1977-78 Intensive Lake Surveys in New Jersey

SUMMARY REPORT

by Kenneth Wagner
Lakes Management Program
Division of Water Resources
NJDEP
1977-78 INTENSIVE LAKE SURVEYS
IN NEW JERSEY

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New Jersey Department of Environmental Protection

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PART I: Lakes Studied

General Methods

Comprehensive Glossary
PREFACE

The Division's Bureau of Water Quality Planning and Management initiated its intensive lake survey program during the spring of 1977. These surveys are an outgrowth of the on-going lake inventory and classification program. Fifteen (15) lakes were surveyed, primarily based on priorities established by "208" Areawide Planning Programs. Those selected included an urban lake, suburban and rural lakes, and reservoirs. The trophic status of these lakes ranges from oligotrophic to highly eutrophic.

These surveys were designed to determine lake dynamics and trophic conditions, utilizing field observations, nutrient concentrations and biological analyses and indices. Point and non-point sources of nutrients are differentiated and quantified wherever possible. Recommendations are made regarding the control of excessive nutrient loading and methods for lake rehabilitation.

The intensive lake surveys were performed during a one (1) year period. Samples were taken monthly at lake inlets and outlets, from all point sources in the watersheds, and upstream from all discharges. In-lake surface and bottom samples (where appropriate) were taken during the spring, summer and autumn. Analyses were conducted for physical, chemical, bacteriological and other biological parameters.

Surveys on these diversified lake ecosystems will aid "208" planning groups in developing their areawide water resources management plans, provide basic input to facilities planning, and will assist local communities in their quest for funding under the Federal Clean Lakes Program. A second group of thirty (30) lake surveys is scheduled to begin during December, 1978. Surveys such as these play an integral part in achieving the goals of the Clean Water Act of 1977 and provide a basic tool to the citizens of this state for obtaining high quality water for recreation and water supply uses.

Robert J. Kotch, Supervisor
Lakes Management Program
1977-1978 Intensive Survey Lakes
N.J. Lakes Management Program
Division of Water Resources, NJDEP

Monmouth County Area:
  Deal Lake
  Allentown Lake

Upper Raritan Area:
  Sunset Lake
  Round Valley Reservoir

Northeast Study Area:
  Speedwell/Pocahontas Lakes
  Boonton Reservoir
  Branchbrook Park

Upper Delaware Area:
  Saxton/Waterloo Lakes
  Allamuchy Pond

Lower Delaware Area:
  Rainbow Lake
  Clark's Pond

Cape May Area:
  Dennisville Lake
  Ludlam's Pond
General Methods

Samples were taken monthly at all lake inlets and outlets (or as close as possible to the inlet or outlet). Additional samples were taken at any known point-source discharges within the watershed. Measurements of certain physical and chemical parameters were made in the field, along with qualitative observations. Algal analysis was carried out at the New Jersey Department of Environmental Protection Scotch Road Laboratories, while chemical and bacteriological analyses were performed by the New Jersey Department of Health Laboratories in Trenton.

Three times during the year (summer, fall, and spring) in-lake samples were taken by boat, and some additional measurements were made (Secchi disk readings, depth, dissolved oxygen profile, temperature, and chemical parameters at vertical intervals). This data was incorporated into the overall analysis where appropriate.

Additional special samples were taken if necessary, usually involving qualitative analysis of various parameters. This data was generally used to supplement the monthly sample results.

Additional data was obtained by contacting appropriate agencies or individuals, such as Municipal Offices, United States Geological Survey, or other state offices.
Abiotic — pertaining to any non-biological factor or influence, such as geological or meteorological characteristics.

Adsorption — external attachment to, the process by which a molecule becomes attached to the surface of a particle.

Aphotic Zone — dark zone, below the depth to which light penetrates. Generally equated with the zone in which most photosynthetic algae can not survive, due to the light deficiency.

Assimilative Capacity — ability to incorporate inputs into the system. With lakes, the ability to absorb nutrients without showing extremely adverse effects.

Background Value — value for a parameter that represents the conditions in a system prior to a given influence in space or time.

Best Management Practices — (BMP's) State-of-the-art techniques and procedures used in an operation such as farming or waste disposal in order to minimize pollution or waste.

Biota — Plant and animal life.

Biotic — pertaining to biological factors or influences, concerning biological activity.

Bloom — excessively large standing crop of algae, usually visible to the naked eye.

CFS — cubic feet per second, a measure of flow.

Chlorophyll — photosynthetic pigment found in most plants, generally proportional in quantity to the plant biomass present.

Chlorophyte — green algae, algae of the division Chlorophyta.

Chrysophyte — golden or yellow-green algae, algae of the division Chrysophyta.

Confluence — meeting point of two rivers or streams.

Cosmetic — acting upon symptoms or given conditions without correcting the actual cause of the symptoms or conditions.
Cryptophyte — algae of variable pigment concentration, with various other unusual features. Algae of the division Cryptophyta, which is often placed under other taxonomic divisions.

Cyanophyte — bluegreen algae, algae of the division Cyanophyta.

Deoxygenation — depletion of oxygen in an area, used often to describe possible hypolimnetic conditions.

Detention Basin — artificially or naturally dug out area acting as a holding pond, delaying the movement of water into a system or downstream in that system. Used in lake and river management to give physical, chemical and biological processes a chance to purify water before it enters a system or given part of a system.

Diatom — specific type of chrysophyte, having a siliceous frustule (shell) and often elaborate ornamentation, commonly found in great variety in fresh or saltwaters. Often placed in its own division, the Bacillariophyta.

Dinoflagellate — unicellular algae, usually motile, having pigments similar to diatoms and certain unique features. More commonly found in saltwater. Algae of the division Pyrrhophyta.

Domestic Wastewater — water and dissolved or particulate substances after use in any of a variety of household tasks or systems such as sanitary systems or washing operations.

Dystrophic — trophic state of a lake in which large quantities of nutrients may be present, but are generally unavailable (due to organic binding or other causes) for primary production. Often associated with acid bogs.

Epilimnion — upper layer of a stratified lake. Layer that is mixed by wind and has a higher average temperature than the hypolimnion. Roughly approximates the euphotic zone.

Euglenoid — algae similar to green algae in pigment composition, but with certain unique features related to food storage and cell wall structure. Algae of the division Euglenophyta.

Eutrophic — high nutrient, high productivity trophic state generally associated with unbalanced ecological conditions and poor water quality.

Eutrophication — process by which a body of water ages, most often passing from a low nutrient concentration, low productivity stage to a high nutrient concentration, high productivity stage. Eutrophication is a long-term natural process, but it can be greatly accelerated by man's activities. Eutrophication as a result of man's activities is termed cultural eutrophication.
French Drain — water outlet which allows fairly rapid removal of water from surface, but then allows subsurface percolation. Generally consists of sand and gravel layers under grating or similar structure, at lowest point of a sloped area. Water runs quickly through the coarse layers, then percolates through soil, usually without the use of pipes. The intent is the purification of most percolating waters.

Groundwater — water in the soil or underlying strata, subsurface water.

Hydraulic detention time — lake water retention time, amount of time that an average random water molecule spends in a water body; time that it takes for water to pass from an inlet to an outlet of a water body.

Hypolimnion — lower layer of a stratified lake. Layer that is mainly without light, generally equated with the aphotic zone, and has a lower average temperature than the epilimnion.

Intermittant — non-continuous, generally referring to the occasional flow through a set drainage path. Flow of a discontinuous nature.

Leachate — water and dissolved or particulate substances moving out of a specified area, usually a landfill, by a completely or partially subsurface route.

Leaching — process whereby nutrients and other substances are removed from matter (usually soil or vegetation) by water. Most often this is a chemical replacement action, prompted by the qualities's of the water.

Lentic — standing, having low motion. Refers to lakes and impoundments.

Limiting Nutrient — that nutrient of which there is the least quantity, in relation to its importance to plants. The limiting nutrient will be the first essential compound to disappear from a productive system, and will cause cessation of that productivity at that time. The chemical form in which the nutrient occurs and the nutritional requirements of the plants involved are important here.

Limnology — the comprehensive study of lakes, encompassing physical, chemical and biological lake conditions.

Loading — inputs into a receiving water that exert a detrimental effect on some subsequent use of that water.

Lotic — flowing, moving. Refers to streams or rivers.
Macrophyte – higher plant, macroscopic plant, plant of higher taxonomic position than algae, usually a vascular plant. Aquatic macrophytes are those macrophytes that live completely or partially in water.

Mesotrophic – an intermediate trophic state, with variable but moderate nutrient concentrations and productivity.

MGD – million gallons per day, a measure of flow.

Nitrogen-fixation – the process by which certain bacteria and bluegreen algae make organic nitrogen compounds (initially $\text{NH}_4^+$) from elemental nitrogen ($\text{N}_2$) taken from the atmosphere or dissolved in the water.

Non-point Source – a diffuse source of loading, possibly localized but not distinctly defineable in terms of location. Includes runoff from all land types.

Oligotrophic – low nutrient concentration, low productivity trophic state, often associated with very good water quality, but not necessarily the most desireable stage, since often only minimal aquatic life can be supported.

Periphyton – attached forms of plants and animals, growing on a substrate. Often dominant algae form in flowing waters.

Photic Zone – illuminated zone, surface to depth beyond which light no longer penetrates. Generally equated with the zone in which photosynthetic algae can survive and grow, due to adequate light supply.

Photosynthesis – process by which primary producers make organic molecules (generally glucose) from inorganic ingredients, using light as an energy source. Oxygen is evolved by the process as a byproduct.

Phytoplankton – algae suspended, floating or moving only slightly under their own power in the water column. Often the dominant algae form in standing waters.

Point Source – a specific source of loading, accurately defineable in terms of location. Includes effluents or channeled discharges that enter natural waters at a specific point.

Potable – usable for drinking purposes, fit for human consumption.

Primary Productivity (Production) – conversion of inorganic matter to organic matter by photosynthesizing organisms. The creation of biomass by plants.
Riffle Zone — stretch of a stream or river along which morphological and flow conditions are such that rough motion of the water surface results. Usually a shallow rocky area with rapid flow and little sediment accumulation.

Runoff — water and its various dissolved substances or particulates that flows at or near the surface of land in an unchanneled path toward channeled and usually recognized waterways (such as a stream or river).

Secondary Productivity — the growth and reproduction (creation of biomass) by herbivorous (plant-eating) organisms. The second level of the trophic system.

Sedimentation — the deposition of solids of varying nature on the bottom of a lake or stream bed.

Stagnant — motionless, having minimal circulation or flow.

Standing Crop — current quantity of organisms, biomass on hand. The amount of live organic matter in a given area at any point in time.

Stratification — process whereby a lake becomes separated into two relatively distinct layers as the result of temperature and density differences. Further differentiation of the layers usually occurs as the result of chemical and biological processes. In most lakes, seasonal changes in temperature will reverse this process after some time, resulting in the mixing of the two layers.

Succession — the natural process by which land and vegetation patterns change, proceeding in a direction determined by the forces acting on the system.

Tertiary Productivity — the growth and reproduction (creation of biomass) by organisms that eat herbivorous (plant-eating) organisms. The third level of the trophic system.

Thermocline — boundary level between the epilimnion and hypolimnion of a stratified lake, variable in thickness, and generally approximating the maximum depth of light penetration and mixing by wind.

Trophic State — the stage or condition of an aquatic system, characterized by biological, chemical and physical parameters.

Taxon (Taxa) — any hierarchical division of a recognized classification system, such as a genus or species.

Watershed — drainage basin, the area from which an aquatic system receives water.
PART II: General Lake Information and Individual Report Summaries

Allamuchy Pond
Allentown Lake
Boonton Reservoir
Branchbrook Park Lake
Clark's Pond
Deal Lake
Dennisville Lake/Ludlam's Pond
Rainbow Lake
Round Valley Reservoir
Saxton Lake/Waterloo Lake
Speedwell Lake/Pocahontas Lake
Sunset Lake
LAKE NAME: Allamuchy Pond

LAKE LOCATION:

USGS Quadrangle: Tranquility Lat: 40°54'40" Long: 74°49'00"
County: Warren County
Municipality: Allamuchy Township

LAKE STATUS: (Public or Private): Mostly public (PM-2), but a small portion (about 4 acres near the outlet) owned by Villa Madonna Convent, and part of the State-owned acreage is included in the land area leased to a farmer.

LAKE SIZE:

Average Depth Approximately 10 ft. (3.05 M)
Range of Depth to 25 ft. (7.62 M)
Area 49.2 acres (19.9 hectares)
Volume 160.4 million gal. (607,000 M3)

WATERSHED INFORMATION:

Size about 800 acres (1.25 sq. mi.) or 324 hectares (3.24 sq. km.)

Land use Farmland and pasture land comprise about 0.25 sq. mi., residential and business areas make up about 0.1 sq. mi., and the rest of the watershed is woodland.

WATER AND NUTRIENT SOURCES:

Tributaries 1 actual inlet tributary, with 3 branches upstream (1 from Neirtown, called inlet # 2, and 2 from Woodland, called inlet #1 after their confluence).
Springs Springs in lake bottom

Effluents None known

Runoff May be considerable from farm and pasture land during rainy periods, flowing into the tributary just upstream of the lake. Also has runoff input from Neirtown.
Precipitation Long-term avg. = 48.8 in/yr (124 cm/yr)
1977 = 48.1 in (122 cm)
Other

LAKE USE:

Present Fishing, but usually only ice fishing in the winter, due to heavy summer weed growths.
Past Commercial ice operation, fishing, boating, swimming.

Potential Fishing, boating.

STUDY PERIOD: 5/77 - 6/78
CONCLUSIONS

Allamuchy Pond is suffering from accelerated eutrophication, and experiences high nutrient concentrations, dissolved oxygen deficiencies and nuisance growths of macrophytes and algae. As many as five tributaries supply water to the pond, along with some springs in the bottom of the pond, but the inputs from some sources are not believed to be very significant. Two tributaries merge and then flow between pasture and cropland south of the pond, with a small stream from Weirtown entering at the north end of the farm. Runoff from the pasture and cropland of the farm, and from animal pens and residential/business areas in Weirtown contribute significant inputs to these tributaries, which then enter the lake as a single stream. This is by far the largest and most enriched tributary, and provides the most significant inputs to the pond. The other tributaries are intermittent, and act mainly as drainage paths for woodland areas. None of the direct inputs are believed to be very significant.

The tributary that passes by the farm was not adequately sampled, but those values that were obtained indicated poor water quality with a slightly elevated pH and alkalinity, and high phosphorus and nitrogen levels (total phosphate averaging 0.34 mg/l and total nitrogen averaging 3.6 mg/l.)

The tributary from Weirtown was more adequately sampled, and also had poor water quality. However, most average nutrient values were not quite as high as for the main tributary, with total phosphate at 0.18 mg/l and total nitrogen at 3.1 mg/l. The pH and alkalinity were somewhat higher though, at averages of 8.1 and 157 mg/l, respectively.

The morphology of Allamuchy Pond is like that of a bowl with an irregular, wide rim. The average rim depth is about six feet, and the entire outlet cove is included. The bowl occupies the center of the lake, and has an average depth of twenty to twenty five feet. The rim area had lesser concentrations of phosphorus in the water column, and was choked by dense growths of macrophytes and filamentous green algae during the warmer months. The average total phosphate concentration was 0.23 mg/l, while the average total nitrogen level was about 3.2 mg/l. The pH averaged 8.0, with an average alkalinity of 96 mg/l. Dissolved oxygen levels were sometimes very low, but the average level was an acceptable 7.5 mg/l.

Conditions in the bowl were similar with respect to pH, alkalinity and most nutrient values, although phosphorus concentrations (both forms) were a bit higher than at the outlet (total phosphate averaged 0.34 mg/l). The State Surface Water Quality Standard for phosphorus was contravened at both the outlet and in-lake stations, and in both studied tributaries. Phosphorus is more likely to limit productivity in the system than nitrogen, but due
to the rather large concentrations, nutrients are probably not the major limiting factor. Temperature and dissolved oxygen profiles showed weak stratification below 10 to 12 feet of depth, with severe summer dissolved oxygen deficiencies in the hypolimnion. The role of internal nutrient recycling in the eutrophication of Allamuchy Pond is uncertain, but it is likely that such recycling is very important at the present time. Macrophytes have access to some bottom deposits, and probably release some nutrients into the water column. Deoxygenation of the hypolimnion also facilitates phosphorus recycling.

Bacteriologically, animal wastes and some residential runoff give the studied tributaries some large bacterial populations, and the State Surface Water Quality Standard for fecal coliform was contravened in the tributary from Weirtown. Total coliform geometric means were greater than 1000 MPN/100 ml, generally indicating poor water quality. In the pond itself, a few higher values were obtained for the measured bacteriological parameters, but geometric means were all fairly low, indicating no health hazards or major effects by the bacterial inputs on the pond itself.

The macrophyte populations of the rim area were very dense at times, and were dominated by Potamogeton crispus (Curly-leaf Pondweed) and Myriophyllum spicatum (Eurasian Watermilfoil). Associated algae included filamentous green algae (in dense mats), chlorococcalean green algae and various bluegreen algae. While the microscopic algae were seldom dominant at the outlet, cell concentrations were often high, and the chlorophyll a concentration (from microscopic algae) averaged 48.15 mg/m³, a very high value.

In the open waters of the pond macrophytes were rarely seen, and bluegreen algae dominated the phytoplankton during part of the year. Light and temperature limited winter growth, and the spring sampling produced a small assemblage of pollution-tolerant forms from many algal divisions. Cell concentrations were variable, but averaged out to a high 86000 cells/ml, with only a moderate average chlorophyll a level (13.81 mg/m³). Diversity was depressed throughout the lake, and dominance was often great. Poor water quality conditions were indicated.

The water quality indices employed supported the conclusions drawn here, and eutrophic conditions were indicated overall. Phosphorus may limit productivity at times (especially in the rim area), but other factors such as light or competitive inhibition are probably more important factors during much of the year. Most species present are pollution tolerant, and nutrient enrichment is high, but little indication of organic pollution was given by the indices.
On the basis of the accumulated data and analyses made, it can be concluded that Allamuchy Pond is in a eutrophic state. Great productivity (resulting in nuisance conditions) and dissolved oxygen deficiencies can be expected for years to come, until the pond becomes a marsh or meadow, unless restorative action is taken.
GENERAL INFORMATION

LAKE NAME: Allentown Lake (Conines Millpond)

LAKE LOCATION:
USGS Quadrangle: Allentown  Lat. 40°10'40" Long. 74°35'00"
County: Monmouth
Municipality: Allentown Borough and Upper Freehold Township

LAKE STATUS: (Public or Private) Public FW-2

LAKE SIZE:
Average Depth: 2.9 ft (0.88 M)
Range of Depth: To 10 ft (3.05 M)
Area: 31.8 acres (12.9 Hectares)
12.2 acres in Allentown
19.6 acres in Upper Freehold
Volume: 30 million gal. (113,500 M³)

WATERSHED INFORMATION:
Size: Approx. 5000 acres (2023 Hectares) sending water into Allentown Lake before other lakes. 10,930 acres (4423 Hectares) including area sending water into Imlaystown Lake before Allentown Lake.
Land use: 75% agricultural 20% forested 5% developed (mostly residential)

WATER AND NUTRIENT SOURCES:
Tributaries: Doctors Creek
Negro Run
Springs: None known
Effluents: (Point Sources): None known
Runoff: Some from vicinity of lake, much into tributaries from farmland.
Precipitation: 40.17 in. (long term avg.) 51.18 in. (1977) (102 cm.) (130 cm.)
Other: Possibly some septic input from residences around Lake, but not indicated as a major influence.

LAKE USE:
Present: Some fishing
Past: Boating, fishing, swimming
Potential: Boating, fishing, swimming

STUDY PERIOD: 5/77 through 5/78
Conclusions

The indications of the data are that Allentown Lake is experiencing accelerated eutrophication as a result of nutrient loading from runoff from the agricultural lands surrounding its tributaries. Increased sediment loads and biological production are causing the lake to be filled in rapidly. Increasing productivity in the lake is manifested primarily as aquatic macrophytes, but algal blooms would be expected in the absence of the macrophytes. As it is, this lake would be classified as eutrophic.

Phosphorus appears to be the limiting nutrient, although light may become a factor when growth is dense. The retention time for water in the lake is rather low, which is normally a retardant to eutrophication, but in this case the nutrient and sediment loadings, due to runoff, are great enough to overshadow the effect of rapid flushing rate.

With the macrophyte situation as it is, flow could be expected to continue to decrease in all peripheral areas of the lake, and filling will continue until only a stream within a marshy meadow remains. Any restorative action will have to include both reduction of nutrient inputs and elimination of nutrient reserves along with some action to make the environment less favorable for macrophyte growth.
LAKE NAME: Boonton Reservoir

LAKE LOCATION:
USGS Quadrangle Boonton Lat. 40°53'00" Long. 74°24'30"
County Morris
Municipality Boonton and Parsippany - Troy Hills

LAKE STATUS: (Public or Private) Private - Jersey City Bureau of Water

LAKE SIZE:
Average Depth 25 ft (7.62 M)
Range of Depth To 94 ft (28.65 M)
Area 780 acres (315.7 hectares)
Volume 7620 Million Gal. (28.8 Million M³) at spillway level. Often as much as 7 ft. below spillway during heavy usage.

WATERSHED INFORMATION:
Size 119 sq. mi. (308 sq. km.)
Land use Heavily Industrial/residential along Rockaway River and Industrial/residential/forested along tributaries.

WATER AND NUTRIENT SOURCES:
Tributaries One Inlet, Rockaway River, fed by several tributaries upstream; Beaver Brook, Mill Brook and Green Pond Brook. Unknown
Springs
Effluents See Point Source Data (On Flow Data Sheet)
Runoff residential and some woodland runoff. Large drainage area.
Precipitation Long-term avg. = 44.93 in/yr (114.1 cm/yr)
1977 = 54.99 in (139.7 cm)
Other

LAKE USE:
Present Potable Water Supply - Jersey City, Fishing by permit
Past Potable water supply, Fishing
Potential Potable water supply, Fishing

STUDY PERIOD: 6/77 to 6/78
CONCLUSIONS

Boonton Reservoir is experiencing accelerated eutrophication as the result of various point and non-point source inputs. Non-point input sources include precipitation, residential and woodland runoff, and possibly some septic systems. Point sources include effluents from eleven plants involved in a variety of production processes, with sewage included in some effluents. Two sewage treatment plants also discharge in the study area.

Effluent quality was generally moderate to poor in relation to stream conditions at most plants, but flows were relatively low, making total inputs of given nutrients rather small. Phosphorus was shown to be more important than nitrogen in this system, and phosphorus loads from various sources were calculated from the accumulated data. No annual individual point-source phosphorus input exceeded 300 lbs/yr, while the total input to the reservoir was 27100 to 28600 lbs/yr. All together, point-source phosphorus inputs totalled 1145 to 1545 lbs/yr, or about 4.0 to 5.7% of the total load. This is not considered to be particularly significant. Non-point sources accounted for at least 94% of the total phosphorus load to the reservoir. The major phosphorus source appeared to be residential runoff from the highly developed areas along the Rockaway River, especially within eight miles of the Boonton Reservoir inlet.

Of the 27100 to 28600 lbs of phosphorus entering the reservoir annually, 17100 to 18600 lbs remain there (60 to 69%). This amounts to a retained load of 2.46 to 2.67 g P/m²/yr. Vollenweider's Model indicates that reservoir phosphorus loading should not exceed 0.75 g/m²/yr in order for the reservoir to maintain an oligotrophic status. To keep the reservoir from becoming eutrophic, the load must be kept below 1.48 g/m²/yr. As can be seen, the present load exceeds both of these critical values. Also, at the inlet of Boonton Reservoir, the Surface Water Quality Standard for phosphorus (0.05 mg/l) is contravened, with the average phosphorus concentration at 0.063 mg/l. This concentration has been substantially reduced by the time the water reaches the reservoir outlet.

Going back to the point-source inputs, the pH values for the effluents were generally somewhat elevated, alkalinity levels were extremely variable, and average dissolved oxygen concentrations were adequate. However, low dissolved oxygen values were recorded at some time for most effluents. Average values for the various forms of nitrogen were generally moderate. In all of these cases, even the most excessive inputs did not seem significant in terms of the overall loading picture. Likewise, while the temperatures of many effluents were elevated, the relatively small flows negated the possibility of any major thermal pollution.
Other measured parameters, such as oil and grease and heavy metals, were found to have occasionally high values, but average values were usually well within suggested limits, and total loads were very small. Yet localized adverse impacts could be expected as a result of all the various point-source inputs, and there is some question regarding the significance of these inputs in the long-term loading and degradation of Boonton Reservoir.

In light of the high degree of variability of the quality of each effluent over time, high variability of treatment plant efficiency or industrial process wastes is suggested. Reduction of this variability, by consistent (and highest possible) efficiency, would reduce inputs. And all inputs have some effect on the system, however small.

The morphology of the Rockaway River is such that inputs are reduced at least somewhat before the water reaches the reservoir, and the reservoir itself acts as a huge sink for various inputs. Inputs may enter the reservoir in large pulses, as indicated by general river data and the frequency of floods in the watershed. Some of these inputs may reach the outlet, due to the proximity of the inlet, but much of the nutrient load remains in the reservoir. The physical arrangement of the inlet and outlet lead to decreased circulation and increased hydraulic detention time in most of the reservoir. These conditions can both aid and hinder nutrient recycling and primary productivity in a water body.

Samples taken right at the outlet, at the surface, show relatively good to moderate water quality. The pH is somewhat elevated at an average of 8.0, but no other water quality problems are indicated. Samples taken twenty-five feet below the outlet surface show a decreased pH (down to an average of 7.1), but also show a decreased average dissolved oxygen concentration (down to 7.7 from 10.4 mg/l), with several very low individual values (as low as 2.6 mg/l). The reservoir does stratify (at between 25 and 40 feet), and the differences between surface and deep samples indicate that the raised surface pH results mainly from photosynthetic activity (by algae) and that the higher surface dissolved oxygen level is primarily the result of aeration by the wind and algal photosynthesis. The decreased oxygen levels at 25 feet and below are probably the result of oxygen use in decomposition and inadequate replenishment.

In-lake boat samples show relatively similar water quality to that of the outlet (both above and below the thermocline). However, inadequate data prevents the drawing of definite conclusions. It appears that phosphorus limits growth during the warmer months, and that overall surface water quality is moderate. More information on nutrient recycling and deoxygenation in this reservoir is needed, but it is suggested that the hypolimnion of Boonton Reservoir is deoxygenated during the summer and possibly nutrient-rich.
Total coliform counts were low to moderate at all river and reservoir stations, and in the effluents of most point sources. Average fecal coliform levels were excessive in the Hewlett-Packard Outfall #1 effluent (at a geometric average of 468 MPN/100ml), but this value was reduced by dilution upon entrance of the effluent to Hibernia Brook. Most effluent fecal coliform geometric averages were less than 50 MPN/100 ml. Green Pond Brook, which receives effluents from Picatinny Arsenal operations, had occasionally high fecal coliform counts. This indicated possibly large inputs by those effluents, but the geometric average was quite acceptable at 50 MPN/100ml. Fecal Streptococci levels were lower than the fecal coliform levels in the effluents.

At the inlet to the reservoir, total coliform counts were moderate, at an average of 850 MPN/100ml, and the fecal coliform geometric average exceeded the Surface Water Quality Standard (200 MPN/100ml), at 318 MPN/100ml. Fecal Streptococci concentrations had a geometric average of 114 MPN/100ml, and fecal coliform to fecal Streptococci ratios yielded variable source information. Residential runoff, especially from the nearest residential areas, is suspected as the major source of bacteria at the inlet.

At the outlet of the reservoir and at all in-lake stations the measured bacterial populations were relatively small, and no bacterial standards were contravened. Good to fair water quality was indicated.

Little data on primary productivity and community structure in the Rockaway River or its tributaries was collected, but no nuisance conditions were observed. In Boonton Reservoir, macrophytes are not a significant portion of the plant biomass, mainly due to limitations imposed by the depth of the reservoir.

Algae biomass in the reservoir is generally moderate, with chlorophyll a values averaging between 8 and 17 mg/m$^3$ for the in-lake surface stations. Cell counts were often high, mainly due to the presence of small-celled bluegreen algae. There were some moderate blooms, and the species composition of the algae community was indicative of eutrophic conditions. Dominance was moderate to high, and diversity was generally moderate, although rather variable. Bluegreen algae, chlorococcacean green algae, and pollution tolerant diatoms were the most abundant algae.

Nutrient concentrations were suitable for the support of moderate algae biomass, which is consistent with the observed chlorophyll a data. Yet the algae community structure and species composition are indicative of a highly productive system. The data implies that this reservoir is in transition from mesotrophic to eutrophic conditions, a supposition supported by the phosphorus loading analysis.
At the outlet, algae populations are somewhat smaller and slightly more balanced. While unrepresentative of the reservoir as a whole, they do indicate that the water at the outlet (especially that portion taken for drinking purposes) is not obviously hazardous with regard to algae contaminants at this time. However, large scale bluegreen blooms could eventually render the reservoir water unfit for drinking or bathing. Present treatment of the water drawn from the reservoir for potable use is adequate to eliminate any possible present algal impurities observed during this study.

The water quality indices employed indicated variable conditions, ranging from the lower mesotrophic range to the moderately eutrophic region of the trophic scale. The possibility of organic pollution was demonstrated by Palmer's Index, and Nygaard's Index indicated a transition from mesotrophic to eutrophic conditions. Evenness values indicated moderately balanced to unbalanced ecological conditions, and Carlson's Indices gave extremely varied trophic level indications, with an average solidly in the mesotrophic range.

On the basis of the accumulated data and analysis performed, Boonton Reservoir can be said to be in a mesotrophic state, moving rapidly toward eutrophic conditions. A reduction of nutrient inputs will be needed to halt this progression, and even then it may be some time before a new equilibrium is reached in the reservoir, unless in-lake corrective measures are taken.
LAKE NAME: Branchbrook Park Lake (a series of ponds)

LAKE LOCATION:

USGS Quadrangle Orange
County Essex
Municipality Newark

LAKE STATUS: (Public or Private)
Public (FW-3)

LAKE SIZE:

<table>
<thead>
<tr>
<th>Average Depth</th>
<th>Upper Pond = 2 ft. (0.61 M)</th>
<th>Middle Pond = 6.7 ft. (2.04 M)</th>
<th>Lower Pond = 4 ft. (1.22 M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of Depth</td>
<td>To 4 ft. (1.22 M)</td>
<td>9 ft. (2.74 M)</td>
<td>6 ft. (1.83 M)</td>
</tr>
<tr>
<td>Area</td>
<td>37.5 acres collectively (15.2 hectares)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>61.2 million gallons (232,000 M³)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WATERSHED INFORMATION:

Size about 2 square miles (5.18 sq. km.)
Land use 100% residential

WATER AND NUTRIENT SOURCES:

<table>
<thead>
<tr>
<th>Tributaries</th>
<th>No standard inlets, several springs feed a pipe that runs into the Upper Pond.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Springs</td>
<td>Several feed the inlet pipe at the Upper Pond.</td>
</tr>
<tr>
<td>Effluents</td>
<td>None, but a malfunctioning sewer line has occasional inputs.</td>
</tr>
<tr>
<td>Runoff</td>
<td>Significant quantities from adjacent fields, roads, and area storm sewers.</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Long-term average = 53.90 inches/year (136.9 cm./yr.)</td>
</tr>
<tr>
<td>Other</td>
<td>1977 = 53.80 inches (136.6 cm.)</td>
</tr>
</tbody>
</table>

LAKE USE:

Present Some fishing, Some Boating, aesthetics, Ice Skating
Past Fishing, boating, aesthetics, Ice Skating
Potential Fishing, Boating, aesthetics, Ice Skating

STUDY PERIOD. 5/77 to 7/78
CONCLUSIONS

Branchbrook Park is experiencing accelerated eutrophication as the result of elevated nutrient inputs from a variety of sources. Spring and well water used to feed the Upper Pond is of moderate to poor quality, residential runoff is channelled to the Lower Pond, and a malfunctioning sewer line occasionally allows direct inputs of domestic wastewater. The park area around the ponds provides some runoff inputs, but much of the water crossing the surface of this area percolates through the soil and is diverted from the ponds by a drainage pipe system.

The Surface Water Quality Standard for phosphorus (0.05 mg P/l) is exceeded at all stations, including the inlet pipe at the Upper Pond, with average values ranging from 0.06 to 0.13 mg P/l. Biologically available phosphorus levels are considerably lower during algal blooms, indicating possible phosphorus limitation of growth at times. Nitrogen levels in the system are rather high, and appear more than adequate to support observed primary productivity (See TKN and NO₃-N values). NH₃-N and NO₂-N concentrations are moderate to low, and no associated hazards are indicated. Grease and oil concentrations were often high in some areas.

The pH is slightly elevated, as a result of the combined influence of elevated primary production and relatively high alkalinity. The average pH values in the system ranged from 7.4 to 8.0, and average alkalinity ranged from 92 to 179. Average dissolved oxygen levels are adequate at most stations, although the average value for the Lower Pond inlet area is 5.4 mg/l, contravening the Surface Water Quality Standard of 6.0 mg/l. This is mainly attributed to the subsurface inlet source. Yet all the ponds experienced occasional low dissolved oxygen levels, with some values lower than 3.0 mg/l. In such an apparently well-aerated system this indicates a high rate of decomposition and/or respiration, which is commensurate with the large quantities of organic matter produced and retained in the system.

Various physical characteristics of Branchbrook Park Lake facilitate its eutrophication. The hydraulic detention time is at least two weeks, and probably averages out to more than a month. There is no flow from the outlet of the Lower Pond during certain critical summer dry periods. The system is also shallow, which allows for greater recycling of nutrients. Sedimentation is primarily the result of internal production and deposition, but various construction activities in the park area (most recently in the vicinity of the Senior Citizens Center) have contributed considerable sediment loads over the years.
Bacterial populations in the ponds are fairly large, and poor water quality is indicated. Fecal coliform counts are occasionally high in all areas, and the geometric mean exceeds the Surface Water Quality Standard at the outlet of the Middle Pond. Residential and park land runoff and the occasional overflowing domestic sewer pipe outlet are all possibly significant outside sources of bacteria in the ponds.

The watershed is sparsely vegetated, outside of the actual park area, which contains largely ornamental vegetation. The ponds themselves experience dense growths of several nuisance macrophytes, mainly *Potamogeton crispus* and *Myriophyllum spicatum*. There are also heavy algal blooms in this system, with bluegreen algae and species of the green algae orders Chlorococcales and Volvocales dominating. Almost all algal species present are pollution-tolerant, preferring nutrient-enriched waters. Average chlorophyll $a$ and cell concentrations were quite high. Diversity was moderate, but higher than expected. Dominance was fairly high, but was lower than might be expected as the result of multiple species blooms.

The water quality indices employed indicated upper mesotrophic to eutrophic conditions for the ponds, with great potential for primary productivity. Phosphorus was again indicated as a possible growth-limiting factor, although light and temperature are also critical at times. Turbidity in the system is great, as the result of both algal cell concentrations and suspended non-living matter. Some organic pollution of this system is expected, but is not strongly implied by the indices. Diversity and dominance are highly variable in this system, with average values in the moderate range.

The lake can presently be characterized as eutrophic, but does not have to remain this way. To improve the water quality of this system, both reduction of detrimental external inputs and inactivation of internal nutrient reserves will be necessary. Removal of the large deposits of organic matter may also be essential to reducing excessive macrophyte growths.
GENERAL INFORMATION

LAKE NAME: CLARKS POND (UPPER, MAIN and LOWER)

LAKE LOCATION:
USGS Quadrangle: BRIDGETON Lat. 39°23'25"/Long. 75°12'20" (MAIN POND)
County: CUMBERLAND
Municipality: FAIRFIELD TOWNSHIP

LAKE STATUS (Public or Private): UPPER - Private; MAIN and LOWER - Public (ALL FV-2)

LAKE SIZE:
Average Depth: UPPER - 4 ft. (1.2M); MAIN - 6 ft. 3 in. (1.9M), and LOWER - 3 ft. (0.9M)
Range of Depth: UPPER - 10 ft. (3.0M); MAIN - 15 ft. (4.6M), and LOWER - 7.0 ft. (2.1M)
Area: UPPER POND - 11 acres (4.5 Hectares); MAIN POND - 37 acres (15.0 Hectares), and LOWER POND - 38 acres (15.4 Hectares)
Volume: UPPER - 14.3 million gal. (.05 million M^3); MAIN - 76.6 million gal. (.05 million M^3), and LOWER - 37.0 million gal. (.14 million M^3)

WATERSHED INFORMATION:
Size: Approximately 10 square miles
Land Use: UPPER - residential; MAIN - residential and wooded, and LOWER - protected Fish and Game land, wooded.

WATER AND NUTRIENT SOURCES:
Tributaries: MILL CREEK
Springs: Headwaters fed by springs in wooded areas
Effluents: None known
Runoff: From residential developments on both sides of upper and main lake
Precipitation: Long-term avg. = 40.26 in./yr. (102.3 cm/yr), 1977 = 41.98 in. (106.6 cm)
Other: Possibly some septic input from residences

LAND USE:
Present: Some swimming, fishing, boating (with difficulty)
Past: Swimming, fishing, boating
Potential: Swimming, fishing, boating

STUDY PERIOD: 9/77 - 3/73
CONCLUSIONS

Nutrient inputs to the Clark's Pond system (includes three ponds) include agricultural, residential and woodland runoff, and possibly some septic system inputs. However, total inputs do not appear to be great, and internal recycling is probably the major source of nutrients in the system. The shallowness of parts of the system and the presence of rooted aquatic macrophytes make the nutrient reserves on the bottoms of the ponds more significant.

Clark's Pond is an acid system (pH of about 5.0 to 5.8), with relatively low major nutrient concentrations in the water column (total phosphate of about 0.03 to 0.06 mg/l, total nitrogen of 2.1 to 2.3 mg/l). Phosphorus is the most likely limiting nutrient in this system. Alkalinity is also very low in the system (averaging 5 to 13 mg/l). Dissolved oxygen levels are variable in the system. Station averages were generally acceptable, but occasional low values resulted from the slow decomposition of large organic deposits (especially in the Upper Pond) and inadequate replenishment of the oxygen supply. The heavy growths of macrophytes observed in certain areas were largely responsible for this condition.

Bacteriologically, the system is in good condition. Station averages for all measured bacteriological parameters were generally low. Occasional high values were recorded, but the cause of such elevated values was not determined. Septic inputs are a possible cause, but this is not certain and the overall effect is not very significant.

Sedimentation of the Upper Pond was extensive, but external inputs were apparently not the major source of sediment. Large organic deposits have resulted from internal macrophyte production (up to 75% surface cover). Macrophyte populations were smaller in the deeper Main Pond, and sedimentation was not as great. Macrophyte populations were again large in the Lower Pond, and large organic deposits were observed.

The species composition of the macrophyte populations of the Upper and Main Ponds were quite similar, with Nuphar advena (Yellow Water Lily) and Utricularia sp. (Bladderwort) as the dominant plants. In the Lower Pond, Myriophyllum spicatum (Eurasian Watermilfoil) dominated. The distribution of the rooted aquatic plants is closely tied to the placement of organic deposits and shallowness of the system, while Utricularia appears to be a superior competitor for water column nutrients in shallower waters.

Algal populations in the ponds were small (cell concentrations averaged 360 to 800 cells/ml, with chlorophyll a averages of 1.25 to 9.76 mg/l/m$^3$), and the species composition was typical of acid water/low available nutrient systems. Some pollution tolerant algae were present, mainly those associated with organic enrichment.
The presence of these species was undoubtedly linked to the observed organic deposits. Measured diversity was not very high, but the low cell concentrations and insensitivity of the methods of analysis may have caused some species to go unnoticed. No specific dominance was observed, and good overall water quality was indicated by the algal community.

The various water quality indices employed yielded values indicative of moderate to good water quality, with overall conditions in the lower mesotrophic range. No significant nutrient enrichment was indicated by the species composition based indices, and good water quality was implied by the chemical/physical parameter based indices.

Considering the data and associated analyses, Clark's Pond can be considered a lower mesotrophic system. The shallowness of the system and the large nutrient reserves are leading to an unfortunate macrophyte problem, especially in the Upper and Lower Ponds, but the water quality in the system is generally good.
GENERAL INFORMATION

LAKE NAME: DEAL LAKE

LAKE LOCATION:

USGS Quadrangle - # 24, Asbury Park, Lat. 40°13'45"; Long. 74°0'30"
County - Monmouth
Municipality - Asbury Park City, Interlaken-Boro, Allenhurst Boro, Loch Arbour, Deal Boro, Ocean Twp., Neptune Twp.
LAKE STATUS: (Public or Private) PUBLIC FW-2

LAKE SIZE:

Average Depth - 5.3 feet (1.6 M)
Range of Depth - Up to 10 feet (3 M)
Area - 144 Acres (58 Hectares)
Volume - 245.2 million gallons (928,000 M³)

WATERSHED INFORMATION:

Size - 4,400 acres (1,780 Hectares)
Land use - Mainly residential/business, with some light industry, waste disposal, and forested areas.

WATER AND NUTRIENT SOURCES:

Tributaries - Hollow Brook, Hog Swamp Brook, and 5 other unnamed tributaries.
Springs - Some at headwaters of streams, but seemingly not the major water source.
Effluents - (Point Sources): Lapin Products, 1501 Allen St. Asbury Park.
Runoff - Considerable, especially from residential area storm sewers. Some overland flow directly to lake.
Precipitation- 44.56 in./yr. (long-term avg.); 50.90 in./yr. (1977) (113.2 cm) (129.3 cm)
Other - Neptune Twp. Landfill and Delisa Landfill, localized non-point sources, contribute some leachate and runoff.

LAKE USE:

Present - Some fishing and boating
Past - Swimming, fishing, boating
Potential - Swimming, fishing, boating.

STUDY PERIOD: 5/77 -- 8/78
Conclusions:

Biological data indicates that Deal Lake falls into the lower range of the eutrophic category, while chemical data indicates a condition in the upper mesotrophic category. There are many fine gradations in trophic state classification, and the fluctuations of Deal Lake under the multiple influence of its tributaries makes absolute assignment difficult. But the data obviously shows accelerating eutrophication, and a classification of meso-eutrophic (lower range of the eutrophic state) is justified. From this study and past information, it is apparent that the condition of the lake is deteriorating, and will continue to do so unless corrective action is taken.

Nitrogen : Phosphorus ratios, algal data, and various trophic state index relationships indicate that phosphorus limits primary productivity in Deal Lake. The nitrogen and phosphorus supplies are adequate to support elevated primary productivity, and when other conditions are favorable, blooms occur. Very high $\text{NH}_3$-N concentrations were also noted in tributary #1, indicating great nitrogen input, and possible toxicity.

The major sources of nutrients include non-point sources such as runoff and seepage from residential areas, golf courses, and the two landfills (especially Neptune Township Landfill), and one point source, effluent from Lapin Products Inc. (which exceeds the phosphorus effluent standard). While nutrient concentrations in all tributaries have a definite impact on the lake water, the flow in tributary #1, Hollow Brook, is by far the greatest, and would appear to have the greatest effect on the lake. Inlet tributaries #2 and 7 have the next greatest flows, but the greatest nutrient concentrations occur in the tributaries with least flow. This makes assignment of impact priorities difficult, but does indicate that none of the tributaries can be completely ignored.

Sediment loading to the lake is greatest from tributaries #1 and 7, mainly due to construction. The lake is gradually becoming shallower, and seems to be well oxygenated. Some localized oxygen deficiencies are to be expected, though, in quiet areas containing larger quantities of macrophyte or algal remains.

A fair portion of the nitrogen and phosphorus entering the lake is being incorporated into the sediments by one means or another, and may be made available for further production later, depending on conditions. Inlets of the tributaries and quieter portions of the lake (such as lagoons or large areas outside the main channel) are particularly likely to harbor large nutrient reserves and organic matter deposits.
Bacteriological parameters indicate fair to poor lake water quality, but no standards are contravened. However, several of the tributaries exceed the limit for fecal coliform, and overall water quality is not good. Residential runoff and Neptune Township Landfill leachate are suspected as the primary sources of bacteria.

Primary productivity shows great fluctuations in the lake, and bluegreen algae blooms and heavy macrophyte growths do occur. Species composition indicates poor water quality, and temperature seems to be the primary control over productivity. Various trophic state indices indicate fair to poor water quality.

Accelerated eutrophication and deterioration of water quality and general lake condition is occurring in Deal Lake. The lake has been subjected to the studied influences for some time, and is unable to cope with the nutrient loadings and other abuses it has been experiencing.
LAKE NAME: Dennisville Lake (Johnson Pond)

LAKE LOCATION:
USGS Quadrangle Woodbine Lat. 74°49'30" Long. 39°11'30"
County Cape May
Municipality Dennis Township

LAKE STATUS: (Public or Private) Private FW-2

LAKE SIZE:
Average Depth 2.5 feet (.75M)
Range of Depth Up to 6 feet (1.82 M) at dam, but most of the lake is below 4 feet (1.22 M) in depth
Area 100 Acres (40.5 hectares)
Volume 81.3 million gallons (308,000 M³)

WATERSHED INFORMATION:
Size 3264 acres (1321 hectares)
Land use Nearly all wooded, with about 25 residences, a small campground, a few small fields, and the Woodbine State Colony.

WATER AND NUTRIENT SOURCES:
Tributaries One unnamed tributary with two branches
Springs Several (about 7) between the stream origin and the lake.
Effluents STP at Woodbine's State Colony at .18 MGD
Runoff Mostly from woodland, but some from residences, and a campground, and farmland (minimal).
Precipitation Long-term average = 40.30 inches (102.4 cm) 1977 avg. = 37.23 inches (94.6 cm)
Other Possibly some septic inputs from homes and campground by lake

LAKE USE:
Present Swimming, boating, fishing (all when possible)
Past Swimming, boating, fishing (on regular basis)
Potential Swimming, boating, fishing (on regular basis)

STUDY PERIOD: 8/77 through 7/78
LAKE NAME: Ludlam's Pond (Holly Lake)

LAKE LOCATION:
- USGS Quadrangle: Woodbine
- County: Cape May
- Municipality: Dennis Township

LAKE STATUS: (Public or Private) Private FW-2

LAKE SIZE:
- Average Depth: 1.5 feet (.46 M)
- Range of Depth: Up to 6 feet (1.82 M) at dam, but most of lake is below 3 feet (.91 M) in depth
- Area: 55 Acres (22.3 Hectares)
- Volume: 27.1 million gallons (103,000 M³)

WATERSHED INFORMATION:
- Size: 1690 Acres (684 hectares)
- Land use: Almost entirely wooded, with about 15 residences.

WATER AND NUTRIENT SOURCES:
- Tributaries: One unnamed tributary with two branches
- Springs: Several along stream before the lake.
- Effluents: None
- Runoff: Almost entirely from woodland, although two roads are crossed by tributary branches, making some unnatural inputs possible.
- Precipitation: Long-term avg. = 40.30 inches (102.4 cm) 1977 avg. = 37.23 inches (94.6 cm)
- Other: None Known

LAKE USE:
- Present: Swimming, Boating, Fishing
- Past: Swimming, Boating, Fishing
- Potential: Swimming, Boating, Fishing

STUDY PERIOD: 8/77 through 7/78
CONCLUSIONS

The data indicates that Dennisville Lake is experiencing accelerated eutrophication as the result of the direct discharge of effluent from the Woodbine State Colony sewage treatment plant into the main branch of the lake's only tributary. Other possible negative influences on the system have been ruled out or shown to be of minimal significance in relation to the effluent impact. Variable values for the measured parameters reflect the influence of biological and physical processes along the stream above the lake, along with variable flow. Nevertheless, the acquired data is sufficient to assign Dennisville Lake to the eutrophic stage in the classification scheme.

The Ludlam's Pond system, a very similar system (with regard to background conditions) that lacks the influence of any treatment plant discharge, has conditions that fit mainly into the lower mesotrophic category. This leads to an interesting comparison, since Dennisville Lake would be expected to be much more chemically and biologically similar to Ludlam's Pond, if the treatment plant discharge had never entered the Dennisville Lake system. Some differences would undoubtedly persist, but the major factor in the differentiation of these systems is the treatment plant effluent.

Specifically, Dennisville Lake is experiencing high phosphorus concentrations, elevated pH and greatly increased primary productivity, compared to Ludlam's Pond. Nitrogen concentrations are also increased, but not as significantly as for the previously named parameters. Alkalinity, dissolved oxygen and bacterial populations show no significant differences. Further comparison, between the west branch and the east or main branch of the Dennisville Lake tributary, would seem to further indicate the similarity between the background water of the Dennisville Lake and Ludlam's Pond systems, while underscoring the influence of the sewage treatment plant effluent.

Phosphorus appears to be the major limiting factor for primary production in both systems, but other factors such as acidity in both systems and nitrogen and light in the Dennisville Lake system may be important during the highly productive months. A fair portion of the phosphorus entering Dennisville Lake is remaining there, either as live organic matter or in the sediments. A portion of this supply is likely to be recycled, allowing for further production. There does not appear to be any significant phosphorus accumulation in Ludlam's Pond waters or sediment.
Aquatic macrophytes do not appear to be a significant problem in either lake, although proper management of Ludlam's Pond may be preventing any nuisance development there. Algal productivity is not a problem during most of the year in Ludlam's Pond, but is causing nuisance conditions much of the time in Dennisville Lake. The species composition, dominance and biomass characteristics of the two systems differ considerably, with the Dennisville data indicating very poor water quality. Various water quality indices were employed with varying results, but in general the conclusions drawn here were supported.

Cosmetic treatment of the Dennisville Lake situation is possible, but any long term solution to the problem will have to involve removal or advanced treatment of the sewage treatment plant effluent and removal or inactivation of the nutrient reserves presently in the lake.
LAKE NAME: Rainbow Lake

LAKE LOCATION:
USGS Quadrangle Millville - Lat. 39°29'55" Long. 75°06'50"
County Salem
Municipality Pittsgrove Township

LAKE STATUS: (Public or Private) Private (FW-2)

LAKE SIZE:
Average Depth 3 ft. (0.91 M)
Range of Depth to 6 ft. (1.83 M)
Area 77.5 acres (31.4 Hectares)
Volume 75.5 Million gal. (286,000 M3)

WATERSHED INFORMATION:
Size Below Parvin and Thundergust Lakes, about 7.8 sq. km. (3 sq. mi)
Land use Mostly residential on the east side of the lake, agricultural with a few residences and some woodlands on the west side. The tributaries are bordered by swamp in most areas.

WATER AND NUTRIENT SOURCES:
Tributaries Muddy Run - From Parvin Lake, the main tributary.
Springs Lummis Marsh Brook - minor tributary on east side of lake
Effluents None known
Runoff Some from agricultural areas in the watershed, possibly a little from residences near lake or Muddy Run
Precipitation Long-term avg. = 40.26 in/yr (102.3 cm/yr)
1977 = 41.98 in (106.6 cm)
Other Reports of illegal sewage discharges into the Muddy Run or onto adjacent land by septic tank cleaning service trucks

LAKE USE:
Present Some swimming, fishing, boating
Past Swimming, fishing, boating
Potential Swimming, fishing, boating

STUDY PERIOD: 6/77 to 7/78
Conclusions

Rainbow Lake receives water from two tributaries with varying water qualities. Muddy Run, the larger of the two tributaries, receives agricultural and some residential runoff, and may also be receiving some septic wastes. The septic wastes may enter the stream by the flow of contaminated groundwater, or possibly by illegal disposal by a septic tank cleaning service. However, no definite proof of either was uncovered.

The water quality in Muddy Run is generally poor. Turbidity was generally high, and total phosphate levels marginally exceeded the State Surface Water Quality Standard on the average, at 0.16 mg/l. Nitrogen levels were moderate to high (all forms), with total nitrogen levels averaging 2.8 mg/l. The pH was quite variable, but averaged a near-neutral 6.9, and alkalinity was fairly low (average of 17 mg/l). Dissolved oxygen levels were always acceptable.

Lummis Marsh Brook, the smaller of the tributaries, receives inputs from largely unknown non-point sources. Some septic wastes may also enter this stream, but agricultural runoff and natural decomposition in adjacent swampy areas are the most likely major input sources. Water quality is generally better than in Muddy Run, with much lower turbidity and an average total phosphate level of 0.08 mg/l. Most forms of nitrogen had average values very similar to those in Muddy Run, but nitrate-nitrogen concentrations were very high, averaging 3.1 mg/l. The pH was acidic, at an average of 5.8, and the alkalinity to pH4 was very low, averaging 8 mg/l. Dissolved oxygen levels were generally acceptable in this stream, too.

At the lake outlet the water chemistry is very similar to that at the Muddy Run station, with nearly identical average pH, alkalinity and nitrogen (all forms) values. The total phosphate values were slightly lower at the lake outlet, and the average concentration (0.13 mg/l) was slightly less than the State Water Quality Standard. At the in-lake station, the average total phosphate concentration was 0.21 mg/l, exceeding the State Standard.

The average values for other chemical parameters were quite similar to those at the lake outlet and in Muddy Run. Dissolved oxygen levels in the lake were fairly uniform when tested, and bordered on the lower limit of acceptability in some cases. No stratification was observed, and wind aeration kept decomposition from depleting the oxygen supply. Plant activity can be assumed to add oxygen during the day and to remove it at night. Due to the large standing crop of algae in Rainbow Lake, fluctuations in dissolved oxygen levels may be considerable.

Bacteriologically, the system does appear to be in relatively good condition. Total coliform, fecal coliform and fecal Streptococci levels were variable (sometimes very high), but all geometric means were low to moderate values, resulting in compliance
with the State Surface Water Quality Standard for fecal coliform. Fecal coliform to fecal Streptococci ratios did not yield any particularly useful information regarding bacterial input sources.

Macrophytes did not form a very significant portion of the aquatic plant biomass in this system. Some Elodea was observed in Muddy Run, while some Myriophyllum was found in Rainbow Lake. The algae were more abundant, with cell concentrations for the lake averaging 31000 to 48000 cells/ml (outlet and in-lake station averages). Chlorophyll a averages for the two lake stations were 21.4 and 27.2 mg/m². The cell concentrations and chlorophyll a levels at the Muddy Run station were similar to those of the lake, while the values for Lummis Marsh Brook were much smaller.

Several bluegreen algae blooms were recorded for the lake and Muddy Run, and the algal flora for these stations were considered pollution tolerant. Chlorococcalean greens, bluegreens, and pollution tolerant diatoms were the most abundant algae. The fact that the blooms (not normal in the stream environment) were also found upstream in Muddy Run means that such populations were washed out of upstream lakes. This suggests that the observed eutrophication problem extends beyond the Rainbow Lake study area. Dominance was either very low or very high, averaging out to a moderate value. Diversity followed a similar pattern.

The water quality indices employed gave fairly consistent indications of upper mesotrophy to lower eutrophy (using average values). The biotic community goes through periods of extreme imbalance, and the species composition is indicative of a eutrophic environment. Phosphorus appears to be the limiting factor in this system at least part of the time, but light and temperature are undoubtedly important factors at times.

On the basis of the accumulated data and various analyses, Rainbow Lake can be categorized as a lower eutrophic lake. It is not certain that the lake is rapidly getting worse, but conditions are certainly not improving. More work is needed to discern the relative importance of the tributary inputs and internal recycling to the present state of the lake. It appears that the Muddy Run inputs are most significant, and reductions of these inputs might improve the lake's condition greatly. However, as the result of past potential accumulation of nutrients in the shallow lake, internal recycling might keep the system in a highly productive phase for quite some time after any major input reductions. The shallowness of the system encourages such a situation, while the low hydraulic detention time deters it. More detailed investigation is needed here.
LAKE NAME: ROUND VALLEY RESERVOIR

LAKE LOCATION:

USGS Quadrangle  Flemington, Lat. 40°37', Long. 74°50'
County Hunterdon
Municipality Clinton

LAKE STATUS: (Public or Private) Public (FW-2)

LAKE SIZE:

Average Depth  71 ft. (21.6M)
Range of Depth  160 ft. (48.8M)
Area  2,350 acres (951 hectares)
Volume  54,267 million gal. (205.4 million M³)

WATERSHED INFORMATION:

Size: Surrounding drainage area is only about 3 square miles, but this artificial reservoir was filled by pumping in water from the Raritan River
Land use: Wooded, recreational use; includes boat launch area, swimming facility, picnic and camping areas.

WATER AND NUTRIENT SOURCES:

Tributaries: No real inlets. Water pumped in from Raritan River
Springs: Some in bottom of reservoir
Effluents: None, although water can be and has been pumped into the reservoir
Runoff: Some woodland runoff from small surrounding watershed
Precipitation: Long-term Avg. = 43.39 in/yr (110.2 cm/yr)
              1977 = 50.01 in  (127 cm)
Other

LAKE USE:

Present: Swimming, boating, fishing
Past: Swimming, boating, fishing
Potential: Potable water, swimming, boating, fishing

STUDY PERIOD: 6/77 - 7/78
CONCLUSIONS

Round Valley Reservoir, after being formed from a horseshoe-shaped ridge (Cushetunk Mountain) and filled with Raritan River water, had rather poor initial water quality. Since it has a very long hydraulic detention time and minimal nutrient inputs, natural biological, chemical and physical processes have been able to act on the system over the past decade to purify the water.

The result has been a great improvement in water quality, and the reservoir has become a popular recreational facility. It has an excellent fish population and an algal community that is large enough to support the observed secondary and tertiary production, yet not nearly large enough to cause nuisance conditions. In the shallower areas, dense macrophyte growths often occur, and recreational areas have been treated for the reduction of these growths. Yet in areas not used for recreational purposes, these growths are beneficial, functioning collectively as an important part of the fish habitat and as a nutrient sponge. Overall, the system appears to have very well balanced ecological conditions, and is one of the highest quality aquatic environments in New Jersey.

As regards water chemistry, nutrient concentrations are generally low, with total phosphorus averaging about 0.01 mg/l, and total nitrogen at about 2.1 mg/l.

The pH is slightly basic, averaging 7.5, and the alkalinity to pH 4 averages about 46 mg/l, a relatively low but acceptable value.

The reservoir stratifies in late spring and becomes destratified in the fall, with the summer thermocline at 25 to 40 feet of depth. The dissolved oxygen concentrations in both the epilimnion and hypolimnion are fairly high, with no deoxygenation of the hypolimnion and a lowest observed level of 6.0 mg/l.

The quality of the water in the boat launch area is not as good as in the open waters of the reservoir, probably as a combined result of shallowness and man's influence. Similar water quality is expected for the swimming area. Nevertheless, these areas have at least moderate water quality, and do not have any observable effect on the main body of the reservoir.

Bacteriologically, the system is in good condition as regards coliform and fecal Streptococci levels. Slightly higher levels were found in the boat launch area and would be predicted for the swimming area, but good water quality was still indicated.

The water quality indices employed all gave indications of good water quality, in the oligotrophic or lower mesotrophic range of conditions. The indices utilizing algal quantities or species composition gave no indication of any significant pollution or enrichment. The indices using chlorophyll a or phosphorus concentrations indicated a low to moderate potential for primary productivity.
On the basis of the accumulated data, Round Valley Reservoir can be considered on the borderline between oligotrophy and mesotrophy. It has moved toward this condition from more mesotrophic or almost eutrophic conditions. This water quality improvement is the result of the purifying action of natural processes, aided by minimal nutrient inputs and long hydraulic detention time. The reservoir is presently at its optimal condition with respect to its value to man. Greater nutrient concentrations or productivity could lead to ecological imbalances, while continued decreases in nutrient concentrations or primary production could severely restrict the quantity of aquatic life that the reservoir could support.

This system should be guarded and watched over carefully, since it is such a valuable resource. Hopefully, it has reached an aquatic and ecological equilibrium, at least as regards present influences on the system. If and when large-scale pumping of reservoir water for domestic use begins, further changes could be expected. But if consideration is given and care taken, such potential use of the reservoir does not necessarily have to reduce or impair its present value or uses.
LAKE NAME: Saxton Lake

LAKE LOCATION:

USGS Quadrangle: Tranquility (Longitude 74°47'30" - Latitude 40°53'45"")
County: Morris and Warren
Municipality: Mount Olive Township and Allamuchy Township

LAKE STATUS: (Public or Private): Public (and some Privately Owned Sections)

LAKE SIZE:

Average Depth: 5 feet (1.52 M)
Range of Depth: To 10 feet (3.05 M)
Area: 60 acres (24.3 hectares)
Volume: 97.9 million gallons (370,400 M³)

WATERSHED INFORMATION:

Size: Total of 70.0 square miles (181.3 sq. km.), but only 9.5 square miles (24.6 sq. km.) downstream of Waterloo Lake.
Land use: about 90% forested and 10% residential, excluding area upstream of Waterloo Lake.

WATER AND NUTRIENT SOURCES:

Tributaries: Musconetcong River, which receives water from two (2) unnamed tributaries near the Saxton Lake Inlet.
Springs: None known, but probably some at the tributary headwater lakes (includes Deer Park Lake).
Effluents: None after Waterloo Lake.
Runoff: Woodland (and possibly some residential) runoff.
Precipitation: Long term avg. = 48.8 in./yr. (124 cm./yr.)
1977 = 48.1 in./yr. (122 cm./yr.)
Other: Possibly some septic inputs from lakeside residences (about 60 homes).

LAKE USE:

Present: Boating, fishing.
Past: Swimming, boating, fishing.
Potential: Swimming, boating, fishing.

STUDY PERIOD: 5/77 to 6/78
LAKE NAME: Waterloo Lake

LAKE LOCATION:

USGS Quadrangle: Stanhope (Longitude 74°45'00" - Latitude 40°55'00"
County: Morris and Sussex
Municipality: Mount Olive Township and Byram Township
LAKE STATUS: (Public or Private): Public FW-2

LAKE SIZE:

Average Depth: 4 feet (1.22 M)
Range of Depth: To 9 feet (2.74 M)
Area: 48 acres (19.4 hectares)
Volume: 62.3 million gallons (235,900 M3)

WATERSHED INFORMATION:

Size: Total of 60.5 square miles (156.7 sq. km.), but only 30.8 square miles (79.8 sq. km.) downstream of Lake Musconetcong.
Land use: about 50% forested, with about 30% residential/industrial, and 20% open area (farmland, gravel pits, etc.).

WATER AND NUTRIENT SOURCES:

Tributaries: Musconetcong River, which in turn receives water from Wills and Lubbers Run between Waterloo Lake and Lake Musconetcong.
Springs: None known, but probably some at tributary headwaters.
Runoff: Woodland and residential runoff, plus some landfill leachate.
Precipitation: Long-term avg. = 48.8 in./yr. (124 cm./yr.)
1977 = 48.1 in./yr. (122 cm./yr.)
Other: Possibly some septic inputs from Waterloo Village.

LAKE USE:

Present: Fishing, aesthetics
Past: Fishing, aesthetics
Potential: Fishing, aesthetics, possibly boating and swimming if made more accessible.

STUDY PERIOD: 5/77 to 6/78
CONCLUSIONS

The stretch of the Musconetcong River between Lake Musconetcong and Waterloo Lake is experiencing large inputs of nutrients, mainly from the developed areas at Stanhope and Lockwood and the Musconetcong sewage treatment plant in Mount Olive Township. Other inputs exist, such as those from the U.S. Mineral Products discharges, the Byram Twp. Consolidated School sewage treatment plant, and runoff or leachate from area landfills, but these are relatively insignificant (compared to the major inputs). A substantial load of nutrients is also contributed by the waters leaving Lake Musconetcong. A great decrease in nutrient load, especially phosphorus, occurs in the river just before the Waterloo Lake inlet.

Inputs below Waterloo Lake are greatly decreased, and the nutrient load remains relatively constant until it passes out of the section of the river under study. Almost no phosphorus build-up occurs in Waterloo Lake, and while a quantitatively large build-up was detected in Saxton Lake, that build-up is proportionately small in relation to the total load passing through the lake. The passage of most of the phosphorus load through both lakes is the result of relatively large flows and low hydraulic detention times for the lakes.

Phosphorus is the most likely limiting nutrient for this system, but water velocity and light probably limit productivity at certain times and places. Nutrient concentrations are generally large throughout the system, and water in both lakes exceeds the Surface Water Quality Standard of 0.05 mg P/l on the average. Nitrogen quantities (and apparently micronutrient levels) were adequate to support great productivity when other conditions were favorable, and nuisance conditions occurred in both lakes and along slow flowing stretches of the river during the warmer months. It is important to note that despite the large phosphorus load, increased phosphorus inputs might lead to even worse nuisance conditions at times.

Non-rooted floating macrophytes and attached submerged macrophytes were the abundant forms in nuisance growths, along with mats of the green alga Hydrodictyon. Trailing growths of the periphytic green alga Cladophora were also occasionally large. Other pollution tolerant species were present, but were overshadowed by the above growths during the summer. Total productivity and biomass for the year were great as a result of the extensive summer growths of a few macrophyte and algae species. Still, the overall number of species present was much larger than expected for such a system.
The large summer populations of algae and macrophytes exert a strong influence on dissolved oxygen in the system. Between community respiration, decomposition, and reduced aeration by wind (due to surface growths), dissolved oxygen supplies are almost totally depleted in Saxton Lake at times, and are somewhat depressed in Waterloo Lake on occasion. Elevation of pH is also caused by these growths, although the chemical inputs to the system are also responsible for the observed pH levels.

Bacterial levels in the water leaving Lake Musconetcong were not particularly high, but inputs from developed areas along the river, Lubbers Run and Wills Brook greatly increased total coliform, fecal coliform and fecal Streptococci concentrations. The Surface Water Quality Standard for fecal coliform bacteria (geometric mean of 200 MPN/100 ml) was exceeded along most of Wills Brook, in the effluents of the sewage treatment plants, and on the surface of Waterloo and Saxton Lakes. A potential health hazard therefore exists. Fecal coliform:fecal Streptococci ratios were not overly useful in identifying the nature of the major source of bacteria, but the raw data shows that inputs from the Musconetcong STP are very substantial, and indicates that present chlorination is inadequate to control bacterial outputs from the plant. While bacterial outputs from the Consolidated School STP were not nearly as great as those from the Musconetcong STP, chlorination at that plant is apparently also inadequate.

The various water quality indices employed in this study produced varying and conflicting results. As a result of the exclusion of algal mats and macrophyte growths from the quantitative analyses, many index values suggested less polluted conditions than actually existed. Other less affected indices produced values indicative of a moderately eutrophic environment.

Considering the data analyses and observations made, both Waterloo and Saxton Lakes can be classified as moderately eutrophic. However, their state is the result of continued nutrient inputs, and is not dependent on any long-term nutrient build-up and recycling process. Consequently, nutrient input reductions, especially as regards phosphorus, should yield corresponding increases in water quality. Cessation of eutrophication, and probably a reversal of present trends could then be expected, since the flushing rate for the two lakes is high. Corresponding improvement in the condition of the Musconetcong River should alleviate some of the problems and nuisances presently encountered there, and would certainly increase the chances of fish survival in this trout maintenance area. Treatment of the symptoms of eutrophication would be fruitless in this case.
LAKE NAME: Speedwell Lake

LAKE LOCATION:
USGS Quadrangle Morristown
County Morris
Municipality Morristown & Morris Township

LAKE STATUS: (Public or Private) Public FW-2

LAKE SIZE:
Average Depth 4.5 ft. (1.37 M)
Range of Depth to about 8 ft. (2.44 M)
Area 27 acres (10.9 hectares)
Volume 39.4 Million Gal. (149,300 M³)

WATERSHED INFORMATION:
Size approx. 25 sq. mi. (64.8 sq. km.)
Land use residential, industrial, wooded

WATER AND NUTRIENT SOURCES:
Tributaries Whippany River and its tributaries.
Springs None Known
Effluents 3 STP's discharge into the river or its tributaries within 4 miles of the lake.
Runoff Some residential, some woodland runoff.
Precipitation Long-term avg. = 47.6 in/yr (120.9 cm/yr)
1977 = 50.3 in. (127.8 cm.)
Other Possibly some septic inputs, but not significant (only a few homes by lake).

LAKE USE:
Present Fishing, aesthetics, some boating
Past Fishing, boating, swimming
Potential Fishing, boating, swimming

STUDY PERIOD: 5/77 through 5/78
LAKE NAME: Pocahontas Lake

LAKE LOCATION:
USGS Quadrangle Morristown
County Morris
Municipality Morristown

LAKE STATUS: (Public or Private) Public FW-2

LAKE SIZE:
- Average Depth 5 ft. (1.52 m)
- Range of Depth To about 8 ft. (2.44 m)
- Area 14.5 acres (5.9 hectares)
- Volume 23.7 Million Gal. (89,700 m³)

WATERSHED INFORMATION:
- Size approx. 26 sq. mi. (67.3 sq. km)
- Land use residential, industrial, wooded

WATER AND NUTRIENT SOURCES:
- Tributaries Whippany River from Speedwell Lake, with a small Tributary in between.
- Springs None Known
- Effluents Same as for Speedwell Lake
- Runoff Residential, plus some woodland and railroad runoff.
- Precipitation Long term avg. = 47.6 in/yr (120.9 cm/yr)
  1977 = 50.3 in. (127.8 cm)
- Other

LAKE USE:
- Present Fishing, aesthetics
- Past Fishing, boating
- Potential Fishing, boating

STUDY PERIOD: 5/77 through 5/78
CONCLUSIONS

Speedwell and Pocahontas Lakes are receiving excessive quantities of nutrients and sediment, but do not consistently exhibit all the features of a eutrophic environment. Low hydraulic detention time, along with some turbidity, appears to be minimizing the effects of the eutrophication that is taking place. Nutrient concentrations are high, alkalinity, pH and dissolved oxygen values are moderate, and chlorophyll a and cell concentrations are relatively low. Diversity was fairly high, and no extreme dominance was observed. Severe nuisance conditions did not occur during this study, but would be predicted for low flow conditions. A sizeable portion of the present species composition of the lakes is dislodged periphyton, and quantitative indications point toward eutrophic conditions. Under lower water velocity, or possibly even with the present velocity but on a longer time scale, a shift in community structure to a more conventional eutrophic lake biota could be expected.

Inputs to the Whippany River are large, even upstream of the area studied. Concentrations of phosphorus in the river or its tributaries exceed the 0.05 mg/l Surface Water Quality Standard upstream of the sewage treatment plants in the study area, and the concentrations of phosphorus and other nutrients in the effluents of the plants are very high. However, the small flow of the Delbarton School STP makes its inputs relatively insignificant in the overall picture. The inputs from the Greystone Park State Hospital STP amount to about ten percent of the maximum load, measured at the inlet of Speedwell Lake, while the major contributor is the Butterworth STP, which accounts for about seventy-six percent of the maximum load. The remainder of the inputs, about twelve percent, come from residential and some woodland runoff. There is also significant residential runoff entering the lakes directly (especially Pocahontas Lake), which was not accurately quantified in this study.

Phosphorus will limit productivity in these lakes before nitrogen does, but nutrients do not appear to be the limiting factor in the study area at this time. However, present productivity could be reduced and the risk of future productivity problems minimized if significant reductions in phosphorus loading were made. Placing effluent limitations on the sewage treatment plants would yield great reductions, but would still not provide the 90% overall reduction necessary to keep the phosphorus concentration at the inlet to Speedwell Lake below 0.05 mg/l. Phosphorus is accumulating in both lakes at rates greatly exceeding those considered permissible by Vollenweider, even with the low hydraulic detention times of these lakes.

Quantities of nitrogen in the system are adequate to support excessive primary productivity, and ammonia levels are occasionally high enough to create toxic conditions for some distance downstream of each sewage treatment plant discharge. However, dissolved oxygen concentrations are usually sufficient to convert most ammonia to nitrate before it reaches the lakes.
Bacteriologically, the system is in acceptable condition, with total coliform, fecal coliform and fecal Streptococci levels indicating no health hazards or unusual conditions. Geometric means for fecal coliform were well within the Surface Water Quality Standard of 200 MPN/100 ml. Chlorine levels were occasionally high in the effluent of the Butterworth STP, but the plant is effectively eliminating a potentially large bacterial input. Bacterial populations, while not excessive at any point in the system, do increase in the lakes. The bacterial inputs of direct residential runoff into the lakes are apparently quite significant for this system.

The water quality indices employed in the analysis of compiled data yielded explainable but often non-supportive results. The indices suggest great potential for productivity, but little realization of this potential. Diversity and evenness are high, suggesting relatively balanced ecological conditions. Species composition-based indices give variable and conflicting results, with few strong indications of advanced eutrophication. Chemistry-based indices suggest decidedly eutrophic conditions. Various physical factors interfere with the validity of the indices, but the general indication is one of advanced eutrophication without all the symptoms of a eutrophic environment. Whether or not these symptoms will be acquired will depend on continued activities within the drainage basin and certain external factors, such as natural changes in the flow through the system.
LAKE NAME: Sunset Lake

LAKE LOCATION:

USGS Quadrangle: Gladstone (and Bernardsville) Lat. 40°38'25" Long. 74°37'40"
County: Somerset
Municipality: Bridgewater Township

LAKE STATUS: (Public or Private) Private (FW-2)

LAKE SIZE:

Average Depth: 2.3 ft. (.70 M)
Range of Depth: to 9 ft. (2.74 M)
Area: 15.0 Acres (6.1 Hectares)
Volume: 1.85 Million Gallions (7000 M³)

WATERSHED INFORMATION:

Size: Approx. 1 sq. mile (2.6 sq. km.)
Land use: Mostly residential, some forested land.

WATER AND NUTRIENT SOURCES:

Tributaries: 2 small tributaries merge into Chambers Brook
Springs: None Known, although possibly some in lake.
Effluents: No typical effluents, but a nearby domestic sewer manhole occasionally overflows.
Runoff: Excess from residences on land all around lake.
Precipitation: Long-term avg. = 44.93 in/yr (114.1 cm/yr)
1977 = 56.13 in. (142.6 cm.)
Other: Possibly some septic input from residences not yet sewer.
Also, considerable sediment input from construction in area.

LAKE USE:

Present: Swimming, fishing and boating
Past: Some Swimming, fishing and boating
Potential: Swimming, fishing and boating

STUDY PERIOD: 6/77 through 7/78
CONCLUSIONS

Sunset Lake is acting as a detention basin for the products of watershed development, and the quality of water passing through the lake is improved slightly by such passage. Residential and woodland runoff in this area carry a relatively large sediment load and a moderate nutrient load, especially where construction activities are involved. There is also a poorly designed sewerline that overflows through a manhole near the lake's inlet.

At the inlet, the Surface Water Quality Standard for phosphorus is contravened, and the sediment load is often very large. Direct inputs of sediment to the lake are also significant. The water is often turbid after storms, and the progression of sediment from construction sites to the lake is visually obvious. Much of the sediment and phosphorus loads remains in the lake, and the phosphorus standard was not contravened at the outlet. Quantities of nitrogen, while adequate to support much primary production, were not really excessive. The concentration of available phosphorus may indeed limit production in the lake, since the orthophosphate concentration is much smaller than the total phosphate concentration in the incoming waters.

The pH of the lake water is slightly elevated, but the alkalinity is not, and primary production does not seem to account for the rise in all cases. Dissolved oxygen values are generally high, and very few values below 6 mg/l were detected during the study. The shallowness of the system allows for good aeration, and decomposition and respiration in the lake apparently cause no significant deficiencies.

Bacterial inputs at the inlet are high, and the Surface Water Quality Standard for fecal coliform is greatly exceeded by the geometric average for this station. A combination of human and animal wastes are responsible, coming from the malfunctioning sewerline, runoff, and possibly some septic tank leaching. By the time the water reaches the outlet, bacterial populations are moderate and no state standards are contravened.

The low hydraulic detention time, turbidity and possibly low available phosphorus concentrations result in moderate primary productivity in the lake. Algal cell counts were generally low, and no blooms were recorded. Chlorophyll a values were occasionally elevated, but averaged out to a moderate level at all stations. The algae present included some pollution-tolerant forms, but few strong indications of eutrophy were given. Algal quantity, quality, and community structure were generally indicative of a system in transition from mesotrophic to eutrophic conditions. Macrophytes (Myriophyllum) were sometimes abundant, but no long-term, extensive population was observed. Turbidity may be responsible for the lack of continual heavy macrophyte growth in this otherwise apparently optimal macrophyte environment, possibly...
along with some substrate deficiencies (much loose sand). However, the eventual establishment of dense macrophyte populations could be expected in this shallow system, probably within the next 5 years.

Water quality indices employed gave varying values, due to the fluctuating characteristics of incoming waters and relatively low hydraulic detention time. Average values were indicative of a system in the upper mesotrophic range of conditions. Primary production is slightly less than might be expected on the basis of phosphorus concentrations, but a variety of factors may be responsible for this, including turbidity, flow, and phosphorus availability.

Considering the data, Sunset Lake appears to be in an upper mesotrophic state, and is moving toward eutrophic conditions. Poor construction practices in the watershed and inputs typical of residential areas are impacting the lake, and can be expected to continue to do so until corrective action is taken.
PART III: Discussion

Spectrum of Lake Types and Conditions

Common Problems Facing New Jersey Lakes

Measuring Water Quality - Utility of Various Parameters and Indices

Evaluation of Other Limnological Information and Procedures used in making Trophic State Determinations

Suggestions for Future Studies

General Lakes Management and Restoration work needed in New Jersey
DISCUSSION

Spectrum of Lake Types and Conditions:

A total of fifteen lakes were studied, but there were two sets of two lakes which were situated in series on a given waterway, leaving thirteen independent systems studied. Of the thirteen aquatic systems, eight were found to be eutrophic. Two others were categorized as in an upper mesotrophic state, and still two more were assigned to the lower mesotrophic state. One system was considered to be on the borderline between oligotrophy and mesotrophy.

While thirteen systems is a rather small sampling of New Jersey's 1000+ lakes, it is a fairly representative grouping. Lakes of various depths, geographic areas and watershed sizes were selected, and a very wide variety of nutrient sources had inputs to the studied lakes. These nutrient input sources included wastewater treatment facilities, farmland (cattle and crops) runoff, urban runoff, industrial operations, woodland runoff, and groundwater flow. Average depths ranged from 1.5 ft (0.46M) to 71 ft. (21.6M), while watershed areas were between 1.0 and 120 square miles (2.6 to 308 square kilometers).

By totaling the quantified or estimated inputs by each contributing general source of nutrients for all of the studied systems and dividing each source's total by the total inputs to all of the systems studied, the following table is generated:

<table>
<thead>
<tr>
<th>General Nutrient Source</th>
<th>Average Contribution (as % of total inputs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban (Residential) Inputs</td>
<td>36.0</td>
</tr>
<tr>
<td>Farm-related Inputs</td>
<td>26.9</td>
</tr>
<tr>
<td>Sewage-related Inputs</td>
<td>20.0</td>
</tr>
<tr>
<td>Woodland (Natural) Inputs</td>
<td>16.5</td>
</tr>
<tr>
<td>Industrial Inputs</td>
<td>0.6</td>
</tr>
</tbody>
</table>

As can be seen, the normally non-point source inputs from urban areas are the greatest, with farm inputs (also usually non-point source inputs) second and sewage inputs (most often point-source inputs) third in average magnitude. Inputs from natural sources (usually woodland runoff or subsurface flow) are fourth and inputs from industrial sources are last in terms of average quantities contributed. It must be remembered that these are generalizations based on the thirteen systems studied, and may apply only to those systems as a group. However, they do seem fairly representative of New Jersey lakes on the whole.
Yet in fact, a single general source contributed over half of the total inputs to each system, with that major source varying from system to system. Of the thirteen systems studied, five were considered to be most affected by urban inputs, three were believed to be most affected by farm-related inputs, three were determined to be most affected by sewage inputs, and two systems appeared to be primarily affected by woodland inputs. Only industrial inputs were not found to be the major nutrient source in any case. Yet no nutrient source contributed 100% of the total nutrient load, so multiple sources were responsible for the system's condition in each case.

Geographic location appears to be significant in determining the major source of nutrients for a given New Jersey lake. Urban inputs tended to be much more significant in the northern New Jersey systems than in the southern New Jersey systems, while farm inputs (mainly agricultural) and woodland inputs were more significant in the southern systems than in the northern areas. The significance of sewage inputs showed no geographical pattern. These statements are quite logical when one considers the patterns of population distribution and land use in this state.

The 1977-78 Intensive Lake Surveys, if assumed to be representative of New Jersey lakes as a group, indicate a preponderance of eutrophic lakes. Mestrophic lakes are not uncommon, but oligotrophic lakes appear to be rare in this state. One type of lake to be noted is the dystrophic lake, a category into which at least two of the studied lakes might be placed. However, productivity in the studied lakes was higher than expected for typical dystrophic lakes due to man's influence, and it seemed more appropriate to place these lakes in the mesotrophic category. However, there are truly dystrophic lakes in New Jersey.

Natural causes (especially shallowness) and man's influence appear to be the main reasons why there are very few (if any) truly oligotrophic lakes in New Jersey. Most New Jersey lakes are man-made to begin with, and these lakes tend to be very shallow (less than 6 ft. average depth). Shallowness generally precludes oligotrophy, and human-caused inputs to most New Jersey lakes speed up the aging process of lakes (accelerated eutrophication).

Consequently, mesotrophic and eutrophic lakes are abundant in New Jersey, and restoration is often necessitated before effective lake management programs can be instituted.
Common Problems Facing New Jersey Lakes:

As the result of various past investigations into water quality in New Jersey, and especially from the 1977-78 Intensive Lake Surveys, the following influences can be listed as the major factors in the degradation of New Jersey's lakes:

1. The general development of watersheds into urban/business/industrial communities results in increased nutrient, sediment and bacterial inputs into aquatic systems. This is in part unavoidable, but inadequate or inconsiderate design, construction and operation can accentuate the problem. Large scale paving and the construction of storm sewer systems that empty directly into a waterway result in very variable flows and allow for increased inputs of all types. People, by their very nature and their concentration in this state, frequently form an obstacle to maintaining clean lakes.

2. Poor or inefficient land use practices result in increased inputs to aquatic systems, especially nutrients and sediments. This problem is related to the first major influence discussed, but is completely avoidable. Improper application or complete disuse of best management practices in farm operations and development (actual construction work) results in the entrance of huge quantities of sediment to New Jersey's aquatic systems. Lakes, having much greater hydraulic detention times than most stretches of river or stream, become the eventual resting place for much of this sediment. The sediment itself bears nutrients that can result in nuisance growths, but additional nutrients enter aquatic systems via runoff from farms (crops and cattle) and construction sites, due to inadequate ground cover and overfertilizing. The implementation of good soil conservation techniques is clearly lacking in many areas of this state. Recent and current legislation regarding soil conservation should improve this situation.

3. Lack of advanced wastewater treatment and inadequate consideration of water quality in wastewater treatment facility design and operation result in large nutrient inputs to New Jersey's waterways. Bacterial inputs are sometimes considerable also. While the influence of sewage-related inputs on water quality ranked third in overall importance, according to the 1977-78 Intensive Lake Surveys, sewage inputs are almost always the major factor in determining water quality when such inputs are present. Problems related to sewage inputs to aquatic systems (including septic wastes) are to some extent unavoidable, since humans make waste and it must be disposed of; however, the extent to which these inputs affect New Jersey's waters is much too great.
Preventable septic system and treatment plant malfunctions occur, and this State's waterways are often forced to suffer as the result of inadequate treatment facility or septic system design or the economic infeasibility of advanced wastewater treatment.

4. The high frequency of naturally shallow or shallow man-made lakes in New Jersey increases the impact of nutrient and sediment inputs to aquatic systems in this State. The majority of New Jersey lakes have an average depth of less than six feet, facilitating macrophyte growth and internal recycling of nutrients. Some of these shallow lakes are in good condition, but none have yet been found that could be called oligotrophic. While not the ultimate panacea, depth alone goes a long way toward maintaining acceptable water quality in a lake in the face of increased inputs. Nuisance conditions are less frequent in New Jersey's deeper lakes, and it is generally believed that the water quality of these lakes can be greatly improved by input reductions alone without any major in-lake restoration work. Lack of depth makes lake restoration and management more difficult.
Measuring Water Quality - Utility of Various Parameters and Indices:

A variety of parameters and indices were used to measure water quality in the lakes studies, and the cumulative indication of all these factors was used to assign a trophic state designation to each lake. The reliability of the individual indications of the parameters and indices was variable, but the cumulative indication of all the factors seemed very sound. The results illustrate the importance of basing conclusions on the indications of multiple factors, rather than just one or two measured parameters. Some parameters or indices were more useful than others, and the usefulness of some was limited by the methods of measurement or natural background interferences in the aquatic systems studied. The following is an evaluation of the parameters or indices used as indicators of water quality and trophic state in these studies:

1. Algal Cells Per Milliliter: The yearly average cell concentration is a good indicator in most cases. However, interference can arise in the form of extensive growths of macrophytes, which tend to competitively reduce phytoplankton populations, even in heavily nutrient-enriched waters. Also, a large cell concentration of bluegreen algae may contain no more biomass than an average green algae concentration, making certain comparisons difficult.

2. Algal Quality: In the hands of a competent investigator, qualitative algal analysis can yield valuable information about an aquatic system. However, some quantitative data (cell counts, chlorophyll or dry weight) is essential to support qualitative analyses.

3. Community Structure: Analysis of the structure of the biotic community is a very effective tool in measuring water quality. It combines qualitative and quantitative measurements, and facilitates comparisons with other systems. Only the algal portion of the aquatic community was analyzed in depth in these studies, but very significant indications were still obtained. Even more significance could be attached to community structure analysis if the other components (such as macrophytes, zooplankton and fish) were adequately measured. Community structure analysis, which involves measuring the quantity, quality, distribution and interactions of the organisms in an aquatic system, is probably the best indicator of aquatic conditions. However, it is not really a single indicator, since it takes many individually measured parameters (such as diversity, cell concentration, and qualitative indications) into consideration.
4. Percentage of Algae in Given Groups: Essentially, this is part of the community structure analysis, but has some use by itself. By knowing the typical patterns of dominance and succession for given lake types, the distribution of algal biomass among the major algal groups can yield significant information. It is generally not a strong indicator but is useful in conjunction with quantitative data.

5. Diversity (numbers of taxa present): This indicator is also incorporated into the community structure analysis, but may yield some useful indications by itself. In general, by the methods used in these studies, low diversities indicated very low or very high nutrient concentrations, while high diversities indicated moderate nutrient concentrations. More sensitive methods of analysis or coupling with qualitative data would strengthen the indications obtained.

6. Chlorophyll a Concentration: Quantitatively, this was a very useful indicator. The yearly average concentration gave a reasonable indication of trophic state, but winter values were depressed in all cases by light and temperature limitations. Therefore, spring, summer and fall values were more representative of actual water quality, with summer values alone giving very strong indications.

7. Algal Biomass: Accurate quantitative biomass measurements were not made in these studies, although chlorophyll measurements and cell concentrations gave a reasonable estimate of algal quantities. Algal growth was visually appraised as high, medium or low, but dry weight or ash-free weights would have been more useful. Such measurements would compliment algal cell concentration and chlorophyll data. Such biomass measurements of the macrophyte community would be useful, too.

8. Secchi Disk Readings: Secchi disk visibility measurements give a rather undefinable measure of water quality, which is based on an inverse relationship between phytoplankton concentration and light penetration of water. However, great interference can result from non-algal sources of turbidity, severely limiting the overall usefulness of this parameter. Nevertheless, this parameter has some value in estimating light conditions in an aquatic system and is quickly and easily measured.

9. Temperature: This is an easily measured parameter and is very useful in ecological studies but has little value as a water quality indicator.
10. **pH:** As with temperature, pH is very useful in ecological studies, but has limited value as a water quality indicator. At very high or very low values it indicates unusual and possibly hazardous conditions, but other parameters are needed to adequately characterize a system.

11. **Alkalinity to pH 4:** This parameter has roughly the same value as pH in characterizing water quality. It gives more of an indication of a system's ability to assimilate acid inputs than the system's actual condition.

12. **Dissolved Oxygen:** This is a very useful parameter in defining water quality, and enables one to predict many of the other qualities of a system. Nearly all aquatic life depends on an adequate supply of oxygen, and a variety of factors contribute to its concentration value at any given time. In conjunction with some basic knowledge of a system's oxygen sources and demands, dissolved oxygen measurements can be an extremely useful tool in classifying the system. Measurements from all times of day are most useful, but only daytime readings were made in these studies.

13. **Total Phosphate and Orthophosphate:** These parameters are very useful by themselves, and form the basis for many indices. There is much controversy over what portion of the phosphorus in a system is biologically available, but orthophosphate measurements can be used to approximate the minimum quantity available, while total phosphate values can be used to approximate the maximum available quantity. Any measurement of phosphorus in an aquatic system is usually useful, since phosphorus is the most common limiting nutrient. Phosphorus measurements are more useful when obtained in conjunction with the measurement of other chemical parameters.

14. **Forms of Nitrogen (TKN, NO₃-N, NO₂-N, NH₃-N):** These parameters are almost as useful as phosphorus, since nitrogen is an essential plant nutrient and the interactions of the various forms of nitrogen are important in most aquatic systems. These parameters alone do not tell the whole story, but are invaluable to an accurate characterization of a system.

15. **Bacterial Parameters (Total and Fecal Coliform, Fecal Streptococci, Ratios):** In these studies, bacterial parameters seemed very useful in determining water quality, but there is some controversy regarding the validity of the indications of bacterial parameters and ratios. It may be true that too little is known about natural background populations to rely heavily on bacterial parameter indications, and the limited survival time of most fecal bacteria in open surface waters often makes the
absolute bacterial population numbers questionable. The ratios of fecal coliform to fecal Streptococci bacteria obtained in these studies were mostly inapplicable to the determination of the type of bacteria source, but were useful in a few cases. More complete bacterial data would be helpful, but present methods of bacterial analysis are not always reliable or practical.

16. Shannon-Weaver Diversity Index and Evenness: The Shannon-Weaver Diversity Index yields a number of limited utility, since it is dependent upon statistical factors that may be unique to a given system, therefore reducing the comparative value of this index. However, the potentially interfering factors can be eliminated by dividing the actual diversity index value obtained by the maximum possible value obtainable under the conditions of the system under study. This value is called the Evenness, and is essentially a decimal rating (a number between 0.0 and 1.0) of community structure, based on the theory that the higher the diversity, the more stable and balanced the community. In these studies, summer evenness values were very useful, but winter values tended to make the yearly average less distinctive. It is a useful parameter in conjunction with qualitative data on the portion of the community measured by the index.

17. Palmer's Indices: These indices are intended to give a measure of pollution, especially by organic compounds, by the use of weighted indicator species of algae. The appearance of significant numbers of these species in water does give a strong indication of organic pollution, but their absence does not necessarily preclude such pollution. Also, these studies revealed other species that appeared to be more significant indicators for New Jersey lakes. This is a common problem of such indices, and limits their usefulness. Palmer's Indices gave only moderately accurate results in these studies overall.

18. Nygard's Indices: These indices are intended to give a measure of the trophic condition of a lake by the use of indicator groups of algae. Ratios of the quantities of certain groups to others are used. Often in these studies there were none of the algae present that are used in the denominators of these equations, making their valid use difficult. However, if a modification was made such that the denominator was always at least one, the indices would be more useful. As it was, the compound index used in these studies produced fairly accurate indications. Improvements could be made, however, and the index was not sufficient alone to predict water quality.
Carlson's Indices: These indices are intended to give a numerical measure of the trophic state of a lake by using values for several parameters in several equations. Phosphorus concentrations, chlorophyll a quantities and Secchi disk readings are the parameter values used, and there are a variety of assumptions made in using them. Phosphorus is assumed to be the limiting nutrient, phytoplankton is assumed to be the major producer of chlorophyll a in the system, and algae concentrations are assumed to be the major factor in controlling light penetration of the water (and therefore the Secchi disk reading). When the above assumptions are true, the indices agree closely and give reliable indications of the trophic state. However, New Jersey lakes harbor a variety of possible interferences, and one or more of the indices was frequently invalid in these studies. Consequently, these indices yielded only moderately accurate indications overall. Also, to properly interpret the index values and judge the validity of the indices in every instance, one must have a degree of basic limnological training that would enable the investigator to make trophic state predictions based on the raw parameter values. Therefore, the value of the indices is primarily communicative, enabling one to mathematically express knowledge that may be acquired by other means. This is true of many of the indicator systems used.
Evaluation of Other Limnological Information and Procedures Used in Making Trophic State Determinations:

1) Flow Measurements: Quantitative measures of flow are essential to nutrient loading analyses, and should be made as accurately and frequently as possible. In these studies the primary source of flow data was U.S.G.S., which had monitoring stations at or near some of the study stations. Some flow data was also obtained from meters at individual point sources, and a few measurements were made in the field by N.J.D.E.P. personnel. However, flow data for some stations was inadequate and severely limited some loading analyses. U.S.G.S. and point-source data should be supplemented with field measurements made with a portable flowmeter at each station whenever samples are taken.

2) Site Selection: Selection of sampling sites is generally based on three factors;

a) the need for information from a given area or point,
b) the representative nature of a given area or point, and
c) the accessibility of the site.

An effort was made to select sampling stations for each system such that valid information was acquired for;

a) the inlets of a lake
b) the outlets of a lake
c) the lake itself
d) all point sources upstream of the lake
e) a point upstream of any sampled point source
f) important confluences or suspect stretches of stream

The sites selected proved to be essential and representative, but not always accessible in a practical sense. Selecting sites as near to a road as possible is generally a good practice, but practicality must be sacrificed if making the site convenient significantly decreases its representativeness or the validity of the information obtained from it. The importance of various stations should be ascertained by several samplings, and special attention given to the major stations. This was not always done in these studies.
Since these studies were primarily lake surveys, emphasis should be placed on the lake stations. This was not always done, hindering accurate characterization of some lakes. The lake data obtained was very useful, and showed the extreme importance of in-lake sampling. Chemical data from inlets and outlets was also very useful, but biological data from these sites was not as useful or representative of lake conditions as that obtained from the in-lake stations.

It is also often useful to take samples from special sites of interest, such as storm drains during storms or farm land during periods of peak runoff. Such supplementary information can be very valuable in testing suppositions made on the basis of data obtained from the regular sampling sites. This was rarely done, and made some conclusions more speculative than desired. Thoroughness is the key to success in limnological studies.

3) Sampling Frequency: Logically, it is best to sample as frequently as possible. However, as matter of practicality, the scientific research community generally finds a sampling interval of about two weeks to be acceptable for lake surveys. The two week period stems mainly from the time necessary for a complete algae turnover. Sampling at a frequency of twice a month will greatly decrease the probability that a major event will be missed, but may not be necessary. While such a sampling frequency is very desirable, longer intervals may be applicable, depending upon the system under study. Sampling every two weeks was found to be impractical for surveys conducted by the state, since finite manpower and resources had to be applied on a priority basis. One month intervals were used in these studies, which seemed a fair compromise between desired accuracy and practicality. While a two week sampling frequency is still recommended whenever possible, the observed one month intervals do not seem to have adversely affected the results of these surveys. Biological and chemical characterization of the lakes seemed entirely adequate, except where factors other than sampling frequency interfered. Also, when New Jersey lakes experience water quality problems or biological nuisances, they tend to experience these difficulties for periods of time much longer than one month. Therefore, for the purposes of these studies (trophic state determination and general characterization of water quality problems), sampling intervals of longer than two weeks seem applicable and acceptable. While sampling more frequently would tend to clarify the situation and increase the accuracy and validity of characterizations and conclusions, it is not believed that it would have changed any of the findings or conclusions of these studies.
4) Land Use and Drainage Basin Size Considerations: Recent literature indicates that nutrient loss from soil is very variable, depending on soil type and land use, but that generalized values can be applied. Forested land can be expected to lose the least amount of nutrients per year, with agricultural lands losing more nutrients. Urban inputs often contain the greatest nutrient quantities. So it is possible to make quantitative estimates of yearly inputs to a system from non-point sources, or at least to give an idea of what might be expected according to land use. Quantitative estimates were not given in this fashion in these studies (subtraction of point source inputs from total inputs was used to estimate non-point source inputs), but general expectations for water quality were expressed in terms of land use in the watershed. More theoretical loading could be used to supplement the data base acquired through such studies as these.

As regards drainage basin size, this areal value was used in conjunction with the value for lake area to form a ratio which could be used to obtain a general feel for potential water quality problems, especially when land use data is considered. The larger the drainage basin area to lake area ratio, the greater the expected nutrient inputs and the greater the probability of water quality problems. Charts exist that show anticipated conditions according to the ratio of watershed to lake area and general land use considerations. This was used but not emphasized in these studies, and proved to be a useful tool in predicting water quality or explaining observed conditions.

5) Limiting Nutrient Analysis: Several approaches to limiting nutrient determinations are commonly used today, including analysis of algal cell contents, analysis of overall system nutrient concentrations, and analysis of the potential response of a system to nutrient additions under controlled conditions (algal assay). The last approach is generally considered to be most accurate, but was somewhat impractical in these studies. Since chemical measurements were being made all over the system to determine input sources and quantities, it was convenient to use the second approach. This involves observation of a system's actual response to changing nutrient concentrations over the course of the study and application of conclusions from limnological literature to the observed ratios of nutrient concentrations (mainly phosphorus and nitrogen). This method was generally effective, but incorporates considerable uncertainty at times. Support from algal assays is desirable. Also, it must be remembered that nutrients are not always the limiting factor in a system, and provisions must be made for determining the influence of such potential limiting factors as light, temperature and current. A combination of in situ measurements and observations and laboratory algal assays would be an excellent approach to limiting factor analysis.
6) Vollenweider's Model and Other Loading Analyses: Predictions of lake conditions according to the indications of loading analyses based on the quantities and partitioning of nutrients (especially phosphorus) in a system are useful in trophic state determination and lake management. Controversy over the validity or usefulness of various models presently exists, and the individual investigator must recognize the appropriate applications and limitations of the various models.

In these studies, Vollenweider's Model was used in most cases, although the indications of this model were weakened whenever the studied system had a very short hydraulic detention time. Overall, the indications given by the model correlated well with observed conditions, and the model had some use in determining how far above or below acceptable phosphorus loading limits the system was. However, more credibility could be given to such analysis if multiple modeling systems were applied, with conclusions based on the overall indications obtained. Where additional analysis is impossible or impractical, Vollenweider's Model appears to give suitable results alone, as long as phosphorus is the system's limiting nutrient. Modifications of the model are also possible if the investigator has a good knowledge of the variables in the studied system and the limitations of the model, and such modification may be desirable.
Suggestions for Future Studies:

The 1977-78 Intensive Lake Surveys were successful, but improvement is certainly possible and future studies should benefit from analysis of the shortcomings of these studies. As a result of such analysis, the following changes in general approach and parameters emphasized can be recommended:

1) A good pre-study investigation of the system to be studied should be carried out, enabling investigators to make better judgements on site selection and related considerations.

2) To increase efficiency and allow the institution of necessary modifications, a mid-study evaluation of approach and progress should be made.

3) More comprehensive and accurate site selection is needed. Representativeness is essential, and efforts should be made to make all stations as accessible as possible. Also, no potential nutrient source should be deleted from the sampling program until it has been sampled several times and deemed insignificant.

4) More in-lake sampling should be performed, and great emphasis given to the results of this sampling. Lake perimeter, inlet and outlet samples are useful, but trophic state designations should be made primarily on the basis of in-lake sample data. Sediment (bottom muck) samples should also be taken in the lakes for the purpose of determining quantities and availability of nutrients and toxic compounds therein.

5) Sporadic sources of nutrients should be sampled wherever and whenever possible. Such sources as stormsewers and farm runoff may be very important.

6) Since inputs to a system may vary considerably with weather conditions, efforts should be made to sample during a variety of weather conditions.

7) Samples should be taken as frequently as possible, but sampling thoroughly should be stressed. For New Jersey lakes it appears that sampling frequency can be sacrificed for thoroughness when practicality intervenes. Two week intervals would be optimal, but one month intervals appeared adequate for the 1977-78 studies.
8) Dissolved oxygen readings should be taken at various times under various conditions. Night time dissolved oxygen readings may be very useful, especially if plant biomass is very great. A series of readings from dusk until about noon of the next day might show an interesting and informative progression.

9) More flow measurements are needed. A portable flowmeter should be used to take a flow measurement at each station when it is sampled, unless there is extensive flow data available for the site or a permanent flow meter is in operation there (such as with many effluent discharges).

10) Limiting nutrient analysis should be carried out by algal assay, and the general growth potential of the water assessed. This would be a useful supplement to the present analyses, and has great potential in eutrophication studies. Additional equipment, lab space and personnel would be required, however.

11) More modeling should be incorporated into the studies. The use of several models could yield much insight into the system under study, and the potential comparisons of theoretical and actual values would be useful not only in the study but in the broad field of limnology. Predictions of responses to various actions would also be more reliable if checked and supported by the use of models.

12) The following parameters should be emphasized (used as the primary basis for trophic state determination) in future studies; a) Community structure - a "superparameter" that includes biomass, quality indications of organisms present, and evenness at each trophic level (although special attention may frequently be given to producers). Specific single parameters of use here include evenness as derived from the Shannon-Weaver Diversity Index, chlorophyll a concentration, dry weight or ash-free weight, and various judgemental or mathematical quality indices.

b) Dissolved oxygen concentrations

c) Phosphorus concentrations (all forms)

d) Nitrogen concentrations (all forms)
General Lakes Management and Restoration Work Needed in New Jersey:

Considering the results of the 1977-78 Intensive Lake Surveys and other studies of aquatic systems in New Jersey, the following management and restoration needs can be singled out as essential to the preservation or improvement of water quality in New Jersey's lakes:

1) The need for extensive control of non-point source inputs, especially of nutrients and sediment.

2) The need for planned development that addresses environmental considerations, or the prevention of development in certain areas.

3) The need for advanced wastewater treatment (with phosphorus and possibly nitrogen removal schemes) in many of the treatment facilities in New Jersey.

4) The need for an examination and evaluation of septic systems in many watersheds, coupled with necessary corrective action.

5) The need for the institution of best management practices in many operations, especially construction activities and farm operations (both crop and cattle).

6) The need for a large scale dredging project, aimed at restoring heavily silted-in lakes to their pre-degradation depths and deepening potentially troublesome lakes.

7) The need for the development and use of innovative management and restoration techniques in New Jersey, where population density and geological considerations often interact to cause water quality problems and the accelerated eutrophication of lakes.

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