INTRODUCTION

The Amnicon/Dowling Lake and Sanitary District (ADLSD) has been concerned about deteriorating water quality in both Amnicon and Dowling Lakes. In spring of 1994, the Sanitary District was awarded a Lake Management Planning Grant which is being implemented under the direction of C.J. Owen & Associates.

One of the objectives of the Planning Grant is to establish an imagery land use database for both lakes and to identify landuse factors that may be contributing to the deteriorating water quality. A.W. Research Laboratories was hired to conduct an Aerial Lakeshore Analysis (ALA) of Amnicon/Dowling Lakes to fulfill this objective.

The following is the ALA report for Amnicon/Dowling Lakes. The data was acquired during an overflight on June 24, 1994.

The report provides a base document for conducting the following:

a. documenting the state of eutrophication at a point in time.
b. defining the conditions which led to the eutrophication of the lake.
c. defining the next steps necessary to correct the polluting conditions.
d. planning, implementing and assessing lake restoration procedures.

Amnicon/Dowling Lakes provides a scenic environment for its residents and visitors along with areas of ideal habitat for a diversity of wildlife and fish. The homes along the lake's shoreline provide valued seasonal and year-round lake living. The beauty and recreational environment that Amnicon/Dowling Lakes provide is the basic reason that families and individuals have invested in their lakeshore property.

As is the situation throughout all of life's forms, the environment dictates the quality of life in a given geographical area. Amnicon/Dowling Lake and its watershed provides the environment for its inhabitants. The goal of this project is to restore and preserve that environment.

Restoration and preservation will be accomplished by providing the lake residents with an understandable data base which defines the effects of past and current land use practices on the water quality of Amnicon/Dowling Lake. The data will generate a decision making tool for future landuse planning and lake maintenance.

PREFACE and USAGE INSTRUCTIONS

This report is designed as a base document for the monitoring and improvement of Amnicon/Dowling Lakes.

The various sections of this report are designed to guide and prioritize the confirmation of the documented situations by the Amnicon/Dowling Lake & Sanitary District, local units of government, and above all, the residents of the lake.

This report is a reference document. The basic definitions of each section are as follows:

SECTION	DEFINITION
Introduction	States the need and purpose for the study.
Lake Data Summary	Includes the estimated number of residences (dwellings) that existed during the overflight, miles of shoreline, dwellings per mile of shoreline, average feet of shoreline per dwelling.
Color Code – Color Coded Map	Describes the environmental conditions which have been observed in the imagery, at each map position.
Imagery	Contains the image data (slides) numerically correlated to the Color Coded Map.
Analysis/Conclusion	Describes the physical and chemical observations which are used to confirm (groundtruth) the aerial analysis. This section also points out specific areas for further investigation and gives recommendations.
Groundtruthing Forms	Explanation of the parameters to be sampled and the forms used for the groundtruthing.

II. Spring/Summer/Fall 1995

A. Use the ALA report to prioritize the nutrient sources and areas to be groundtruthed. Present the slides and analysis to the residents as an educational tool to instruct them on how to use Best Management Practices on their property. Even if the Sanitary District decides to install a centralized sewer system, Best Management Practices should be applied to all properties to minimize loading from runoff.

B. The wetland areas should be sampled to determine if they are retaining nutrients or flushing nutrients to the lake. An appropriate management plan for the wetlands should be developed based on the results of the sampling.

III. Winter 1995-6

A. Prepare and present a Shoreline Restoration Plan based on this report, groundtruthing information, user perception, water quality assessment, and lake morphometry. The plan will define the specific activities and response mechanisms necessary to manage the lake. The following concerns should be included in the plan:

1. Keep the lake's environment within the established user perception guidelines.
2. Stabilize any increased eutrophication of the lake.
3. Define the procedures and maintenance tasks necessary to accomplish the goals in items one and two immediately above.

IV. Summer 1996 - Future

A. Begin implementation of the management plan.

A quality assurance plan should be implemented after the installation of a centralized sewer/storm water system (if that option is chosen) to ensure that all residences have been hooked up and that old septic systems have been properly pumped and abandoned.

RECOMMENDATIONS

The Aerial Lakeshore Analysis identifies the following landuses affecting Amnicon/Dowling Lakes in order of priority.

1. Septic systems.

2. Point sources such as a ditch, creek or culvert.

3. Runoff from impermeable areas such as driveways and roofs, especially if these areas are closer to the lake than seventy–five feet.

It is recommended that the Amnicon/Dowling Lake Association carry out the following actions:

I. Fall/Winter 1994

A. Determine if there is available data regarding point sources. If no such data exists, a decision will need to be made to either move ahead with a sewer/storm water system or gather the point source data.

   1. Research the options for centralized sewer/storm water systems

   2. If point source data is to be gathered; a sampling plan should be designed, to be implemented by spring of 1995 or sooner.

   3. Determine general groundwater flow and possibility of aquifer contamination especially in the low lying areas.

B. Develop a mechanism to begin strict enforcement of zoning ordinances for future construction or remodeling projects.

If there is no reliable data regarding the frequency, volume and concentration that these numerous point sources contribute, it is difficult to evaluate whether the point source influence is greater than the septic system influence.

One strategy would be to incorporate storm water/culvert management into a centralized sewer system, thereby solving both problems at the same time.

If a centralized sewer system is pursued, the hydrologic effects it will have on the lake need to be evaluated. The aquifer and eventually the lake levels could decrease, resulting in larger beach areas and higher concentrations of nutrients. This will be especially evident the first several years before the effect of decreased nutrient inputs are realized.

In addition to the septic and point source risk are other anthropogenic influences. The past and current landuse practices by lakeshore owners and land owners within the watershed and near shore area have a direct effect on the eco-systems in the littoral zone (the area less than fifteen feet deep). It was for this reason that zoning ordinances were developed with tight restrictions on lake shore property.

The slide analysis shows almost total noncompliance with zoning ordinances on both lakes. The significance of this is the amount of nutrient loading that is being contributed to the lakes from a variety of runoff sources such as impermeable areas (rooftops), lawn and garden fertilizer, roads and shoreline erosion. Although these impacts may be secondary to the septic and point source impacts, because they occur so frequently, the accumulated effect over time appears to be considerable.

There are many residences and boat houses located within 75 feet of the shoreline, this proximity contributes nitrogen and phosphorus to the lake through runoff from the roof and other impermeable areas.

The practice of maintaining a lawn adjacent to the water's edge should be discouraged. This situation presents an opportunity for lawn fertilizers and chemicals to flow uninterrupted into the lake. Homeowners should work with the DNR and/or County Planning & Zoning to install berms to control runoff from steep hillsides and impervious areas and riprap to prevent erosion, where appropriate. Ice ridges that may form in the winter should be left intact because they function as a natural berm to prevent yard runoff.

5. Hydrogeology sensitivity of the area.
   Approximately 24% of the shoreline of Amnicon is at or near the same elevation as the lake, creating a high risk situation for the ground water. The risk involved with low lying areas is that it is almost impossible to avoid discharging effluent to the groundwater (and eventually the lake) unless mound systems are being used. There were very few mound systems observed on these lots.

Additional information regarding septic systems acquired from the 1994 survey:

* 51.9% of the septic systems are septic–drainfield.
* 19% of the systems are privies.
* 64% of the systems are $\geq$ 10 years of age with 38% $\geq$ 20 years of age.
* 21% of the systems reside $\leq$ 20 feet from a water resource.
* 41% of the systems do not receive regular ($\leq$ 2 year interval) maintenance (pumping).

There is a possibility that the groundwater may be contaminated in the low lying areas, in which case a public water system may need to be included in the centralized sewer system project.

POINT SOURCES

Twenty three percent of the Amnicon lots and nineteen percent of the Dowling lots exhibit known or suspected point sources including culverts along the road.

Factors that determine the seriousness of point sources include:

1. the number of point source occurrences
2. how often they flow
3. the volume they contribute
4. what pollutants they contribute
5. the concentration they contribute

How much nutrient loading is actually occurring from the point sources is calculated by combining the data from 1–5.

Discussion, continued

According to the analysis, septic systems and point sources are the greatest influence on nutrient loading for both lakes. A number of factors need to be considered before a decision can be made regarding which source (septic systems or point sources) is the more serious threat.

SEPTIC SYSTEMS

Eighty seven percent of the lots on both lakes met one or more the criteria on page 10 for septic influence.

Factors that determine the seriousness of septic influence include:

1. The number of lots on the lake that are developed.
   Amnicon: 149 lots in the three and a half miles of lakeshore that are developed.
   Dowling: 82 lots in 2 miles of lakeshore

   This averages out to 125 feet/lot which makes both lakes very densely developed. Amnicon/Dowling lakes are zoned predominantly RR-1 and the minimum acceptable standard for lot width for RR-1 zoning is 150 feet. and an area of 30,000 square feet.

2. The number of structures on each lot that generate sewage.
   Many of the lots appear to have more than one inhabited residence.

3. The number of residences that are inhabited all year.
   According to the survey conducted by C.J. & Associates in January of 1994, 47.5 % of the properties are primary residents.

4. Second tier development of lots.
   The east shore of both lakes is beginning to show second tier development.

The following table presents the number and percentage of lots that exhibit the above influences.

AMNICON LAKE

	# OF LOTS	% OF LOTS
Septic	129	87
Runoff	90	60
Point (known & suspected)	41	28
Toxic	10	7

DOWLING LAKE

	# OF LOTS	% OF LOTS
Septic	71	87
Runoff	68	82
Point (known & suspected)	20	24
Toxic	1	1

DISCUSSION

The focus of this study is to evaluate the affect of anthropogenic (shoreline development) related pollutants on the water quality of Amnicon/Dowling Lakes. Anthropogenic pollutants fall into several categories: septic, various sources of runoff, point sources and toxic sources. The criteria used to evaluate the affect each property is having on water quality is listed below:

Septic influence:

*residences that appear to be built before 1974.
*lots that appear to be less than 30,000 square feet.
*property that is on or nearly on the same elevation as the lake level.
*residences that are very large or have been recently remodeled.
*property that has very healthy or dense aquatic vegetation in the near shore area.
*evidence of animal wastes.

Runoff influences

*property that has any structure within 75 feet of the shore.
*property that indicates use of lawn or garden fertilizer within 100 feet of the shoreline.
*property that indicates shoreline erosion.
*roads that are within 100 feet of the shoreline.
*agriculture.

Point sources:

*evidence of a creek or ditch on the property.
*culverts within 100 feet of the shoreline.
*hoses within 100 feet of the shoreline.

Toxic influences:

*evidence of a dump.
*businesses or structures that may be handling hazardous waste.
*evidence of unhealthy or dead vegetation.

CONCLUSIONS

Amnicon Lake is located in Douglas County, Wisconsin. It has 5.1 miles of lake shore, with an average depth of ten feet and a maximum depth of thirty one feet. The shoreline has several bays, and three major inlets, a permanently flowing inlet from Dowling Lake on the east side and two intermittent feeder streams from adjoining marshland on the north shore. There is a small island in the southern half of the lake.

Most of the land suitable for development has been populated, with the northeast shore showing development in the second tier. .

Dowling Lake has 1.9 miles of lake shore with an average depth of seven feet and a maximum depth of thirteen feet. The shoreline has no large bays, one major outlet to Amnicon Lake on the west side and no major inlets.

Most of the land suitable for development has been populated, with the east central shore showing development in the second tier.

The following conclusions are based on the results of the slide analysis. The slide analysis will provide a guide to:

1. ensure that nothing is overlooked during groundtruthing;
2. determine if there are problems which need immediate attention;
3. provide an individualized educational tool for each landowner.

According to the analysis, septic systems and point sources are the greatest influence on nutrient loading for both lakes. A number of factors need to be considered before a decision can be made regarding which source (septic systems or point sources) is the more serious threat.

METHODOLOGY

Aerial imaging has long been utilized to rapidly survey broad land areas. The technique allows the user to cover a considerable amount of area in a short time frame. The aerial perspective also allows the user to see things that would be obscured from the ground perspective. The visual image record can be reviewed under various protocols to detect evidence of conditions the user is interested in. Since that review can take place in a controlled laboratory situation, it can be more consistent than field review.

This methodology uses Aerial Lakeshore Analysis (ALA) to locate pollution inputs and their effects where manifested near the water/upland interface, and to provide visual data for future uses.

AERIAL LAKESHORE ANALYSIS (ALA)

The ALA provides a low altitude oblique view of shorelines; presented in visible and infrared range, 35mm slides of every 300 to 500 feet of lakeshore. Oblique imaging allows an image analyst to see beneath trees and shrubs, and to view both vertical embankments and horizontal land surfaces at the same time. For nonpoint source pollution detection, ALA is a successful methodology because a comprehensive view is provided of the lake, streams, wetlands and adjacent upland area. In this area, local and upper watershed influences are often manifested as noticeably unusual vegetative patterns, land use, or bank conditions.

1994 LAKE DATA SUMMARY OF AMNICON LAKE

Number of shoreline lots (not dwellings) observed: Lots on the Lake	148
Total miles of shoreline analyzed	5.11
Lots per mile of total shoreline	29
Average feet of shoreline per dwelling (3.5 miles of developed shoreline))	125

1994 LAKE DATA SUMMARY OF DOWLING LAKE

Number of shoreline lots (not dwellings) observed: Lots on the Lake	82
Total miles of shoreline analyzed	1.95
Lots per mile of total shoreline	41
Average feet of shoreline per dwelling	125

Recommendations

The following recommendations are made by C.J. Owen and Associates as a result of the 1994 Lake Amnicon and Dowling lake management project:

1. A concerted effort must be made to explore alternative waste management alternatives for Lake Amnicon and Dowling, including, but not limited to, centralized waste treatment systems and holding tank technology. This effort must be carried out with all due haste, with full disclosure to members of the district and effected parties.

2. Closer ties must be made and consultation must be established between the Amnicon/Dowling Lake Management and Sanitary District and the local agency responsible for zoning ordinances so that a critical review of any expansion and/or development could be reviewed by the commissioners prior to construction.

3. A stronger Lakes Management Organization must be established with discreet objectives related to watershed and in-lake management issues, thereby freeing sanitary district member to address the waste treatment needs of the district members (this may mean establishment of a sub-committee for with oversight by the commissioners of the Lake Management and Sanitary District).

4. Establish a steering committee to direct the lake-wide implementation of watershed BMP's for Lake Amnicon and Lake Dowling.

5. Establish a steering committee to follow-up on the recommendations for the establishment of a integrated macrophyte management plan.

6. Work to implement recommendations as a result of the Areal Lakeshore Analysis, performed by A.W. Research.

The periphyton artificial substrata colonization survey was most successful on Lake Amnicon for identifying spatial differences in colonization rates. Greatest biomass accumulation was associated with highly developed areas of shoreline and proximity to roads. This method was less successful in Dowling Lake, presumably due to the highly colored nature of the water, which limits light penetration.

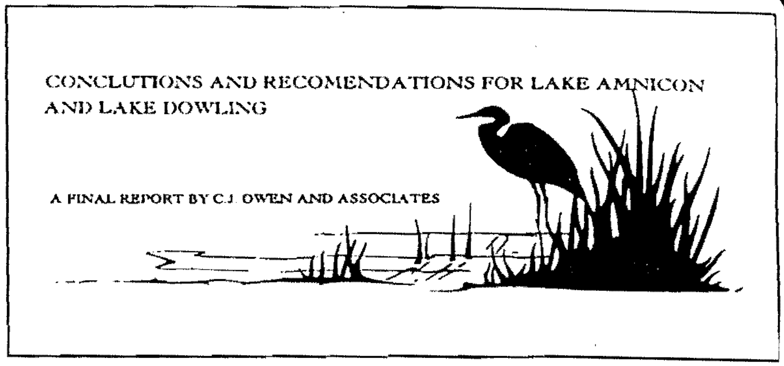
Areal lakeshore analysis of Amnicon and Dowling provided convincing circumstantial evidence to district members as to the high occurrence rate of possible septic, run-off, point source and toxic influences on the lakes. Although estimates of the percent of lots exhibiting these influences may be overstated by A.W. Research, the obvious influences can not be refuted. The data evaluation performed by A.W. Research on possible septic influences on the lakes is sound in its assumptions and conclusions (i.e. number of shoreline feet per lot, number of structures producing waste per lot and the presence of second tier development).

Conclusions drawn by A.W. Research as to the sensitivity of the lakes to hydrologic nutrient inputs is further supported by the soil characterization survey performed by the US Department of Agriculture in 1969. This survey suggests poor soil types for treatment of human waste by drainfield type systems. Recommendations by A.W. Research for the establishment of watershed BMP's and the need for more control over zoning ordinances is supported by C.J. Owen and Associates.

Results from the macrophyte synoptic surveys for Lake Amnicon and Dowling indicate a healthy, diverse community. Any control strategies for the lakes should be limited in its scope and should follow the development of an integrated macrophyte management plan, as outlined by C.J. Owen and Associates.

Re-evaluation of the soil survey conducted in 1969 by the US Department of Agriculture, further supports the conclusion that nutrient loading from lakeshore/watershed residential properties are most likely, impacting the water quality of both lakes. Soil types in general were not appropriate for the use of drainfield type systems.

CONCLUSIONS AND RECOMMENDATIONS AS A RESULT OF THE 1994 LAKE AMNICON/ DOWLING LAKE MANAGEMENT PROJECT



Conclusions

Clearly, results from this study indicate the progressive eutrophication of both Lake Amnicon and Lake Dowling. Dramatic improvements in the manner in which lakeshore/watershed residences relate to the lakes needs to be addressed. The lack of sound shoreline best management practices (i.e. BMP's) has undoubtedly accelerated the process of eutrophication. As a result of water quality degradation, there was the early presence and persistence of blue-green algal blooms in both Lake Amnicon and Dowling, detracting from the recreational use of both lakes.

The high rate of production in these lakes has undoubtedly resulted in high organic loading and in turn, high rates of decomposition. This decomposition process utilizes dissolved oxygen, depleting its concentration in the water. However, because of the shallow nature of the lakes, results in weak thermal stratification, re-aeration due to wind mixing was evident. In contrast, during ice cover this decomposition continues without the advantage of the re-aeration process which may lead to fish stress or winter fish kills, if the winter anoxic layer continues to increase in depth for these lakes.

Chemical and physical data collected for Lake Amnicon and Dowling further support the eutrophic classification of these lakes. TSI's based on chlorophyll, secchi and TP all indicate a system eutrophic in nature. Further, TP:DIN ratios suggest systems co-limited by nitrogen and phosphorus, indicating systems sensitive to inputs of both nitrogen and phosphorus form septic systems and run-off.

Although limited by economic constraints (i.e. number of samples was limited), near-shore bacteria sampling did indicate areas of elevated Fecal Coliform, Fecal Streptococcus and E. Coli. These data however were inconclusive and only suggest areas of possible septic input.

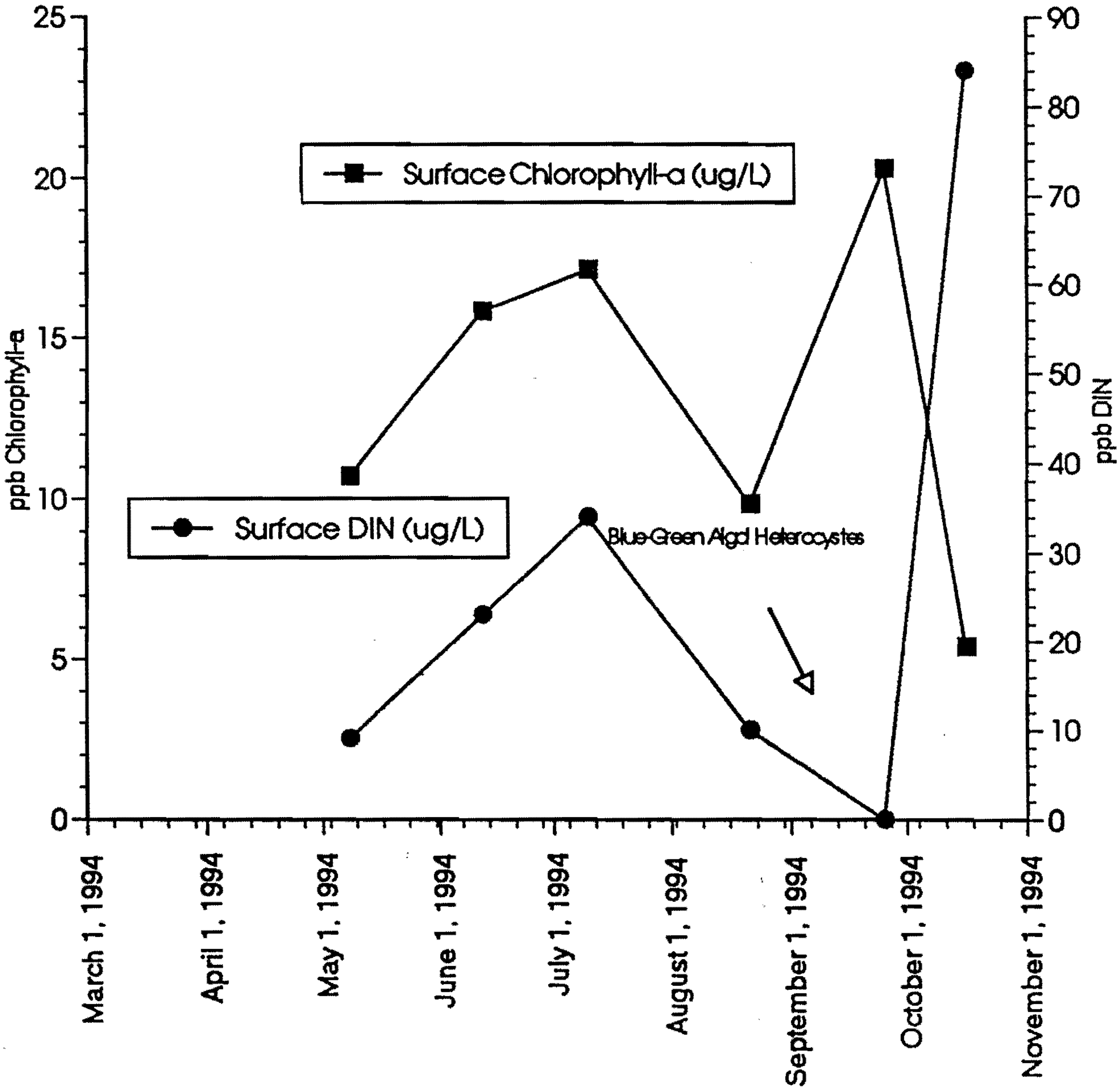
Near-shore conductivity did show areas of elevated ion input, these areas being associated with heavy development and proximity to roads. These elevations are most likely due to increased ion-loading from residential properties to ground water and/or surface run-off.

Dissolved Inorganic Nitrogen

Dissolved Inorganic nitrogen (DIN) data from Dowling Lake was extremely low, with the highest levels found in the October hypolimnetic sample at 84 ppb. Mean DIN levels for Dowling Lake, including epilimnetic and hypolimnetic samples was 27.1 +/- 28.7 ppb. A rapid decline of both NO3+NO2 and NH4 to below dectection at the surface occurred during periods of rapid algal growth. This resulted in the formation of heterocystic blue-green algae.

DIN:TP Ratios

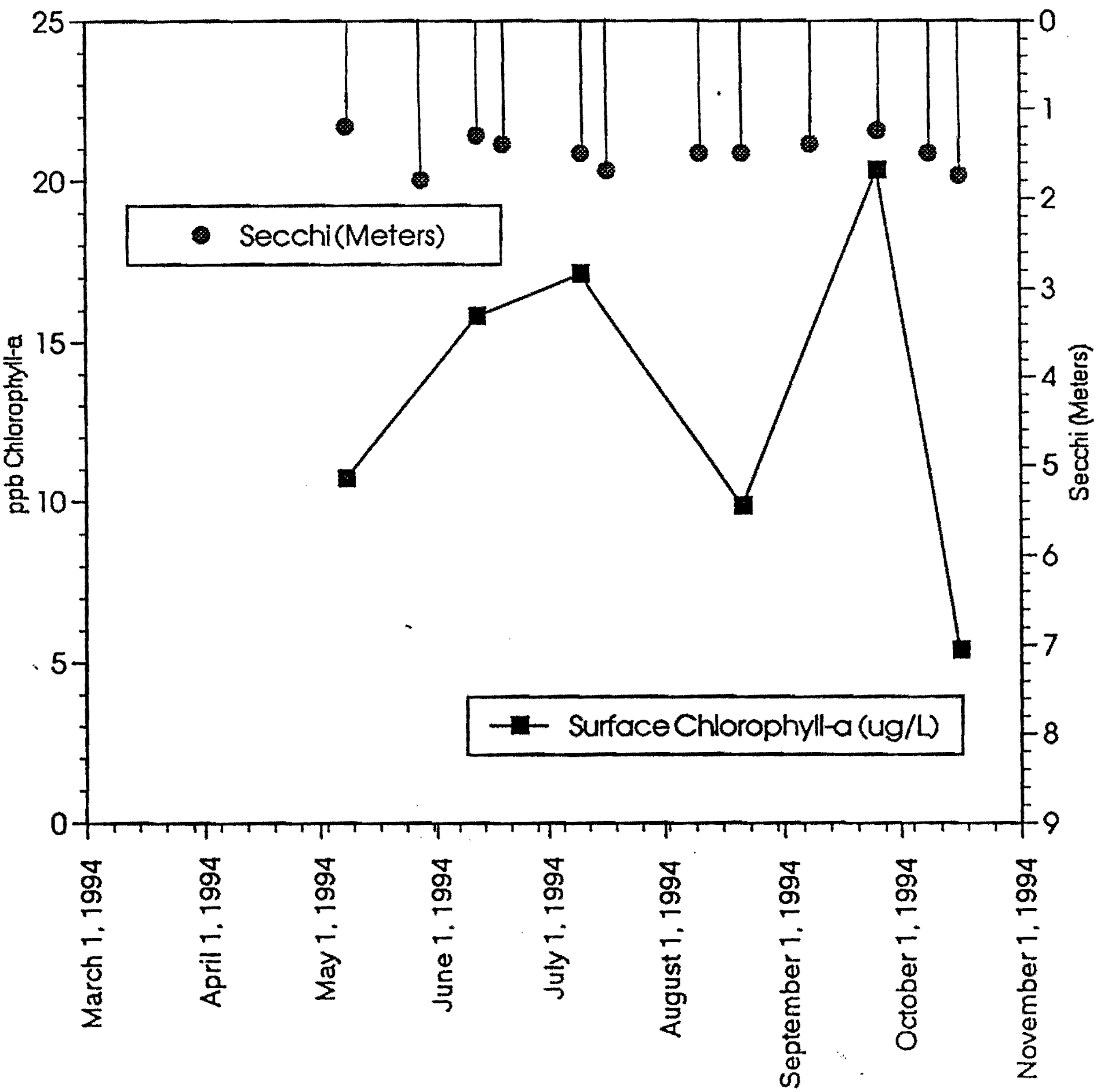
DIN:TP ratios ranged from 0 in September to 2 in October. Mean summer DIN:TP ratio was 0.48 +/- 0.42. This suggests a system limited by nitrogen. A plot of the relationship of Chlorophyll to DIN follows:



Chlorophyll and Secchi

Chlorophyll results for May through October ranged form 5.4 ppb to 20.3 ppb. Early increases in algal biomass (May-June) are expressed as moderately high chlorophylls, ranging from 10.7 ppb to 17.1 ppb. Peak chlorophyll levels were in September at 20.3 ppb. Mean summer chlorophyll was 14.7 ppb (n=5). This level results in a Carlson's C-TSI of 57, further classifying the lake as eutrophic.

Secchi depths for Dowling Lake ranged from 1.75 to 1.25 meters. Mean sampling period secchi depth was 1.48 meters (n=12), with summer mean of 1.46 meters (n=10). This results in a Carlson's S-TSI for the entire data set of 54.4 and 54.4 for the summer data set. This TSI level indicates a lake "eutrophic " in nature. The results of the chlorophyll and secchi data are expressed in the following plot:

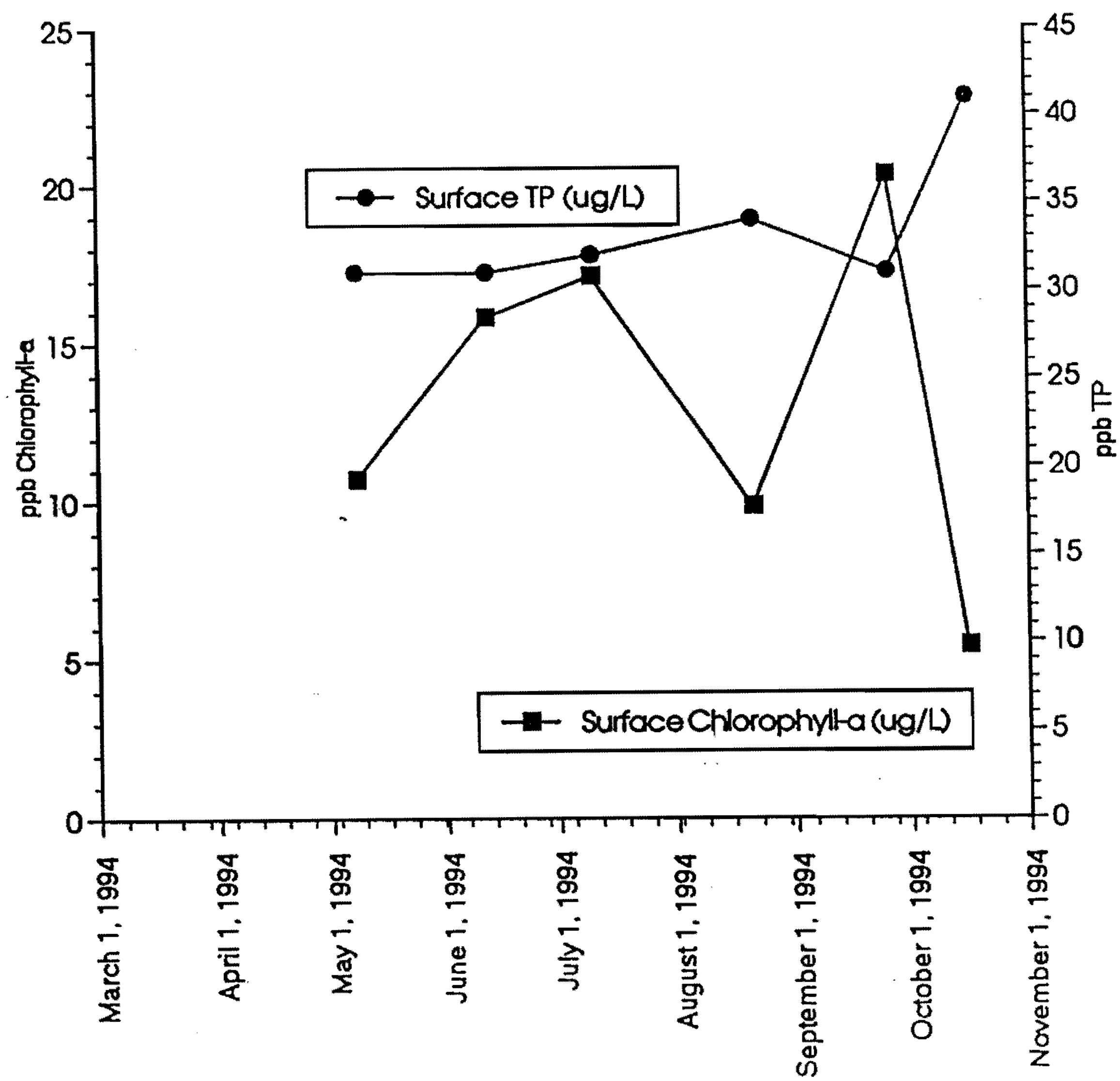


Dowling Lake Chemical Results

Chlorophyll-a and Total Phosphorus

Total Phosphate

Total phosphate (TP) for Dowling Lake was also stable throughout the sampling period, ranging form 31 to 41 ppb. The mean surface TP was 33.3 ppb, which results in a Carlson's TP-TSI of 54.6. This TSI results in a classification of "eutrophic" for Dowling Lake. Hypolimnetic TP was also comparable with surface values, ranging from 26-46 ppb. This is presumably due to the lack of an established thermolcline and a weak anoxic zone during the sampling period, minimizing the mobility of phosphate from sediment. Levels of ortho-phosphate determined by C.J. Owen and Associates during the sampling period were below the detectable levels of 2 ppb. TP remained stable during periods of rapid increase in algal biomass, suggesting that most phosphate determined as TP was unavailable at thatr moment sampled, presumably bound intercellularly in algae and any introduction of ortho-phosphate is utilized rapidly by the growing algal biomass. This dada suggest a system that is limited by phosphate and/or nitrogen. The relationship of TP to chlorophyll, and in turn algal biomass, is expressed in the following plot:

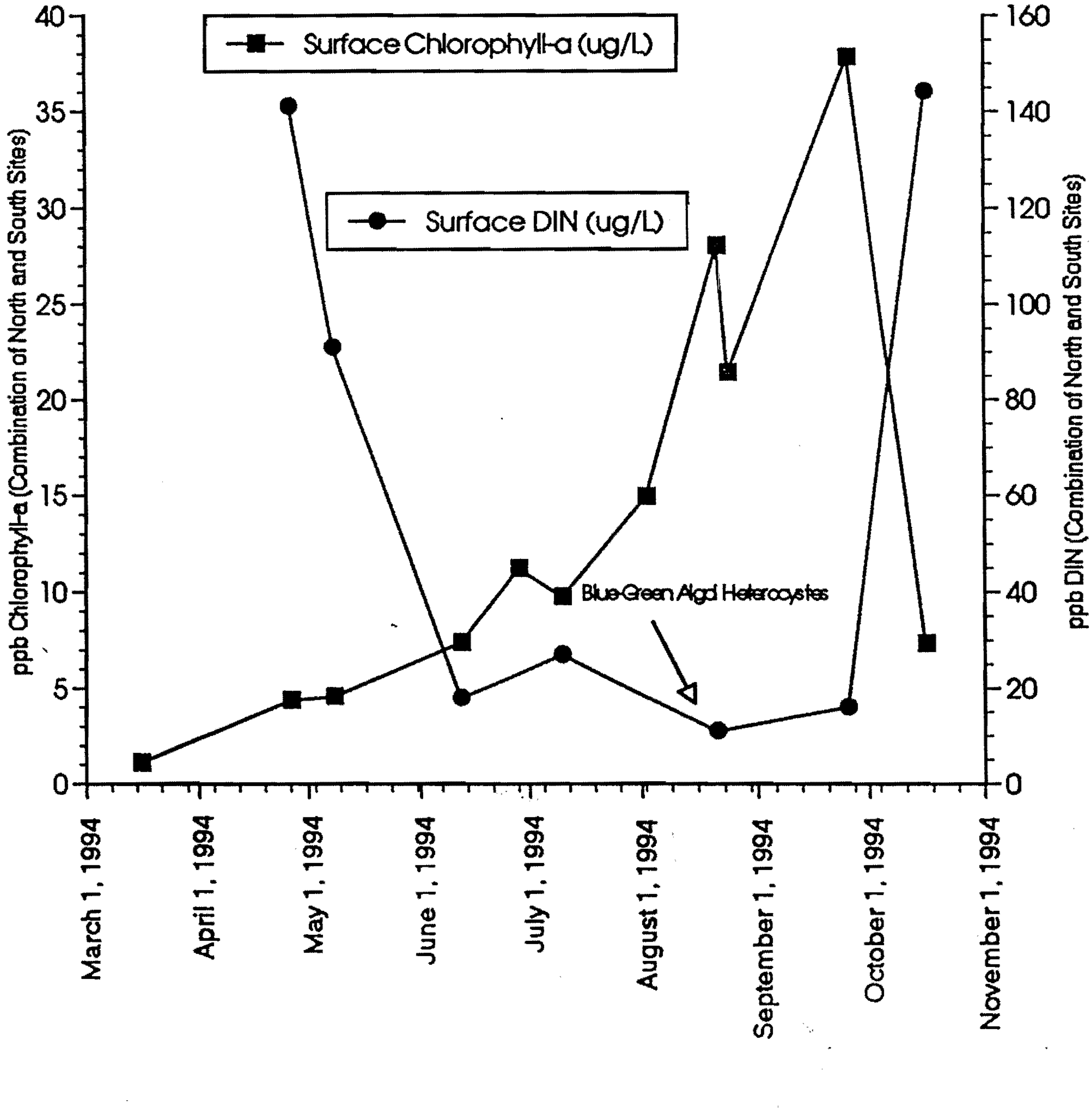


Dissolved Inorganic Nitrogen

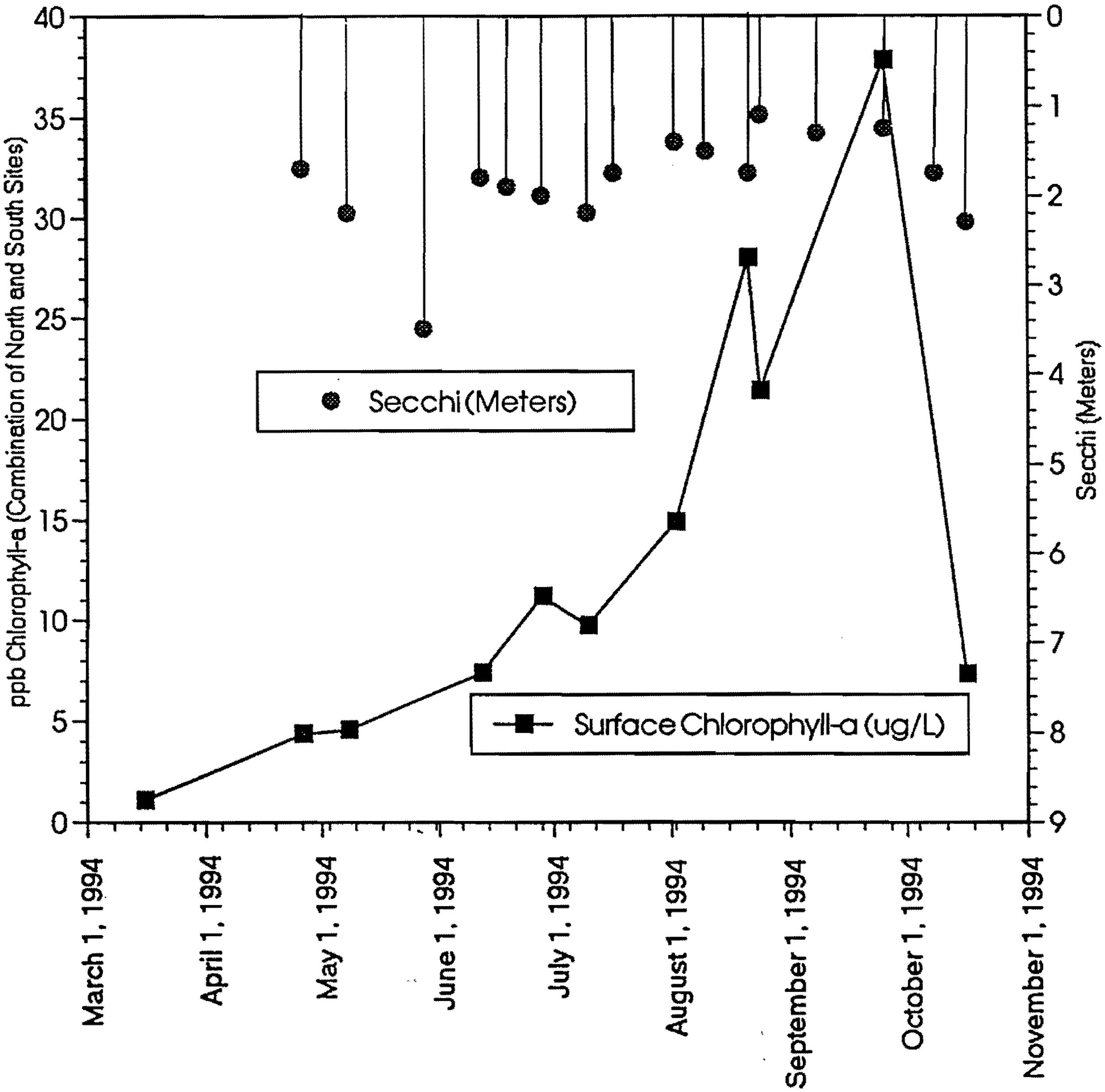
Dissolved Inorganic nitrogen (DIN) data from Amnicon Lake was low, with the highest levels found in the may hypolimnetic sample at 140 ppb. Mean DIN levels for Dowling Lake, including epilimnetic and hypolimnetic samples was 60.1 +/- 62.5 ppb. A rapid decline of both NO3+NO2 and NH4 to below dectection at the surface occurred during periods of rapid algal growth. This resulted in the formation of heterocystic blue-green algae.

DIN:TP Ratios

DIN:TP ratios ranged from .36 in September to 3 in October. Mean summer DIN:TP ratio was 0.74 +/- 0.36. This suggests a system limited by nitrogen. A plot of the relationship of Chlorophyll to DIN follows:



Secchi depths for Lake Amnicon ranged from 3.5 meters to 1 meter. Mean secchi depth for the entire sampling period was 1.9 meters (n=28) and for summer sampling 1.8 meters (n=18). This results in a Carlson's S-TSI of 51 for the entire data set and 52 for summer readings. This TSI indicates a lake eutrophic in nature. The results from the chlorophyll and secchi data can be found in the following plot:



Total Phosphate

Total phosphorus (TP) for Lake Amnicon was stable throughout the sampling period, ranging from 18 to 27 ppb. The mean surface TP was 23 ppb, which results in a Carlson's TP-TSI of 47. This TSI results in a classification for Lake Amnicon as (late) mesoeutrophic to (early) eutrophic. This value is consistent with historical values for Amnicon Lake. TP also remained relatively low in the hypolimnion of Lake Amnicon, presumably due to the lack of an established anoxic zone. Levels of ortho-phosphate determined by C.J. Owen and Associates during this project were consistently below the level of detection of 2 ppb for the surface waters of Amnicon Lake. Furthermore, there was not a significant decline in TP as a result of algal blooms in August and September. These data suggest that most phosphate, measured as TP, in the system is redistributed into algal biomass making it unavailable for continued growth were any phosphate entering the system as ortho-phosphate is immediately used by the growing algal biomass. These data further suggest a system that is limited by phosphate or co-limited by phosphate and nitrogen.

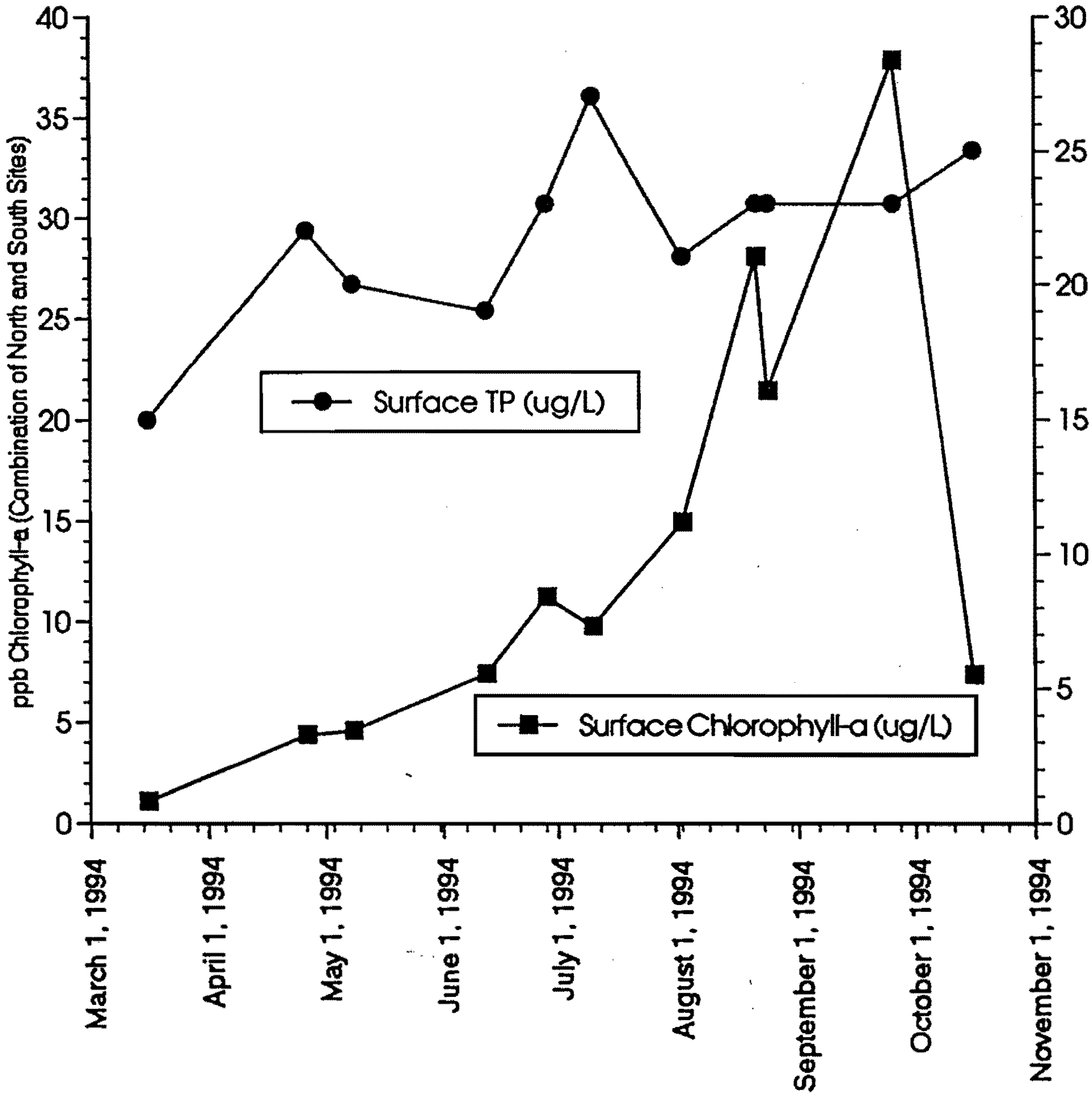
Chlorophyll and Secchi

Chlorophyll results for March through May were low, typically below 5 ppb. In June, chlorophyll rapidly increased from 7 ppb to over 30 ppb in September. Mean summer (May-September) chlorophyll was 16.75 ppb (n=8). This value results in a Carlson's C-TSI of over 58, indicating a lake that is eutrophic in nature. In ecoregion terms, this value is more typical of lakes found in the North Central Hardwoods ecoregion, south of Amnicon, than in the Northern Lakes and Forests ecoregion, the typical ecoregion type of Lake Amnicon (Heiskary and Wilson 1990). These high chlorophyll readings also correlate to the high algal biomass found in the phytoplankton sampling performed by C.J. Owen and Associates.

Lake Amnicon Chemical Results

Chlorophyll-a and Total Phosphorus

Results indicate no difference in surface total phosphorous and in chlorophyll-*a* for the south v.s. the north site of Lake Amnicon. These data were combined to generate the following plot:



Amnicon and Dowling Water Column Nitrogen Characterization

The most recent data on the dissolved inorganic nitrogen (DIN) pool (nitrate+nitrite + ammonium) from the DNR-Long Term Trend Lakes data is limited to spring sampling. However, the data does indicate low DIN for Amnicon ($\leq$ 150 µg N/L during spring sampling), when DIN should be maximal due to spring runoff and lake overturn. If an estimate of the depletion rate of this N-pool is calculated (assuming no external input of N), DIN depletion would occur approximately 8 days after maximum concentration:

Mesotrophic Primary Production (PPr)≈ 25mg Carbon/m^3•hr (Wetzel 1975)
Maximum Mid-Summer Day Length ≈ 10 hr/Day
Total PPr per Day ≈ 250 µg Carbon/L/Day (Conservative)
Assume 40% Rh :
Net PPr ≈ 150 µg Carbon/L/Day
Carbon/Nitrogen Uptake Ratio ≈ 7:1 (Redfield Ratio-1958)
Nitrogen Uptake ≈ 21µg Nitrogen/L/Day
ΔT = 8 Days to deplete DIN pool.

The major objective in nitrogen characterization of the water column of Amnicon and Dowling was to:

1) determine if the systems are co-limited with respect to nitrogen and phosphorus (important in developing control mechanisms for limiting nutrient input);

2) determine if a depletion of DIN in mid-summer was associated with changes in algal community structure, with DIN depletion corresponding to the formation of scum forming (N_2-fixing) blue-green algal blooms;

3) assess the possible anthropogenic influences (septic/lawn fertilization) on DIN inlake dynamics, given the highly mobile nature of DIN with respect to phosphorus.

Water Column Chlorophyll-*a*, Secchi Depth, Total Phosphorus and Dissolved Inorganic Nitrogen Characterization

Amnicon Lake

The ongoing DNR-Long Term Trend Lake Monitoring Program has a systematic sampling regime for water column phosphorus and chlorophyll-*a* characterization. The major objective for this study, with respect to phosphorus and chlorophyll-*a* determination in Amnicon, was to:

1) assess if spatial differences in total phosphorus and chlorophyll-*a* concentrations exist in the isolated, densely vegetated, southwest corner of Amnicon vs. the historical DNR sampling site (important to assess possible nutrient influences effecting this portion of the lake).

Dowling Lake

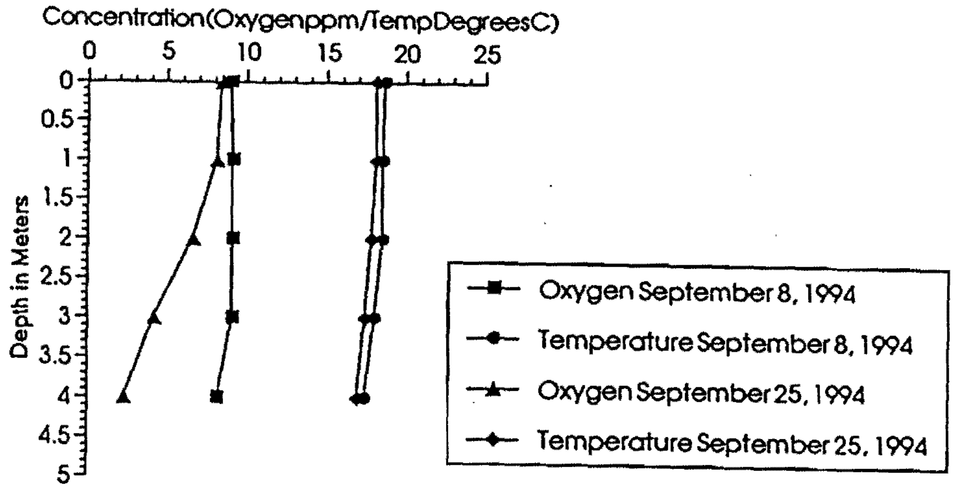
The major objectives for this study, with respect to phosphorus and chlorophyll-*a* in Dowling Lake, were to:

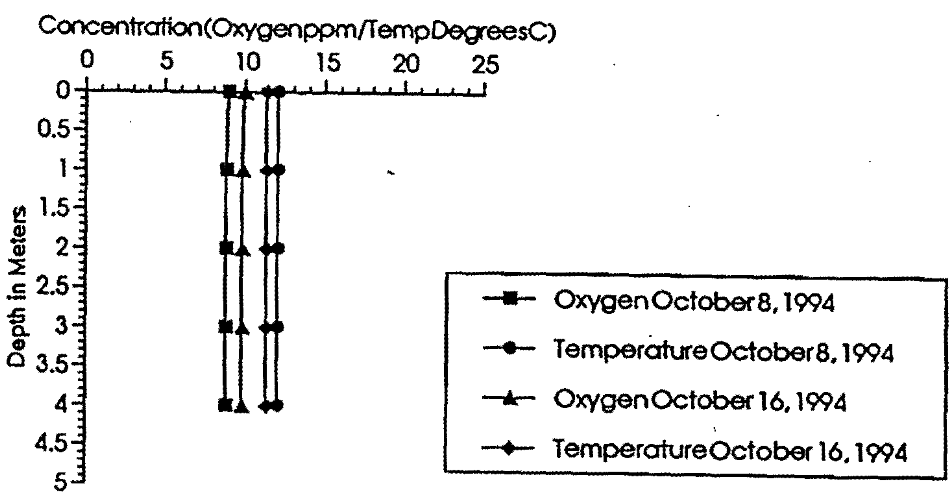
1) Establish a baseline data set for phosphorus and chlorophyll-*a* in Dowling Lake;

2) use the phosphorus data in the determination of nutrient ratio indices to determine limiting nutrients;

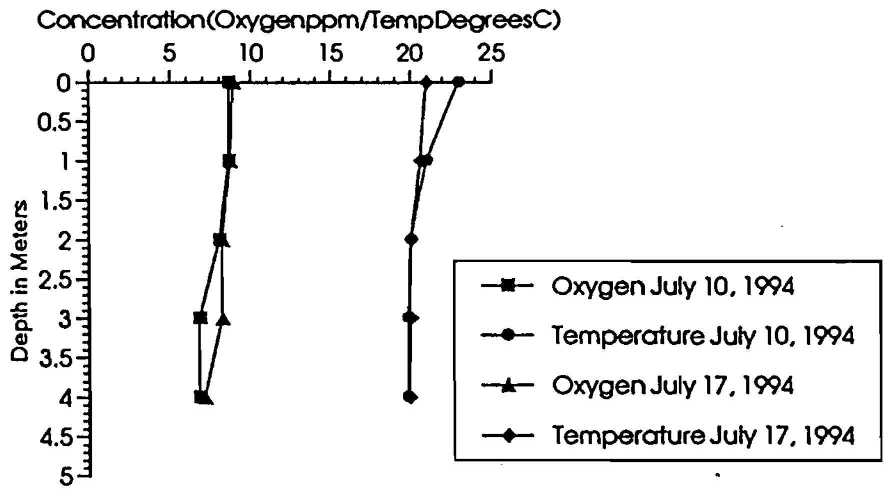
3) use these data to determine current TSI's for Dowling Lake.

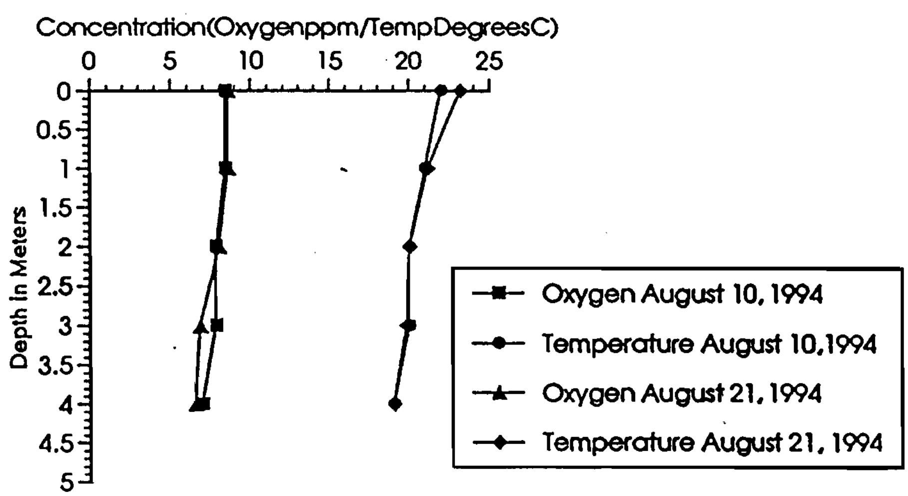
Dowling Lake Dissolved Oxygen and Temperature Profiles Cont.



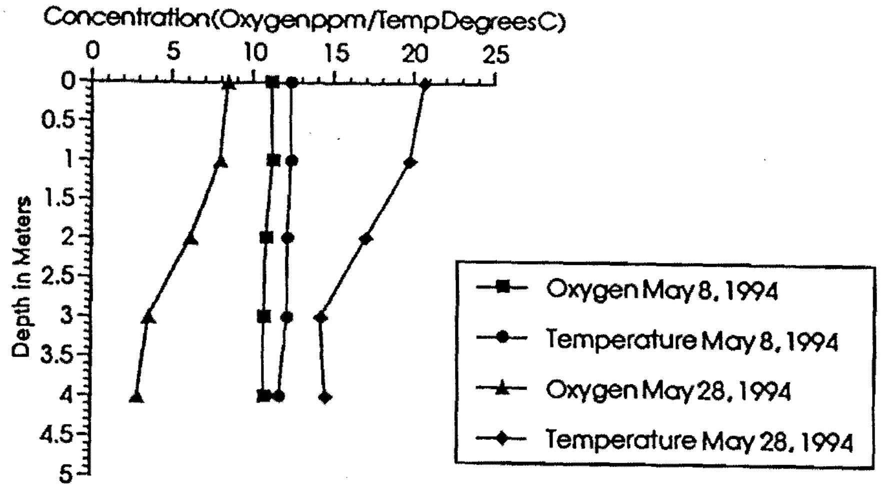


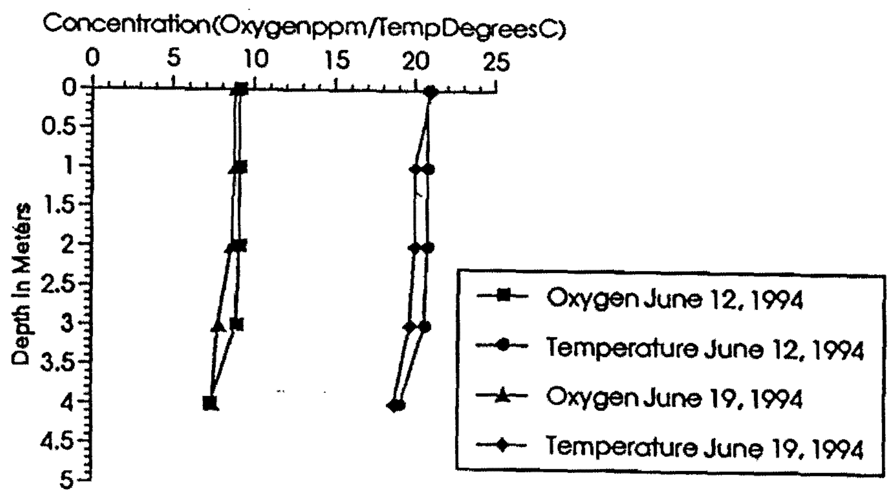
Dowling Lake Dissolved Oxygen and Temperature Profiles Cont.





Dowling Lake Dissolved Oxygen and Temperature Profiles

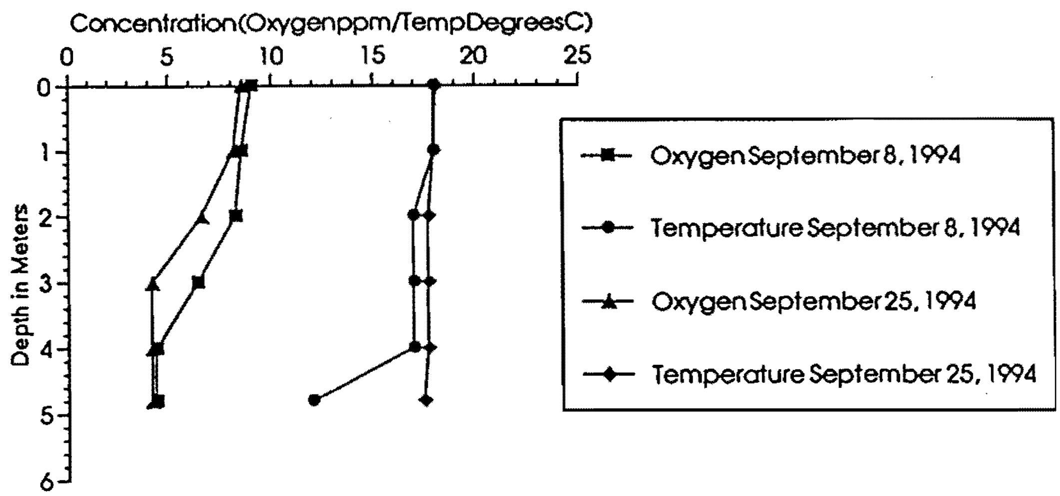


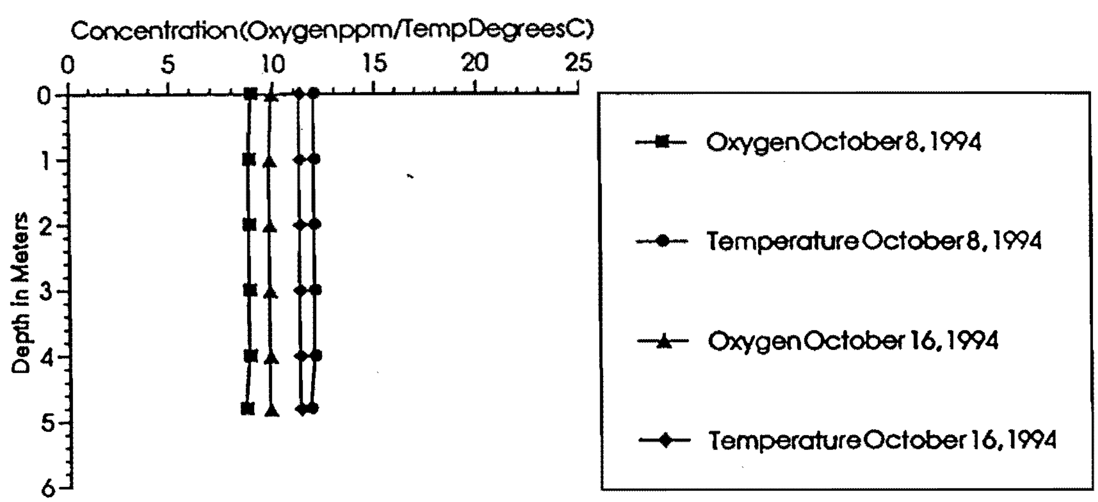


Dowling Lake Dissolved Oxygen and Temperature Results

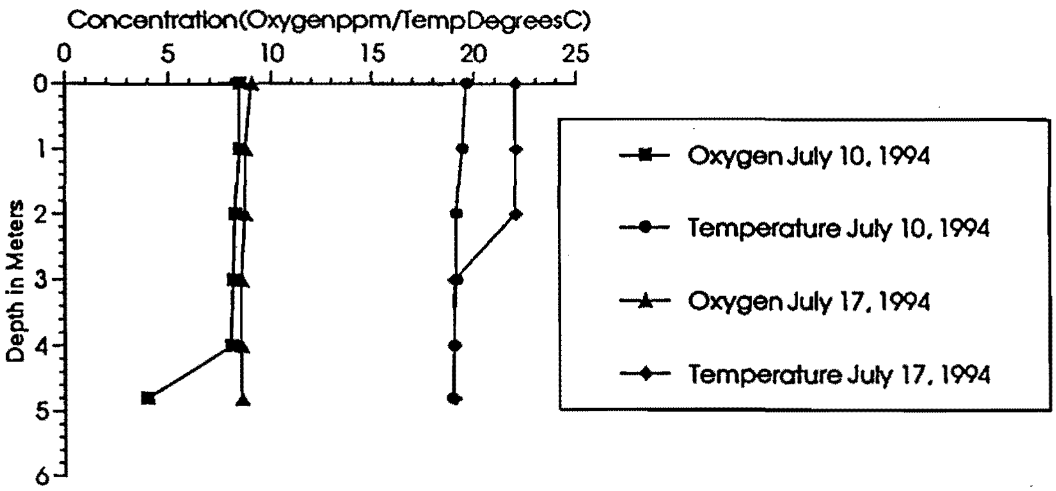
Dowling Lake contained dissolved oxygen concentrations at or above saturation for the sampling dates. Temperature also was isothermal throughout the sampling period. These conditions are the result of the shallow nature of the lake, allowing wind mixing down to the hypolimnion. Again, earliest sampling dates were in May, and further investigations need to be performed on oxygen dynamics during the winter period.

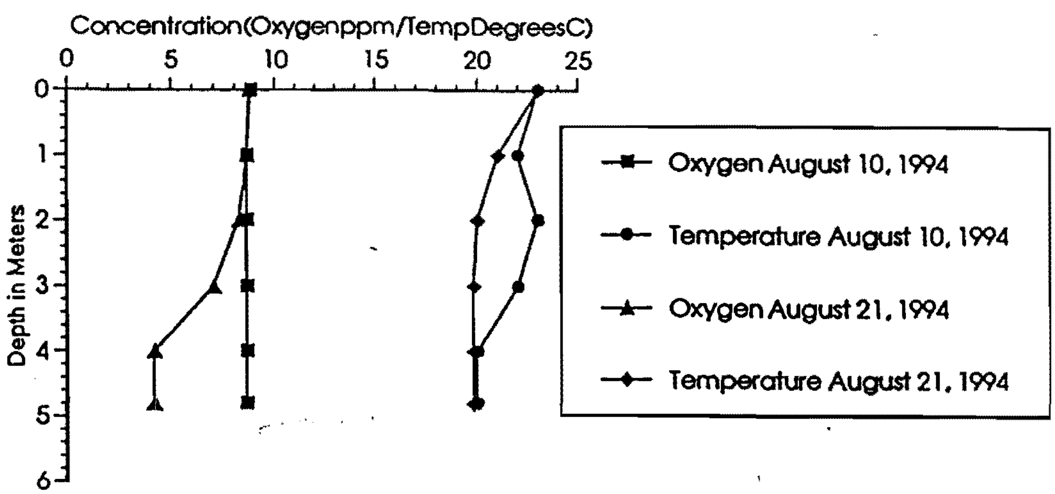
Lake Amnicon South Site Dissolved Oxygen and Temperature Profiles Cont.



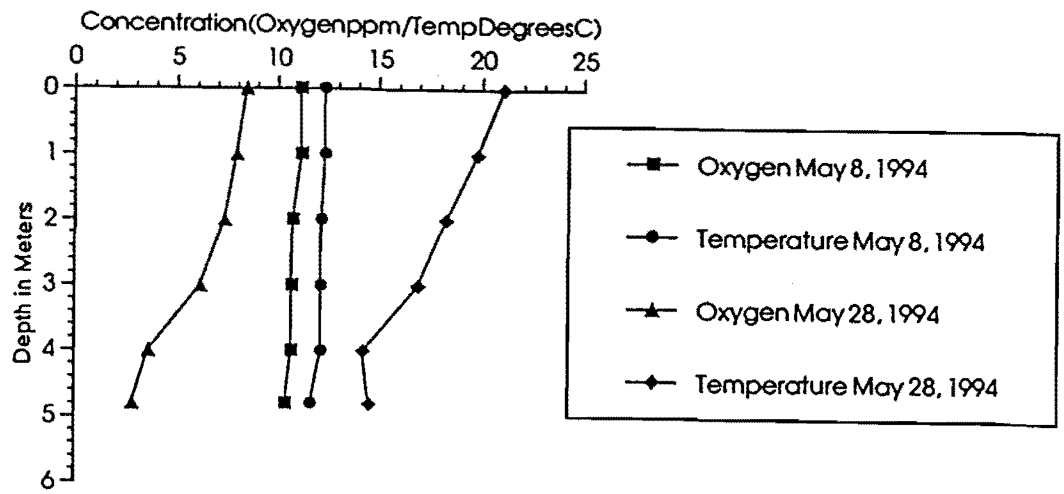


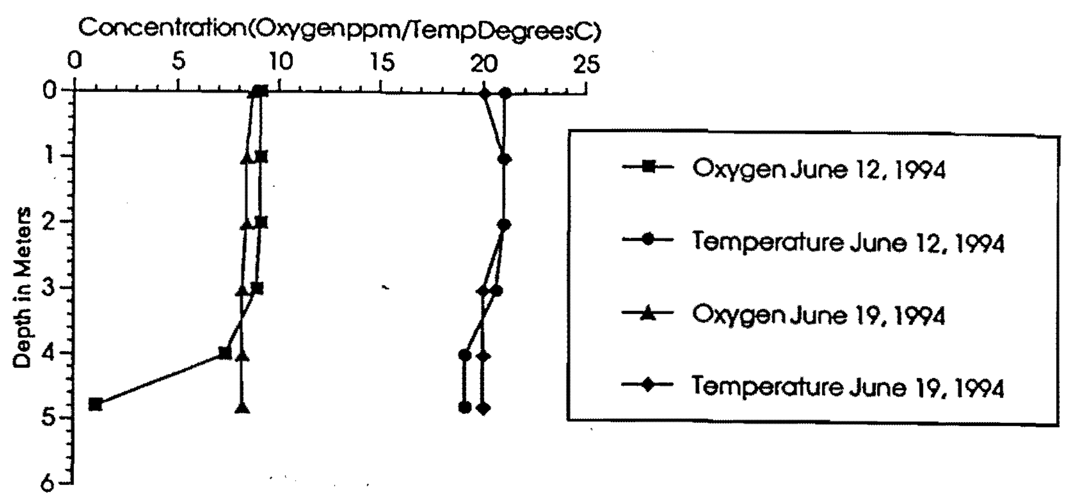
Lake Amnicon South Site Dissolved Oxygen and Temperature Profiles Cont.





Lake Amnicon South Site Dissolved Oxygen and Temperature Profiles



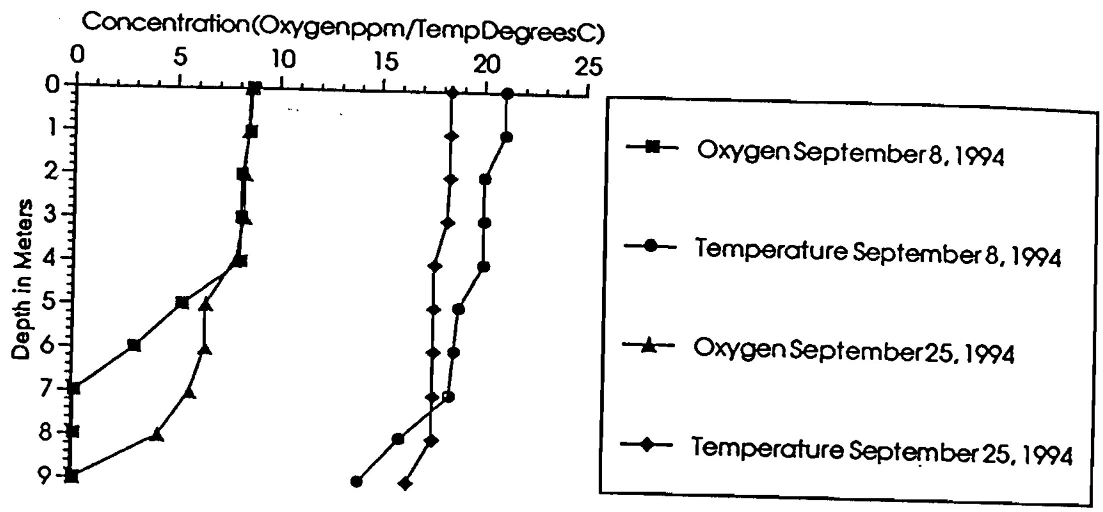


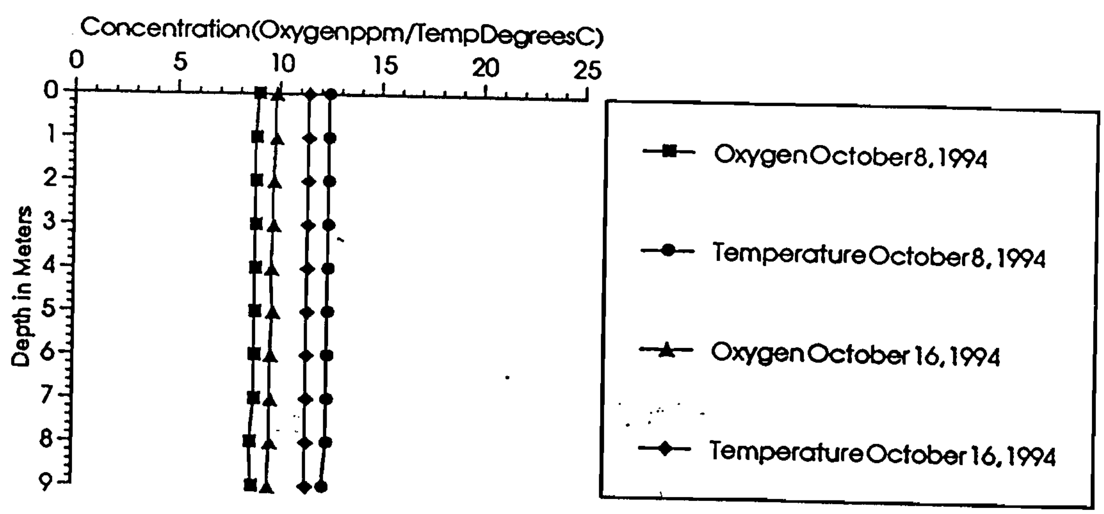
Lake Amnicon South Site Dissolved Oxygen and Temperature Results

Results form the south site of Lake Amnicon indicate high oxygen conditions throughout the sampling dates. Super-saturated conditions did show up in lake July and persist until September, an indication of a high rate of production and wind mixing. This site remained isothermal for the duration of the sampling. This is a result of the shallow nature of the site and its location in a restriction of the lake near the outflow, resulting a high rate of wind mixing and relatively high flow.

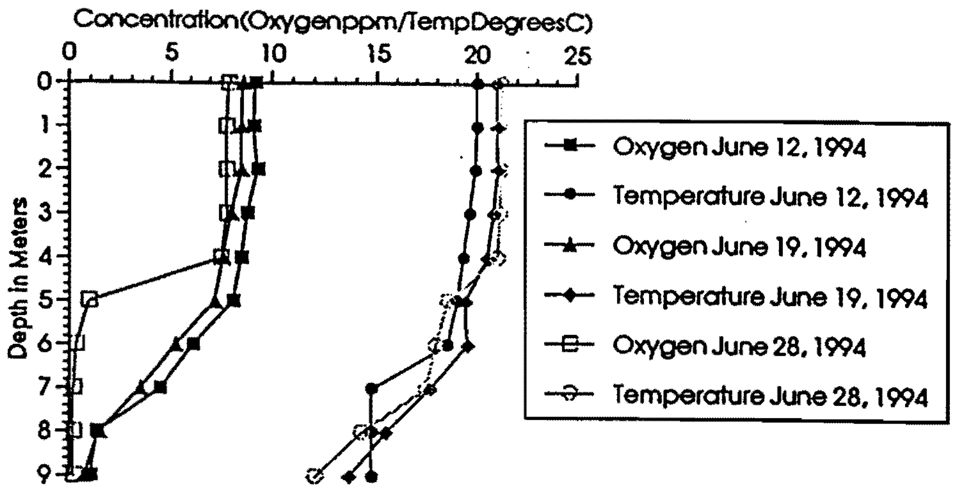
Data does not exist on how this portion of the lake reacts to high organic loading from the summer production. Because of its shallow nature it should, however, be monitored.

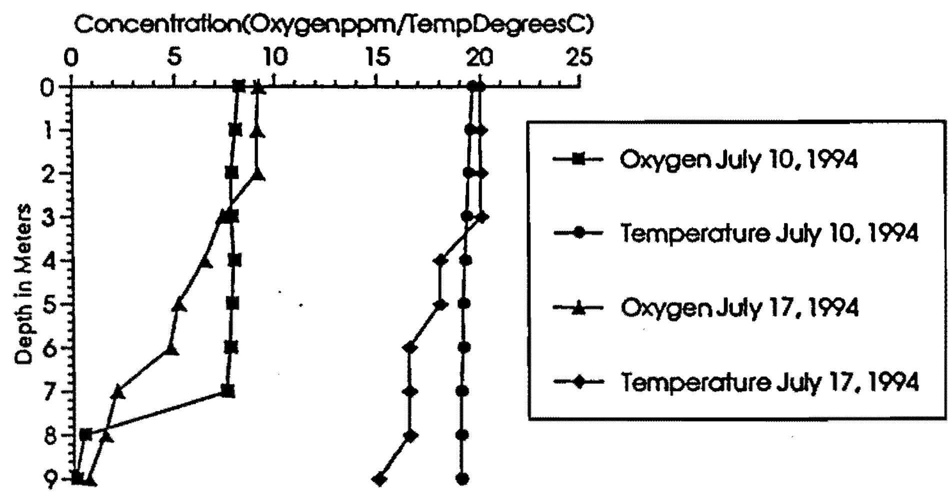
Temperature and Dissolved Oxygen for Lake Amnicon Cont.

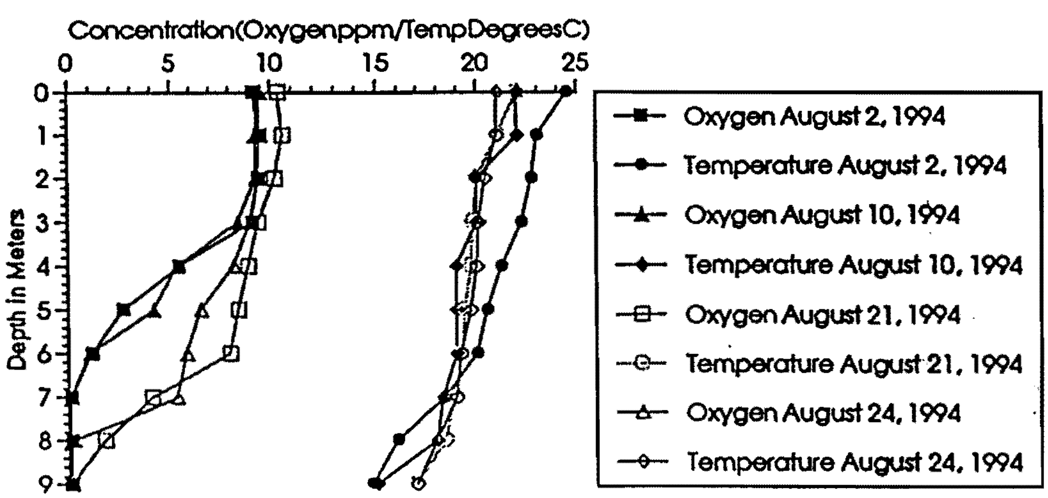




Temperature and Dissolved Oxygen for Lake Amnicon Cont.







Lake Amnicon Dissolved Oxygen and Temperature Results

Oxygen and temperature readings taken through 16" of ice on March 16, 1994 by the Wisconsin DNR, indicates a system that is isothermal, with surface DO readings of 6.0 mg/L at 2.2°C (this is approximately 50% saturation), with DO concentrations dropping to below 1.1 mg/L at 4 meters and continuing to below 0.2 mg/L to a depth of 9 meters. Dissolved oxygen for this sampling date was of some concern because of the large layer of anoxic water between 4 to 9 meters, with less than 50% oxygen saturation in the surface water. Although rates of decomposition are greatly reduced during winter periods, with low rates of metabolism by decomposers, the process (along with oxygen consumption by fish and other organisms) sufficiently reduced the DO in the hypolimnion of Lake Amnicon to levels that may, in the future, result in fish stress or a fish kill. This rate of oxygen depletion is directly related to high rates of summer and fall epilimnetic primary production.

The April 26 sampling was performed during spring over-turn as indicated by isothermal conditions and oxygen saturation through out the water column. DO readings were greater than 10 mg/L from surface to bottom (greater than 90% saturation).

May 8 sampling indicated a system showing signs of surface water warming but still experiencing complete water column oxygen saturation. May 28 sampling showed rapid warming of surface waters and DO depletion occurring below 4 meters, resulting in the first indication of a classic clinograde profile.

Early June sampling (June 12th and June 19th) showed the same trend with weak thermal stratification and slight oxygen depletion in the hypolimnion. However, the June 28 sampling, indicated rapid oxygen depletion below 5 meters with anoxic conditions from 6 to 9 meters. This was the first indication of anoxia in the hypolimnion since ice-off.

Profiles from the July 10 sampling indicated a disruption in the weak June thermal stratification and a re-oxygenation to a depth of 8 meters. Profiles collected on the July 17 sampling indicated the re-establishment of weak thermal stratification. This of is indicative of a polymictic lake.

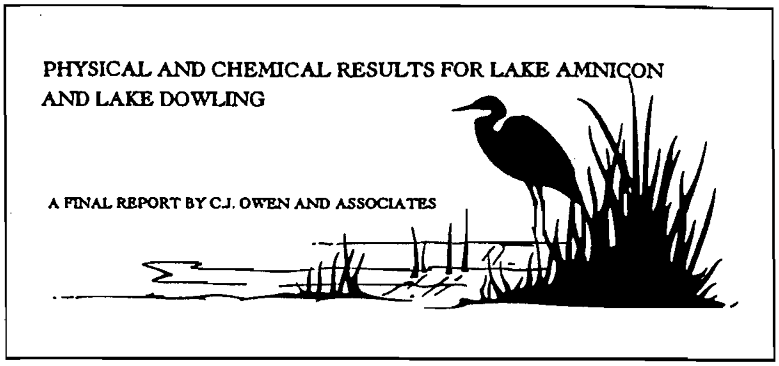
August profiles indicate surface water warming and super-saturation of epilimnetic waters (most likely due to high rates of primary production). Typical anoxia for August samples occurred below 7 meters.

Profiles from September 8 indicate a system still experiencing super-saturation of the epilimnion and weak thermal stratification. Profiles collected on the September 25th sampling indicated a system that was approaching fall over-turn with high DO levels in the epilimnion and hypolimnion. Profiles from October 8th and 16th indicate isothermal conditions and complete oxygenation of the water column.

Results form the north site profiles indicate a system susceptible to wind induced mixing, due to weak thermal stratification. The presence of an anoxic hypolimnion in June is a strong indication of eutrophic conditions. The presence of a super-saturated epilimnion in late July until September is most likely due to high rates of primary production (as indicated by the high chlorophyll reading for these dates). This condition also lends itself to rapid depletion in hypolimnetic oxygen due to high rates of decomposition of organic material produced in the epilimnion.

This high rate of organic production during the summer months and the lack of re-oxygenation in the winter, produces ideal conditions for a expansion of the anoxic layer of water found during the winter months in Lake Amnicon. If increased organic loading occurs, there is a strong possibility of a winter fish kill.

PHYSICAL AND CHEMICAL RESULTS FOR THE 1994 LAKE AMNICON AND DOWLING STUDY



Dissolved Oxygen and Temperatue Profiles

Dissolved oxygen (DO) concentrations range between 0 and 14 mg/L in most Wisconsin lakes. Of concern to lake managers is the summer levels of DO in the hypolimnion. A rapid depletion of DO may indicate high rates of decomposition of organic matter in the hypolimnion which results from a high rate of primary productivity in the epilimnion. A lake with an anoxic (no oxygen) hypolimnion and is thermally stratified by early July, is probably eutrophic. Conversely, a lake with substantial levels of DO (over 5 mg/L) throughout its hypolimnion until late August, despite stable stratification, is probably oligotrophic.

The early development of hypolimnetic anoxiamay result from the following:

- Increased algal growth due to increased nutrient loading causing increased carbonaceous DO depletion.
- Increased NH_4 inputs are exerting their own nitrogenous biological oxygen demand (N-BOD) associated with nitrification.
- Organic matter washing in from shoreline erosion, road runoff, septic fields as well as decomposing organic material are causing the rapid depletion of hypolimnetic oxygen.

In these types of productive lakes a high rate of DO depletion can cause a temperature-DO "squeeze" in which habitat for cool water fish is severely restricted because the necessary thermal habitat is anoxic (Coutant 1984).

The objective for bi-monthly DO and temperature profiles in Lake Amnicon and Dowling was to:

1) determine an accurate date for the onset of hypolimnetic anoxia for both lakes;

2) apply these data in the determination of both areal and volumetric hypolimnetic oxygen deficits as a measure of trophic status and the impact on cool-water fisheries functional habitat.

Because of the behavior of water, many lakes in temperate climates tend to stratify, or form layers, especially during the summer. In spring, just before a lake's ice cover melts, the water near the bottom will be at ~4°C. Water above will be cooler, approaching 0°C just under the ice. As warming occurs and the ice melts, the surface water heats up (increasing in density), sinking and eventually resulting in the entire water column becoming isothermal or uniform at 4°C. When the surface water temperature (i.e. density) is equivalent to the temperature (i.e. density) of the bottom water, complete wind mixing will occur. As the season progresses, surface water then begins to warm (decreasing its density) and eventually this less dense water may not be able to penetrate the more dense (cooler) bottom water. The inverse process may occur in the fall with surface cooling and whole lake mixing. This pattern of spring over-turn, summer stratification and fall over-turn is typical of deeper temperate lakes that develop a winter ice cover. Lakes with this pattern of two mixing periods are referred to as dimictic. Many shallow lakes, however, do not stratify in the summer or stratify for only short periods of time. Lakes that stratify and de-stratify numerous times during the summer are known as polymictic lakes. Both polymictic and dimictic lakes are common in Wisconsin.

The greatest amount of biological activity occurs in the summer when peak photosynthetic activity is driven by high solar radiation. Furthermore, as stated above, most lakes in temperate climates are either polymictic or dimictic, resulting in periods of stratification. During these periods of stratification, epilimnetic oxygen concentration tend to remain high, but in lakes with high productivity, hypolimnetic oxygen drops because it is cut-off from sources of oxygen and by oxygen consumption due to decomposition and respiration. If this condition persists, anoxia will occur.

The following are temperature and dissolved oxygen profiles for Lake Amnicon and Dowling performed by C.J. Owen and Associates and the Wisconsin DNR during the 1994 sampling season.