Richmond, Virginia 23261

June 24, 1986

VIRGINIA POWER

Mr. Richard N. Burton
Executive Director
State Water Control Board
2111 Hamilton Street
Richmond, Virginia 23230

Dear Mr. Burton:

By letters of April 14 and June 30, 1983, Virginia Electric and Power Company ("Virginia Power") requested alternative effluent limitations for thermal discharges from its North Anna Power Station under Section 316(a) of the Clean Water Act and Section 6.15(m) of the Virginia State Water Control Board's ("SWCB's") regulations. Virginia Power then prepared a Section 316(a) Demonstration Study Plan. The SWCB staff and the Technical Advisory Committee ("TAC") appointed by the SWCB reviewed and suggested modifications to the Study Plan. During 1984 and 1985, Virginia Power conducted extensive studies of Lake Anna and the North Anna River pursuant to that Study Plan, as modified. During that time, Virginia Power prepared three interim reports and provided copies of those reports and the underlying data to the SWCB staff and TAC members. Periodic meetings were held with the staff and TAC to discuss the data, the progress to date and future study plans. The SWCB's NPDES permit for North Anna required that Virginia Power submit a draft final report on the study by July 1, 1986.

Enclosed with this letter is the Final Report on the North Anna Section 316(a) Demonstration. The Final Report was prepared by Virginia Power to summarize

and analyze the Section 316(a) Study. The report was reviewed by the SWCB staff and the TAC and was modified as a result of their comments and suggestions. The Final Report consists of two volumes. The first includes the analyses and presentations of the data collected for the study. Chapter 2 of that volume is a summary of the Final Report. The second volume consists of six appendices that set forth much of the data base and other information gathered during the study.

In Virginia Power's view, the Final Report demonstrates (a) that operation of North Anna has not resulted in "prior appreciable harm" to the biological community, and (b) that effluent limitations more stringent than the present limitations on thermal discharges from the North Anna Power Station are not necessary to assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in Lake Anna and the North Anna River.

Virginia Power bases its conclusions on the results of six years of pre-operation and eight years of operation studies, including the more intensive studies in 1984-85. The results indicate that the biological community in Lake Anna and the North Anna River is abundant, diverse and healthy, and the changes that were observed during the studies were a result of the natural river-to-lake transition (following impoundment of the river in 1972), reservoir maturation, natural population fluctuations, and stocking of non-indigenous fishes in the lake and not a result of the station's thermal discharges. Lake Anna has a standing crop of fish that is comparable to other

lakes in this area of the country and is highly regarded by sport fishermen for the abundance and size of its sport fishes, especially largemouth bass.

Virginia Power's Section 316(a) Demonstration focused on indigenous species in Lake Anna but, at the same time, examined non-indigenous species introduced into the lake. In our view, the Section 316(a) Study demonstrates that the balanced, indigenous community of fish and other aquatic organisms in Lake Anna and the North Anna River is healthy and thriving and is protected and propagating. Also in our view, the various non-indigenous species introduced in the lake are healthy and growing, and striped bass, in particular, has become very popular for sport fishermen. The studies also show, as expected, that two non-indigenous species (striped bass and walleye) are not self-sustaining in the lake but require periodic stocking. As Virginia Power made clear at the outset of these studies, it was entirely willing to study these non-indigenous species but maintains that these species are not to be considered as indigenous for purposes of judging the Section 316(a) Demonstration.

Another approach for judging the success of a Section 316(a) demonstration is set forth in EPA's "316(a) Technical Guidance Manual" (draft of May 1, 1977). That manual provides that a thermal discharge will be deemed acceptable and the Section 316(a) demonstration successful if the study adequately supports the following conclusions:

(1) A balanced, indigenous community has been maintained;

(2) The Community has not sustained prior appreciable harm;

(3) A shift toward nuisance species in the receiving water has not occurred and is not likely to occur;

(4) A zone of passage will not be impaired to the extent that it will not provide for normal movement of populations of dominant species of fish, and economically important species of fish, shellfish and wildlife;

(5) There will be no adverse impact on threatened or endangered species;

(6) There will be no destruction of rare or unique habitat; and

(7) The use of biocides, such as chlorine, has not resulted in appreciable harm to the community.

In our view, the Section 316(a) study and demonstration support each of these criteria. The Final Report and this letter address and adequately support the first four criteria. Criterion 5 does not apply to this Section 316(a) study because there are no known threatened or endangered aquatic species in Lake Anna or downstream in the North Anna River. Bald eagles are a threatened or

endangered wildlife species and have been observed at Lake Anna, but no nesting sites have been documented. Criterion 6 does not apply to this Section 316(a) study because there are no rare or unique habitats, such as limited areas of concentrated spawning, in Lake Anna or the North Anna River. Finally, criterion 7 does not apply since the North Anna Power Station utilizes a mechanical cleaning method and not chlorination to control bio-fouling in the cooling water system.

In any ecological study, such as the North Anna 316(a) demonstration, many physical, chemical and biological variables are identified which may influence the abundance, composition and structure of the aquatic community. Although specific cause and effect relationships are difficult to ascertain within a specified time period because of the complexity of the ecosystem, the absence of measurable and obvious harm is indicative of an acceptable environmental quality. A follow-up monitoring program designed to collect data in a consistent and standardized manner will provide a means of verifying the conclusions developed from the short-term study and measure any changes that might occur in future years.

Virginia Power recognizes the tremendous secondary resource (primarily recreation) available to the citizens of Virginia by the creation of Lake Anna as a primary cooling water supply for the North Anna Power Station. The Company sincerely believes that the demonstration supports the conclusion that no specific damage has been demonstrated in the findings of the Section 316(a) study. It is the Company's policy to exercise leadership in anticipating and

providing for the future needs of our consumers in a manner consistent with the environment. Therefore, the Company proposes the institution of a resource management and enhancement program which will perpetuate the value of the resource. The Company feels that any enhancement program can best be accomplished through continued cooperative projects and activities with state agencies.

In furtherance of these objectives, Virginia Power proposes the following environmental study program which will be reviewed every three years for revision and change in scope.

(1) A monitoring program will be continued that will include fish population (e.g. electrofish, gill net, rotenone) and water quality (i.e. temperature and dissolved oxygen profiles) studies conducted seasonally on Lake Anna (Upper, Mid- and Lower Lake), the Waste Heat Treatment Facility (WHTF) and the North Anna River below the dam. Continuous temperature monitoring recorders (ENDECO) will be maintained at selected locations and monthly secchi disc and chlorophyll (a) samples will be collected in the lake (Upper, Mid- and Lower) and WHTF. Lake Anna benthic samples will also be collected to monitor the Asiatic clam, Corbicula fluminea, population.

(2) Specific detailed studies of the life history and habitat requirements of selected important fish species in Lake Anna, the

WHTF and the North Anna River will be conducted in cooperation with the Virginia Commission of Game and Inland Fisheries. These studies may include age and growth analyses, food habits and availability, reproductive development, disease, condition and distribution. Primary species currently include largemouth bass, striped bass and smallmouth bass. The studies will not necessarily be conducted at the same time with all species, and the species of interest may change as data are analyzed and the environment changes.

(3) Analysis of the summer habitable zone for striped bass will continue, using methods consistent with the Section 316(a) study. Virginia Power will also investigate the feasibility of improving the striped bass habitat in the WHTF.

(4) During the course of the Section 316(a) study period, Virginia Power promoted graduate research on various aspects of the Lake Anna and North Anna River ecology. Virginia Power plans to develop, in association with Virginia colleges and universities, a specific research program oriented toward graduate students. Financial assistance will be provided to selected students whose studies apply to current monitoring and research interests of the Company.

(5) The Company will assist the Virginia Commission of Game and Inland Fisheries in developing and supporting lake management programs which will maximize the use of the resource (e.g. threadfin shad harvest, striped bass stocking strategies and angler access facilities). The initial fish structure enhancement efforts by the Company have been viewed as successful. About 12 additional fish structures will be installed in Lake Anna as appropriate sites are identified and budgeted.

Although the Section 316(a) studies were completed in December, 1985, Virginia Power has continued monitoring [(1) and (2) above] the aquatic community in Lake Anna, the WHTF and the North Anna River. Other aspects of the proposed monitoring program will be implemented in 1987 because of budget year constraints.

Based on the Final Report and the reasons set forth in this letter, Virginia Power requests that the SWCB, in their September 1986 meeting, find that the thermal effluent limitations in the present NPDES permit (as modified) for the North Anna Power Station satisfy the Section 316(a) standard. We also request that the SWCB modify the NPDES permit for North Anna as follows:

(1) delete Special Condition No. 4 and add the following special condition:

> Pursuant to a Study Plan approved by the Board, Virginia Power conducted a § 316(a) study in 1984-85 and submitted a § 316(a) Demonstration on June 24, 1986. The Board reviewed the study and demonstration and

> found that effluent limitations more stringent than the thermal limitations included in this permit are not necessary to assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in Lake Anna and the North Anna River downstream of the lake.

(2) revise Special Condition No. 9 to read:

> The temperature monitoring program shall consist of continuous temperature recorders as noted on Figure 1 with measurements recorded hourly at the surface of stations 1-9 and 11, and at a depth of 3 meters at Station 10. Temperature readings will be reported by monthly maximum hourly daily temperatures, and monthly mean of daily high, mean and low values in degrees Celsius. Reports are to be submitted quarterly within 90 days of the end of the quarter.

We would be pleased to respond to any questions or meet with you or your staff to discuss this further.

Sincerely,

B. M. Marshall
Manager
Water Quality

Enclosures

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North Anna Power Station Section 316(a) Demonstration

June 1986

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Virginia Power appreciates the timely responses provided by the staff of the SWCB and the members of the 316(a) Technical Advisory Committee.

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GLOSSARY

aerobic - requires air or free oxygen to maintain life processes.

allochthonous - referring to materials transported into a system, for example, minerals and organic matter transported into streams and lakes.

anaerobic - does not require air or free oxygen to maintain life processes.

annuli - circular bands on a fish scale each representing the end of one year's growth.

anoxic - without oxygen.

appreciable harm - damage to a balanced, indigenous community, or to community components as reflected by the overall abundance, diversity and structure.

artificial substrate - contained amount of substrate of known surface area placed on the bottom of a body of water for benthic macroinvertebrate colonization.

autochthonous - referring to materials produced within a system, for example, organic matter produced, or minerals cycled, within streams or lakes.

availability - potential for use.

balanced indigenous community - assemblage of species of fish, shellfish and wildlife, including the biota at other trophic levels that are necessary as a part of the food chain or otherwise ecologically important to the maintenance of the community.

benthic macroinvertebrate - invertebrate that can be seen without the aid of magnification and lives on or near the substrate.

benthos - community of organisms living in or on the substrate.

BTU (British Thermal Unit) - quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2°F.

°C - degree Celsius (Centigrade).

cladoceran - small freshwater macroscopic crustacean, sometimes called a water flea, that ranges in size from 0.2-3.0 mm.

clinograde - describes a curve of oxygen distribution that drops sharply through the epilimnion.

community - assemblage of species inhabiting a common environment and interacting with one another.

competition - utilization of a resource by two or more species when the resource is limited.

copepod - small macroscopic crustacean found in fresh or saline waters, generally 0.3-3.2 mm in length.

cover - object that can provide shade, shelter or visual isolation.

date of commercial operation - date generation unit was declared by utility owner to be available for the regular production of electricity; usually related to satisfactory completion of qualification tests as specified in the purchase contract and in accounting policies and practices of utility.

dendritic - branching in appearance.

density - quantity per unit volume, unit area or unit length.

detritus - organic debris from decomposing plants and animals.

diffusivity - the quantity of heat passing normally through a unit area per unit time divided by the product of specific heat, density and temperature gradient.

dimictic - describes a lake that circulates freely twice a year in the spring and fall, and is directly stratified in summer and inversely stratified in winter.

diurnal - pertaining to a daily 24 hour cycle or an organism that is active during the day and inactive at night.

diversity - measure of variety.

dynamic - in a state of constant change.

effluent - liquid waste of industrial processing; a liquid which flows away from a containing space to a main waterway.

emergence - period when immature aquatic insect forms leave the water and change into the adult form.

emergent - large-leaved aquatic plant that extends out of the water into the air.

ENDECO - as used in text, a registered acronym for the Environmental Devices Corporation Type 109 Recording Thermograph.

entrainment - transfer of fluid by friction from one water mass to another, usually occurring between currents moving in respect to each other; in a biological sense, those organisms that are smaller than the intake screen mesh and pass through cooling systems.

epilimnion - upper layer of the water column where the change in temperature is less than 1°C per meter of increasing depth.

euphotic - depth zone of a body of water in which photosynthesis takes place and beyond which effective light fails to penetrate.

eutrophic - "rich food," abundant in nutritive matter.

far-field - area where the receiving water body's hydrodynamics and dispersion processes dominate the effluent plume dynamics.

fecundity - reproductive potential of an organism (e.g. number of eggs produced).

flow - rate at which water passes a given point, typically measured in cubic meters per second or cubic feet per second (cfs).

focus - center point of a fish scale from which radii are measured.

forage - food for animals, especially when taken by browsing or grazing.

gonadosomatic index - index of the state of development of the gonads (gonad weight/body weight x 100).

gradient - change in elevation over distance.

gross electrical energy generated (MWH) - electrical output of the generation unit during the report period as measured at the output terminals of the turbine generator, in megawatt hours.

gross thermal energy generated (MWH) - thermal energy produced by the generation unit during the report period as measured or computed by the licensee in megawatt hours.

growth increment - increase in body length over time (e.g. one year).

habitat - physical, biological and chemical environment.

habitable zone - zone, as in a reservoir, that ensures survival and continued growth of an organism.

heat sink - object that retains heat (e.g. a reservoir).

herbivore - feeding on plants

hydraulics - characteristics of streams (width, depth, velocity) determined by flow.

hypolimnion - region below the thermocline.

ichthyoplankton - egg and larval stages of fish suspended in the water column.

indigenous - existing and having originated naturally in a particular region or environment.

lacustrine - belonging to or produced by lakes.

Lake Anna - 3885 hectare (9600 acre) reservoir (lake) that provides condenser cooling water for North Anna Power Sation.

lentic - associated with contained waters (e.g. ponds, reservoirs, lakes).

lotic - associated with flowing waters.

Lower Lake - area of the reservoir below the benthic Mid Lake station downlake to the dam.

macrophyte - macroscopic, usually attached plant in the littoral zone of the lake.

metalimnion - see thermocline.

microhabitat - small, distinctly specialized and effectively insulated habitat.

Mid-Lake - area of the reservoir including the Route 208 bridge downlake to the benthic Mid Lake station.

molting - shedding of all or part of an organism's outer covering; in arthropods, periodic shedding of the exoskeleton to permit increase in size.

monomictic - lake which circulates freely in the winter and stratifies directly in the summer.

MWe - megawatts electrical, the unit of measurement that designates electrical output of the generating unit.

MWt - megawatts thermal, the unit of measurement that designates the thermal power of the generating unit.

Nameplate Rating (Gross MWe) - nameplate power designation of the generator in megavolt amperes (MVA) times the nameplate power factor of the generator. NOTE: The nameplate rating of the generator may not be indicative of the maximum or dependable capacity, since some other item of equipment of a lesser rating (e.g. turbine) may limit generating unit output.

near-field - area where the effluent's initial velocity and buoyancy dominate the effluent plume dynamics.

NPDES - National Pollutant Discharge Elimination System, a permit system under which effluent limitations and monitoring requirements are set forth in permits to permit holders.

NSSS Thermal Power Rating - nuclear steam supply system (primary) which recognizes all the heat generated by the system, expressed in megawatts.

oligotrophic - "scant food," poor in nutritive matter.

operational - period after the power station became operational in April 1978 through the end of the study period, Dec. 1985.

optimum - most favorable condition.

parameter - measurable quantity.

periphyton - community of single-celled, filamentous or colonial algae and associated microfauna attached to underwater surfaces.

physiographic - based on natural abiotic factors (e.g., geology, topography, hydrology).

phytoplankton - plant community of single-celled or colonial organisms that live suspended in the water column.

piscivorous - feeding on fish.

planktivorous - feeding on plankton.

plankton - aquatic plants and animals that live suspended in the water column.

pool - area of water with little or no measurable current.

population - any group of individuals of one species that occupy a given area at the same time.

predaceous - adapted to predation (the eating of live organisms).

preferred - chosen when alternatives exist.

pre-operational - period from the creation of Lake Anna in 1972 up through March 1978, when Unit 1 became operational.

productivity - rate of accumulation of biomass, energy and nutrients.

qualitative - examined but not measured in a numerically comparable manner.

quantitative - measured in a numerically comparable manner.

reach - stream segment.

reactor thermal power - maximum power of the reactor authorized by the NRC, expressed in megawatts.

reservoir - articifical lake where water is collected and kept in quantity for use.

riffle - shallow area in a stream with substantial current.

riverine - belonging to or produced by rivers.

rotifer - microscopic aquatic or semi-aquatic animal, generally less than 1 mm long, found in fresh or saline water.

rough fish - fish that is neither a sport fish nor an important food for sport fish.

seston - particulate organic matter.

spillover - coming over or through a dam.

submergent - large-leaved aquatic plant that is completely under water.

substrate - bottom materials of a streambed or lake.

sympatric - occurring together.

thermal preferendum - thermal habitat "preferred" by a species after a period of adjustment.

thermocline - zone in the water column where there is a decrease in temperature equal to or greater than 1°C per meter (also referred to as the metalimnion).

third-order consumer - organism which feeds on another organism, which in turn feeds on the primary producers of an ecosystem.

tolerance - capacity to endure a wide range of environmental conditions.

total scale radius - length of a fish scale from the focus to the outer edge of the embedded portion.

trophic - associated with food.

Upper Lake - area of the reservoir uplake from the Route 208 bridge.

warmwater - body of water where temperatures typically exceed 20°C.

WHTF (Waste Heat Treatment Facility) - a 1376 hectare (3400 acre) cooling facility that dissipates heat from the power station's discharge before it reaches the reservoir.

year class - year a fish was hatched.

young-of-year - fish in their first year of life (Age 0).

zooplankton - community of microscopic or macroscopic, floating, aquatic invertebrate animals.

their analysis to the Board. In a memorandum dated June 22, 1982, and presented at the June 27-29, 1982 Board meeting, the staff reported its interpretation of the temperature data from the fixed monitoring stations indicated the operation of one unit "caused only a few violations of the temperature standards both for maximum temperature and increases above natural temperature" and the "operation of two units (from December 1980) resulted in frequent violations of the 3°C rise above natural temperature standards." The staff's analysis of the biological data indicated the biota were not showing an "extreme impact due to thermal enrichment." Continued temperature and biological monitoring were recommended by the staff and approved by the Board.

The Federal Clean Water Act contained a provision, Section 316(a), that permitted those discharging heat into the waters of the United States to conduct environmental studies and attempt to demonstrate that shellfish, fish and wildlife were not being harmed by the discharges. In view of the SWCB's staff interpretation of the temperature data and the alleged violations of state water quality standards, the Company found it necessary to employ the §316(a) option.

On April 14, 1983 Virginia Power filed a letter with the SWCB stating its intent to request alternate effluent limitations under Section 316(a) of the Clean Water Act and to conduct a Section 316(a) demonstration on Lake Anna and the North Anna River. The Board approved the request in June, 1983. The objective of the study was to

demonstrate that the thermal discharge limitations in the SWCB permit issued for the power station were as stringent as necessary to assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in and on Lake Anna and the North Anna River.

The 316(a) demonstration was conducted during 1984 and 1985 pursuant to a detailed plan of study agreed upon by the SWCB, a State appointed Technical Advisory Committee (TAC) and Virginia Power. It constitutes a Section 316(a) Hybrid Type I-III Demonstration in support of Virginia Power's request for alternate thermal effluent limitations for thermal discharges from the North Anna Power Station. This hybrid demonstration is non-predictive and incorporates most aspects of a Type I demonstration (absence of prior appreciable harm) and the negotiated-type characteristics of a Type III study.

This report constitutes fulfillment of the requirements for the §316(a) demonstration which was conducted in accordance with state and federal guidelines and with the approval of the State Water Control Board and its Technical Advisory Committee.

1.1 Content and Scope for 316(a) Demonstration

Statement of Purpose

Scientists recognize that changes in the temperature regime of surface waters caused by heated water discharges may have effects on aquatic life that can range

from beneficial to adverse. The purpose of this Section 316(a) Demonstration is to provide an objective, scientific assessment of effects of the existing thermal discharge from the North Anna Power Station on the aquatic biological community in Lake Anna, and in the North Anna River downstream of that reservoir. This assessment can then be used to help answer whether the thermal components of the discharge have caused, or might reasonably be expected to cause appreciable harm (U.S. EPA 1974) to those biological communities to the extent of interfering with the protection and propagation of a balanced, indigenous population (community) of shellfish, fish, and wildlife (U.S. EPA 1977).

Many environmental factors (physical, chemical and biological) are known to influence and control the reproduction, growth, survival and distribution of aquatic organisms, such that their diversity, abundance, and spatial distribution may vary between day and night, seasonally, and from year to year. A major challenge involved with performance of such assessments as the present one is to distinguish the nature and magnitude of effects caused by the North Anna Power Station's thermal discharge from that inherent variability caused by the host of other environmental factors.

An aquatic thermal monitoring program should involve obtaining reliable and appropriate ecological data with an adequate background data base in order to attempt to distinguish normal successional and seasonal changes from

direct thermal effects. A single variable is difficult to isolate in a complex ecological system such as Lake Anna and ecological field studies rarely provide unequivocal evidence of direct cause and effect relationships. Therefore, impact assessment from a biological standpoint should be related to the total effect on the ecosystem. This holistic approach allows scientists to consider the resiliency of biological systems to imposed perturbations.

Approach and Format

The approved 316(a) Plan of Study and Demonstration for the North Anna Power Station (VEPCO 1984) is based on five years (1973-1977) of pre-operational, and eight years (1978-1985) of post-operational studies, of which those of the last two years (1984-1985) were more intensified. Water quality, water temperature and biological studies were conducted at sampling stations in each of the upper arms, middle, and lower portion of Lake Anna and in the North Anna River below the reservoir. The Plan of Study included all major biological categories or subcommunities (phytoplankton, periphyton, aquatic macrophytes, zooplankton, macroinvertebrates, fishes and waterfowl) typically examined in comprehensive studies of aquatic communities (U.S. EPA 1974, 1977).

Two principal analytical approaches were used for this demonstration:

a. Comparisons of biological community characteristics at sampling stations during years of study prior to

operation of and thermal discharge from the North Anna Power Station (control years), with the same characteristics observed at the same sampling stations during years (effect years) with the power station operating; i.e. pre-operation/operation comparisons in the form of trend analysis.

b. Comparisons of biological characteristics observed during years of station operation among sampling stations located within the area of Lake Anna where water temperature is altered by the thermal discharge (near-field effects stations), and sampling stations located outside of that area (far-field control stations).

As appropriate, the results from these analyses for Lake Anna are compared with those reported in the scientific literature from studies of thermal discharges into other bodies of water.

The format of this demonstration is typical of many scientific reports and papers. The general introduction (Chapter 1) precedes the Summary Assessment (Chapter 2). Background information on physical, engineering, hydrothermal, and water quality characteristics of the North Anna Power Station, and Lake Anna (Chapter 3), and North Anna River (Chapter 5), is needed as foundation for the key parts of this demonstration, the biological assessments of thermal effects contained in Chapters 4, 6 and 7. Chapter 8 provides a listing of the literature cited in this demonstration. The intent is for this to be a concise and

readable, interpretive, scientific report and not a voluminous, encyclopedic compilation of all data and information accumulated to date (CEQ 1978). In keeping with this objective, important additional information not essential for inclusion in the body of the report is included or referenced in Appendices A through F. The data base in Appendix B primarily includes data collected during 1984 and 1985.

Assessment Criteria

The thermal discharge will be deemed acceptable and the demonstration successful if the assessment adequately supports the following conclusions (U.S. EPA 1977):

a. A balanced, indigenous community has been maintained.

b. The community has not sustained prior appreciable harm.

c. A shift toward nuisance species in the receiving water has not occurred and is not likely to occur.

d. A zone of passage will not be impaired to the extent that it will not provide for normal movement of populations of dominant species of fish, and economically important species of fish, shellfish, and wildlife.

e. There will be no adverse impact on threatened or endangered species.

f. There will be no destruction of rare or unique habitat.

g. The use of biocides such as chlorine has not resulted in appreciable harm to the community.

For an existing thermal discharge of several years' duration, such as that from the North Anna Power Station described in Chapter 3, the criterion of ultimate importance is (a) the maintenance of a balanced, indigenous community. This is true because demonstrated maintenance of a balanced, indigenous community encompasses the other criteria. For an existing electric generating station as this one, and unlike a proposed station, satisfaction of the criteria can be observed and need not be predicted. Moreover, the higher temperatures in the Waste Heat Treatment Facility (Chapter 7) have been used to observe responses of aquatic life and to assess probable effects of higher water temperatures in Lake Anna that would result from simultaneous, maximum-capacity operation of both North Anna Power Station units, a condition which has not occurred during the history of the station to date.

There are no known threatened or endangered aquatic species in Lake Anna or downstream in the North Anna River. Bald eagles have been observed at Lake Anna; however, no nesting sites have been documented. There are no rare or unique habitats, such as limited areas of concentrated spawning. Also, the power station utilizes a mechanical cleaning method and not chlorination to control bio-fouling in the circulating water system. Hence criteria e, f or g do not require further examination in this demonstration.

Thus, this demonstration focuses primarily on the first criteria (a) by assessing species composition and abundance of major component biotic categories that comprise the community of aquatic life in Lake Anna and in the downstream North Anna River.

Information Sources

Studies performed by consultants and scientific staff of Virginia Power at North Anna during the past 16 years are the primary sources of information for this demonstration. Studies performed from 1969-1972 provided information on the water chemical quality and biology of the North Anna River before it was impounded in 1972 by Virginia Power to form Lake Anna, which was designed as the source for cooling water for the proposed 4-unit power station.

After impoundment in 1972, sampling stations were established in each major segment of Lake Anna (the tributary-dominated upper arms, mid-lake, and the lower lake) and in the adjacent Waste Heat Treatment Facility for study of a wide variety of water quality (including water temperature) and biological parameters. These studies were performed with some modifications for five years (1973-1977) prior to start up of Unit 1 in 1978, and an additional six years (1978-1983) with power station operation prior to preparation of a formal detailed study plan for this 316(a) Demonstration. This plan of study was carried out with some interim modifications, agreed upon by all parties, during the years 1984 and 1985.

Quality Assurance and Control

Virginia Power prepared a study program outline agreed upon in November 1983 by the SWCB, TAC and Virginia Power and, based on that outline, prepared a detailed Section 316(a) Demonstration Study Plan of Lake Anna and the Lower North Anna River. The study plan follows the criteria in: (1) Section 316(a) of the Clean Water Act; (2) 40 C.F.R. Part 125, Subpart H; (3) EPA's draft "Interagency 316(a) Technical Guidance Manual" (May 1, 1977); and (4) various decisions by the EPA Administrator concerning Section 316(a). Virginia Power used these as the primary references for design of the study.

Many of the sampling procedures followed in the 316(a) Study Plan were taken directly from Virginia Power's North Anna Environmental Laboratory Procedures Manual, which predates the 316(a) study and describes all activities of the Lake Anna Environmental Laboratory, e.g. job descriptions, field and laboratory programs, field and laboratory safety procedures, and maintenance schedules. The manual, which is required reading for all staff members, was updated in 1985 to include agreed upon modifications in the original 316(a) study program.

The SWCB appointed seven environmental representatives with diverse backgrounds to an advisory committee (TAC) to assure guidelines for the 316(a) demonstration would be followed by Virginia Power throughout the study period. Members of the committee were: Dr. Richard Collins (co-chairman and facilitator), Institute for

Environmental Negotiations, University of Virginia; Dr. Charles Coutant (co-chairman), Environmental Sciences Division, Oak Ridge National Laboratory; Mr. David Bailey, Virginia Office, Environmental Defense Fund; Mr. Richard Codell, Office of Waste Management, U.S. Nuclear Regulatory Commission; Mr. Robert Kelsey (replaced Mrs. Karla Gustafson - Marjanen in 1985), Fish and Wildlife Service, U.S. Department of the Interior; Mr. Lawrence Liu, Water Permits Division, U.S. Environmental Protection Agency, Region III; and Mr. Charles Sledd, Virginia Commission of Game and Inland Fisheries. Mr. Richard Ayers served as representative for the SWCB.

Members of TAC defined their charge to be to ensure quality of the 316(a) demonstration, both in the design and throughout the period of data collection. In that sense the role of TAC was to advise the SWCB specifically by commenting on the adequacy of the plan, evaluating the adequacy and degree of rigor with which staff members were carrying out procedures, providing interpretation of data, and making recommendations to the SWCB on alternatives for further action.

Virginia Power retained its own scientific advisory committee consisting of Dr. Weldon Larimore, Illinois Natural History Survey; Dr. Gerald Lauer, EA Engineering Science and Technology, Inc.; and Dr. James Reed, Jr., James R. Reed and Associates. Virginia Power retained the committee to review and provide advice on the 316(a) demonstration.

Internal and external quality controls were initiated and implemented by Virginia Power. Dr. William S. Woolcott, University of Richmond, served as a quality control scientist to observe and report on the effectiveness of the procedures used in each program (Appendix C). Also, specialists were contracted to verify identifications of organisms in the different collections.

1.2 Regulatory History Affecting the North Anna Power Station's Thermal Discharge

The North Anna Nuclear Power Station utilizes a once-through cooling configuration that incorporates a waste heat treatment facility to transfer a significant quantity of the station's rejected heat to the atmosphere. It incorporates an impoundment (Lake Anna) that has an adequate volume to supply cooling water to the operating units under the most severe drought conditions and still remain a multipurpose reservoir. Adequate storage capacity is also available to increase the minimum flows in the reach of the North Anna River downstream from the dam to a level that increases the potential beneficial uses of the stream.

Engineering plans incorporating the design concepts were developed in 1967 for the power station and cooling facility. In 1968, these were submitted to the Virginia State Water Control Board as a part of an application for an Industrial Waste Discharge Permit. The application was placed on the Board's agenda for the July 1968 meeting. The Staff presented the application at the meeting, and after

hearing no objections to the project, the Board issued Permit No. 1912.

The Virginia State Corporation Commission held a series of hearings on the proposed facility in 1970. A Certificate of Convenience and Necessity was issued on June 12, 1970. This Certificate memorialized a minimum release of 40 cfs from the dam for downstream uses, a value that has been a part of nearly all certificates and permits issued by state and federal agencies subsequent to that date.

Applications were filed with the Atomic Energy Commission (now Nuclear Regulatory Commission - NRC) and the Construction Permit for Unit 1 was issued on February 11, 1971 and for Unit 2 on February 19, 1971.

The federal government became involved in the water permitting process after the passage of the Water Quality Improvement Act of 1970 (Public Law 91-224). Section 21(b) of that law required a state to issue a certificate indicating that there was reasonable assurance a discharge from a permitted facility would not violate applicable state water quality standards. The U. S. Army Corps of Engineers could, upon the receipt of the certificate, issue a federal permit under Section 13, the Refuse provision of the 1899 Rivers and Harbors Act. The State Water Control Board issued a Section 21(b) Certificate for discharges from the proposed North Anna Nuclear Power Station on February 11, 1972.

Congressional passage of Public Law 92-500, the Federal Water Pollution Control Act (Clean Water Act - CWA),

in the fall of 1972 again changed the regulatory and permitting procedures. The Certificate of Assurance issued under the provisions of Section 21(b) of the Water Quality Improvement Act was no longer a valid instrument and an application was filed for a certificate under Section 401 of the Clean Water Act that would assure a discharge would not violate state water quality standards. The State Water Control Board issued the certificate for the construction and operation of Units 1 and 2 on August 29, 1973.

Under the Clean Water Act, state-issued Industrial Waste Discharge Permits also were superseded by National Pollutant Discharge Elimination System (NPDES) permits under Section 402. An application for the permit was filed and processed by the State Water Control Board. Other state and federal agencies were notified of the Board's intention to issue the permit and the proposed action was advertised by public notice. No objections or opposition to the granting of the permit was received and the NPDES Permit No. VA0052451 was issued for Units 1 and 2 in June, 1977.

NPDES Permit No. VA0052451 contained the effluent limitations for contaminants that could be discharged from the various point sources from the power station. All limitations were in accordance with the applicable EPA guidelines for steam electric power generating sources (40 CFR, Part 423) except for pH where a more stringent range of 6.0-8.5 was applied. The heat rejection rate to the lake was limited to 13.54×10^9 Btu/hr minus the heat removed in the WHTF.

Paragraph 6, Special Conditions, of the permit allowed the Company to request alternative effluent limitations under Section 316(a) of the Clean Water Act. Heat was recognized as a "different" type of pollutant in the Clean Water Act and NPDES permittees were provided an opportunity to demonstrate more stringent limitations on thermal discharges were not necessary to assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in the receiving waters. Lake Anna and the North Anna River downstream from the dam were named as the receiving waters for the thermal discharges.

The Nuclear Regulatory Commission issued the Operating License for Unit 1 on November 26, 1977 and for Unit 2 on August 21, 1980. Unit 1 went into commercial operation in June, 1978 and Unit 2 in December, 1980.

Comprehensive environmental monitoring programs were conducted on the North Anna River prior to the impoundment of Lake Anna. The programs were continued after the lake was formed in order to follow the biological successional stages in the new reservoir. The hydrothermal modeling studies initiated during the conceptual stages of the facility were continued and expanded as the state-of-the-art of the 1960s underwent exponential growth in capabilities during the 1970s. Several state and federal permits issued for the facility included provisions for environmental monitoring. All reports generated from the studies were made a part of the public record and submitted to the appropriate state and federal agencies.

After it was alleged that the thermal discharges were causing violations of the temperature standards applicable to Lake Anna and the North Anna River, the Company exercised the Section 316(a) option available in paragraph 6 of the NPDES permit. The studies were initiated in January, 1984 and terminated in December 1985.

This report describes the data collected during the pre-operational and operational period with special emphasis on the 1984-85 study.

1.3 Characteristics of the North Anna River Prior to Impoundment of Lake Anna

The North Anna River, a primary tributary of the York River system, originates in the upper Piedmont Province of Virginia in Albemarle and Orange Counties and flows southeast for a distance of about 96.54 km (60 river miles) before joining the South Anna River to form the Pamunkey River. Historically, the flow of the river varied sharply with rainfall. The average discharge from 1929 to 1951 recorded at the U.S. Geological Survey gauge at Doswell, Virginia was 11.24 cubic meters per second (m^3/s) [397 cubic feet per second (cfs)] with a maximum annual average of 14.5 m^3/s and a minimum of 0.03 m^3/s. A record flood in August 1969 produced a maximum flow of 688.18 m^3/s (24,300 cfs).

Prior to impoundment the North Anna River was impacted by acid mine drainage from Contrary Creek, a major tributary. Land adjacent to Contrary Creek had been the site of extensive iron pyrite mining operations during the

period 1882-1920, as well as other mining activity prior to 1882.

The North Anna River above the mouth of Contrary Creek was typical of Piedmont Virginia headwater streams. The stream banks were a mixture of clay and sand with vegetation consisting of bottomland hardwood forest and associated understory. The stream bed was approximately 3 m below the general terrain and was characterized by a combination of riffles, runs and pools. Sand bars and gravel were common; larger rubble occurred near bridge crossings. The number of aquatic habitats present, as in other zones of the North Anna River, was greatly influenced by water level and the effects of flow. During high water many shoreline areas were inundated and provided good habitat for macrobenthos and fishes. At times of low flow the number of habitats was greatly reduced.

The flora and fauna of the North Anna River above the mouth of Contrary Creek were typical of normal, small to medium streams of the area (Acad. Nat. Sci. of Phila. 1955; Va. Comm. of Game and Inland Fisheries 1968; Reed and Simmons 1972). Species numbers were high and the kinds of species were those typically found in natural streams that have not been adversely affected by pollution.

Contrary Creek was a 13.68 km (8.5 mile) long tributary of the North Anna River. The creek's watershed is a part of the mineral belt of Virginia and extensive deep mining operations were developed in the 1800's and operated until the early 1900's. The primary mineral extracted from

the mines was iron pyrite (FeS_2), but other elements, including gold, were present in the seams. Large tailings (gob) piles were located in the creek's flood plain area and acidic, mineral-rich seepage water entered the creek and flowed into the North Anna River. The banks were severely eroded and continuing erosion of the mine tailings created an adverse impact on the North Anna River and its biota.

Downstream from the mouth of Contrary Creek, the North Anna River showed evidence of severe physical and biological alteration. The river was larger from that point downstream and consisted of large pool areas with occasional bedrock outcroppings. The bottom was typically shifting sand or mud with some patches of gravel. At times of low water an orange colloidal floc was common in still and slack water. The stream had a barren appearance in contrast to the headwater sections above the mouth of Contrary Creek.

Density and diversity of fishes and macrobenthos were reduced when compared to those of the upstream areas. Ten species of fishes and 31 species of macrobenthos were collected in the North Anna River directly below the confluence with Contrary Creek, compared to 19 and 55, respectively, directly above the confluence (Reed and Simmons 1972). Farther downstream, the subtle effects of acid pollution were more evident than gross deterioration of habitat or water quality. The numbers and kinds of organisms showed reductions for approximately 24.14 km (15 miles) downstream, although the features of the physical habitat and the ambient water quality appeared satisfactory for aquatic life.

It was apparent much of the pre-impoundment basin of the North Anna River had been affected by acid mine drainage from Contrary Creek and that there was a persistent effect (Reed and Simmons 1972). The biological recovery zone, as defined with mussels (shellfish, Mollusca) as indicator species, was located in an area of the river near the confluence with the South Anna River (37 km downstream from Lake Anna). Potential but barren habitats for mussels were also located in other areas of the North Anna River, which suggested preferred mussel substrate was not a limiting factor.

In conclusion, pre-impoundment studies indicate degradation of the North Anna River was due to constant leaching of acid mine drainage from the tailings piles along Contrary Creek (Acad. Nat. Sci. of Phila. 1955; Va. Comm. of Game and Inland Fisheries 1968; Reed and Simmons 1972). Land reclamation of the spoils areas along Contrary Creek and the creation of Lake Anna were viewed as positive measures to ameliorate the effects of Contrary Creek on the lower North Anna River (Reed and Simmons 1972).

1.4 Lake Anna

From its inception, Lake Anna was designed as a multipurpose facility to accommodate both the power station and recreational users. When flooded in 1972, the rolling terrain of the North Anna River valley created a dendritic lake (Fig. 1.-1). Shoreline development of permanent and vacation homes soon followed, along with the development of

several marinas and campgrounds. A state park has been established using Lake Anna as its keystone. Abandoned roadbeds were left intact to serve, where accessible, as paved boat ramps. Clearcutting the lake bottom prior to filling has resulted in acres of water safe for skiers, power boaters and sailboaters. The Virginia Commission of Game and Inland Fisheries recognized Lake Anna's multiple use potential and began a management plan by stocking several species of fish. The result to date has been the creation of a lake with ever-increasing popularity for sport fishermen.

The water quality in Lake Anna is characterized as being good to excellent. Turbidity levels are generally low except during periods of heavy inflows from the tributary streams. All municipal and industrial wastes, except heat, that are generated in the drainage basin are treated prior to discharge and no resulting adverse aquatic responses are apparent.

Water entering the lake from the Contrary Creek drainage basin causes periodic fish kills in the upper reaches of the inundated creek. The pH of the creek water remains around 3 and dissolved iron, zinc, and copper levels are high. (Aaron Mills, personal communication).

The SWCB initiated a project in 1976 to reclaim a section of the Contrary Creek watershed area. Partial funding for the activity was provided by the Environmental Protection Agency. Heavy equipment was used to level and regrade the tailings piles and to establish contours that

would minimize erosion. Digested sewage sludge, lime, and fertilizer was mixed with the upper layer to provide nutrients and organic matter. The area was seeded with a grass mixture to provide permanent soil stabilization.

The reclamation project was partially successful in that it greatly reduced the quantity of material that is eroding into the creek. The acidity of the creek water is neutralized as it mixes with lake water and the heavy metals are removed from water column by absorption on and settling of clay particles. Chemical precipitation and co-precipitation with iron may also be involved in zinc and copper ion loss from the lake water.

The hydrology of Lake Anna is different form most other lakes and reservoirs in that during station operation the Lower Lake reach has an induced circulation pattern. The cooling water volume discharged at Dike 3 of the WHTF is drawn uplake by the circulating water pumps. This circulation pattern results in a deepening of the epilimnetic layer and the development of a dynamic system resistant to summer stagnation. The deeper epilimnetic layer also increases the volume of oxygenated water in the lake and decreases the acreage of benthic substrate that would normally be anaerobic during summer months.

Water temperature in the epilimnetic layer of Lake Anna reached or very closely approached the maximum values that could be attained during July, 1983 and July, 1985. Water temperature levels in the Lower Lake are dependent upon the level of power generation (Btu input), volume rate

of flow of the cooling water pumps, and the prevailing meteorological conditions (wet and dry bulb temperatures, wind speed and direction, incident solar radiation, etc.). An estimated 15-20 days are required for the system to reach a value that can loosely be called steady-state.

Pre-operational temperature data indicate maximum lake temperatures usually occur in July of each year. Station operating data for 1983 and 1985 indicate high levels of generation occurred during and prior to July. In addition, 1983 was a low rainfall and above average temperature summer. These factors combined to produce environmental conditions which aid in an evaluation of near worst case temperature structure in Lake Anna.

2. SUMMARY ASSESSMENT

This chapter is a summary of this Final Report on the North Anna Section 316(a) Demonstration. It is divided into three parts: (1) introduction; (2) environmental assessment of Lake Anna; and (3) environmental assessment of North Anna River.

2.1 Introduction

Virginia Power impounded the North Anna River in 1972 and formed Lake Anna (Lake Anna or the reservoir). The reservoir was designed to provide condenser cooling water for the North Anna Power Station. Virginia Power also designed and constructed a Waste Heat Treatment Facility (WHTF) to receive the power station's cooling water and to transfer most excess heat from the water to the atmosphere before discharge to the lower part of the reservoir. The power station's first unit became operational in April 1978, and the second unit, in August 1980.

Virginia Power and others have conducted extensive pre-operational (1972-77) and operational (1978-85) studies of temperature (and other water quality parameters) and the aquatic community in Lake Anna and the North Anna River downstream of Lake Anna. In 1984-85, Virginia Power conducted more intensive studies based on its Section 316(a) Study Plan. This plan resulted from the Company's decision

in 1983 to conduct a Section 316(a) study to seek to

demonstrate (paraphrasing the language of Section 316(a)) limitations more stringent than the present limitations on thermal discharges from the power station are not necessary to assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in Lake Anna and the North Anna River. Because the power station has operated and had thermal discharges for eight years, the study and demonstration are a hybrid Type I-III study that primarily seeks to demonstrate that operation of the power station has not resulted in "prior appreciable harm" to the biological community.

This Final Report on the North Anna Section 316(a) Demonstration reviews the six years of pre-operational and eight years of operational studies and assesses the results of those studies.

2.2 Environmental Assessment of Lake Anna

This part consists of two subparts: (a) physical characteristics of Lake Anna and the power station; and (b) biological summary and assessment of Lake Anna.

Physical Characteristics of Lake Anna and the Power Station

The impoundment of the North Anna River in 1972 and the flooding of its rolling river valley created Lake Anna. The lake is 27 km long with a surface area of 3885 hectares and 438 km of shoreline. It is fed by many rivers and streams (two main ones are the North Anna River and the Pamunkey Creek) and contains a substantial number of coves

and inlets. Several marinas, a park and many permanent and vacation homes have been built along its extensive shoreline. In other words, the reservoir is multipurpose -- it serves the power station, recreational users and home owners and provides additional water to the river downstream during low flow periods.

Lake Anna gradually changes from riverine upstream to lacustrine downstream. It can be divided into three different parts: (1) Upper Lake; (2) Mid Lake; and (3) Lower Lake (see Fig. 1.-1). The Upper Lake is primarily riverine, shallow (average depth of 4 m) and slightly stratified in summer. The Mid Lake is more lacustrine and stratified. It also receives waters from Contrary Creek that, because of years of mining on its shores, are high in heavy metals and low in pH. Formation of Lake Anna has ameliorated the adverse effects of acid mine drainage from Contrary Creek on downstream reaches. The Lower Lake is deeper (average depth of 11 m) and displays lacustrine characteristics (e.g. more vertical gradients of light, temperature and decomposition). It is stratified in summer and mixed in winter. The summer epilimnion was generally 2-5 m deep during pre-operational years, and 8-10 m during operational years, apparently because of greater mixing from the discharge at Dike 3 and withdrawal of deeper water at the power station intake. This mixing and withdrawal has also increased the depth at which a dissolved oxygen concentration of 5 ppm is found from approximately 5 m (pre-operational) to 9 m (operational).

The power station has a once-through cooling system. It withdraws cooling water from the south shore of Mid Lake and discharges it into a discharge canal. The design temperature increase across the condensers at maximum power station load is 7.6°C, but could be increased or decreased depending on the power station load and the number of intake pumps operating. The discharge canal is about 1100 m long and 8 m deep and discharges into the WHTF. The WHTF was formed by diking off a portion of Lake Anna and consists of three cooling segments interconnected by canals. The cooling water residence time in the WHTF is approximately 14 days and varies inversely with the condenser flow rate. More than half of the power station's rejected heat is dissipated in the WHTF. The only discharge from the WHTF is at Dike 3 into the Lower Lake not far from the dam. The discharge is a submerged, high velocity jet that results in rapid mixing with Lower Lake waters of comparable depth.

In almost eight years of operation, the power station has operated at 75-100% of maximum possible power station load for nine quarters; 50-75% for eight quarters; and less than 50% for 14 quarters. Generally, 1982 and 1984 were low load summers, and 1983 and 1985, high load summers.

Virginia Power has conducted extensive temperature monitoring in Lake Anna. Results of that monitoring indicate the shallower Upper Lake and Mid Lake warm earlier in spring and reach maximum temperatures in early summer, and the Lower Lake with its greater depth and volume warms

more slowly but retains the heat later in the year. It is estimated that the power station probably contributes an additional one-tenth the amount of natural heat that enters the system on summer days. The highest hourly and mean monthly of daily maximum temperatures recorded in the reservoir have been in July in the Upper and Mid-Lake in both pre-operational (hourly, 33.7°C; and mean monthly, 30.2°C; both during 1977 in the Upper Lake) and operational (hourly, 33.5°C; and mean monthly, 30.8°C; both during 1983 in the Mid-Lake) years. Nutrients (from flooded farmland) were abundant in Lake Anna in the years following impoundment of the river, but have since stabilized and support a thriving biological community. Other physical and chemical parameters were studied and found to be within normal ranges for Piedmont reservoirs.

Biological Summary and Assessment of Lake Anna

The years of studies of the biological communities in Lake Anna included each of the major categories (see Fig. 4.-1). These assessments examine the community over time and, to the extent possible, identify any effects from power station operations, by three methods -- comparisons of results from (a) pre-operational with operational years; (b) Lake Anna with other reservoirs; and (c) Lower Lake with Upper and Mid Lake areas.

Phytoplankton - The primary producers in the Lake Anna aquatic community are phytoplankton and, to a lesser degree, periphyton and aquatic macrophytes. Studies in the

reservoir indicate phytoplankton abundances gradually increased from 1972 through 1976, increased substantially in 1977, decreased substantially in 1978 and increased gradually through 1985. This pattern occurred throughout the reservoir, but was most pronounced in the Upper Lake. This is a typical successional pattern for new reservoirs which generally take 5-10 years to reach biological stability. The pattern includes a temporary maximum in 1977, a decline in 1978 (with a return to more "normal" conditions and a sharp reduction in nutrients), and a long-term gradual increase thereafter. In each year, phytoplankton has been more abundant in the Upper Lake and gradually less abundant in the Mid-Lake and then the Lower Lake. This is a typical longitudinal pattern for reservoirs and corresponds with the availability of habitat and nutrients in the different parts of the reservoir. Approximately 55 phytoplankton genera were identified during pre-operational years and 77 genera during operational years. Dominant forms were diatoms, green algae, blue-green algae and cryptomonads. The phytoplankton community structure is similar to that found in other reservoirs. Cryptomonads apparently immigrated to the reservoir in the early 1980's, and by 1984-85 were the most abundant species in the phytoplankton community throughout the reservoir from November through March. The growth of crytomonads is similar to that found in other reservoirs. In the Upper Lake, blue-green algae tend to be most abundant in summer. No nuisance growths of algae were identified during the

studies. Macrophyte abundance depended to a large degree on human disturbances and was lower in areas with shoreline development.

Zooplankton - The zooplankton community has remained stable and moderately diverse since 1975 after the initial years of transition from river to lake. This is consistent with the transitions found at other newly impounded lakes. Since then, lakewide average annual densities and diversity have remained fairly constant. Annual densities in Mid Lake and Lower Lake have exhibited no significant differences, and those in the Upper Lake are gradually increasing. There is moderate diversity in Mid Lake and Lower Lake and more diversity in the Upper Lake. The Upper Lake supports a more abundant, diverse and somewhat different zooplankton community than the other two areas of the reservoir. This is consistent with the greater availability of phytoplankton, other food and favorable habitat in the Upper Lake and is similar to findings for feeder arms of other reservoirs. The zooplankton generally exhibited the usual spring-summer peak. Seasonal density trends varied, generally throughout the reservoir, but there were some shifts in peaks in Mid Lake and Lower Lake from July during pre-operational years to April-May during operational years. This, too, is similar to findings at other cooling reservoirs. The dominant organisms are rotifers (Rotifera) and three dominant genera (*Polyarthra*, *Keratella* and *Bosmina*) have been the same during pre-operational and operational years. There have been no

unusual or nuisance zooplankton populations observed. After the river-to-lake transition years of 1972-75, the zooplankton community in Lake Anna has been stable and moderately diverse and has had no major changes in community composition or diversity during pre-operational and operational years. There are no significant differences between the zooplankton community found in Mid Lake and that found in Lower Lake. Lake Anna's zooplankton annual abundance cycles and community composition are typical of eastern, temperate reservoirs.

Benthic Macroinvertebrates - The benthic community in Lake Anna has undergone two distinct changes since impoundment of the river in 1972, but neither appears related to power station operation. First, during the river-to-lake transition in 1972-76, there were increases in abundance and changes in community composition as riverine species decreased and lacustrine species increased. After 1976, abundances decreased in 1976-80, fluctuated in 1981-83 and gradually increased in 1984-85. As to composition and diversity, 111 taxa were identified in pre-operational years, and 124 taxa in operational years, 60 of which had not been seen in the earlier years. These changes that occurred were found throughout the reservoir and estimates of community abundance and composition are similar to other eastern reservoirs.

The second change was the immigration and sharp increase in 1979-81 of the Asiatic clam, *Corbicula fluminea*, until it became the most abundance species throughout the

reservoir. In recent years, this species' population has stabilized in the Lake Anna biological community, as it has in other reservoirs.

These two changes were found throughout the reservoir, and there were no significant differences during pre-operational and operational years between the areas of the reservoir. There are no benthic nuisance species, except possibly the clams whose introduction and increased abundance is unrelated to power station operation. Lake Anna's benthic community's abundance, diversity and composition are similar to those in other temperate reservoirs.

Fishes - The fish community occupies the upper level of the food chain. Individual species (and the community) can be affected by changes in water quality, phytoplankton, zooplankton, benthic invertebrates, other species of fishes or exploitation by other predators, including man. The fishery in Lake Anna is especially important to the public because of the popularity of sport fishing. Because of the importance of fishes, Virginia Power collected extensive data on fishes in Lake Anna. The studies from 1975 through 1985 used three collection methods -- mid-water gill net, shoreline electrofishing and cove rotenone -- each of which has a different selectivity. The studies also included larval fishes (ichthyoplankton) sampling, creel surveys and special (reproduction, food, age and growth) studies for several major species. Finally, the studies examined striped bass using special studies and

ultrasonic tagging. This section summarizes the results of those studies in three parts: (a) fish community; (b) major indigenous species; and (c) introduced species.

Fish community - From 1975 through 1985, fish of 39 species in 12 families were found in Lake Anna. The community included fishes that previously inhabited the North Anna River and from inundated farm ponds as well as nine (four non-indigenous) species introduced in the reservoir since 1972 by the Virginia Commission of Game & Inland Fisheries. The community structure has remained relatively stable over the study period. The average lake mean standing crop was fairly constant from 1975 to 1984 (232-332 kg/ha) and increased substantially in 1985 (467 kg/ha) because of a large increase in the introduced threadfin shad and an increase in gizzard shad. Shad, carp and sunfish accounted for an average of 86% (with a range of 69-92%) of the biomass in Lake Anna. The fish community structure and mean standing crop for 1975-85 in Lake Anna, for 1984-85 in Lake Anna (with the threadfin shad increase) and for 173 reservoirs in the United States were:

	Lake Anna		173 Other Reservoirs
	1975-85	1984-85	
Predators	13%	15%	2%
Plankton feeders	42%	52%	38%
Bottom feeders	46%	33%	50%
Mean standing crop (kg/ha)	276	382	224

The Lake Anna fish community structure is similar to the "average" reservoir structure and, because of the introduction of threadfin shad, has been improved recently by increasing the predator and plankton feeder proportions.

Ichthyoplankton studies were not extensive. Larvae of eight species were found including largemouth bass and the five most abundant species in the reservoir. Studies indicated spawning times for each species were essentially the same throughout the reservoir, not unlike findings in other reservoirs.

Creel studies in 1985 indicated increased fishing pressure with fewer but larger fish. This coincides with reservoir aging and shifts in angler preferences. Number of citations for largemouth bass (8 pounds or greater) caught in Lake Anna were second highest in Virginia in 1984 and first in 1985. The increasing popularity of Lake Anna with subsequent increased fishing pressure is illustrated by the fact that one marina alone hosted 11 largemouth bass fishing tournaments in 1985.

The fish community abundance, diversity and composition in Lake Anna (with the exception of threadfin shad) have remained relatively stable since 1975. Within the reservoir from 1975-85, there has been a greater biomass and abundance of fishes in the Upper Lake, apparently because of more abundant food and shallower waters. There were no significant differences over seasons or years in diversity for 1981-85 among fishes in the Upper Lake, Mid-Lake and Lower Lake. The community composition in these

three areas varied somewhat because of the different habitat, but there were the same general trends in all three areas during both pre-operational and operational years. The power station operation has caused increased mixing in the Lower Lake, increased the volume of the epilimnion in summer by lowering the thermocline and thus increased the oxygenated zone for indigenous warmwater fish by approximately 27% (from 39-56% of the reservoir volume to 66-94%).

Compared with other reservoirs, Lake Anna has a greater total standing crop of fishes. Distributional trends (e.g. greater biomass in the Upper Lake) and fish community composition are similar to those in other lakes. It has a relatively stable number of species, unlike other lakes where species have declined (probably because fewer or none were introduced in those lakes). The 1984-85 standing crop in Lake Anna was greater than those at three other thermal reservoirs and at three of four non-thermal Southeastern reservoirs.

Over the 11 years of fish studies, there have been changes in fish species and community structure in Lake Anna because of aging of the reservoir, natural population fluctuations and stocking. The fish community structure balance among predators, plankton feeders and bottom feeders appears normal and similar to other reservoirs.

Major indigenous species - The largemouth bass is the premier sport fish and the major indigenous predator species in Lake Anna. From 1975-1985, largemouth bass

standing crop (kg/ha) has been stable. In 1985 Lake Anna led all Virginia lakes with 41 largemouth bass citations. Life history studies of this species indicate its reproduction is similar in pre-operational and operational years and to that found in the literature; its feeding habits are consistent with those reported in the literature; and its age and growth are like those in other Virginia reservoirs.

Bluegill and gizzard shad are major forage species that have been consistently dominant in numbers and biomass throughout the reservoir since 1975. Numbers of smaller gizzard shad have been relatively stable. Smaller gizzard shad have declined in recent years (1979-1983). Yellow perch, a cool water species, has declined since 1976, but white perch, a warm water species, has increased. Black crappie declined in 1978 throughout the reservoir (probably because large fluctuations in this species are normal or the available cover was inadequate), but increased in 1985 (perhaps because of the introduction of threadfin shad and increased underwater habitat constructed by Virginia Power). Common carp numbers have been variable since 1977. Pumpkinseed sunfish have declined since 1977 throughout the reservoir and are now only found in the Upper Lake, but redear sunfish have increased and replaced pumpkinseed in Mid Lake and Lower Lake, probably because it feeds on the newly dominant hard-shelled Asiatic clam, and the pumkinseed feeds on aquatic insects that are more abundant in the Upper Lake.

Introduced species - Four non-indigenous species have been introduced and stocked in Lake Anna since 1972. These compete for food and space with indigenous species, but two (striped bass and walleye) are not self-sustaining.

The striped bass is of primary interest and was studied extensively. Striped bass, which were introduced in 1973 and have been stocked annually since 1975, grow and provide good sport fishing in Lake Anna. The largest striped bass taken in Lake Anna was a 23 lb. 6 oz. fish caught in 1985. Forty citation (15 pounds or greater) striped bass were caught in 1985. This species is not self-sustaining in the reservoir possibly because the flow is not adequate to keep the eggs suspended in the water. Unlike warmwater species thriving in Lake Anna, e.g. largemouth bass, striped bass are a cooler water fish as adults and their summer habitat in the lake is reduced during operational periods. Studies in the lake show striped bass can tolerate as much as 28°C and 2 ppm D.O. for short periods of time, but under these conditions growth may be limited or fish may lose weight (but no mortality was observed). Striped bass of a given length appear to regain in winter and spring the weight lost in summer. Cool summer rainstorms and other meteorological conditions may provide temporary thermal refuges during the summer for the fish. Striped bass length-to-weight condition factors are satisfactory through most of the year. Tracking studies in Lake Anna and the WHTF indicate the fish stays in a narrow band of water at the bottom of the epilimnion in July and

August (bounded by warm water at the surface and low dissolved oxygen at depth) and follow schools of shad through most of the reservoir and WHTF in spring, fall and winter. In general, studies show striped bass grow and provide a good fishery in Lake Anna but the adults are subject to some habitat and growth limitations.

The other major introduced species is threadfin shad. It was introduced in 1983 to provide additional forage for striped bass and other sport fishes. Threadfin shad are extremely sensitive to cold water and could not survive winter temperatures in Lake Anna without the power station's warmwater discharge. They have thrived and provided substantial additional biomass throughout Lake Anna in 1985.

Of the other non-indigenous species, walleye are thriving (but are not self-sustaining), and blueback herring, which are not well established, appear to be reproducing.

Waterfowl - Lake Anna is the largest water body in Virginia's northern Piedmont area and provides a major inland "rest stop" for migratory waterfowl of the Atlantic Flyway, and habitat for both migratory and residential waterfowl. In annual sightings beginning in 1976 and waterfowl sighting surveys in 1984, approximately 78 species of birds were observed. In 1984, the most abundant were Ring-billed Gull, American Coot, Mallard and Canada Goose. These sightings and other information indicate that the impoundment of Lake Anna has created an environment that is

used by a substantial number and wide variety of waterfowl and other birds throughout the year.

2.3 Environmental Assessment of the North Anna River

The river assessment consists of two subparts: (a) physical and chemical characteristics of the North Anna River; and (b) biological summary and assessment of the North Anna River.

Physical and Chemical Characteristics of the North Anna River

Virginia Power and others studied the North Anna River from 1970 (before its impoundment) through 1985, and more intensively in 1981-85. Stations were located at the dam and downstream in the North Anna River and one in the South Anna River for comparison. Those studies indicate the environment of the North Anna River has been substantially improved by its impoundment.

The North Anna River drains 1142 km^2 and joins the South Anna River 37 km downstream from the dam to form the Pamunkey River. The gradient is low below the dam but sharply increases at the fall line approximately 25 km downstream of the dam. Before 1972, flow varied considerably (1 to 24,000 cfs) between years and the water quality was adversely affected by acid mine drainage from Contrary Creek. After 1972, flow has been moderated (40 to 15,700 cfs in 1972-85), including a minimum release of 40 cfs from Lake Anna, and water quality has been substantially

improved by dilution and sedimentation of Contrary Creek drainage. Water quality downstream from the dam is strongly influenced by surface water release from the lake. Flows are less turbid and are more chemically stable than before impoundments. In 1981-85, dissolved oxygen (D.O.) averaged 9.6 mg/l (with a range of 6.7 to 13.8) in the North Anna River with gradually higher levels downstream. There were no substantial differences in D.O. between North and South Anna Rivers. Because of spillover from the dam, nutrient and food organism levels were greater near the dam than farther downstream.

Water temperatures in pre-operational and operational years (both after impoundment) were greater near the dam and decreased downstream during the summer. The maximum hourly temperature (31.9°C) in the North Anna River recorded during a pre-operational year (1977) was in July at a station 1 km below the dam (July mean of daily maximum = 29.1°C). The only hourly temperatures in excess of 32°C in operational years were those recorded at the same station six times (the highest was 32.7°C in August 1983) in a three-week period in the summer of 1983 (August mean of daily maximum = 30.8°C).

Biological Summary and Assessment of the North Anna River

As described above, the impoundment of the North Anna River and the surface water discharges from Lake Anna have stabilized downstream flows and reduced turbidity in the river. This has allowed greater light penetration, less

sedimentation, increased winter temperatures and extended biological growing seasons. These developments, in turn, have stabilized river substrates for increased benthic production, increased growth of algae and macrophytes, and provided more shelter and food for invertebrates and fish. Phytoplankton, zooplankton and drifting invertebrates spill over the dam and nourish aquatic organisms downstream. These factors are less influential farther downstream where the river reverts to a more typical riverine habitat and aquatic community.

During 1971-85, Virginia Power and others have studied periphyton, benthic macroinvertebrates, fish (including ichthyoplankton) and, in particular, smallmouth bass in the North Anna River. Most studies took place in 1981-85 and, most intensively, in 1984-85. Unlike a lake, the major primary producers in a flowing river are usually periphyton.

Periphyton - Periphyton were the major producers in the North Anna River. The dominant species (diatoms) and community composition (50% diatoms) were very similar to the periphyton community in Lake Anna. Their composition in the river was very similar over the 1984-85 period when power station operations varied substantially (from none to two units on line). The community was also similar to that found in other rivers and streams.

Benthic Macroinvertebrates - Studies of benthic macroinvertebrates, especially those in 1984-85, assessed their community by examining density, structure and

diversity. Density depends on seasons, good substrate and available food. The peak benthic density occurred in 1977, the extremely hot dry year that caused high densities of plankton in Lake Anna. During 1981-85, there were similar fall peaks in density of benthic organisms, and average seasonal densities fluctuated about the same at all North Anna River stations. Densities increased from 1984 to 1985, and there were not significant differences between densities in years with increased or decreased power station operations.

Benthic community structure shifted to filter-feeding organisms in the early years after impoundment. The filter-feeders dominated near the dam, but the community structure is more evenly distributed farther downstream. The most abundant benthic taxa recently were three caddisflies that filter-feed on seston from Lake Anna. The types of major groups are now similar to those found in the South Anna River, although there were fewer snails found in the North Anna River. Historically, the cause was probably the acid mine drainage from Contrary Creek that reduced diversity in the North Anna River by 50%. Because of the impoundment, there has been some recovery of snails in the North Anna River in recent years.

The benthic community below the dam is dominated by the caddisflies and is more diverse and evenly distributed downstream. This benthic community has fluctuated in much the same pattern as that in the South Anna River and has stabilized over the last five years. In general, benthic

macroinvertebrates are thriving and available in the food chain in the North Anna River.

Fishes - In pre-impoundment surveys, the fish community in the North Anna River had low abundances and was dominated by species tolerant of poor water quality (because of Contrary Creek). In 1972-80, there was a progressive increase in occurrence and abundance of species typically inhabiting Piedmont streams in central Virginia. In 1981-85, most species in the North Anna River were established and reproducing. In that period, 43 species within 11 families were found. From bimonthly electrofishing in 1984-85, 38 species from 10 families were found in the North Anna River, and 25 species from 8 families in the South Anna River. Of the 14 species found in the North (but not South) Anna River, ten came from Lake Anna and four were rarely collected. Only one, rarely collected, was found in the South (but not North) Anna River. Over the period 1981-85, there was a slight increase in abundances and biomass of fishes in the North Anna River, and annual catches and community composition were consistent at all stations. Two shiners dominated most annual catches, and the five species that dominated catches over 1981-85 had year-to-year variations, but were stable at each station even though power station operations varied substantially during those years. Largemouth bass is the major predatory fish in the river near the dam and is replaced downstream by smallmouth bass. There was greater diversity (and more riverine species) farther downstream from the dam, perhaps

because of more diverse and available "riverine" habitat downstream.

Ichthyoplankton surveys in 1984 found larvae of 23 species, 19 genera and 9 families. These corresponded generally with the species found by electrofishing. The timing and duration of spawning and the sequence of species follow the general pattern of warmwater stream fishes throughout the United States. There was little variation between stations in the commencement of spawning time by a given species.

Smallmouth bass were studied more intensively. This species was generally found downstream but not near the dam where largemouth bass (that are assumed to spill over from the dam) were found. Stocking of young-of-year smallmouth bass near the dam was inconclusive. The downstream North Anna River contains more smallmouth bass preferred habitat (greater gradient, riffles, pools and rock substrate) than the river near the dam. Most of the upstream habitat is less than optimum, and few smallmouth bass are found in the upstream reaches of either the North or the South Anna River. Age and growth studies indicate smallmouth bass in the North Anna River are growing faster than those in many other rivers and streams in the United States and Virginia.

The fish community in the North Anna River appears to be a diverse and typical community that is in dynamic equilibrium. Its abundance and diversity change from near the dam to farther downstream, paralleling changes in

physical features of the river. The different bass populations appear to be distributed in the river based primarily on habitat availability.

3. PHYSICAL, CHEMICAL AND HYDROTHERMAL INFORMATION FOR LAKE ANNA

This chapter describes the many physical relationships between the power station and Lake Anna that could potentially affect changes in natural biological community structures. The aqueous chemical processes, which were detected in the pre-operation period, were expected to change as the reservoir stabilized following inundation. Water quality is dependent upon the geological character of the drainage basin, the fertility of inundated soils, the morphometry of the reservoir and land use practices. As such, it is the foundation for potential biological community success and is important in determining the status, or health of a water body. The following sections provide for a basic understanding of the physical and chemical complexity of Lake Anna.

3.1 Station Locale and Receiving Water Morphometric Characteristics

The Lake Anna dam (latitude 38° 01' 00", longitude 77° 42' 39") was closed by Virginia Power in 1972 impounding 53 km^2 of the North Anna River basin thereby creating a reservoir source of cooling water for the North Anna Power station and a smaller Waste Heat Treatment Facility (WHTF) that dissipates waste heat from the power station to the atmosphere (Fig. 3.1-1). Lake Anna is presently utilized to a large extent by the public for recreation.

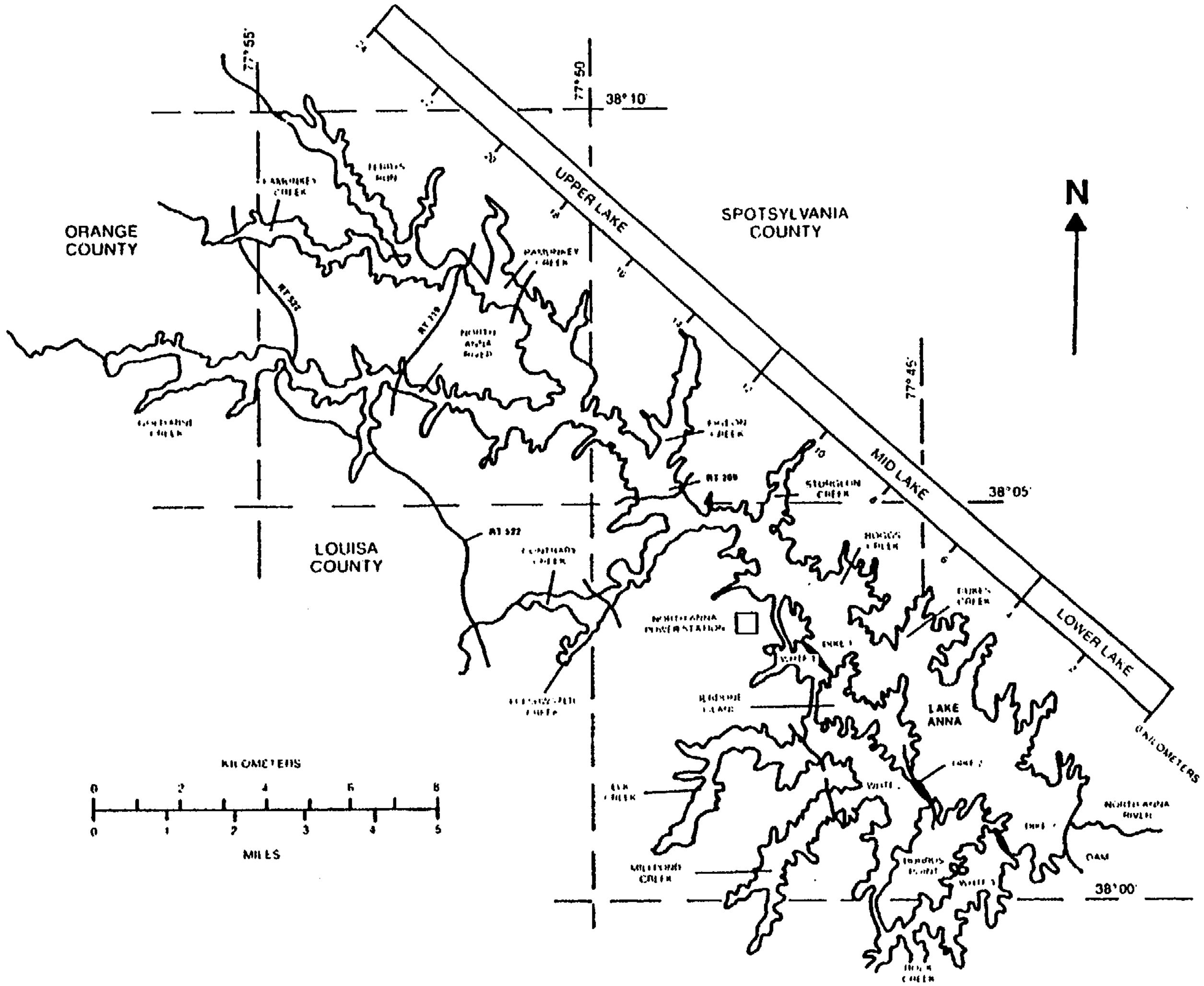

Figure 3.1-1. Generalized map of the North Anna Power Station environs.

Lake Anna is 27 km (17 miles) long with over 438 km (272 miles) of shoreline. It is located in Louisa, Spotsylvania and Orange Counties within the Piedmont province of Virginia. Normal lake elevation is 76 m (250 ft) above mean sea level. The surface area of the reservoir is 38.8 km^2 (9600 acres), the volume is 3 x 10^8 m^3 (8 x 10^{10} gals) and the average depth is 7.6 m (25 ft.) (Table 3.1-1). The mean depth ranges from 4 m upstream from the power plant to 11 m downstream from the plant.

Table 3.1-1. Physical characteristics of Lake Anna, Virginia. (Hydrological characteristics are given in Table 3.4-1)

Surface Area	38.8 km^2 (9600 acres)
* Downstream from plant	20.2 km^2 (4998 acres)
Upstream from plant	18.6 km^2 (4602 acres)
Volume	3 x $10^8 m^3$
Mean Depth	7.6 m (25 ft)
Downstream from plant	11 m (36 ft)
Upstream from plant	4 m (13 ft)
Maximum Depth	24 m (80 ft)
Downstream from plant	24 m (46 ft)
Upstream from plant	14 m (46 ft)
Length	27 km (17 miles)
Shoreline Length	438 km (272 miles)
Elevation above MSL	76.2 m (250 ft)
Maximum Lake Level	76.5 m (251 ft) 1/28/76
Minimum Lake Level	75.4 m (247 ft) 10/24/77

*From the power station to the dam.

3.2 Station Description

This section describes the general features of the North Anna Power Station, a two-unit nuclear plant serviced by a once-through cooling water system. Information is provided detailing the intake structure design, the Waste Heat Treatment Facility and the jet discharge structure at Dike 3.

General Features

The North Anna Power Station generates electricity from the operation of two nuclear power units. Each unit consists of a closed-cycle pressurized, light-water-moderated nuclear steam-supply system, a turbine-generator, and auxiliary equipment. Units 1 and 2 each have an initial reactor thermal power rating of 2775 MWt and a gross electrical output of 947 MWe, with an ultimate design capability of 2900 MWt and an equivalent gross electrical output of 980 MWe. The reactors each contain 157 fuel assemblies (each with 204 rods) with a total UO_2 content of 79.6 megagrams (87.8 tons). Each reactor is refueled on a schedule determined by the number of hours and the level of production it has experienced. Ordinarily, only part (about 1/3) of the fuel is renewed at each predetermined refueling outage.

During operation, the heat generated in each reactor is transferred through the primary pressurized water system to the steam generators. Each unit has three separate closed-cycle loops with one generator per loop.

The steam generators use the heat from the primary systems to produce steam at a constant pressure. This steam is transferred through the closed-cycle secondary loops to the steam turbines which drive the generators to produce electricity. After passing through the turbines, the spent steam is condensed and returned to the steam generators to repeat the cycle.

Circulating Water System

The station has a once-through cooling system (circulating water system) that dissipates waste heat from the turbine condensers and from the auxiliary cooling systems to the environment. The cooling water for the condenser circulating water system and a service water system is withdrawn from Lake Anna through two screenwells (one screenwell per unit) located in a cove north of the station. A screenwell contains four individual bays with each bay equipped with a trash rack, a traveling screen, and a vertical motor-driven circulating water pump (Fig. 3.2-1). The trash racks consist of. 1.3 cm wide by 8.9 cm thick vertical bars spaced 10.2 cm on center. The travelling screens, constructed of 14 gauge wire with 9.5 mm square openings, are designed to automatically rotate once every 24 hours or whenever a predetermined pressure differential exists across the screens. Debris accumulated by the trash racks is removed by horizontally traversing mechanical rakes and then collected in hoppers which discharge it into wire baskets for disposal as solid waste.

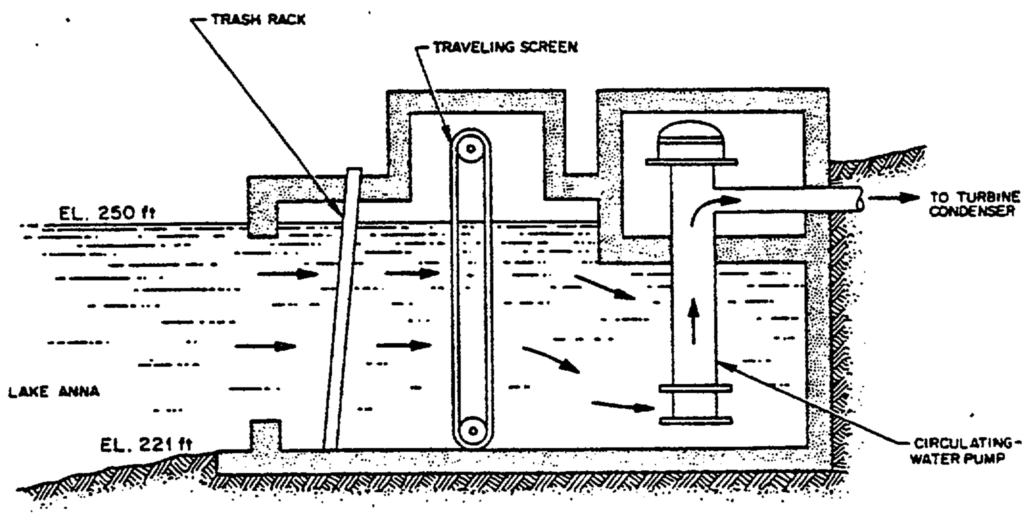

Figure 3.2-1. Intake bay with trash rack, traveling screen and circulating water pump.

After the cooling water passes through the station it is released to the WHTF via a cooling-water discharge canal which has a bottom width of 30 m, side slopes of 1:2.5 and a length of approximately 1100 m. The WHTF consists of three cooling segments interconnected by canals that were constructed with dimensions similar to the discharge canal. The three dikes separating the WHTF from the main reservoir consist mostly of compacted earthen materials. Riprap slope protection extends on both slopes from elevation 242 ft. to 250 ft. Dike 3 is approximately 610 m (2000 ft) in length and includes the concrete structure through which the water from the WHTF is discharged into the reservoir (Fig. 3.2-2). There are six potential submerged openings through which the water can flow (Fig. 3.2-3). Stop log sections, constructed of wood and concrete are used to maintain a differential head, with attendant design velocity 2 m/s (7 ft/s) through the openings, for mixing of outflow from the WHTF with the main reservoir. A 215 m (700 ft) long section of Dike 3 is constructed at elevation 77.2 m (253.5) that serves as an emergency spillway between the WHTF and reservoir during periods of high water levels.

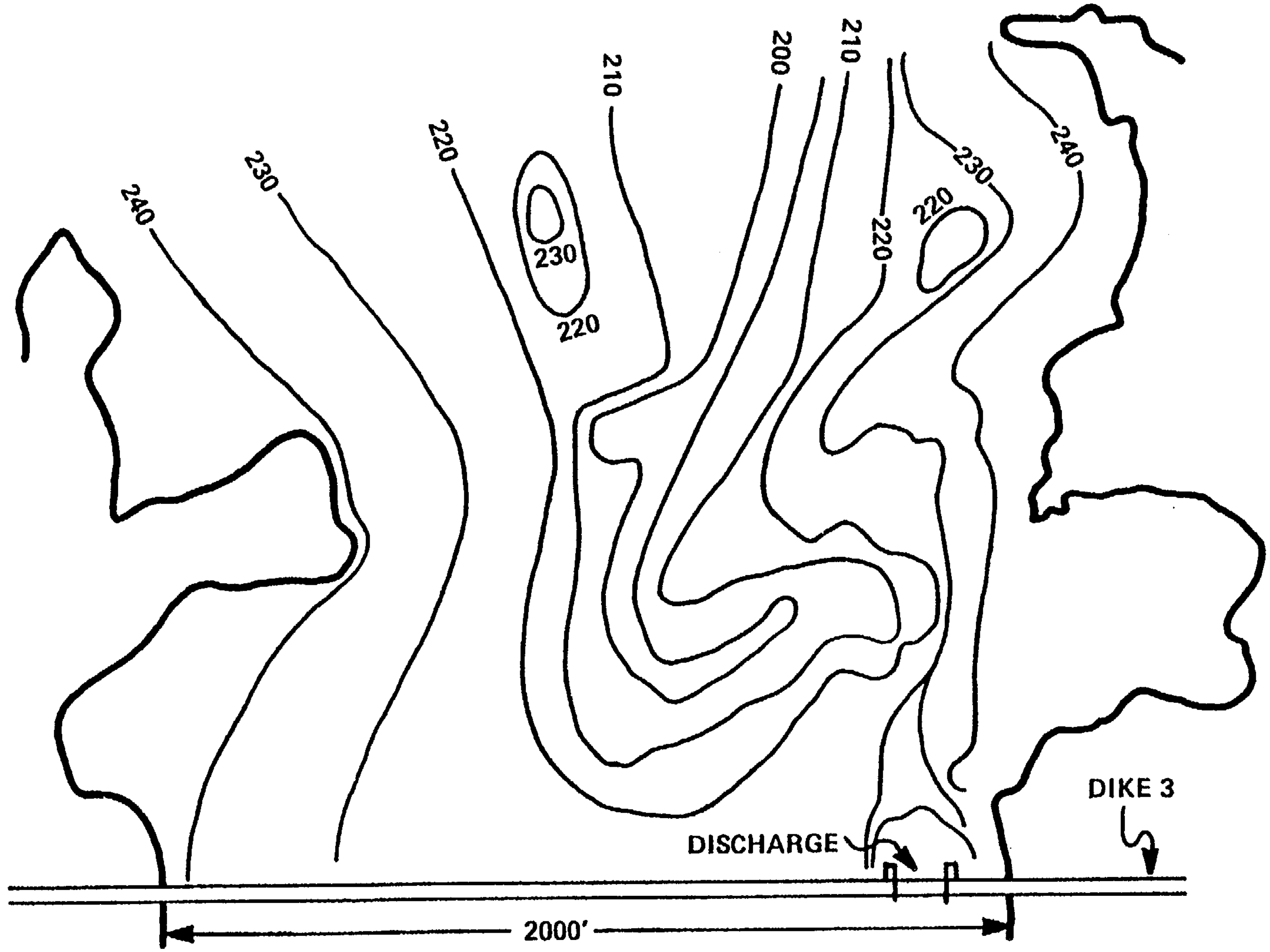

Figure 3.2-2. Location of the discharge structure in Dike 3 and bottom topography of the proximate main lake. Elevations are in above mean sea level.

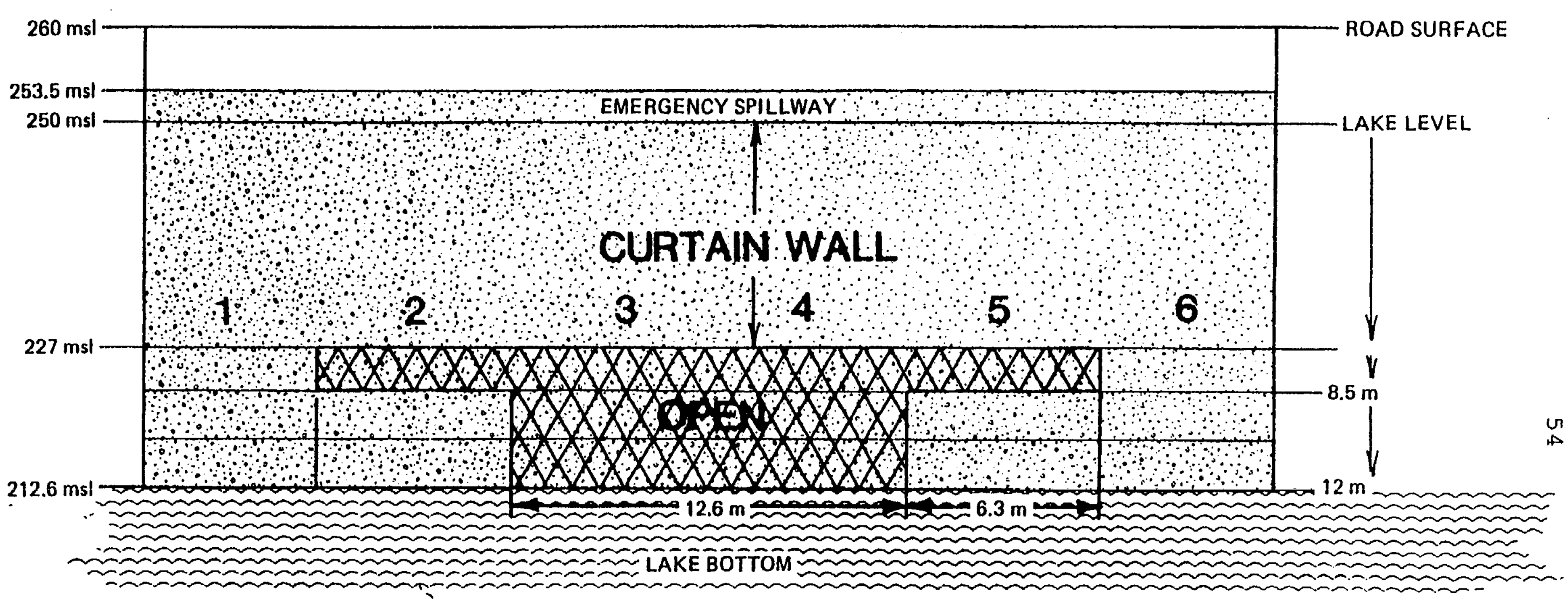

Figure 3.2-3. Dike 3 discharge structure dimensions.

3.3 Operational Characteristics

This section describes the station's cooling water requirements, the effect on water temperatures, plant efficiency and heat rejection rates. The section is concluded with an historical summary of station operation (1978-1985).

Circulating Water Flow Characteristics

Eight vertical circulating water pumps, each rated at 15 m^3/s (238,200 gpm) pump water from the lake through the station's condensers to the discharge canal. At least three pumps are required for each operating unit during the summer months when intake water temperatures are in excess of 23.9°C (75°F). During colder months, the units are capable of operating more efficiently with reduced condenser flow rates. The measured velocity of flow into the intake structure is approximately 0.2 m/s (0.6 f/s).

Water is withdrawn over the top 10 m of the lake from 76.2 - 67.4 m MSL (250 - 221 ft) and is discharged into the WHTF where the residence time is inversely proportional to the condenser flow rate. According to estimates made by the consultant for the Lake Anna cooling model (Appendix F), the cooling water residence time in the WHTF is approximately 14 days with eight pumps operating.

Cooling Water Temperature Rise

The temperature increase across the condensers at design station load is 7.6°C (14.5°F), based on condenser flow rates of 60 m^3/s (2123 cfs) per unit. Because the condenser temperature rise is inversely proportional to the condenser flow rate and directly proportional to the heat rejection rate, a reduction in flow with no change in the unit load would result in a water temperature increase.

$$\text{Increase in temperature across the condensers} = \frac{\text{Heat rejection rate for two units}}{\text{Condenser Flow} \times \text{Specific Heat} \times \text{Conversion Factor} \times \text{Number of Units}}$$

Heat rejection rate = Btu/hr

Condenser Flow = # pumps x 238,200 gpm

Specific heat = $\frac{1.0\ \text{Btu}}{\text{lb} - {}^\circ\text{F}}$

Conversion factor = $\frac{500.5\ \text{lb}}{\text{gpm-hr}}$

At lower condenser flow rates of 45 m^3/s per unit (3 pumps), the temperature increase of the water passing through the condenser would be approximately 25% greater than at 60 m^3/s or 10.2°C (18.3°F), and the residence time of the effluent in the WHTF would increase proportionally allowing more time for dissipation of the heat. However, if both units were operating at maximum load and one unit went off line (but the pumps remained in operation as is regularly the case) the resulting discharge temperature would reflect a 50% reduction in temperature rise due to the dilution effect by circulating water pumps of the down unit.

Heat Rejection Rates

At maximum operation, the approximate heat load rejected in each of the two condensers is 1840 MWt (or a total of 3680 MWt) minus in-plant losses (typically 5%). Each unit is capable of producing (has a nameplate rating of) approximately 947 MWe (electrical energy). The station is currently licensed to operate at a reactor thermal power rating of 2775 MWt (NSSS rating of 2787 MWt). The NSSS rating recognizes the total amount of heat produced in the steam system and is the sum of the electrical energy produced plus the waste heat that has not been converted to electricity. The efficiency at which the station can generate electrical energy (nuclear stations average 32.7% conversion) is primarily dependent upon the temperature and pressure of the steam generated and directly affects the amount of energy lost as waste heat to the environment.

When a unit is operating at a specific load and at a specific efficiency, the waste heat load remains virtually constant. The waste heat load can be expressed in Btu/hr (British Thermal Units) by the following conversion:

$$\text{Heat Rejection Rate} = \left(\text{Unit NSSS Output (MWt)} - \text{Gross Electrical Output (MWe)}\right) \times \frac{3.413 \times 10^{6}\,\text{Btu}}{\text{MW-hr}} \times \#\text{Units}$$

Monthly mean heat rejection rates since April 1978 are listed in Table 3.3-1 with monthly mean station load and pump operation percentages. Reducing the condenser flow rate from four pumps to three does not significantly affect the heat rejection rate because the design of the power

Table 3.3-1. North Anna monthly operation data, 1978-1985.

YEAR	MONTH	MEAN STATION LOAD (%)	MEAN PUMP OP (%)	MEAN HEAT REJECTION RATE (BTU/HR)
1978	1	0.0	5.0	.
	2	0.0	14.0	.
	3	0.0	25.0	.
	4	6.2	50.0	.
	5	20.5	44.0	.
	6	41.5	50.0	4.74E+09
	7	42.5	74.0	5.46E+09
	8	47.4	52.0	6.15E+09
	9	36.0	44.0	4.65E+09
	10	42.4	74.0	5.46E+09
	11	47.4	85.0	6.07E+09
	12	46.6	100	6.01E+09
1979	1	41.4	93.0	5.37E+09
	2	43.0	56.0	5.54E+09
	3	44.5	38.0	5.73E+09
	4	0.0	34.0	0.00E+00
	5	44.0	56.0	5.69E+09
	6	48.7	46.0	6.30E+09
	7	47.4	50.0	6.28E+09
	8	49.5	50.0	6.47E+09
	9	35.1	69.0	3.70E+09
	10	0.0	31.0	0.00E+00
	11	0.0	25.0	0.00E+00
	12	0.0	32.0	0.00E+00
1980	1	5.0	64.0	7.34E+08
	2	38.4	59.0	5.13E+09
	3	48.8	58.0	6.33E+09
	4	42.7	38.0	5.50E+09
	5	35.2	70.0	4.59E+09
	6	32.5	82.0	4.27E+09
	7	47.4	93.0	6.19E+09
	8	50.3	81.0	6.38E+09
	9	62.6	92.0	6.07E+09
	10	85.4	79.0	5.73E+09
	11	47.2	66.0	5.74E+09
	12	63.5	71.0	7.06E+09
1981	1	42.8	38.0	5.23E+09
	2	48.7	39.0	5.89E+09
	3	47.0	44.0	5.64E+09
	4	82.0	90.0	9.20E+09
	5	79.0	85.0	1.00E+10
	6	78.6	84.0	9.95E+09
	7	47.4	88.0	6.10E+09
	8	59.8	92.0	7.62E+09
	9	93.4	100	1.19E+10
	10	55.6	92.0	7.02E+09
	11	94.0	82.0	1.19E+10
	12	96.6	75.0	1.23E+10

Table 3.3-1 (continued).

YEAR	MONTH	MEAN STATION LOAD (%)	MEAN PUMP OP (%)	MEAN HEAT REJECTION RATE (BTU/HR)
1982	1	85.6	75.0	1.09E+10
	2	93.6	75.0	1.20E+10
	3	54.6	52.0	7.62E+09
	4	43.2	41.0	5.59E+09
	5	11.0	38.0	1.47E+09
	6	25.0	30.0	3.03E+09
	7	9.3	40.0	1.15E+09
	8	1.0	38.0	1.38E+08
	9	47.2	38.0	5.93E+09
	10	49.6	38.0	6.28E+09
	11	47.6	64.0	6.07E+09
	12	48.3	64.0	6.16E+09
1983	1	37.5	38.0	4.77E+09
	2	47.6	67.0	6.04E+09
	3	73.6	75.0	9.36E+09
	4	51.6	41.0	6.45E+09
	5	42.0	57.0	5.37E+09
	6	79.3	92.0	1.00E+10
	7	92.2	100	1.17E+10
	8	99.4	98.0	1.26E+10
	9	95.8	100	1.24E+10
	10	60.8	92.0	7.75E+09
	11	96.6	75.0	1.22E+10
	12	96.1	75.0	1.22E+10
1984	1	60.4	75.0	7.71E+09
	2	71.6	75.0	9.35E+09
	3	95.8	75.0	1.21E+10
	4	81.0	75.0	1.01E+10
	5	61.6	63.0	7.75E+09
	6	48.0	50.0	6.11E+09
	7	43.1	50.0	5.46E+09
	8	3.2	38.0	3.67E+08
	9	0.8	38.0	1.42E+08
	10	39.2	38.0	4.95E+09
	11	74.2	75.0	9.29E+09
	12	84.2	75.0	1.06E+10
1985	1	97.9	75.0	1.22E+10
	2	84.4	75.0	1.06E+10
	3	79.3	75.0	1.00E+10
	4	88.7	75.0	1.11E+10
	5	98.8	75.0	1.24E+10
	6	99.3	75.0	1.26E+10
	7	91.4	88.0	1.16E+10
	8	72.4	75.0	9.13E+09
	9	82.5	75.0	1.05E+10
	10	80.2	75.0	1.01E+10
	11	54.9	50.0	6.92E+09
	12	51.8	50.0	6.56E+09

station limits the conversion efficiency. A reduction in the volume rate of flow of the cooling water results in; 1) an increase in condenser discharge temperature, 2) an increase in the residence time in the WHTF and 3) a decrease in the relative temperature of the discharge at Dike 3. Considering that more than one-half of the station's rejected heat is dissipated in the WHTF, the two-unit heat loading of about 0.2 MWt/acre on the Lower Lake is rather slight in comparison with loadings of 0.5-1.0 MWt/acre found at many other large cooling reservoirs (Jerka and Harleman 1979; Tetra Tech 1981).

Historical Summary of Net Generation

Unit 1 became operational in April 1978 and had been operating on a commercial basis for two years when Unit 2 was completed. It began operating in August 1980 and was declared to be in commercial operation in December 1980 (Figs. 3.3-1 and 3.3-2). In seven and one-half years of operation, 75-100% (considered maximum two-unit operation) of the total station load was sustained during nine of the 31 quarters: three winter quarters (1982, 1984 and 1985), two spring quarters (1981 and 1985), two summer quarters (1983 and 1985) and two fall quarters (1981 and 1983). Eight quarters maintained loads of 50-75% (considered equivalent to one unit operating at 100% load), and the remaining 14 operated at less than 50% total load (Table 3.3-2).

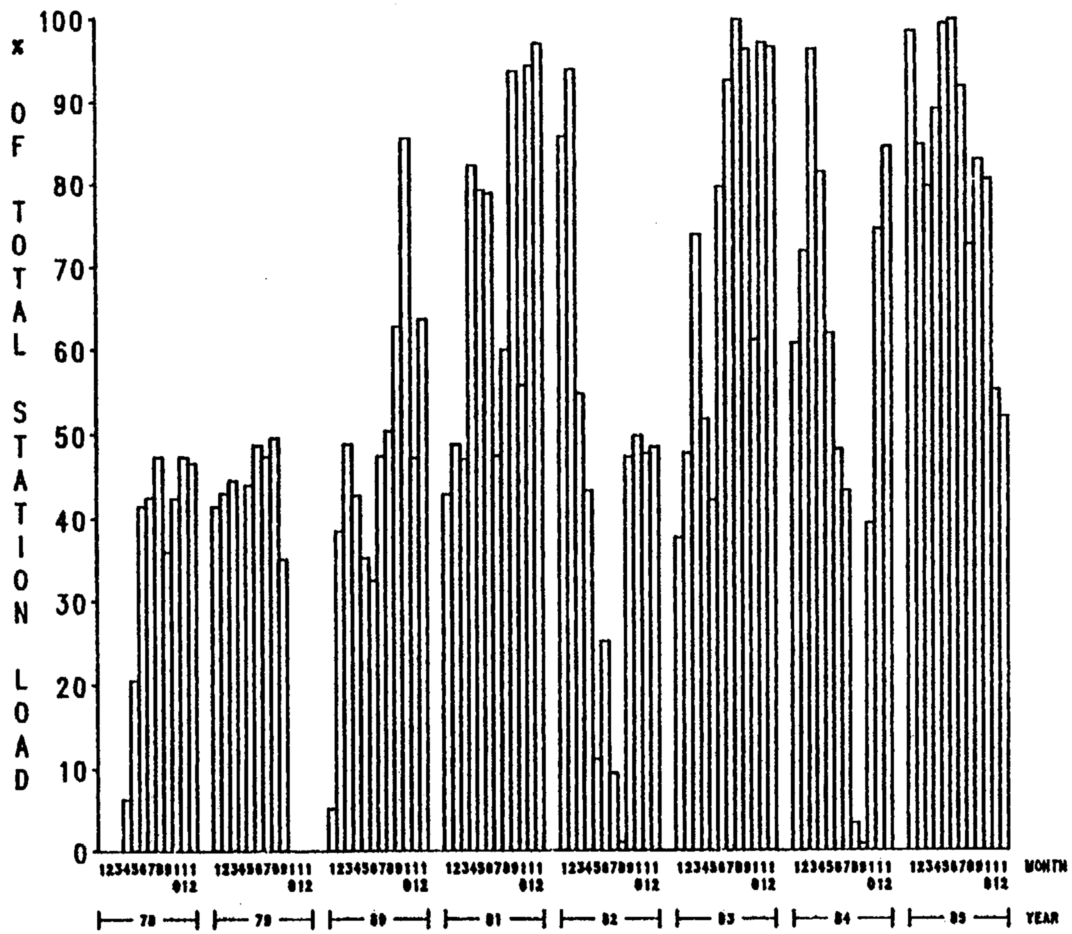

Figure 3.3-1. Monthly mean percent of total station load for the North Anna Power Station, 1978-1985.

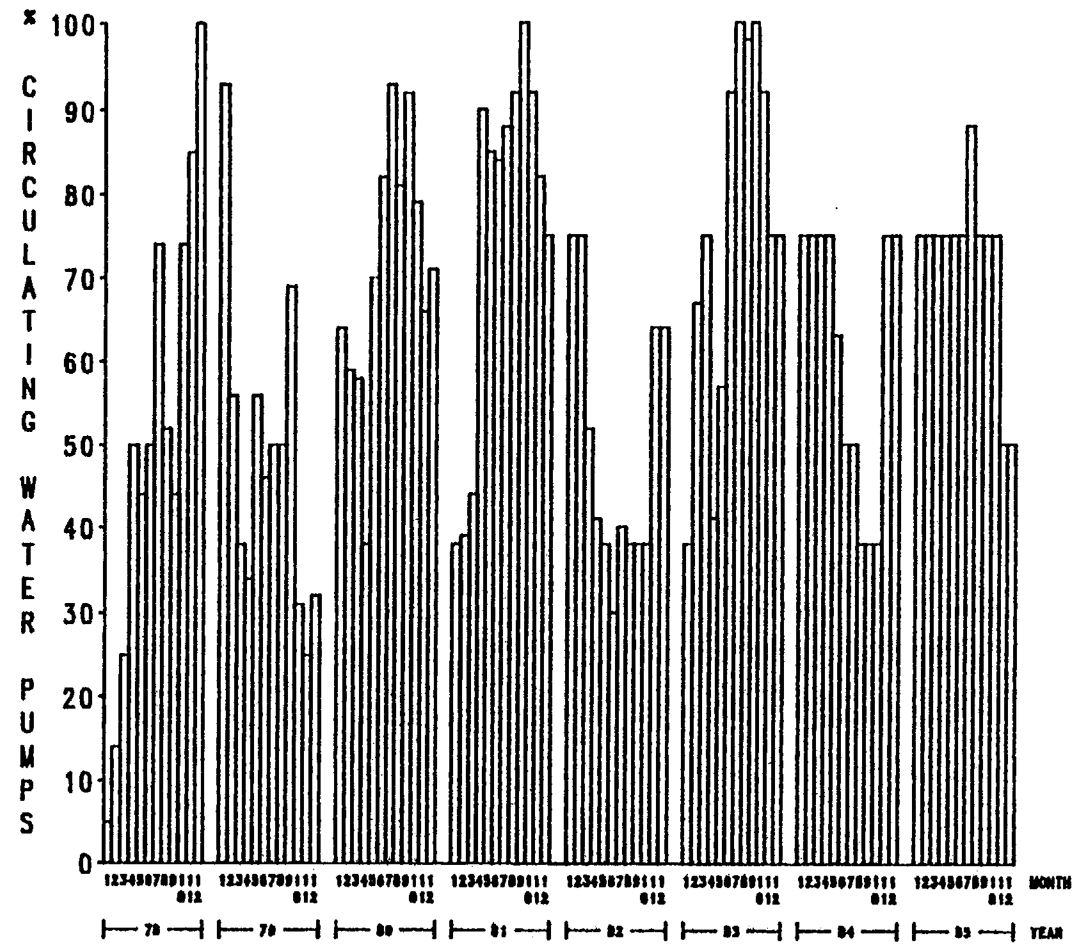

Figure 3.3-2. Monthly mean percent of total circulating water pump capacity for the North Anna Power Station, 1978-1985.

Table 3.3-2. Seasonal summary of North Anna Power Station operation (percent of total station load), 1978-1985.

	Winter (Jan-March)	Spring (April-June)	Summer (July-Sept.)	Fall (Oct.-Dec)
1978	0	23	42	45
1979	43	31	44	0
1980	31	37	53	65
1981	46	80	67	82
1982	78	26	19	48
1983	53	58	96	84
1984	76	64	16	66
1985	87	96	82	62
# Quarters at 75-100%	3	2	2	2

3.4 Lake Anna Hydrological Characteristics

The efficiency of a water system to process and trap organic constituents is critically dependent on the length of the retention time. Reservoirs with long retention times are generally dominated by autochthonous organic constituents. Lake Anna is a tributary-fed oligo-mesotrophic, dimictic reservoir with a relatively small drainage area/surface area ratio (22.9) and a relatively long hydraulic retention time (465 days; Table 3.4-1).

Table 3.4-1 Hydrological characteristics of Lake Anna, Virginia. (Physical characteristics are given in Table 3.1-1).

Drainage area	888 km^2	(343 sq. miles)
Drainage area/surface area	22.9	
Average annual inflow	2.4 $x_3 10^8 m^3$	($8.2X10^9$ ft^3)
Average inflow rate	7.6 m^3/s	(270 cfs)
Hydraulic retention time	1.25 yrs	(456 days)
Average release from dam	6.2 m_3^3/s	(220 cfs)
Minimum release from dam	1.1 m^3/s	(40 cfs)

The average annual inflow to Lake Anna is about 7.6 m^3/s (270 cfs). Lake level is maintained by three radial gates in the dam, and two near-surface skimmers. The minimum release to the river is 1.1 m^3/s but the annual discharge averages 6.2 m^3/s.

Prevailing winds in the vicinity of the power station are seasonally directed. During the summer, winds generally blow from south-southeast through west-southwest. In winter months, the direction is predominantly north to northeast. Local wind circulations are induced by the rolling terrain and lake drainage influences.

The lake basin is characterized by igneous and metamorphic rock underlayments (Fig. 3.4-1) that typically produce soft water low in carbonate ions. Iron sulfates are often present in groundwater under acidic conditions. Three inactive pyrite mines and mining spoils piles (0.12 denuded km^2) are contributing high concentrations of dissolved metals and acid leachate to Contrary Creek, which drains 60 km^2 of Louisa County and discharges into Lake Anna 3 km upstream from the power station. The average annual flow of Contrary Creek is 0.2 m^3/s (7.3 cfs) where it empties into Lake Anna. The effects of acid mine drainage from Contrary Creek were evident for several miles downstream prior to the impoundment of Lake Anna. However, the reservoir has ameliorated the negative effects of peak pollutants downstream from the dam by diluting the influent.

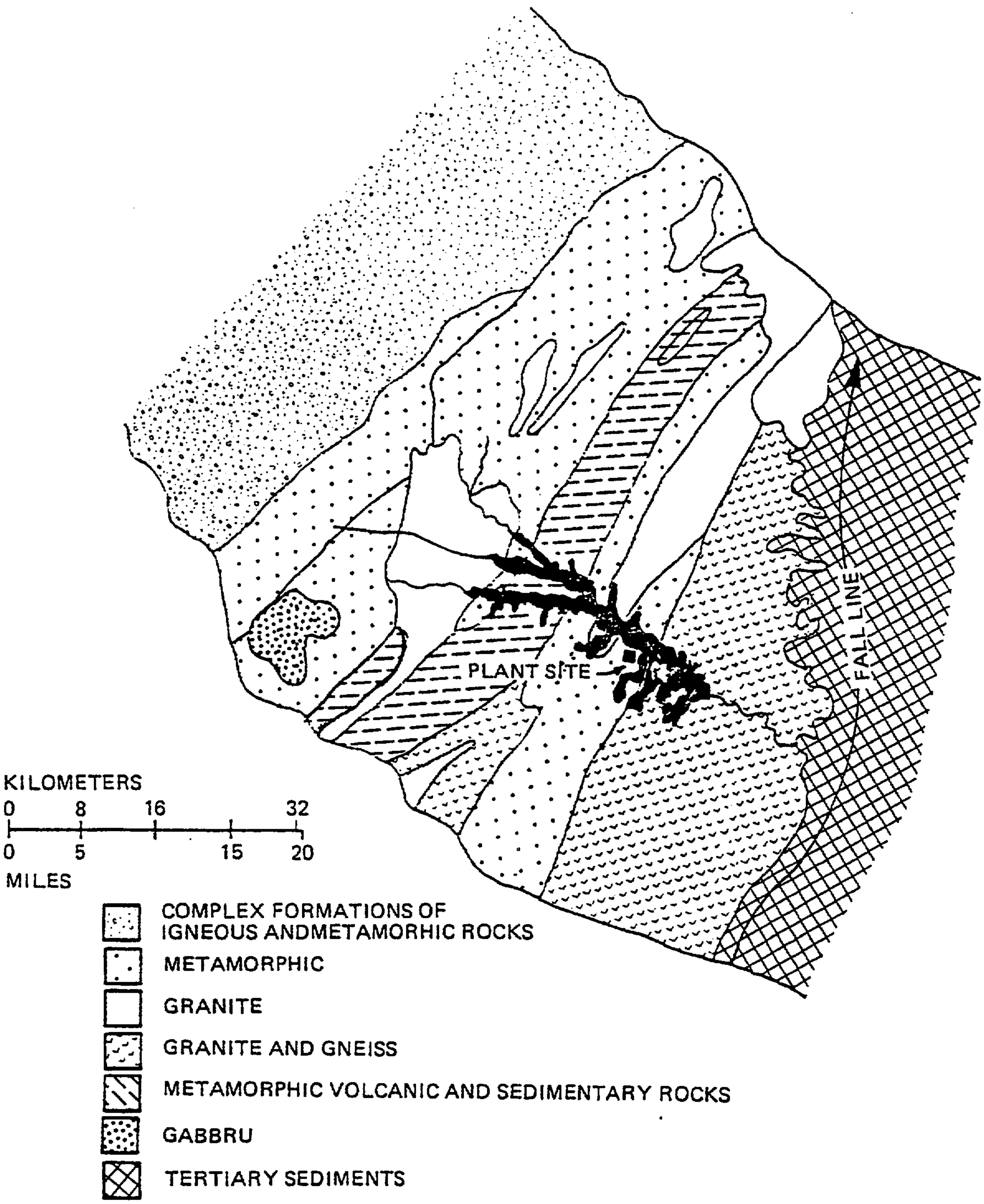

Figure 3.4-1. Geologic map of the Piedmont Province in the vicinity of the North Anna Power Station (Virginia Department of Conservation and Economic Development/Division of Water Resources, 1970).

3.5 Hydrothermal Characteristics

This section summarizes the 1984-1985 field temperature surveys which were designed to define the characteristics and extent of the thermal plume emanating from the discharge at Dike 3. It also describes the data base that pre-dates the present study. An assessment of the seasonal heat budget dynamics and maximum lake temperatures is followed by a discussion of Lower Lake temperature increases (measured and predicted values). Comparisons are made to show epilimnetic temperature differences in pre- and operational years between Upper and Lower Lake stations. Annual curves show the expected periodic shift attributable to two-unit summer operation. The 1983 operational data coincide with the most extreme (worst case) meteorological conditions experienced since the power station started operating in 1978. The temperature distributions in the Lower Lake are related to the design of the release structure and to the condenser flow rate. Vertical temperature profiles illustrate pre-operation and operational effects on stratification near the dam. A discussion of far-field analyses concludes this section.

Information Base For Evaluation

Temperature data have been collected extensively in Lake Anna for the purpose of determining temperature patterns and establishing the necessary foundation for biological evaluations. Station locations and depths are summarized in Table 3.5-1, and are indicated on the lake map

Table 3.5-1. Summary of temperature stations for the three programs, respective depths, and coincidental stations.

Plume Survey Stations	(Quarterly Profiles) Respective Depths (m)	Water Quality Stations	(Monthly Profiles) Depths (m)
A (1-5)	(9,15,16,21,7)	Dam	(0-19)
B (1-5)	(18,18,12,6,16)	Dike 3 Endeco	(0- 7)
C (1-5)	(15,19,11,4,6)	Burrus Point	(0- 9)
D (1-5)	(9,19,19,18,11)	Mid Lake	(0-12)
E (1-5)	(18,14,6,15,18)	Intakes	(0-11)
F (1-5)	(10,11,20,18,18)	Rt. 208 Bridge	(0-11)
G (1-5)	(16,19,15,16,7)	Contrary Creek	(0- 7)
H (1-5)	(2,6,15,16,16)	Pamunkey Arm	(0- 7)
I (1-5)	(11,13,11,10,14)	North Anna Arm	(0- 7)
J (1-3)	(10,14,13)		
K (1-3)	(3,7,15)		
L (1)	(7)		
M (1)	(8)		
N (1)	(7)		

Endeco Recorders (Hourly, Continuous)
T=Near Surface, M=Mid depth, B=Near bottom

Stations	Instrument Depths (m)
NALST10	(3)
NALTHIS (T,M,B)	(1,7,14)
NALINT	(1)
NAL208 (T,M,B)	(1,5,10)
NAL719N (T,M,B)	(1,3,6)
NAL719S (T,M,B)	(1,3,6)

Coincidental Stations

Plume	Endeco	Water Quality
	NALST10	Dike 3 Endeco
D-4	NALBRPT	
	NALINT	Intakes
	NAL208	Rt. 208 Bridge
N	NAL719S	North Anna Arm
M	NAL719M	Pamunkey Arm

(Fig. 3.5-1). Equipment and methodologies are described in detail in Appendix D. Basically three types of temperature data exist: (1) Hourly records were developed at seven sites in the reservoir with in-situ recording ENDECO thermographs. Three instruments were secured to positions along a vertical cable corresponding to a near-surface depth (approximately one meter), a mid-depth and near-bottom depth (approximately one meter off the bottom) at five of those sites (NALBRPT, NALTHIS, NAL208, NAL719N and NAL719S) . The other two sites have near-surface instruments only (NALST10 and NALINT). This data base consists of data collected from the latter half of 1974 through 1985. (2) Monthly profile records were generated at nine sites in the reservoir with portable instruments. Eight of these sites correspond to sampling locations for phytoplankton, chlorophyll, zooplankton, dissolved oxygen profiles, water quality, nutrients and metals. Historical records date back to 1974 but are less complete in some of the earlier years. These data are useful for comparing annual and seasonal stratification patterns. (3) Plume surveys were conducted on a quarterly schedule (Feb., May, Aug., Nov.) in 1984 and 1985. Periodic monthly surveys were made to supplement the data base. These surveys included 14 transects in the reservoir with 1-5 measurement points along each transect. A total of 54 profiles were made. In 1985, dissolved oxygen profiles were recorded simultaneously with the temperature profiles from May - September. These are discussed further in Section 3.6, Water Quality Assessment, Section 4.4,

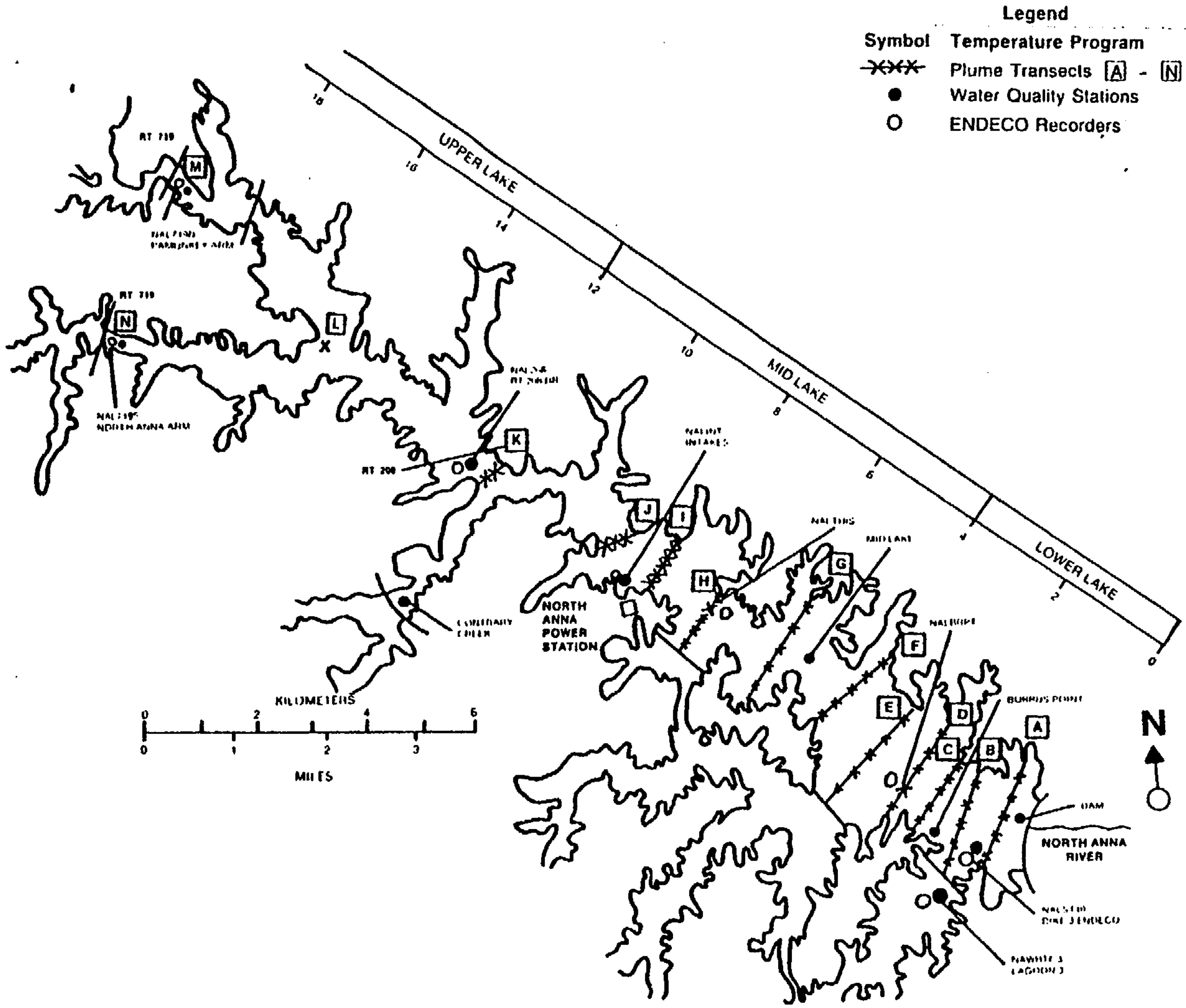

Figure 3.5-1. Temperature stations for the three programs (plume surveys, water quality surveys and ENDECO recorders).

Largemouth Bass Life History Studies and Striped Bass Studies. From 1978 to 1983, monthly synoptic surveys were conducted to determine diurnal temperature variation. They consisted of hourly temperature profiles measured at meter intervals during eight-hour daytime periods at 17 locations. A few special synoptic surveys were performed during the pre-operational years.

Hydrothermal Assessment

During the pre-operational period, it was evident from synoptic survey data that diurnal summertime temperature fluctuations of 2°C in the surface layer occurred in both the Upper and Lower Lake. The maximum hourly temperature ever recorded in Lake Anna occurred before the station had begun operating; 33.7° on 7/19/77 at Upper Lake station NAL719NT (Table 3.5-2). On the same day, 33.1°C was recorded at Mid-Lake station NALTHIST, exceeding all other Mid and Lower Lake temperatures during the pre-operation. Maximum hourly temperatures were commonly seen in the Upper Lake during the summer period. A comparison was made between pre-operation and operation longitudinal profiles with similar Upper Lake temperatures (Fig. 3.5-2). The Lower Lake temperatures were (1) raised by the heated effluent in 1985, especially noticeable in March and (2) were lower than Upper Lake temperatures in 1977 (pre-operation) for the months shown.

The maximum monthly means (calculated from daily maxima) coincided with the months and station locations of

Table 3.5-2 Maximum hourly surface ENDECO temperatures measured in Lake Anna during July and August by year (1975-1985), monthly mean power levels, and generalized station locations.

June	Monthly Mean Power Level %	Maximum Hourly Temperature (C)	Generalized Station Location
1975	0.0	31.0	Upper Lake
1976	0.0	31.7	Upper Lake
1977	0.0	29.3	Upper Lake
1978	41.5	31.1	Upper Lake
1979	48.7	28.2	Upper Lake
1980	32.5	29.6	Upper Lake
1981	78.6	33.1	Upper Lake
1982	25.0	29.7	Upper Lake
1983	79.3	31.6	Upper Lake
1984	48.0	33.2	Upper Lake
1985	99.3	29.3	Upper Lake
July			
1975	0.0	30.9	Upper Lake
1976	0.0	31.3	Upper Lake
1977	0.0	33.7	Upper Lake
1978	42.5	32.2	Upper Lake
1979	47.4	30.3	Upper Lake
1980	47.4	32.9	Upper Lake
1981	47.4	31.6	Lower Lake
1982	9.3	32.6	Upper Lake
1983	92.2	33.5	Mid Lake
1984	43.1	29.6	Mid Lake
1985	91.4	31.0	Upper Lake
August			
1975	0.0	32.0	Upper Lake
1976	0.0	30.2	Upper Lake
1977	0.0	32.9	Upper Lake
1978	47.4	31.7	Upper Lake
1979	49.5	31.3	Upper Lake
1980	50.3	33.1	Lower Lake
1981	59.8	31.2	Lower Lake
1982	1.0	30.4	Upper Lake
1983	99.4	32.4	Upper Lake
1984	3.2	32.0	Upper Lake
1985	72.2	31.9	Upper Lake

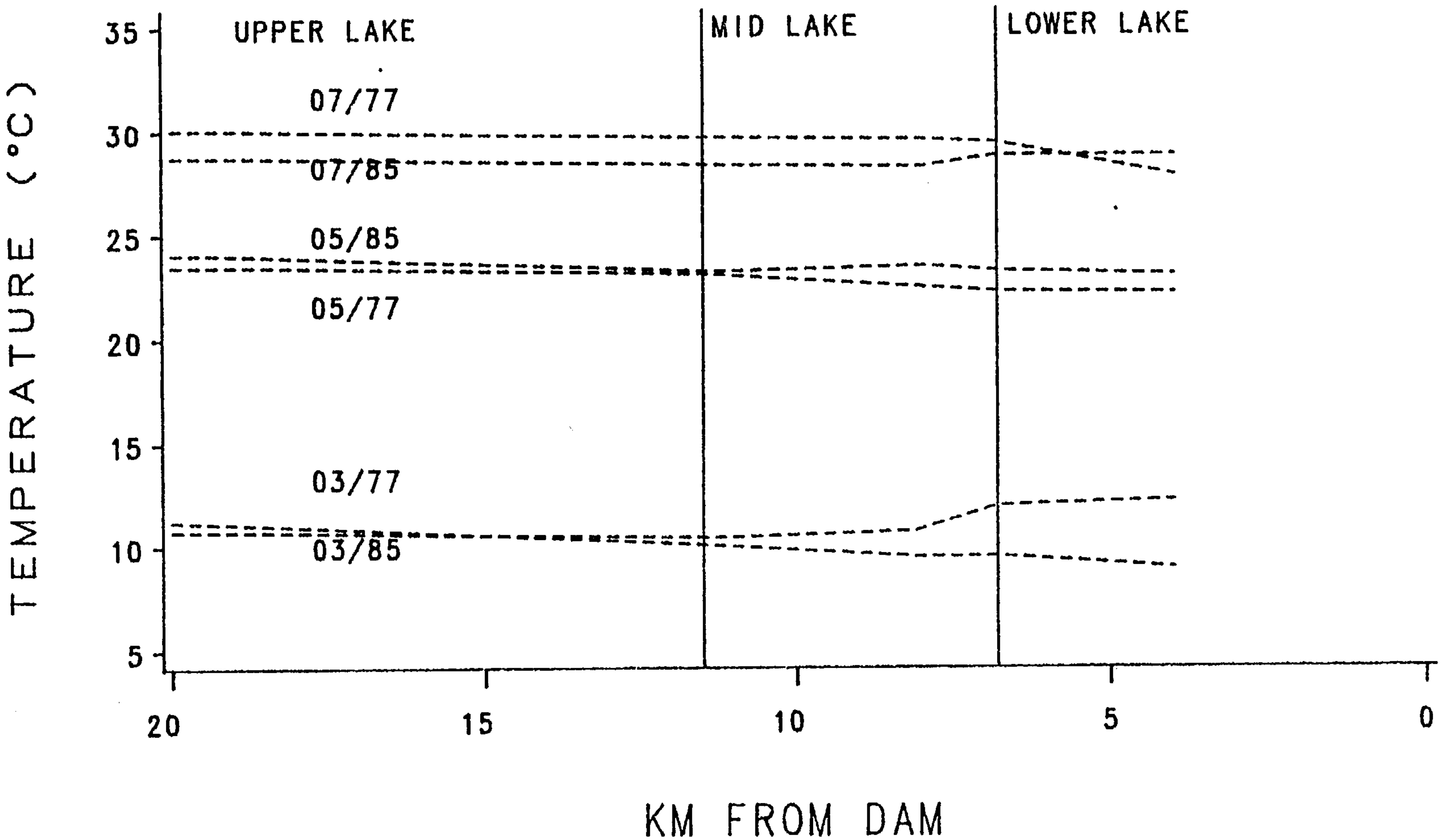

Figure 3.5-2. Longitudinal temperature profile of surface ENDECO monthly means of daily maxima during pre-operation and two-unit operation (months March, May and July).

the maximum hourly temperatures for both pre-operation and operational periods. The pre-operation maximum monthly mean was 30.2°C at NAL719NT in July 1977 (Table 3.5-3) compared to 30.8°C at NALTHIST in August 1983 for operational years.

The maximum hourly temperature recorded in Lake Anna during operational years was 33.5°C, from Mid-Lake station NALTHIST (7/21/83). Higher temperatures have been recorded in two local water supply reservoirs: Lake Chesdin near Petersburg, Virginia, 39.0°C; Occoquan Reservoir in Fairfax County, Virginia, 35.0°C (personal communication with Lois S. Thacker 1984, Dr. Barron L. Weand 1985, respectively).

Several factors contribute to the heat budget of a water body in addition to the heat that is removed from the steam cycle of the power production process. According to Lawler et al. (1978), the heat discharged from a 1000 MWe nuclear reactor is essentially equivalent to the natural heating of a square mile of receiving water surface area on a summer day. Slightly less than half of the surface area (48%) of Lake Anna is uplake from the power station. The average depth uplake from the station is approximately 4m, in contrast to an average depth of 11m downstream from the station. The North Anna Power station generates approximately 1900 MWe of electrical energy. Lake Anna and the WHTF have a combined surface area of about 51.8 km^2 (20 sq. miles), so the power station probably contributes an additional one-tenth the amount of natural heat that enters the system on summer days. Whether the additional one-tenth

Table 3.5-3. Monthly mean water temperatures (C) calculated from surface ENDECO station daily maxima in Lake Anna, Virginia.

Dup 3

YEAR	MONTH	NAL719ST	NAL719NT	NAL208T	NALINT	NALTHIST	NALBRPTT	NALST10
1974	8	28.5	28.9	26.5	27.7	26.7	27.4	.
	9	25.5	25.9	25.8	24.6	.	24.4	.
	10	18.0	18.2	17.2	17.8	17.1	18.0	.
	11	13.0	13.7	13.7	13.8	13.7	14.0	.
	12	5.4	5.8	7.1	7.4	7.6	7.9	.
1975	1	4.8	4.8	5.5	5.8	5.8	5.9	.
	2	5.5	5.5	5.3	5.5	5.4	5.1	.
	3	8.4	8.4	7.7	7.6	7.4	7.1	.
	4	13.3	12.8	12.3	11.8	11.4	11.5	.
	5	22.7	.	22.3	21.7	21.0	21.0	.
	6	27.7	.	27.4	27.1	26.6	26.4	.
	7	28.6	.	28.6	28.1	27.6	28.5	.
	8	29.6	.	29.8	29.3	29.2	29.0	.
	9	24.0	.	24.2	24.1	23.8	26.3	.
	10	19.8	19.1	19.8	20.0	19.9	18.8	.
	11	14.9	14.7	15.4	15.4	15.5	16.7	.
	12	6.9	6.8	8.7	8.9	9.1	.	.
1976	1	3.3	3.2	3.7	5.4	3.9	.	.
	2	6.7	6.6	5.9	.	5.4	.	.
	3	12.4	12.3	11.4	11.6	10.9	.	.
	4	18.2	18.2	17.1	16.8	16.7	.	.
	5	20.9	21.0	20.2	19.8	.	21.2	.
	6	26.7	26.8	25.9	25.7	.	25.4	.
	7	28.0	29.0	28.3	28.1	.	28.0	.
	8	27.8	28.0	27.4	27.4	.	27.1	.
	9	24.6	24.7	24.3	25.6	23.5	25.1	.
	10	17.4	17.3	17.8	.	17.7	.	.
	11	8.4	9.0	10.0	9.2	10.2	9.6	.
	12	3.7	4.1	5.2	5.4	5.5	5.9	.

Table 3.5-3 (continued).

YEAR	MONTH	NAL719ST	NAL719NT	NAL208T	NALINT	NALTHIST	NALBRPTT	NALST10
1977	1	3.1	3.4	3.4	3.1	3.0	2.8	.
	2	5.0	5.3	5.0	4.6	4.8	4.3	.
	3	11.3	11.1	10.0	9.4	9.4	8.9	.
	4	17.9	18.4	17.5	17.0	17.0	16.6	.
	5	23.6	23.4	23.0	22.4	22.2	22.1	.
	6	25.2	25.4	24.9	24.2	24.1	24.1	.
	7	30.0	30.2	29.6	29.5	29.3	27.7	.
	8	29.2	29.2	28.5	28.4	28.1	.	.
	9	26.2	25.9	25.7	25.6	28.3	.	.
	10	17.8	17.6	17.8	17.8	.	.	.
	11	13.4	13.6	13.8	14.5	11.9	12.0	.
	12	5.6	6.5	7.0	7.8	7.4	7.4	.
1978	1	2.6	.	3.3	3.7	3.7	3.5	.
	2	2.5	.	3.1	3.3	3.5	2.5	.
	3	4.1	8.5	6.3	5.8	7.6	7.4	.
	4	15.3	14.7	13.8	13.2	13.2	13.2	.
	5	20.8	26.2	19.8	19.1	19.3	19.0	.
	6	27.9	27.8	26.8	26.1	25.8	25.2	.
	7	29.6	29.8	28.6	28.5	28.3	28.4	.
	8	30.3	30.1	29.4	29.5	29.3	29.8	.
	9	27.5	25.9	27.1	27.1	27.1	27.6	.
	10	19.5	20.2	19.7	19.9	21.4	20.5	.
	11	14.2	13.0	15.0	15.6	.	16.6	.
	12	8.1	8.6	9.7	10.6	.	11.5	.
1979	1	3.5	3.9	4.6	5.9	5.2	7.0	.
	2	2.7	2.8	2.8	3.1	3.1	3.5	.
	3	9.0	8.5	7.1	7.1	7.6	8.8	.
	4	15.5	15.4	14.7	13.9	14.2	14.2	.
	5	22.6	22.3	21.4	19.8	20.6	19.9	.
	6	26.5	25.7	25.1	.	24.6	24.2	.
	7	28.4	27.9	27.6	28.5	27.3	27.3	.
	8	.	28.5	.	28.0	28.1	27.9	.
	9	22.9	25.5	23.2	25.4	25.4	25.4	.
	10	18.9	18.8	19.2	19.2	19.4	19.0	.
	11	13.7	13.7	14.2	14.3	14.4	14.0	.
	12	7.6	8.2	9.2	9.0	9.3	8.6	.

Table 3.5-3 (continued).

YEAR	MONTH	NAL719ST	NAL719NT	NAL208T	NALINT	NALTHIST	NALBRPTT	NALST10
1980	1	4.3	4.7	5.2	5.6	5.9	5.5	.
	2	4.6	4.5	3.8	4.0	4.2	5.3	.
	3	6.2	7.8	7.0	7.1	7.3	8.2	.
	4	.	16.1	15.3	14.8	14.7	14.7	.
	5	23.7	22.7	21.9	21.1	19.0	21.2	.
	6	26.5	26.6	26.1	25.0	.	25.2	.
	7	29.9	30.3	29.6	28.7	30.2	29.0	.
	8	.	30.1	30.0	29.9	30.3	30.6	.
	9	24.3	27.5	27.5	27.7	28.0	28.5	.
	10	19.0	19.4	20.1	20.8	21.0	21.9	.
	11	11.2	11.7	12.8	13.7	14.1	14.8	.
	12	6.1	6.5	7.7	8.5	9.1	9.8	.
1981	1	4.4	3.9	3.4	3.8	4.1	4.5	.
	2	5.3	5.2	4.0	5.0	5.3	6.0	.
	3	8.5	8.3	10.1	8.1	8.4	9.0	.
	4	16.2	16.9	15.5	15.0	15.2	15.7	.
	5	21.4	21.6	20.1	20.5	20.7	21.4	.
	6	28.4	28.4	.	27.5	27.8	27.9	.
	7	29.4	29.4	29.3	29.1	29.3	29.5	.
	8	28.1	27.9	28.7	28.1	28.4	28.6	.
	9	24.9	25.2	25.7	25.9	26.2	26.7	.
	10	17.6	17.7	18.9	18.9	19.4	.	.
	11	12.0	12.0	13.5	14.0	14.5	.	.
	12	5.1	5.5	7.1	8.6	9.1	9.7	.
1982	1	2.6	3.1	3.1	4.5	5.2	7.0	.
	2	3.8	3.9	4.3	5.7	6.7	8.7	.
	3	8.7	8.7	8.8	9.4	9.4	10.6	.
	4	14.3	14.5	13.8	13.4	13.1	13.8	.
	5	23.6	23.3	22.2	22.0	.	22.3	.
	6	26.1	26.4	25.3	25.1	27.4	25.0	.
	7	30.1	30.0	29.5	29.7	29.4	28.4	.
	8	28.8	28.5	28.1	28.4	28.1	27.2	.
	9	25.0	25.2	24.8	24.8	24.2	25.0	.
	10	19.4	19.6	19.7	19.6	19.4	20.6	.
	11	14.0	14.3	14.4	14.1	.	.	.
	12	9.5	9.7	10.6	10.9	9.4	10.3	.

Table 3.5-3 (continued).

YEAR	MONTH	NAL719ST	NAL719NT	NAL208T	NALINT	NALTHIST	NALBRPTT	NALST10
1983	1	5.5	5.6	6.4	7.1	7.1	8.0	.
	2	4.9	5.0	5.0	5.8	6.2	7.2	.
	3	9.9	9.9	9.4	9.4	9.9	11.0	.
	4	13.5	13.2	12.8	12.6	13.0	13.7	.
	5	21.8	22.1	20.5	20.1	19.8	19.6	.
	6	28.1	28.5	26.9	26.5	26.3	26.0	.
	7	30.3	30.4	30.3	30.2	30.8	30.2	.
	8	30.2	29.9	29.3	.	30.3	30.7	31.2
	9	27.1	26.6	27.0	.	27.7	28.6	27.5
	10	20.1	19.7	20.5	19.2	21.5	22.2	22.8
	11	13.1	12.9	14.3	15.2	15.2	16.3	17.3
	12	6.8	6.8	8.7	10.4	10.4	12.2	12.7
1984	1	4.2	4.0	3.7	5.4	5.5	7.0	7.2
	2	7.8	7.6	6.2	6.9	7.5	8.7	8.9
	3	8.7	8.6	8.4	9.5	10.6	11.5	12.2
	4	14.2	13.7	13.3	13.8	12.0	14.9	14.9
	5	21.7	21.6	20.6	20.3	20.4	20.7	20.2
	6	28.3	28.9	27.2	27.2	27.0	26.7	25.7
	7	27.7	27.6	27.4	27.7	27.7	27.8	27.5
	8	29.5	29.4	28.5	28.8	29.0	28.4	27.4
	9	25.4	25.1	24.9	25.2	24.9	24.8	24.1
	10	20.5	20.2	20.4	19.8	20.0	20.0	20.1
	11	13.7	13.7	14.8	15.3	15.1	16.3	17.0
	12	8.9	8.2	10.7	11.4	10.9	12.9	13.5
1985	1	5.1	.	6.2	7.3	.	9.5	10.4
	2	5.3	.	4.3	5.4	.	7.7	8.7
	3	10.4	11.1	10.4	10.7	11.9	12.2	13.1
	4	17.8	17.6	17.2	17.1	17.3	17.9	17.6
	5	24.0	24.2	23.2	23.4	23.2	23.0	22.9
	6	27.0	26.7	26.5	26.1	26.5	26.6	26.3
	7	28.7	28.8	28.3	28.2	28.7	28.7	28.7
	8	28.5	28.8	27.8	28.5	28.6	28.6	28.8
	9	27.1	27.0	27.1	27.3	27.8	27.7	27.7
	10	21.3	21.0	21.7	22.1	22.8	23.2	23.3
	11	15.3	15.2	16.2	16.5	16.8	18.0	18.0
	12	7.4	7.6	9.3	9.8	9.9	11.2	11.5

raises the water temperature significantly depends on the rates of heat loss through radiation and evaporation that must balance total input during midsummer.

Hydrothermal Characteristics

A survey of 61 United States nuclear station designs indicated that the temperature rise across condensers averaged 10.8°C with a range of from 5.6 to 18.0°C (U.S. Atomic Energy Commission 1969). The North Anna condenser design, as modified in 1986, results in a 7.6°C temperature rise during the summer months and a 15.5°C temperature rise in the winter months. The effluent discharges into the Waste Heat Treatment Facility where more than half of the excess temperature is transferred to the atmosphere. The water re-enters the lake through a submerged jet discharge structure designed to provide 180° entrainment of lake water. Temperatures increases in the vicinity of NALST10 parallel far-field characteristics of other water bodies that receive thermal discharges.

Massachusetts Institute of Technology (MIT) used synthetic meteorological data for 1957-1966 (R. M. Parsons Laboratory 1977) and a mathematical model to simulate temperatures in the lake at various stations under varying meteorological and operating conditions. The predicted maximum and minimum monthly mean natural water temperatures enclose the range of temperatures that might be expected for the month of July over a ten-year period (Fig. 3.5-3). The measured monthly mean temperatures for the 11 year study

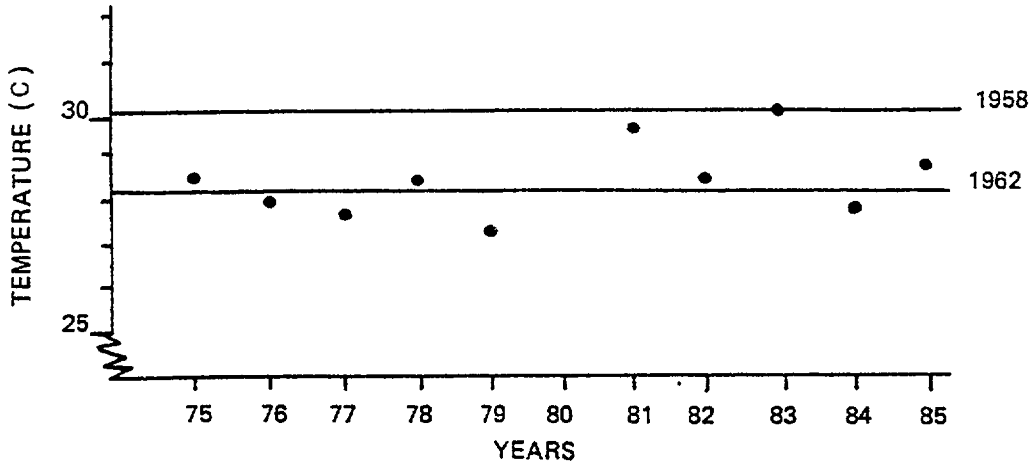

Figure 3.5-3. July monthly means of daily maximum surface water temperatures at Burrus Point (NALBRPTT). Reference lines indicate maximum and minimum natural temperatures for July (monthly means of daily maximum temperatures) simulated by the model for 1957-1966.

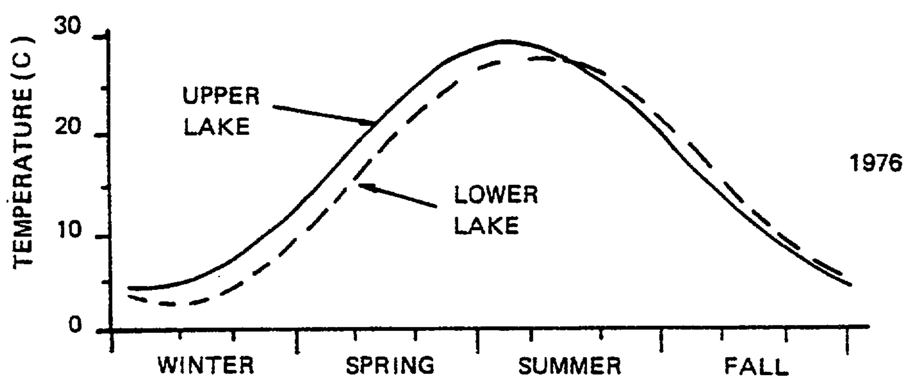

Figure 3.5-4. Surface water temperatures (from regression analyses) at Upper Lake station NAL719NT and Lower Lake station NALBRPTT for 1976 (pre-operation).

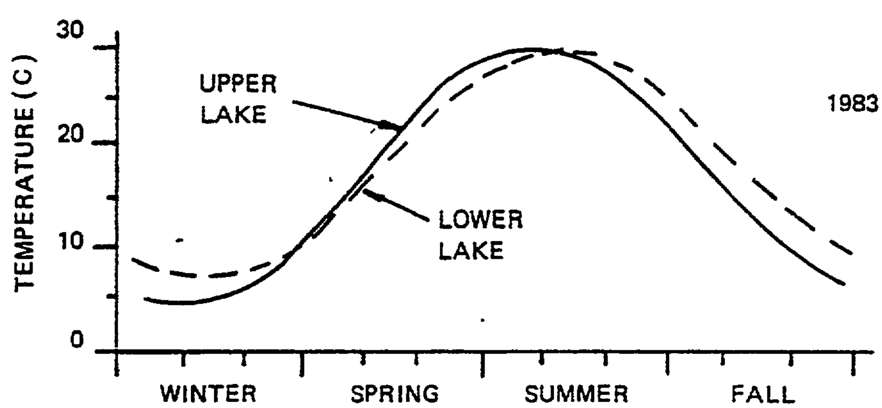

Figure 3.5-5. Surface water temperatures (from regression analyses) at Upper Lake station NAL719NT and Lower Lake station NALBRPTT for 1983 (operational).

period encompassing pre-operation and one and two unit operations are plotted to show their relationships to the predicted values. Data indicate the July monthly means of the daily maximum temperatures recorded are within the limits of those that would have been recorded under natural conditions. The mathematical model received actual data when it became available for time varying power plant and meteorological inputs and for water temperatures, and was calibrated on several occasions (Jirka et al. 1977; Wells et al. 1982). Final calibration of the model was completed in 1984 (Appendix F). More recently, Dr. E. Eric Adams performed regression analyses using monthly water temperature, air temperature and plant operating data. He confirmed predictions of the recently calibrated model that the Lower Lake temperature increase above normal with two units operating is about 2°C in the summer.

Pre-operational temperature data collected from Upper Lake and Lower Lake stations indicated the tributary inflows into the more shallow upper areas warmed more quickly in the spring. A closer examination of the data indicated the water in the Upper Lake was also warmer into the early summer and that it reached a higher maximum temperatures than the water in the Lower Lake. The large volume of water in the Lower Lake retained heat longer as the natural inputs decreased.

ENDECO thermograph data were used to compare annual Upper Lake and Lower Lake temperature curves from a pre-operational year (1976) and a year with high 2-unit

operational levels (1983). A transformation was used to remove diel oscillations and produce a smooth annual curve.

Temperature = $B_o + B_1$, cosine Ø + B_2 sine Ø + residual

The angle Ø is a function of the Julian date:

$$Ø = \frac{\text{Julian date}}{\text{days in year}} * 360$$

Date	Ø (in degrees)
Jan 1	0
July 2	180
Dec 31	360

The intercept (B_o) and the coefficients for the cosine and sine terms (B_1 and B_2) were estimated from the data using a regression analysis procedure (Statistical Analysis System, SAS Institute, Cary, N.C.). Annual curves for 1976 and 1983 at an Upper Lake surface (NAL719NT) and a Lower Lake surface station (NALBRPTT) are shown in Figures 3.5-4 and 3.5-5 on preceding page. In 1976 (without thermal additions from the power station) the Lower Lake temperatures lagged about 2-3 weeks behind the Upper Lake from February through July, and surface temperatures were warmest in the Lower Lake from mid-July through December. In 1983, Lower Lake surface temperatures exceeded Upper Lake temperatures except during the spring and early summer. In neither year, 1976 or 1983, did the Lower Lake produce absolute maximum temperatures (see Table 3.5-2). Station operation apparently caused (1) the Lower Lake to be more closely aligned with Upper Lake temperatures in spring, (2) the peak summer temperatures of both sections to be similar (whereas Lower Lake was cooler

pre-operation) and (3) the heat retention of the Lower Lake to be prolonged.

An effluent not significantly warmer than the receiving water lacks buoyancy but does enhance vertical entrainment into the thermal plume. The jet mixing at Dike 3 (which utilizes a submerged discharge and a high-velocity design) maximizes the dilution achieved in the Lower Lake. Plume survey results show during the hottest month of the year (July) near maximum operating conditions do not produce a distinct plume in the Lower or Mid-Lake (Fig. 3.5-6). Power level and circulating water pump values represent means for the month in which the survey was taken. In fact, the results show nearly uniform temperatures in the horizontal layers. During other months of the year, (Appendix B, Figs. 1-19), it is difficult to differentiate between the thermal discharge and seasonal warming and cooling trends. Modeling studies (Wells et al. 1982) determined mixed layer depths on the order of 7-10 m (20-30 ft) gradually decreasing beyond the turbulent mixing zone of the jet until the intake to the power station was reached where the depth was only 5-7 m (15 ft). Dr. Adams (Adams et al. 1985) determined the average diffusivities for the one pre-operational year studied (1976) and the three years of reduced pumping (1979, 1982 and 1984) were similar and approximately five times lower than the diffusivities computed for years with six to eight pumps operating (1980, 1981 and 1983). The computed diffusivities for 1976, 1979, 1982 and 1984 were all comparable to those found in similar

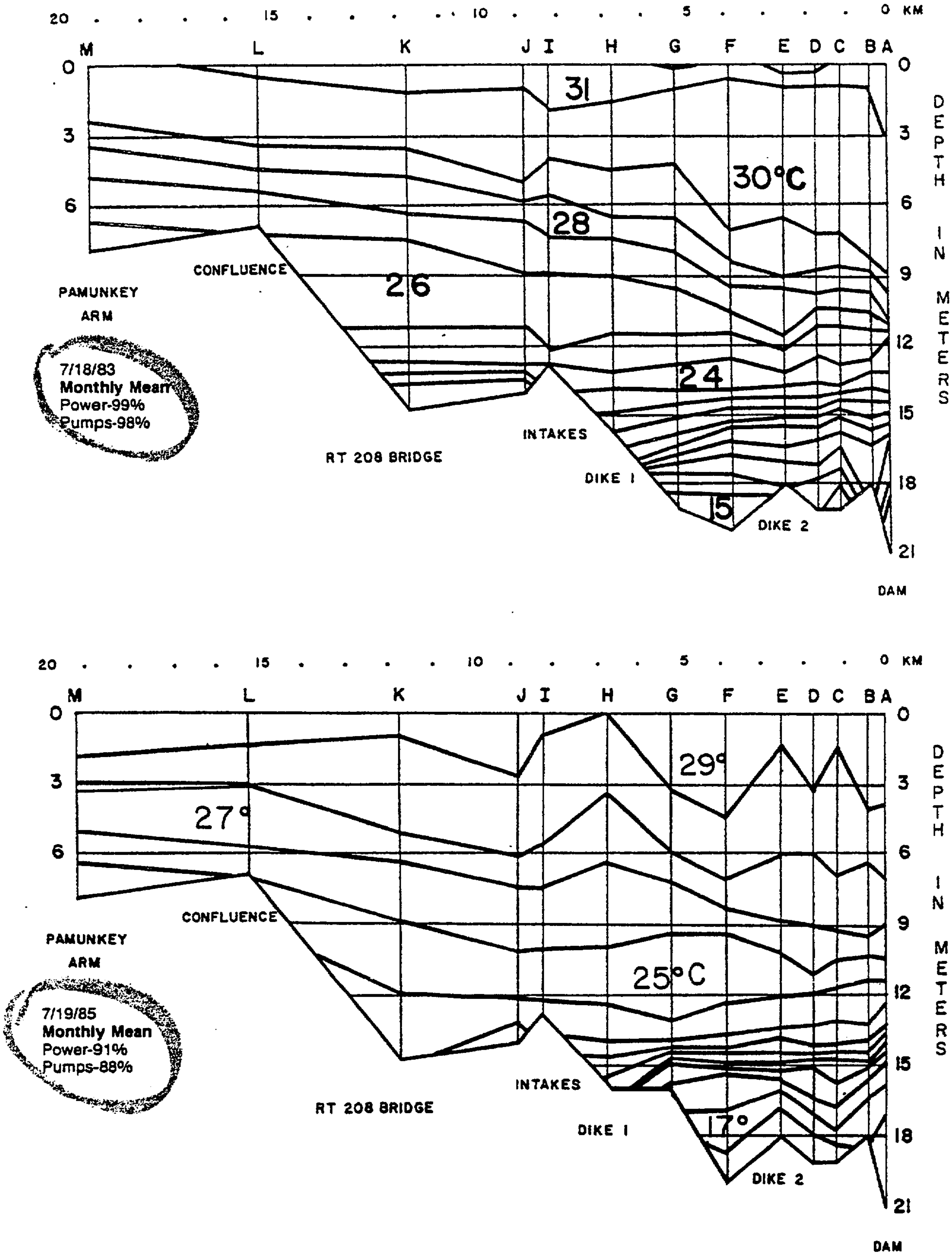

Figure 3.5-6. Water temperatures in Lake Anna from the deepest station in transects A-M measured during thermal plume surveys and near maximum station operation.

size natural lakes (Jassby and Powell 1975). These current studies had identified a definite relationship between the condenser flow rate and both the time rate of change of bottom temperature and the computed vertical diffusivity (both measures of vertical mixing).

A classical vertical temperature profile for a stratified lake resulted from data collected at the Dam station in July of 1976 (Fig. 3.5-7). The epilimnion (upper mixed layer) extended down 5 m. Below this depth the temperature began to drop rapidly (at a rate greater than 1°C per meter). This zone of rapid temperature change (thermocline) extended to 10m which corresponded to the upper boundary of the hypolimnion. The hypolimnion and the epilimnion, each relatively isothermal had a temperature difference of approximately 14°C. The two "pools" of water, with their significant differences in density, are separated by the thermocline.

The Dam station pre-operational temperature profiles (May-August) for 1976 were combined with operational profiles for 1985 (Figure 3.5-8). Warming occurred sooner in the spring of 1985 than in 1976, with a distinct thermocline evident in 1985 In June, the shallow epilimnion extended to 2m in 1976 in contrast to the deep epilimnion reaching to 10m in 1985. The epilimnion continued to warm through July during both years, with the depth reaching 5m in 1976 and dropping to 8m in 1985. The hypolimnion was relatively thermally stable during the May-July period of the pre-operational year, but this did

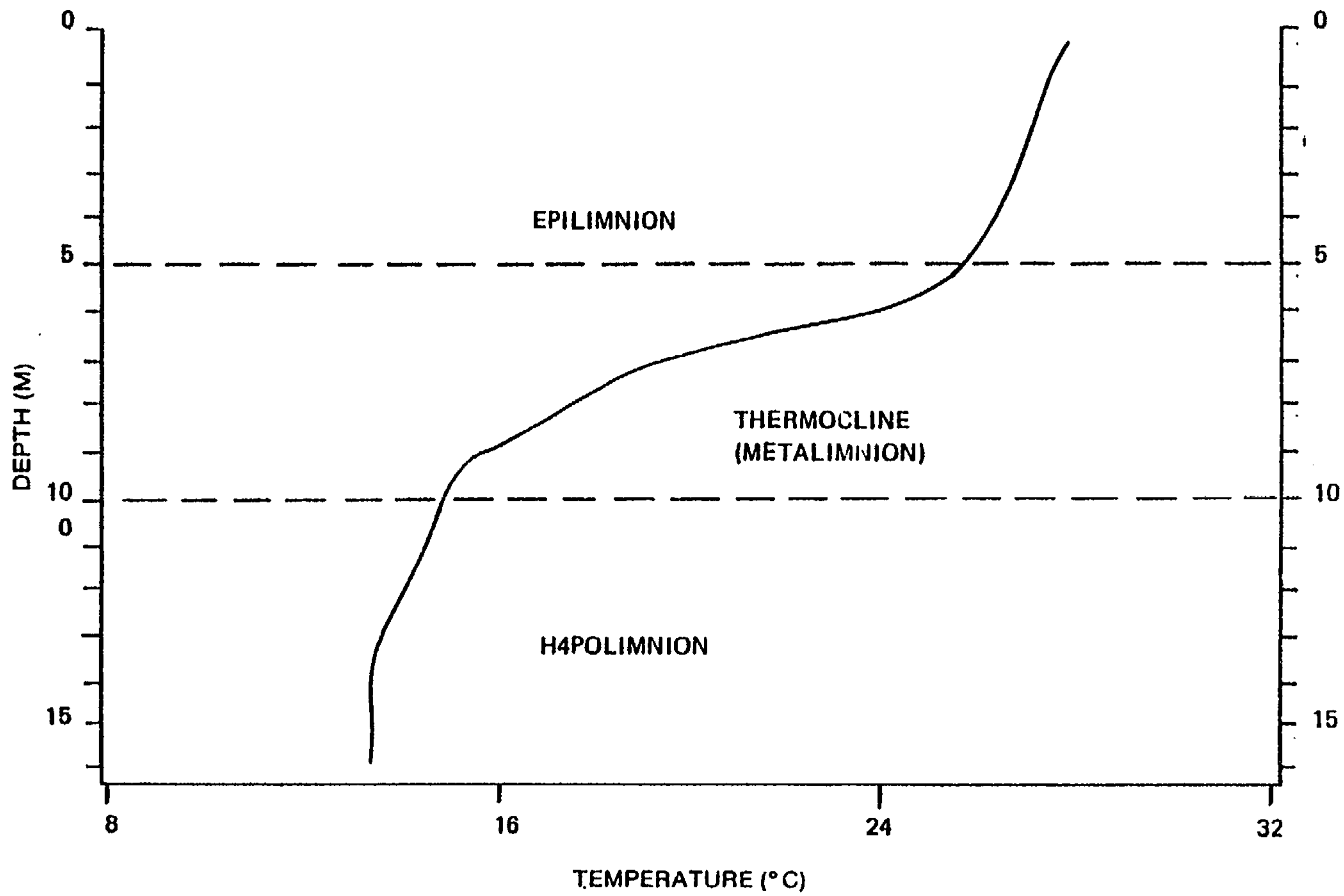

Figure 3.5-7. Vertical temperature profile at the Dam station for July, 1976 (pre-operational).

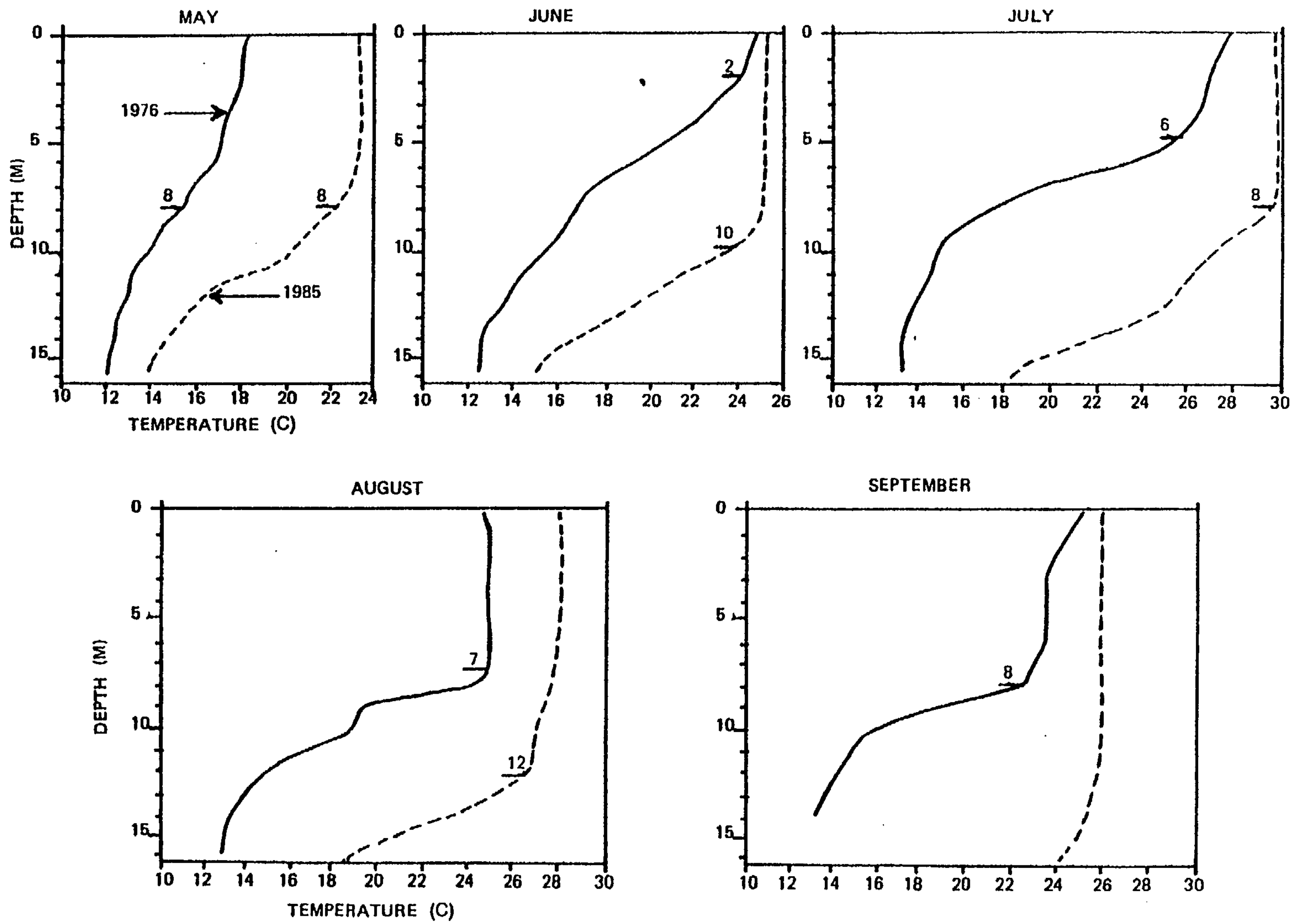

Figure 3.5-8. Vertical profiles at the Dam station for **1976** (pre-operational) and **1985** (operational), showing the lower boundary of the epilimnion and depth (m).

not occur during 1985. The late August surveys indicated that the trend had reversed and epilimnetic cooling was in progress, more rapid in the pre-operational year. A pool of cool hypolimnetic water remained at the end of the summer 1976, but was exhausted in 1985. In summary, power station operation increased the volume and average temperature of the epilimnion while exhausting the hypolimnion

Classical definitions as applied to lakes cannot be applied indiscriminately to reservoirs because there is considerably more spatial heterogeneity in a reservoir. The reservoir gradient from the tributaries to the dam usually encompasses a shift from a riverine to a lacustrine ecosystem. The Lower Lake portion of Lake Anna is more lacustrine than the Upper Lake, with vertical gradients of light, temperature, and decomposition processes that control primary productivity. As discussed earlier, there was a classical distribution of epilimnetic and hypolimnetic waters during the pre-operation summer of 1976 (Fig. 3.5-7). The same was evident during 1973-1977 (pre-operational), 1982 and 1984 (low-level operation). The euphotic zone usually extends well into the epilimnion during summer stratification and oxygen concentrations are greatly dependent upon photosynthesis (see Section 4.1). Because of the relatively high concentration of oxygen, the epilimnion constitutes the majority of the productive lake volume. There were periods when dissolved oxygen levels in the epilimnion exceeded the saturation values. Levels from 120% to 130% of saturation were observed at the Upper Lake

stations in May 1984 and April 1985. Rapid seasonal warming decreases the solubility of dissolved gas (which is directly proportional to the partial pressure of the gas) and if the surface waters are not agitated by wave actions, a supersaturated condition can result. During this period the mixing of epilimnetic and hypolimnetic waters does not occur because of the density differences between the two.

Lakes that exhibit a clinograde oxygen profile (Fig. 3.5-9) are characterized by a rapid decrease in dissolved oxygen through the metalimnion and an anoxic hypolimnion. These lakes are productive and are generally classified as eutrophic, but not necessarily in the original sense of being concentrated with nutrients (Hutchinson 1975). The primary mechanisms of dissolved oxygen removal include animal, plant and bacterial respiration and chemical oxidation. In practically all lakes, the hypolimnetic oxygen deficit results from the oxidation of organic matter that originates in the lake itself (photosynthetically) or that enters the lake (in suspension or in solution). In new reservoirs, there is also oxidation (decomposition) of organic matter in soils that were innundated. The same reactions that are responsible for the removal of oxygen cause the release and accumulation of nitrogen and phospate compounds and other nutrients. Carbon dioxide and carbonate concentrations tend to show a general inverse relationship to oxygen. Anoxic conditions also favor the production of methane and the reduction of sulfates to hydrogen sulfides through chemosynthetic processes of sulfur bacteria.

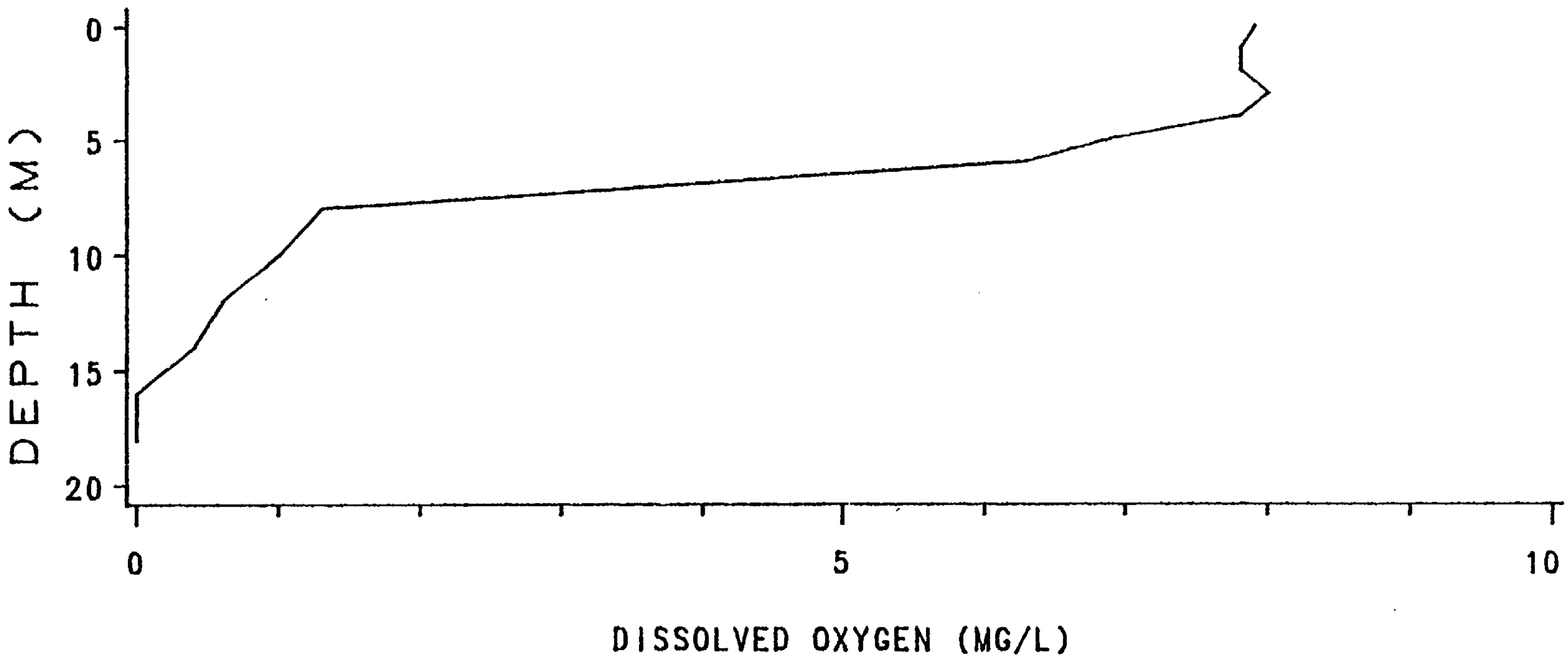

Figure 3.5-9. Clinograde oxygen profile at the Dam station, Lake Anna, Virginia, for July, 1976.

As only a few species of plants and animals are adapted to inhabiting the hypolimnion, an analysis was carried out to determine if a relationship existed between station operation and the volume of the epilimnion. For the purposes of this analysis, the epilimnion was defined as that portion of the water column where the change in temperature is less than 1°C per meter of depth. The "epilimnion depth" corresponds to the lower boundary of the epilimnion as well as the upper boundary of the thermocline. The "oxygenated depth" refers to that point below which dissolved oxygen levels are less than 5 mg/l. Five water quality stations were selected to represent the entire reservoir (North Anna Arm, Rt. 208 Bridge, Intakes, Mid-Lake and Dam). Temperature and dissolved oxygen values were calculated by averaging across the five stations for each month, volumes were calculated from a hypsographic curve of the reservoir basin (Fig. 3.5-10). Results are shown in Table 3.5-4.

The epilimnion is expanded by station operation variables throughout the summer months (June - September). The maximum depth at which oxygen remained greater than or equal to 5 mg/l was also closely related to station operation variables in the later months of the summer (August and September). An examination of Table 3.5-4 for the month of August indicates that there were eight years including all the pre-operation years (1973-1977), and years with low levels of station operation (1979, 1982 and 1984) in which the oxygen levels dropped below 5 mg/l at 4-6 m.

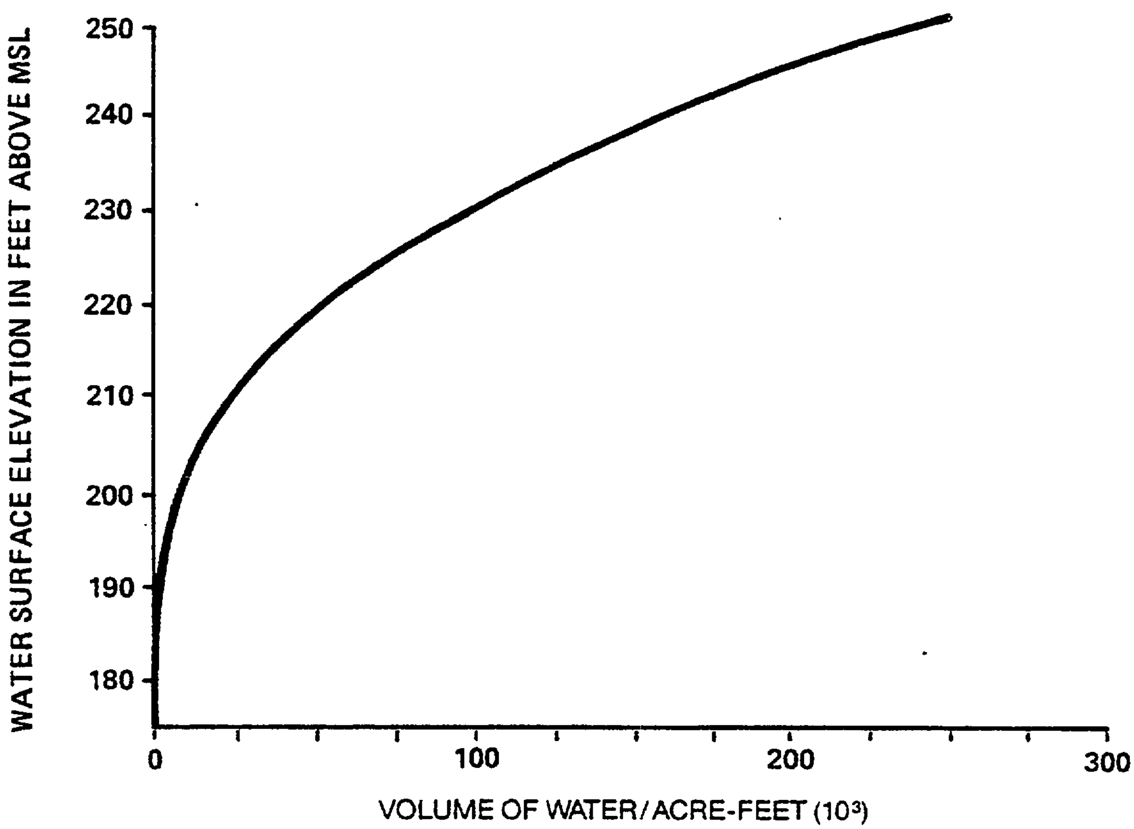

Figure 3.5-10. Stage volume relationship of Lake Anna, Virginia.

Table 3.5-4. Depth, volume and percentage of Lake Anna epilimnion and oxygenated water related to station load and circulating water pump operation. The stations used in this analysis are monthly water quality sites including the North Anna Arm, Rt. 208 Bridge, Intakes, Mid Lake and Dam. Both temperature and dissolved oxygen values were obtained by averaging across the five stations for each month.

YEAR	MONTH	POW LEVEL MONTH AVE %	CIRC PUMPS MONTH AVE %	EPILIMNION DEPTH (METERS)	OXYGENATED DEPTH (METERS)	EPILMNION VOLUME (ACRE-FEET)[1]	OXYGENATED VOLUME (ACRE-FEET)[2]	EPILIMNION % OF LAKE VOLUME	OXYGENATED % OF LAKE VOLUME
73	5	0	0	5	NO DATA	122000	NO DATA	51	NO DATA
	6	0	0	1	8	28000	172000	12	72
	7	0	0	3	3	79000	79000	33	33
	8	0	0	4	4	101000	101000	42	42
	9	0	0	6	5	140000	122000	59	51
74	5	0	0	4	NO DATA	101000	NO DATA	42	NO DATA
	6	0	0	4	7	101000	157000	42	66
	7	0	0	3	8	79000	172000	33	72
	8	0	0	4	5	101000	122000	42	51
	9	0	0	6	5	140000	122000	59	51
75	5	0	0	3	16	79000	233000	33	97
	6	0	0	3	5	79000	122000	33	51
	7	0	0	4	5	101000	122000	42	51
	8	0	0	3	5	79000	122000	33	51
	9	0	0	10	8	196000	172000	82	72
76	5	0	0	20	18	236000	235000	99	98
	6	0	0	5	5	122000	122000	51	51
	7	0	0	5	6	122000	140000	51	59
	8	0	0	7	6	157000	140000	66	59
	9	0	0	6	8	140000	172000	59	72
77	5	0	0	2	NO DATA	54000	NO DATA	23	NO DATA
	6	0	0	4	NO DATA	101000	NO DATA	42	NO DATA
	7	0	0	2	5	54000	122000	23	51
	8	0	0	4	5	101000	122000	42	51
	9	0	0	7	6	157000	140000	66	59
78	5	21	44	3	NO DATA	79000	NO DATA	33	NO DATA
	6	42	50	9	6	185000	140000	77	59
	7	43	74	13	4	219000	101000	91	42
	8	47	52	11	8	206000	172000	86	72
	9	36	44	14	4	222000	101000	93	42
79	5	44	56	9	10	185000	196000	77	82
	6	49	46	8	8	172000	172000	72	72
	7	47	50	8	6	172000	140000	72	59
	8	50	50	8	6	172000	140000	72	59
	9	35	69	11	10	206000	196000	86	82

Table 3.5-4 (continued).

YEAR	MONTH	POW LEVEL MONTH AVE %	CIRC PUMPS MONTH AVE %	EPILIMNION DEPTH (METERS)[1]	OXYGENATED DEPTH (METERS)[2]	EPILMNION VOLUME (ACRE-FEET)	OXYGENATED VOLUME (ACRE-FEET)	EPILIMNION % OF LAKE VOLUME	OXYGENATED % OF LAKE VOLUME
80	5	35	70	10	11	196000	206000	82	86
	6	33	82	13	7	219000	157000	91	66
	7	47	93	13	6	219000	140000	91	59
	8	50	81	13	8	219000	172000	91	72
	9	63	92	13	9	219000	185000	91	77
81	5	79	85	13	17	219000	234000	91	98
	6	79	84	9	8	185000	172000	77	72
	7	47	88	15	8	232000	172000	97	72
	8	60	92	15	10	232000	196000	97	82
	9	93	100	18	16	235000	233000	98	97
82	5	11	38	4	6	101000	140000	42	59
	6	25	30	4	5	101000	122000	42	51
	7	9	40	7	6	157000	140000	66	59
	8	1	38	8	5	172000	122000	72	51
	9	47	38	11	11	206000	206000	86	86
83	5	42	57	6	19	140000	236000	59	98
	6	79	92	9	5	185000	122000	77	51
	7	92	100	11	8	206000	172000	86	72
	8	99	98	14	8	222000	172000	93	72
	9	96	100	19	19	236000	236000	98	98
84	5	62	63	0	19	0	236000	0	98
	6	48	50	2	6	54000	140000	23	59
	7	43	50	8	6	172000	140000	72	59
	8	3	38	9	5	185000	122000	77	51
	9	1	38	12	11	213000	206000	89	86
85	5	99	75	11	11	206000	206000	86	86
	6	99	75	10	9	196000	185000	82	77
	7	91	88	8	8	172000	172000	72	72
	8	72	75	12	9	213000	185000	89	77
	9	83	75	16	13	233000	219000	97	91

[1] Epilimnion - defined as that portion of the water column where delta temperature is less than 1 degree per meter.

[2] Oxygenated - defined (for the purpose of this analysis) as that portion of the water column where dissolved oxygen is greater than or equal to 5 mg/l.

The other five years with higher levels of station operation maintained August oxygen concentrations of 5 mg/l or more to a depth 8-10 m. From 5 m to 9 m there is a corresponding increase in reservoir volume from 1.5 x 10^8 to 2.3 x $10^8 m^3$ (from 122,000 to 185,000 acre-feet or approximately 27% of the reservoir volume). On the basis of this analysis, there is a beneficial influence of station operation on the volume of oxygenated waters in the lake. This may be equated to an increase in living space for indigenous species that inhabit the warm epilmnion of Lake Anna.

A definite relationship exists in Lake Anna between the lower boundary of the epilimnion and the lower boundary of well-oxygenated water for the months of August and September. The epilimnion is, by definition, a mixed layer and usually does correspond to the well-oxygenated zone in Lake Anna. The expected pattern is one where oxygen stratification nearly parallels temperature stratification; however, variations can exist under different circumstances (Appendix B-Figs. 20-24). When light penetrates below the depth of the thermocline, oxygen levels may be higher due to photosynthetic activity. Oxygenated water within the reservoir may also be transported from one location to another by currents and eddy conduction. Currents in Lake Anna result from surface wind activity and by circulation induced by the circulating water pumps. Wind-induced turbulence is probably the predominant factor in spring and fall overturn, whereas pumping appears to have an overriding effect on the movement of water during summer stratification.

3.6 Water Quality Studies

This section summarizes the water quality sampling surveys for dissolved oxygen, pH, alkalinity, turbidity, nutrients and heavy metals, designed to evaluate seasonal and/or annual variations and to determine changes related to station operation. A discussion that relates classical lake definitions to reservoir systems describes the longitudinal and vertical gradients that are evident in the Lake Anna water quality data. Results of an analysis between station operation variables and stratification characteristics are followed by a review of the general water quality data, land use in the vicinity of Lake Anna and the status of nutrients throughout the reservoir. An overview of the Contrary Creek reclamation project by the Virginia State Water Control Board begins the dissolved metals data presentation, and includes a discussion of correlation analyses with the nutrient data. This section is concluded with summary statements of the more significant water quality findings.

Information Base for Evaluation

Water quality sampling station locations and the parameters measured are shown in Table 3.6-1 and Figure 3.6-1. The program was developed to be representative of the entire system (Upper, Mid and Lower Lake) with supplemental sampling of the different strata in conjunction with phytoplankton and zooplankton studies. Detailed descriptions of the sampling and analytical procedures used during the study are in Appendix D.

Table 3.6-1. Water quality parameters and stations that were sampled in Lake Anna during the study period, 1984-1985.

WATER QUALITY PARAMETERS	GENERALIZED SAMPLING DEPTHS
Temperature (°C)	Profiles (surface-bottom)
Dissolved Oxygen (mg/l)	Profiles (surface-bottom)
pH	Surface, Mid, Bottom
Alkalinity (mg/l as CaCO3)	Surface, Mid, Bottom
Turbidity (NTU)	Surface, Mid, Bottom
Ammonia Nitrogen (NH_3, mg/l)	Surface, Mid, Bottom
Nitrate Nitrogen (NO_3-N, mg/l)	Surface, Mid, Bottom
Total Phosphate (T-PO_4, mg/l)	Surface, Mid, Bottom
Orthophosphate (O-PO_4, mg/l)	Surface, Mid, Bottom
Dissolved Iron (Fe, mg/l)	Surface, Mid, Bottom
Dissolved Copper (Cu, mg/l)	Surface, Mid, Bottom
Dissolved Zinc (Zn, mg/l)	Surface, Mid, Bottom
Dissolved Lead (Pb, mg/l)	Surface, Mid, Bottom

WATER QUALITY STATIONS	STATION DEPTHS (M)
Dam	19
Dike 3 Endeco	7
Burrus Point	9
Mid Lake	12
Intakes	11
Rt. 208 Bridge	11
Contrary Creek	7
Pamunky Arm	7
North Anna Arm	7

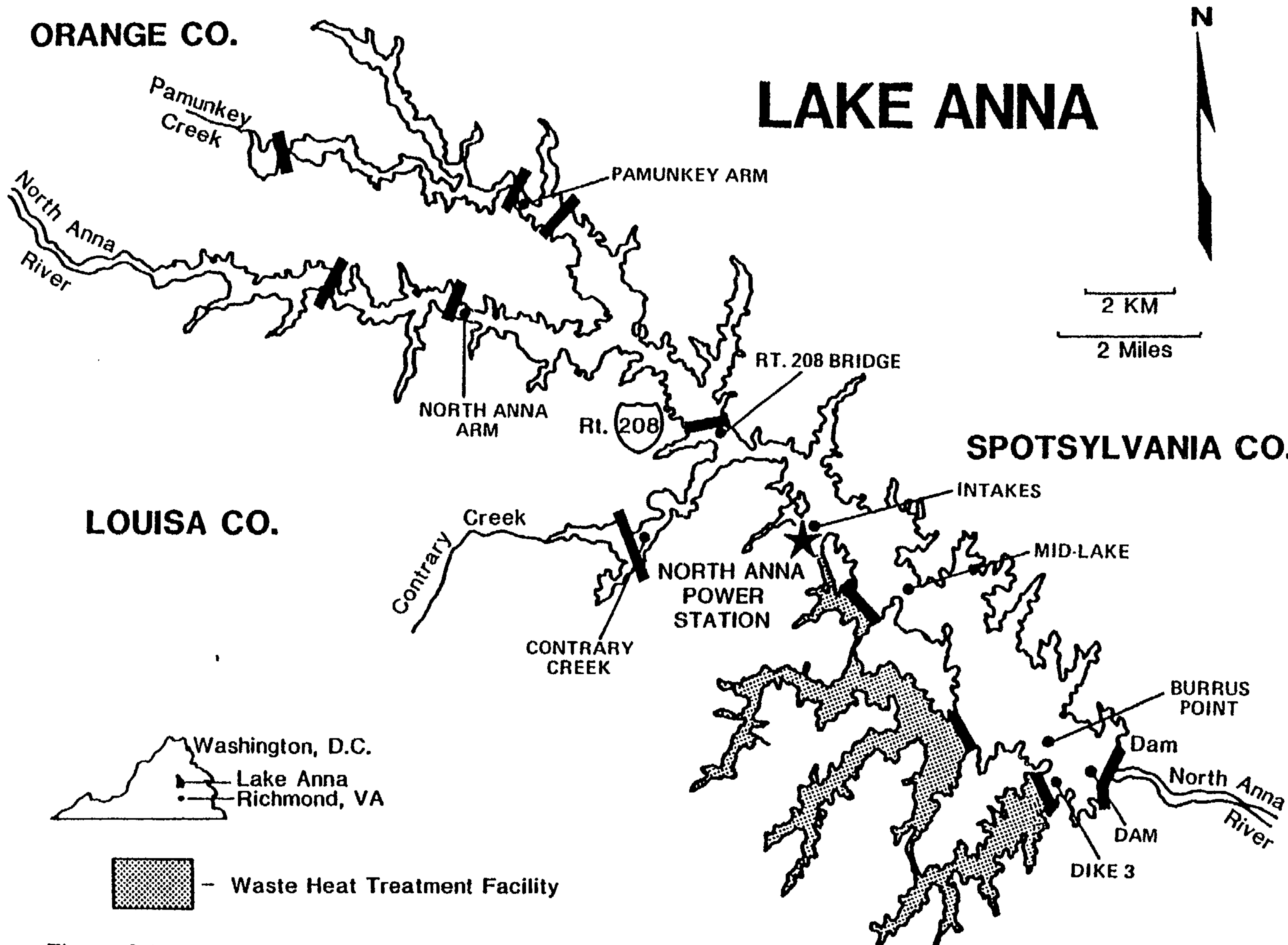

Figure 3.6-1. Location of 316(a) water quality sampling stations.

Land Use

In 1977, a study was performed by a consultant (Schultz 1977) to document the land uses around the reservoir as well as the changes that had taken place since inundation from 1972-1976. It also documented the zoning regulation changes in the tri-county area bordering on Lake Anna. The study required a team of several individuals to carry out the necessary field work which included record searches, interviews with real estate developers and surveys of residential, commercial and industrial areas in the three counties (Orange, Louisa, Spotsylvania). The study area was approximately 251 km^2 (more than 100,000 acres) with 53% of the total in Louisa County, 38% in Spotsylvania County and 9% in Orange County. From 1972, when the basin was inundated and the study began, to 1976 when the study was completed, approximately 21% of the 53 km^2 (21,078 acre) study area had changed use. The reservoir and Virginia Power facility encompassed 18% of the original study area (46 km^2 or 18,206 acres). Of the remaining 3% that changed use, 7 km^2 (2667 acres) became new residential areas and 0.5 km^2 (205 acres) were developed for recreational use. It was stated that many of the residential areas were not fully developed but the acreage was still included in the total.

According to the Louisa County Comprehensive Plan drafted in March 1985, the area surrounding Lake Anna is zoned for low density residential with one or less units per acre. An increase in the number of second or vacation homes has occurred in recent years. By 1985, about 1,000 one acre

lots had been subdivided. An additional 24-26 km^2 (15-16 sq. miles) had been zoned for one acre lots which have the potential to create about 8,000 more lots. The county projects that fewer than one-fourth of these lots will ever be developed. The possibility that the area ever will be served with central water or sewer is remote because of the prohibitive expense required to overcome topographic and low density problems.

The Comprehensive Plan also states Louisa County is no longer dominated by agriculture and that future changes in the population will occur as a result of factors external to the county (changes and growth in Charlottesville and Richmond). The 1980 census revealed more than half of the employed people that lived in Louisa worked elsewhere. The agricultural census showed the amount of land used for agricultural purposes has declined slightly over the last fifteen years. In 1982, 28% of the total land in Louisa County was farmland (3/4 of which was pastureland or woodland, 1/4 harvested cropland). Cattle operations will continue to be the major occupation for most farm businesses. Pasture will be the primary land use, with croplands supporting primarily corn and hay.

Spotsylvania County has designated land adjacent to the reservoir, where most of the growth is expected to occur, as the Lake Anna Community Settlement Area. The Planning Commission expected the 1970 population to double by 1985 (County of Spotsylvania, Virginia 1980), but according to the opinion of the County Administrator (Payne

1985), that estimate may be somewhat conservative for the settlement area. Development was expected to be oriented towards recreation, retirement and seasonal activities of low density and low intensity. On-site well and septic disposal systems were to be used exclusively and the gross density was not to exceed one housing unit per acre. Recreational commercial centers were expected to consist of development clusters (marinas and other recreational facilities), with sites selected carefully in consideration of potential impact to the lake. Prior to the advent of Lake Anna, the principle activity within the settlement area consisted of agriculture and forestry. There had been a persistent decline in agricultural activity, but the current investment pattern has stabilized the former general economic decline.

Water Quality Assessment

The headwaters of the York River Basin generally have excellent water quality although heavy metal leachates and low pH waters from abandoned mining activities have adversely affected some tributary streams. In general, the water in the upper tributary streams is soft and low in carbonate ions reflecting the absence of limestone deposits in the drainage basin. The clay soils of the Piedmont Physiographic Province are high in iron, highly acidic and highly erodible. Approximately 65% of the Piedmont Province lacks a nutrient-rich topsoil layer, requiring farmers to rely on regular application of fertilizers.

Differences among the watersheds of the Upper and Lower Lake stations in Contrary Creek are primarily responsible for water quality differences between these areas. The Upper Lake has more riverine characteristics than the Lower Lake, a larger surface area-to-volume ratio, higher rates of sedimentation, and horizontal gradients in channel morphology and flow velocity. Turbidity, alkalinity and pH values were generally higher in the Upper Lake than in the Lower Lake (Appendix B-Table 1).

Mean annual turbidities since 1981 ranged from 6-10 NTU's in the Upper Lake, 2-5 NTU's in the Lower Lake and Contrary Creek (Table 3.6-2). Differences between the Upper and Lower Lake are more obvious in monthly mean comparisons (Fig. 3.6-2). Hypolimnetic samples generally had higher turbidity values than epilimnetic samples. The majority of values greater than 15 NTU's occurred during the spring runoff period of February, March and April.

Alkalinity annual means ranged from 14-16 mg/l (as $CaCO_3$) at Upper Lake Stations since 1981, 8-12 mg/l at Lower Lake Stations, and 4-8 mg/l in Contrary Creek (Table 3.6-2). The virtual absence of limestone in this region accounts for alkalinity values of less than 40 mg/l (as $CaCO_3$). Lake-wide annual means (excluding the Contrary Creek station) decreased from 13.1 mg/l in 1981 to 11.7 mg/l in 1985. Contrary Creek annual means have ranged from 4.2-8.2 mg/l during that period. It is possible Contrary Creek is moderating the alkalinity of the Lower Lake. Mild, seasonal variations in the Upper Lake appeared as winter-spring

Table 3.6-2. Annual means of water quality parameters in Lake Anna, Virginia, by station, 1972-1985.

STATION	YEAR	ALK MG/L	TURB NTU	PH
NORTH ANNA ARM	1975	21.1	.	6.8
	1976	1.8	.	6.7
	1977	21.3	.	6.3
	1978	13.3	.	6.6
	1979	15.7	.	6.9
	1980	18.2	.	4.5
	1981	15.7	6.0	6.9
	1982	14.4	6.7	7.1
	1983	14.5	6.9	7.1
	1984	15.0	6.2	7.1
	1985	14.0	7.2	7.1
PAMUNKEY ARM	1975	20.7	.	6.7
	1976	8.7	.	7.0
	1977	22.9	.	6.8
	1978	12.2	.	6.6
	1979	15.9	.	6.9
	1980	17.3	.	6.8
	1981	14.6	5.8	6.9
	1982	14.8	7.0	7.1
	1983	14.5	8.8	7.1
	1984	15.1	10.2	7.1
	1985	14.2	7.4	7.1
RT 208 BRIDGE	1972	17.9	.	6.4
	1973	20.4	.	6.5
	1974	20.0	.	6.6
	1975	19.6	.	6.7
	1976	4.1	.	6.7
	1977	19.7	.	6.7
	1978	14.5	.	6.8
	1979	14.1	.	6.8
	1980	15.9	.	6.5
	1981	11.7	3.1	6.8
	1982	11.0	2.8	6.9
	1983	11.4	2.8	7.0
	1984	10.3	5.2	6.9
	1985	10.1	2.6	7.0
CONTRARY CREEK BRIDGE	1972	0.0	.	3.8
	1973	8.2	.	4.8
	1974	6.5	.	5.2
	1975	6.1	.	5.6
	1976	3.5	.	3.2
	1977	10.3	.	6.2
	1979	.	.	5.0
	1980	.	.	5.9
	1981	8.2	3.9	6.3
	1982	4.4	2.9	5.5
	1983	5.0	3.2	5.6
	1984	4.2	4.3	5.3
	1985	5.8	5.0	6.2

Table 3.6-2. (continued).

STATION	YEAR	ALK MG/L	TURB NTU	PH
INTAKE	1972	18.0	.	6.6
	1973	16.8	.	6.7
	1974	18.0	.	6.7
	1975	17.8	.	6.8
	1976	2.0	.	6.9
	1977	18.9	.	7.1
	1978	14.8	.	6.8
	1979	14.5	.	6.6
	1980	16.1	.	6.7
	1981	11.4	3.2	6.8
	1982	10.4	2.4	7.0
	1983	10.3	2.2	6.9
	1984	9.2	3.3	6.9
	1985	9.3	2.1	7.0
MID LAKE	1973	19.3	.	6.6
	1974	20.7	.	4.1
	1975	19.8	.	6.1
	1976	1.9	.	7.0
	1977	20.3	.	6.8
	1978	15.4	.	6.9
	1979	14.7	.	6.8
	1980	15.9	.	6.6
	1984	8.8	2.9	6.9
	1985	9.6	2.0	6.9
DAM	1972	16.7	.	6.8
	1973	17.1	.	6.8
	1974	19.4	.	6.8
	1975	20.4	.	4.9
	1976	1.9	.	6.8
	1977	20.2	.	6.9
	1978	15.7	.	6.8
	1979	14.9	.	6.8
	1980	15.8	.	6.5
	1981	12.1	4.6	6.8
	1982	10.5	2.4	6.8
	1983	11.1	2.7	6.9
	1984	9.4	3.0	6.8
	1985	10.9	2.1	6.9
DIKE 3 ENDECO	1984	8.3	2.4	6.8
	1985	9.7	2.1	6.9
BURRUS POINT	1984	8.7	2.6	6.9
	1985	9.6	2.0	7.0

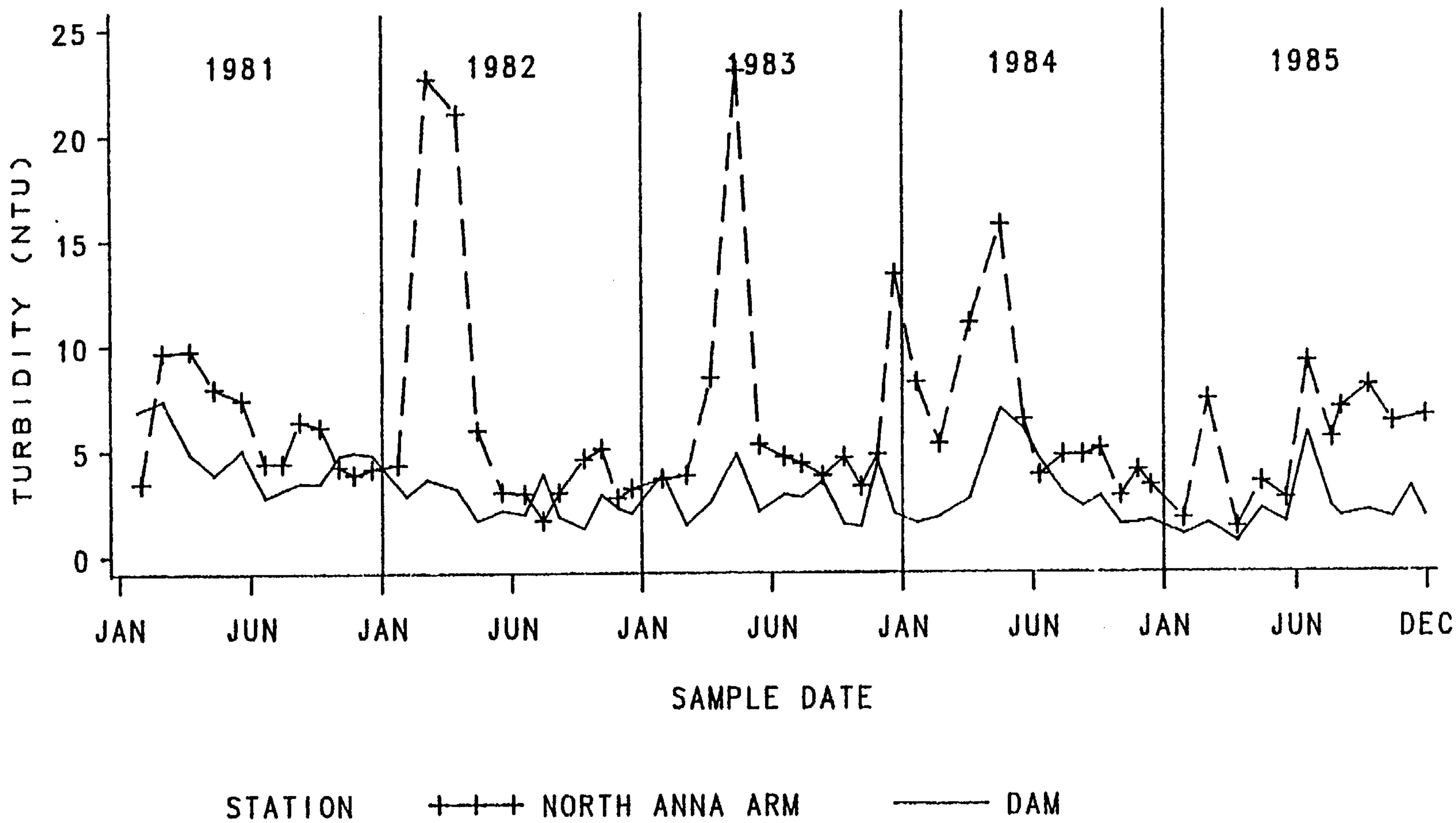

Figure 3.6-2. Monthly mean turbidity levels in water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

increases/summer-fall decreases in the epilimnion. Slight increases occurred in the Lower Lake hypolimnion during the summer.

The annual mean pH in the Upper Lake was consistently near 7.1, approximately 6.9 in the Lower Lake and 5.7 in Contrary Creek. Since 1981, the lowest pH recorded at the Contrary Creek Bridge was 3.8 (bottom sample) in February 1984 (Appendix B-Table 1). When the stream bed was first inundated in 1972, the average pH in Contrary Creek was approximately 4.0.

Most of the pre-operation nutrient data reflect recent inundation of farmland and associated elevated nutrient levels which have tapered off as the reservoir has aged. In recent years, nutrient levels have remained consistently low (Table 3.6-3) (Fig. 3.6-3). Trends that tend to be parameter-specific have been identified, where possible.

Minimum concentrations of ammonia in Lake Anna generally occurred in the spring and maximums occurred in the fall and early winter (Figure 3.6-4). During summer months, high ammonia levels occurred most frequently in hypolimnetic samples. Annual means by station since 1972 (Table 3.6-3) reflect higher concentrations in the early years following inundation, more evident in the Upper Lake, but since 1979, the maximum ammonia concentration was recorded in a surface sample from the Dam station in December 1983 (0.84 mg/l).

Table 3.6-3. Annual means of nutrients (mg/l) in Lake Anna, Virginia, by station, 1972-1985.

STATION	YEAR	NH3_N (MG/L)	O_PO4 (MG/L)	T_PO4 (MG/L)	NO3_N (MG/L)
NORTH ANNA ARM	1973	0.88	0.07	0.74	0.70
	1974	0.78	0.24	0.55	0.80
	1975	0.14	0.06	0.26	0.52
	1976	0.13	0.06	0.19	0.79
	1977	0.12	0.02	0.29	0.25
	1978	0.06	0.0	0.04	0.07
	1979	0.03	0.0	0.07	0.11
	1980	0.03	0.0	0.06	0.14
	1981	0.06	0.01	0.05	0.95
	1982	0.04	0.01	0.03	0.25
	1983	0.06	0.02	0.05	0.60
	1984	0.04	0.01	0.03	0.18
	1985	0.04	0.0	0.01	0.07
PAMUNKEY ARM	1974	1.18	0.33	0.48	1.10
	1975	0.15	0.09	0.25	0.71
	1976	0.21	0.05	0.21	0.75
	1977	0.12	0.03	0.38	0.21
	1978	0.03	0.01	0.05	0.07
	1979	0.07	0.0	0.06	0.16
	1980	0.07	0.0	0.05	0.18
	1981	0.07	0.01	0.04	0.75
	1982	0.06	0.01	0.02	1.41
	1983	0.07	0.02	0.05	0.83
	1984	0.10	0.02	0.04	0.22
	1985	0.06	0.01	0.02	0.07
RT 208 BRIDGE	1984	0.07	0.24	0.01	0.02
	1985	0.06	0.11	0.01	0.02
CONTRARY CREEK BRIDGE	1984	0.05	0.11	0.0	0.01
	1985	0.06	0.07	0.0	0.01
INTAKES	1973	0.46	0.13	0.63	1.90
	1974	0.29	0.05	0.05	2.30
	1978	0.07	0.0	0.03	0.18
	1979	0.04	0.0	0.05	0.17
	1980	0.02	0.0	0.03	0.23
	1981	0.10	0.01	0.02	0.75
	1982	0.06	0.01	0.02	1.11
	1983	0.08	0.01	0.03	0.51
	1984	0.07	0.02	0.03	0.20
	1985	0.07	0.02	0.03	0.12
MID LAKE	1984	0.08	0.24	0.02	0.03
	1985	0.08	0.12	0.02	0.03
BURRUS POINT	1984	0.07	0.22	0.0	0.02
	1985	0.08	0.13	0.01	0.06

Table 3.6-3. (continued).

1DIKE 3 ENDECO	1984	0.08	0.22	0.01	0.02
	1985	0.08	0.13	0.04	0.04
DAM	1972	0.17	0.05	0.09	3.50
	1973	0.37	0.06	0.64	2.00
	1974	0.46	0.04	0.46	1.70
	1975	0.11	0.02	0.12	0.50
	1976	0.11	0.02	0.18	0.59
	1977	0.07	0.02	0.39	0.24
	1978	0.08	0.0	0.05	0.17
	1979	0.03	0.0	0.04	0.17
	1980	0.04	0.0	0.02	0.20
	1981	0.09	0.04	0.03	0.83
	1982	0.06	0.0	0.01	1.19
	1983	0.21	0.01	0.03	0.60
	1984	0.09	0.01	0.02	0.22
	1985	0.12	0.0	0.0	0.12

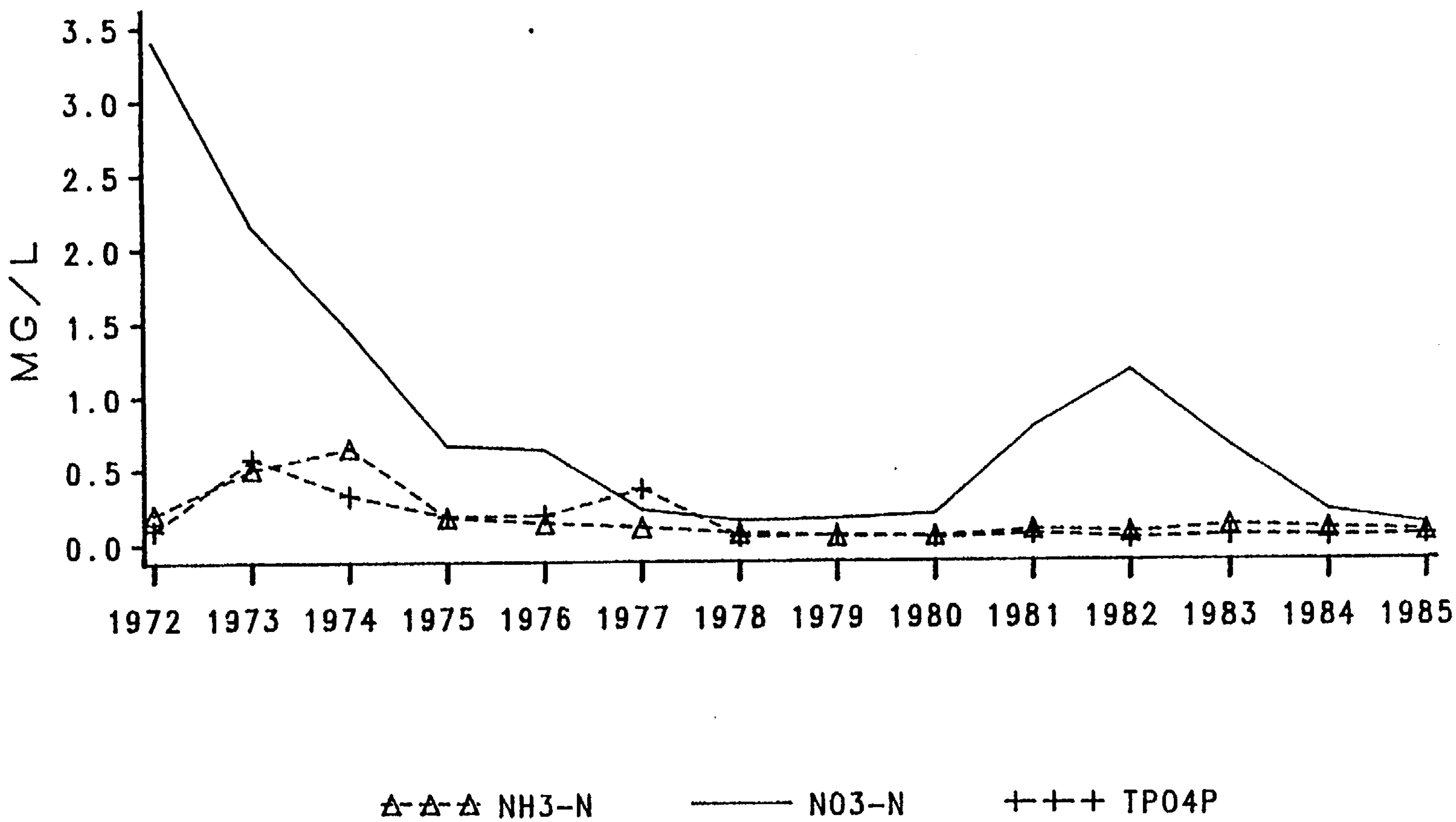

Figure 3.6-3. Annual nutrient means for Lake Anna, Virginia, since 1972, excluding Contrary Creek data.

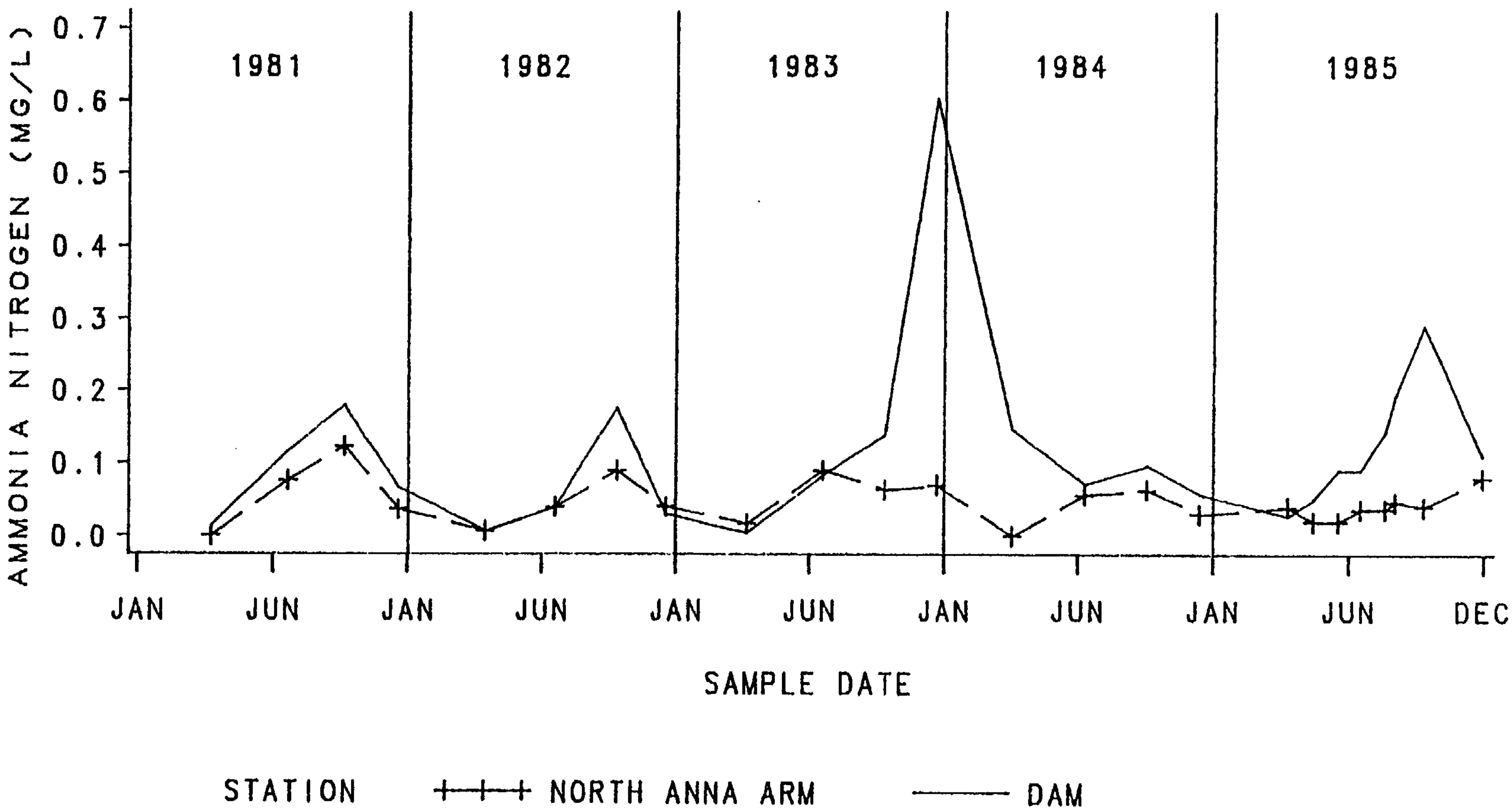

Figure 3.6-4. Monthly mean ammonia nitrogen concentrations in water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

Nitrate nitrogen levels were generally highest in the early spring and lowest in late summer (Fig. 3.6-5). Annual means since 1972 (Table 3.6-3) reflect decreasing concentrations over the years with Lower Lake values usually in excess of Upper Lake values. The maximum concentration measured since 1979 was 3.16 mg/l from a Pamunkey Arm hypolimnion sample in March 1983.

Maximum phosphate levels generally occurred during the spring to early summer and were slightly more concentrated in the Upper Lake (Fig. 3.6-6). In most lakes, soluble phosphate concentrations decline from relatively high winter levels at the start of spring to low levels throughout the summer up until early winter. The maximum value since 1979 (0.90 mg/l) occurred in an epilimnion sample at the Dike 3 Endeco stations in April 1985 (Appendix B-Table 1). According to the analysis, it was in the form of ortho-phosphate, but the next month concentrations were below detection limits at that station. Although it is only required in small amounts, phosphorus is a common phytoplankton growth limiting element because of the geochemical shortage in many drainage basins.

Since 1981, the highest concentrations of dissolved metals (iron, copper and zinc) in Lake Anna were measured at the Contrary Creek Bridge station. The Upper Lake drainage also contributed metals to the reservoir. This entire area lies in a pyrite-gold belt of the Piedmont Physiographic Province, a mineral rich area mined extensively during the 19th and 20th centuries for pyrite ore. Over 5.4×10^6

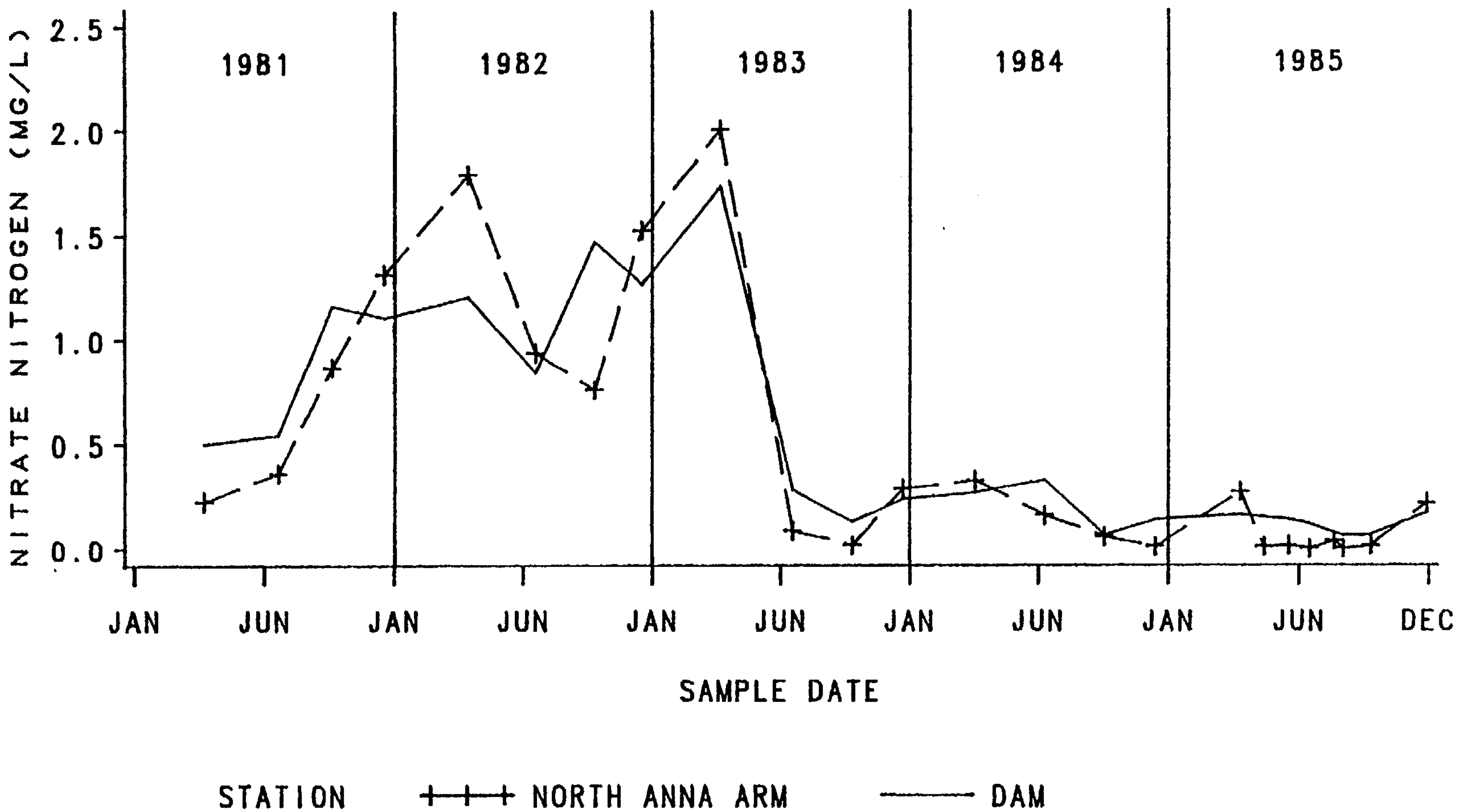

Figure 3.6-5. Monthly mean nitrate nitrogen concentrations in water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

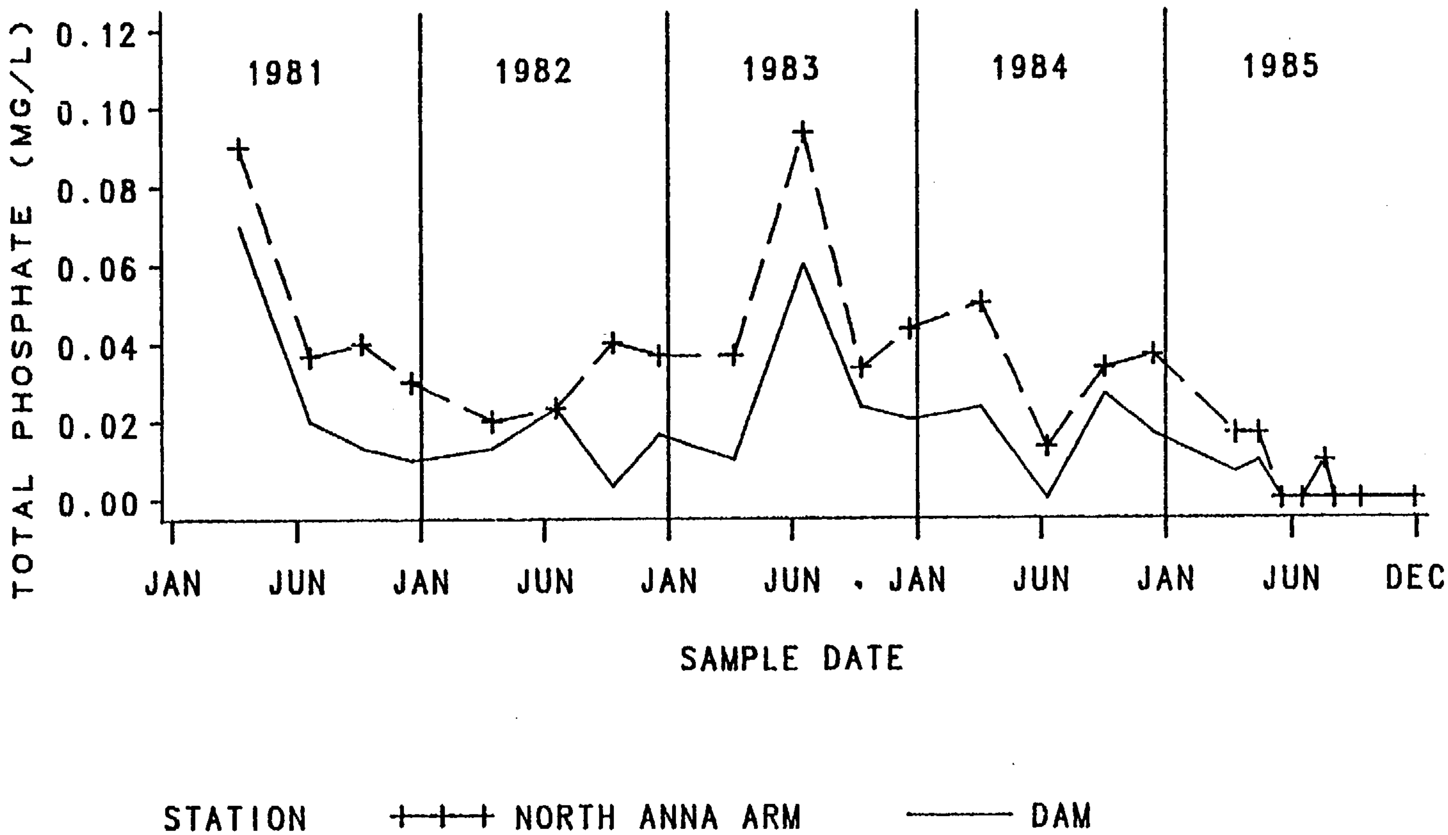

Figure 3.6-6. Monthly mean total phosphate concentrations inn water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

megagrams (six million tons) of ore were produced from three deep-shaft mines on Contrary Creek, and large volumes of waste denuded about 12 hectares creating a severe acid mine drainage problem. After determining the presence and extent of heavy metals that were leaching into Contrary Creek in 1971, the Virginia State Water Control Board initiated action in 1976 to reclaim two of the mining areas. Subsequent monitoring by the VSWCB failed to show marked improvements downstream from the reclaimed sites (Hinkle 1982), but Virginia Power monitoring data collected from the upper impounded section of Contrary Creek (Rt. 652 Bridge) have indicated relatively stable water quality conditions in recent years (Table 3.6-4).

Iron concentrations were highly variable throughout Lake Anna for several years, but since 1980 have stablized considerably (Fig. 3.6-7). Historically, concentrations generally have been low during the spring and have increased to maximum levels in mid summer. The hypolimnetic concentration (1984-1985) averaged more than twice that of epilimnetic concentrations. The maximum value (22.1 mg/l) since 1979 was measured in a sample from the Rt. 208 Bridge hypolimnion in September 1979. Soluble iron is characteristic of an anoxic hypolimnion.

Copper has occurred at relatively low concentrations in Lake Anna (Table 3.6-4) with little difference between the Upper and Lower Lake stations (Fig. 3.6-8). It was detected in only 6% of samples collected from 1984-1985 and only at the Contrary Creek Bridge, Rt.

Table 3.6-4. Annual means of dissolved metals (mg/l) in Lake Anna, Virginia, by station, 1975-1985.

STATION	YEAR	FE (MG/L)	CU (MG/L)	ZN (MG/L)	PB (MG/L)
NORTH ANNA ARM	1975	2.17	0.01	0.0	0.03
	1976	0.33	0.01	0.0	0.0
	1977	0.45	0.0	0.0	0.0
	1978	0.69	0.0	0.0	0.0
	1979	1.33	0.0	0.0	0.0
	1980	0.37	0.0	0.01	0.0
	1981	0.19	0.0	0.0	0.01
	1982	0.22	0.01	0.01	0.01
	1983	0.30	0.01	0.01	0.07
	1984	0.25	0.0	0.01	0.0
	1985	0.25	0.0	0.0	0.0
PAMUNKEY ARM	1975	1.20	0.02	0.01	0.02
	1976	0.30	0.01	0.0	0.0
	1977	0.60	0.0	0.0	0.0
	1978	0.56	0.0	0.0	0.0
	1979	0.73	0.0	0.0	0.0
	1980	0.34	0.0	0.0	0.0
	1981	0.20	0.0	0.0	0.0
	1982	0.20	0.02	0.02	0.02
	1983	0.32	0.01	0.01	0.03
	1984	0.29	0.0	0.01	0.0
	1985	0.27	0.0	0.01	0.0
RT 208 BRIDGE	1975	1.70	0.01	0.02	0.04
	1976	0.70	0.02	0.0	0.0
	1977	0.86	0.0	0.0	0.0
	1978	0.42	0.0	0.0	0.0
	1979	2.75	0.0	0.02	0.0
	1980	0.32	0.0	0.02	0.0
	1981	0.15	0.0	0.01	0.0
	1982	0.14	0.01	0.02	0.06
	1983	0.13	0.01	0.03	0.0
	1984	0.24	0.0	0.0	0.0
	1985	0.13	0.0	0.01	0.0
CONTRARY CREEK BRIDGE	1975	1.59	0.06	0.19	0.06
	1976	C.47	0.08	0.05	0.0
	1977	1.67	0.06	0.03	0.0
	1978	0.80	0.05	0.18	0.01
	1979	1.48	0.18	0.23	0.0
	1980	1.13	0.03	0.19	0.01
	1981	0.32	0.10	0.16	0.0
	1982	0.53	0.08	0.30	0.01
	1983	0.81	0.08	0.47	0.05
	1984	0.76	0.05	0.28	0.0
	1985	0.70	0.02	0.17	0.0

Table 3.6-4. (continued).

STATION	YEAR	FE (MG/L)	CU (MG/L)	ZN (MG/L)	PB (MG/L)
INTAKES	1976	0.46	0.05	0.0	0.0
	1978	0.48	0.01	0.0	0.0
	1979	0.62	0.0	0.0	0.0
	1980	0.50	0.0	0.01	0.0
	1981	0.13	0.0	0.01	0.0
	1982	0.10	0.02	0.02	0.03
	1983	0.10	0.01	0.02	0.03
	1984	0.16	0.0	0.01	0.0
	1985	0.09	0.0	0.01	0.0
1MID LAKE	1984	0.14	0.0	0.01	0.0
	1985	0.10	0.0	0.01	0.0
BURRUS POINT	1984	0.11	0.0	0.01	0.0
	1985	0.09	0.0	0.01	0.0
DIKE 3 ENDECO	1984	0.12	0.0	0.01	0.0
	1985	0.10	0.0	0.01	0.0
DAM	1975	0.75	0.03	0.02	0.94
	1976	3.24	0.01	0.0	0.0
	1977	0.23	0.0	0.0	0.0
	1978	0.50	0.0	0.0	0.0
	1979	0.57	0.0	0.0	0.0
	1980	0.49	0.01	0.02	0.0
	1981	0.17	0.0	0.01	0.0
	1982	0.14	0.02	0.02	0.02
	1983	0.11	0.02	0.03	0.01
	1984	0.19	0.0	0.02	0.0
	1985	0.36	0.0	0.03	0.0

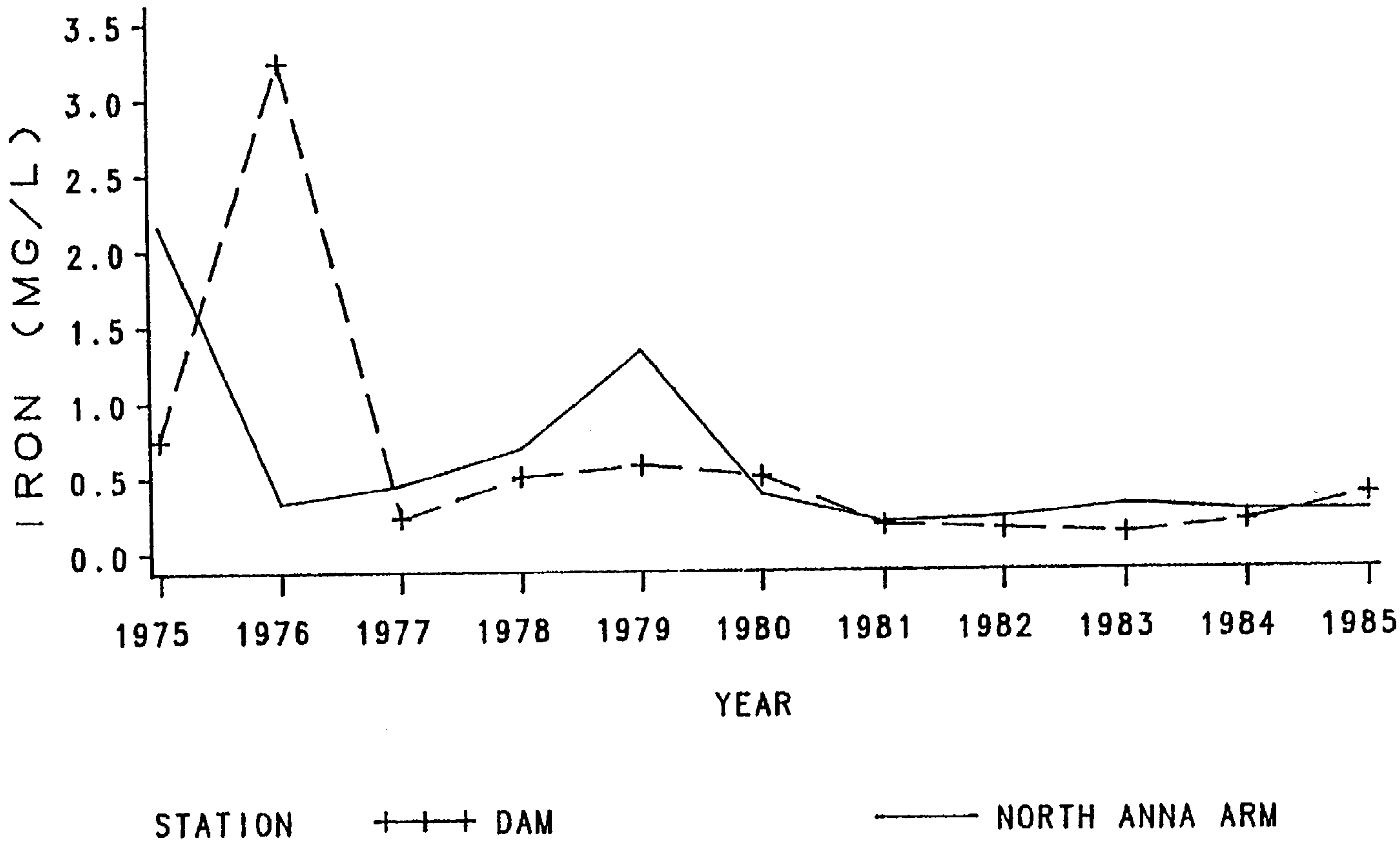

Figure 3.6-7. Monthly mean iron concentrations in water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

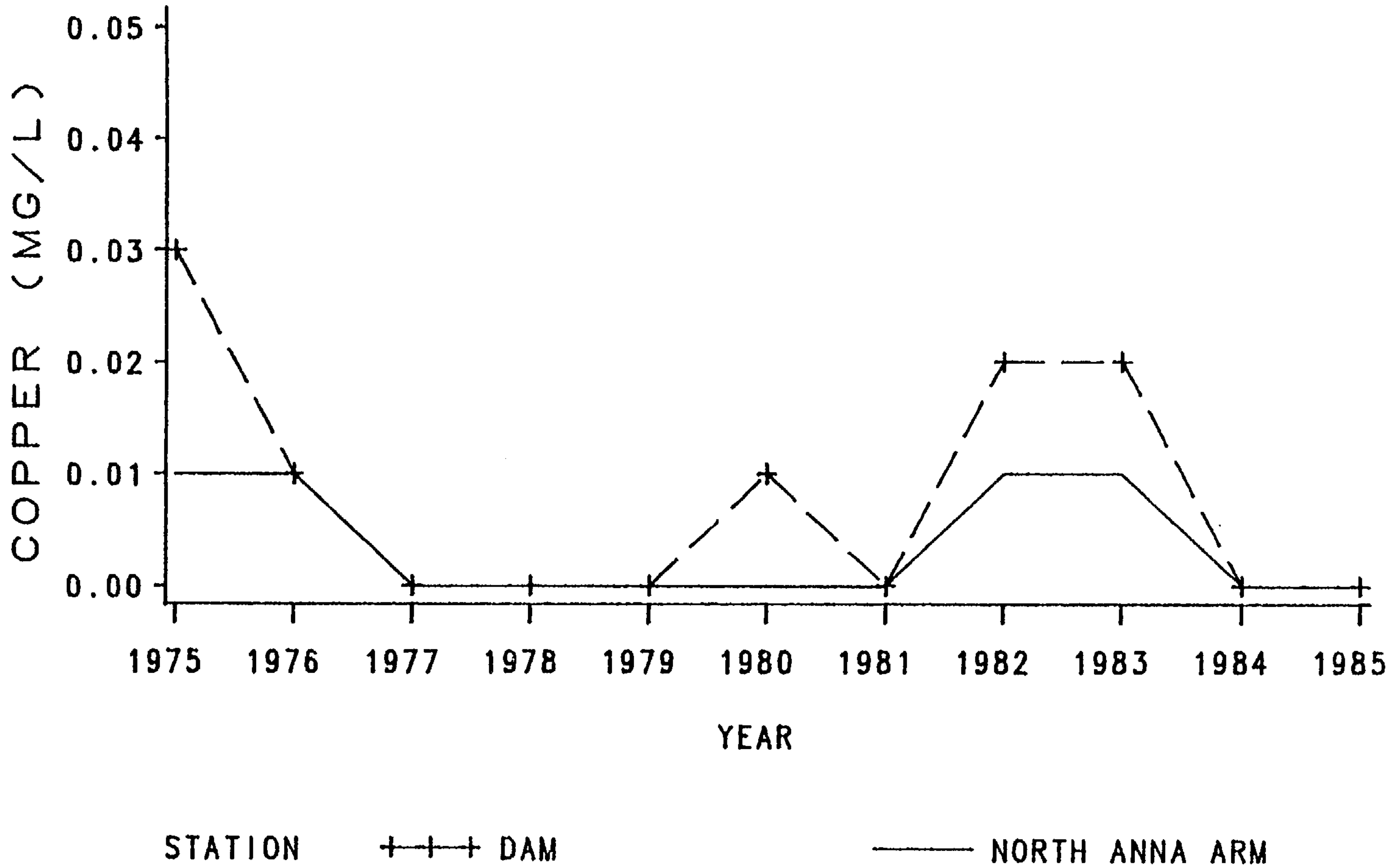

Figure 3.6-8. Monthly mean copper concentrations from water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

208 Bridge and the Dam stations (Appendix B-Table 1). The maximum concentration since 1979 (1.1 mg/l) occurred in a Rt. 208 Bridge hypolimnion sample in September 1980.

The highest concentrations of zinc occur at the Contrary Creek Bridge station (Table 3.6-4). Since 1979, there has been a gradual increase in low levels at the Dam station (Fig. 3.6-9). Since 1979, the maximum value of 1.14 mg/l was recorded for a Contrary Creek surface sample in March 1983.

Lead was detected very infrequently overall, but did occur at several stations in March 1982. The maximum value since 1979 occurred in a surface sample in March 1982 at Rt. 208 Bridge (0.38 mg/l) and recurred in March 1983 in a bottom sample from the North Anna Arm. After September 1983, lead was not detected in any of the 342 samples collected from Lake Anna (limit of detection was 0.01 mg/l) (Fig. 3.6-10).

Summary

Water quality in the headwaters of the York River Basin is generally good although there had been some degradation from the wastes of 19th and 20th century pyrite mining activites. Construction activities that are occurring as a result of the formation of Lake Anna are expected to remain of low density and low intensity, oriented towards retirement and seasonal activities. The fertility of the soil in the watershed is relatively poor requiring the regular use of fertilizers for crop

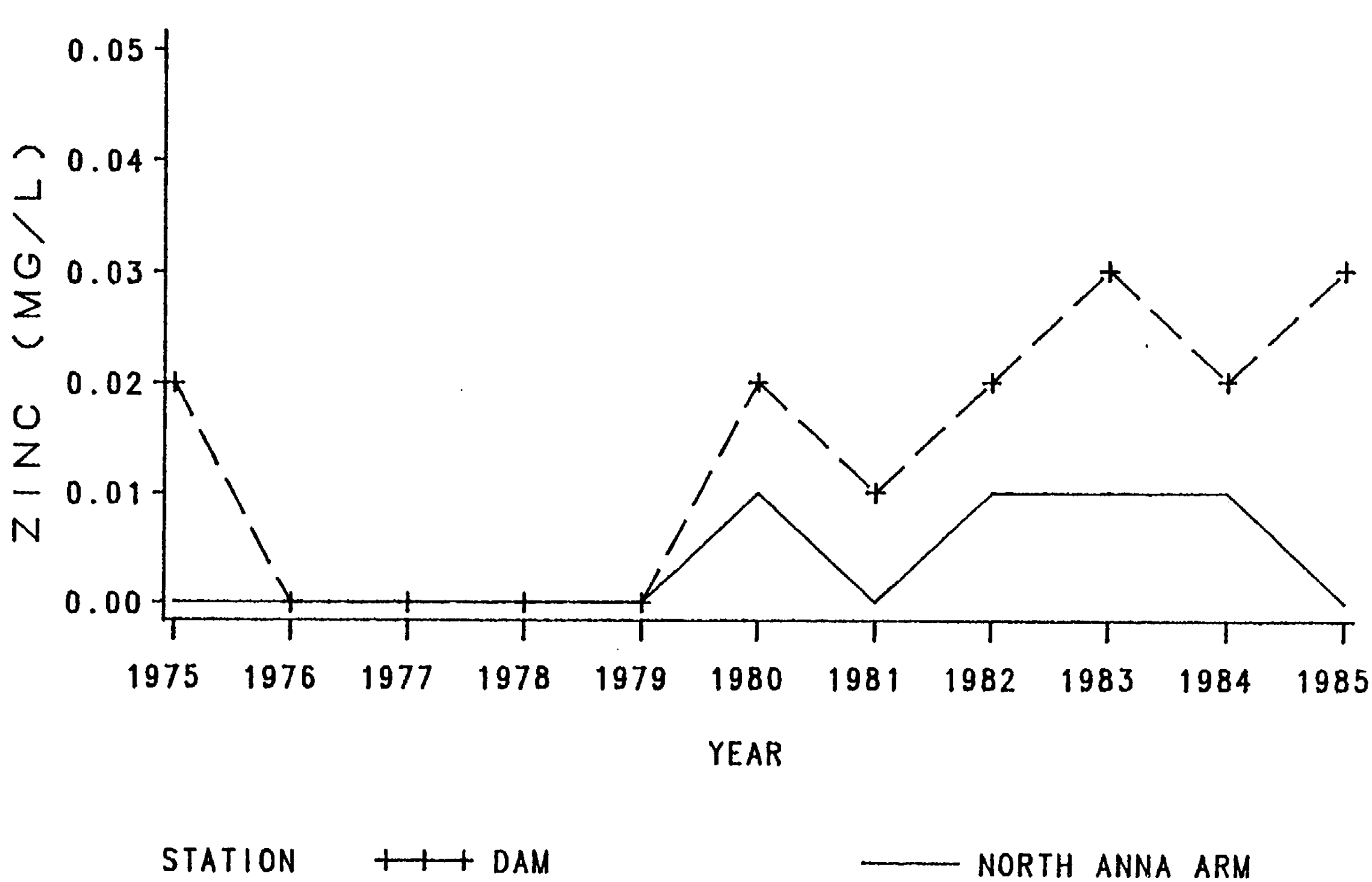

Figure 3.6-9. Monthly mean zinc concentrations in water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

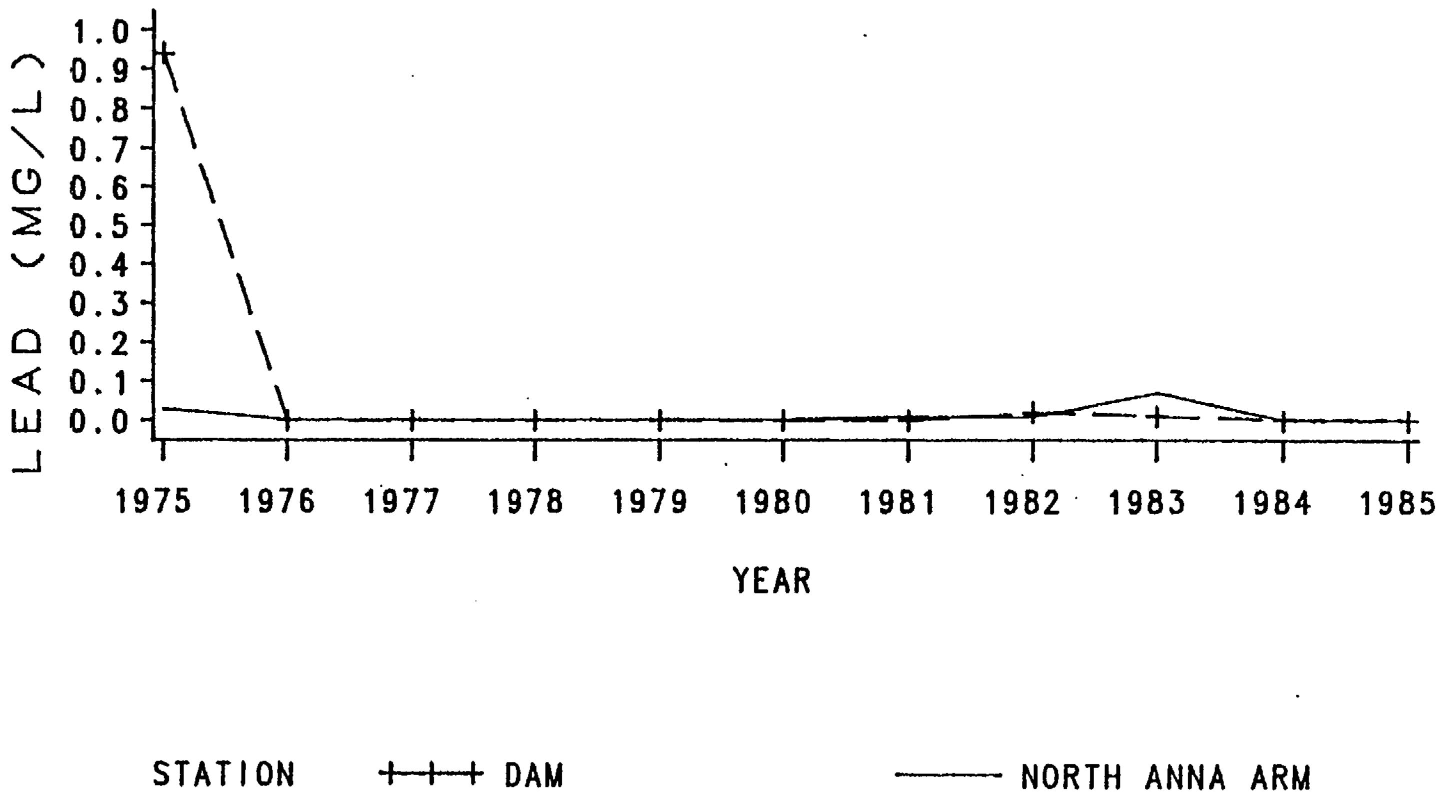

Figure 3.6-10. Monthly mean lead concentrations in water samples from an Upper Lake station (North Anna Arm) and a Lower Lake station (Dam), Lake Anna, Virginia. Includes surface, mid and bottom depth samples.

production. Agricultural activity has been declining in recent years.

As evidenced by historical nutrient data, the reservoir has stablized since the inundation. There does not appear to be an excess of nutrients compared to other regional lakes (Virginia Power 1985a) nor the imminent danger of water quality degradation in the reservoir. Heavy metals do not appear to be influencing the aqueous ionic balance with the possible exception of hypolimnetic iron concentrations which does not pose a threat to the biota.

During the summer months of pre-operation and operational years with little station activity, poorly oxygenated (often anoxic) conditions existed in approximately 49% of the total reservoir volume in August when minimums occur. When station pumping activity increased, dissolved oxygen concentrations improved in (equaled or surpassed 5 mg/l) in approximately 27% of the volume of the reservoir concurrent with temperature increases and an increase in the volume of the epilimnion. Oxygen stratification did not always parallel temperature stratification in Lake Anna, but a highly significant positive correlation does exist between the variables selected to represent each of these patterns. Operation of the circulating water pumps increased the depth of oxygenated water in the Lower Lake. The available data indicate the habitable space is increased for warm-water indigeneous species and decreased for anaerobes because of the reduced volume of the hypolimnion in Lake Anna.

4.0 BIOLOGICAL ASSESSMENT OF LAKE ANNA

This chapter assesses the influence of elevated temperatures caused by the North Anna Power Station's cooling water discharge on the biological community that inhabits Lake Anna. Information obtained primarily from pre-operational (1972-1977) and operational studies (1978-1985) of Lake Anna, as well as some information from publications on other pertinent studies, form the basis for this assessment.

The structure (species composition and abundance) of the aquatic community in Lake Anna began to develop in 1972 with closure of the dam and the impounding of the flow of the North Anna River. Typically, developing communities in such new reservoirs exhibit fairly rapid changes in structure and productivity during about the first 5-10 years of aging before attaining a condition of relative stability (Kimmel and Groeger 1986; Baxter 1977; Jenkins 1977). In all likelihood, most indigenous species of aquatic life now present in Lake Anna were contributed in spillover from ponds in the watershed and from streams that became tributaries to the lake. The fish species stocked in the lake for an expansion of the fisheries resources are an exception. Two of these, striped bass and walleye, could not persist indefinitely without repeated stocking because of absence of suitable spawning habitat. Another, threadfin shad, can perpetuate itself in Lake Anna, but only the warm

water from the North Anna Power Station enables this species to survive through the winter season.

Inherent differences in the hydrology, morphology, water temperature, and water chemistry between the Upper Lake (tributary dominated), the Mid-Lake and the Lower Lake result in biological differences which should be considered in the assessment. The upper shallow tributary dominated arms of the lake normally have higher spring and early summer water temperatures than the mid and lower portion (See Section 3.5).

The community of organisms indigenous to any particular locale or body of water, such as Lake Anna, consists of those that have had access, and which are able to live (tolerate), grow, and reproduce in that particular habitat. There are a host of environmental factors (physical, chemical, and biological), which may individually or collectively determine which species persist, and how well each species is able to compete with the others in each body of water. The factor most closely approaching the critical minimum needed by a species will tend to be the limiting factor (Liebig 1840). Similarly, a population may be controlled by the qualitative or quantitative excess of any one of several factors that approach the limits of tolerance for that species (Shelford 1913). The optimum condition(s) for reproduction, growth, and survival lies somewhere between the minimal and maximum tolerance limits.

Being located in a warm temperate zone latitude, Lake Anna is populated for the most part by eurythermal

species, i.e. species that can tolerate (survive) a wide range of water temperatures, from near-freezing (0° C = 32° F), to in excess of 32° C (89.9° F) to 39° C (104°F) (U.S. EPA 1972, 1976; Jinks et al. 1981). Most of these species reproduce in some segment of the temperature range between 10 C (40 F) and 30 C (86 F) and most of the annual growth by eurythermal species also occurs within this temperature range. However, their preferred temperature and upper limit of optimum temperature range for growth, when other factors are not limiting, are usually only a few degrees less than their upper incipient lethal temperature limit (Coutant 1972).

The increase in water temperature resulting from the North Anna thermal discharge occurs mostly in the lower portion of Lake Anna. The temperature increase immediately after initial mixing (at the in-situ recording thermograph station - NALSTIO) rarely exceeds a few degrees Celsius. With that increment, the summer water temperature of the Lower Lake more closely approximates that of the Upper Lake. However, most of the hourly maximum temperatures recorded for Lake Anna, with monthly mean 2-unit power station operation up to 99.4 percent capacity since 1980, continue to occur in the upper and mid-portions of the lake (see Table 3.5-1). More detailed information about the influence of the North Anna Power Station's thermal discharge on the temperature regimes and water quality of Lake Anna are presented in Chapter 3 to provide pertinent bases and perspectives for assessment of effects on the biological community (Fig. 4.-1).

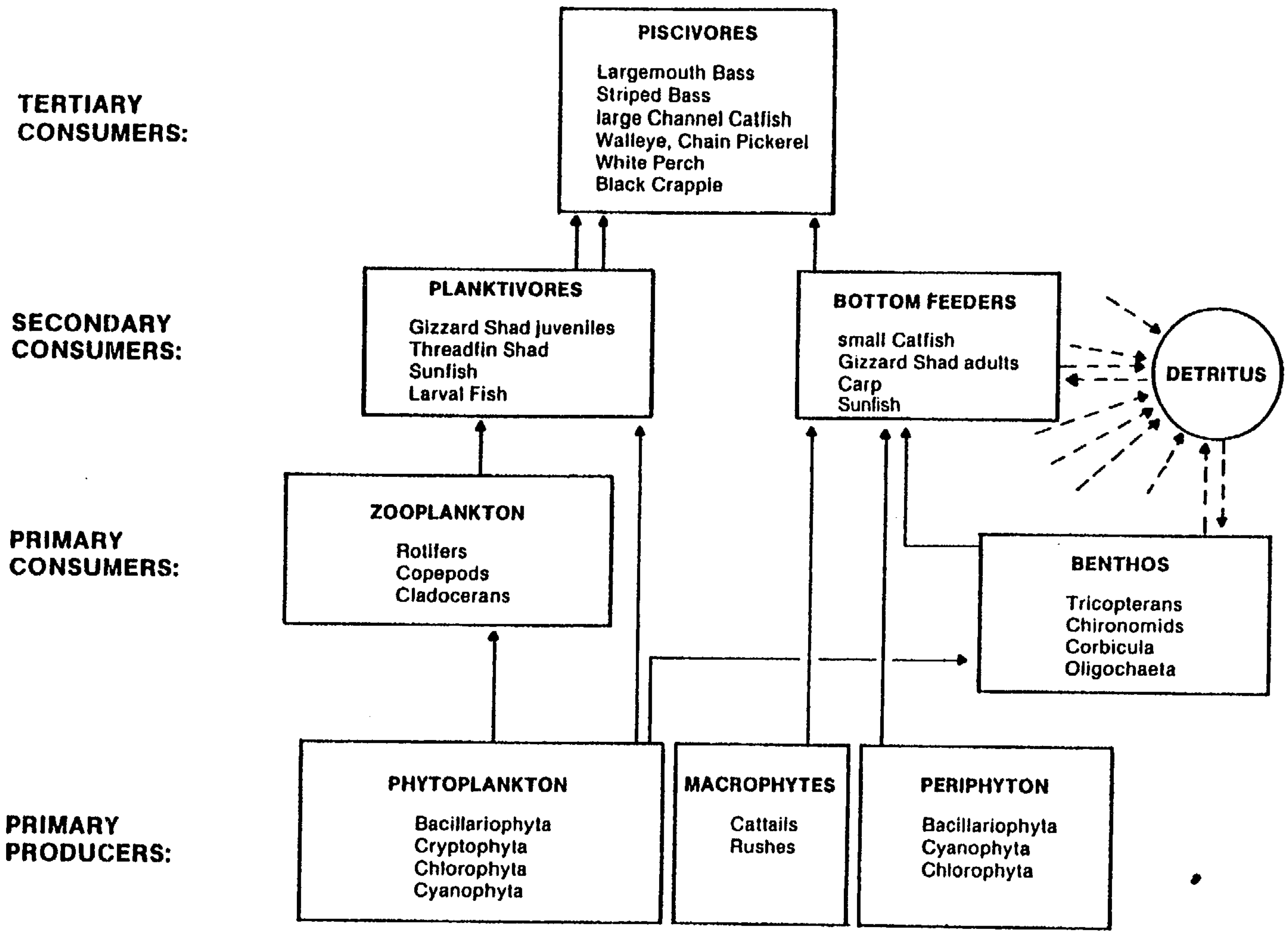

Figure 4.-1. Tropic structure for the Lake Anna, Virginia aquatic community.

In addition to computation of total numbers, means, ranges and percent species composition (relative abundance), many other statistical and mathematical methods were attempted as aids to interpretation of the extensive body of information on pertinent physical, chemical, biological and power station operation variables. These methods included graphical analyses; test for normality of data; log transformation; coefficient of variation; analyses of variance; regression analyses; correlation analyses; Duncan's multiple range test; cluster analyses; indices for species diversity, richness and eveness; catch-per-unit effort (CP/E); proportional stock density (PSD) and the morphoedaphic index (MEI). The methods found to be most informative and useful included graphical analyses, Duncan's multiple range test, cluster analyses, analyses of variance and species diversity.

In the chapters which follow, information on species composition and abundance from studies during pre-operational and operational years, and from sampling stations throughout Lake Anna, is compared for each biotic category in an attempt to discern evidence of prior appreciable harm to major components, or to the overall structure of the community of fish, shellfish, and wildlife, in and on Lake Anna.

4.1 Primary Producers

Introduction

In aquatic ecosystems the primary producers capture solar energy while synthesizing organic compounds from inorganic chemicals. This is a critical function because their product is the source of the nutrients and energy used by the consumers (Fig. 4.-1). The primary producers in a lake include phytoplankton, aquatic macrophytes, and periphyton. Of the three, phytoplankton are the major producers in all but very shallow lakes. The occurrence of the producers is determined by the resources they require and the distribution of those resources in the aquatic environment. The general occurrence of aquatic producers is described below by group beginning with the phytoplankton.

Phytoplankton

Phytoplankters are single-celled or simple-colonial organisms that live suspended in the water column. Consequently, they occur in the open water or limnetic zone of a lake. When the lake is thermally stratified they are most abundant in the epilimnion where light intensities are high and where the turbulence keeps resuspending them (Hogan and Adair 1982). In the absence of stratification, their vertical distribution tends to be less concentrated.

The abundance of phytoplankters depends on the difference between population gains through cell division

and population losses due to settling and herbivory. Cell division occurs with a frequency of two to ten times per month (Hutchinson 1967; Kimmel et al. 1984). The rate of replication is regulated mainly by the availability of nutrients and light and by the water temperature. Optimum temperature for growth depends on the taxon. The maximum temperature that algae can withstand is also species-specific but ranges from 33 to 45°C (Patrick 1969). However, given sufficient light and given the temperature preferred by a species, phosphate availability generally limits phytoplankton production. Nitrogen may also play a regulation role in conjunction with phosphorous, and silica is an important element for diatoms. Because the light, temperature, and nutrient regimes change vertically, horizontally, and temporally in lakes, changes occur in the composition and abundance of the community.

The phytoplankton community also has a patchy horizontal distribution. Because of their small size (several µm in diameter) and limited motility, their local distribution is strongly affected by current. In terms of a reservoir, higher Upper-lake nutrient concentrations and other differences encourage a gradient of decreasing phytoplankton density towards the lower end of the reservoir (Campbell 1978).

Changes in the phytoplankton community also occur over time and can be dramatic. Because phytoplankton tend to be regulated by the physical, biochemical, and biological factors in their environment, their community structure is

somewhat predictable. In temperate lakes the diatom (Bacillariophyta) phytoplankters tend to dominate the community from late fall through mid-spring. Because winter abundance tends to be low, the diatoms generally exhibit a density peak in the spring and occasionally one in the autumn. During this period the phytoplankton cell density is also low with a minimum reached in December. Green algae (Chlorophyta) frequently supplant the diatom dominants in mid-summer. They are in turn replaced by a late-summer or autumnal abundance of blue-greens (Cyanophyta) or dinoflagellates (Pyrrhophyta) (Hogan and Adair 1982; Hutchinson 1967). Although several other phytoplankton divisions are present in the community, the four groups mentioned above are typically the prominent ones.

Macrophytes and Periphyton

Aquatic macrophytes are large plants, both emergent and submerged, that inhabit shallow water areas. Periphyton consists of algae, usually single-celled or filamentous species, that are attached to benthic or macrophytic surfaces. Whereas phytoplankton occur in the open waters of a lake, macrophytes and periphyton are the main producers in the littoral zone, the shallows and margins of the lake. Macrophytes tend to be highly productive for they are rooted in sediment with more nutrients than are available to the phytoplankton and they have abundant sunlight. However, lakes range from turbid to clear and oligotrophic. Either of these two extremes may inhibit macrophyte success. In

turbid waters there may be insufficient light for any but emergent macrophytes to survive. In oligotrophic waters, nutrients may be too scarce to support many macrophytes. Periphyton would also seem to be similarly restricted for it is also composed of sedentary plants. Between these two extremes, the factors controlling macrophyte and periphyton occurrence are wave action, current, substrate particle size and stability, and temperature (Chambers and Kalff 1985). The mechanical variables are perhaps more important to periphyton because of their minute size.

In this connection it is useful to emphasize that the littoral zone is an area of extremes. The nutrient and organic matter concentrations fluctuate widely and inversely with the degree of mechanical disturbance. Water temperature changes in the littoral zone are more drastic due to the relatively low thermal capacity of the small water volume compared to deeper portions of reservoirs. Because emergent macrophytes are also exposed to the atmosphere they must withstand the even greater fluctuations in temperature of the air.

In general, light penetration is the major factor controlling macrophyte and periphyton occurrence. The actual depth of colonization may be estimated at 2.7 to 3.0 times the Secchi depth; approximately the compensation point (Davis and Brinson 1980). As a result, the upper, more turbid part of a reservoir would have a shallower macrophyte or littoral zone than the lower reservoir.

The major seasonal pattern in the macrophyte community is a vernal emergence of shoots from overwintering seeds or roots. The biomass peaks in late summer. Thereafter, with the decline of daylength, light penetration and water temperature, the shoot material dies.

In temperate lakes the periphyton community is principally composed of diatoms. Seasonal compositional change is mainly evidenced when filamentous green and blue-green algae become prominent during the summer. There is also a seasonal change in periphyton production with the greatest biomass being present in the summer.

Information Base For Evaluation

The phytoplankton community of Lake Anna, Virginia was collected in whole water (unfiltered) samples monthly from September 1972 through the spring of 1981 (Reed and Simmons 1976; Simmons 1977; Simmons 1978; Reed 1979; Reed 1980; and Reed 1981). All of these data were employed routinely in the analyses for the current report except for portions of the 1977 data. Phytoplankton was also collected in 1984-85 (Appendix B-Table 1). The taxa in part of the samples were identified by Dr. Greeneville B. Hall.

Over all years the Utermohl method was used to obtain density estimates of the phytoplankton (Lund et al. 1958). However, from 1976 through 1981 the lowest taxonomic unit used was the genus. In all other years the lowest unit used was the species level. This prohibits certain detailed taxonomic comparisons. Also, at least from 1976 through

1981 densities were based on counts of five Whipple fields. In 1984 to 1985 the densities were based on one hundred fields whenever possible. This leads to differences in precision of the data. During 1984-85 taxonomic identifications followed Whitford and Schumacher (1984) and Prescott (1962).

The 1984-85 sample stations are shown in Figure 4.1-1. During 1972-80 the phytoplankton community was generally sampled twice during June, July and August. It was sampled monthly in the remainder of the year. However, some winter months were not sampled due to ice conditions. Over the 1972-85 period, five stations were consistently sampled: Rt. 208 bridge, Intake, Midlake, Dam and Waste Heat Treatment Facility 3 (WHTF-3). Although the samples collected prior to 1984 were collected from various depths, only those from 0 and 4 meters (m) were sampled consistently enough to be used in the analyses. In 1978, stations were added in the following areas: North Anna Arm, Pamunkey Arm, Dike 3, and Burrus Point. Also, during August 1984, five additional stations between the Intakes and Dike 3 were sampled to determine whether the existing stations were providing data representative of the phytoplankton in that area.

The periphyton community of the North Anna River was sampled from May through October 1976 and from March through August 1977 (Simmons 1977; Simmons 1978). From February through September 1984 it was sampled monthly at two stations in the lake (Rt. 208 bridge and Dike 3), and at

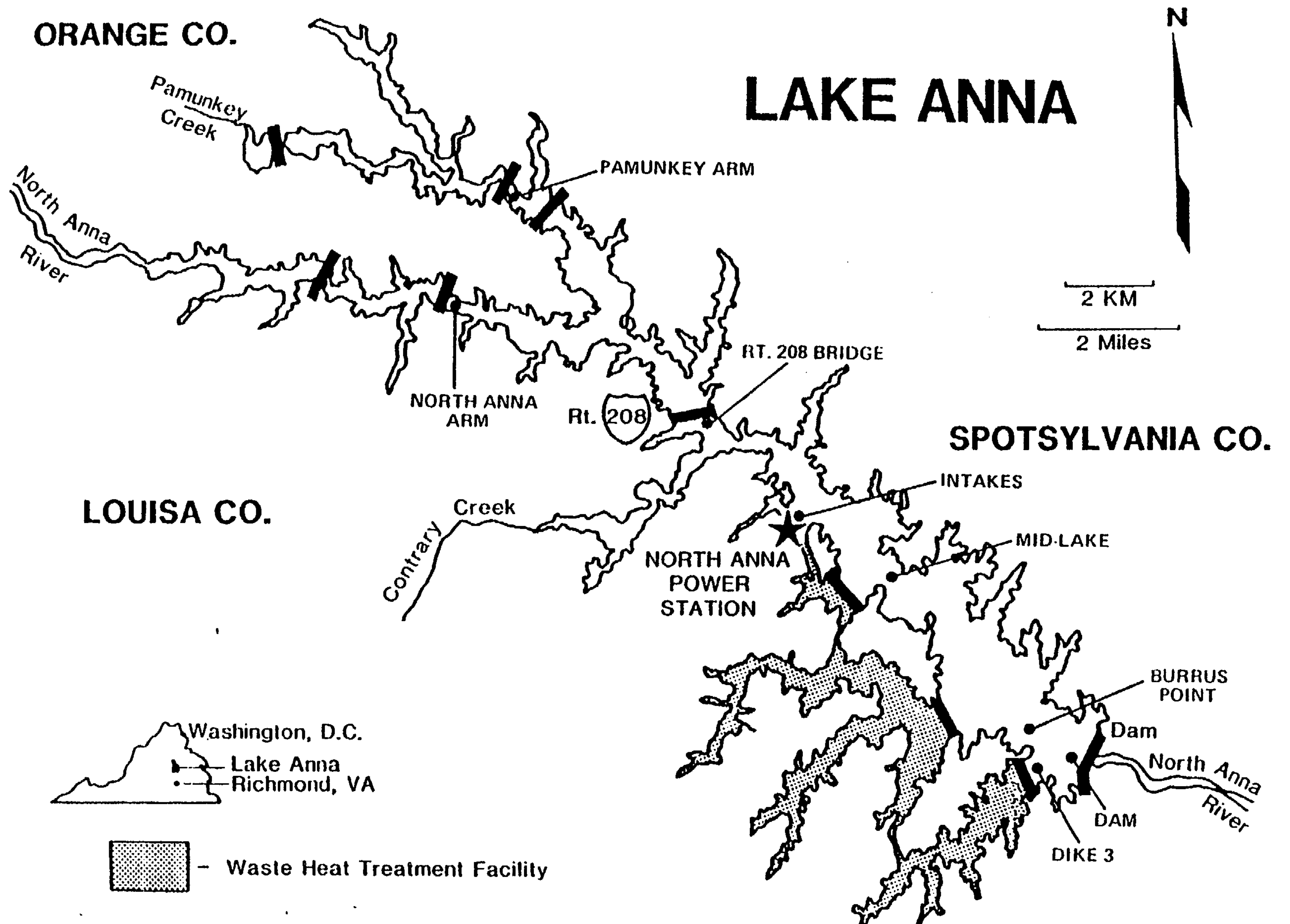

Figure 4.1-1. Location of 316(a) phytoplankton sampling stations.

two stations in the North Anna River (Rt. 601 Louisa and Rt. 1 bridge crossings). Thereafter, monthly sampling was continued in the river in all but high water months. In the lake, subsequent samples were collected in October 1984, and in May, August and October 1985. Also, lake periphyton samples collected after September 1984 were taken from submerged rocks rather than from periphytometers (Appendix B-Table 2).

Chlorophyll *a* determinations were made in all historical sample years in which phytoplankton was collected from November 1972 through 1980 (Reed and Simmons 1976; Simmons 1977; Simmons 1978; Reed 1979; Reed 1980; Reed 1981). However, these values were derived using absorbance wavelengths and equations different from those used in 1984-85. Comparisons to 1984-85 data must take this into account (Wartenberg 1978). In 1984-85 chlorophyll *a* was also extracted from the phytoplankton and periphyton (Appendix B-Tables 3 and 4). From the beginning of the study through September 1984, periphyton chlorophyll samples were collected from periphytometer slides. Thereafter they were collected from submerged rocks. Secchi disc depth readings were recorded at the phytoplankton stations during 1984-85 and during many of the historical sample years (Appendix B-Table 3).

Macrophytes were surveyed in 1976 to obtain a species list for Lake Anna (Simmons 1977). They were again surveyed in 1984 on the southern shore of the lake between the Intake area and Dike 3. The latter survey resulted in a

shoreline map of the aquatic macrophytes. Taxonomic identifications in 1984 and 1985 followed Radford et al. (1968).

Assessment

Phytoplankton

Temporal Pattern in the Phytoplankton Community

The overall temporal pattern of phytoplankton density in Lake Anna from 1972 to 1985 is exemplified in Figure 4.1-2 by the averaged records for three consistently sampled stations below the Rt. 208 bridge. These records indicate that the density was highly variable but gradually increased from 1972 through 1977. In 1977 the densities in every month at the Dam station exceeded its monthly average in the previous year. In 1978 the phytoplankton abruptly decreased in mean density and variance (see coefficient of variation values in Appendix B-Table 5). Thereafter the average annual density increased gradually through 1985 (Appendix B-Table 6).

With the exception of 1977, the general 1972-85 pattern of rapid rise, temporary maximum, decline, and then long-term gradual increase in density is a typical new reservoir successional pattern. Neither taxonomic identification differences nor analytical differences between periods appear to have modified the density fluctuations over the sample period. Consequently, and because the low densities in the 1978-81 period are

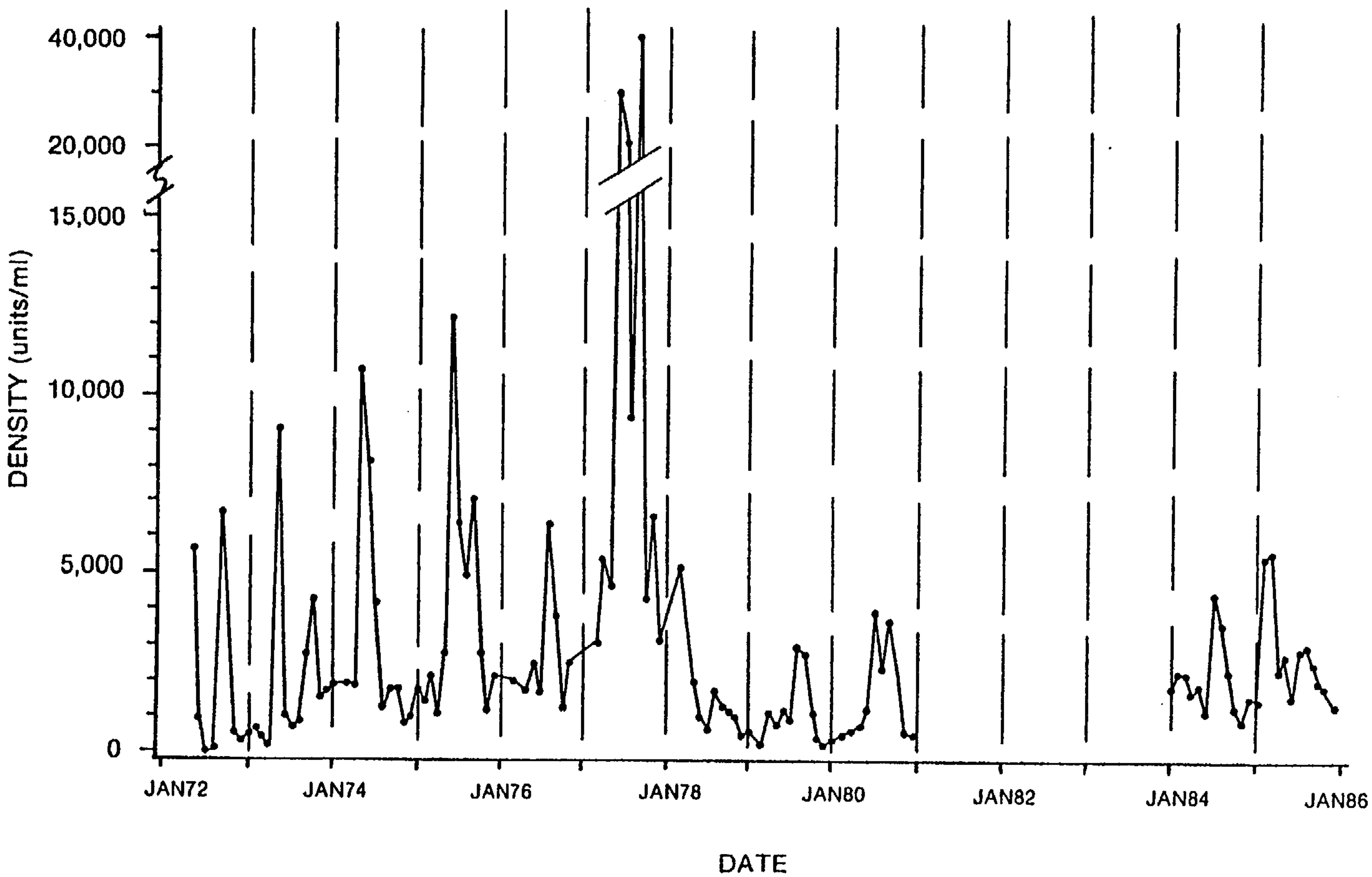

Figure 4.1-2. Mean phytoplankton monthly densities collected at the Intake, Mid-lake, and Dam stations in Lake Anna, Virginia, during 1972-1985. Note the interrupted Y axis.

appropriate predecessors to the 1984-85 data, the depressed densities during 1978 and 1979 are considered part of the successional pattern. The high variation of phytoplankton density early in the reservoir history is also an expected component of the successional phenomenon. However, the 1977 maximum is atypical. The year was one of severe meteorological drought which accompanied the elevated plankton densities.

After the formation of Lake Anna, extensive new limnetic habitat existed for phytoplankton. In addition, the nutrient concentration of the waters rose to high levels compared to the values in 1984-85. The abundant elements in the young reservoir included two that are important to phytoplankton: nitrogen and phosphorous (Fig. 4.1-3). The different forms of dissolved nitrogen stimulate different phytoplankton taxa (Berman et al. 1984). Phosphorus is even more important than nitrogen for encouraging phytoplankton growth (Currie and Kalff 1984). During the history of Lake Anna the solutes: nitrate nitrogen, ammonium nitrogen, orthophosphate and total phosphate reached maximum concentrations in 1973-1974 at both ends of the lake (see Section 3.6). Mean annual phytoplankton productivity also reached an historical maximum in 1974 of 238 $mgC/m^3/day$ (Reed and Simmons 1976). A secondary maximum of total phosphate was reached in 1977. Furthermore, from 1977 to 1978 there was a sharp drop in the concentration of these nutrients (Simmons 1979). For total phosphorus in particular, the lake-wide concentration averaged 0.51 mg/l

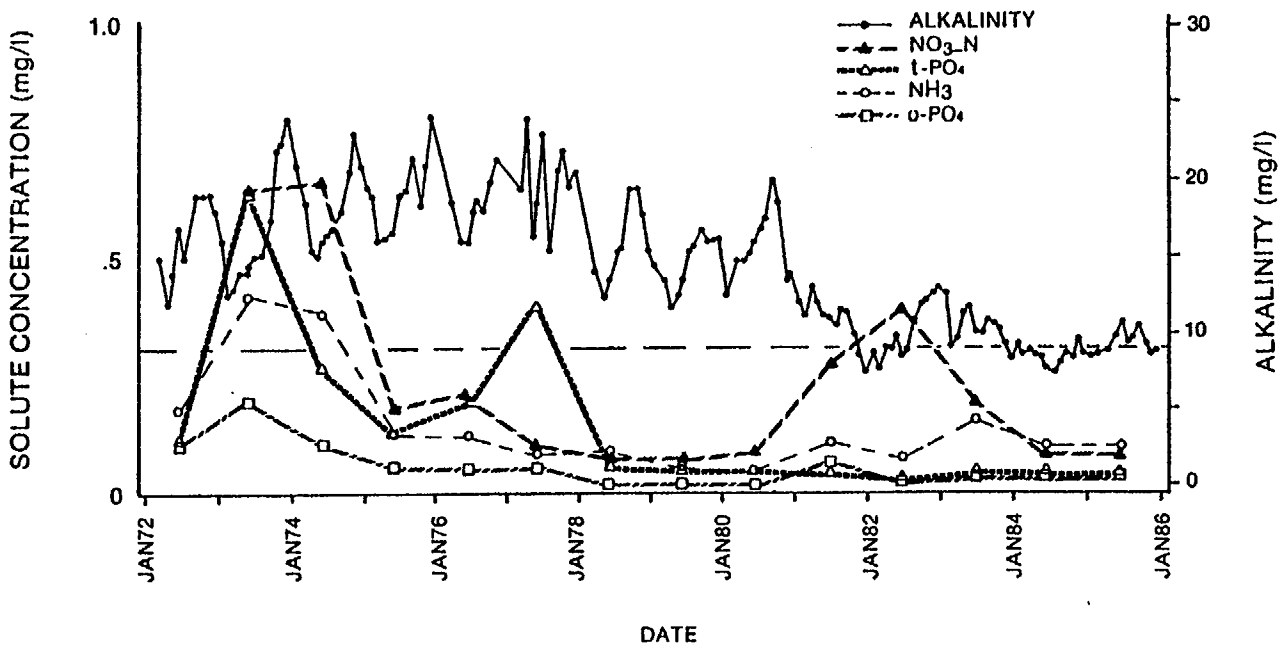

Figure 4.1-3. Monthly alkalinity with average annual total phosphate (t-PO_4), ortho-phosphate (o-PO_4), ammonium nitrogen (NH_3) and nitrate nitrogen (N_NO_3) at the Intake, Mid and Dam Stations in Lake Anna, Virginia. The reference line is the average alkalinity for 1984-85.

from 1973 to 1974. After declining in 1975 and 1976 it rose again to 0.35 mg/l in 1977. Thereafter it decreased at all stations to a low value of 0.04 mg/l and remained below 0.07 mg/l across the lake through 1985. In the arms, nitrate nitrogen dropped from 0.23 mg/l to 0.07 mg/l (an oligotrophic value) from 1977 to 1978 although it did not remain low permanently. Thus, the increase in phytoplankton density in 1977 appears related to the peak in total phosphorus in that year.

Although total phosphorus includes orthophosphate, orthophosphate is not directly important for phytoplankton nutrition. It is absorbed primarily by bacteria. Bacteria in turn release a non-orthophosphate form that is almost entirely absorbed by phytoplankton (Currie and Kalff 1984). Because the relative proportions of the different phosphate forms have changed over reservoir history, the main source of phytoplankton phosphate has also changed. To circumvent a detailed discussion of these fluctuations, the phytoplankton:phosphorus relationship was considered in terms of total phosphorus.

The decrease in phytoplankton density in 1978 paralleled a significant decline in chlorophyll at most stations (Simmons 1979) and thus appears related to the decrease in total phosphorus and nitrate nitrogen. The gradual rise after the 1978 population low could be a result of competitive forces during an assortative phase in the succession of the community (Cody and Diamond 1975). The driving variable over this period would be the oligotrophic

environment, particularly in the lower reservoir. Those algal taxa better able to withstand the oligotrophic conditions would become prevalent. Perhaps the elevated densities observed in 1984 and 1985 due at least in part to the advent of the flagellated cryptomonads represents a shift in community composition towards oligotrophs.

The assortative phase of succession is usually accompanied by a change in species composition. When the genera identified during the phases of lake history are compared, a distinct increase in genera is observed from the 1978-80 period to the 1984-85 period (Appendix B-Table 7). No equivalent change occurs from the pre-operation period 1972-76 to the early operation period 1978-1980.

Spatial Pattern in the Phytoplankton

Based on an unbalanced Analysis of Variance (GLM Procedure, SAS Institute Inc. 1985) of the natural logarithm of phytoplankton density at all lake stations, and for the years 1978 onwards, there was a strong density gradient decreasing towards the dam (Appendix B-Table 8). In nearly all comparisons the Upper Lake harbored the most dense phytoplankton communities with the North Anna arm leading the Pamunkey arm in the operational period. The next most dense samples were found at the Rt. 208 bridge station. In the last two years of collection the Intake station densities averaged greater than the remainder of the lake. Down lake from the Intakes the Burrus Point station tended to have more phytoplankton than the turbulent water station

in front of the Dam. Finally, the Dike 3 and Mid Lake stations had intermediate and similar densities.

Over the last two years of study the phytoplankton density gradient was accompanied in all months by a parallel gradient in chlorophyll *a* concentration from the arms to the Dam. The chlorophyll gradient is shown in Figure 4.1-4 for selected months. In 1985, the highest chlorophyll values were achieved in March when the concentration averaged 25 $\pm$ 1.6 mg/m^3 ($\pm$ standard error) in the Upper Lake and 6 $\pm$ 0.2 mg/m^3 in the Lower Lake (see also Appendix B-Table 9 for a Rt. 208 bridge:Dam comparison). By April it had declined to 3 $\pm$ 0.5 mg/m^3 in the Lower Lake and by June it had decreased to 16 $\pm$ 1.0 mg/m^3 in the Upper Lake. Thereafter the chlorophyll concentration remained relatively stable through October. The lowest chlorophyll *a* values across the lake were observed in autumn. However, in the Upper Lake they did not drop below 11.6 mg/l and in the Lower Lake they did not decrease below 0.3 mg/l.

Because the algal chlorophyll *a* concentration and biomass are directly proportional, statements about temporal and.spatial variation in chlorophyll values apply equally to algal biomass.

The average chlorophyll *a* concentration within lake regions (Upper, Mid and Lower) varied only slightly from 1984 to 1985. However, the pattern of monthly chlorophyll concentrations was somewhat different. In 1984 the maximum concentrations were reached in late summer rather than in late winter although the regional maxima were similar to

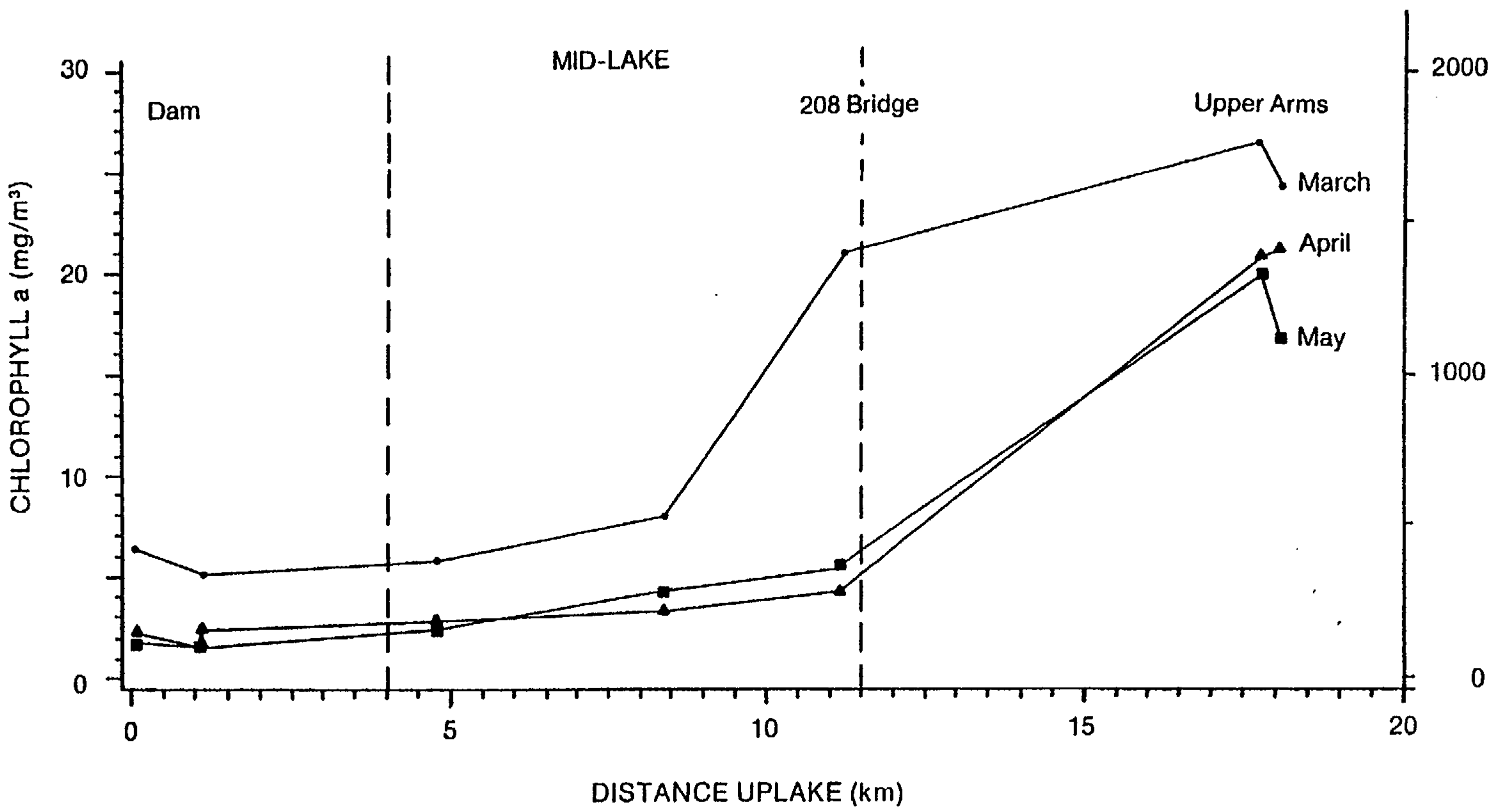

Figure 4.1-4. Chlorophyll a and biomass concentrations on Lake Anna, Virginia. Points are monthly averages across two depths and two replicates for selected months in 1985.

those reached in 1985. The 1984 maxima were 27 + 1.8 mg/m^3 in the Upper Lake and 3 $\pm$ 0.3 mg/m^3 in the Lower Lake. Also, although usually there was more than a 25% difference in algal chlorophyll between the North Anna and Pamunkey arms in any month of 1984-85, it was not possible to predict which arm would have the highest concentration.

The chlorophyll patterns in 1984-85 are not unusual. For example, at Lake Norman in North Carolina, over a five year study period (1974-79) the maximum chlorophyll average occurred in September and the minimum was observed in May (Rodriguez 1982). This corresponds to the pattern observed in 1984 in Lake Anna. The 1984-85 Lower Lake values also compare favorably with Lake Norman where the monthly chlorophyll average was 2.6-5.0 mg/m^3 (Lake Anna had an average of 1.8 mg/m^3). Meanwhile, Lake Anna had very high chlorophyll values in the Upper Lake; those at Lake Norman ranged from 0.3 to 18 mg/m^3. This implies a more nutrient-rich environment for phytoplankton in the arms of Lake Anna.

There was no indication in most years and areas of a significant difference between the 0 and 4m phytoplankton densities (Appendix B-Table 6). Algal chlorophyll <u>a</u> was also similar between depths. This lack of biologic stratification in the winter is expected. Its absence in the summer was probably due to the epilimnion being deep enough to permit free circulation between the 0 and 4m sample depths. The light gradient was steep enough that the Secchi disc depth averaged 2m deeper in the Lower Lake

compared to the Upper Lake compared to the Upper Lake from 1984 through 1985. Examples of this gradient for selected months are presented in Figure 4.1-5. However, the insolation gradient apparently did not affect phytoplankton density as much as the thermal uniformity.

Pattern in the Phytoplankton Divisions

The dominant (most abundant) phytoplankton groups in Lake Anna during the 1972 to 1981 period were the diatoms, the green algae and the blue-green algae. By 1984 cryptomonads had entered the community and were the leading dominants in the Lower Lake. In the Upper Lake they shared the dominant position with the blue-greens. The contribution of each of these groups to the community and their spatial and temporal variation is considered below.

Diatoms

The general pattern of diatom abundance at the Dam station shown in Figure 4.1-6 is representative of diatom density in the lake from the Intakes to the Dam. Density was plotted logarithmically because of the broad range of densities. During pre-operational years, diatoms gradually became more abundant. Each year they reached maximum density between May and June, and they occasionally peaked again in the autumn. This bimodal pattern is typical of freshwater diatoms (Hutchinson 1967). The abundance pattern persisted into the operation period except the spring peak occurred between February and March, at least two months

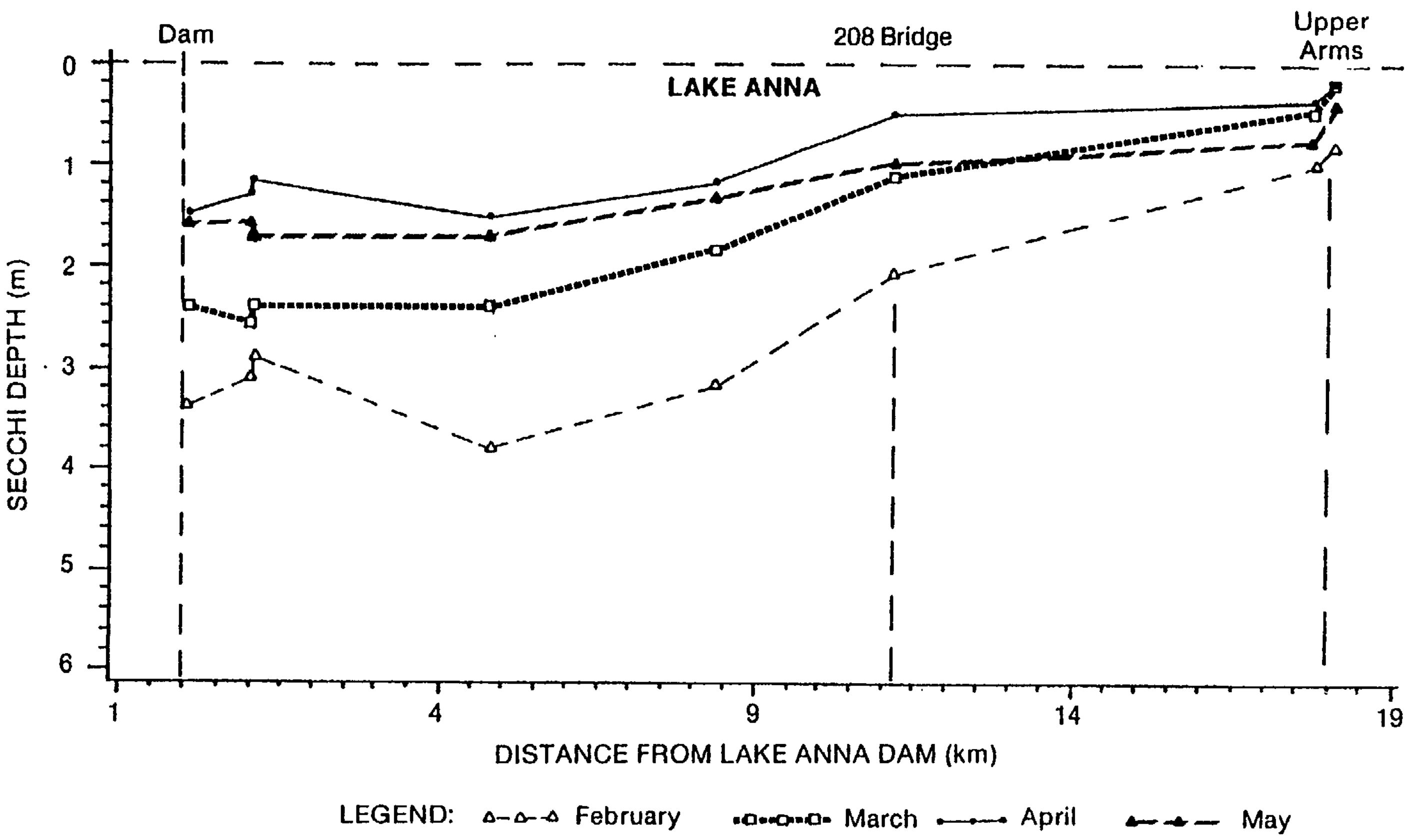

Figure 4.1-5. Secchi depths at phytoplankton collection stations on Lake Anna, Virginia, in selected months of 1984.

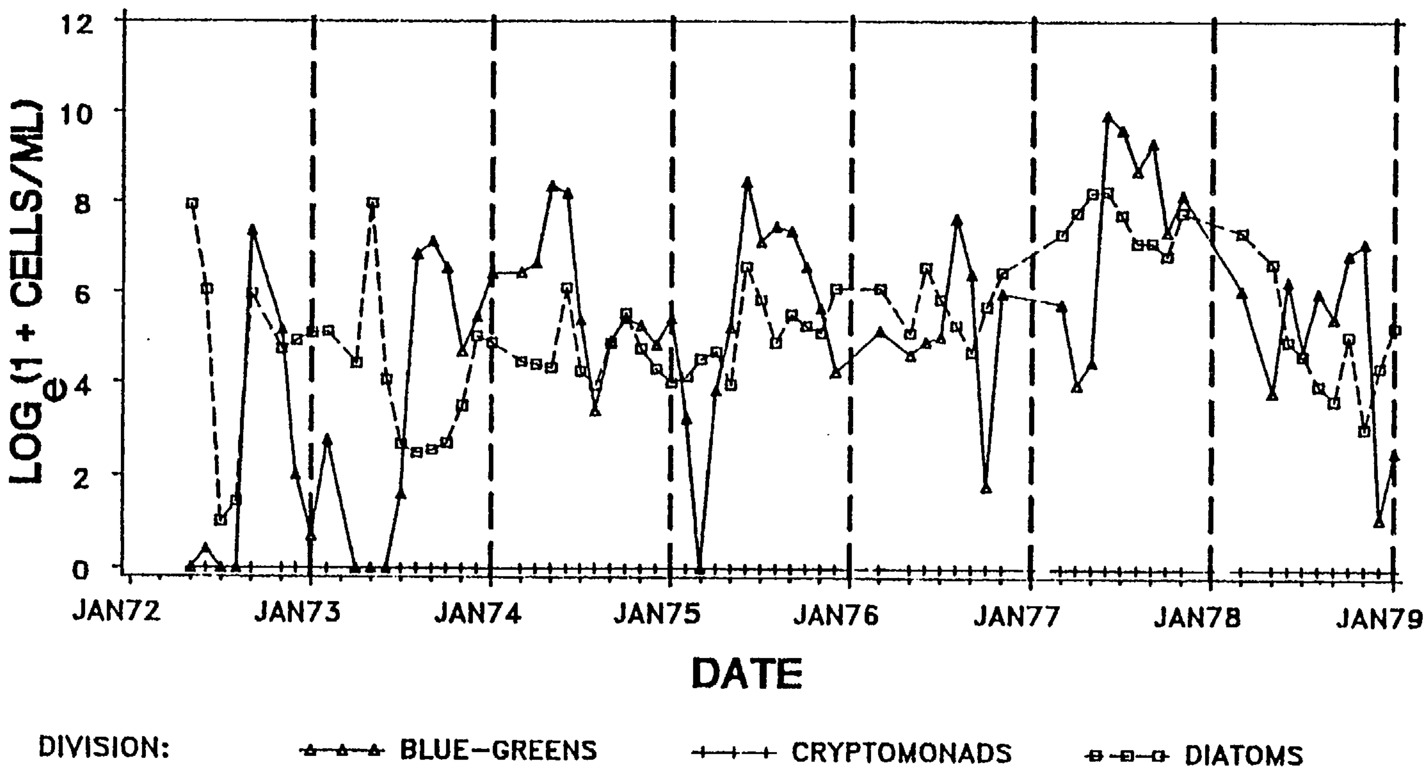

Figure 4.1–6. Density of selected phytoplankton divisions in Lake Anna, Virginia, at the Dam station.

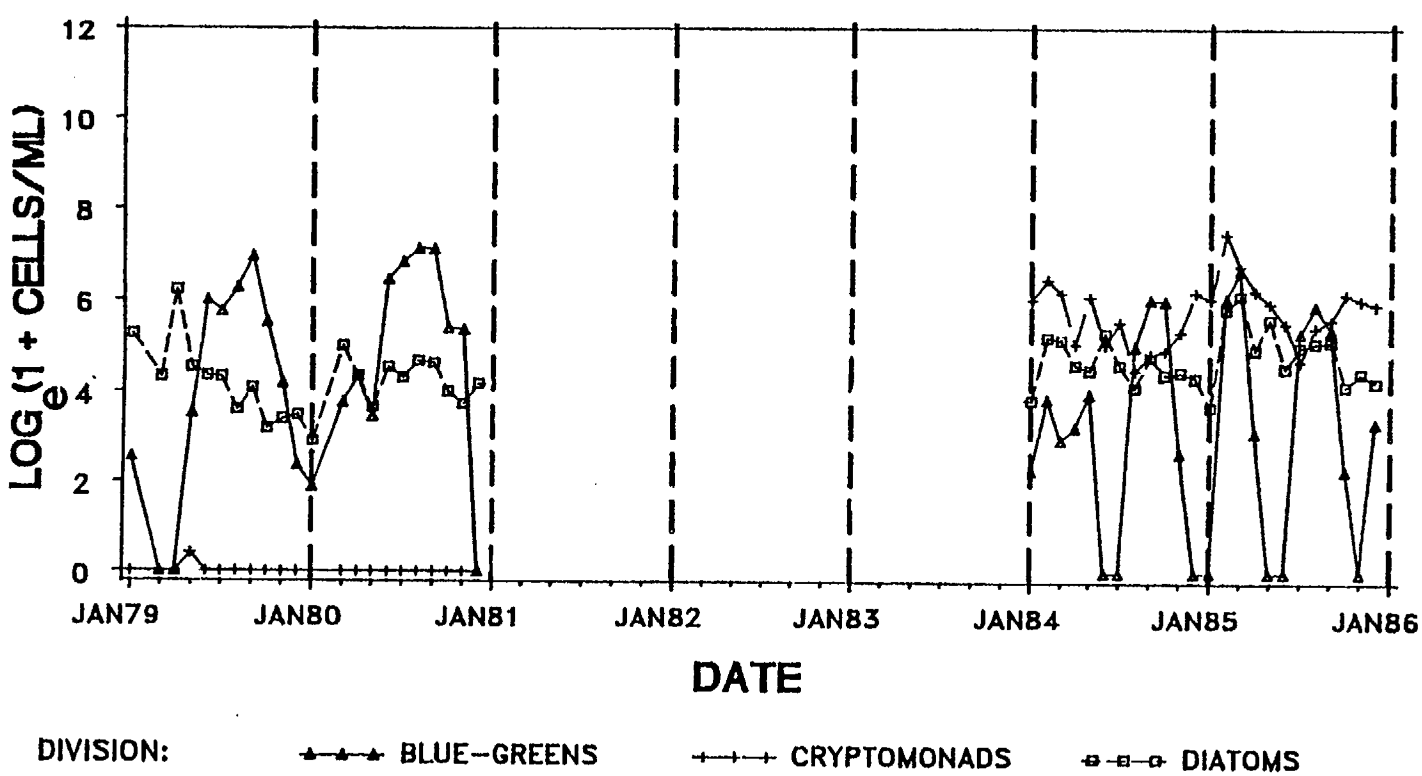

Figure 4.1-6. (Continued).

earlier than during the pre-operation years. In the Upper Lake the diatom seasonal abundance pattern was not very consistent (Fig. 4.1-7), perhaps because of the shortage of data. However, from 1984 to 1985 diatoms in the Upper Lake tended to be more abundant in the winter.

At most sample stations the average annual size of the diatom population paralleled that of the phytoplankton community illustrated in Figure 4.1-2. However, the rate of increase in diatom abundance from 1979 to 1985 was greater in the Upper Lake. At the Dam station for example, there was a 2.4-fold density increase from 1979-80 to 1984-85. Meanwhile, from the lake arms to the Rt. 208 bridge the average cell count was 245 cells/ml in 1979-80 and 2,208 cells/ml in 1984-85, representing a 9-fold increase. The cause of the difference is unknown.

After several months of relatively high abundance in the new reservoir the diatoms became relatively minor community components until the end of 1976 (Appendix B-Fig. 1). From 1976 through the spring of 1979 they were the most abundant group each winter and spring. This dominance of the community by diatoms began to weaken in the winter of 1979-80. Initially they were replaced by green algae but by 1984-85 the diatoms had been displaced as cool-month dominants by the cryptomonads. In the Upper Lake there was a similar alteration in the diatom population from 1972 through 1985 (Appendix B-Fig. 2). One noteworthy difference is that the decline of diatom dominance observed in the Lower Lake began at least two years earlier (in the spring of 1978) in the Upper Lake.

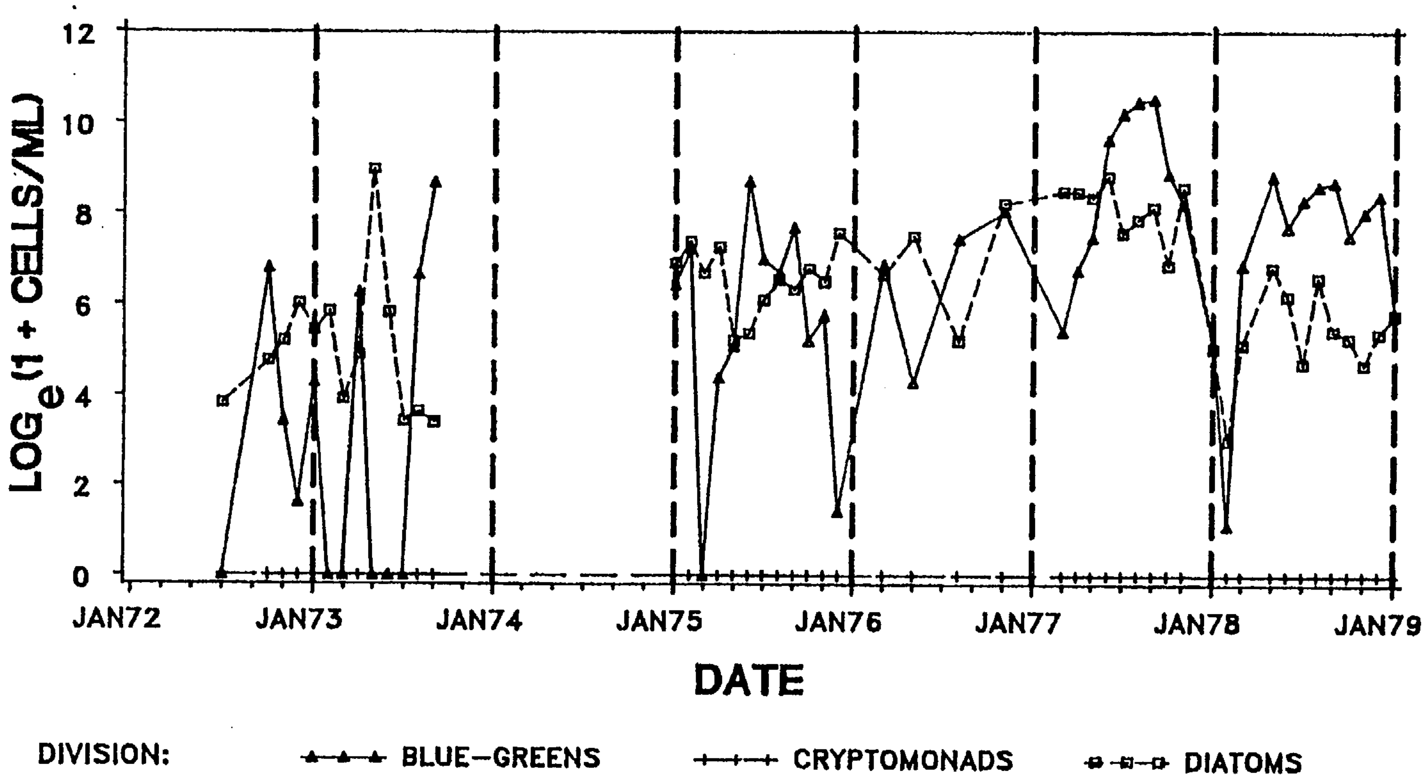

Figure 4.1-7. Density of selected phytoplankton divisions in Lake Anna, Virginia, at the Upper Lake and Rt. 208 bridge stations.

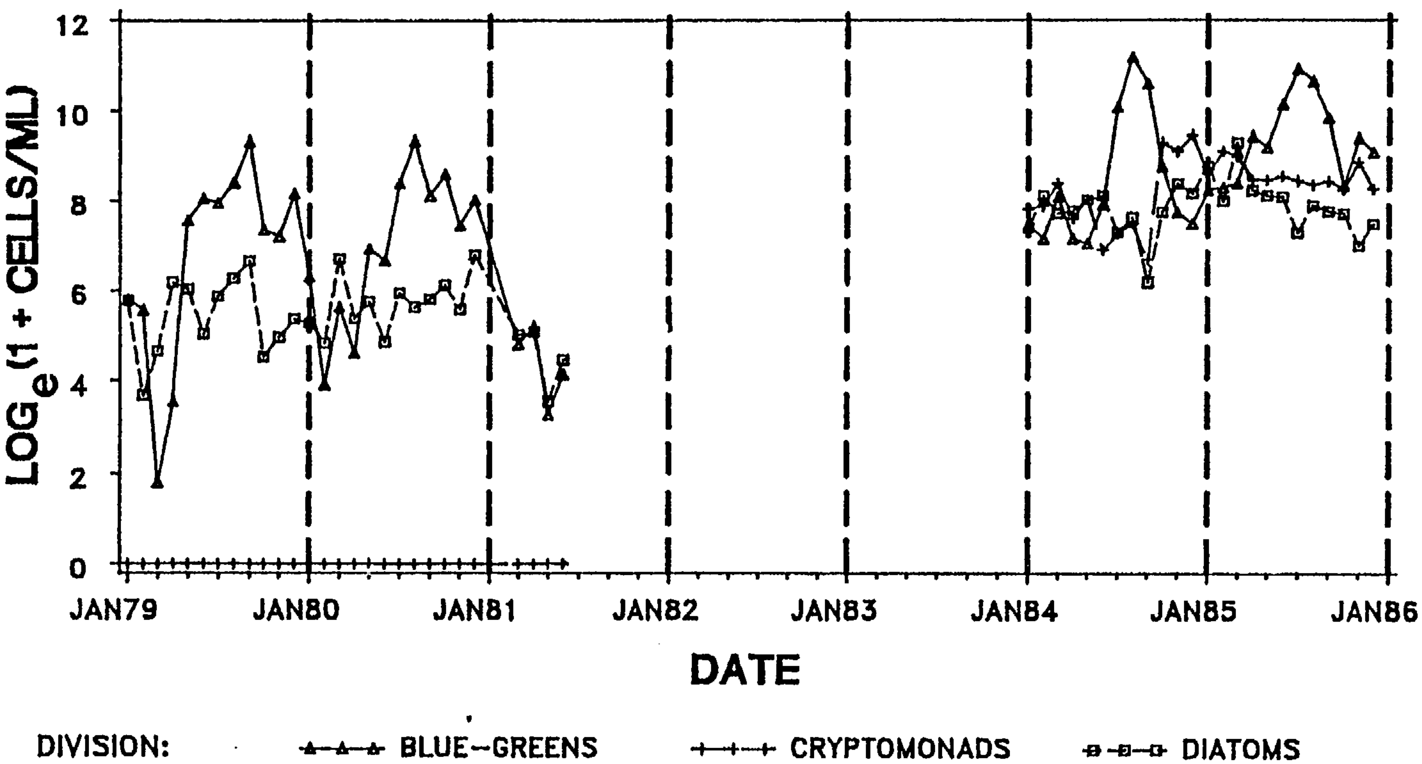

Figure 4.1-7. (Continued).

Cryptomonads

Cryptomonads (Cryptophyta) were not present in samples collected through the spring of 1981 with the possible exception of two samples in 1979 and one in 1980. When phytoplankton sampling was resumed in January 1984, the cryptomonads were already a major constituent of the community (Figs. 4.1-6, 4.1-7). Thus, the cryptomonads probably first appeared in Lake Anna sometime during the early 1980's. Their late appearance may be related to their more frequent occurrence in oligotrophic environments and the late development of these conditions in Lake Anna.

In the Lower Lake, cryptomonads were most abundant in the autumn, winter and spring months and generally dominated or codominated the community in those seasons (Appendix B-Fig. 1). However, throughout the year they were virtually ubiquitous; they were observed in almost every phytoplankton sample. In the Upper Lake they were much less prominent. They were dominant in fewer months, and when dominant they usually shared the lead position with another division.

During 1984-85 the cryptomonads dominated the Mid Lake and Lower Lake communities from November through May or June. In mid-summer their relative density averaged only 10%. Cool-season maximums for cryptomonads were also observed at Lake Norman (Rodrigues 1982) and are typical of this group generally (Likens 1985). From 1984 to 1985 the cryptomonads had the highest average abundance of any algal division in the lake below the Rt. 208 bridge station which

is in keeping with the oligotrophic habitat of cryptomonads. Cryptomonads also exhibited a trend of increasing relative density in the community from the arms to the Dam. For example, from the Upper Lake to Rt. 208 bridge cryptomonad relative density doubled and it again nearly doubled from the Rt. 208 bridge to the remaining stations.

Green Algae

Green algae are warm season species that were most abundant in Lake Anna during the summers. At all stations they followed the successional pattern except that their average density in the Lower Lake from 1978 through 1985 was relatively unchanged. In the Upper Lake their density increased substantially from 1980 to 1985 (Fig. 4.1-7).

In terms of community composition, the Upper Lake community from 1977 until 1981 tended to be dominated by green algae when the green algae were not at their peak abundance from January through March/May. In this period their relative density frequently exceeded 75% at the Rt. 208 bridge. In 1984-85 the relative density of the green algae was reduced at all stations. In the Upper Lake they were dominant over only brief periods including April-May in 1984 and September-October in 1985. In the Lower Lake this group's dominance of the community was somewhat greater but still restricted to the warm months of July-August 1984 and July-October 1985 (Appendix B-Fig. 1).

Blue-green Algae

From 1974 to 1976 the blue-green algae exhibited a relatively constant average annual density of 1,400 cells/ml in Lake Anna (Figs. 4.1-6 and-7). They reached an all time high density in the drought of 1977 averaging 5,860 cells/ml in the Lower Lake and 13,968 in the Upper Lake. The main blue-green genera represented in the community in 1977 were Aphanocapsa, Lyngbya and Microcystis. From 1978 through 1980 this group tended to have densities similar to those of the pre-drought years and they tended to be very abundant for several months in the summer. Their period of abundance extended into the autumn in the Upper Lake. By 1984, the period of blue-green abundance was restricted at all lake stations. In the Lower Lake densities were bimodal in 1984-85 with peaks in the winter-spring and summer-autumn periods. These Lower Lake density peaks were lower than those exhibited for most of the reservoir's history. Meanwhile, blue-greens in the Upper Lake achieved high densities during a single period extending from May through September. Also, with the exception of 1977, blue-green densities in the Upper Lake in 1984-85 were higher than in previous years.

In terms of community composition, in recent years, blue-green algae have dominated the Upper Lake during the summer. Although blue-greens were prominent in the Lower Lake prior to the 1980's, recently they have been only moderately important for a short period in the winter and summer seasons. They and the other divisions have been partially replaced as dominants by the cryptomonads.

Periphyton

The periphyton community in Lake Anna was nearly continuously dominated by diatoms (Fig. 4.1-8). The only recorded exception was June 1984 when the blue-green algae temporarily became co-dominants with the diatoms at the 208 Bridge site, and when the green algae became co-dominants with the diatoms at Dike 3. In both summers the green algae and blue-green algae appeared to become more abundant than in the winter. In this respect the periphyton exhibited a pattern similar to that observed in the North Anna River.

The most abundant diatom genus in the lake was *Achnanthes* sp.. In addition, *Syndedra* sp., *Navicula* sp. and *Eunotia* sp. were frequently common. *Tabellaria* sp. was less common as were *Cyclotella* sp. and *Melosira distans*, two taxa that occurred more frequently at the Rt. 208 bridge than at Dike 3. The typical blue-greens were the same as those occurring in the river: *Chroococcus* sp., *Oscillatoria* sp. and *Anabaena* sp.. Finally, the important green algae included *Mougeotia* sp. and *Oedogonium* sp.

Between 1984 and 1985 the relative density records at the Rt. 208 bridge station were comparable (Fig. 4.1-8). At Dike 3, closer to the influence of the station, there was a slight increase in blue-green algae relative abundance in the May and October samples (Fig. 4.1-9). There was also a strong decrease in diatoms in October. These are not the effects expected in a thermally enriched stream, but are largely expected fluctuations of this patchy and unstable flora.

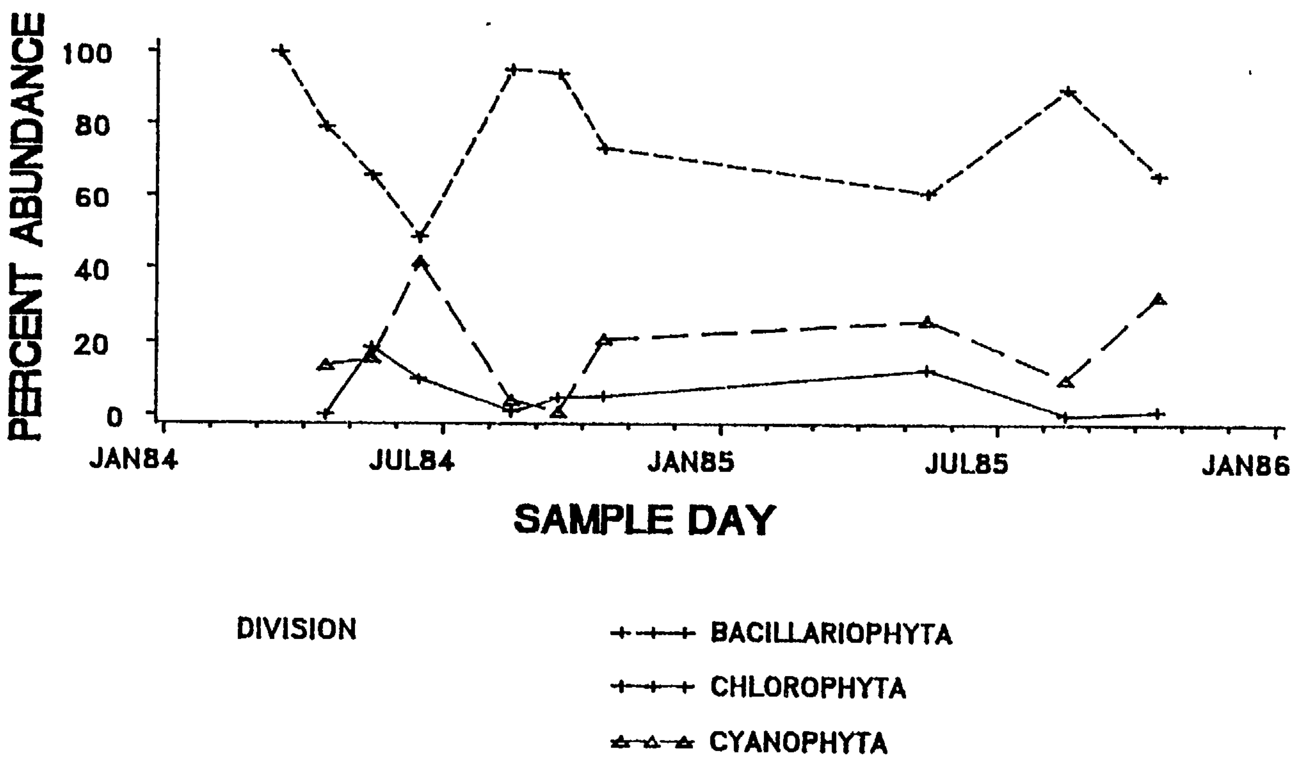

Figure 4.1—8. Relative abundance of periphyton at Lake Anna, Virginia, at the Rt. 208 bridge area.

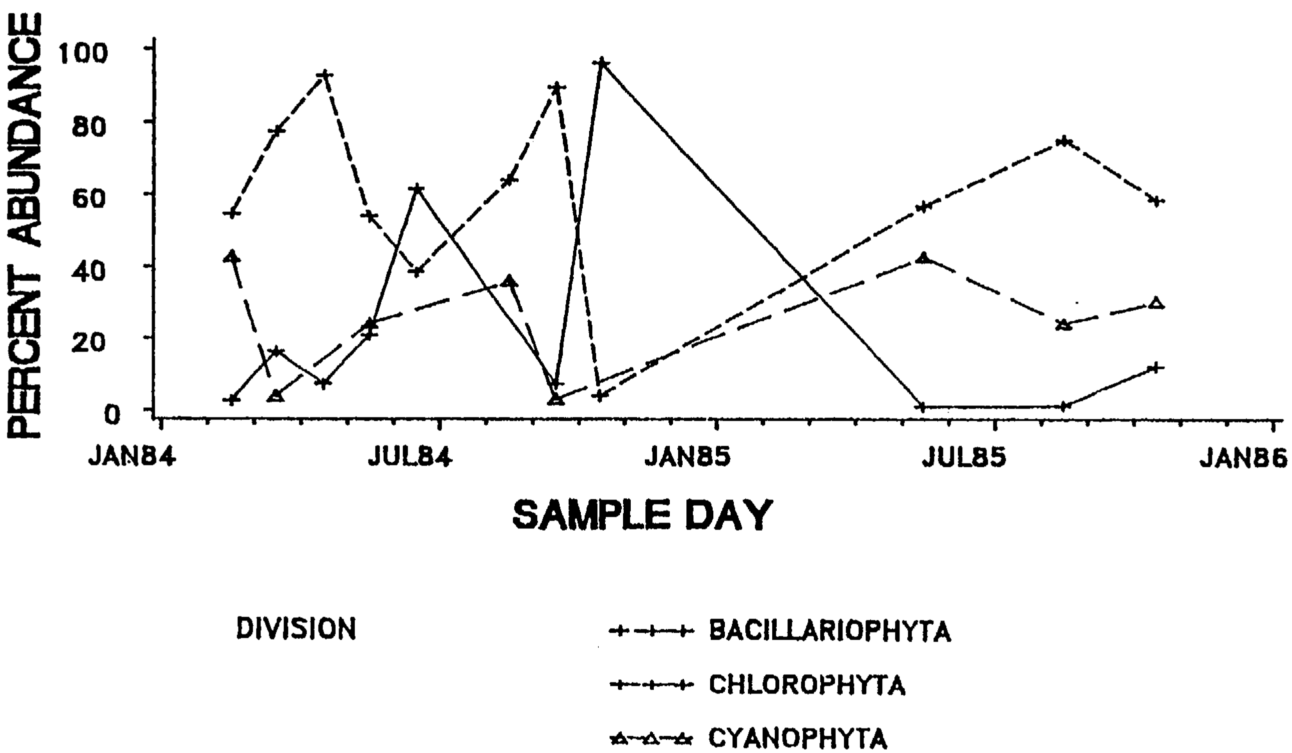

Figure 4.1—9. Relative abundance of periphyton at Lake Anna, Virginia, at the Dike 3 area.

From March through September of 1984, chlorophyll samples were collected from periphytometers to provide biomass estimates of the periphyton in Lake Anna. Over that period, monthly chlorophylls averaged 0.4 mg/m^2. In September 1984 the collections were taken from permanent benthic surfaces in the littoral zone rather than from periphytometers. The changeover was made to ensure that samples could be collected when desired; the periphytometers were being vandalized. Chlorophyll _a_ values abruptly rose after this sampling change and remained above 7.6 mg/m^2 during succeeding sample months. Thus, the increased chlorophyll (or biomass) concentration from 1984 to 1985 appears to be due to the collection technique modification. Biologically it reflects the difference in the mass of periphyton that can accumulate during a one month period on the periphytometers, and the amount that can accumulate during a season on the benthic surfaces.

Over the period when periphyton collections were taken from benthic surfaces, lake periphyton biomass reached a peak in May (Appendix B-Table 10). The remaining months averaged 812 mg/m^2. During most of this period the periphyton biomass was greater in the Lower Lake. In May 1985 for example, the average was 1,574 mg/m^2 at the Rt. 208 bridge and 3,036 mg/m^2 at Dike 3. This difference is probably related to the increased light penetration through the water column in the Lower Lake compared to the Mid-Lake.

Macrophytes

The total shoreline sampled for macrophytes was 24km (Fig. 4.1-10). The shoreline was divided into seven segments for surveying purposes. The boundaries between the segments are indicated on the map by capital letters.

In the survey area the substrate is primarily clay. In the upper 3.4km and in the lower 6.7km of the area it is tan or yellow and underlain by metamorphosed granite. In the central 14km it is a dark to bright red, ferrous clay. At rare spots the substrate is rock, either friable, metamorphosed granite or basalt. The clays were extensively wave-eroded on the lake side of islands and on unprotected shores and points. As a result, 40% of the shores were slick clay surfaces devoid of vegetation (Appendix B-Table 11).

Though the sample area was not completely modified by human activity, 19% of the shore was severely impacted by clearings for swimming, placement of rip-rap walls, general shore clearings, as well as grazing by cattle. Macrophytes were largely absent from these human-disturbed areas. The total unvegetated shoreline due to unstable clays, human activity and bare rock was 62%. The remaining shore was occupied by a limited collection of plant species.

On vegetated stretches of shoreline in the survey area, cattail (*Typha latifolia*) was by far the most abundant emergent macrophyte dominating 70% of the vegetated shores. Other common emergents and their prominence were: bullrush (*Juncas* sp.) 18%, rush (*Scirpus* spp.) 5%, squarestem

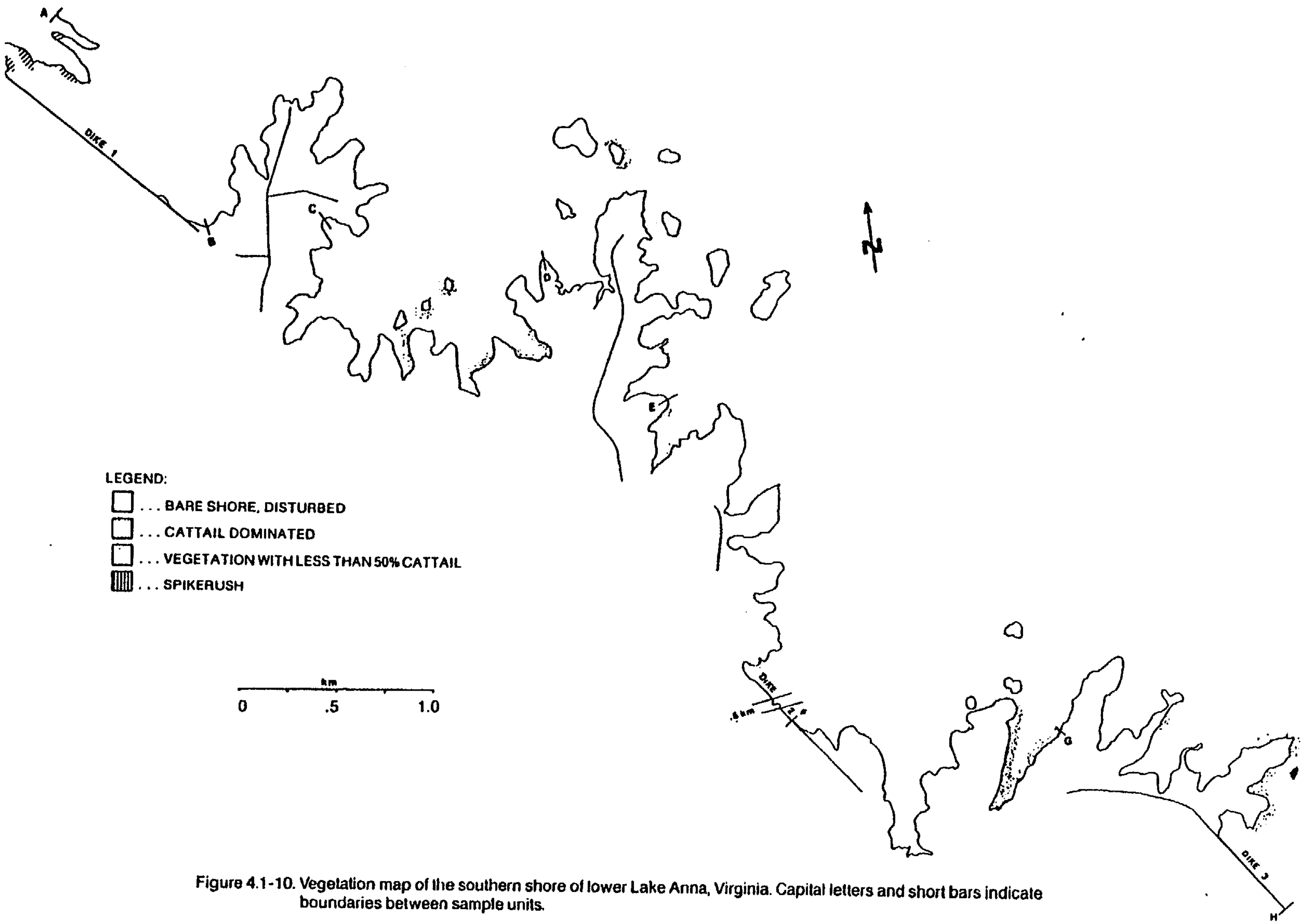

Figure 4.1-10. Vegetation map of the southern shore of lower Lake Anna, Virginia. Capital letters and short bars indicate boundaries between sample units.

spikerush (*Eleocharis quadrangulata*) 4%, slender spikerush (*E. acicularis*) 2% and burreed (*Sparganium chlorocarpum*) 1%. In general, where the macrophyte beds were thick they were associated with a thin, shoreward zone of forbs and sedges including *Dulichium arundinaceum*, *Scirpus* sp., *Juncas* spp. and *Rhynchospora* sp.. The vegetation zone on slightly higher ground was typically composed of the shrubs *Alnus rugosa* and *Cephalanthus occidentalis*, of the trees *Salix nigra* and *Acer rubrum* and several species of grass. The associated submerged vegetation was composed almost exclusively of four taxa. Slender spikerush was a submergent along 50% of the shores in the Lower Lake. It inhabited the zone from approximatley 0.4m depth out to 1m depth or more. However, it varied greatly in density and usually only sparsely populated the shallows. Najas (*Najas* spp.) was much less common and appeared to occupy areas unoccupied by slender spikerush. *Ludwigia palustris* was found rarely in the submerged zone and *Potamogeton* spp. including *P. diversifolius* were found in select, quiet shallows.

With the exception of the uppermost shores of the study area, which are protected from wave action, the study segments showed equal degrees of natural disturbance (mainly by wave action. That notwithstanding, there was a gradient of decreasing cattail and spikerush abundance and of increasing bullrush abundance down-lake. Also, the middle section (D-E) had a high macrophyte presence. The D-E macrophyte prominence is related to th protection afforded

by the islands in that area and to the relatively shallow water and reduced wave erosion. Cattail beds are dense and common there. Excluding that area, the average cattail occurrence was twice as high in the upper part of the study area compared to the lower part (24% vs. 11%). This seems to be a result of human intervention because shoreline disturbance by humans in the upper part of the survey area was only one-half that in the lower 9.8km (14% vs. 27%). The absence of squarestem spikerush and slender spikerush from most of the study area except in section A-B may reflect an inability to migrate successfully to the lower lake.

All macrophytes listed in the above discussion were also found in Lake Anna during the pre-operational years (Simmons 1977). At that time distribution was also dependent on substrate type and protection from disturbance forces. Finally, as was true then, the macrophyte community is still evolving.

Summary

From 1972 to 1985 the phytoplankton community in Lake Anna changed in terms of density and composition. For the most part, these changes appear to be related more to natural environmental factors than to station operation. The relatively high abundances from 1972 through 1976 are interpreted as a response to the high nutrient concentrations in the same period compared to those in 1984-85. The elevated density in 1977 was accompanied by and probably resulted from changes associated with the drought that year. One change that may have affected the phytoplankton in 1977 was an increase in phosphate throughout the lake.

Phytoplankton density decreased abruptly in the Lower Lake in 1978. The thermal enrichment of the Lower Lake was not sufficient to elevate the water temperatures above the lethal threshold for phytoplankton. Also, because the temperature elevation was only a few degrees Celsius, a resulting density change in the phytoplankton might be difficult to detect. In addition, although the temperature effects did not extend to the Upper Lake, the Upper Lake phytoplankton density also declined from 1977 to 1978. Thus, the thermal changes in the Lower Lake resulting from station operation do not appear to have been the cause of the decline in phytoplankton density from 1977 to 1978. Rather, nutrient fluctuations, particularly phosphate concentration changes, appear related to the fluctuation in phytoplankton density.

From 1978 through 1985 there was a gradual rise in phytoplankton density in the Lower Lake. There was a similar increase in the community in the Rt. 208 bridge and Upper Lake areas which are at least 10km above the point of thermal discharge into Lake Anna at Dike 3. Thus, the 1978 to 1985 phytoplankton density increase appears to be a general phenomenon associated with lake maturation.

From 1978 through 1985 there was also a major change in phytoplankton community composition. The cryptomonads, a group of flagellates which had not been found in any samples collected prior to 1979, were the dominants or codominants in the phytoplankton community during most of the year from 1984 to 1985. In the Upper Lake the three previously dominant algal divisions increased in abundance from 1978 to 1985. Thus, in the Upper Lake the introduction of cryptomonads resulted in the addition of a fourth abundant group that was dominant or codominant during the autumn and winter seasons. Meanwhile, in the Lower Lake with the addition of the cryptomonads the blue-green algae clearly decreased in peak abundance and in breadth of abundance period. Thus, in the Lower Lake the cryptomonads have apparently replaced the blue-greens for at least part of the year.

The cryptomonads also appear to have affected the dominant position of the two other abundant algal divisions, the green algae and diatoms. The green algae, while exhibiting a large density increase in the Upper Lake, maintained a relatively constant density in the Lower Lake

from 1978 through 1985. Over this period the cryptomonads became more numerous and thereby dominated the winter season which had previously been dominated by green algae. Unlike the green algae, diatoms increased in density over the 1978-85 period. However, their increase in the Lower Lake was much lower than in the Upper Lake and in the Lower Lake their total density was exceeded by that of the cryptomonads. As a result, the relative abundance of diatoms in the Lower Lake was reduced in 1984-85, particularly in the winter.

These compositional changes in the phytoplankton community have occurred from 1978 through 1985, a period when station operation generally increased. However, they do not appear to have resulted from station operation. Rather, they appear to result from the development of oligotrophic conditions, particularly in the Lower Lake, and the attendant advent of the cryptomonads. The increased number of phytoplankton genera also suggest that the community may be changing in a successional sense that is unrelated to operational regime. One compositional change that may be related to station operation is the Lower Lake shift of the spring diatom abundance peak to a time at least two months earlier than during pre-operational years.

The periphyton densities from 1984 to 1985 do not have a pattern that corresponds with station operation variables.

In the area of Lake Anna from the intakes to the dam, macrophyte occurrence is strongly related to human

disturbance. This pattern and the inherent high variability of the littoral environment contraindicates that environmental modification due to station operation would affect macrophyte occurrence. Finally, noxious macrophytic species were not observed in the study area.

In summary, the indigenous phytoplankton, periphyton and macrophyte communities in Lake Anna exhibit the composition and structure typical in a young, natural aquatic ecosystem. The periphyton community changes from 1984 to 1985 were seasonally related rather than operationally related. In the shallow water habitat of the macrophytes, disturbance was the most influential variable. It limited the composition and extent of the community so much that station effects, if any, could not be detected in the Mid- and Lower Lake. Finally, alterations in the phytoplankton community that have occurred since the station began operating appear to be primarily due to natural, successional processes accompanying reservoir maturation.