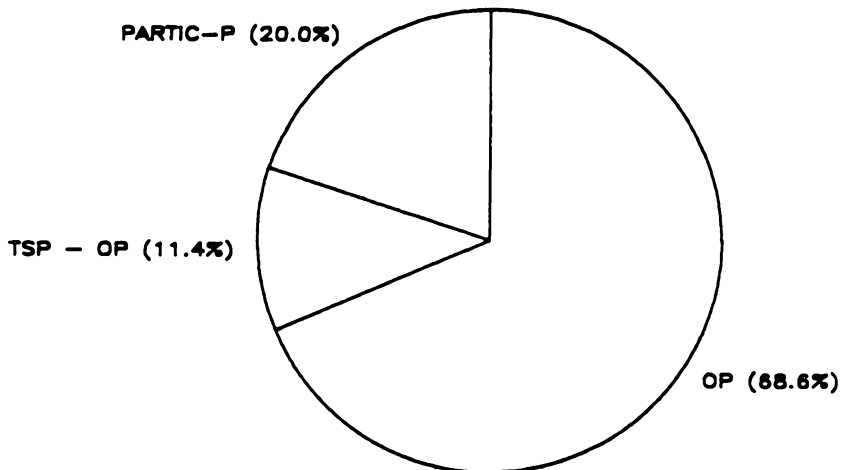
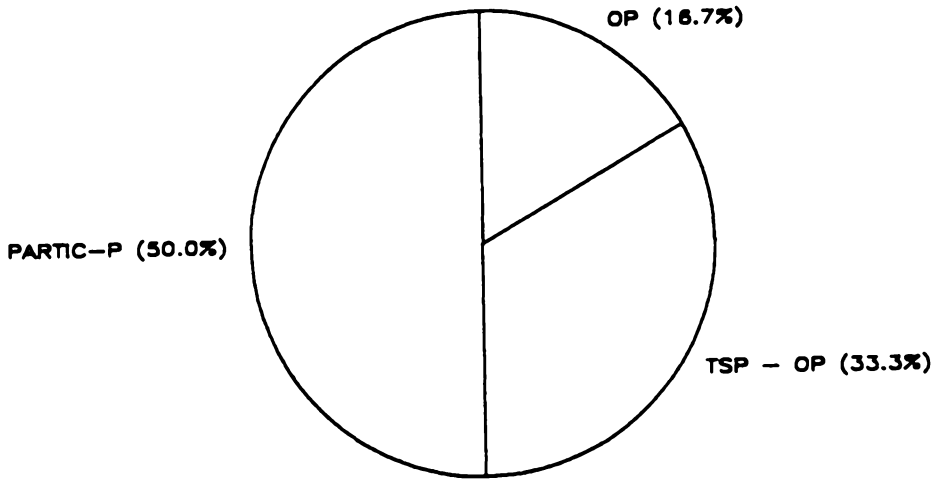


Figure 41. Mean phosphorus distribution in South Run during baseflow (top) and runoff (bottom) conditions, November, 1984 - May, 1986.

NORTH FORK (BR04)
BASEFLOW P DISTRIBUTION TP = 0.06 mg/L



NORTH FORK (BR04)
RUNOFF P DISTRIBUTION TP = 0.10 mg/L

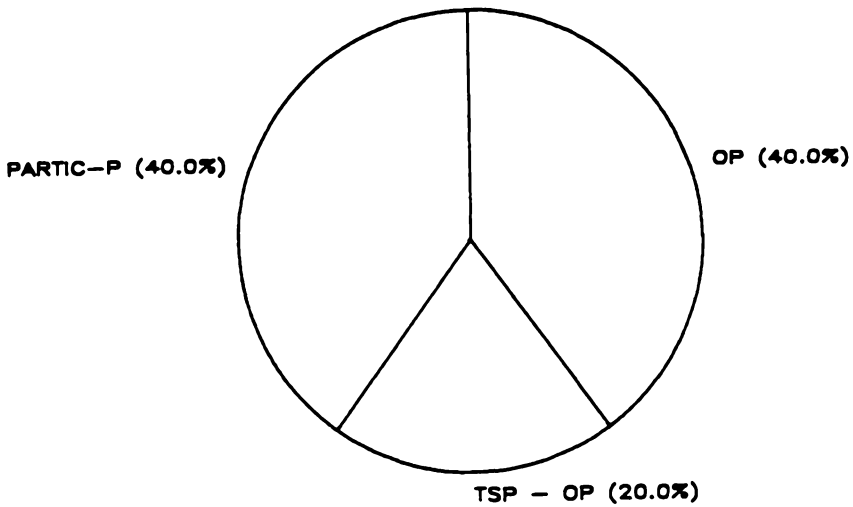


Figure 42. Mean phosphorus distribution in North Fork during baseflow (top) and runoff (bottom) conditions, November, 1984 - May, 1986.

significantly greater amount than in Broad Run.

As with nitrogen, the South Run phosphorus profile changed the least of the three streams, from baseflow to runoff conditions. Particulate-P increased significantly during stormflow in Broad Run as did its organic nitrogen and suspended solids concentrations. In contrast, North Fork showed an increase in average OP, rather than particulate-P, during runoff conditions.

Stream Flows and Loading Estimates

The stream gage on Broad Run at Buckland has been in operation since 1950, and is maintained by the State Water Control Board (56). Automatic sampling apparatus was installed in 1978 by the Occoquan Watershed Monitoring Laboratory. Discrete samples are collected according to gage height during stormflow conditions and are composited to accurately represent the pollutant load carried by the flow. Grab samples are collected and analyzed weekly to represent baseflow water quality. The average discharge of Broad Run at this location, based 33 years of data, is 52.8 cfs (56).

In the summer of 1986, most of the tributaries to Lake Manassas ceased to flow due to drought conditions. South Run and Broad Run continued to flow. Field measurements to determine stream discharge were taken at BR02 in South Run

on July 16, 1986. Discharge calculations indicated a flow of 0.32 cfs. On July 14, 1986, the flow in Broad Run was recorded as 1.46 cfs. North Fork's flow was too low to measure accurately during this period.

Although the area drained by North Fork is slightly larger than that drained by South Run, it appears to have a lower overall input to Lake Manassas, not only in terms of relative nutrient concentrations, as shown previously, but also in terms of flow. The Vint Hill Farms Permit to Discharge, as issued by the Virginia State Water Control Board, allows a contribution of 0.246 MGD (0.38 cfs) to South Run. During very dry periods, the discharge from Vint Hill probably represents a substantial portion, if not all, of the flow in South Run. As a result, South Run contributes a greater percentage of flow to the reservoir than one would expect from the size of its drainage area. And while the flow in Broad Run represents by far the largest water contribution to the reservoir, Vint Hill's continuous discharge of high nitrogen and phosphorus concentrations can still be considered an important loading factor for Lake Manassas. Both these tributaries will therefore be considered in estimating annual loading rates.

Stream loading calculations are often only gross estimations due to the unavailability of flow data on all tributaries that contribute flow to a lake. The stream gaging

at the Broad Run station and the discharge record at the Vint Hill Farms Treatment facility, however, provide invaluable information for estimating loading rates to Lake Manassas, especially since these two stream appear to be the most important.

The Vint Hill Farms discharge is a point source because it is a continuous, relatively consistent, pollutant exporter to South Run. Discharge Monitoring Reports (DMR) filed monthly with the State Water Control Board provided the data used to calculate the average daily loading rates during the period October, 1984 through April, 1986 (appendix Table A-4).

The estimated daily loading rates, based on monthly averages, for total phosphorus and total suspended solids are shown in Table XX. The average concentration of total phosphorus in Vint Hill Farms discharge was 2.8 mg/L. The average daily discharge was 1.5 kg/d. NPDES requirements allow an effluent of 2.5 mg/L total phosphorus concentration and an average of 2.0 kg/d total phosphorus to be discharged to South Run. The total nitrogen (TN) loading rate is based on an analysis performed by the Virginia Consolidated Laboratory Services on a sample collected by the SWCB in August, 1985. Total nitrogen concentration was determined to be 23.5 mg/L, not unusual for a trickling filter plant effluent.

TABLE XX. ESTIMATES OF BASEFLOW LOADINGS FROM BROAD RUN AND SOUTH RUN ONTO LAKE MANASSAS

SOURCE	LOADING					
	DAILY (kg/d)			YEARLY (kg/yr)		
	TP	TN	TSS	TP	TN	TSS
BROAD RUN						
Baseflow	2.0	72	194	730	26,280	70,810
SOUTH RUN						
Vint Hill Discharge	2.3	22	18.6	840	8030	6790
TOTAL	4.3	94	213	1570	34,310	77,600

Loadings from baseflow in Broad Run (Table XX) are means calculated from 56 sample analyses and the accompanying flows (Appendix Table A-9). Baseflow conditions were then assumed for 365 days per year to arrive at annual loading rates. These loading values represent an average flow of 27 cfs, which is about half of the average discharge of 52.8 cfs. Using these baseflow loading estimates, South Run contributed 43 percent of the total phosphorus, 23 percent of the total nitrogen, and 5 percent of the total suspended solids to Lake Manassas on an annual basis during the period studied.

Storm loading rates were more difficult to ascertain. No stormflows were measured on South Run, and not all storms were monitored on Broad Run. The results presented in Table XXI represent twelve storms which were monitored from February, 1985 through April, 1986, on Broad Run. The storm events represented a total of 45.9 centimeters of rainfall. Rain data were collected from a gage at the water treatment plant at Lake Manassas. Normal rainfall for this area is 100 centimeters (57), which is a little more than twice the amount that was represented in the storms monitored. Assuming a proportionately greater load would result from greater rainfall, stormflow loading on a yearly basis for phosphorus (Table XXII) was estimated from storms for which data is available. These loading rates

TABLE XXI. COMPOSITE STORM DATA FOR BROAD RUN
AT BUCKLAND (ST70).

STORM #	DATE	FLOW (cfs)	TP	LOADINGS (kg)		RAINFALL (cm)
				TN	TSS	
85032	2-01-85	471	1879	11942	552082	4.9
85043	2-12-85	655	3145	14117	1576511	3.8
85081	3-22-85	59	41	1010	6921	2.9
85151	5-31-85	73	57	1259	24977	3.0
85293	10-20-85	79	95	1570	15187	7.4
85307	11-03-85	289	940	6224	392793	5.6
85326	11-22-85	134	84	1079	29227	3.0
85332	11-28-85	151	163	2643	42537	3.9
86035	2-03-86	105	60	1491	18639	2.1
86049	2-17-86	148	193	2598	78537	1.7
86073	3-14-86	213	1058	6177	647939	3.6
86105	4-15-86	168	461	2790	205896	4.0
	MEAN	212	681	4408	299271	3.8
	MEDIAN	150	178	2620	60537	3.7
	SUM	2545	8176	52900	3591246	45.9

TABLE XXII. ESTIMATES OF STORMFLOW PHOSPHORUS LOADINGS
FROM BROAD RUN ONTO LAKE MANASSAS

Loading Values Used in Calculations	PHOSPHORUS LOADING	
	Annual (kg/yr)	Surficial (g/m ² /yr) *
MEAN	17,921	6.27
MEDIAN	4811	1.68
SUM	17,819	6.23

* Surface Area of Lake Manassas: 706 acres or 2.86×10^6 m²

were calculated as both mean and median loads. Mean- and sum-based loading estimates are almost the same, and are about eleven times the baseflow loading estimates. Median-based estimates are much lower. A probability plot of total phosphorus storm loads (Figure 43) indicates the median load at the 50 percent point. The steep upward curve at the higher load values accounts for the mean being much higher than the median load, and indicates that a few storms can carry very large nutrient loads.

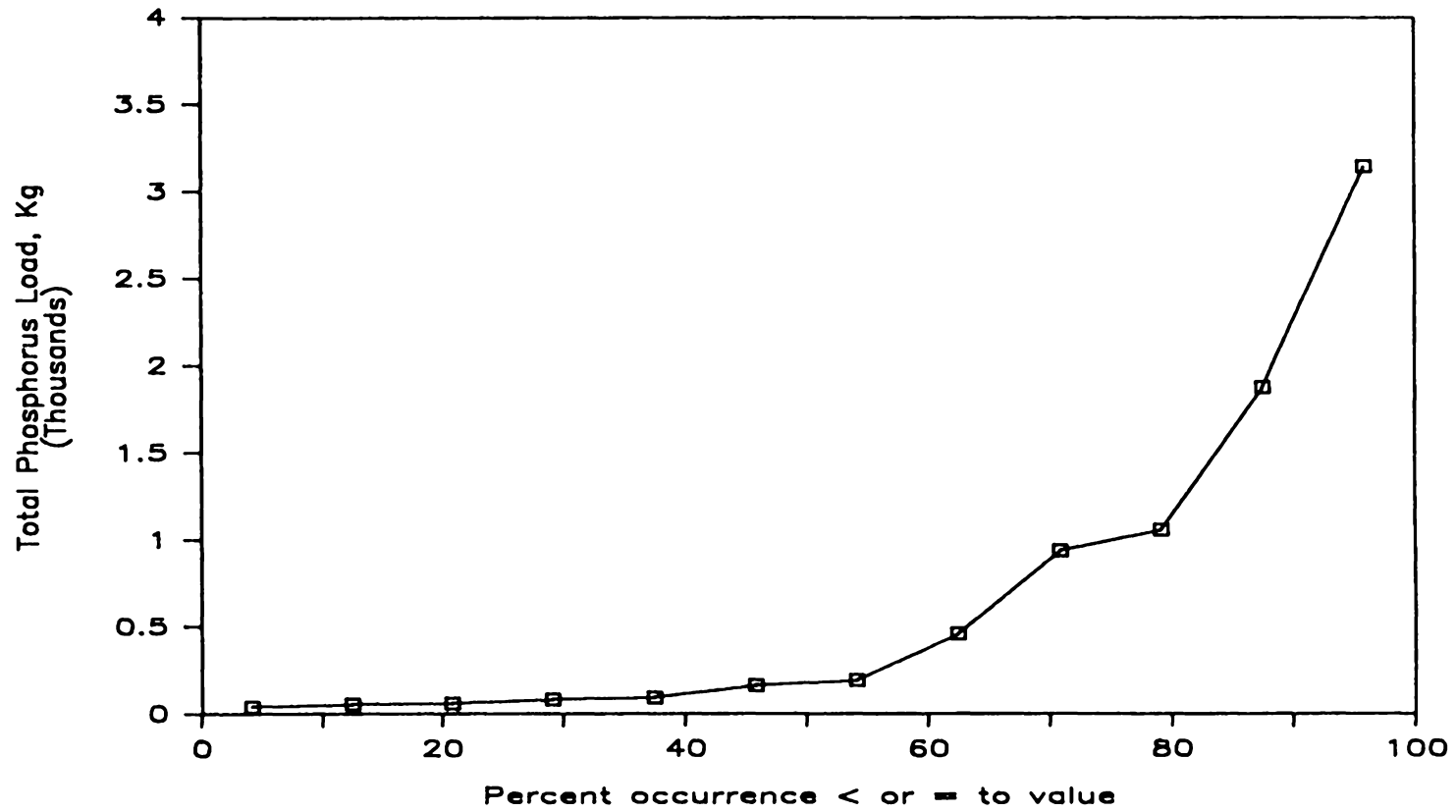


Figure 43. Probability plot of phosphorus storm loads, Broad Run at Buckland (ST70).

V. DISCUSSION

PHYSICAL CHARACTERISTICS

Lake Manassas can be classified as a dimictic lake of the temperate zone, freely circulating in spring and autumn, and stratifying in the summer into distinct epilimnetic and hypolimnetic layers. Inverse stratification occurs during ice coverage in winter. Spring overturn occurs in March, and autumn overturn occurs in November. The lower portion of the reservoir (represented by Stations LM01, LM02, and LM04) appears to remain intensely stratified throughout the summer. However, lower than normal precipitation (Table XXIII) was observed in the summer of 1985, and because samples were never collected immediately following a major storm event it was not possible to determine any destratifying effects that might have occurred in the main part of the reservoir.

The epilimnion of Lake Manassas extended to a depth of 10 feet for most of the summer. In August of 1985, temperatures at a depth of 15 feet were the same as at the surface of the lower reservoir stations. An increase in tributary flow as indicated by the Broad Run gage at that time may have caused some of the apparent depression of the epilimnion, but without knowing the pool level of the

TABLE XXIII. MONTHLY PRECIPITATION AT LAKE MANASSAS
FOR 1985 AND 1986 AS COMPARED TO AVERAGE
PRECIPITATION AT WASHINGTON, D.C.
(after Ruffner, ref. 57)

	Average Precipitation at Washington, D.C., 1936-1975. (inches)	Precipitation Measured at Manassas Treatment Plant (inches)	
	AVERAGE	1985	1986
January	2.59	0.65	1.36
February	2.61	3.92	1.89
March	3.36	2.23	1.46
April	2.88	0.90	2.91
May	3.91	4.78	
June	3.54	1.71	
July	4.10	1.20	
August	4.75	2.02	
September	3.34	1.99	
October	2.76	6.11	
November	2.96	5.42	
December	3.20	0.59	
Total	40.00	31.52	

reservoir, one has difficulty ascertaining the effects of specific inflow events on the epilimnetic volume and the total volume of the reservoir. The depth-volume curve (Figure 6) could be a useful tool in determining these effects if pool levels were known.

Dissolved oxygen concentrations in the hypolimnion began decreasing in April and remained less than one mg/L below a 15-foot depth through October, at the deeper stations. Stations in the upper reservoir (LM05 and LM06) and in the North Fork arm (LM03) occasionally became nearly devoid of oxygen at the bottom (Figures 13, 15, and 16) despite the lack of thermal stratification. It is possible that more of these bottom waters would have been found to be oxygen deficient than these data indicate because the "bottom" samples were collected anywhere from one to four feet above the actual sediment surface.

On one occasion, destratification appears to have been followed by restratification at LM01 in October, 1985. The dissolved oxygen concentration (Figure 10), temperature, and ammonia concentration (Figure 28) were similar at the surface and the bottom levels of this station on October 4, 1985. In contrast, on the sampling dates before and after that date, surface and bottom samples had markedly different characteristics, indicative of the difference in the water quality between epilimnetic and hypolimnetic waters.

Because the bottom sample collected on October 4 was only at 25 feet, as compared to samples at the more normal depth of 40 feet (which were collected on the preceding and following sampling dates), it probably was not taken at the bottom depth of this station. The observed phenomenon most likely represented a partial turnover of the reservoir indicated by the extending of the epilimnion to 25 feet. Other sampling locations, greater than 25 feet, exhibited a similar deepening of the epilimnion.

Based on full-pool level, the volume of the epilimnion as a percentage of the total volume can be calculated. Assuming an epilimnetic depth of ten feet during summer stratification, the epilimnion comprises 55 percent of the total volume of the reservoir. The volume of the reservoir (15.8 million cubic meters or 4.2 billion gallons) calculated during this study was difficult to verify from past records. It is generally believed that the volume of the reservoir is 5.8 billion gallons. However, according to the original calculations by the engineering firm that designed the spillway, Lake Manassas contains 4.1 billion gallons at full pool level (58). Since an accurate measure of the capacity of the reservoir is of obvious importance, further investigation into this discrepancy would be advisable.

LAKE PRODUCTIVITY AND NUTRIENT DYNAMICS

ALGAL PRODUCTIVITY

High dissolved oxygen concentrations near the surface of a lake are often an indication of excessive algal growth, and supersaturation always signals excessive growth. Supersaturation of DO often occurred in Lake Manassas (Figures 17-19), predominantly in summer. The highest concentrations of DO were measured at LM05 and LM06 where the zone of supersaturation occasionally extended to a depth of ten feet.

Values of percent dissolved oxygen saturation for a particular station, however, did not correspond well to chlorophyll a concentrations (Figure 44). Surface DO concentrations may have been affected by purely physical events such as wind action or changing air temperature, both of which can cause changes in epilimnetic heat content, which, in turn, affects the saturation point of oxygen, although not to the point of supersaturation. In addition, the chlorophyll a analyses may have been better correlated with DO-saturation values if those samples had been collected at the depth where peak oxygen concentration as percent saturation occurred.

Chlorophyll a concentrations generally were not high in comparison to those in nearby Occoquan Reservoir. In fact,

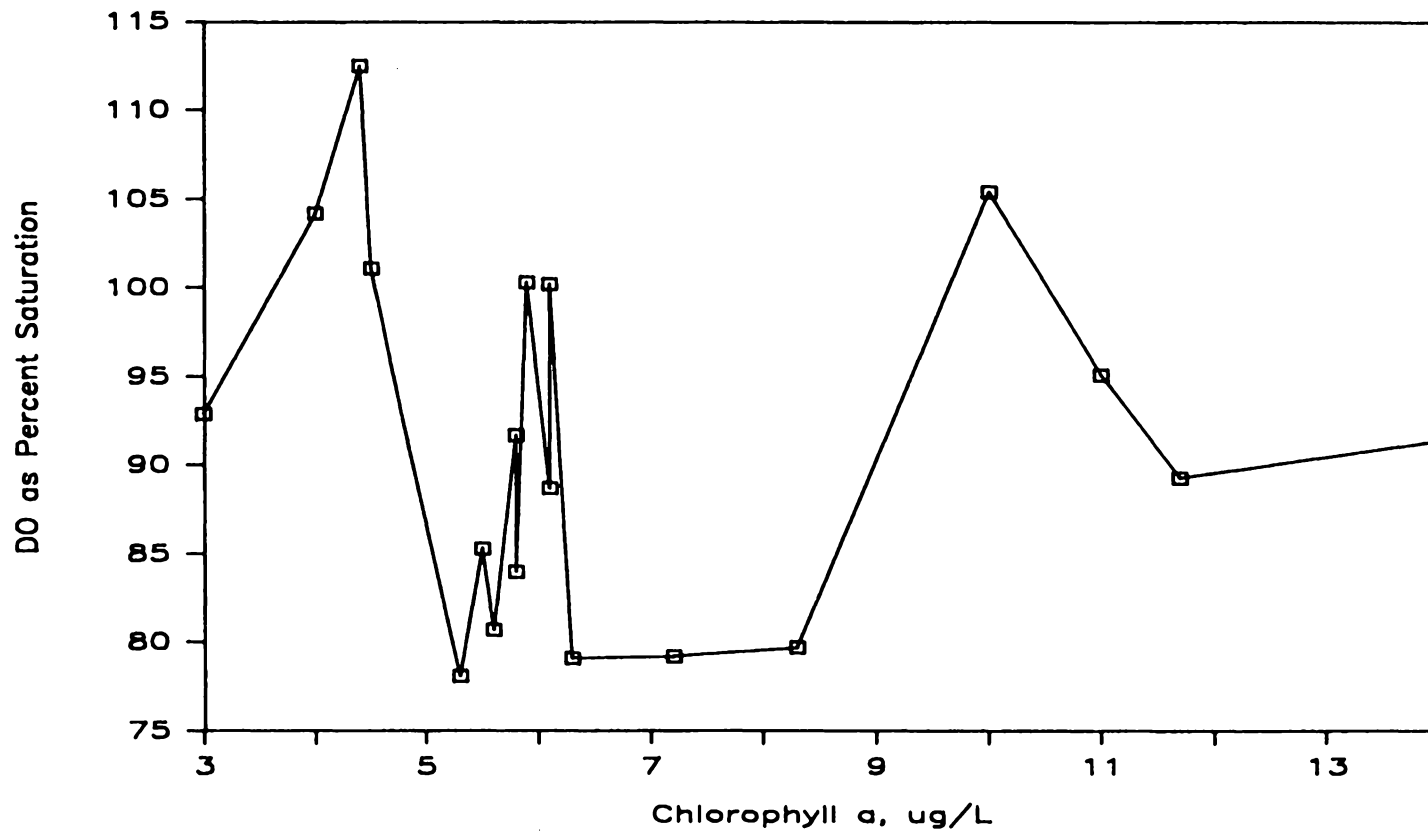


Figure 44. Relationship of chlorophyll *a* and dissolved oxygen in Lake Manassas at Station LM01.

the average summer chlorophyll a concentration of 7.2 ug/L was slightly less than the overall average chlorophyll a concentrations of 8.0 ug/L, which represented samples collected from October, 1984 through April, 1986. In other words, peak chlorophyll a concentrations were not found in the summer months when one would expect photosynthesis to be occurring at its highest rate. The addition of copper sulfate probably affected algal populations in the spring after it was applied, but it is unlikely that the algicide affected summer chlorophyll a concentrations. Table XXIV summarizes the average summer concentrations for chlorophyll a and for Secchi disk depth for each station. Station LM06 appears to be significantly more productive than the other stations. Probably because of the high level of available nutrients (orthophosphorus in particular) contributed by South Run.

Mean chlorophyll a concentration, mean Secchi disk depth, and mean depth at each station are depicted in Figure 45, and represent values determined from October, 1984 through April, 1986. The highest mean chlorophyll a levels occurred at the same stations where the Secchi disk depths were the lowest. Except for the North Fork arm (LM03), average productivity, as reflected in the surface chlorophyll a concentrations and Secchi depth, increased with decreasing mean depth.

TABLE XXIV. MEAN SUMMER CHLOROPHYLL a CONCENTRATIONS
AND SECCHI DISK DEPTH IN LAKE MANASSAS
JUNE - SEPTEMBER, 1985

Station	Chlorophyll <u>a</u> (ug/L)	Secchi Disk Depth (meters)
LM01	4.6	1.35
LM02	6.1	1.46
LM03	7.4	1.41
LM04	6.5	1.44
LM05	6.7	1.02
LM06	11.6	0.74

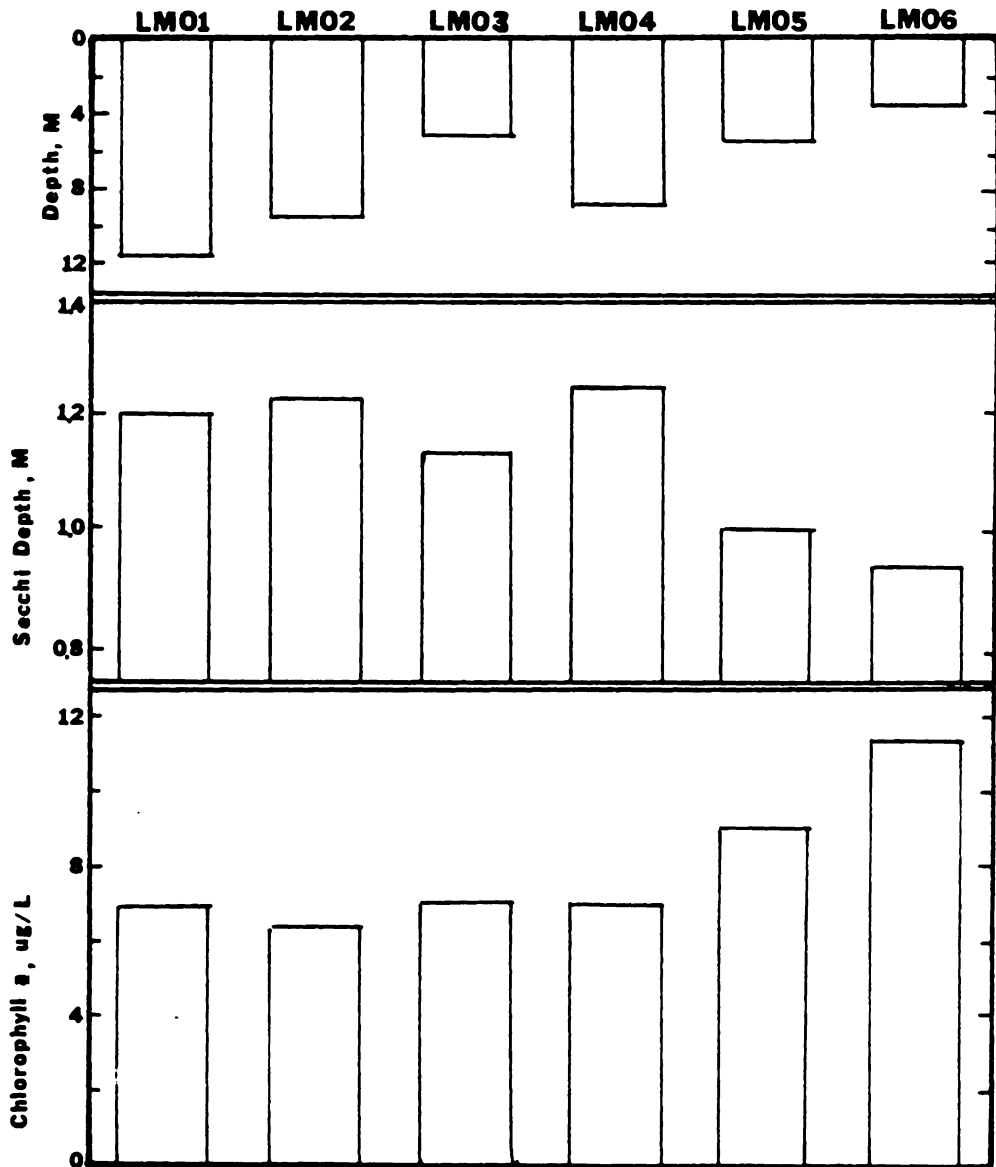


Figure 45. Mean chlorophyll a concentration, mean secchi depth, and mean station depth for each sampling site on Lake Manassas.

All stations in the lower body of the reservoir (LM01, LM02, and LM04) were similar in chlorophyll a concentration and variation (Figures 21, 22, and 24). The three stations exhibited characteristic peaks in chlorophyll a concentrations during spring turnover, although at the confluence of North Fork and Broad Run (LM02), the peaks were less dramatic. Copper sulfate addition after turnover each spring (Table X) may have exaggerated the peaks in chlorophyll a since subsequent samples probably reflected the effect of the algicide on the phytoplankton population.

The productivity at the North Fork reservoir station (LM03) was less than that in the upper reservoir at a similar depth (LM05) (Figure 45). The mean Secchi depth, which is less than the values at stations of similar productivity, might be affected by turbidity caused by the greater amount of mixing that occurs at this station as incoming flow disrupts stratification.

The upper reservoir was considerably more productive than the lower reservoir, especially at the station farthest from the spillway, LM06 (Figure 26). During the summer of 1985, chlorophyll a concentrations at LM06 increased steadily, as the level of the reservoir decreased and the depth at this station was reduced. A decrease in chlorophyll a, on September 11 and October 16, 1985, appeared to immediately follow periods of observed precipitation. The

high levels of chlorophyll a measured in November and December of that year, however, may be attributed to quiescent periods of seven to ten days that followed major storm events. Despite cooler water temperatures, nutrients made available by these storm events apparently caused a marked increase in algal growth, as shown in chlorophyll a concentrations of 25 and 26 ug/L in November and December, respectively, the highest levels found in the reservoir for all the samples analyzed.

NUTRIENTS

In general, at the surface of the reservoir, the distribution of the various phosphorus and nitrogen species was relatively consistent. Yet Station LM06, and to a lesser extent, Station LM05, had markedly different water quality characteristics from the rest of the reservoir. In addition, North Fork arm, for the most part, is not influenced by factors in the main body of the reservoir. It is convenient, therefore, to discuss nutrient dynamics in terms of the upper reservoir, the lower reservoir, and the North Fork arm.

Upper Reservoir

The influence of Broad Run and South Run were evident in the upper reservoir. At Station LM06, which is below

both tributaries, total phosphorus (0.04 mg/L) and total nitrogen (0.95 mg/L) concentrations at the surface were greater than at the other stations locations. The greater concentration of total phosphorus may be due to the resuspension of particulate phosphorus from the sediment as well as the influx from Broad Run itself (Figure 40). The greater mean nitrogen concentration found at LM06 was because of the greater concentrations of oxidized nitrogen (Figure 27). South Run had a very high mean baseflow concentration of oxidized nitrogen (2.03 mg/L) compared to the other tributaries (Table XVIII). Under both baseflow and runoff conditions, mean total nitrogen concentrations were three times greater in South Run than in Broad Run.

South Run contributed a significant amount of phosphorus in its most readily form, orthophosphorus, to Lake Manassas. Because orthophosphorus was found only in very low concentrations in the reservoir, it is obvious that this species is being converted in the upper reservoir. Because phosphorus is suspected to be a limiting nutrient in the lake, it is probable that the greater level of productivity found in the upper reservoir was a result of the phosphorus input by South Run.

Since the upper reservoir did not stratify in the summer into two distinct layers, surface and bottom mean nutrient concentrations were more similar to each other

than those found in well-stratified waters of the lower reservoir. On one occasion it appeared that a bottom sample, taken at LM06 on August 22, 1985, contained a phosphorus concentration four times greater than normal (Figure 36), possibly indicating sediment release of phosphorus associated with anaerobic hypolimnetic conditions. Dissolved oxygen was measured at 0.8 mg/L at the depth of 15 feet where this sample was collected.

On closer examination, however, the relatively high concentration of phosphorus observed was probably because the sample contained resuspended sediment. Soluble phosphorus was only a small fraction (0.02 mg/L) of the total phosphorus (0.18 mg/L) found. The TKN concentration was 1.05 mg/L and the total suspended solid concentration was 74 mg/L, both the greatest found at that station. According to a stream discharge reading taken at the Broad Run at Buckland gage, a four-fold increase in stream discharge occurred around the time this sample was taken. Resuspension of the sediment from mixing, therefore, would not be unexpected.

Nitrogen to phosphorus ratios were calculated based on concentrations in the reservoir prior to stratification in both 1985 and 1986 (Table XVI). The large difference in ratios that was found between the two years illustrates the problem of trying to use results from a single sampling

date to represent the phosphorus in the reservoir that is available during spring turnover. As an alternative, mean concentration values, calculated using more of the available data, were used to estimate available nutrients. Table XXV presents total N to total P ratios based on overall mean concentrations, as well as on mean summer concentrations, at each station. Despite the greater nutrient concentrations at LM06, the N:P ratio is not significantly different from the rest of the reservoir. N:P ratios based on mean summer concentrations, however, indicate phosphorus to be more limiting in the upper reservoir than in the lower reservoir during the summer of 1985.

Lower Reservoir

The lower portion of the reservoir exhibits a clino-grade oxygen profile as described by Wetzel (Figure 2) which is typical of lakes in a eutrophic condition. In summer, hypolimnetic oxygen depletion is well established by early June (Figures 11, 12 and 14).

Epilimnetic concentrations of ammonia nitrogen, which remained relatively low during the summer, increased during overturn in the autumn. The greatest surface concentrations of $\text{NH}_3\text{-N}$ were found in November of 1985, throughout the reservoir. On October 4, 1985, high $\text{NH}_3\text{-N}$ concentrations coincided with the partial overturn of the reservoir,

TABLE XXV. N:P RATIOS IN LAKE MANASSAS BASED ON OVERALL MEAN CONCENTRATIONS AND MEAN SUMMER CONCENTRAIONS OF SURFACE SAMPLES

STATION	MEAN OVERALL CONC. (mg/L)			MEAN SUMMER CONC. (mg/L)		
	TN	TP	N:P Ratio	TN	TP	N:P Ratio
LM01	0.77	0.03	26	0.51	0.03	17
LM02	0.74	0.03	25	0.51	0.03	17
LM03	0.78	0.03	26	0.46	0.03	15
LM04	0.73	0.03	24	0.53	0.03	18
LM05	0.79	0.03	26	0.52	0.03	17
LM06	0.95	0.04	24	1.06	0.04	26

which apparently brought deeper, ammonia-rich waters to the surface. Depletion of oxidized nitrogen occurred in the surface waters at all reservoir stations from July until November, 1985. This was probably due to assimilation by phytoplanktonic organisms.

Total phosphorus concentrations in the epilimnion generally peaked during spring overturn, then remained at a relatively constant concentration of 0.02 to 0.03 mg/L for the rest of the year. Detection of orthophosphorus in the epilimnion was rare.

The hypolimnion apparently remained effectively cut off from epilimnetic circulation for the duration of the summer. As decomposition of organic matter occurred in the sediments, using up the available oxygen, nutrient concentrations changed near the sediment surface. In accord with the early work done by Mortimer (38), oxygen depletion was followed by a decrease in oxidized nitrogen and an increase in ammonia, total phosphorus, alkalinity, and conductivity. Figures 46 and 47 show these changes at Station LM01. Stations LM02 and LM04 have similar profiles.

Under aerobic conditions, oxidized nitrogen predominated over ammonia (Figure 46, bottom) which, in turn, rapidly increased under anaerobic conditions, reaching its maximum bottom level concentration of 1.73 mg/L on October 16, 1985. Increases in conductivity observed at the bottom

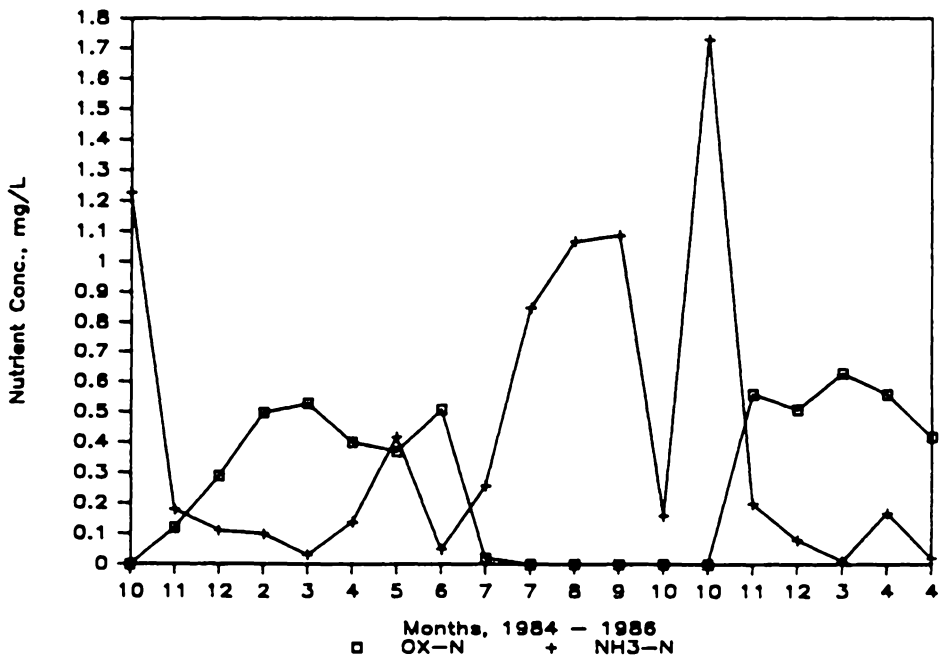
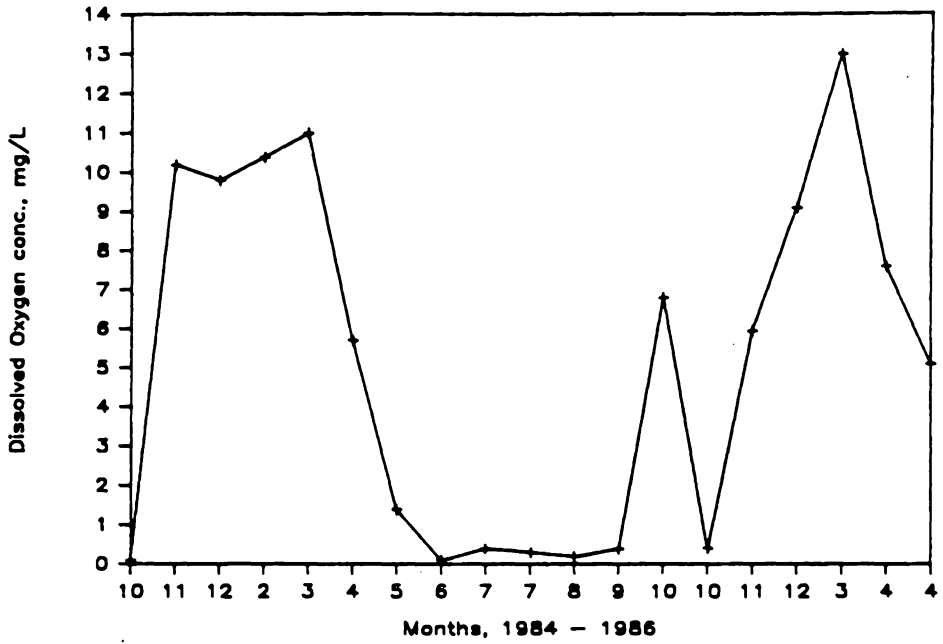


Figure 46. Dissolved oxygen variation (top) and oxidized and ammonia nitrogen variation (bottom) in the bottom waters of Lake Manassas at Station LM01.

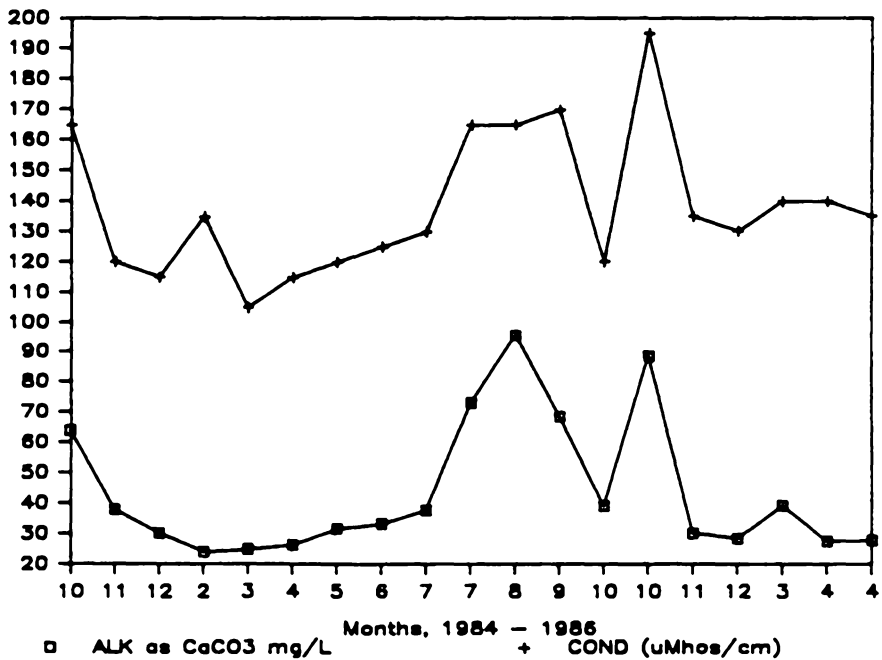
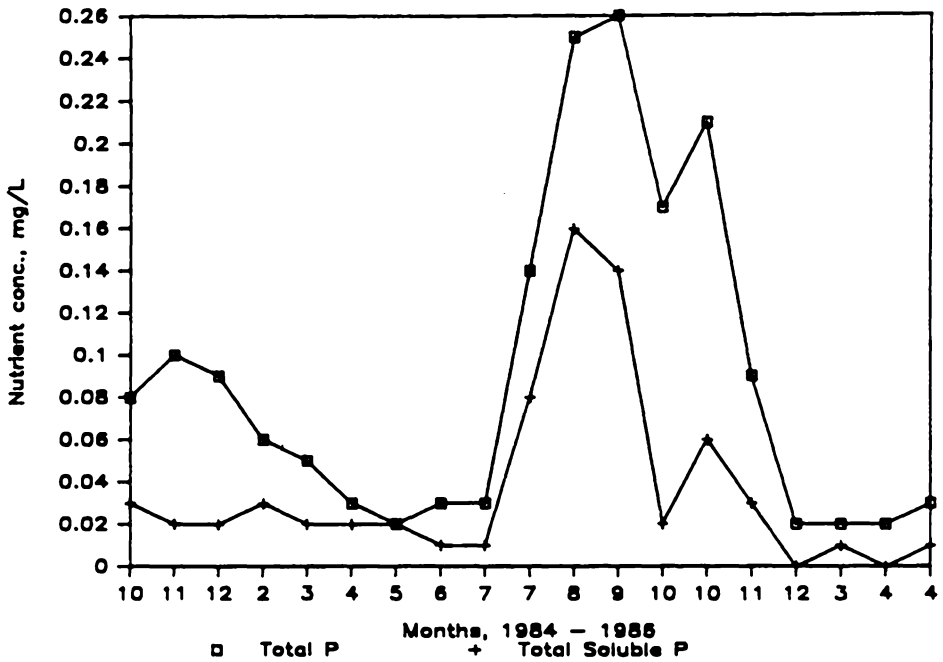


Figure 47. Soluble and total phosphorus variations (top) and alkalinity and conductivity variations (bottom) in bottom waters of Lake Manassas at Station LM01.

depth of Station LM01 paralleled the change in alkalinity measurements (Figure 47, bottom), as ammonia and phosphorus levels increased during anaerobic conditions.

Note that the increase in total phosphorus was mostly due to an increase in the soluble fraction (Figure 47, top) thus indicating that the mechanism was probably sediment release, perhaps due to reduction of ferric and manganese phosphates. In addition, orthophosphorus concentrations were determined to be the major portion of the total soluble fraction. There was some evidence that this increased orthophosphorus concentration at the bottom depths was made available to organisms in the euphotic zone. Total phosphorus concentrations increased slightly at the surface of the lower reservoir stations on October 4, 1985, as a partial turnover of the reservoir occurred. Orthophosphorus would probably be immediately assimilated by phytoplankton and therefore would not show up in later sample analysis.

Total nitrogen to total phosphorus ratios in the reservoir (Table XXV) were calculated based on mean concentrations of surface sample analyses collected from October, 1984 through April, 1986, and on mean summer concentration from June through September, 1985. These values can be compared to values reported in the literature (Table II). Ratios greater than 17 indicate phosphorus-limiting conditions. Ratios from 10 to 17 indicate N and/or P limiting

conditions. Most of the ratios calculated indicate P limiting conditions. Ratios based on summer mean concentrations (Table XXV) suggest a borderline case in North Fork arm (LM03), however, where nitrogen and/or phosphorus may be limiting. The upper reservoir station of LM06 appears to be the most phosphorus-limited during summer months, as mentioned previously.

N:P ratios are often defined by researchers as an inorganic nitrogen to inorganic phosphorus relationship, because only these forms are considered to be available for algal growth. Available phosphorus is usually considered to be a quantity somewhat greater than the orthophosphorus, analyzed as soluble reactive phosphorus, that is present in water, but the relationship to analytical test results is difficult to establish. Often a fraction of total phosphorus or total soluble is considered available for algal growth. Using several suggested methods to estimate bioavailable phosphorus (59), the resulting calculation of TN:TP ratios ranged from a low of twelve to a high of 62 in the reservoir. Regardless of the specific values used for the TN:TP ratio, it would be safe to assume that Lake Manassas is phosphorus-limited.

North Fork Arm

Stratification and hypolimnetic oxygen depletion did

occur in the North Fork arm (Figure 13). However, similar to the upper reservoir, as the water level in the reservoir decreased during the dry summer of 1985, the depth of the epilimnion extended to the bottom of Station LM03. Super-saturated oxygen concentrations were found less frequently (Figure 19) and mean chlorophyll a concentrations were lower (Figure 45) than at a similar depth in the upper reservoir, indicating that North Fork arm behaves differently, as a separately body of water than the rest of the reservoir.

Because the mean surface concentrations of nutrients were fairly consistent with the rest of the reservoir (Table XII), a higher flushing rate in this relatively narrow portion may account for its lower productivity. Mean Secchi disk transparency was greater than one would expect from its mean chlorophyll a concentration (Figure 45), which probably indicates the the presence of more suspended sediment. Bottom sample analyses (Table XIII), show concentrations of all nutrient forms to be much lower than any of the other station locations, again indicating a greater level of vertical mixing. North Fork did show a pattern similar to the rest of the reservoir in that oxidized nitrogen was not detected in any surface or bottom samples collected in the summer.

The North Fork tributary carried higher concentrations

of nitrogen and phosphorus than did Broad Run. These higher concentrations, however, were far less than the concentrations found in South Run. The effect of these nutrient contributions, therefore, was less evident than in the upper reservoir because of the higher flushing rate as well as the lower concentrations. As compared to Broad Run and South Run, North Fork contributes a significant portion of its nitrogen load as organic nitrogen (Figures 37-39). However, the concentration of TKN in the North Fork arm was not any greater than in the rest of the reservoir.

LAKE MODELS

Two approaches to lake classification will be considered: the Trophic State Index, which utilizes in-lake water quality data, and the Vollenweider Model, which assumes phosphorus-limiting conditions and predicts lake trophic status by calculating phosphorus loading onto the lake.

Trophic State

The trophic condition of a lake may be defined in terms of its mean chlorophyll a concentration, total phosphorus concentration, and Secchi disk transparency (Tables IV and V). Mean summer values for the entire reservoir in 1985 were 7.2 ug/L of chlorophyll a, 31 ug/L of total phospho-

rus, and 1.24 m for Secchi disk depth. Table V presents various ranges of chlorophyll a concentrations that have been used to define the trophic condition of a lake. These values would predict that Lake Manassas would be mesotrophic. However, according to EPA - NES delineations, eutrophic conditions prevail if the total phosphorus concentration is greater than 20 ug/L and the Secchi disk depth is less than 2.0 meters. As defined by these parameters, Lake Manassas would be considered eutrophic.

Trophic State Index

Carlson's Trophic State Indices (TSIs) were calculated using concentrations in the reservoir during spring overturn (Table XV). Values obtained for total phosphorus and Secchi disc depth were markedly different for 1985 and 1986. It may be that overturn effects last only a few days and, thus, are not accurately represented by the samples that were collected. A major storm event occurred in 1985 four days prior to lake sampling. The higher concentrations of nutrients found in the samples on that date could have reflected the nutrient load brought in by that storm. Additionally, in the first 3 months of 1986, rainfall was 2 inches less than the previous year, which in turn was almost 2 inches below normal. One would generally expect decreased nutrient export with a lesser amount of rainfall.

Carlson (26) discussed the problem of what the best time of year would be to collect samples on which the TSI calculations should be based. Spring overturn phosphorus concentrations may accurately represent the total mean concentration of phosphorus in a lake, a concept used in most predictive loading models, but, as Carlson noted, overturn concentrations may be difficult to obtain because overturn periods may not coincide with sampling. Carlson developed the indices by using summer values to provide the best agreement of total phosphorus with the algal parameters, chlorophyll a and Secchi disk transparency. For this reason, the TSIs for Lake Manassas were recalculated, based on mean concentrations found in surface samples collected from June through September, 1985. The TSI of Lake Manassas is 54 for total phosphorus, 50 for chlorophyll a, and 57 for Secchi disk transparency. These values correlate well with each other. A TSI value of 50 is generally considered the lower limit of eutrophy.

Carlson (27) noted that lakes with a TP:TN ratio of less than 26:1 by weight have significant deviations in the algal-nutrient relationship. The phosphorus - chlorophyll relationship used by Carlson to develop the TSIs is predicated on the algae being phosphorus-limited. A low correlation between the chlorophyll and phosphorus indices could indicate nitrogen-limiting conditions. However, Lake

Manassas shows good correlation of the indices, confirming phosphorus as the growth-limiting nutrient.

Carlson also noted that impoundments showed marked differences in TSI relationships as compared to natural lakes. The difference between the calculated transparency and chlorophyll indices might be explained by an interference from non-algal suspended material containing phosphorus.

Table XXVI illustrates the trend in summer productivity from the spillway to the upper reaches of the reservoir. North Fork had a greater chlorophyll a concentration than Station LM05 in the upper part of the reservoir. The station farthest from the spillway (LM06) had indices for both chlorophyll and transparency almost 10 points higher than those at the dam. Rainfall during this period was almost 11 inches below normal. It is possible, therefore, that the nutrients brought in by tributary streams remained in the upper reservoir, accounting for the higher TSIs. This phenomenon may also have occurred in the North Fork arm since its mean summer chlorophyll a concentration was the next to the highest level observed in the reservoir, at 7.4 ug/L. This is of particular interest, since the overall productivity in the North Fork arm was shown to be lower because of the probable higher flushing rate.

TABLE XXVI. TROPHIC STATE INDICES FOR LAKE MANASSAS BASED ON MEAN SUMMER VALUES, JUNE - SEPTEMBER, 1985

Station	Total P ug/L	P TSI	Chlorophyll <u>a</u> ug/L	<u>a</u> TSI	Secchi Disk meters	Disk TSI
LM01	28	52	4.6	46	1.35	56
LM02	28	52	6.1	48	1.46	54
LM03	28	52	7.4	50	1.41	55
LM04	28	52	6.5	49	1.44	55
LM05	32	54	6.7	49	1.02	60
LM06	40	57	11.6	55	0.74	64
Total Reservoir:		54		50		57

The Vollenweider Model

A relationship between annual phosphorus loading rates and lake trophic conditions was developed by Vollenweider (32). "Acceptable" and "excessive" loadings are related to the mean depth of the lake (H), and the annual flushing rate, (p), which is calculated by dividing annual inflow by lake volume. For Lake Manassas, $H_p = 23$ m/year, where

$$H = 7.7 \text{ m}$$

$$\text{Annual inflow} = 4.7 \times 10^7 \text{ m}^3/\text{yr}$$

$$\text{Lake volume} = 1.57 \times 10^7 \text{ m}^3$$

Annual inflow was based on the average discharge of Broad Run gaged at Buckland. Lake volume was based on capacity of the lake at spillway height, 285 feet above sea level. The volume used in this model was the 4.2 billion gallons calculated by the author.

Annual phosphorus loadings were calculated for South Run and Broad Run based on their yearly baseflow contribution of phosphorus (Table XX) and on a surface area for Lake Manassas of 2.86 million square meters (706 acres). Loading from South Run was calculated from discharge reports from Vint Hill Farms. Broad Run's loading was based on an average baseflow phosphorus concentration of 0.03 mg/L. The surface area was based on the a lake volume of 4.2 billion gallons. South Run contributed $0.19 \text{ g/m}^2/\text{yr}$ and Broad Run contributed $0.26 \text{ g/m}^2/\text{yr}$ to Lake Manassas.

These values are plotted on the Vollenweider Model in Figure 48. Lake Manassas lies below the "excessive" loading curve.

While South Run contributed only a small percentage of the flow to Lake Manassas as compared to Broad Run, the phosphorus loading from South Run was very significant during baseflow conditions. According to Vollenweider's model, if Vint Hill Farms discharge was eliminated, Lake Manassas would receive "acceptable" phosphorus loading from Broad Run during baseflow conditions (Figure 48).

However, it has been determined that Lake Manassas is, in fact, a eutrophic lake. Therefore, according to Vollenweider's concept, Lake Manassas should be receiving an "excessive" amount of phosphorus. Phosphorus loads from stormflow did contribute a significant amount of phosphorus to Lake Manassas. Table XXII presented estimated stormflow phosphorus loadings from Broad Run. One calculation estimated this load to be as much as 18,000 kilograms of phosphorus per year from Broad Run.

If storm loading rates, which have been calculated from median stormload values ($1.68 \text{ g/m}^2/\text{yr}$), were added to baseflow loadings and plotted on the Vollenweider graph, Lake Manassas would then lie in the eutrophic zone. In fact, storm loadings that were calculated using other approaches (Table XXII) are greater than $6 \text{ g/m}^2/\text{yr}$, which is the

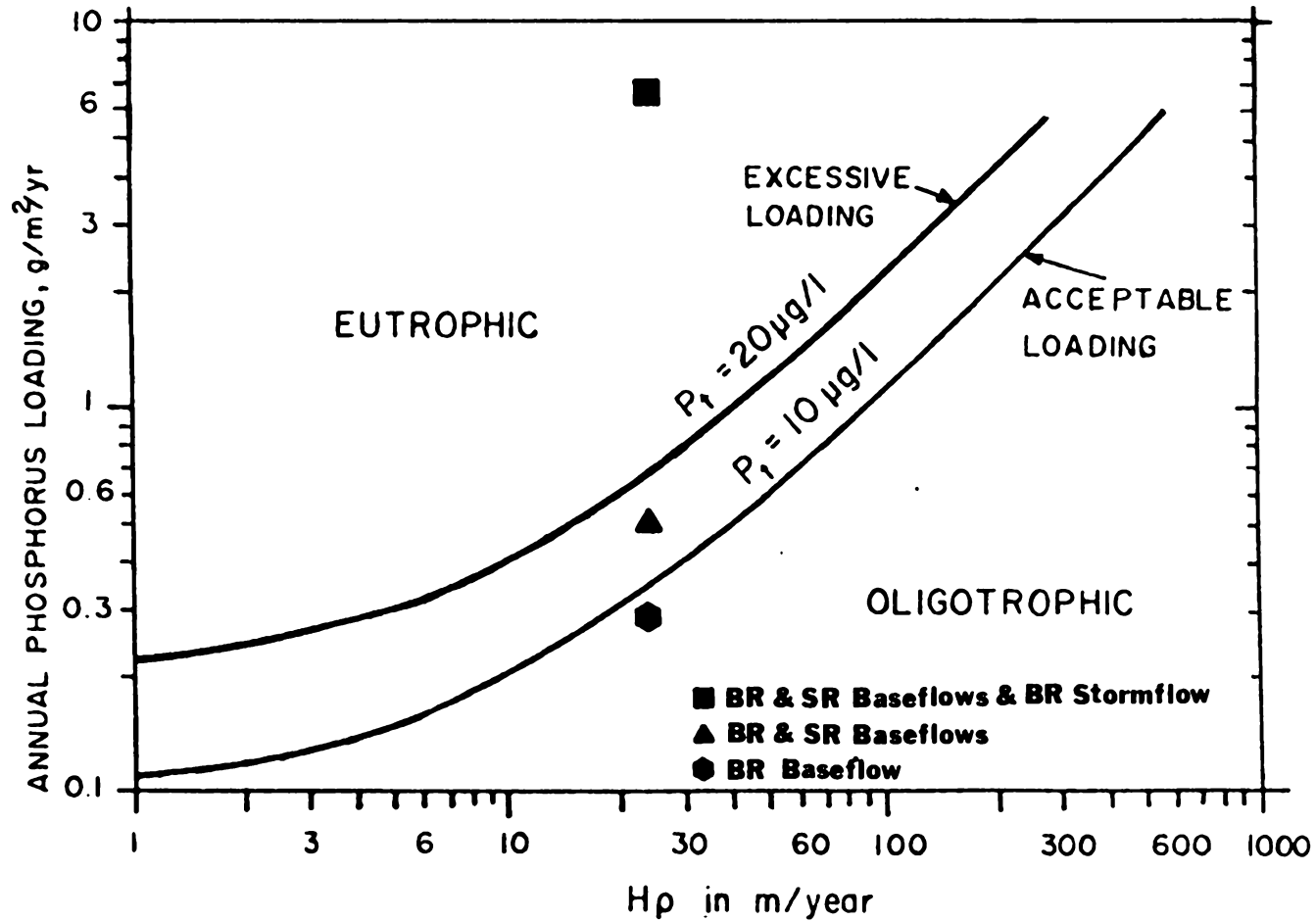


Figure 48. Comparison of baseflow and stormflow loadings of phosphorus from Broad Run and South Run with the Vollenweider loading guidelines.

maximum value on the Vollenweider graph. When only considering the most conservative estimation of storm phosphorus loading from Broad Run and not considering other storm inputs from other streams, which, indeed, must occur, Lake Manassas did receive an "excessive" amount of phosphorus. Thus, the model predicts Lake Manassas to be eutrophic, in accordance with the other criteria already presented.

FUTURE OUTLOOK

Lake Manassas is located at the perimeter of the greater Washington Metropolitan area. The City of Manassas and adjacent areas have experienced a rapid growth in population in the past ten years. The doubling of the water treatment plant's output has occurred in response to this growth. According to a report by the Metropolitan Washington Council of Governments, Prince William and Loudoun counties will be the fastest-growing localities in the metropolitan area during the next 25 years. The northern portion of Prince William county, part of which is tributary to Lake Manassas, is expected to triple its current population of 9000 by the year 2010 (60). The other portions of the Lake Manassas watershed will probably experience a similar increase in population because much of it

lies along the Interstate 66 corridor, a rapidly developing area.

Seventy-five percent of the Lake Manassas watershed is now forest, idle land, and pastureland (61). Current land use conditions can be expected to change dramatically as the population increases. Nutrient export rates (Table IX) generally are greater for most of the residential and commercial land uses that will probably replace a significant portion of the undeveloped acreages in the drainage basin during the next few decades.

Agricultural areas, which are about 14 percent of the Lake Manassas basin, may be a significant source of nitrogen and phosphorus loading, especially those areas that drain directly into the reservoir. Tributary Stations BR05 and BR06 had mean stormflow concentrations of total nitrogen and total phosphorus (Table XIX) that were twice as high as Broad Run's and approached concentrations found in South Run, below Vint Hill Farms discharge point. Although these stations were on relatively small tributaries, they represent areas of land with a large portion of agriculture use.

Agricultural practices often employ pesticides and herbicides. These can be washed into adjacent streams and then to downstream lakes and reservoirs. Samples of both raw and finished water from the Manassas water treatment

plant have periodically been collected by the Occoquan Watershed Monitoring Laboratory as part of a monitoring program for synthetic organic compounds. The sample analyses, primarily for herbicides and pesticides, have resulted in the detection of several of these compounds. In the raw water, butyl benzyl phthalate, diethyl phthalate, dioctyl phthalate, paraquat, propazine, and tetrachloroethylene have been detected. With the exception of paraquat, all these compounds have also been found in finished water. Thus, synthetic organic compounds have been shown to already be present in Lake Manassas in small quantities. Herbicide and pesticide use is not limited to agricultural applications. Lawn maintenance, roadside weed control, turfgrass maintenance, and insect control by chemical application is not uncommon in residential and commercial areas.

Recent rezoning of land bordering the north shore of Lake Manassas is an especial environmental concern. The Robert Trent Jones International is planned as an 803-acre resort and conference center including residential areas and three golf courses. About 25 percent of the planned development is currently in agriculture uses (8). Of particular concern is the fact that golf greens and fairways have long been known to be treated with high levels of fertilizers, herbicides, and insecticides. The U.S. Environ-

mental Protection Agency earlier this year banned the use of two chemicals used on golf courses: the insecticide Diazinon, and a fungicide containing cadmium used since the 1940s (62, 63).

A significant part of the management of golf greens is the frequent application of nitrogen-containing fertilizers. Leaching and runoff losses of applied nitrogen may be a potential source of nitrogen loading onto Lake Manassas. Studies have shown that the type of nitrogen-containing fertilizer used, the type of soil, the time of year, and irrigation rate all influence nitrogen losses and its concentration in runoff and leachate. Brown, et al. (64, 65) found, when they compared nitrogen source effects, that nitrate losses were greatest after applications of soluble sources of nitrogen and least after organic controlled-release sources were applied. Potential for high concentrations in runoff and leachate was found to be greatest during periods of low plant nitrogen use and heavy rainfall or irrigation. Depending on the type of rooting media used in the greens, leachate from greens fertilized by quick-release materials had concentrations as high as 326 mg/L nitrate as N. Runoff concentrations exceeded 30 mg/L.

Without control of runoff and leachate, nitrate loading onto the reservoir from the proposed golf course development would be a serious problem. However, the use of Best

Management Practices (BMPs) to control runoff is planned for the area. The Northern Virginia Planning District Commission used a water quality model to evaluate the use of BMPs at the site (7). Assuming the removal efficiencies of BMPs to be 14 percent for total nitrogen, and the utilization of BMPs to their fullest extent (100% coverage), it was projected that total nitrogen loading onto the lake would be 30 to 35 percent in excess of the expected loading from the area if land use was as originally planned under the Comprehensive Plan.

Leaching of nitrate into the groundwater might also present a significant problem, because of the proximity of the proposed development and the water quality standard of 10 mg/L $\text{NO}_3\text{-N}$. The interaction of groundwater with the reservoir is not known.

Sediment washoff during the construction phase of the project is another important factor to be considered. During construction of Interstate 66, Broad Run carried sediment several miles downstream into the upper part of the reservoir. Even with the limited amount of development now in the watershed, 6 feet of silt was measured at the base of the Lake Manassas dam in October, 1986 (2).

One positive element of the proposed development is that the responsibility for fertilizer and herbicide application will be under the direction of one entity. This

will provide for better control of the area, and presumably more professional management. In addition, an expanded lake and site monitoring program will be carried out by the Occoquan Watershed Monitoring Laboratory for the City of Manassas. It is important that such a program be maintained so that a current database will be available to detect, early on, any adverse effects the development might have on the reservoir water quality. In this regard, it is recommended that consideration be given to both nutrients and herbicides in the vicinity of the development. It would also be prudent to evaluate groundwater on the site, so that any contamination by herbicides or by nitrates could be detected.

Lake Manassas is a valuable regional resource, and will become more so in the coming years. It is imperative that studies such as this one continue to be made, so that the reservoir is protected to the best of our technical capabilities.

VI. CONCLUSIONS

From the results of the research described in this thesis, the following conclusions were derived:

1. Lake Manassas has a capacity at full pool of 4.2 billion gallons (15.8 million cubic meters). This volume is substantially less than the commonly quoted value of 5.8 billion gallons.
2. Lake Manassas is an eutrophic body of water. Conditions in the upper reservoir were significantly more eutrophic than the rest of the lake, thereby reflecting the impact of available nutrients provided by South Run.
3. Lake productivity, as characterized by chlorophyll a concentration and Secchi disk transparency, was greater in the upper portion of the reservoir, but as a whole, was not very high. Although algal blooms have been known to occur in the reservoir, none were evident during the period of study.
4. Nitrogen to phosphorus ratios in the water column indicate that the limiting nutrient in Lake Manassas is phosphorus.

5. According to the Vollenweider model, the current phosphorus loading to the lake predicts eutrophic conditions. The majority of the phosphorus is contributed by stormwater runoff.
6. While Broad Run contributes the vast majority of flow to Lake Manassas, South Run and North Fork are also significant sources of flow. The distribution of nitrogen and phosphorus forms in these tributaries differ significantly from each other.
7. Stormflow runoff from Broad Run contributes a large amount of nitrogen, phosphorus, and suspended solids to the reservoir. Runoff from storms was estimated to contribute seven to 25 times the annual phosphorus loading from baseflow.
8. South Run had the highest mean concentrations of all nutrient species determined for any of the tributaries that were monitored. This was true during both baseflow and storm runoff conditions.
9. Phosphorus loading by South Run, which was primarily due to the Vint Hill Farms Station discharge, was determined to be greater than the baseflow loading by Broad Run. This was in spite of the vastly greater flow in Broad Run.

VI. RECOMMENDATIONS

As the study of Lake Manassas continues, the following are recommended:

1. A complete investigation into the discrepancy in lake volume discovered by the author should be undertaken. Lake Manassas is widely believed to contain 1.6 billion gallons more water at full pool than that calculated by both the author and the original design engineers.
2. Flow measurements on South Run and North Fork, during both baseflow and runoff conditions, should be performed to provide information for a more precise determination of nutrient loadings from these sources.
3. A staff gage should be placed at the reservoir spillway, and a record maintained, so that the volume of water in the reservoir can be easily determined at any given time.
4. Because of the development planned for the north shore of Lake Manassas, an additional sampling site, between Stations LM04 and LM05, in the unnamed inlet on the north shore, should be added to the water-quality monitoring program.

5. The frequency of reservoir water-quality monitoring should be increased to biweekly during the period from April through October.
6. A more definitive study of algal productivity and a determination of the composition of the phytoplanktonic population should be undertaken.
7. Groundwater monitoring for nitrates and herbicides at the Robert Trent Jones site should be implemented.
8. Herbicide monitoring in the vicinity of the development site, and of the raw and finished water from the Manassas treatment plant, should be increased after the golf courses are in operation.

VII. REFERENCES CITED

1. Simmons, Catherine T., "Manassas, Virginia, 1873-1973: One Hundred Years of a Virginia Town," M.A. Thesis, Madison College, Harrisonburg, Virginia (1973).
2. Whetzel, Wade, Chief Operator, City of Manassas Water Treatment Facility, Greenwich, Virginia, personal communication.
3. Commonwealth of Virginia, Department of Conservation and Economy, Geologic Map of Virginia (1963).
4. Randall, C. W., Grizzard, T. J., and Hoehn, R. C., "The Effect of Upstream Control Measures on a Water Supply Reservoir." Journal of the Water Pollution Control Federation, 46, 2687-2702 (1978).
5. Virginia State Water Control Board, "Policy for Waste Treatment and Water Quality in the Occoquan Watershed." Richmond, Virginia. Adopted July 26, 1971.
6. Northern Virginia Planning District Commission, "Profile of Nonpoint Pollution Management Activities in the Occoquan Basin." Annandale, Virginia (1985).
7. Jones-Saunders Associates, "Residential Planned Community Zoning Report, Robert Trent Jones International, Prince William County, Virginia," Chatham, New Jersey (1986).
8. Northern Virginia Planning District Commission, "Nonpoint Pollution Analysis of the Robert Trent Jones International Rezoning Proposal." Final report. Annandale, Virginia (1986).
9. McLaughlin, S. G., "Reservoir Sediment Exchange of Phosphate, Ammonia, and Metals Under Anaerobic and Aerobic Conditions," M.S. Thesis, VPI & SU, Blacksburg, Virginia (1981).
10. Wetzel, R. G., Limnology. W. B. Saunders Company, Philadelphia, PA., 743 p. (1975).

11. Hammer, M. J. and MacKichan, K. A., Hydrology and Quality of Water Resources. John Wiley & Sons, Inc., New York, N. Y., 486 p. (1981).
12. Hutchinson, G. E., A Treatise on Limnology, Volume I. John Wiley & Sons, Inc., New York, N. Y. 1036 p. (1975).
13. Masters, G. M., Introduction to Environmental Science and Technology. John Wiley & Sons, Inc., New York, N. Y., 404 p. (1974)
14. Likens, G. E., ed., Nutrients and Eutrophication: The Limiting Nutrient Controversy, Special Symposia I. American Society of Limnology and Oceanography, Inc., Lawrence, Kansas, 328 p. (1972).
15. Sawyer, C. N., "Fertilization of Lakes by Agricultural and Urban Drainage." Journal of New England Water Works Association, 61, 2, 109-127 (1947).
16. Davison, W., Reynolds, C. S., and Finlay, B. J., "Algal Control of Lake Geochemistry, Redox Cycles in Rostherne Mere, U. K." Water Research, 19, 2, 265-267 (1985).
17. Shannon, E. E. and Brezonik, P. L., "Relationship Between Lake Trophic State and Nitrogen and Phosphorus Loading Rates." Environmental Science and Technology, 6, 8, 719-725 (1972).
18. Benefield, L. D., Judkins, J. F., and Weand, B. L., Process Chemistry for Water and Wastewater Treatment. Prentice-Hall, Inc., Englewood Cliffs, N. J., 510 p. (1982).
19. Stumm, W. and Morgan, J. J., Aquatic Chemistry. John Wiley & Sons, Inc., New York, N. Y., 780 p. (1981).
20. Vallentyne, J. R., Panel discussion for "Nutrients and Eutrophication - Prospects and Options for the Future." in Likens, G. E., ed., Nutrients and Eutrophication: The Limiting Nutrient Controversy, Special Symposia I. American Society of Limnology and Oceanography, Inc., pp. 297-318 (1972).
21. Odum, E. P., Ecology, the Link Between the Natural and the Social Sciences. Holt, Reinhart, and Winston, New York, N. Y., 244 p. (1975).

22. Forsberg, C. "Present Knowledge of Limiting Nutrients." in Restoration of Lakes and Inland Waters. Proceedings International Symposium on Inland Waters and Lake Restoration. Portland, Maine. Sept. 8-12, 1980. EPA 440/5-81-010, Office of Water, USEPA, Washington, D. C., p. 37 (1980).
23. Garn, H. S. and Parrott, H. A., "Recommended Methods for Classifying Lake Conditions, Determining Lake Sensitivity, and Predicting Lake Impacts." Forest Service, Eastern Region, Hydrology Paper 2, U.S. Dept. of Agriculture, Washington, D. C. (1977).
24. Reckhow, K. H., "Quantitative Techniques for the Assessment of Lake Quality." Office of Water Planning and Standards, EPA-440/5-79-015, USEPA, Washington, D.C. (1979).
25. Walker, W. W., Jr., "Use of Hypolimnetic Oxygen Depletion Rate as Trophic State Index for Lakes." Water Resources Research, 15, 6, 1463-1470 (1979).
26. Carlson, R. E., "A Trophic State Index for Lakes." Limnology and Oceanography, 22, 361-369 (1977).
27. Carlson, R. E., "Using Trophic State Indices to Examine the Dynamics of Eutrophication." in Restoration of Lakes and Inland Waters. Proceedings International Symposium on Inland Waters and Lake Restoration. Portland, Maine. Sept. 8-12, 1980. EPA 440/5-81-010, Office of Water, USEPA, Washington, D. C., pp. 218-221 (1980).
28. Virginia State Water Control Board, Water Quality Standards, Publication No. RB-1-80 (1982).
29. Dillon, P. J. and Rigler, F. H., "The Phosphorus - Chlorophyll Relationship in Lakes." Limnology and Oceanography, 19, 5, 767-773 (1974).
30. Vighi, M. and Chiaudani, G., "A Simple Method to Estimate Lake Phosphorus Concentrations Resulting from Natural Background Loadings." Water Resources, 19, 8, 987-991 (1985).
31. Dillon, P. J. and Kirchner, W. B., "The Effects of Land Use on the Export of Phosphorus from Watersheds." Water Research, 9, 135-148 (1975).

32. Vollenweider, R. A., "Input - Output Models with Special Reference to the Phosphorus Loading Concept in Limnology." Schweizerische Zeitschrift fur Hydrologie, 37, 53-83 (1975).
33. Novotny, V. and Chesters, G., Handbook of Nonpoint Pollution Sources and Management. Van Nostrand Reinhold Company, New York, N. Y., 555p. (1981).
34. Dillon, P. J., "A Critical Review of Vollenweider's Nutrient Budget Model and Other Related Models." Water Resources Bulletin, 10, 969-989 (1974).
35. Imboden, D. M., "Phosphorus Model of Lake Eutrophication." Limnology and Oceanography, 19, 2, 297-304 (1974).
36. Kirchner, W. B. and Dillon, P. J., "An Empirical Method of Estimating the Retention of Phosphorus in Lakes." Water Resources Research, 2, 1, 82-83 (1975).
37. Lee, G. F., Rast, W., and Jones, R. A., "Eutrophication of Water Bodies: Insights for an Age-Old Problem." Environmental Science and Technology, 12, 900-908 (1978).
38. Mortimer, C. H., "Chemical Exchange Between Sediments and Water in the Great Lakes - Speculation on Probable Regulatory Mechanisms." Limnology and Oceanography, 16, 2, 387-404 (1971).
39. Holdren, G. C., Jr., and Armstrong, D. E., "Factors Affecting Phosphorus Release from Intact Lake Sediment Cores." Environmental Science and Technology, 14, 1, 79-87 (1980).
40. Grobler, D. C. and Davies, E., "The Availability of Sediment Phosphorus to Algae." Water South Africa, 5, 3, 114-122 (1979).
41. Larsen, D. P., Schults, D. W., and Malueg, K. W., "Summer Internal Phosphorus Supplies in Shagawa Lake, Minnesota." Limnology and Oceanography, 26, 4, 740-743 (1981).

42. Mayer, L. M., Liotta, F. P., and Norton, S. A., "Hypolimnetic Redox and Phosphorus Cycling in Hypereutrophic Lake Sebasticook, Maine." Water Research, 16, 1189-1196 (1982).
43. Mawson, S. J., Gibbons, H. L., Jr., Funk, W. H., and Hartz, K. E., "Phosphorus Flux Ratio in Lake Sediments." Journal of the Water Pollution Control Federation, 55, 8, 1105-1110 (1983).
44. Sonzogni, S., Chapra, S. C., Armstrong, D. E., and Logan, T.J., "Bioavailability of Phosphorus inputs to Lakes." Journal of Environmental Quality, 11, 4, 555-563 (1982).
45. Young, T. C., DePinto, J. V., Flint, S. E., Switzenbaum, M. S., and Edzwald, J. K., "Algal Availability of Phosphorus in Muncipale Wastewater." Journal of the Water Pollution Control Federation, 54, 11, 1505-1516 (1982).
46. DePinto, J. V., Young, T. C., and McIlroy, L. M., "Great Lakes Water Quality Improvement: The Strategy for Phosphorus Discharge Control is Evaluated." Environmental Science and Technology, 20, 8, 752-759 (1986).
47. Anderson, J. M., "Effect of Nitrate Concentration in Lake Water on Phosphorus Release from the Sediment." Water Research, 16, 1119-1126 (1982).
48. Grizzard, T. J., Randall, C. W., Sherman, T. E., Weand, B. W., and Hoehn, R. C., "Management of Sediment Phosphorus Cycling by Nitrate Addition." Paper presented at Congres Nitrates dans les Eaux, Paris, France, October 22-24, 1985.
49. Suess, M. J. "Health Aspects of Eutrophication. in Restoration of Lakes and Inland Waters. Proceedings International Symposium on Inland Waters and Lake Restoration. Portland, Maine. Sept. 8-12, 1980. EPA 440/5-81-010, Office of Water, USEPA, Washington, D. C., pp. 356-358 (1980).
50. Virginia State Water Control Board, Best Management Practices Handbook. Planning Bulletin No. 322 (1981).

51. Omernik, J. M., The Influence of Land Use on Stream Nutrient Levels. USEPA, Office of Research and Development, EPA-600/3-76-014, Corvallis, Oregon (1976).
52. Brown, F. X. and Grizzard, T. J., "Nonpoint Sources Literature Review, Journal WPCF, 51 (6), 1428-1444 (1979).
53. Walker, W. W., "Significance of Eutrophication in Water Supply Reservoirs." Journal of the American Water Works Association, 75, 1, 38-42 (1983).
54. Bernhardt, H. "General Impacts of Eutrophication on Potable Water Preparation." in Restoration of Lakes and Inland Waters. Proceedings International Symposium on Inland Waters and Lake Restoration. Portland, Maine. Sept. 8-12, 1980. EPA 440/5-81-010, Office of Water, USEPA, Washington, D. C., pp. 359-363 (1980).
55. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 16th Edition. APHA, Washington, D. C., 1268 p. (1985).
56. U.S. Geological Survey, Water Resources Data - Virginia, Water Year 1984, USGS Water Resources Data Report VA-84-1 (1985).
57. Ruffner, J. A. and Bair, F. E., The Weather Almanac, Gale Research Company, Detroit, Michigan (1977).
58. Strickland, James, Engineer, Hayes, Seay, Mattern and Mattern, Roanoke, Virginia, personal communication.
59. Collins, C. D. and Siegfried, C. A., "Bioavailable Phosphorus as an Alternative to Total Phosphorus in Development of Nutrient Loading - Trophic Relationship." Proceedings Lake and Reservoir Management: Practical Applications, 4th Annual Conference and International Symposium of the North American Lakes Management Society, October 16-19, 1984, pp. 20-23 (1985).
60. Metropolitan Washington Council of Governments, "Growth Trends to the Year 2010: Forecast for the Metropolitan Washington Area." Washington, D. C. Report issued September, 1986.

61. Sweet, Rita, Engineer, Northern Virginia Planning District Commission, Annandale, Virginia, personal communication.
62. American Chemical Society, Chemical and Engineering News, 64, 2, p. 26 (1986).
62. American Chemical Society, Chemical and Engineering News, 64, 41, p. 10. (1986).
64. Brown, K. W., Duple, R. L., and Thomas, J. C., "The Influence of Season and Fate on Fate of N Applied Golf Greens." Agronomy Journal, 69, 667-671 (1977).
65. Brown, K. W., Thomas, J. C., and Duple, R. L., "Nitrogen Source Effect on Nitrate and Ammonia Leaching and Runoff Losses from Greens." Agronomy Journal, 74, 947-950 (1982).

APPENDIX TABLES

TABLE A-1. SURFACE WATER STANDARDS FOR SURFACE PUBLIC WATER SUPPLIES PROMULGATED BY THE VIRGINIA STATE WATER CONTROL BOARD IN 1981 (reference 28).

CONSTITUENT	CONCENTRATION (MG/L)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chloride	250
Chromium	0.05
Copper	1.0
Foaming agents (measured as methylene blue active substances)	0.5
Iron (soluble)	0.3
Lead	0.05
Manganese (soluble)	0.05
Mercury	0.002
Nitrate (as N)	10
Phenols	0.001
Selenium	0.01
Silver	0.05
Sulfate	250
Total dissolved solids	500
Zinc	5.0
Chlorinated Hydrocarbon Insecticides:	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
Chlorophenoxy Herbicides:	
2,4-D	0.1
2,4,5-TP (Silvex)	0.01
Radioactivity:	picocurie/liter
Combined radium-226 and radium-228	5
Gross alpha particle activity	15

TABLE A-2. ANALYTICAL METHODS USED AT OCCOQUAN WATERSHED MONITORING LABORATORY FOR THE ANALYSIS OF CHLOROPHYLL, SUSPENDED SOLIDS, AND NUTRIENTS (SM=STANDARD METHODS, 15th EDITION).

PARAMETER	METHODOLOGY
Chlorophyll <u>a</u>	SM #1002G pp. 1067-1072
Total Suspended Solids	SM #209C pp. 94-95
Nitrate and Nitrite Nitrogen	Technicon Method 100-70W Nitrate and Nitrite in Water and Wastewater. Technicon AutoAnalyzer II System. Sample handled according EPA #353.2 1-6.9 Acid-washed glassfiber filters are used prepare samples. Values reported together as Oxidized Nitrogen
Ammonia Nitrogen	EPA Region V CRL Procedure: Automated Phenolate/Nitroprusside Spectrophotometric Determination. Technicon AutoAnalyzer II System. Acid-washed glassfiber filters are used prepare samples. Exceptions are listed under Note #1.

TABLE A-2. CONTINUED

PARAMETER	METHODOLOGY
Total Kjeldahl Nitrogen	<p>Technicon Method #695-82W: Individual/Simultaneous Determination of Nitrogen and/or Phosphorus in BD Acid Digests. Technicon AutoAnalyzer II System.</p> <p>Samples digested according to EPA #351.2 section 7 with modifications listed under Notes #2, #3, and #4.</p>
Soluble Kjeldahl Nitrogen	<p>Samples filtered through acid-washed glassfiber filters then analyzed the same as TKN.</p>
Total Phosphorus	<p>Technicon Method #695-82W: Individual/Simultaneous Determination of Nitrogen and/or Phosphorus in BD Acid Digests. Technicon AutoAnalyzer II System.</p> <p>Samples digested according to EPA #351.2 section 7 with modifications listed under Notes #2, #3, and #4.</p>
Total Dissolved Phosphorus	<p>Samples filtered through acid-washed glassfiber filters then analyzed the same as Total P.</p>

TABLE A-2. CONTINUED

PARAMETER	METHODOLOGY
Soluble Reactive Phosphorus	<p>Technicon Method #155-71W: Orthophosphate in Water and Seawater. Technicon AutoAnalyzer II System.</p> <p>Acid-washed glassfiber filters are used prepare samples.</p> <p>See Note #5 for exception.</p>

NOTES

1. Sulfuric acid is not added to the sampler wash water or the stock standard solution.
2. 4 ml. of digestion solution instead of 5 ml. is added to 20 ml. of sample prior to digestion.
3. Samples are digested at 200 C for 1.5 hours then at 375 C for a total time of 4 hours.
4. After digestion samples are diluted with 20 ml. of distilled water.
5. The developed color is measured at 660 nm.

REFERENCES

1. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 15th Edition. APHA, Washington, D. C. (1981).
2. U. S. Environmental Protection Agency, "Methods for the Examination of Water and Wastes." USEPA, EMSL, Cincinnati, Ohio, (EPA-600/4-79-020) (1979).
3. "Operation Manual for the Technicon Autoanalyzer II-C System." Technicon Industrial Systems, Tarrytown, New York, (1980).

TABLE A-3. PLANIMETERED AREAS OF THE CONTOURS OF LAKE MANASSAS FROM UNITED STATES GEOLOGICAL SURVEY MAPS "THOROUGHFARE GAP" AND "GAINESVILLE" QUADRANGLES (1:24,000 SCALE).

CONTOUR LINE ELEVATION (M.S.L.)	AREA (ACRE)
285 (surface)	706
280	576
270	369
260	220
250	58
240	26
230	12

TABLE A-4. VINT HILL FARMS STATION'S AVERAGE MONTHLY DISCHARGE OF TOTAL PHOSPHORUS AND TOTAL SUSPENDED SOLIDS, OCTOBER, 1984 - APRIL, 1986. BASED ON DISCHARGE MONITORING REPORTS FILED WITH VIRGINIA WATER CONTROL BOARD.

MONTH	MGD	TSS (mg/L)	TSS (kg/d)	TP (mg/L)	TP (kg/d)
NPDES LIMIT:	0.246	20	18	2.5	2.0
10/84	0.149	13	7.5	2.3	1.3
11/84	0.145	15	8.5	2.5	1.8
12/84	0.124	16	7.5	3.0	1.5
01/85	0.117	18	8.5	3.7	1.6
02/85	0.143	13	7.4	3.3	1.6
03/85	0.105	19	7.8	3.3	1.3
04/85	0.106	15	6.2	2.8	1.1
05/85	0.131	9	4.5	1.7	0.8
06/85	0.126	10	4.8	2.3	1.1
07/85	0.121	10	4.8	2.3	1.1
08/85	0.142	12	6.4	2.3	1.2
09/85	0.128	13	6.7	2.5	1.2
10/85	0.149	14	9.3	2.5	1.5
11/85	0.192	20	15	2.9	2.1
12/85	0.139	17	9.8	2.3	1.4
01/86	0.132	22	11	2.7	1.3
02/86	0.186	19	14	2.0	1.4
03/86	0.165	25	16	3.1	1.9
04/86	0.152	60	36	5.6	3.1

TABLE A-5. FIELD DATA FROM LAKE MANASSAS
OCTOBER, 1984 - JULY, 1986.

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C	
STATION LM01					
10-31-84	1	7.95	84.0	18	
	2.5	7.95	84.0	18	
	5	8	84.5	18	
	7.5	7.9	83.4	18	
	10	7.8	82.4	18	
	15	6	63.4	18	
	20	4.6	47.6	17	
	25	0.4	4.1	16	
	30	0.1	1.0	15.5	
	35	0.1	1.0	14.5	
	40	0.1	1.0	14	
	11-27-84	1	11	91.7	7.5
		2.5	10.9	90.9	7.5
5		10.9	90.9	7.5	
7.5		10.8	89.0	7	
10		10.7	88.1	7	
15		10.7	88.1	7	
20		10.5	86.5	7	
25		10.5	86.5	7	
30		10.5	86.5	7	
35		10.2	84.0	7	
40		10.2	84.0	7	
12-11-84		1	10.1	79.1	5
		2.5	10	78.3	5
	5	10	78.3	5	
	7.5	10	78.3	5	
	10	10	78.3	5	
	15	10	78.3	5	
	20	10	78.3	5	
	25	10	78.3	5	
	30	9.8	76.7	5	
	35	9.8	76.7	5	
	40	9.8	76.7	5	

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM01				
6-12-85	1	9.3	112.5	25
	2.5	8.9	107.7	25
	5	8.7	104.3	24.5
	7.5	8.4	99.8	24
	10	8.1	96.2	24
	15	2.1	23.1	20
	20	0.2	2.0	16.5
	25	0.15	1.4	13
	30	0.4	3.6	11
	35	0.2	1.8	10
	40	0.1	0.9	10
	7-10-85	1	8.2	101.1
2.5		8	98.6	26
5		7.7	94.9	26
7.5		6.6	79.9	25
10		5.15	62.3	25
15		1.85	21.6	23
20		0.45	4.7	17.5
25		0.4	3.9	14
7-24-85	1	7.4	92.9	27
	2.5	7.35	92.2	27
	5	7.2	90.4	27
	7.5	7.2	89.5	26.5
	10	6.8	84.6	26.5
	15	0.9	10.7	24
	20	0.35	3.7	18
	25	0.35	3.4	14
	30	0.3	2.8	12
	35	0.3	2.7	11
8-22-85	1	6.55	80.7	26
	2.5	6.55	80.7	26
	5	6.4	78.9	26
	7.5	6.4	78.9	26
	10	6.25	77.0	26
	15	6.15	75.8	26
	20	0.6	6.9	22.5
	25	0.3	3.1	17
	30	0.2	1.9	14
	35	0.2	1.9	12.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C	
STATION LM01					
2-26-85	1	11.4	89.3	5	
	2.5	11.2	87.7	5	
	5	11.2	87.7	5	
	7.5	11.2	87.7	5	
	10	11	85.0	4.5	
	15	10.9	84.2	4.5	
	20	10.8	83.5	4.5	
	25	10.8	83.5	4.5	
	30	10.8	83.5	4.5	
	35	10.8	83.5	4.5	
	40	10.7	81.6	4	
	45	10.4	79.3	4	
	3-26-86	1	11.4	96.3	8
		2.5	11.4	95.1	7.5
		5	11.2	92.3	7
7.5		11.1	91.4	7	
10		11.1	91.4	7	
15		11.1	91.4	7	
20		11	90.6	7	
25		11	90.6	7	
30		11	90.6	7	
4-30-85		1	9.3	100.3	19
	2.5	9.3	99.2	18.5	
	5	9.2	98.2	18.5	
	7.5	9.2	98.2	18.5	
	10	8.8	92.0	17.5	
	15	7.7	73.1	13	
	20	7.55	67.7	10.5	
	25	7.4	65.6	10	
	30	7	61.3	9.5	
	35	5.7	49.9	9.5	
	5-22-86	1	9.2	104.2	21.5
		2.5	9.2	104.2	21.5
5		9.1	103.1	21.5	
7.5		9	101.0	21	
10		9	101.0	21	
15		6.5	68.7	18	
20		4.2	40.3	13.5	
25		4.7	42.6	11	
30		3.7	32.8	10	
35		2.3	20.4	10	
40		1.4	12.4	10	

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM01				
9-11-85	1	6.8	85.3	27
	2.5	6.8	85.3	27
	5	6.7	84.1	27
	7.5	6.7	84.1	27
	10	6.7	84.1	27
	15	3.9	47.6	25.5
	20	0.8	9.3	23
	25	0.55	5.8	18
	30	0.5	4.9	14.5
	35	0.4	3.8	13.5
10-4-85	1	7.25	79.7	20
	2.5	7.2	79.2	20
	5	7.15	78.6	20
	7.5	7.15	78.6	20
	10	7.15	78.6	20
	15	7.1	78.1	20
	20	7.1	78.1	20
	25	6.8	74.8	20
10-16-85	1	8.15	88.7	19.5
	2.5	8.15	88.7	19.5
	5	8.15	88.7	19.5
	7.5	8.15	88.7	19.5
	10	8.15	89.6	20
	15	7.35	80.0	19.5
	20	5.7	61.4	19
	25	2.4	25.4	18
	30	0.8	8.1	16
	35	0.45	4.4	14
11-13-85	40	0.4	3.8	13
	1	8.05	78.1	14
	2.5	8	77.6	14
	5	8	77.6	14
	7.5	7.65	74.2	14
	10	7.6	73.7	14
	15	7.4	71.8	14
	20	7	67.9	14
	25	6.85	65.7	13.5
	30	6.85	65.7	13.5
35	7.3	69.3	13	
40	6.9	65.5	13	
45	5.95	56.5	13	

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM01				
12-10-85	1	9.5	79.2	7.5
	2.5	9.4	76.5	6.5
	5	9.4	76.5	6.5
	7.5	9.2	73.9	6
	10	9.2	73.9	6
	15	9.2	73.0	5.5
	20	9.4	74.6	5.5
	25	9.25	73.4	5.5
	30	9.2	72.0	5
	35	8.9	73.3	7
	40	9.1	75.0	7
	2-13-86	1	12.9	93.3
2.5		12.9	93.3	2
5		12.9	93.3	2
7.5		12.9	93.3	2
10		12.8	92.6	2
15		12.8	92.6	2
20		12.7	91.8	2
25		12.7	91.8	2
3-11-86	1	12.8	95.1	3
	2.5	12.8	95.1	3
	5	12.8	95.1	3
	7.5	12.8	95.1	3
	10	12.8	95.1	3
	15	12.8	95.1	3
	20	12.8	93.8	2.5
	25	12.8	93.8	2.5
	30	12.8	93.8	2.5
	35	12.8	93.8	2.5
4-9-86	40	13	95.3	2.5
	1	10.1	100.2	15
	2.5	10	99.2	15
	5	10	99.2	15
	7.5	10	99.2	15
	10	9.9	96.1	14
	15	10	92.8	12
	20	10	88.6	10
	25	10	87.5	9.5
	30	9.6	83.0	9
	35	8.6	73.5	8.5
	40	7.6	65.0	8.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C	
STATION LM01					
4-30-86	1	10.4	105.4	16	
	2.5	10.4	105.4	16	
	5	10.3	104.4	16	
	7.5	10.3	104.4	16	
	10	10.2	103.3	16	
	15	10.1	93.7	12	
	20	8.4	76.2	11	
	25	8.4	76.2	11	
	30	7.6	68.1	10.5	
	35	6.9	61.8	10.5	
	40	6.2	54.9	10	
	45	5.1	45.2	10	
	5-21-86	1	8.7	97.6	21
		2.5	8.7	97.6	21
5		8.9	99.8	21	
7.5		8.9	99.8	21	
10		9.1	102.1	21	
15		6.6	66.9	16	
20		5.9	59.8	16	
25		5.2	48.3	12	
30		5	46.4	12	
35		4.2	38.1	11	
40		1.9	17.2	11	
6-11-86	1	8.35	103.8	26.5	
	2.5	8.5	104.8	26	
	5	8.6	106.0	26	
	7.5	8.8	108.5	26	
	10	8	97.7	25.5	
	15	2.9	31.6	19.5	
	20	1	9.9	15	
	7-9-86	1	8.2	104.8	28
2.5		7.9	100.9	28	
5		7.7	98.4	28	
7.5		7.9	97.4	26	
10		7.7	93.2	25	
15		5.8	67.6	23	
20		0.9	9.3	17	
25		0.8	7.5	12.5	
30		0.7	6.4	11.5	
35		0.7	6.3	11	
40		0.7	6.3	10.5	
45	0.8	7.2	10.5		

TABLE A-5. CONTINUED (STATION LM02 FIELD DATA)

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM02				
10-31-84	1	8.2	86.6	18
	2.5	8.2	86.6	18
	5	8.2	86.6	18
	7.5	8.2	86.6	18
	10	8.1	85.6	18
	15	6.1	63.8	17.5
	20	4	41.4	17
	25	0.5	5.1	16
	30	0.1	1.0	15
	35	0.1	1.0	15
11-27-84	1	10.6	89.5	8
	2.5	10.6	88.4	7.5
	5	10.5	87.6	7.5
	7.5	10.4	85.7	7
	10	10.4	85.7	7
	15	10.3	84.8	7
	20	10.2	84.0	7
	25	10.2	84.0	7
	30	10.2	84.0	7
	35	10.2	84.0	7
12-11-84	1	10	78.3	5
	2.5	10	78.3	5
	5	9.8	76.7	5
	7.5	9.8	76.7	5
	10	9.8	76.7	5
	15	9.7	76.0	5
	20	9.6	75.2	5
	25	9.4	73.6	5
	30	9.4	73.6	5
	35	9.4	73.6	5
2-26-85	1	11.6	90.8	5
	2.5	11.6	90.8	5
	5	11.2	86.6	4.5
	7.5	11.1	85.8	4.5
	10	11	83.9	4
	15	11	83.9	4
	20	11	83.9	4
	25	10.9	83.2	4
	30	10.8	82.4	4
	35	10.6	80.9	4

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM02				
3-26-85	1	11	90.6	7
	2.5	11	90.6	7
	5	11	89.5	6.5
	7.5	10.9	88.7	6.5
	10	10.9	88.7	6.5
	15	10.9	88.7	6.5
	20	10.8	87.9	6.5
	25	10.8	87.9	6.5
	30	10.6	86.2	6.5
	4-30-85	1	9.65	104.0	19
2.5		9.6	103.5	19
5		9.5	101.4	18.5
7.5		9.35	98.8	18
10		9.2	97.2	18
15		7.2	68.3	13
20		7.15	64.8	11
25		7.1	62.9	10
30		6.8	59.5	9.5
5-22-85		1	9.1	102.1
	2.5	9.1	102.1	21
	5	9.1	102.1	21
	7.5	9	100.0	20.5
	10	8.8	96.8	20
	15	6	62.1	17
	20	4.1	39.3	13.5
	35	1.7	15.1	10
6-12-85	1	8.95	109.3	25.5
	2.5	8.95	108.3	25
	5	9.3	112.5	25
	7.5	9.2	111.3	25
	10	9.2	111.3	25
	15	1	10.8	19
	20	0.15	1.5	15.5
	25	0.05	0.5	12
	30	0.05	0.5	11

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM02				
7-10-85	1	8.5	104.8	26
	2.5	8.5	104.8	26
	5	7.85	96.7	26
	7.5	7.75	94.7	25.5
	10	6.4	77.4	25
	15	1.35	15.7	23
	20	0.3	3.1	17.5
	25	0.3	2.8	13
	30	0.3	2.8	11.5
	7-24-85	1	7.15	88.9
2.5		7.1	88.3	26.5
5		7.05	87.7	26.5
7.5		7.05	86.9	26
10		7.05	86.9	26
15		1.7	20.6	25
20		0.4	4.2	18
25		0.3	2.9	14
30		0.3	2.8	12
8-22-85		1	5.8	70.8
	2.5	6.1	74.5	25.5
	5	5.8	70.8	25.5
	7.5	5.8	70.8	25.5
	10	5.7	69.6	25.5
	15	5.65	69.0	25.5
	20	0.5	5.7	22
	25	0.3	3.0	16
	30	0.2	1.9	14
	9-11-85	1	7.1	89.1
2.5		6.85	86.0	27
5		6.85	86.0	27
7.5		6.7	84.1	27
10		6.6	82.8	27
15		4.5	54.5	25
20		0.5	5.8	23
25		0.3	3.2	18
30		0.3	2.9	14.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM02				
10-4-85	1	6.85	75.3	20
	2.5	6.75	74.2	20
	5	6.7	73.7	20
	7.5	6.55	72.0	20
	10	6.5	71.5	20
	15	6.45	70.9	20
	20	6.4	70.4	20
	25	6.6	72.6	20
	30	0.05	0.5	16
	10-16-85	1	8.45	90.2	18.5
2.5		8.45	92.0	19.5
5		8.3	89.5	19
7.5		8.2	88.4	19
10		7.9	85.2	19
15		7.4	79.8	19
20		5.8	61.9	18.5
25		2.6	27.5	18
30		0.6	6.3	18
11-13-85		1	8.3	81.4	14.5
	2.5	8.3	81.4	14.5
	5	8.05	79.0	14.5
	7.5	8.05	78.1	14
	10	7.95	77.1	14
	15	7.7	74.7	14
	20	7.6	72.9	13.5
	25	8	76.8	13.5
	30	7.8	74.9	13.5
	12-10-85	1	9.8	82.7	8
2.5		9.65	81.5	8
5		9.45	79.8	8
7.5		9.45	79.8	8
10		9.25	78.1	8
15		9.3	78.5	8
20		9.15	77.3	8
25		9.4	79.4	8
30		9.05	75.5	7.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM02				
3-11-86	1	12.8	95.1	3
	2.5	12.8	95.1	3
	5	12.8	95.1	3
	7.5	13.1	97.3	3
	10	13	96.6	3
	15	12.9	95.8	3
	20	12.9	95.8	3
	25	12.9	95.8	3
	30	12.9	95.8	3
	4-9-86	1	10.2	99.0	14
2.5		10.2	99.0	14
5		10	97.0	14
7.5		10	97.0	14
10		10	94.9	13
15		9.8	88.9	11
20		9.4	82.3	9.5
25		8.8	76.1	9
30		8.8	76.1	9
4-30-86	1	10.4	107.6	17
	2.5	10.4	107.6	17
	5	10.6	108.5	16.5
	7.5	10.6	107.4	16
	10	10.3	99.9	14
	15	10.1	93.7	12
	20	8.6	78.0	11
	25	8.4	76.2	11
	30	7	63.5	11
5-21-86	1	9	102.9	22
	2.5	9.2	105.2	22
	5	8.9	99.8	21
	7.5	8.9	97.9	20
	10	8.6	92.7	19
	15	6.6	66.9	16
	20	4.8	46.1	13.5
	25	4.2	39.0	12
	30	3	27.2	11

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM02				
6-11-86	1	8.6	106.0	26
	2.5	8.3	103.2	26.5
	5	7.9	98.3	26.5
	7.5	7.5	92.4	26
	10	7.2	88.7	26
	15	2.8	30.5	19.5
	20	0.85	8.6	16
	25	0.5	4.8	13.5
	30	0.3	2.8	12.5
	7-9-86	1	7.7	98.4
2.5		7.6	97.1	28
5		7.5	95.8	28
7.5		7.7	95.8	26.5
10		7.4	88.7	24.5
15		3.6	41.2	22
20		0.9	9.3	17
25		0.9	8.4	12.5
30		0.7	6.3	11

TABLE A-5. CONTINUED (STATION LM03 FIELD DATA)

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM03				
10-31-84	1	7.5	79.2	18
	2.5	7.35	77.6	18
	5	7.2	76.1	18
	7.5	7	73.9	18
	10	6.9	72.9	18
	15	5.5	57.5	17.5
11-27-84	1	10.2	86.1	8
	2.5	10.2	86.1	8
	5	10.2	85.1	7.5
	7.5	10.2	85.1	7.5
	10	10.2	85.1	7.5
	15	9.8	81.7	7.5
12-11-84	20	9.6	80.1	7.5
	1	10.3	81.7	5.5
	2.5	10.2	80.9	5.5
	5	10.1	79.1	5
	7.5	10.1	79.1	5
	10	10	78.3	5
2-26-85	15	10	78.3	5
	20	9.8	76.7	5
	1	11.4	91.6	6
	2.5	11.3	88.5	5
	5	11.3	88.5	5
	7.5	11.2	87.7	5
3-26-85	10	11.2	86.6	4.5
	15	10.8	83.5	4.5
	1	11.5	94.7	7
	2.5	11.4	93.9	7
4-30-85	5	11.4	92.7	6.5
	7.5	11.2	91.1	6.5
	10	11.2	90.0	6
	15	11.2	90.0	6
	1	9.5	100.3	18
	2.5	9.3	98.2	18
4-30-85	5	9.3	97.2	17.5
	7.5	9.3	97.2	17.5
	10	9.15	94.7	17
	15	9	92.1	16.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM03				
5-22-85	1	8.85	99.3	21
	2.5	8.7	97.6	21
	5	8.3	91.3	20
	7.5	7.5	80.9	19
	10	6.8	72.6	18.5
	15	5.1	52.2	16.5
6-12-85	1	9.2	115.5	27
	2.5	9.1	114.2	27
	5	9.1	114.2	27
	7.5	9.1	114.2	27
	10	8.8	108.5	26
	15	2.3	25.8	21
7-10-85	20	0.2	2.0	16
	1	8.45	105.1	26.5
	2.5	8.2	102.9	27
	5	7.3	90.8	26.5
	7.5	6.6	81.3	26
	10	5.7	70.3	26
7-24-85	15	1.6	19.0	24
	1	6.9	85.0	26
	2.5	6.9	85.0	26
	5	6.8	83.8	26
	7.5	6.55	80.7	26
	10	6.3	77.6	26
8-22-85	15	5.1	62.3	25.5
	1	5.45	66.0	25
	2.5	5.45	66.0	25
	5	5.4	65.3	25
	7.5	5.3	64.1	25
	10	5	60.5	25
9-11-85	1	7.2	90.4	27
	2.5	7.15	89.7	27
	5	7.1	89.1	27
	7.5	5.2	64.7	26.5
	10	4.3	53.0	26
	14	2.2	26.6	25
10-4-85	1	5.6	61.6	20
	2.5	5.55	61.0	20
	5	5.45	59.9	20
	7.5	5.4	58.8	19.5
	10	5.3	57.7	19.5
	15	5	54.4	19.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM03				
10-16-85	1	8	85.4	18.5
	2.5	7.9	86.0	19.5
	5	7.8	84.9	19.5
	7.5	7.85	84.6	19
	10	7.3	78.7	19
11-13-85	1	8.8	87.3	15
	2.5	8.6	84.4	14.5
	5	8.6	84.4	14.5
	7.5	8.5	83.4	14.5
	10	8.2	80.4	14.5
12-10-85	15	6.7	65.0	14
	1	9.9	82.6	7.5
	2.5	9.8	82.7	8
	5	9.65	81.5	8
	7.5	9.65	81.5	8
3-11-86	10	9.6	81.1	8
	15	9.6	81.1	8
	1	12.4	97.1	5
	2.5	12.4	95.8	4.5
	5	12.6	97.4	4.5
	7.5	12.6	97.4	4.5
4-9-86	10	12.6	97.4	4.5
	15	12.6	96.1	4
	20	12.6	94.9	3.5
	1	9.8	95.1	14
	2.5	10	97.0	14
	5	10.1	98.0	14
4-30-86	7.5	10.2	99.0	14
	10	9.8	94.0	13.5
	15	9.8	94.0	13.5
	1	9.8	100.3	16.5
	2.5	10.4	105.4	16
5-21-86	5	10.4	103.1	15
	7.5	10.4	98.7	13
	10	8.8	81.7	12
	15	8.8	79.8	11
	1	8.4	97.0	22.5
	2.5	8.4	96.1	22
	5	9	101.0	21
	7.5	8.8	96.8	20
	10	8.6	92.7	19
	15	6.4	64.8	16

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM03				
6-11-86	1	8.3	98.6	24
	2.5	8.8	106.5	25
	5	8.5	102.9	25
	7.5	8.5	102.9	25
	10	8.25	99.8	25
	15	3.4	36.3	18.5
7-9-86	1	7.6	97.1	28
	2.5	7.6	97.1	28
	5	7.5	95.8	28
	7.5	7.6	95.4	27
	10	6.9	83.5	25
	15	3.6	41.6	22.5

TABLE A-5. CONTINUED (STATION LM04 FIELD DATA)

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM04				
10-31-84	1	8.1	87.3	19
	2.5	8.2	87.5	18.5
	5	8.1	86.4	18.5
	7.5	8.2	87.5	18.5
	10	8.1	86.4	18.5
	15	5.45	57.0	17.5
	20	3.7	38.3	17
	25	0.2	2.0	16
	30	0.1	1.0	15
11-27-84	1	10.8	91.2	8
	2.5	10.4	87.8	8
	5	10.4	85.7	7
	7.5	10.4	85.7	7
	10	10.4	85.7	7
	15	10.4	85.7	7
	20	10.2	84.0	7
	25	10.1	83.2	7
	30	10.1	83.2	7
12-11-84	1	10	78.3	5
	2.5	10	78.3	5
	5	10	78.3	5
	7.5	10	78.3	5
	10	10	78.3	5
	15	10	78.3	5
	20	10	78.3	5
	25	10	78.3	5
	30	10.2	77.8	4
2-26-85	35	10.2	77.8	4
	1	11.2	87.7	5
	2.5	11.2	87.7	5
	5	11.2	87.7	5
	7.5	11	86.1	5
	10	11.1	85.8	4.5
	15	10.9	84.2	4.5
	20	10.8	83.5	4.5
	25	10.8	83.5	4.5
30	10.8	83.5	4.5	

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM04				
3-26-85	1	11.2	92.3	7
	2.5	11.2	92.3	7
	5	11.2	92.3	7
	7.5	11.2	92.3	7
	10	11.1	90.3	6.5
	15	11	89.5	6.5
	20	11	89.5	6.5
	25	11	89.5	6.5
	30	10.9	88.7	6.5
	35	10.9	88.7	6.5
4-30-85	1	9.65	104.0	19
	2.5	9.6	103.5	19
	5	9.6	102.4	18.5
	7.5	9.35	98.8	18
	10	9.1	96.1	18
	15	7.5	71.2	13
	20	7.2	65.3	11
	25	6.75	59.8	10
	30	6.6	57.8	9.5
	5-22-85	1	9.4	106.5
2.5		9.4	106.5	21.5
5		9.4	105.4	21
7.5		9.3	104.3	21
10		9.1	101.1	20.5
15		5.9	61.0	17
20		3.6	34.5	13.5
25		2.8	25.4	11
30		2.55	22.9	10.5
6-12-85		1	9.3	114.6
	2.5	9.25	114.0	26
	5	8.7	107.2	26
	7.5	8.85	107.1	25
	10	8.1	96.2	24
	15	2.3	25.5	20.5
	20	0.3	3.1	16.5
	25	0.15	1.4	13
	30	0.1	0.9	11.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM04				
7-10-85	1	8.3	102.3	26
	2.5	8.3	102.3	26
	5	8.2	101.1	26
	7.5	7.3	90.0	26
	10	5.9	71.4	25
	15	0.6	7.0	23
	20	0.4	4.2	18
	25	0.4	4.0	15
7-24-85	1	7	87.1	26.5
	2.5	7	87.1	26.5
	5	7	87.1	26.5
	7.5	7	87.1	26.5
	10	7	86.3	26
	15	1.95	23.6	25
	20	0.3	3.2	18
	25	0.3	2.9	14
8-22-85	1	6.35	78.3	26
	2.5	6.2	76.4	26
	5	6.2	76.4	26
	7.5	6.2	76.4	26
	10	6.2	76.4	26
	15	4.5	55.5	26
	20	0.8	9.1	22
	25	0.3	3.0	16
	30	0.2	1.9	14
	9-11-85	1	6.8	85.3
2.5		6.8	85.3	27
5		6.7	84.1	27
7.5		6.6	82.8	27
10		6.6	82.8	27
15		3.8	46.4	25.5
20		0.7	8.2	23.5
25		0.4	4.3	18.5
10-4-85	1	7.4	82.2	20.5
	2.5	7.3	81.1	20.5
	5	7.15	78.6	20
	7.5	7.1	78.1	20
	10	7	77.0	20
	15	6.9	75.9	20
	20	6.95	76.4	20
	25	3.9	42.5	19.5
	30	0.45	4.5	15.5

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM04				
10-16-85	1	8.3	90.4	19.5
	2.5	8.3	90.4	19.5
	5	8.3	90.4	19.5
	7.5	8.3	90.4	19.5
	10	8.3	90.4	19.5
	15	7.8	84.1	19
	20	6.15	66.3	19
	25	4.9	52.3	18.5
11-13-85	1	8.6	84.4	14.5
	2.5	8.4	82.4	14.5
	5	8.4	82.4	14.5
	7.5	8.3	80.5	14
	10	7.75	75.2	14
	15	7.5	72.8	14
	20	7.45	72.3	14
	25	7.5	72.8	14
12-10-85	1	9.8	82.7	8
	2.5	9.6	81.1	8
	5	9.45	79.8	8
	7.5	9.3	78.5	8
	10	9.3	77.6	7.5
	15	9.2	76.7	7.5
	20	9.2	76.7	7.5
	25	9.2	76.7	7.5
3-11-86	30	9.1	75.9	7.5
	1	13.2	98.1	3
	2.5	13.2	98.1	3
	5	13.2	98.1	3
	7.5	13.2	98.1	3
	10	13.4	99.5	3
	15	13.4	99.5	3
	20	13.4	99.5	3
4-9-86	25	13.4	99.5	3
	30	13.4	99.5	3
	1	10.2	99.0	14
	2.5	10.2	99.0	14
	5	10.2	99.0	14
	7.5	10.2	100.1	14.5
	10	10	97.0	14
	15	10	90.7	11
	20	10	88.6	10
	25	9.2	79.6	9
	30	9.2	79.6	9

TABLE A-5. CONTINUED

DATE	DEPTH ft	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM04				
4-30-86	1	10.2	105.5	17
	2.5	10.6	109.7	17
	5	10.6	109.7	17
	7.5	10.6	108.5	16.5
	10	10.4	105.4	16
	15	9.9	91.9	12
	20	8.8	80.7	11.5
	25	8.6	78.0	11
	30	7.4	67.1	11
	5-21-86	1	9.2	105.2
2.5		9.6	107.7	21
5		9.6	107.7	21
7.5		9.9	111.0	21
10		9.9	107.8	19.5
15		6.9	68.4	15
20		5.4	52.4	14
25		4.6	42.7	12
30		3.3	30.6	12
6-11-86		1	8.6	106.0
	2.5	8.3	103.2	26.5
	5	7.9	98.3	26.5
	7.5	7.5	92.4	26
	10	7.2	88.7	26
	15	2.8	30.5	19.5
	20	0.85	8.6	16
	25	0.5	4.8	13.5
	30	0.3	2.8	12.5
	7-9-86	1	7.4	94.5	28
2.5		7.4	94.5	28
5		7.4	94.5	28
7.5		7.7	95.8	26.5
10		7.7	93.2	25
15		2.8	32.0	22
20		0.9	9.3	17
25		0.8	7.6	13
30		0.6	5.6	12

TABLE A-5. CONTINUED

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM05				
4-30-85	1	9.6	103.5	19
	2.5	9.55	102.9	19
	5	9.55	101.9	18.5
	7.5	9.4	100.3	18.5
	10	8.45	87.4	17
	15	5.7	53.5	12.5
	20	4.8	42.5	10
5-22-85	1	9.95	113.8	22
	2.5	9.9	113.2	22
	5	9.9	113.2	22
	7.5	9.8	111.0	21.5
	10	9.65	108.2	21
	15	5.85	61.8	18
	20	1.9	18.4	14
6-12-85	1	8.6	106.0	26
	2.5	8.6	106.0	26
	5	8.6	106.0	26
	7.5	8.6	106.0	26
	10	4.7	54.8	23
	15	0.4	4.3	19
	20	0.2	2.0	15.5
7-10-85	1	8.1	99.8	26
	2.5	8.1	99.8	26
	5	8.1	99.8	26
	7.5	7.6	93.7	26
	10	6.3	76.2	25
	15	1.2	14.1	23.5
	20	0.35	4.1	23
7-24-85	1	7.4	92.0	26.5
	2.5	7.4	92.0	26.5
	5	7.4	92.0	26.5
	7.5	7.4	91.2	26
	10	7.35	90.6	26
	15	6.6	81.3	26
8-22-85	1	6.7	82.6	26
	2.5	6.7	82.6	26
	5	6.7	82.6	26
	7.5	6.5	80.1	26
	10	6.5	79.4	25.5

TABLE A-5. CONTINUED (STATION LM05 FIELD DATA)

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM05				
10-31-84	1	8.5	91.6	19
	2.5	8.45	91.1	19
	5	8.4	89.6	18.5
	7.5	8.1	86.4	18.5
	10	7.9	84.3	18.5
	15	7.4	78.2	18
	20	0.3	3.1	16.5
11-27-84	1	11.6	95.6	7
	2.5	11.6	95.6	7
	5	11.6	95.6	7
	7.5	11.6	95.6	7
	10	11.5	94.7	7
	15	11.4	93.9	7
	20	11.4	93.9	7
12-11-84	1	10.4	81.4	5
	2.5	10.4	81.4	5
	5	10.4	81.4	5
	7.5	10.4	81.4	5
	10	10.4	81.4	5
	15	10.4	80.4	4.5
	20	10.4	80.4	4.5
2-26-85	1	11.2	92.3	7
	2.5	11.2	91.1	6.5
	5	11	88.4	6
	7.5	10.8	84.6	5
	10	10.8	84.6	5
	15	10.8	84.6	5
	20	10.4	80.4	4.5
3_26-85	1	11.9	98.0	7
	2.5	11.8	97.2	7
	5	11.8	97.2	7
	7.5	11.8	96.0	6.5
	10	11.6	94.4	6.5
	15	11.6	93.2	6
	20	11.5	92.4	6

TABLE A-5. CONTINUED

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM05				
9-11-85	1	6.3	78.4	26.5
	2.5	6.3	78.4	26.5
	5	6.2	77.1	26.5
	7.5	6.2	77.1	26.5
	10	6.2	77.1	26.5
	15	6.1	75.2	26
10-4-85	1	7.8	86.6	20.5
	2.5	7.7	85.5	20.5
	5	7.45	81.9	20
	7.5	7.35	80.8	20
	10	7.3	80.3	20
	15	7.3	80.3	20
10-16-85	20	7.2	78.4	19.5
	1	8.65	95.1	20
	2.5	8.6	93.6	19.5
	5	8.35	90.9	19.5
	7.5	7.9	85.2	19
	10	7.6	81.9	19
11-13-85	15	5.9	63.6	19
	1	9.4	91.2	14
	2.5	9.4	91.2	14
	5	9.05	85.9	13
	7.5	8.6	82.5	13.5
	10	8.25	78.3	13
12-10-85	15	8.4	79.7	13
	20	8.05	76.4	13
	1	11.1	92.6	7.5
	2.5	11.1	91.4	7
	5	11.1	91.4	7
	7.5	10.9	89.8	7
3-11-86	10	10.8	89.0	7
	15	10.8	89.0	7
	20	10.4	85.7	7
	1	13.1	99.9	4
	2.5	13.3	100.1	3.5
	5	13.4	100.9	3.5
	7.5	13.6	102.4	3.5
	10	13.6	102.4	3.5
	15	13.8	103.9	3.5
	20	13.8	103.9	3.5

TABLE A-5. CONTINUED

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM05				
4-9-85	1	9.8	97.2	15
	2.5	9.8	97.2	15
	5	9.6	95.2	15
	7.5	9.6	95.2	15
	10	9.6	95.2	15
	15	9.4	85.2	11
4-30-85	1	10.8	110.6	16.5
	2.5	10.8	110.6	16.5
	5	10.8	110.6	16.5
	7.5	10.8	110.6	16.5
	10	10.3	105.5	16.5
	15	10.3	99.9	14
5-21-86	20	7.9	71.6	11
	1	9.4	111.7	24
	2.5	9.4	110.6	23.5
	5	9.4	109.6	23
	7.5	9.6	110.9	22.5
	10	8.9	96.9	19.5
6-11-86	15	5.6	57.9	17
	20	3.2	31.1	14
	1	9.4	114.8	25.5
	2.5	9.6	117.2	25.5
	5	9.3	113.6	25.5
	7.5	8.8	106.5	25
7-9-86	10	6.9	80.4	23
	15	0.8	8.5	18.5
	1	7.7	97.5	27.5
	2.5	7.6	97.1	28
	5	7.5	95.0	27.5
	7.5	7.5	94.1	27
	10	7.5	92.4	26
	15	3	35.0	23
	20	0.9	8.9	15

TABLE A-5. CONTINUED

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM06				
6-12-85	1	8	96.8	25
	2.5	7.9	95.6	25
	5	6.2	72.3	23
	7.5	3.4	38.9	22
	10	1.55	17.4	21
7-10-85	1	7.6	93.7	26
	2.5	7.6	93.7	26
	5	7.5	93.3	26.5
	7.5	7.4	91.2	26
	10	5.8	70.2	25
7-24-85	1	7.25	91.0	27
	2.5	7.25	91.0	27
	5	7.25	91.0	27
	7.5	7.2	89.5	26.5
	10	6.55	81.5	26.5
8-22-85	1	6.85	84.4	26
	2.5	6.8	83.8	26
	5	6.45	79.5	26
	7.5	6.4	78.9	26
	10	6.2	76.4	26
	15	0.8	9.7	25
9-11-85	1	6.3	78.4	26.5
	2.5	6.3	78.4	26.5
	5	6	74.6	26.5
	7.5	5.9	73.4	26.5
10-4-85	1	8	88.0	20
	2.5	7.95	87.4	20
	5	7.45	81.1	19.5
	7.5	7.15	77.9	19.5
10-16-85	1	8.7	94.7	19.5
	2.5	8.4	91.5	19.5
	5	7	75.5	19
	7.5	6.55	70.6	19
11-13-85	1	9.8	98.2	15.5
	2.5	9.8	98.2	15.5
	5	9.2	92.2	15.5
	7.5	8.2	81.3	15
	10	7.65	75.9	15

TABLE A-5. CONTINUED (STATION LM06 FIELD DATA)

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM06				
10-31-84	1	8.6	92.7	19
	2.5	8.55	92.2	19
	5	8.4	90.6	19
	7.5	8.3	89.5	19
	10	6.5	68.7	18
	15	4.7	49.6	18
11-27-84	1	12.1	100.9	7.5
	2.5	12.1	100.9	7.5
	5	12	98.9	7
	7.5	12	98.9	7
	10	12	98.9	7
12-11-84	1	11.1	84.7	4
	2.5	11	83.9	4
	5	11	83.9	4
	7.5	11	83.9	4
	10	11	83.9	4
2-26-85	1	10.8	91.2	8
	2.5	11.2	92.3	7
	5	11.1	88.0	5.5
	7.5	10.8	84.6	5
	10	10.8	84.6	5
	15	10.4	81.4	5
3_26-85	1	11.6	95.6	7
	2.5	11.6	95.6	7
	5	11.6	95.6	7
	7.5	11.6	93.2	6
	10	11.6	93.2	6
4-30-85	1	9.9	106.7	19
	2.5	9.75	105.1	19
	5	9.75	104.0	18.5
	7.5	9.55	101.9	18.5
	10	9.1	96.1	18
	15	5.8	55.0	13
5-22-85	1	10.1	114.4	21.5
	2.5	10	113.3	21.5
	5	10	112.2	21
	7.5	10	112.2	21
	10	10	112.2	21

TABLE A-5. CONTINUED

DATE	DEPTH	DO mg/L	% DO SATURATION	TEMP deg C
STATION LM06				
12-10-85	1	11.4	93.9	7
	2.5	11.4	93.9	7
	5	11.4	93.9	7
	7.5	11.4	93.9	7
	10	11.4	93.9	7
3-11-86	1	12.4	99.6	6
	2.5	12.4	99.6	6
	5	12.6	101.2	6
	7.5	12.4	99.6	6
	10	12.4	99.6	6
4-9-85	1	9.6	93.2	14
	2.5	9.6	93.2	14
	5	9.6	93.2	14
	7.5	9.6	93.2	14
	10	8.8	82.6	12.5
4-30-85	1	10.4	107.6	17
	2.5	10.4	106.5	16.5
	5	10.4	106.5	16.5
	7.5	10.4	105.4	16
	10	10.2	99.0	14
5-21-86	1	9.4	109.6	23
	2.5	9.6	111.9	23
	5	9.4	108.5	22.5
	7.5	7.2	82.3	22
	10	7.2	77.6	19
6-11-86	1	9.05	113.6	27
	2.5	9.6	119.4	26.5
	5	9.2	113.4	26
	7.5	8.2	99.2	25
	10	3.9	46.3	24

TABLE A-6. ANALYSES OF SURFACE AND BOTTOM SAMPLES FROM LAKE MANASSAS, OCTOBER, 1984 - APRIL, 1986.

ID	MO	DY	YR	HR	MN	DEPTH ft	DO mg/L	TEMP deg C	pH	ALK mg/L	COND umho/cm	SECCHI in
STATION LM01												
SURFACE SAMPLES												
1998	10	31	84	8	40	1	7.95	18	6.8	31.9	100	86
2102	11	27	84	10	33	1	11	7.5	6.4	32	115	37
2195	12	11	84	9	15	1	10.1	5	7	31.2	95	49
2383	2	26	85	10	35	1	11.4	5	6	25.2	120	35
2432	3	26	85	9	50	1	11.4	8	5.9	24.5	105	34
2553	4	30	85	8	45	1	9.3	19	7.1	26.3	115	55
2692	5	22	85	8	6	1	9.2	21.5	6.8	28.3	115	37
2852	6	12	85	8	54	1	9.3	25	7.2	30.1	115	54
3029	7	10	85	8	37	1	8.2	26	7.7	30.9	115	51
3097	7	24	85	10	19	1	7.4	27	7.6	32.5	115	62
3294	8	22	85	7	10	1	6.55	26	7.4	36.8	115	57
3506	9	11	85	10	19	1	6.8	27	6.9	32.1	125	42
3693	10	4	85	9	45	1	7.25	20	6.9	35.1	120	49
3767	10	16	85	7	52	1	8.15	19.5	7	43.4	110	47
3946	11	13	85	9	10	1	8.05	14	6.7	31	130	49
4061	12	10	85	11	14	1	9.5	7.5	6.3	27.6	120	38
6124	3	11	86	11	57	1	12.8	3	6.9	32.5	135	50
6500	4	9	86	9	3	1	10.1	15	6.7	26	125	40
6600	4	30	86	10	5	1	10.4	16	7.5	27	130	46
BOTTOM SAMPLES												
1999	10	31	84	8	50	40	0.1	14	6	64	165	
2103	11	27	84	10	43	40	10.2	7	6.7	38	120	
2196	12	11	84	9	25	40	9.8	5	6.8	30.2	115	
2384	2	26	85	10	46	45	10.4	4	6.7	24	135	
2433	3	26	85	9	58	30	11	7	6.3	25	105	
2554	4	30	85	8	54	35	5.7	9.5	6.3	26.4	115	
2693	5	22	85	8	16	40	1.4	10	5.6	31.7	120	
2853	6	12	85	9	4	40	0.1	10	5.8	33.3	125	
3030	7	10	85	8	44	25	0.4	14	6.5	37.8	130	
3098	7	24	85	10	29	40	0.3	11	6.5	73.1	165	
3295	8	22	85	7	19	35	0.2	12.5	6.9	95.7	165	
3507	9	11	85	10	28	35	0.4	13.5	6.3	68.5	170	
3694	10	4	85	9	52	25	6.8	20	6.7	39.1	120	
3768	10	16	85	8	2	40	0.4	13	6.9	88.6	195	
3947	11	13	85	9	21	45	5.95	13	6.5	30.1	135	
4062	12	10	85	11	24	40	9.1	7	6.3	28.4	130	
6125	3	11	86	12	7	40	13	2.5	6.9	39.3	140	
6501	4	9	86	9	13	40	7.6	8.5	6.1	27.6	140	
6601	4	30	86	10	16	45	5.1	10	6.9	27.9	135	

TABLE A-6. CONTINUED

ID	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	CHLA	PHPA
.....milligram per liter.....									ug/L	
STATION LM01										
SURFACE SAMPLES										
1998	0	0.01	0.02	0.04	0.34	0.43	0.04	2	5.8	0.6
2102	0	0.02	0.03	0.19	0.69	0.73	0.12	5.5	5.8	0.6
2195	0	0.02	0.04	0.12	0.49	0.65	0.23	3.5	6.3	2
2383	0.01	0.03	0.05	0.07	0.56	0.62	0.51	1	11.7	2.2
2432	0	0.02	0.05	0.02	0.71	0.82	0.55	7.5	14	1.9
2553	0	0.02	0.03	0.02	0.46	0.57	0.29	3.5	5.9	
2692	0	0.01	0.03	0	0.54	0.76	0.13	5	4	
2852	0	0.02	0.03	0.04	0.52	0.64	0.03	3	4.4	
3029	0	0.02	0.03	0.02	0.41	0.48	0	4.5	4.5	
3097	0	0.02	0.02	0.04	0.4	0.41	0	2.5	3	1
3294	0	0.03	0.03	0.03	0.58	0.59	0	4	5.6	0.6
3506	0	0.01	0.03	0.01	0.29	0.42	0	4.5	5.5	1.7
3693	0	0.02	0.03	0.09	0.48	0.54	0	4	8.3	3.1
3767	0	0	0.02	0.1	0.31	0.47	0	4	6.1	
3946	0	0.01	0.02	0.02	0.36	0.43	0.41	4	5.3	1
4061	0	0	0.02	0.07	0.42	0.45	0.51	4.8	7.2	1.2
6124	0	0.01	0.02	0.02	0.31	0.38	0.62	3.8	11	
6500	0.01	0.02	0.03	0.05	0.35	0.47	0.54	3	6.1	0.5
6600	0	0.01	0.03	0.02	0.35	0.46	0.41	3.6	10	0.9
BOTTOM SAMPLES										
1999	0.03	0.03	0.08	1.23	1.73	2.03	0	30		
2103	0.01	0.02	0.1	0.18	0.73	0.88	0.12	48		
2196	0	0.02	0.09	0.11	0.54	0.7	0.29	39		
2384	0.01	0.03	0.06	0.1	0.57	0.76	0.5	5		
2433	0	0.02	0.05	0.03	0.67	0.88	0.53	8.5		
2554	0	0.02	0.03	0.14	0.55	0.55	0.4	2.5		
2693	0.01	0.02	0.02	0.42	0.89	0.89	0.37	4		
2853	0	0.01	0.03	0.05	0.41	0.47	0.51	9.5		
3030	0	0.01	0.03	0.26	0.55	0.65	0.02	9.5		
3098	0.06	0.08	0.14	0.85	1.43	1.59	0	23		
3295	0.14	0.16	0.25	1.07	1.8	2	0	34		
3507	0.12	0.14	0.26	1.09	1.78	1.98	0	48		
3694	0	0.02	0.17	0.16	0.55	1.14	0	178		
3768	0.05	0.06	0.21	1.73	2.36	3.02	0	62		
3947	0.02	0.03	0.09	0.2	0.62	0.83	0.56	30		
4062	0	0	0.02	0.08	0.41	0.46	0.51	8		
6125	0	0.01	0.02	0.01	0.36	0.43	0.63	4.4		
6501	0	0	0.02	0.17	0.46	0.49	0.56	2		
6601	0	0.01	0.03	0.02	0.3	0.44	0.42	3.4		

TABLE A-6. CONTINUED

ID	MO	DY	YR	HR	MN	DEPTH ft	DO mg/L	TEMP deg C	pH	ALK mg/L	COND umho/cm	SECCHI in
STATION LM02												
SURFACE SAMPLES												
2000	10	31	84	9	10	1	8.2	18	6.5	32.5	105	81
2104	11	27	84	11	7	1	10.6	8	6.5	31.8	110	36
2197	12	11	84	9	40	1	10	5	7.3	30	105	45
2385	2	26	85	10	57	1	11.6	5	6.4	24.5	130	38
2434	3	26	85	10	27	1	11	7	6.4	24.5	105	31
2555	4	30	85	9	37	1	9.65	19	7	26.9	115	53
2694	5	22	85	9	7	1	9.1	21	6.8	25.7	110	38
2854	6	12	85	9	20	1	8.95	25.5	7.5	29.8	115	54
3031	7	10	85	8	56	1	8.5	26	7.9	33.5	120	58
3099	7	24	85	8	57	1	7.15	26.5	7.5	31.2	120	64
3296	8	22	85	7	36	1	5.8	25.5	7.1	37.9	115	57
3508	9	11	85	9	15	1	7.1	27	6.9	33.4	120	56
3695	10	4	85	10	5	1	6.85	20	6.7	34.7	120	52
3769	10	16	85	8	14	1	8.45	18.5	7	34.1	120	48
3948	11	13	85	9	49	1	8.3	14.5	6.7	30	125	41
4063	12	10	85	10	3	1	9.8	8	6.2	27.2	120	44
6126	3	11	86	11	38	1	12.8	3	6.6	31.2	135	49
6502	4	9	86			1	10.2	14	6.3	26.5	135	47
6602	4	30	86			1	10.4	17	7.3	25.8	125	43
BOTTOM SAMPLES												
2001	10	31	84	9	19	35	0.1	15	6	43.1	135	
2105	11	27	84	11	16	35	10.2	7	6.9	33.1	120	
2198	12	11	84	9	49	35	9.4	4	7	35.9	115	
2386	2	26	85	11	6	35	10.6	4	6.5	24	135	
2435	3	26	85	10	35	30	10.6	6.5	6.9	24.2	110	
2556	4	30	85	9	45	30	6.8	9.5	6.4	26.5	115	
2695	5	22	85	9	16	35	1.7	10	5.9	31.2	120	
2855	6	12	85	9	28	30	0.05	11	6.1	31.4	125	
3032	7	10	85	9	4	30	0.3	11.5	6.4	39.7	135	
3100	7	24	85	9	5	30	0.3	12	6.3	42	140	
3297	8	22	85	7	44	30	0.2	14	6.7	68.5	145	
3509	9	11	85	9	23	30	0.3	14.5	6.2	61.3	165	
3696	10	4	85	10	13	30	0.05	16	6.5	61.5	170	
3770	10	16	85	8	22	30	0.6	18	6.5	38.9	130	
3949	11	13	85	9	57	30	7.8	13.5	6.7	28.8	130	
4064	12	10	85	10	11	30	9.05	7.5	6.6	27.6	130	
6127	3	11	86	11	46	30	12.9	3	6.6	41.1	135	
6503	4	9	86	9	48	30	8.8	9	6.1	26.5	145	
6603	4	30	86	10	48	30	7	11	6.4	26.5	130	

TABLE A-6. CONTINUED

ID	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	CHLA	PHPA
.....milligram per liter.....									ug/L	
STATION LM02										
SURFACE SAMPLES										
2000	0	0.01	0.02	0.03	0.36	0.4	0.03	3	6.7	
2104	0.01	0.02	0.03	0.17	0.66	0.8	0.11	5.5		
2197	0	0.02	0.03	0.11	0.47	0.52	0.18	3.5	4.1	2.6
2385	0	0.02	0.05	0.04	0.5	0.61	0.43	2	4.9	0
2434	0	0.02	0.04	0.02	0.6	0.7	0.51	7	6.7	1
2555	0	0.02	0.03	0	0.48	0.59	0.27	2	5.6	
2694	0	0.02	0.03	0.01	0.52	0.76	0.15	8	5.8	0
2854	0	0.01	0.02	0.04	0.48	0.55	0.05	3.5	4.7	2
3031	0	0.02	0.03	0.02	0.4	0.49	0	1.5	5.4	0
3099	0.01	0.01	0.03	0.04	0.35	0.45	0	3	6.1	1.9
3296	0	0.02	0.04	0.02	0.54	0.57	0	2.5	6.3	3
3508	0.01	0.01	0.02	0.02	0.25	0.42	0	3	8.1	0.7
3695	0	0.02	0.03	0.12	0.54	0.55	0	3.5	6.8	2.1
3769	0	0	0.02	0.06	0.28	0.36	0	3.5	8.9	1.3
3948	0	0.01	0.03	0	0.36	0.41	0.39	4	8.4	
4063	0	0.01	0.02	0.07	0.4	0.41	0.49	4.4	7.4	7.1
6126	0	0.01	0.03	0	0.29	0.37	0.58	4.2	10	2
6502	0	0.01	0.02	0.05	0.34	0.43	0.53	3	4.7	2.3
6602	0	0	0.02	0.02	0.34	0.41	0.42	3.8	7.4	
BOTTOM SAMPLES										
2001	0.01	0.01	0.05	0.55	0.86	1.05	0	16		
2105	0	0.02	0.03	0.15	0.62	0.71	0.12	6		
2198	0.01	0.03	0.05	0.12	0.48	0.64	0.32	6		
2386	0.01	0.03	0.08	0.07	0.51	0.81	0.5	13.5		
2435	0.01	0.02	0.04	0.02	0.65	0.86	0.53	9		
2556	0	0.02	0.03	0.14	0.6	0.61	0.38	2.5		
2695	0.01	0.02	0.04	0.4	0.83	0.92	0.37	5		
2855	0.01	0.01	0.06	0.13	0.46	0.56	0.53	26.5		
3032	0.01	0.02	0.05	0.42	0.68	1.03	0	15.5		
3100	0.03	0.04	0.09	0.67	0.83	0.94	0	15.5		
3297	0.11	0.13	0.24	0.93	1.58	1.77	0	41		
3509	0.07	0.08	0.18	0.82	1.42	1.66	0	47		
3696	0.01	0.03	0.06	1.44	1.59	1.84	0	30		
3770	0	0.01	0.05	0.31	0.6	0.89	0	14		
3949	0	0.02	0.03	0.06	0.42	0.42	0.53	6.8		
4064	0.01	0.01	0.05	0.08	0.38	0.56	0.51	18.8		
6127	0	0.01	0.03	0.01	0.36	0.42	0.57	5.2		
6503	0	0	0.02	0.12	0.38	0.39	0.58	2		
6603	0	0.02	0.04	0.16	0.41	0.52	0.46	12.2		

TABLE A-6. CONTINUED

ID	MO	DY	YR	HR	MN	DEPTH ft	DO mg/L	TEMP deg C	pH	ALK mg/L	COND umho/cm	SECCHI in
STATION LM03												
SURFACE SAMPLES												
2002	10	31	84	9	35	1	7.5	18	6.6	32.4	105	68
2106	11	27	84	11	31	1	10.2	8	7.1	32.6	110	36
2199	12	11	84	9	58	1	10.3	5.5	6.9	30	110	50
2387	2	26	85	11	15	1	11.4	6	5.8	25.1	120	30
2436	3	26	85	10	10	1	11.5	7	5.9	24.1	105	37
2557	4	30	85	9	19	1	9.5	18	6.7	26.5	115	42
2696	5	22	85	8	42	1	8.85	21	6.7	26.8	115	37
2856	6	12	85	9	42	1	9.2	27	6.9	29.7	115	57
3033	7	10	85	9	14	1	8.45	26.5	7.8	31.6	120	56
3101	7	24	85	8	37	1	6.9	26	7.3	31.8	115	52
3298	8	22	85	8	1	1	5.45	25	7	33.6	120	49
3510	9	11	85	8	58	1	7.2	27	7.5	32.6	115	65
3697	10	4	85	10	25	1	5.6	20	6.6	33.8	120	44
3771	10	16	85	8	37	1	8	18.5	6.8	33.7	120	41
3950	11	13	85	9	31	1	8.8	15	6.9	31	125	40
4065	12	10	85	9	49	1	9.9	7.5	6.6	27.4	120	47
6128	3	11	86	11	19	1	12.4	5	6.6	34.9	130	48
6504	4	9	86	9	28	1	9.8	14	6.4	26.1	130	47
6505	4	30	86	10	22	1	9.8	16.5	7.3	26.7	125	44
BOTTOM SAMPLES												
2003	10	31	84	9	40	15	5.5	17.5	6.3	34.2	105	
2107	11	27	84	11	37	20	9.6	7.5	7	31.5	120	
2200	12	11	84	10	4	20	9.8	5	6.7	30.7	115	
2388	2	26	85	11	20	15	10.8	4.5	6.1	23.8	115	
2437	3	26	85	10	15	15	11.2	6	6.4	24.7	110	
2558	4	30	85	9	24	15	9	16.5	6.7	25.7	115	
2697	5	22	85	8	47	15	5.1	16.5	6.2	27.4	120	
2857	6	12	85	9	48	20	0.2	16	6.7	30.8	130	
3034	7	10	85	9	19	15	1.6	24	6.6	33.2	120	
3102	7	24	85	8	42	15	5.1	25.5	7.1	32.8	125	
3299	8	22	85	8	5	10	5	25	6.9	40.8	120	
3511	9	11	85	9	3	14	2.2	25	6.7	33.2	130	
3698	10	4	85	10	30	15	5	19.5	6.6	34.4	125	
3772	10	16	85	8	41	10	7.3	19	6.6	34	125	
3951	11	13	85	9	36	15	6.7	14	6.7	30.9	135	
4066	12	10	85	9	54	15	9.6	8	6.7	27.6	120	
6129	3	11	86	11	25	20	12.6	3.5	6.6	36.1	135	
6505	4	9	86	9	33	15	9.8	13.5	6.3	26.1	135	
6605	4	30	86	10	27	15	8.8	11	6.7	26.3	130	

TABLE A-6. CONTINUED

ID	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	CHLA	PHPA
.....milligram per liter.....									ug/L	
STATION LM03										
SURFACE SAMPLES										
2002	0	0.01	0.02	0.07	0.37	0.44	0.04	1	3.1	1
2106	0.01	0.02	0.07	0.16	0.69	0.69	0.11	5	4.9	
2199	0	0.02	0.03	0.12	0.45	0.52	0.16	4	7.1	
2387	0.01	0.02	0.05	0.02	0.44	0.64	0.72	3		
2436	0	0.02	0.05	0.01	0.54	0.78	0.5	9.5	5	1.2
2557	0	0.02	0.03	0.01	0.47	0.6	0.29	1.5	5.9	0.3
2696	0	0.01	0.03	0.01	0.5	0.7	0.15	4.5	5.5	1.7
2856	0	0.01	0.03	0.03	0.48	0.59		4.5	4.7	2.6
3033	0	0.02	0.03	0.03	0.37	0.48	0	2	5.8	2.4
3101	0	0.02	0.03	0.01	0.34	0.44	0	4.5	9.6	2.3
3298	0	0.02	0.03	0.01	0.5	0.5	0	4.5	7.3	0.3
3510	0	0.01	0.02	0.02	0.3	0.42	0.01	3	9.5	0.5
3697	0	0.02	0.03	0.18	0.53	0.56	0	6.5	8.9	2.8
3771	0	0	0.02	0.06	0.29	0.4	0	4.5	9.3	1.4
3950	0	0.02	0.03	0	0.33	0.45	0.34	4.4	10	1.1
4065	0	0.01	0.02	0.06	0.38	0.44	0.48	3.6	7.8	2
6128	0	0.02	0.03	0	0.41	0.41	0.43	4	7.8	3.2
6504	0.01	0.03	0.04	0.05	0.73	0.77	0.54	2	5.6	1.8
6505	0	0.01	0.03	0.03	0.35	0.56	0.42	4.2	9.6	0.9
BOTTOM SAMPLES										
2003	0	0.01	0.03	0.07	0.39	0.45	0.04	3.5		
2107	0.01	0.02	0.04	0.19	0.65	0.73	0.11	8		
2200	0	0.02	0.06	0.1	0.46	0.72	0.14	29		
2388	0.01	0.03	0.05	0.05	0.44	0.66	0.8	3.5		
2437	0	0.02	0.04	0.01	0.65	0.86	0.48	5.5		
2558	0	0.02	0.04	0.04	0.47	0.61	0.3	13		
2697	0	0.02	0.04	0.13	0.6	0.71	0.3	9		
2857	0	0.02	0.04	0.11	0.51	0.6	0.15	9.5		
3034	0	0.02	0.04	0.1	0.42	0.52	0	7.5		
3102	0	0.02	0.05	0.03	0.34	0.54	0	9.5		
3299	0	0.01	0.03	0.04	0.47	0.55	0	4.5		
3511	0	0.01	0.04	0.02	0.38	0.5	0	9.5		
3698	0	0.02	0.04	0.1	0.52	0.63	0.02	14		
3772	0	0.01	0.03	0.07	0.32	0.41	0.02	8.5		
3951	0	0.02	0.07	0.01	0.3	0.34	0.38	6		
4066	0	0.01	0.02	0.05	0.36	0.42	0.47	4.4		
6129	0	0	0.02	0	0.36	0.47	0.49	5		
6505	0	0	0.02	0.06	0.27	0.36	0.55	3		
6605	0	0.02	0.03	0.07	0.34	0.4	0.48	3.4		

TABLE A-6. CONTINUED

ID	MO	DY	YR	HR	MN	DEPTH ft	DO mg/L	TEMP deg C	pH	ALK mg/L	COND umho/cm	SECCHI in
STATION LM04												
SURFACE SAMPLES												
2004	10	31	84	9	55	1	8.1	19	7.3	31.6	100	81
2108	11	27	84	11	46	1	10.8	8	6.6	32.9	110	36
2201	12	11	84	10	15	1	10	5	7.2	30.8	115	56
2389	2	26	85	11	30	1	11.2	5	6.5	23.1	105	36
2438	3	26	85	10	23	1	11.2	7	6.1	23.3	105	31
2559	4	30	85	9	56	1	9.65	19	7	25.8	115	50
2698	5	22	85	9	35	1	9.4	21.5	6.9	27.8	115	40
2858	6	12	85	10	2	1	9.3	26	6.6	29.7	115	52
3035	7	10	85	9	28	1	8.3	26	7.9	31.8	120	56
3103	7	24	85	9	12	1	7	26.5	7.5	31	120	63
3300	8	22	85	8	44	1	6.35	26	6.9	34.3	115	52
3512	9	11	85	9	30	1	6.8	27	6.9	32.6	120	61
3699	10	4	85	10	45	1	7.4	20.5	6.8	34	120	52
3773	10	16	85	8	58	1	8.3	19.5	6.8	33.5	120	50
3952	11	13	85	10	3	1	8.6	14.5	6.7	30.1	125	44
4067	12	10	85	10	21	1	9.8	8	6.4	26.2	120	45
6130	3	11	86	10	56	1	13.2	3	6.6	54.3	135	56
6506	4	9	86	9	57	1	10.2	14	6.3	26.9	135	40
6606	4	30	86	10	52	1	10.2	17	7.4	26.1	120	50
BOTTOM SAMPLES												
2005	10	31	84	10	3	30	0.1	15	6.8	49	130	
2109	11	27	84	11	54	30	10.1	7	6.7	32.5	115	
2202	12	11	84	10	24	35	10.2	4	7.1	28.9	115	
2390	2	26	85	11	38	30	10.8	4.5	6.5	23	115	
2439	3	26	85	10	32	35	10.9	6.5	6.7	24.3	110	
2560	4	30	85	10	4	30	6.6	9.5	6.3	25.5	115	
2699	5	22	85	9	43	30	2.55	10.5	5.9	30.4	125	
2859	6	12	85	10	10	30	0.1	11.5	5.6	29.9	120	
3036	7	10	85	9	35	25	0.4	15	6.7	45.6	135	
3104	7	24	85	9	19	25	0.3	14	6.3	42.8	140	
3301	8	22	85	8	53	30	0.2	14	6.6	71.6	155	
3513	9	11	85	9	37	25	0.4	18.5	6.2	56.2	150	
3700	10	4	85	10	53	30	0.45	15.5	6.6	62.4	185	
3774	10	16	85	9	5	25	4.9	18.5	6.4	34.4	125	
3953	11	13	85	10	10	25	7.5	14	6.6	30	130	
4068	12	10	85	10	29	30	9.1	7.5	6.4	27.2	130	
6131	3	11	86	11	4	30	13.4	3	6.6	34.3	135	
6507	4	9	86	10	5	30	9.2	9	6.1	26.6	145	
6607	4	30	86	11	0	30	7.4	11	6.3	26.8	130	

TABLE A-6. CONTINUED

ID	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	CHLA	PHPA
.....milligram per liter.....									ug/L	
STATION LM04										
SURFACE SAMPLES										
2004	0	0.01	0.03	0.03	0.39	0.41	0.03	1.5	3.7	0.5
2108	0.01	0.02	0.03	0.16	0.69	0.69	0.09	5	3.8	
2201	0	0.02	0.03	0.11	0.45	0.52	0.2	4.5	6.7	
2389	0.01	0.04	0.06	0.07			0.53	2.5	8.8	0.3
2438	0	0.02	0.06	0.02	0.66	0.95	0.52	6.5	16	1.9
2559	0	0.02	0.03	0	0.43	0.5	0.27	2.5	4.7	0.9
2698	0	0.02	0.03	0.03	0.46	0.72	0.13	6	5.5	
2858	0	0.01	0.03	0.04	0.49	0.6	0.05	2	6.3	0.9
3035	0	0.01	0.03	0.01	0.37	0.44	0	4.5	5.7	0.6
3103	0	0.01	0.03	0.02	0.3	0.39	0	4	4.3	0.6
3300	0.01	0.01	0.03	0.01	0.44	0.5	0	3	8.8	1.3
3512	0	0.01	0.02	0	0.36	0.39	0	3	7.4	
3699	0	0.01	0.03	0.09	0.43	0.53	0	3.5	8.4	2
3773	0	0	0.02	0.05	0.3	0.38	0.01	3.5	6.1	0.3
3952	0	0.01	0.03	0	0.33	0.36	0.37	4	7.1	1.6
4067	0	0.01	0.02	0.06	0.35	0.41	0.49	3.2	6.2	2.8
6130	0	0	0.02	0	0.37	0.47	0.67	4	10	0.1
6506	0	0.01	0.02	0.03	0.29	0.38	0.54	2	4.9	
6606	0	0	0.02	0.02	0.34	0.45	0.43	3.6	8	
BOTTOM SAMPLES										
2005	0.02	0.03	0.14	0.55	0.89	1.26	0	39		
2109	0.01	0.02	0.04	0.16	0.7	0.7	0.11	6.5		
2202	0	0.02	0.04	0.12	0.53	0.55	0.38	5		
2390	0.01	0.04	0.06	0.07			0.51	3		
2439	0	0.02	0.05	0.03	0.65	0.79	0.52	10.5		
2560	0	0.02	0.03	0.11	0.55	0.58	0.37	3.5		
2699	0.01	0.02	0.03	0.26	0.7	0.7	0.41	4		
2859	0.01	0.02	0.05	0.23	0.51	0.63	0.42	15.5		
3036	0.02	0.03	0.09	0.59	0.83	0.9	0	26		
3104	0.03	0.04	0.09	0.51	0.8	0.88	0	16		
3301	0.07	0.09	0.21	0.96	1.36	1.72	0	54		
3513	0.04	0.04	0.11	0.66	0.83	1.15	0	36		
3700	0.01	0.02	0.08	1.2	1.46	1.88	0	38		
3774	0	0.01	0.03	0.12	0.41	0.54	0	9.5		
3953	0	0.02	0.03	0.03	0.31	0.38	0.46	6		
4068	0	0.02	0.05	0.08	0.35	0.51	0.49	12		
6131	0	0	0.03	0	0.35	0.5	0.63	7		
6507	0	0	0.02	0.09	0.28	0.36	0.59	4		
6607	0	0.02	0.03	0.12	0.4	0.46	0.47	8		

TABLE A-6. CONTINUED

ID	MO	DY	YR	HR	MN	DEPTH ft	DO mg/L	TEMP deg C	pH	ALK mg/L	COND umho/cm	SECCHI in
STATION LM05												
SURFACE SAMPLES												
2006	10	31	84	10	15	1	8.5	19	7	31.7	100	64
2110	11	27	84	9	40	1	11.6	7	6.3	32.1	105	35
2203	12	11	84	10	33	1	10.4	5	6.8	30.8	95	45
2391	2	26	85	11	50	1	11.2	7	6.6	21.8	105	30
2440	3	26	85	10	40	1	11.9	7	6.6	24.5	105	28
2561	4	30	85	10	17	1	9.6	19	7	26.9	115	43
2700	5	22	85	9	59	1	9.95	22	7.1	26.9	115	38
2860	6	12	85	10	58	1	8.6	26	7.3	30.4	115	47
3037	7	10	85	9	43	1	8.1	26	7.7	32.1	120	41
3105	7	24	85	9	28	1	7.4	26.5	7.6	32.4	120	45
3302	8	22	85	9	2	1	6.7	26	7.4	44	115	34
3514	9	11	85	9	46	1	6.3	26.5	6.7	32.8	125	34
3701	10	4	85	11	10	1	7.8	20.5	7	39.7	120	43
3775	10	16	85	9	10	1	8.65	20	7	33.4	120	45
3954	11	13	85	10	19	1	9.4	14	6.9	29.9	130	40
4069	12	10	85	10	48	1	11.1	7.5	6.7	27.9	120	39
6132	3	11	86	10	21	1	13.1	4	6.9	51.5	115	49
6508	4	9	86	10	10	1	9.8	15	6.3	26.6	135	34
6608	4	30	86	11	7	1	10.8	16.5	7.4	26.7	120	45
BOTTOM SAMPLES												
2007	10	31	84	10	21	20	0.3	16.5	6.7	35.7	110	
2111	11	27	84	9	46	20	11.4	7	6.5	33.6	105	
2204	12	11	84	10	39	20	10.4	4.5	6.6	49.8	115	
2392	2	26	85	11	56	20	10.4	4.5	6.7	21.5	105	
2441	3	26	85	10	46	20	11.5	6	6.8	24.2	110	
2562	4	30	85	10	23	20	4.8	10	7.3	28.2	120	
2701	5	22	85	10	5	20	1.9	14	5.9	29.8	130	
2861	6	12	85	11	4	20	0.2	15.5	6.1	33.2	125	
3038	7	10	85	9	49	20	0.35	23	6.8	37.7	125	
3106	7	24	85	9	33	15	6.6	26	7.5	32.5	125	
3303	8	22	85	9	6	10	6.5	25.5	7	36.6	120	
3515	9	11	85	9	51	15	6.1	26	6.3	34.7	125	
3702	10	4	85	11	16	20	7.2	19.5	6.9	36.1	125	
3776	10	16	85	9	15	15	5.9	19	6.4	34.9	125	
3955	11	13	85	10	25	20	8.05	13	6.7	30	130	
4070	12	10	85	11	54	20	10.4	7	6.3	27	120	
6133	3	11	86	10	27	20	13.8	3.5	6.9	84.8	135	
6509	4	9	86	10	15	15	9.4	11	6.2	26.6	140	
6609	4	30	86	11	13	20	7.9	11	6.6	26.8	130	

TABLE A-6. CONTINUED

ID	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	CHLA	PHPA
.....milligram per liter.....									ug/L	
STATION LM05										
SURFACE SAMPLES										
2006	0	0.01	0.02	0.02	0.41	0.45	0.02	0	3.9	1.8
2110	0	0.02	0.04	0.13	0.61	0.75	0.09	6	7.8	1.6
2203	0	0.02	0.04	0.11	0.45	0.57	0.28	4	6.7	0.3
2391	0.02	0.04	0.07	0.06	0.59	0.71	0.7	4	6.3	0
2440	0	0.02	0.05	0.01	0.58	0.83	0.51	7	14	1.8
2561	0	0.02	0.03	0	0.4	0.52	0.26	4.5	12	
2700	0	0.02	0.03	0.01	0.56	0.77	0.12	5.5	5.2	
2860	0	0.01	0.03	0.03	0.46	0.58	0.05	2.5	7.2	
3037	0	0.02	0.03	0.04	0.42	0.51	0	5	6.8	0.7
3105	0.03	0.02	0.03	0.06	0.31	0.42	0	5.5	4.3	
3302	0.01	0.01	0.04	0.02	0.46	0.6	0	6.5	8.7	1.7
3514	0	0.02	0.03	0.02	0.3	0.43	0	6.5	6.7	0.3
3701	0	0.02	0.03	0.1	0.44	0.58	0	6	8.9	2.8
3775	0	0	0.02	0.06	0.42	0.48	0	5	9	0
3954	0	0.02	0.03	0	0.28	0.36	0.4	4.4	17	3.5
4069	0	0.02	0.04	0.03	0.36	0.53	0.48	4.8	25	0.5
6132	0	0	0.02	0	0.33	0.45	0.73	5	11	1.2
6508	0	0.01	0.03	0.05	0.32	0.45	0.56	5	5.6	1.1
6608	0	0	0.02	0.02	0.31	0.44	0.4	4	7	0.8
BOTTOM SAMPLES										
2007	0	0.02	0.04	0.13	0.59	0.64	0.05	8.5		
2111	0.01	0.02	0.08	0.12	0.66	0.71	0.11	38.5		
2204	0	0.03	0.04	0.08	0.46	0.68	0.31	7.5		
2392	0.02	0.05	0.08	0.1	0.64	0.87	0.61	6		
2441	0	0.02	0.05	0.01	0.69	0.8	0.51	8		
2562	0	0.02	0.05	0.17	0.63	0.71	0.32	11.5		
2701	0.01	0.01	0.05	0.3	0.78	0.85	0.33	13.5		
2861	0	0.02	0.05	0.16	0.57	0.65	0.34	12		
3038	0	0.02	0.05	0.22	0.56	0.65	0	14		
3106	0	0.01	0.03	0.02	0.41	0.47	0	3.5		
3303	0.01	0.02	0.04	0.01	0.38	0.53	0	7		
3515	0	0.02	0.05	0.06	0.36	0.48	0	15.5		
3702	0	0	0.06	0.11	0.44	0.64	0	32		
3776	0	0	0.05	0.14	0.57	0.73	0	13.5		
3955	0	0.02	0.05	0.09	0.52	0.61	0.56	10		
4070	0	0.02	0.03	0.04	0.36	0.4	0.54	5.5		
6133	0	0	0.02	0.02	0.41	0.44	0.74	5		
6509	0	0	0.02	0.07	0.3	0.44	0.57	6		
6609	0	0.01	0.03	0.05	0.39	0.45	0.46	6.6		

TABLE A-6. CONTINUED

ID	MO	DY	YR	HR	MN	DEPTH ft	DO mg/L	TEMP deg C	pH	ALK mg/L	COND umho/cm	SECCHI in
STATION LM06												
SURFACE SAMPLES												
2008	10	31	84	10	40	1	8.6	19	7.2	33	100	58
2112	11	27	84	10	6	1	12.1	7.5	6.6	33	115	36
2205	12	11	84	10	52	1	11.1	4	6.9	30.5	115	47
2393	2	26	85	12	7	1	10.8	8	6.7	22.4	105	29
2442	3	26	85	10	58	1	11.6	7	6.4	23.9	105	29
2563	4	30	85	10	36	1	9.9	19	6.9	26.6	115	46
2702	5	22	85	10	24	1	10.1	21.5	7.3	28.5	115	35
2862	6	12	85	11	12	1	8	25	7.6	30.4	110	40
3039	7	10	85	9	56	1	7.6	26	7.5	34.2	120	35
3107	7	24	85	9	43	1	7.25	27	7.5	32.3	120	35
3304	8	22	85	9	21	1	6.85	26	6.9	35.7	115	16
3516	9	11	85	10	1	1	6.3	26.5	6.7	33.5	125	21
3703	10	4	85	11	30	1	8	20	6.8	35.2	120	38
3777	10	16	85	9	24	1	8.7	19.5	6.9	34.3	125	34
3956	11	13	85	10	35	1	9.8	15.5	6.9	29.8	125	38
4071	12	10	85	11	37	1	11.4	7	6.8	27.5	120	45
6134	3	11	86	10	3	1	12.4	6	7.1	36.8	125	56
6510	4	9	86	10	21	1	9.6	14	6.3	26.4	130	34
6610	4	30	86	11	20	1	10.4	17	7.3	27.1	120	44
BOTTOM SAMPLES												
2009	10	31	84	10	45	15	4.7	18	6.8	35.5	110	
2113	11	27	84	10	10	10	12	7	6.6	32.7	115	
2206	12	11	84	10	56	10	11	4	6.7	34.8	115	
2394	2	26	85	12	12	15	10.4	5	6.6	21.9	105	
2443	3	26	85	11	2	10	11.6	6	6.8	24.7	110	
2564	4	30	85	10	41	15	5.8	13	6.5	27.6	120	
2703	5	22	85	10	28	10	10	21	6.9	27.2	115	
2863	6	12	85	11	16	10	1.55	21	6.2	32.5	120	
3040	7	10	85	10	0	10	5.8	25	7.3	32.9	125	
3108	7	24	85	9	47	10	6.55	26.5	7.3	31.3	120	
3305	8	22	85	9	26	15	0.8	25	6.2	41.3	120	
3517	9	11	85	10	4	7.5	5.9	26.5	6.7	34.4	125	
3704	10	4	85	11	33	7.5	7.15	19.5	6.8	35.6	130	
3778	10	16	85	9	27	7.5	6.55	19	6.7	34.5	125	
3957	11	13	85	10	39	10	7.65	15	6.6	30.5	125	
4072	12	10	85	11	41	10	11.4	7	6.6	27.5	120	
6135	3	11	86	10	7	10	12.4	6	6.9	53.8	125	
6511	4	9	86	10	25	10	8.8	12.5	6.2	26.6	135	
6611	4	60	86	11	24	10	10.2	14	7	26.3	130	

TABLE A-6. CONTINUED

ID	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	CHLA	PHPA
.....milligram per liter.....									ug/L	
STATION LM06										
SURFACE SAMPLES										
2008	0	0.02	0.03	0.01	0.4	0.53	0.03	3	4.4	
2112	0	0.02	0.04	0.12	0.56	0.71	0.11	6.8	13	0
2205	0.01	0.02	0.04	0.08	0.49	0.55	0.46	4	4.9	1.5
2393	0.01	0.03	0.05	0.03	0.43	0.48	0.74	4	2.6	0.8
2442	0	0.02	0.06	0.01	0.6	0.85	0.51	10.5	15	0.7
2563	0	0.02	0.03	0	0.48	0.63	0.26	3.5	4.9	
2702	0			0.01			0.11	7.5	4.7	
2862	0	0.02	0.03	0.05	0.48	0.62	2.67	3	9.6	2.5
3039	0	0.02	0.04	0.05	0.46	0.51	0	7.5	11	4
3107	0	0.02	0.04	0.01	0.38	0.5	0	5	12.3	3.2
3304	0	0.02	0.05	0	0.41	0.6	0	10.5	15	2.1
3516	0	0.02	0.04	0.03	0.34	0.41	0	15.5	10.1	3.2
3703	0	0	0.03	0.05	0.44	0.6	0	8.5	20	4.8
3777	0	0	0.03	0.06	0.42	0.54	0	5	13	0.6
3956	0	0.02	0.04	0	0.39	0.54	0.42	5.2	25	5.5
4071	0	0.02	0.04	0.02	0.44	0.63	0.51	4.8	26	4.6
6134	0	0	0.02	0	0.36	0.43	0.81	4	8	0.4
6510	0	0.02	0.03	0.06	0.33	0.38	0.54	6	7.1	2.2
6610	0	0.01	0.02	0	0.34	0.44	0.4	4.6	11	0
BOTTOM SAMPLES										
2009	0	0.02	0.05	0.08	0.51	0.65	0.04	8.5		
2113	0	0.02	0.07	0.11	0.62	0.81	0.11	24.5		
2206	0.01	0.03	0.04	0.08	0.53	0.6	0.52	5.8		
2394	0.02	0.04	0.08	0.09	0.73	0.75	0.67	7		
2443	0	0.02	0.06	0.01	0.68	0.84	0.51	10.2		
2564	0	0.02	0.04	0.04	0.41	0.53	0.29	11.5		
2703	0	0.02	0.04	0.02	0.65	0.88	0.14	9.5		
2863	0	0.02	0.04	0.17	0.61	0.62	0.3	7		
3040	0	0.02	0.04	0.03	0.4	0.51	0	10.8		
3108	0	0.02	0.04	0.02	0.36	0.5	0	8.8		
3305	0.01	0.02	0.18	0.19	0.62	1.05	0	74		
3517	0	0.02	0.05	0.03	0.46	0.47	0	24.5		
3704	0	0	0.03	0.07	0.44	0.57	0	12.5		
3778	0	0	0.03	0.06	0.57	0.6	0	9		
3957	0	0.02	0.04	0.02	0.31	0.46	0.43	7		
4072	0	0.02	0.05	0.01	0.42	0.62	0.51	9.8		
6135	0	0	0.02	0.02	0.35	0.37	0.82	5		
6511	0	0.02	0.06	0.07	0.39	0.49	0.54	21		
6611	0	0.02	0.05	0.02	0.4	0.47	0.4	6		

TABLE A-7. LAKE MANASSAS' TRIBUTARY STREAM ANALYSES
NOVEMBER, 1984 - MARCH, 1986.

ID	DATE	HR	MN	DO	TEMP	PH	ALK	COND
				mg/L	deg C		mg/L	umho/cm
STATION ST70 - BASEFLOW								
2049	11 12	84	10 25	10.8	7.5	7	37.6	120
2181	12 10	84	9 12	13.3	2	7.2	29.1	105
2258	1 8	85	12 0	12.8	4.5	6.5	32.4	115
2312	2 5	85	8 53	14.6	-1	6.1	32.3	105
2418	3 12	85	8 48	11.4	6	6.5	49.7	110
2521	4 16	85	9 1	9.75	14	6.4	38.3	100
2674	5 20	85	8 8	8.65	16	7.2	43.3	120
2899	6 19	85	8 14	7.7	20.5	6.8	52.3	120
3048	7 15	85	8 59	6.7	27	7.6	51.9	135
3211	8 12	85	9 14	6.8	24	6.9	53.3	170
3474	9 9	85	8 3	5.8	25	7.1	60.8	150
3722	10 7	85	11 15	9.4	18	6.8	45.2	110
3969	11 18	85	9 50	10.2	8	6.7	31.9	135
4046	12 9	85	9 33	10.8	2.5	6.8	29.1	120
4149	1 13	86	9 45	12.6	1	6.8	27.9	.
4248	2 10	86	9 40	13.2	3.5	6.8	25.2	.
6117	3 10	86	9 48	9.1	5	7	41.7	.
STATION ST70 - RUNOFF								
2172	12 6	84	11 35	.	.	.	.	.
2300	2 1	85	9 8	.	.	.	.	.
2585	5 3	85	7 59	.	.	.	.	.
2665	5 17	85	8 19	.	.	.	.	.
3325	8 25	85	16 30	.	.	.	.	.
3622	9 27	85	9 58	.	.	.	.	.
3793	10 21	85	9 0	.	.	.	.	.
3894	11 4	85	9 3	.	.	.	.	.
4079	12 13	85	10 10	.	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE			OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS
.....milligram per liter.....											
STATION ST70 - BASEFLOW											
2049	11	12	84	0.00	0.02	0.02	0.02	0.28	0.30	0.43	0.5
2181	12	10	84	0.00	0.02	0.03	0.01	0.30	0.35	0.99	2
2258	1	8	85	0.00	0.02	0.04	0.01	0.23	0.27	0.84	3.8
2312	2	5	85	0.03	0.06	0.08	0.08	0.66	0.79	0.98	4.2
2418	3	12	85	0.00	0.02	0.02	0.00	0.34	0.34	0.58	2
2521	4	16	85	0.00	0.02	0.02	0.01	0.31	0.34	0.36	0.5
2674	5	20	85	0.01	0.03	0.04	0.01	0.35	0.35	0.69	5
2899	6	19	85	0.01	0.02	0.04	0.02	0.43	0.45	0.30	6
3048	7	15	85	0.00	0.01	0.03	0.02	0.40	0.45	.	11.5
3211	8	12	85	0.01	0.02	0.04	0.08	0.39	0.39	0.00	9.5
3474	9	9	85	0.01	0.02	0.05	0.04	0.50	0.68	0.02	0.2
3722	10	7	85	0.00	0.02	0.03	0.01	0.42	0.44	0.00	3.5
3969	11	18	85	0.00	0.02	0.04	0.02	0.25	.	0.58	1.6
4046	12	9	85	0.00	0.02	0.02	0.02	0.18	0.23	1.04	2.2
4149	1	13	86	0.00	0.01	0.02	0.03	0.13	0.20	0.91	1.2
4248	2	10	86	0.01	0.02	0.04	0.04	0.37	0.44	1.25	4.5
6117	3	10	86	0.00	0.02	0.02	0.00	0.22	0.28	0.83	4.2
STATION STATION ST70 - RUNOFF											
2172	12	6	84	0.02	0.05	0.11	0.02	0.43	0.50	0.79	16
2300	2	1	85	0.00	0.02	0.02	0.01	0.27	0.27	0.91	12.5
2585	5	3	85	0.00	0.02	0.04	0.03	0.34	0.46	0.65	16
2665	5	17	85	0.00	0.03	0.04	0.03	0.37	0.38	0.77	5
3325	8	25	85	0.00	0.02	0.04	.	0.36	0.69	0.04	2
3622	9	27	85	0.01	0.02	0.04	0.03	0.29	0.30	0.02	7
3793	10	21	85	0.00	0.03	0.04	0.01	0.40	0.40	0.00	3
3894	11	4	85	0.03	0.03	0.57	0.07	0.57	1.99	0.82	308
4079	12	13	85	0.00	0.02	0.02	0.06	0.17	0.17	0.82	3

TABLE A-7. CONTINUED

ID	DATE	HR	MN	DO	TEMP	PH	ALK	COND
				mg/L	deg C		mg/L	umho/cm
STATION BR02 - BASEFLOW								
2043	11 12	84	9 45	9.5	8	6.9	43.3	285
2175	12 10	84	11 30	12.2	3.5	7.1	36.4	145
2252	1 8	85	11 10	12.1	4	6.2	33.1	135
2306	2 5	85	11 0	12.2	1	6	44.4	115
2412	3 12	85	10 6	10.7	7.5	6.5	35.4	145
2515	4 16	85	9 30	9.9	14.5	6.4	46.4	195
2668	5 20	85	8 27	8.7	18	7	41.6	215
2893	6 19	85	8 57	8.1	20	7.1	58.9	335
3043	7 15	85	9 21	5.7	24.5	7.2	65.3	485
3201	8 12	85	9 10	8.1	20.5	7.1	58.2	715
3471	9 9	85	8 15	5.2	22	7.1	87.6	640
3711	10 7	85	11 25	8.6	12.5	6.9	54.9	585
3963	11 18	85	10 31	8.9	10	6.5	30.5	200
4040	12 9	85	10 40	10.3	4	6.6	29	165
4143	1 13	86	9 20	10.4	3	6.6	39.7	.
4242	2 10	86	10 7	13.2	3	6.8	28.3	.
6111	3 10	86	10 14	10.1	6	7.2	39.7	.
STATION BR02 - RUNOFF								
2069	11 19	84	15 17	.	.	.	.	.
2166	12 6	84	10 55	.	.	.	.	.
2294	2 1	85	10 13	.	.	.	.	.
2579	5 3	85	8 14	.	.	.	.	.
2659	5 17	85	8 47	.	.	.	.	.
3319	8 25	85	15 55	.	.	.	.	.
3617	9 27	85	9 40	.	.	.	.	.
3787	10 21	85	8 32	.	.	.	.	.
3888	11 4	85	9 42	.	.	.	.	.
4073	12 13	85	9 50	.	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE			OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS
.....milligram per liter.....											
STATION STATION BR02 - BASEFLOW											
2043	11	12	84	0.20	0.24	0.26	0.06	0.68	0.68	2.32	0.5
2175	12	10	84	0.06	0.10	0.12	0.18	0.59	0.68	0.65	3.5
2252	1	8	85	0.06	0.08	0.13	0.14	0.59	0.72	0.58	4
2306	2	5	85	0.08	0.09	0.15	0.07	0.65	0.79	0.45	1.5
2412	3	12	85	0.19	0.22	0.25	0.14	0.76	0.85	0.94	5
2515	4	16	85	0.32	0.38	0.41	0.17	0.75	0.84	1.47	3
2668	5	20	85	0.19	0.22	0.23	0.02	0.44	0.44	1.35	2
2893	6	19	85	0.37	0.39	0.41	0.04	0.68	0.74	2.54	2.5
3043	7	15	85	0.70	0.70	0.70	0.05	0.62	0.65	.	3
3201	8	12	85	.	0.56	0.56	0.03	0.59	0.60	6.22	0.5
3471	9	9	85	0.77	0.79	0.82	0.04	0.79	0.82	5.07	3.5
3711	10	7	85	0.71	0.71	0.77	0.03	0.72	0.72	6.71	2.5
3963	11	18	85	0.20	0.26	0.28	0.14	0.71	.	1.42	0.8
4040	12	9	85	0.10	0.14	0.17	0.48	.	.	0.98	2.4
4143	1	13	86	0.19	0.25	0.28	1.31	.	1.55	2.11	2
4242	2	10	86	0.05	0.06	0.09	0.10	0.57	0.57	0.65	3
6111	3	10	86	0.06	0.10	0.12	0.06	0.42	0.56	0.62	3
STATION STATION BR02 - RUNOFF											
2069	11	19	84	0.15	0.18	0.25	0.47	1.17	1.41	1.05	8
2166	12	6	84	0.05	0.08	0.11	0.25	0.82	1.04	0.55	8
2294	2	1	85	0.13	.	.	0.20	0.77	0.92	0.72	13
2579	5	3	85	0.24	0.26	0.29	0.99	1.76	1.88	2.58	6
2659	5	17	85	0.16	0.21	0.26	0.12	0.70	0.84	0.93	26
3319	8	25	85	0.53	0.53	0.55	0.07	0.93	1.26	5.90	5
3617	9	27	85	0.54	0.54	0.56	0.17	0.96	0.96	3.10	10
3787	10	21	85	0.47	0.47	0.48	0.42	1.08	1.16	2.65	4
3888	11	4	85	0.06	0.09	0.54	0.69	1.02	1.60	0.35	70
4073	12	13	85	0.08	0.12	0.14	0.24	0.71	0.77	1.18	4.4

TABLE A-7. CONTINUED

ID	DATE	HR	MN	DO mg/L	TEMP deg C	PH	ALK mg/L	COND umho/cm
STATION BR03 - BASEFLOW								
2044	11 12	84	9 24	12.1	7	7.3	46.2	300
2253	1 8	85	11 25	12.8	4	6.3	33.3	135
2516	4 16	85	9 43	8	15.5	6.6	39.6	160
2669	5 20	85	8 38	9.4	16	7.2	43.3	195
2894	6 19	85	9 16	7.8	20	7	47	240
3044	7 15	85	9 37	7.8	25	7.5	65.6	470
3202	8 12	85	8 35	5	20	7.1	63.8	665
3472	9 9	85	8 40	8.8	22	7.5	86.1	260
3712	10 7	85	11 2	8.7	11.5	6.9	61.2	515
3964	11 18	85	11 0	10.1	10	6.7	36.8	100
4041	12 9	85	11 12	11.8	3	6.9	34.2	170
4144	1 13	86	9 12	11.6	1.5	6.9	37.8	.
4243	2 10	86	10 15	12.8	3.5	6.8	29.4	.
6112	3 10	86	10 39	9.6	11.5	7.2	44	.
STATION BR03 - RUNOFF								
2070	11 19	84	15 1	.	.	.	.	.
2167	12 6	84	10 10	.	.	.	.	.
2580	5 3	85	8 21	.	.	.	.	.
2660	5 17	85	8 58	.	.	.	.	.
3320	8 25	85	16 15	.	.	.	.	.
3618	9 27	85	9 32	.	.	.	.	.
3788	10 21	85	8 17	.	.	.	.	.
3889	11 4	85	9 52	.	.	.	.	.
4074	12 13	85	9 40	.	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE		OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	
.....milligram per liter.....											
STATION STATION BR03 - BASEFLOW											
2044	11	12	84	0.15	0.18	0.18	0.01	0.45	0.47	2.00	0.5
2253	1	8	85	0.04	0.07	0.09	0.04	0.45	0.52	0.61	2.5
2516	4	16	85	0.08	0.11	0.17	0.10	0.59	0.75	0.74	12
2669	5	20	85	0.15	0.18	0.18	0.02	0.40	0.46	0.94	2.5
2894	6	19	85	0.12	0.14	0.18	0.05	0.54	0.67	1.21	8
3044	7	15	85	0.20	0.20	0.22	0.03	0.50	0.50	.	6.5
3202	8	12	85	0.15	0.17	0.22	0.06	0.51	0.55	2.63	1
3472	9	9	85	0.29	0.30	0.30	0.02	0.48	0.51	0.74	1.5
3712	10	7	85	0.32	0.42	0.43	0.01	0.67	0.70	3.13	3
3964	11	18	85	0.16	0.18	0.19	0.03	0.51	.	1.51	0.8
4041	12	9	85	0.09	0.12	0.14	0.10	0.57	0.59	1.40	1.6
4144	1	13	86	0.13	0.16	0.16	0.54	0.94	0.94	2.17	0.5
4243	2	10	86	0.05	0.07	0.09	0.06	0.49	0.52	0.91	3
6112	3	10	86	0.05	0.08	0.10	0.02	0.35	0.46	0.98	4.2
STATION STATION BR03 - RUNOFF											
2070	11	19	84	0.15	0.17	0.20	0.09	0.72	0.86	1.16	4
2167	12	6	84	0.06	0.09	0.12	0.19	0.70	0.79	0.61	7
2580	5	3	85	0.13	0.19	0.20	0.05	0.77	0.83	2.62	6
2660	5	17	85	0.15	0.20	0.26	0.01	0.60	0.79	1.62	28
3320	8	25	85	.	0.18	0.24	0.00	0.51	0.58	2.34	1
3618	9	27	85	0.42	0.42	0.43	0.04	0.75	0.81	4.04	4
3788	10	21	85	0.40	0.40	0.42	0.02	0.83	0.83	3.00	3
3889	11	4	85	0.07	0.09	0.47	0.15	0.93	1.61	0.53	88
4074	12	13	85	0.07	0.09	0.11	0.08	0.53	0.61	1.45	2.8

TABLE A-7. CONTINUED

ID	DATE	HR	MN	DO mg/L	TEMP deg C	PH	ALK mg/L	COND umho/cm
STATION BR04 - BASEFLOW								
2045	11 12	84	11 10	9	7.5	7.1	76.8	255
2177	12 10	84	8 33	12.7	2	7.1	27.8	115
2254	1 8	85	12 20	12.6	3.5	6.2	28.4	125
2308	2 5	85	10 40	10.2	-1	6.2	38.6	105
2414	3 12	85	9 26	10.1	6.5	6.5	39.9	110
2517	4 16	85	8 35	8.15	14	6.4	77.9	165
2670	5 20	85	7 32	7.2	16	7.1	111	230
2895	6 19	85	7 40	2.5	20	6.5	116	310
3045	7 15	85	8 32	3.5	24	7.2	195	510
3713	10 7	85	12 8	6.1	13	6.1	82.6	340
3965	11 18	85	9 18	8.8	7.5	6.8	42.1	165
4042	12 9	85	8 58	11.6	1.5	7	34.3	125
4145	1 13	86	10 5	12.3	1	6.7	47.9	.
4244	2 10	86	9 15	13.2	3	6.8	25.8	.
6113	3 10	86	9 9	9.4	6	6.8	27.1	.
STATION BR04 - RUNOFF								
2071	11 19	84	15 52	.	.	.	.	.
2168	12 6	84	12 15	.	.	.	.	.
2296	2 1	85	9 40	.	.	.	.	.
2581	5 3	85	7 34	.	.	.	.	.
2661	5 17	85	7 57	.	.	.	.	.
3321	8 25	85	16 50	.	.	.	.	.
3619	9 27	85	10 20	.	.	.	.	.
3789	10 21	85	9 12	.	.	.	.	.
3890	11 4	85	8 50	.	.	.	.	.
4075	12 13	85	10 25	.	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE		OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	
.....milligram per liter.....											
STATION STATION BR04 - BASEFLOW											
2045	11	12	84	0.02	0.05	0.06	0.01	.	.	0.00	0.5
2177	12	10	84	0.01	0.04	0.05	0.01	0.45	0.51	0.16	4.5
2254	1	8	85	0.02	0.03	0.04	0.02	0.35	0.43	0.13	5
2308	2	5	85	0.01	0.02	0.04	0.01	0.59	0.60	0.35	4.5
2414	3	12	85	0.01	0.01	0.04	0.01	0.43	0.47	0.00	5.5
2517	4	16	85	0.01	0.03	0.04	0.01	0.43	0.49	0.01	1
2670	5	20	85	0.02	0.04	0.07	0.02	0.57	0.57	0.01	4
2895	6	19	85	0.06	0.08	0.16	0.46	1.20	1.27	0.01	9
3045	7	15	85	0.02	0.02	0.10	0.06	0.62	0.97	.	15
3713	10	7	85	0.00	0.04	0.08	0.04	0.71	0.88	0.03	8
3965	11	18	85	0.02	0.03	0.05	0.02	0.40	.	0.02	1.6
4042	12	9	85	0.01	0.02	0.04	0.02	0.30	0.30	0.16	2.8
4145	1	13	86	0.00	0.02	0.03	0.02	0.23	0.24	0.02	3
4244	2	10	86	0.02	0.02	0.04	0.02	0.38	0.45	0.35	16
6113	3	10	86	0.00	0.02	0.03	0.02	0.31	0.35	0.05	7
STATION STATION BR04 - RUNOFF											
2071	11	19	84	0.03	0.06	0.07	0.01	0.51	0.55	0.40	5
2168	12	6	84	0.03	0.06	0.08	0.00	0.51	0.52	0.23	11
2296	2	1	85	0.02	.	.	0.01	0.64	0.73	0.38	33
2581	5	3	85	0.02	0.04	0.08	0.01	0.69	0.80	0.03	25
2661	5	17	85	0.02	0.06	0.07	0.00	0.52	0.62	.	14
3321	8	25	85	0.02	0.04	0.07	0.09	0.68	0.77	0.20	9
3619	9	27	85	0.09	0.11	0.20	0.00	0.56	0.74	0.28	21
3789	10	21	85	0.07	0.09	0.13	0.09	0.79	0.81	0.39	16
3890	11	4	85	0.06	0.08	0.13	0.01	0.67	0.77	0.28	32
4075	12	13	85	0.01	0.02	0.03	0.05	0.36	0.37	.	5.6

TABLE A-7. CONTINUED

ID	DATE	HR	MN	DO	TEMP	PH	ALK	COND
				mg/L	deg C		mg/L	umho/cm
STATION BR05 - BASEFLOW								
2046	11 12	84	10 46	10.6	7	7	121	565
2178	12 10	84	8 49	12.2	2	7	38.6	165
2255	1 8	85	12 10	12.4	4	6.3	27.4	140
2309	2 5	85	10 0	11.2	-1	6.6	26.2	115
2415	3 12	85	9 9	10.8	5.5	6.1	36.8	125
2518	4 16	85	8 50	8.45	13	6.4	73.5	225
2671	5 20	85	7 48	8.6	14	7.1	158	650
2896	6 19	85	7 58	7.6	19	7	136	795
3046	7 15	85	8 48	3.55	26	7.5	186	1030
3966	11 18	85	9 29	9.7	7	6.6	48.9	185
4043	12 9	85	9 12	11	1.5	6.5	27.2	140
4146	1 13	86	9 55	11.8	1	6.6	47.8	.
4245	2 10	86	9 25	12.9	2.5	6.9	19.1	.
6114	3 10	86	9 26	9.9	4.5	7.1	96.2	.
STATION BR05 - RUNOFF								
2072	11 19	84	15 40	.	.	.	.	.
2169	12 6	84	12 0	.	.	.	.	.
2297	2 1	85	9 19	.	.	.	.	.
2582	5 3	85	7 50	.	.	.	.	.
2662	5 17	85	8 12	.	.	.	.	.
3322	8 25	85	16 40	.	.	.	.	.
3620	9 27	85	10 18	.	.	.	.	.
3790	10 21	85	9 5	.	.	.	.	.
3891	11 4	85	8 57	.	.	.	.	.
4076	12 13	85	10 20	.	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE		OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	
.....milligram per liter.....											
STATION STATION BR05 - BASEFLOW											
2046	11	12	84	0.00	0.02	0.02	0.00	0.27	0.28	0.02	1
2178	12	10	84	0.01	0.03	0.03	0.00	0.21	0.21	0.33	3
2255	1	8	85	0.01	0.02	0.03	0.01	0.26	0.31	0.14	3
2309	2	5	85	0.01	0.03	0.03	0.05	0.59	0.64	0.41	2
2415	3	12	85	0.01	0.02	0.02	0.01	0.32	0.34	0.05	1.5
2518	4	16	85	0.00	0.02	0.02	0.00	0.30	0.30	0.00	1
2671	5	20	85	0.00	0.02	0.04	0.02	0.36	0.45	0.06	5.5
2896	6	19	85	0.01	0.03	0.04	0.02	0.43	0.61	0.16	12
3046	7	15	85	0.01	0.02	0.05	0.26	0.94	1.16	.	.
3966	11	18	85	0.00	0.02	0.03	0.01	0.30	.	0.00	2
4043	12	9	85	0.00	0.02	0.02	0.02	0.22	0.22	0.08	2.8
4146	1	13	86	0.00	0.01	0.02	0.02	0.14	0.21	0.00	8
4245	2	10	86	0.02	0.02	0.03	0.02	0.38	0.38	0.37	4
6114	3	10	86	0.00	0.02	0.02	0.00	0.22	0.22	0.08	3
STATION STATION BR05 - RUNOFF											
2072	11	19	84	0.01	0.05	0.06	0.02	0.53	0.53	0.31	5
2169	12	6	84	0.03	0.07	0.08	0.02	0.53	0.59	0.31	8
2297	2	1	85	0.00	0.05	0.08	0.00	0.60	0.72	0.33	14
2582	5	3	85	0.00	0.03	0.05	0.02	0.72	0.81	0.14	14
2662	5	17	85	0.01	0.06	0.11	0.02	0.63	0.80	0.34	48
3322	8	25	85	0.59	0.65	1.09	0.12	1.52	3.69	1.00	177
3620	9	27	85	0.15	0.15	0.22	0.06	0.85	1.16	0.78	53
3790	10	21	85	0.06	0.07	0.11	0.03	0.67	0.85	0.20	32
3891	11	4	85	0.04	0.04	0.12	0.06	0.60	0.85	0.20	51
4076	12	13	85	0.00	0.02	0.03	0.04	0.23	0.28	0.05	6.4

TABLE A-7. CONTINUED

ID	DATE	HR	MN	DO	TEMP	PH	ALK	COND
				mg/L	deg C		mg/L	umho/cm
STATION BR06 - BASEFLOW								
1449	8 20	84	12	0	.	.	.	.
2047	11 12	84	9	0	7.2	7	6.6	90 185
2179	12 10	84	11	58	12.1	5	6.9	30.1 130
2256	1 8	85	10	50	12.7	3	5.9	52.1 105
2310	2 5	85	10	15	12.8	0	6	37 75
2416	3 12	85	10	38	11.7	10	7	31.4 40
2897	6 19	85	9	31	5.6	19	6.3	126 310
3967	11 18	85	11	17	9.8	9	6.5	53.1 175
4044	12 9	85	8	50	11.6	4	6.9	39 135
4147	1 13	86	8	50	8.15	3.5	6.5	65.4 .
4246	2 10	86	10	29	13.2	3	6.6	23.7 .
6115	3 10	86	10	27	9.4	10	7.4	35.2 .
STATION BR06 - RUNOFF								
2073	11 19	84	14	55	.	.	.	.
2170	12 6	84	10	35	.	.	.	.
2298	2 1	85	10	22	.	.	.	.
2583	5 3	85	8	32	.	.	.	.
2663	5 17	85	9	6	.	.	.	.
3323	8 25	85	16	6	.	.	.	.
3791	10 21	85	8	10	.	.	.	.
3892	11 4	85	10	3	.	.	.	.
4077	12 13	85	9	25	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE		OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	
.....milligram per liter.....											
STATION STATION BR06 - BASEFLOW											
1449	8	20	84	0.01	0.04	0.05	0.03	0.78	0.92	0.00	5
2047	11	12	84	0.00	0.03	0.08	0.04	0.41	0.76	0.02	18
2179	12	10	84	0.04	0.07	0.08	0.09	0.62	0.68	0.81	7
2256	1	8	85	0.03	0.06	0.07	0.00	0.53	0.61	0.03	6.5
2310	2	5	85	0.05	0.08	0.10	0.01	0.67	0.83	0.20	6.5
2416	3	12	85	0.02	0.04	0.16	0.02	0.58	1.30	0.00	16.5
2897	6	19	85	0.01	0.02	0.15	0.10	0.61	1.34	0.15	65.5
3967	11	18	85	0.00	0.02	0.02	0.02	0.28	.	0.00	0.8
4044	12	9	85	0.00	0.02	0.02	0.02	0.24	0.25	0.00	4.4
4147	1	13	86	0.00	0.02	0.03	0.03	0.28	0.29	0.37	10.5
4246	2	10	86	0.02	0.02	0.03	0.02	0.44	0.44	0.09	4
6115	3	10	86	0.00	0.02	0.02	0.00	0.23	0.23	0.00	2.6
STATION STATION BR06 - RUNOFF											
2073	11	19	84	0.05	0.07	0.09	0.02	0.66	0.66	0.06	6
2170	12	6	84	0.06	0.10	0.13	0.01	0.56	0.68	0.12	15
2298	2	1	85	0.04	0.09	0.50	0.02	0.68	2.42	0.11	325
2583	5	3	85	0.01	0.05	0.11	0.00	0.66	0.84	0.05	24
2663	5	17	85	0.01	0.06	0.08	0.01	0.63	0.70	0.04	17
3323	8	25	85	0.01	0.04	0.26	0.27	0.80	2.21	0.01	40
3791	10	21	85	0.20	0.22	0.27	0.06	0.84	1.04	1.25	27
3892	11	4	85	0.14	.	.	0.06	0.91	1.13	1.27	36
4077	12	13	85	0.03	0.05	0.08	0.07	0.55	0.66	0.49	13.6

TABLE A-7. CONTINUED

ID	DATE	HR	MN	DO mg/L	TEMP deg C	PH	ALK mg/L	COND umho/cm
STATION BR07 - BASEFLOW								
2257	1 8	85	11 45	12.1	4.5	6.3	32.9	100
2311	2 5	85	9 15	12.4	2.5	6.1	38.3	105
2417	3 12	85	9 46	11.1	7.5	6.6	27.2	100
2520	4 16	85	9 15	10.2	16	6.5	30.7	95
2673	5 20	85	8 19	9.1	19	7.2	37.1	110
2898	6 19	85	8 36	6.9	20	7.3	41.8	110
3047	7 15	85	9 12	5.65	24.5	7.1	49.8	110
3203	8 12	85	10 30	6.9	23.5	7	56.1	95
3473	9 9	85	8 28	4.8	22	6.9	68.2	170
3714	10 7	85	11 45	7.5	12.5	6.5	70.4	165
3968	11 18	85	10 12	9.4	11.5	6.5	34	120
4045	12 9	85	10 17	10.8	5	6.6	31.8	115
4148	1 13	86	9 30	11.5	4.5	6.7	30.6	.
4247	2 10	86	9 52	13.2	3	6.8	30.1	.
6116	3 10	86	10 6	9.4	5	7.3	31.4	.
STATION BR07 - RUNOFF								
3893	11 4	85	9 34	.	.	.	.	.
3792	10 21	85	8 43	.	.	.	.	.
2584	5 3	85	8 5	.	.	.	.	.
3324	8 25	85	15 51	.	.	.	.	.
4078	12 13	85	10 0	.	.	.	.	.
3621	9 27	85	9 50	.	.	.	.	.
2074	11 19	84	15 25	.	.	.	.	.
2664	5 17	85	8 38	.	.	.	.	.
2299	2 1	85	9 28	.	.	.	.	.
2171	12 6	84	11 15	.	.	.	.	.
STATION BR08 - BASEFLOW								
2176	12 10	84	11 47	12	3.5	7.2	39.5	160
2307	2 5	85	10 25	11	0.5	6	55.8	145
2413	3 12	85	10 26	10.1	7	6.5	43.2	290
STATION BR08 - BASEFLOW								
2295	2 1	85	9 58	.	.	.	.	.

TABLE A-7. CONTINUED

ID	DATE	OP	TSP	TP	NH3-N	SKN	TKN	OX-N	TSS	
.....milligram per liter.....										
STATION STATION BR07 - BASEFLOW										
2257	1 8	85	0.00	0.01	0.03	0.13	0.51	0.58	0.21	6
2311	2 5	85	0.00	0.02	0.04	0.09	0.66	0.79	0.29	4
2417	3 12	85	0.00	0.03	0.05	0.04	0.56	0.66	0.26	7.5
2520	4 16	85	0.00	0.02	0.03	0.02	0.42	0.42	0.11	0.5
2673	5 20	85	0.00	0.02	0.04	0.07	0.41	0.49	0.06	5
2898	6 19	85	0.01	.	0.07	0.13	0.97	1.99	0.18	16.5
3047	7 15	85	0.02	0.03	0.06	0.11	0.64	0.79	.	11.5
3203	8 12	85	0.02	0.05	0.08	0.21	0.86	0.99	0.40	9.5
3473	9 9	85	0.02	0.04	0.08	0.17	0.80	0.99	0.43	14.8
3714	10 7	85	0.00	0.02	0.03	0.20	0.68	0.72	0.61	2
3968	11 18	85	0.00	0.02	0.04	0.44	0.99	.	0.20	3.2
4045	12 9	85	0.00	0.02	0.04	0.28	0.78	0.92	0.24	4
4148	1 13	86	0.00	0.02	0.03	0.16	0.55	0.59	0.31	2.4
4247	2 10	86	0.00	0.00	0.03	0.06	0.41	0.58	0.34	1
6116	3 10	86	0.00	0.02	0.03	0.00	0.36	0.43	0.26	5.5
STATION STATION BR07 - RUNOFF										
3893	11 4	85	0.00	0.02	0.05	0.69	.	.	0.07	22
3792	10 21	85	0.00	0.02	0.03	0.40	0.66	0.66	0.07	6
2584	5 3	85	0.00	0.02	0.04	0.03	0.46	0.74	0.04	10
3324	8 25	85	0.02	0.03	0.12	0.15	0.60	0.99	0.27	45
4078	12 13	85	0.00	0.02	0.03	0.31	0.67	0.73	0.25	4.4
3621	9 27	85	0.01	0.05	0.05	0.17	0.46	0.54	0.21	7
2074	11 19	84	0.00	0.02	0.06	0.40	0.97	1.18	0.13	11
2664	5 17	85	0.00	0.02	0.06	0.03	0.38	0.52	0.01	20
2299	2 1	85	0.00	0.02	0.03	0.12	0.60	0.66	0.25	10
2171	12 6	84	0.00	0.03	0.05	0.25	0.71	0.82	0.17	8
STATION STATION BR08 - BASEFLOW										
2176	12 10	84	0.01	0.03	0.05	0.02	0.30	0.39	0.44	17.5
2307	2 5	85	0.03	0.04	0.08	0.04	0.44	0.54	0.56	25.5
2413	3 12	85	0.02	0.03	0.04	0.03	0.47	0.50	0.40	4
STATION STATION BR08 - BASEFLOW										
2295	2 1	85	0.29	.	.	0.03	1.67	2.66	0.68	62

TABLE A-8. BROAD RUN AT BUCKLAND (ST70) BASEFLOW
CONCENTRATIONS OF TP, TN, AND TSS
NOVEMBER, 1984 - APRIL, 1986.

DATE	TIME	STAGE ft	FLOW cfs	TP mg/L	TN mg/L	TSS mg/L
12 NOV 84	10 25	2.07	26.3	0.02	0.73	0.5
26 NOV 84	12 50	2	20	0.02	1.07	2
3 DEC 84	9 10	2.3	54	0.03	1.36	4
10 DEC 84	9 12	2.25	47	0.03	1.34	2
10 DEC 84	11 5	2.26	48.4	0.03	1.28	2
17 DEC 84	9 14	2.14	33.4	0.02	1.02	2
8 JAN 85	12 0	2.33	58.8	0.04	1.11	3.8
14 JAN 85	9 55	2.05	24.5	0.02	1.26	0.5
28 JAN 85	9 15	2.02	21.8	0.01	1.34	0.8
5 FEB 85	8 53	2.37	65.2	0.08	1.77	4.2
11 FEB 85	9 30	2.11	30.1	0.03	1.47	1.5
25 FEB 85	10 58	2.29	52.6	0.06	1.16	2
11 MAR 85	13 8	2.09	28.1	0.02	0.80	2.8
12 MAR 85	8 48	2.13	32.3	0.02	0.92	2
8 APR 85	9 49	2.09	28.1	0.02	0.69	1
16 APR 85	9 1	2.03	22.6	0.02	0.70	0.5
22 APR 85	9 27	1.96	17.1	0.03	0.94	3.5
29 APR 85	8 16	1.93	15.1	0.03	1.02	2.5
6 MAY 85	10 25	1.9	13	0.03	1.05	5
20 MAY 85	8 8	1.9	13	0.04	1.04	5
3 JUN 85	8 15	1.96	17.1	0.07	1.58	.
10 JUN 85	8 54	1.89	12.6	0.04	1.00	6.5
17 JUN 85	11 39	1.8	8.7	0.03	0.77	5.2
19 JUN 85	8 14	1.74	6.54	0.04	0.75	6
24 JUN 85	9 45	1.67	4.44	0.04	0.65	2.2
8 JUL 85	8 31	1.69	3.04	0.05	0.42	6
15 JUL 85	8 59	1.9	11.5	0.03	0.45	11.5
22 JUL 85	10 45	1.82	7.74	0.04	0.45	6
29 JUL 85	12 30	1.99	17.3	0.04	0.63	6.5
5 AUG 85	11 50	1.85	9.15	0.04	0.33	7
12 AUG 85	9 14	1.75	5	0.04	0.39	9.5
19 AUG 85	8 34	2.07	22.9	0.03	0.40	4.5
26 AUG 85	9 5	2.1	25	0.03	0.44	4
9 SEP 85	8 3	1.83	8.21	0.05	0.70	0.2
16 SEP 85	8 45	1.6	1.6	0.03	0.28	5
23 SEP 85	12 30	1.59	1.53	0.02	0.26	8
30 SEP 85	9 1	1.67	2.72	0.03	0.29	6
7 OCT 85	11 15	1.66	2.56	0.03	0.43	3.5
14 OCT 85	11 30	1.69	3.04	0.02	0.27	2.5
28 OCT 85	9 46	1.96	15.4	0.04	1.20	2

TABLE A-8. CONTINUED

DATE	TIME	STAGE ft	FLOW cfs	TP mg/L	TN mg/L	TSS mg/L
18 NOV 85	9 50	2.1	25	0.04	0.83	1.6
18 NOV 85	10 45	2.12	27	0.02	0.85	1
9 DEC 85	9 33	2.25	40.5	0.02	1.27	2.2
16 DEC 85	13 10	2.18	33	0.03	1.32	1.2
6 JAN 86	8 55	1.99	17.3	0.00	1.06	1.4
13 JAN 86	9 45	2	18	0.02	1.11	1.2
21 JAN 86	14 20	2.19	34	0.04	1.73	4.4
3 FEB 86	12 50	2.16	31	0.02	1.17	2.4
10 FEB 86	9 40	2.43	66.1	0.04	1.69	4.5
24 FEB 86	13 40	2.57	91.3	0.03	1.32	6
3 MAR 86	10 26	2.36	55	0.01	1.30	0
10 MAR 86	9 48	2.32	49	0.02	1.11	4.2
31 MAR 86	13 50	2.15	30	0.00	0.63	1.5
14 APR 86	14 55	2.08	23.6	0.02	0.69	5
21 APR 86	15 0	2.41	62.7	0.03	0.70	0.2
28 APR 86	11 35	2.18	33	0.04	0.71	5.2

**The two page vita has been
removed from the scanned
document. Page 1 of 2**

**The two page vita has been
removed from the scanned
document. Page 2 of 2**