NJ Department of Environmental Protection
Water Monitoring and Standards

AMBIENT LAKES MONITORING NETWORK

Panel 1

Volume 1 of 2

September 2008

State of New Jersey
Jon S. Corzine, Governor

NJ Department of Environmental Protection
Lisa Jackson, Commissioner

NJ Department of Environmental Protection

Land Use Management
Mark N. Mauriello, Assistant Commissioner

Water Monitoring and Standards
Leslie J. McGeorge, Administrator

Bureau of Freshwater & Biological Monitoring
Alfred L. Korndoerfer, Jr., Chief

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AMBIENT LAKES MONITORING NETWORK
Panel 1
(Calendar Year 2005)

Volume 1 of 2

REPORT DESIGN
Alfred L. Korndoerfer, Jr., Bureau Chief
William Honachefsky, Section Chief

PRIMARY AUTHORS
William Honachefsky
Victor Poretti

SUPERVISOR
Victor Poretti

PROJECT OFFICER
Johannus Franken

DATA MANAGEMENT
Thomas Miller
Brian Taylor

FIELD COLLECTION STAFF
Johannus Franken
Thomas Miller
Victor Poretti
Brian Taylor

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EXECUTIVE SUMMARY

The NJ Department of Environmental Protection (NJDEP) initiated a renewed ambient lake monitoring network in 2005. This renewed initiative, which was undertaken by Water Monitoring and Standards' (WM&S) Bureau of Freshwater & Biological Monitoring (BFBM), was in response to deficiencies cited in a 1999 USEPA Office of Inspector General's (OIG) Audit Report [12] of the state's water monitoring programs, recommendations from EPA's "Elements of a State Water Monitoring and Assessment Program" (March 2003) [10], as well as needs identified by the Department's Watershed Management and Water Quality Assessment programs.

Lakes were selected randomly, using EPA's Generalized Random Tessellation Stratified (GRTS) survey design, but in a manner that equalizes selections over all Omerik Level III Ecoregions [8], of which there are six (6) in the state. The GRTS survey design is a plan for selecting the sample area appropriately so that it provides valid data for developing accurate estimates for the entire population or area of interest; in this case the population being New Jersey named lakes. Based on available resources, the network consists of 200 lakes, divided into five Panels of 40 lakes each.

Data is collected to evaluate trophic state of selected lakes and assess the ecological health of the State's lentic water resources. Forty lakes (designated as a Panel) per year are monitored in order to develop baseline, and eventually trend and statewide status, information for New Jersey lakes. Water quality monitoring will take place at up to three in-lake stations that best represent the limnological aspects of the lake. Sites are expected to be sampled three times per year (spring, summer, fall).

In 2005, 40 Panel 1 lakes were sampled. One lake (Menantico Sand Ponds) was, however, deleted from the Panel after sampling was completed because results showed that the lake was under tidal influence, which did not fit the criteria for lake selection. Therefore only 39 lakes were considered sampled for Panel 1. Although the design calls for sampling in the Spring, Summer and Fall, a delay in certification of the analytical lab used resulted in only the Summer and Fall samplings for this Panel.

Of the final 39 lakes that were sampled in 2005, 19 lakes exceeded the New Jersey Water Quality Criteria [7] **http://www.state.nj.us/dep/wms/bwqsa/swqs.htm**
for total phosphorus (TP) of > 0.05 mg/L from at least one in-lake station. When the TP exceeds the SWQC for two sampling visits, the lake is listed as "non-support of aquatic life use" in the New Jersey Integrated Water Quality Monitoring and Assessment Report (Integrated Report) [6] **http://www.state.nj.us/dep/wms/bwqsa/generalinfo.htm** .

Very low dissolved oxygen levels (the SWQC of < 4.0mg/l) were observed in some lakes in the mesotrophic-through-hypereutrophic range during the summer months. When the DO exceeds the SWQC for two sampling visits, the lake is listed as "non-attainment of aquatic life use" in the Integrated Report.

The SWQC for pH is between 6.5 and 8.5 for lakes within waters designated as FW2 waters and between 3.5 and 5.5 designated as PL waters. Elevated pH levels showed a strong correlation to algae concentrations. Lakes with higher pH measurements also had higher chlorophyll "a" concentrations. See Table 1 for lakes listed in the Integrated Report for "non-attainment of aquatic life use" and the parameters in violation. See Volume 2 of this report for all raw data results.

It should be noted that other data or factors, not collected or observed for the Ambient Lakes Monitoring Network can be used to determine how a lake is listed in the Integrated Report. The Integrated Report should be referred to for the definitive assessment of a specific lake and its support, or non-support, of aquatic life use.

NAME	Use Attainment	TP violation	pH violation	DO violations
Allentown Lake	Non Attain	X		
Anchor Lake One	Non Attain		X	
Braddocks Millpond	Non Attain		X	
Butler Pond	Non Attain	X		
Fawn Lake	Non Attain		X	
Hubers Lake	Non Attain	X		X
Kirkwood	Non Attain	X		
Ledells Pond	Non Attain	X		X
Memorial Lake	Non Attain	X		
Peddie Lake	Non Attain	X		X
Pickerel Lake	Non Attain		X	
Vincentown Millpond	Non Attain	X	X if PL waters	X

Table 1. Lakes listed in the Integrated Report as non-attainment of aquatic life use.

Carlson's Trophic State Index (TSI) is used as the basis for estimating the trophic state of New Jersey Lakes. Trophic states range from oligotrophic to hyper-eutrophic, and are viewed as a continuum on this scale. Carlson's TSI is based on the interrelationships of Total Phosphorus (TP), chlorophyll "a", and Secchi disk transparency. Six (6) lakes (Bass Lake, Gilman Lake, Hubers Lake, Indian Lake, Moss Mill Lake, Wapalanne Lake) had a TSI rating of Oligotrophic for at least one station, and only during the fall season. All other lakes sampled had TSI ratings in the Eutrophic range (Mesotrophic, Eutrophic, or Hypereutrophic) for both seasons sampled. As these results demonstrate, (see Volume 2), the trophic state of a lake is highly related to the season. Except for Silver Lake in Gibbsboro, which was mesotrophic for both seasons, oligotrophic and

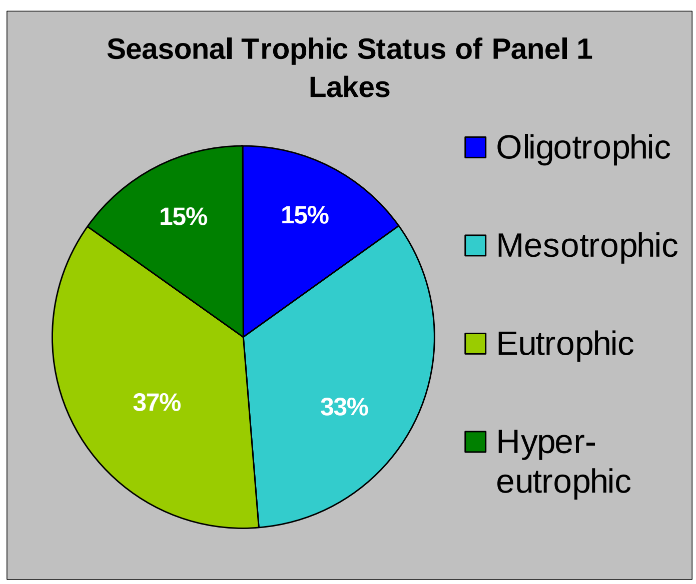


Figure 1. Summary of Seasonal TSI Results.

mesotrophic states only occurred during the fall. This occurrence could not be attributed to a single TSI parameter, as all three parameters decreased in value in relation to the trophic state. Subsequent data collection in all seasons for the remaining network panels will provide more insight on the relationship between trophic state and season.

Data and assessments from this initial Panel of sampling serves as a preliminary estimate of the Statewide status of New Jersey lakes. Lakes entirely oligotrophic were not represented in Panel 1, and the number of lakes exhibiting periods of oligotrophy was very limited. All lakes had periods in a eutrophic state. This demonstrates that all Panel 1 lakes sampled are in, or may be accelerating toward, an entirely eutrophic state.

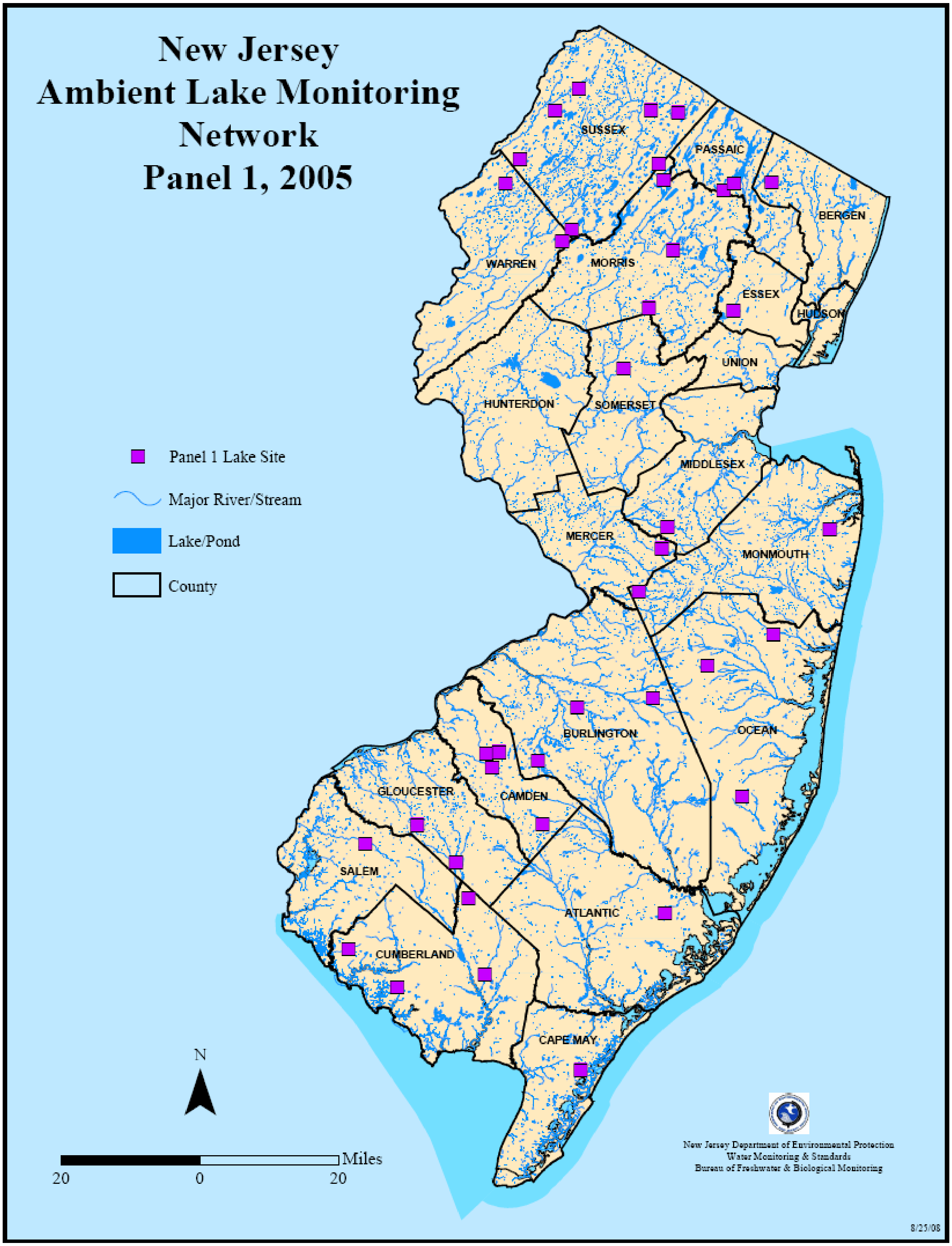


Figure 2. Panel 1 Lakes

INTRODUCTION

Background

In 2003, Water Monitoring & Standard's (WM&S') Bureau of Freshwater and Biological Monitoring (BFBM) formed an Ambient Lake Water Quality Monitoring Workgroup (Lake Workgroup). The workgroup was tasked with developing a monitoring network design optimized to address the ambient lake assessment deficiencies cited in the 1999 USEPA Office of Inspector General's (OIG) Audit Report, [12] the recommendations from EPA's "Elements of a State Water Monitoring and Assessment Program" [10], as well as needs identified by the Department's Watershed Management and Water Quality Assessment programs. Of particular concern to the OIG was that the state needed a network design that would capture the status of lake water quality statewide – a task the OIG felt could only be accomplished by a probabilistically designed network. Members of the Workgroup included representatives from BFBM, the Bureau of Environmental Analysis and Restoration (BEAR) in the Division of Watershed Management (which is responsible for developing TMDLs); the Water Assessment Team (WAT) within WM&S' Bureau of Water Quality Standards and Assessment which is responsible for preparing the Integrated Water Quality Monitoring and Assessment Report; and the USEPA Region 2 Division of Environmental Science and Assessment.

New Jersey Ambient Lakes Monitoring Network

As a result of the recommendations of the "Lake Workgroup", NJDEP initiated a renewed ambient lake monitoring network in 2005. The target population was identified as all lakes, man-made or natural, wholly or partially within New Jersey's political boundaries, excepting water supply reservoirs being actively being managed for potable water supply . Water supply reservoirs are subject to various pumping and water exchange operations, which do not represent the statewide status of New Jersey lakes, and were therefore excluded. A query of the NJDEP's GIS databases indicated a potential sampling population of approximately 1100 named lakes. In order to maximize the applicability of the monitoring for statewide assessments a probabilistically-based design was selected for the renewed network. Towards that end, lakes were selected randomly, using EPA's Generalized Random Tessellation Stratified (GRTS) survey design, but in a manner that equalizes selections over all Omerik Level III Ecoregions [8], of which there are six (6) in the state. Additional design stratifications included defining a lake as a permanent body of water of at least two (2) hectares in size, and a depth of approximately one meter at the deepest point measured. Based on available resources, the network consists of 200 lakes, divided into five Panels of 40 lakes, each Panel sampled once every five (5) years; each lake sampled 3 times per year, during the Spring, Summer and Fall. In 2005, 40 Panel 1 lakes were sampled (see Table 1 and Figure 2). Menantico Sand Ponds was deleted from Panel 1 after sampling was completed because results showed that the lake was under tidal influence. Therefore, only 39 lakes were sampled for Panel 1. A replacement lake will be added for the second sampling round.

Lake Eutrophication (aging) Process

Lakes are frequently divided into two (2) types: oligotrophic and eutrophic. These two types represent the extreme ends of a lake aging (eutrophication) continuum. Some typical characteristics of an oligotrophic lake are greater depth, adequate concentrations of dissolved oxygen from surface to bottom, low nutrients, low quantities of phytoplankton (measured as chlorophyll "a"), little aquatic plant growth, and good water clarity. Eutrophic lakes, in contrast, are usually shallow, have limited dissolved oxygen levels, are rich in nutrients, have persistent aquatic plant and phytoplankton growth, and decreased water clarity (usually due to an increase of phytoplankton levels).

Generally, as the oligotrophic lake ages, it gradually accumulates sediment and nutrients and moves toward and eventually into the eutrophic stage. There is a transitional stage between the oligotrophic and eutrophic conditions and this has been labeled the mesotrophic condition. The lake aging process is a natural process that commonly occurs over thousands of years. This natural aging process is often accelerated, however, by what has been termed *cultural eutrophication* (resulting from human activities). Unlike natural eutrophication, cultural eutrophication can rush oligotrophic type lakes into the eutrophic conditions in a matter of a human generation or two.

To measure the trophic state of the lakes sampled, the Carlson's Trophic State Index (TSI), calculated using Total Phosphorus concentrations, Chlorophyll-a concentrations, and Secchi disk transparency measurements, was selected as the indicator of choice. [3]

Table 2. Panel 1, 2005 Active Sites

SITEID	NAME	COUNTY	MUNICIPALITY
NJW04459-231	Allentown Lake	MONMOUTH	ALLENTOWN BORO
NJW04459-235	Anchor Lake One	CAMDEN	WINSLOW TWP
NJW04459-017	Bass Lake	WARREN	HARDWICK TWP
NJW04459-230	Braddocks Millpond	BURLINGTON	MEDFORD TWP
NJW04459-033	Brainerd Lake	MIDDLESEX	CRANBURY TWP
NJW04459-014	Burnt Mill Pond	CUMBERLAND	VINELAND CITY
NJW04459-037	Butler Pond	ESSEX	LIVINGSTON TWP
NJW04459-025	Cedarville Block Sand & Gravel Company Pond	CUMBERLAND	LAWRENCE TWP
NJW04459-237	Cold Spring Lake	PASSAIC	BLOOMINGDALE BORO
NJW04459-006	Davis Mill pond	CUMBERLAND	STOW CREEK TWP
NJW04459-009	Deer Park Pond	WARREN	ALLAMUCHY TWP
NJW04459-236	Eastern Gate Lake	GLOUCESTER	FRANKLIN TWP
NJW04459-010	Fairview Lake	SUSSEX	STILLWATER TWP
NJW04459-224	Fawn Lake	OCEAN	STAFFORD TWP
NJW04459-005	Gilman Lake	GLOUCESTER	HARRISON TWP
NJW04459-022	Highland Lake 1	SUSSEX	VERNON TWP
NJW04459-001	Hubers Lake	BERGEN	OAKLAND BORO
NJW04459-031	Indian Lake	MORRIS	DENVILLE TWP
NJW04459-002	Kirkwood 18	CAMDEN	VOORHEES TWP
NJW04459-013	Lake Ashroe	SUSSEX	SANDYSTON TWP
NJW04459-019	Lake Ioscoe	PASSAIC	BLOOMINGDALE BORO
NJW04459-034	Lake Manetta	OCEAN	LAKEWOOD TWP
NJW04459-021	Lake Stockholm	SUSSEX	HARDYSTON TWP
NJW04459-223	Ledells Pond	MORRIS	MENDHAM TWP
NJW04459-020	Long Lake	BURLINGTON	PEMBERTON TWP
NJW04459-228	Magnolia Lake	CAPE MAY	DENNIS TWP
NJW04459-229	Memorial Lake	SALEM	WOODSTOWN
NJW04459-032	Menantico Sand Ponds (deleted due to tidal influence)	CUMBERLAND	MILLVILLE CITY
NJW04459-027	Moss Mill Lake	ATLANTIC	GALLOWAY TWP
NJW04459-024	Peddie Lake	MERCER	HIGHTSTOWN BORO
NJW04459-008	Pickerel Lake	OCEAN	JACKSON TWP
NJW04459-023	Pleasant Valley Lake	SUSSEX	VERNON TWP
NJW04459-007	Silver Lake	CAMDEN	CLEMENTON BORO
NJW04459-234	Silver Lake	CAMDEN	GIBBSBORO
NJW04459-040	Sunset Lake	SOMERSET	BRIDGEWATER TWP
NJW04459-015	Vincentown Millpond	BURLINGTON	SOUTHAMPTON TWP
NJW04459-222	Wampum Lake	MONMOUTH	EATONTOWN BORO
NJW04459-036	Wapalanne Lake	SUSSEX	SANDYSTON TWP
NJW04459-233	Watchu Pond	SUSSEX	BYRAM TWP
NJW04459-226	White Rock Lake	MORRIS	JEFFERSON TWP

METHODS and MATERIALS

General Procedures: Sampling was performed on a given lake when there had not been any rainfall within 24 hours prior to sampling. This is to ensure that the sample is representative of the overall condition of the lake and not the condition of the lake only after a rain event. Sample volumes and container types are as described in the respective analytical laboratory's "Quality Manual" and/ or SOP, which have been approved by the Office of Quality Assurance (OQA) and are on file with that Office as part of the laboratory's certification application (copies provided upon request).

Sample Equipment Cleaning: Prior to field sampling, all sample collection equipment is thoroughly cleaned using a phosphate free detergent and rinsed with ultra pure PICO® water several times to ensure no phosphorus contamination is present.

Physical / Chemical Sampling Procedures and Parameters: Samples were collected at multiple lake locations (up to three in-lake stations). In addition, the outlet(s) of each lake were sampled. Samples were collected as per "NJDEP Field Sampling Procedures Manual", 2005.[5] In-lake samples were taken one meter below the surface, unless the lake was stratified or the sampling station had a depth of less than one meter. When a lake is stratified (the seasonal formation of a thermocline) samples will be taken from the epilimnion (upper layer), metalimnion (transition layer), and hypolimnion (lower layer). However, no Panel 1 lakes exhibited characteristics of stratification. While every attempt was made to select lakes with a depth of at least one meter, some lakes had depths of slightly less than one meter. A drop in depth to below one meter was usually attributed to seasonality. In lakes less than one meter deep, samples were collected at 0.5 meters below the surface or mid-depth. Samples were collected using a submerged horizontal sampler. A combination field blank and equipment blank of PICO® water was collected on-site from the submerged horizontal sampler prior to the first sample for each lake (PICO® water, an ultra clean water, is supplied from the BFBM lab system, which is analyzed twice per year at a NJ certified laboratory for applicable parameters).

Prior to sampling each station, the submerged sampler is field rinsed with "water of interest" (i.e. lake water present at each station at the sample depth) three times prior to collecting a sample at each station for the lake. Each individual lake required one dedicated and cleaned submerged sampler. Samples collected from the submerged sampler were analyzed for the following parameters:

- Total Phosphorus
- Nitrite and Nitrate
- Ammonia
- TKN
- Hardness
- Alkalinity
- Turbidity
- Chlorophyll "a".

For stratified lakes, these samples (with the exception of chlorophyll "a") were also collected from the epilimnion, metalimnion, and hypolimnion. Turbidity was also measured from these discrete samples, using a HACH 2100P Turbidity meter. All samples were analyzed at a New Jersey certified laboratory. Analytical results are reported in exact concentrations except when a result is at a level below the method Reporting Limit (RL) and a definitive concentration cannot be determined. In these cases, the result is reported as less than (<) the RL value. For Total Phosphorus, the RL changed near the end of the summer sampling. This was due to an upgrade in analytical instrumentation at the laboratory, resulting in greater sensitivity and a lower RL (see Volume 2, raw data sheets).

An *in situ* top-to-bottom profile was also measured at each in-lake station for:

- Specific Conductance
- pH
- Water Temperature
- Dissolved Oxygen.

Measurements were recorded at one meter depth intervals using a Hydrolab QUANTA multi-parameter meter. Total depth was measured using a Hondex Portable Depth Sounder. Aquatic plants, however, sometimes obstruct the readings of the Depth Sounder. In these cases, measurements were recorded using the Hydrolab QUANTA multi-parameter meter. The Hydrolab probe was lowered until resting on the lake bottom and the total depth was recorded. Transparency was measured using a Secchi Disk.

Sampling was also performed, using the above methods and same parameters, at observed "hot spots". A "hot spot" is defined as a small area of the lake which has unusual characteristics as compared to the rest of the lake. These characteristics include dense algae growth and unusual odor or color. A "hot spot" was sampled at only one lake, Lake Ioscoe, during the 2005 sampling. This "hot spot" was specifically observed as dense algae at this site.

Lake outlets streams were sampled for the same parameters as the in-lake samples, with the exception of transparency. Outlet samples were collected as a "grab" as per "NJDEP Field Sampling Procedures Manual", 2005, [5] http://www.state.nj.us/dep/srp/guidance/fspm/ at a depth representative of the total water column. In situ measurements were also recorded using a Hydrolab QUANTA multi-parameter meter at approximately mid-depth of the average total water column.

Other Parameters Sampled / Measured / or Observed

Aquatic vegetation: A gross estimate of total areal coverage of dominant type(s) of surface macrophytes was recorded. Lake macrophyte areal extent is determined by preparing an aerial photograph map of each lake prior to the sampling date. This is done using the latest version of aerial photography available and using GIS shapefiles for lake identification. The map includes the entire area of the lake so that it can be used for navigation/identification while on the lake. During the summer sampling season, all surface vegetation observed at each lake was marked on the aerial photograph map. This is done using a combination of landmarks (such as houses, bridges, etc.), lake shoreline features and estimated distances to these features. Areal extent is recorded as accurately as possible so it can be transcribed to GIS maps. Upon return to the office, the aerial photograph map is modified with the polygon that best represents the areal extent of the macrophytes present in each lake.

Algal Concentration: As mentioned previously, a sample was collected from the submerged horizontal sampler for chlorophyll "a". Sample analyses were performed by BFBM staff using a modified "EPA Method 445.0" .

Storm Water Outfall Pipes: The presence of storm water outfall pipes was noted and their locations recorded using a Global Positioning Unit (GPU). The diameter of the pipes were measured and the material of their composition was recorded.

CALCULATING CARLSON'S TROPHIC INDEX

Trophic State

As previously noted, *Carlson's Trophic State Index* (TSI) is used for estimating the trophic state of New Jersey Lakes; "state" defined as a measure in a given point in time. Carlson's TSI uses algal biomass as the basis for trophic state classification. Three variables, Total Phosphorus, Chlorophyll "a", and Secchi depth independently estimate algal biomass. These three index variables are interrelated by linear regression models, and should produce the same index value for a given combination of variable values. Any of the three can therefore theoretically be used to classify a waterbody. [3]

Each variable has its limitations, however, in estimating algal biomass to classify a trophic state. Chlorophyll "a" is the most accurate of the three but still has drawbacks as a biomass surrogate. The greatest drawback being that the amount of chlorophyll in an algal cell may vary considerably depending on the condition of the cell and species. Cells that are subject to low light conditions will have more chlorophyll in them than cells exposed to high light. [2] In turbid lakes, phosphorus may be attached to non-algal particles and not available for algal growth, thus making it a poor predictor of trophic state. [2] Similarly, secchi depth measurements can be influenced by a number of abiotic sources such as turbidity, and is a poor predictor in these instances.

Calculating the TSI [3]

Data results for each TSI parameter are converted into common units using the following calculations: [4]

Total Phosphorus TSI	(**TSIP**) = 14.42 ln(TP) + 4.15
Chlorophyll "a" TSI	(**TSIC**) = 9.81 ln (Chl a) + 30.6
Secchi Disk TSI	(**TSIS**) = 60-14.41 ln(SD)

These calculated values can then be placed in the proper TSI category below. Trophic state ranges from oligotrophic to hypereutrophic, and is viewed as a continuum (Figure 3), on this scale.

Oligotrophic. TSI values range from 0 to 40.
Lakes have low nutrient levels, are usually deep, and have high oxygen levels in the bottom waters. These lakes have very few algal blooms.

Mesotrophic. TSI values range from 41-50.
Lakes are in the "middle" of the trophic scale. They have increasing amounts of nutrients and slightly lower amounts of dissolved oxygen. There are temporary algae and aquatic plant problems.

Eutrophic. TSI values range from 51-70.
Lakes are nutrient rich. They are usually shallow, "green" lakes that have limited oxygen levels in the bottom waters. They have persistent algae and aquatic plant problems.

Hypereutrophic. TSI range is >70.
Lakes are very green and have little or no oxygen in the bottom layers. There are extreme algae and aquatic plant problems.

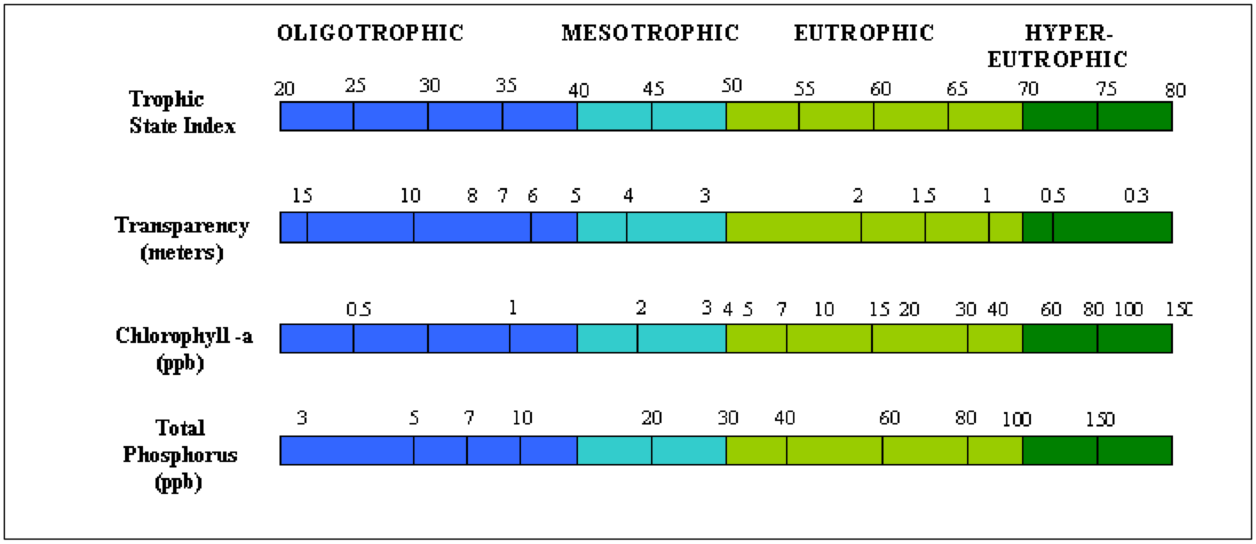


Figure 3. Carlson Trophic State Index viewed as a continuum.[1]

Each lake may have up to three fixed stations per sampling event (season) where parameters used for the TSI were collected. Because each TSI variable has its own strengths and limitations in estimating a lake's trophic state, calculated TSI values at each in-lake station, and for each season, are individually reported (see Volume 2). Although TSI can be calculated for any of the parameters [3] measured, when comparing TSI values priority should be given to Chlorophyll, as it is the most accurate in predicting algal biomass and therefore trophic state. [2]

For the purpose of demonstrating a preliminary approximation of statewide trophic states, TSI values were averaged for each station, and each season. Secchi disk measurements were not used in the calculation of the "average" if the transparency was obscured by vegetation, or the lake was too shallow to give a representative measurement. Furthermore, Total Phosphorus was not used in the "average" if the concentration was below the analytical reporting limit. It should be noted averaging the TSI parameters is merely a convention used to compare lakes on a statewide basis; averaging TSI values does not provide a definitive assessment of an individual lake's trophic state. Each lake should be studied individually to more definitively assess its trophic state. Non-TSI data such as hypolimnetic oxygen, other nutrients, and total plant biomass should be used to further assess a lake.

Emphasis should be made that TSI is not the same as a water quality index, although existing terminology often equates eutrophic lakes with poor water quality. [3] The TSI should serve as standard measurement against which comparisons can be made between the many biological and physical/chemical components of the lake system, and how these components relate to each other and the lake ecosystem as whole.[3] The TSI, along with individual chemical results, lake morphological observations, and expected or designated lake use will allow for the proper management of New Jersey lakes. The Integrated Report should be referred to for the definitive assessment of a specific lake and its support, or non-support, of aquatic life use.

RESULTS AND DISCUSSION

It should be noted that a definitive statewide assessment of New Jersey's lakes cannot be performed until data for the entire network of 200 lakes is collected. Data and assessments from this initial Panel sampling of lakes serve as a preliminary estimate of the Statewide status of New Jersey lakes.

In 2005, 40 Panel 1 lakes were sampled. One lake (Menantico Sand Ponds) was, however, deleted from the Panel after sampling was completed because results showed that the lake was under tidal influence. Therefore only 39 lakes were considered sampled for Panel 1. A replacement lake will be added for the second sampling round. Although the network design calls for sampling in the Spring, Summer and Fall, due to a delay in certification of the analytical lab used for the chemical analysis, only the Summer and Fall samplings could be completed for this Panel.

In this volume of the report a summary of the results from the 2005 – Panel 1 monitoring is presented. A full accounting of the results, by lake sampled, can be found in Volume 2 of this report. A discussion on the relationships between trophic state and the physical/ chemical and biological results follows:

SUMMARY OF IN-LAKE PHYSICAL/ CHEMICAL AND BIOLOGICAL MEASURES

The following is a discussion of the results and their relationship to the trophic state of a lake.

Surface Vegetation

A gross estimate of total areal coverage of dominant type(s) of surface macrophytes was recorded during the summer season, as this would represent the height of the growing period. During the lake visit, all surface vegetation observed was marked on the aerial photograph map for that lake. Areal extent was recorded as accurately as possible so it could be transcribed to GIS maps.

Figure 4. Watchu Pond. Extensive surface vegetation.

Surface vegetation can be described in four ways: none present, minimal (small areas along the shoreline), moderate (larger areas along the shoreline and extending into lake), extensive (majority of lake covered by vegetation as is Figure 4). A direct correlation between vegetation coverage and trophic state could not be determined. Although extensive surface vegetation was not observed in lakes with oligotrophic states, one did have moderate growth. Moderate-to-extensive vegetation was observed in lakes that had mesotrophic through hypereutrophic states. Inversely, absent-to-minimal vegetation was also observed in lakes of all trophic levels.

Compounding the difficulty of relating vegetation to trophic state is the treatment of some lakes to eliminate vegetation from the water. This is often done through the use of herbicides, but dredging and lake lowering are also common practices. At the time of sampling, it usually cannot be determined if plant life is absent due to natural conditions or treatment. Sixteen lakes sampled were permitted through the NJDEP Pesticide Control Program (Table 3). Vegetation observed at these lakes ranged from absent to extensive. (see Volume 2)

NAME	COUNTY	MUNICIPALITY	Pesticide Control Program Permit
Moss Mill Lake	ATLANTIC	GALLOWAY TWP	X
Hubers Lake	BERGEN	OAKLAND BORO	X
Vincentown Millpond	BURLINGTON	SOUTHAMPTON TWP	
Long Lake	BURLINGTON	PEMBERTON TWP	
Braddocks Millpond	BURLINGTON	MEDFORD TWP	
Kirkwood	CAMDEN	VOORHEES TWP	
Silver Lake	CAMDEN	CLEMENTON BORO	
Silver Lake	CAMDEN	GIBBSBORO	X
Anchor Lake One	CAMDEN	WINSLOW TWP	
Magnolia Lake	CAPE MAY	DENNIS TWP	
Davis Mill pond	CUMBERLAND	STOW CREEK TWP	
Burnt Mill Pond	CUMBERLAND	VINELAND CITY	X
Cedarville Block Sand & Gravel Co. Pond	CUMBERLAND	LAWRENCE TWP	
Menantico Sand Ponds	CUMBERLAND	MILLVILLE CITY	
Butler Pond	ESSEX	LIVINGSTON TWP	
Gilman Lake	GLOUCESTER	HARRISON TWP	
Eastern Gate Lake	GLOUCESTER	FRANKLIN TWP	
Peddie Lake	MERCER	HIGHTSTOWN BORO	
Brainard Lake	MIDDLESEX	CRANBURY TWP	
Wampum Lake	MONMOUTH	EATONTOWN BORO	
Allentown Lake	MONMOUTH	ALLENTOWN BORO	
Indian Lake	MORRIS	DENVILLE TWP	X
Ledells Pond	MORRIS	MENDHAM TWP	
White Rock Lake	MORRIS	JEFFERSON TWP	X
Pickerel Lake	OCEAN	JACKSON TWP	
Lake Manetta	OCEAN	LAKEWOOD TWP	X
Fawn Lake	OCEAN	STAFFORD TWP	
Lake Ioscoe	PASSAIC	BLOOMINGDALE BORO	X
Cold Spring Lake	PASSAIC	BLOOMINGDALE BORO	X
Memorial Lake	SALEM	WOODSTOWN	
Sunset Lake	SOMERSET	BRIDGEWATER TWP	X
Fairview Lake	SUSSEX	STILLWATER TWP	
Lake Ashroe	SUSSEX	SANDYSTON TWP	X
Lake Stockholm	SUSSEX	HARDYSTON TWP	X
Highland Lake	SUSSEX	VERNON TWP	X
Pleasant Valley Lake	SUSSEX	VERNON TWP	X
Wapalanne Lake	SUSSEX	SANDYSTON TWP	X
Watchu Pond	SUSSEX	BYRAM TWP	
Deer Park Pond	WARREN	ALLAMUCHY TWP	
Bass Lake	WARREN	HARDWICK TWP	X

Table 3. Panel 1 lakes with Pesticide Control Program permits.

Total Phosphorus

Of the 39 lakes sampled in 2005, 19 lakes exceeded the New Jersey Surface Water Quality Criteria (SWQC) maximum for total phosphorus (TP) of 0.05 mg/L from at least one in-lake sampling station. TP results from all lakes ranged from non-detected to 0.258mg/l in the summer and non-detected to 0.579mg/l in the fall. See Volume 2 for results for each lake.

When the TP exceeds the SWQC for two sampling visits, the lake is listed as "non-support of aquatic life use" in the New Jersey Integrated Water Quality Monitoring and Assessment Report (Integrated Report) [6] See Table 4 for lakes listed in the Integrated Report for "non-attainment of aquatic life use" and the parameters in violation. See Volume 2 of this report for all raw data results.

NAME	Use Attainment	TP violation	pH violation	DO violations
Allentown Lake	Non Attain	X		
Anchor Lake One	Non Attain		X	
Braddocks Millpond	Non Attain		X	
Butler Pond	Non Attain	X		
Fawn Lake	Non Attain		X	
Hubers Lake	Non Attain	X		X
Kirkwood	Non Attain	X		
Ledells Pond	Non Attain	X		X
Memorial Lake	Non Attain	X		
Peddie Lake	Non Attain	X		X
Pickerel Lake	Non Attain		X	
Vincentown Millpond	Non Attain	X	X if PL waters	X

Table 4. Lakes listed in the Integrated Report as non-attainment of aquatic life use.

Phosphorus is essential to the growth of organisms and can be the nutrient that limits primary productivity of a body of water.[9] Of the nutrients analyzed, Total Phosphorus exhibited the best correlation to trophic state and algae concentrations. Lakes with high Total Phosphorus were always in the eutrophic or hypereutrophic range. Furthermore, lakes exceeded the SWQC for Total Phosphorus only while in a eutrophic or hypereutrophic state. When Total Phosphorus levels were elevated, algae concentrations as measured by Chlorophyll "a", were also elevated. When these individual TSI parameters (TP and Chlorophyll "a") are approximately equal, it can be inferred that Total Phosphorus limits the algae growth. If they are not equal, then light or other nutrients are likely the limiting factors. [11]

Although the TSI is not a direct measure of water quality, some correlation can be made between trophic state and Total Phosphorus (TP) concentrations. Lakes which exceeded the SWQC for TP always received a eutrophic or hypereutrophic rating for the season in which TP exceeded the SWQC. Two lakes, Bass Lake and Huber Lake, had a TP result which exceeded SWQC in conjunction with a eutrophic state in the summer season, but recovered to an oligotrophic state in the fall with TP concentrations also decreasing to meet SWQC.

Other Nutrients

The other analyzed nutrients, Total Kjeldahl Nitrogen (TKN, also referred to as organic nitrogen), Total Nitrite + Nitrate Nitrogen, and Ammonia Nitrogen, did not show strong correlations with a lake's trophic state. When a lake was in its oligotrophic state, nutrient levels remained low (results close to the analytical reporting limit). However, when a lake entered a mesotrophic-to-hypereutrophic state, nutrient levels in some lakes rose, although not consistently throughout the entire panel of lakes.

Physical / Chemical Measurements

Dissolved oxygen, temperature, pH, conductivity, and turbidity were measured in the field, while alkalinity and hardness samples were collected using a submerged horizontal sampler. Dissolved oxygen, pH, and turbidity results showed a strong correlation with a lake's trophic state. As expected, temperature showed a strong relationship with dissolved oxygen as low dissolved oxygen only occurred in the summer. Very low dissolved oxygen levels (below the SWQC of 4.0mg/l) were observed in some lakes in the mesotrophic-through-hypereutrophic range during the summer months. When the DO exceeds the SWQC for two sampling visits, the lake is listed as "non-attainment of aquatic life use" in the New Jersey Integrated Water Quality Monitoring and Assessment Report (Integrated Report). (see Table for non-attainment and violation) The majority of lakes with very low dissolved oxygen were shallow (approximately 1 – 2 meters in depth). Shallow depths can limit the ability of a lake to maintain cooler temperatures, because of the penetration of sunlight. As a result, they tend to exhibit unstable dissolved oxygen concentrations. It could not be determined whether lake depth or other factors had the greater influence on low dissolved oxygen concentrations. Furthermore, waters with high algae levels will generally have fluctuating dissolved oxygen levels. Dissolved oxygen rises when algae is in its growth state and respiring, and recedes when algae growth slows. This was demonstrated in five lakes where the dissolved oxygen was super-saturated (greater than 100% saturation) with corresponding high Chlorophyll "a" concentrations (see Figure 5). A diurnal study of lakes with very low dissolved oxygen would be necessary to definitively determine if water level, or algae, is affecting the dissolved oxygen. A similar study would be necessary to record the fluctuating dissolved oxygen where super-saturation was observed.

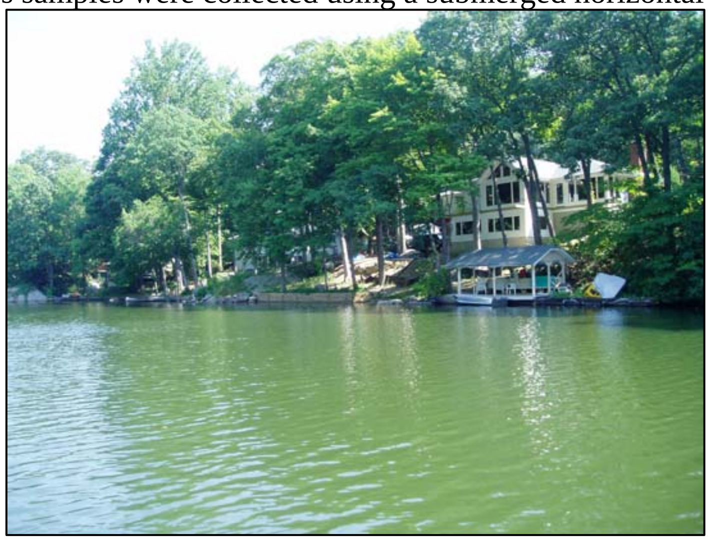


Figure 5. Lake Ioscoe with a high Chlorophyll "a" level and supersaturated dissolved oxygen concentrations.

The SWQC for pH is between 6.5 and 8.5 for lakes within waters designated as FW2 and between 3.5 and 5.5 within waters designated as PL. (see Table for non-attainment and violation) Elevated pH levels showed a strong correlation to algae concentrations. Lakes with higher pH measurements also had higher chlorophyll "a" concentrations. The production of the hydroxyl ion during photosynthesis is likely responsible for the increase in lake water pH when elevated levels of algal chlorophyll were present. Furthermore, lakes with the highest pH measurements also had supersaturated dissolved oxygen concentrations. Both the pH and dissolved oxygen concentrations measured are likely part of the diurnal cycle associated with algae growth. These relationships demonstrate how the trophic state and algae concentration can directly affect the chemical composition of a lake.

Turbidity also showed a strong correlation to a lake's trophic state. Turbidity was always low when a lake was in an oligotrophic or mesotrophic state. Turbidity levels were high when a lake was in a eutrophic state and very high when in a hypereutrophic state (see discussion on "Potential Stressors" for exploration of this relationship).

Conductivity, alkalinity, and hardness results did not show levels outside of expected ranges or correlations with trophic state.

Hot Spots

A "hot spot" is defined as a small area of the lake which has unusual characteristics as compared to the rest of the lake. These characteristics include dense algae growth and unusual odor or color that can indicate contamination which may be tracked to a source. A "hot spot" was sampled at only one lake, Lake Ioscoe, during the 2005 sampling where dense algae growth was observed throughout the water column (Figure 5). There were no significant differences observed in the levels of any parameter measured, as compared to the results from the other in lake stations.

Additional Physical / Chemical Monitoring

Lake Outlet Stream Measurements

All of the Panel 1 lakes, with the exception of Eastern Gate Lake (Gloucester County) and Cedarville Block, Sand, and Gravel Co. Pond (Cumberland County), had outlet streams. These two lakes were created from historic gravel and sand mining operations and not a direct stream impoundment. Outlets were not sampled unless they were actively flowing. It is important to remember that the total phosphorus Surface Water Quality Criteria (SWQC) for streams, 0.1 mg/L, is higher than for lakes.[7] Three outlet streams exceeded the Total Phosphorus (TP) Criteria at the time of sampling. These included outlets from Braddocks Mill Pond, Magnolia Lake, and Wampum Lake. TP concentrations within these lakes also exceeded the SWQC, which is likely having a direct influence on the respective outlet streams.

Figure 6. Memorial Lake Outlet. The receiving stream was greatly impacted by the lake's influence.

An outlet stream is determined to be directly affected by the lake when any parameter exhibits elevated results similar to those in its feeder lake, as observed at Memorial Lake, Figure 6. Approximately 55% of the outlet streams (if present) were affected by their lake's influence in the zone immediately downstream of the impoundment. Gilman Lake had periods in an oligotrophic state, while Silver Lake (in Gibbsboro) was in a mesotrophic state and their outlet streams had similar results to the respective lake. In all other cases where the outlet stream had elevated physical, chemical, and/ or nutrient levels, the upstream lake was in a eutrophic state. In the majority of streams where TP or nutrient concentrations were elevated, those same parameters were also elevated in the feeder lake.

Turbidity was the next parameter in which outlet stream levels were similar to that of the feeder lake. Chlorophyll "a" and dissolved oxygen levels, to a lesser extent than TP and turbidity, were also parameters which exhibited levels similar to that of the feeder lake. Additional sampling stations at intervals downstream in the outlet stream(s) would be necessary to construct a profile of the degree, and zone, of a lake's influence.

TROPHIC STATE INDEX (TSI) DISCUSSION

As previously noted, ***Carlson's Trophic State Index*** (TSI) is used as the basis for estimating the trophic state of New Jersey lakes. The trophic state for lake sampling sites ranges from oligotrophic to hypereutrophic, and is viewed as a continuum on this scale (Figure 3). Carlson's TSI is based on the interrelationships of Total Phosphorus (TP), chlorophyll "a", and Secchi disk transparency.

Oligotrophic Lakes

Lakes entirely oligotrophic were not represented in Panel 1, and the number of lakes exhibiting periods of oligotrophy was very limited. Only 6 of the 39 Panel 1 lakes had stations which were in an oligotrophic state. Bass Lake, Gilman Lake, Hubers Lake, Indian Lake, Moss Mill Lake, Wapalanne Lake (Figure 7) exhibited a TSI rating of oligotrophic for at least one station, but only during the fall season. And of these, none remained in a constant oligotrophic state for both seasons sampled.

Figure 7. Wapalanne Lake, one of six lakes to have an oligotrophic state.

Mesotrophic Lakes

Lakes having periods of a mesotrophic state, which are by definition in transition to a eutrophic state, were more prevalent than oligotrophic states . Thirteen lakes had stations in a mesotrophic state but only one of these, Silver Lake (in Gibbsboro), maintained its mesotrophic state throughout both seasons. However, Silver Lake (in Gibbsboro) is likely to degrade quickly into an entirely eutrophic state due to impacts from its five storm water outfalls and elevated nutrient concentrations.

Eutrophic and Hypereutrophic Lakes

The majority of Panel 1 lakes exhibited TSI ratings in the Eutrophic range (Eutrophic or Hypereutrophic) for both seasons sampled. Figure 8 shows a summary of the percentage of lakes exhibiting each trophic state.

All Panel 1 lakes exhibited degrees of eutrophication depending on the season and / or area of the lake sampled. Accordingly, this data demonstrates that all Panel 1 lakes are in, or accelerating towards, an entirely eutrophic state.

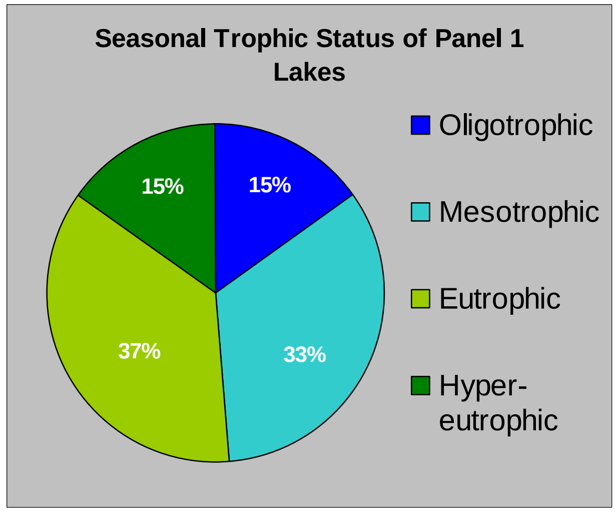


Figure 8. Summary of Seasonal TSI Results.

Relationship Between Trophic State Index and Parameters Measured

It should be noted that a definitive statewide assessment of New Jersey's lakes cannot be performed until data for the entire network is collected, however, certain relationships between trophic state and results were observed. As each Panel is completed, and more data is available, these relationships are anticipated to become more defined.

Figure 9 summarizes the percentage of lakes exhibiting exceedances of key parameters. Figure 10 demonstrates the general relationships between each of the trophic states, and the parameters measured. For these purposes, nutrients are defined as Total Kjeldahl Nitrogen (TKN, also referred to as organic nitrogen), Total Nitrite + Nitrate Nitrogen, and Ammonia Nitrogen. Concentrations were noted as elevated when levels exceeded 0.8 mg/l for TKN and 0.1mg/l for Total Nitrite + Nitrate Nitrogen or Ammonia Nitrogen, as these concentrations are significantly higher than the analytical reporting level for those parameters; 0.1 mg/l and 0.01 mg/l respectively. In-lake dissolved oxygen (DO) levels were of concern when observed either as a low concentration (< 4.0mg/l , and below the SWQC) or a super-saturation (>100%, and indicative of an algae problem). The graphs in Figures 9 and 10 also show the percentage of lakes with storm water outfalls and the percentage of lakes where the outlet stream was affected by its lake. "Affected stream outlets" are those that show similar results to their respective feeder lake when that lake's results are elevated.

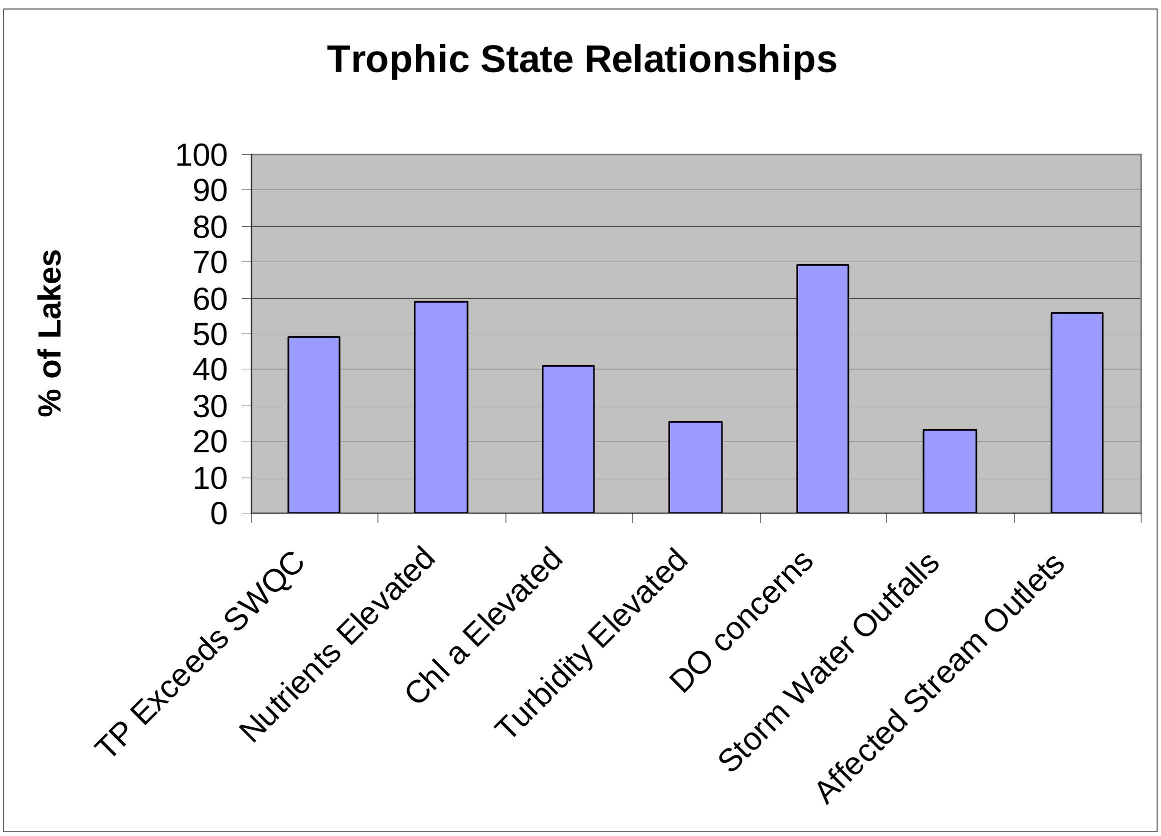
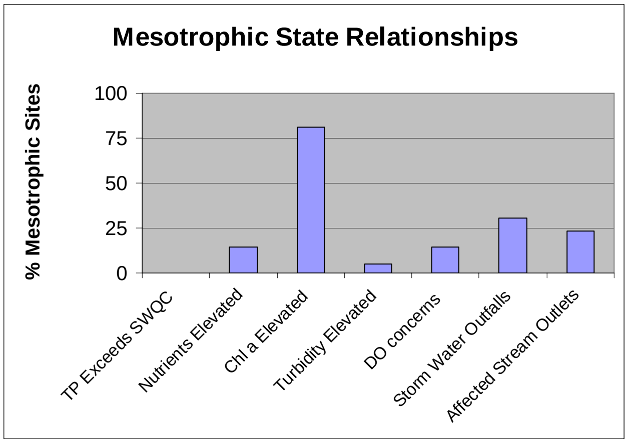
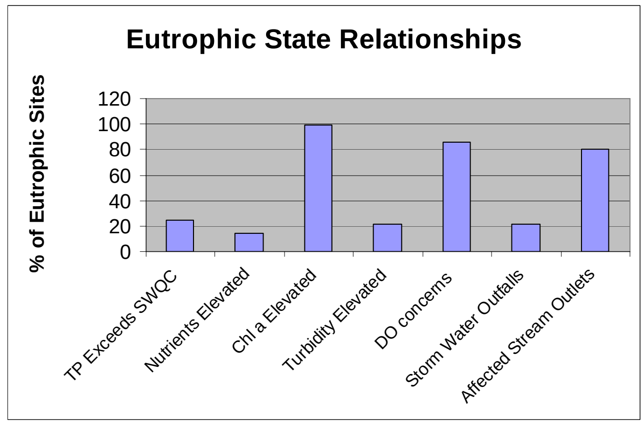


Figure 9. Percentage of lakes showing parameters at significant levels and observations of note.





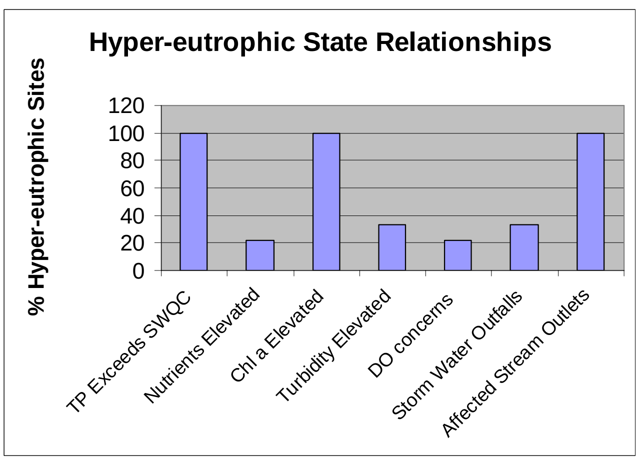


Figure 10. The relationship of individual trophic states with parameters and observations of significance. Lakes exhibiting an oligotrophic state had no parameters at significant levels when in that state.

Seasonal Variation In TSI

As the results demonstrate (see Volume 2), the trophic state of a lake is highly related to the season. Except for Silver Lake in Gibbsboro, which was mesotrophic for both seasons, oligotrophic and mesotrophic states only occurred during the fall. This occurrence could not be attributed to a single TSI parameter, as all three parameters decreased in value in relation to the trophic state. Subsequent data collection in all seasons for the remaining network panels will provide more insight on the relationship between trophic state and season.

POTENTIAL STRESSORS

Storm Water Outfalls

Storm water outfall pipes (Figure 9) were observed at some lakes. These pipes were made of cement, corrugated metal, PVC, or vitrified clay. Eight lakes had storm water outfalls entering the lake. These eight lakes showed a strong relationship between trophic state and elevated nutrient levels. No lake with an oligotrophic state had any outfalls. Only two lakes from this subset of eight, Lake Manetta and Silver Lake (in Gibbsboro), did not exceed SWQC for Total Phosphorus or have elevated nutrient levels. Of the remaining six lakes, five exceeded the SWQC for Total Phosphorus and had elevated nutrients, while one had only elevated nutrients.

Figure 9. Storm water outfalls like this one, draining into Brainerd Lake, can contribute to numerous problems such as: elevated nutrient levels, high turbidity, and the exceedance of SWQC for Total Phosphorus.

In addition to TP, turbidity was also at extremely high levels in seven of the eight lakes with outfall pipes. It is likely that these storm water pipes serve as a conduit for the increased turbidity levels observed. Storm water monitoring studies on these lakes would be helpful to determine the loading of nutrients, and other pollutants, from these outfalls.

RECOMMENDATIONS

Storm water outfalls seem to be a major stressor for lakes. Of the eight lakes with observed outfalls, none exhibited an oligotrophic state. Only two lakes from this subset of eight, Lake Manetta and Silver Lake (in Gibbsboro), did not exceed SWQC for Total Phosphorus or have elevated nutrient levels. Of the remaining six lakes, five exceeded the SWQC for Total Phosphorus and had elevated nutrients, while one had only elevated nutrients. Turbidity was also at extremely high levels in seven of the eight lakes with outfall pipes. It is likely that these storm water pipes serve as a conduit for the increased turbidity levels observed. Storm water monitoring studies on these lakes would be helpful to determine the loading of nutrients, and other pollutants, from these outfalls. Such a study should include analysis at mixing zones of the outfalls.

Dissolved oxygen rises when algae is in its growth state and respiring, and recedes when algae growth slows. This was demonstrated in five lakes where the dissolved oxygen was supersaturated (greater than 100% saturation) with corresponding high Chlorophyll "a" concentrations. A diurnal study of lakes exhibiting either very low or supersaturated dissolved oxygen is necessary to definitively determine if water level or algae is affecting the dissolved oxygen concentrations measured.

Although there exists Surface Water Quality Criteria for TP in lakes, the same cannot be said for other nutrients, namely Total Kjeldahl Nitrogen (TKN), Total Nitrite + Nitrate Nitrogen, and Ammonia Nitrogen. Nutrient levels were observed at elevated levels in some eutrophied lakes. However, a clear correlation between nutrients and water quality and/ or trophic state cannot be made without established criteria.   Studies defining the concentrations at which these nutrients affect water quality are recommended to improve the resolution of lake assessments.

Approximately 55% of the lake outlet streams (if present) were affected by their lake's influence in the zone immediately downstream of the impoundment. In the majority of streams where TP or other nutrient concentrations were elevated, those same parameters were also elevated in the feeder lake. Turbidity, Chlorophyll "a", and dissolved oxygen were also parameters which had similar concentrations to that of the feeder lake. Additional sampling stations at intervals downstream in the outlet stream(s) would be necessary to construct a profile of the degree, and zone, of a lake's influence. Once the USEPA developed and approved biological monitoring methods are available, the addition of lentic biological indices would be advisable. In-stream, lotic, biological monitoring, for both macroinvertebrates and fish, would also be recommended at intervals downstream to determine the lake's effect on the in-stream biota.

Data for the initial Panel of the Ambient Lakes Monitoring Network serves as a preliminary estimate of the statewide water quality status of New Jersey lakes.   Pending the availability of sufficient resources, it is recommended that site specific lentic studies be performed, on individual lakes, to supplement the data collected for statewide status in the Ambient Lakes Monitoring Network.

Additional Information

Additional information on the Ambient Lakes Monitoring Program can be obtained from WM&S' Bureau of Freshwater & Biological Monitoring by calling 609-292-0427 or visiting its website at: www.state.nj.us/dep/wms/bfbm.

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