

**Analysis of Chocorua Lake Water Quality Indicator Data and  
Impact Assessment of Nonpoint Pollution Sources in Chocorua Lake  
Watershed: An Eutrophication Study**

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This compilation of Ji-Seok Kim's research work on Chocorua lake eutrophication problem in academic year of 1997-1998 has been accepted in partial fulfillment of the A.B. degree program in Environmental Studies at Brown University, RI.

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## **Abstract**

Eutrophication, water quality degradation due to nutrition overload, is difficult problem to detect because even a relatively rapid water quality degradation occurs over many years. In first half of my research I concentrated on analyzing 15 years of volunteer water quality data of a small, currently pristine Chocorua Lake in New Hampshire. I attempted to uncover a trend in water quality change by analyzing and presenting the data in various ways. All analysis results showed significant downward trends in water quality indicators and I concluded that a rapid water quality degradation occurred in Chocorua lake over past fifteen years between 1982 and 1996. In later part of my research, I tried to conduct an impact assessment of each nonpoint pollution sources in the watershed to find out which source needs to be regulated in order to prevent further eutrophication of Chocorua lake. Three pollution sources were identified as possible major phosphorus sources based on previous research results and my personal observations. However, I was not able to make a numerical comparison among each phosphorus sources because necessary data did not exist for the time being. Uniqueness of each individual watershed development pattern also made it difficult to extract useful information from other researches and apply them to the Chocorua Lake eutrophication. Nevertheless, my research result should be useful to any reader who is involved in a lake water quality monitoring program.

\* My thesis contains a number of graphical representations of the Chocorua Lake water quality data which should be particularly useful to readers who want to learn how to present water quality indicator data in an effective format.

## **Introduction: Nonpoint pollution, eutrophication and Chocorua lake**

Harmful pollutants are often perceived to be originated from few large ‘point’ sources in urban and industrial areas. For instance, an image of dark smoke stacks of a gigantic factory come to our mind when we think of air pollution sources. Similarly, it is easy to imagine massive dark sewage gushing out of a huge factory pipe when we think of water pollution sources. However our perception of pollution sources can be quite misleading. In fact, a majority of pollution problems are caused by a group of numerous small pollution sources called nonpoint sources. An automobile is a typical example of nonpoint air pollution source. Similarly, road runoff, septic tanks, agricultural runoff and logging operations are the most common examples of nonpoint water pollution sources. These nonpoint pollution sources cause a large percentage of water pollution problems in the U.S. According to the EPA, “nonpoint sources of pollution account for 45%, 76% and 65% of the degradation of estuaries, lakes, and rivers, respectively. ( EPA, 1989 ).” [Palmstorm pg. 1 ] On the other hand, municipal and industrial point source discharge accounts for only 9-30% of the degradation of these water resources. ( EPA, 1989 ). [Palmstorm pg. 1 ]

A water-body can be polluted in many different ways. For example, it can collect excessive amount of heavy metals & organic waste and eventually become toxic and simply inhabitable to lake organisms. Eutrophication is a more common water pollution problem that surfaces when nonpoint pollution sources introduce extra nutrients to a water-body. EPA summarized characteristics of such nonpoint source related eutrophication process in following paragraph on its web site.

Eutrophication is a natural process, but human activities can accelerate eutrophication by increasing the rate at which nutrients and organic substances enter lakes from their surrounding watersheds. Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded streambanks, and similar sources can enhance the flow of nutrients and organic substances into lakes. These substances can overstimulate the growth of algae and aquatic plants, creating conditions that interfere with the recreational use of lakes and the health and diversity of indigenous fish, plant, and animal populations. Enhanced eutrophication from nutrient enrichment due to human activities is one of the leading problems facing our Nation's lakes and reservoirs.

[ U.S. EPA < <http://www.epa.gov/owow/wtr1/305b/trophic.html> > ]

Naturally eutrophication take place over a geological time frame of thousands of years. [ Craycraft pg. 19 ] Thus, an undisturbed lake can stay in a pristine oligotrophic state with clean water quality for thousands of years before its water ages and decays into a less pristine mesotrophic state. For instance, a sediment study at Mirror lake showed that the Mirror lake has been oligotrophic for fourteen thousand years since its birth. [Likens pg. 420 ] However various human activities in a lake watershed are capable of adding a significant amount of nutrients to a lake system and cause it to age and degenerate into a murkier mesotrophic state in as little time as twenty to thirty years. Chocorua lake, NH might be one such lake subjected to human activity related water pollution problem known as ‘cultural eutrophication.’

Chocorua lake is a small sized oligotrophic lake in New Hampshire. It has clear water with minimal biological activity as many other oligotrophic lakes in New Hampshire do. In fact, it was voted as the favorite view on the Rt. 16 in New Hampshire. [ Rt. 16 Corridor Study pg. 46 ] However some signs of cultural eutrophication began appearing in the 1980's and 90's degrading its water quality and rendering its view less beautiful. Visually, lily pads increased their range and density and water became murky during the summers. In addition, algae population more than doubled in the last 18 years.

There is not any large point pollution source in the Chocorua lake watershed. However numerous nonpoint pollution sources exist within the area. First, more than 88 houses are located within the watershed. In addition a paved two lane road (Rt. 16) runs adjacent to the east shoreline. A dirt road runs about 150 yards from the west shoreline. Moreover, some logging operations have been taking place on the northern watershed. All those nonpoint pollution sources are suspected to be adding extra nutrients to the Chocorua lake, causing the lake to become increasingly productive and lose its clean water.

Most lakes have all the necessary components to promote much higher productivity except for two vital nutrients: phosphorus and nitrogen. [ Craycraft pg. 8 ] In other words, limited availability of either phosphorus or nitrogen protects NH lakes from eutrophication. Therefore controlling nitrogen and phosphorus, especially phosphorus, the more limiting nutrient in most NH lakes, should successfully prevent cultural eutrophication. [ U.S. EPA < <http://www.epa.gov/owowwtr1/monitoring/volunteer/spring94/ppresf19.htm> >] Blue green algae are

capable of assimilating gaseous nitrogen from natural atmosphere to a lake ecosystem. [Likens pg. 325 ] and as a practical matter controlling nitrogen supply is almost impossible. [ U.S. EPA < <http://www.epa.gov/owow/wtr1/monitoring/volunteer/spring94/ppresf19.htm> >]

Since nitrogen supply is impractical to regulate, phosphorus is the key nutrient that can be regulated in order to prevent eutrophication problems. A statewide data analysis concluded that 60-70% of total phosphorus originate from nonpoint pollution source. [Chester pg. 13 ] The majority of nonpoint pollution studies have focused on agricultural runoff because phosphorus is a natural component of fertile soil. Erosion of fertile soil from agricultural land and animal manure from farm land have been causing many large scale eutrophication problems national-wide.<sup>1</sup> Fortunately, Chocorua lake watershed does not have any large farmland. Therefore, phosphorus seems to be coming from other sources.

Other nonpoint sources are suspected to be significant sources of phosphorus to small lakes. For instance, the Flint Pond Nutrient Study concluded that about 75% of total phosphorus entering Flint Pond, originates from the septic tanks of 52 houses on shoreline. [ Flint Pond Study pg. 16 ] However, the Chocorua lake volunteer monitoring project coordinator and longtime resident on Chocorua lake watershed, professor Talbot Page suspects that Route 16 runoff might be one of the most prominent phosphorus source to the Chocorua lake. Unnaturally high phosphorus measurement data at Route 16 culverts support his speculation. Also an expert liminologist Jeff Schloss believes that

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<sup>1</sup> 90% of articles in the special nonpoint pollution issue of Conservation were focused on agricultural pollution sources.

Rt. 16 runoff might be the main source of phosphorus as well. Residents are also concerned about proposed logging activities on the northern watershed because logging activities are known to mobilize phosphorus-rich fertile soil to enter streams and stimulate eutrophication of receiving water-bodies. [ Likens pg. 440 ] Lastly, Mirror lake study concluded that temporary unpaved road built for logging operation can be a long-lasting sediment source. [ Likens pg. 440 ] Thus, Chocorua lake road, a dirt road off route 16, might also be a substantial contributor of phosphorus to the lake.

Nonpoint pollution problems are usually much more difficult to mitigate than point pollution problems for several reasons. First, it is very difficult to assess how much each nonpoint source is contributing to the overall problem. In addition, regulating many smaller pollution sources can be significantly more difficult than regulating a single large source. Nonpoint pollution related eutrophication problems seem especially difficult to analyze because pollution sources can not be easily identified and progression of eutrophication can not be easily detected. Fortunately, volunteers have monitored Chocorua lake water quality for past 18 years by collecting indicator data which can be analyzed to reveal its water quality trend history. In addition, they collected 202 phosphorus samples which may help us to identify more prominent phosphorus sources among other suspected sources.

A large amount of potentially useful Chocorua lake data exist such as the water quality data, phosphorus data, aerial photograph, watershed map and etc. Currently, these data are not sufficiently organized enough to give us a clear picture of what has happened in the lake in the past and how it is now. Nevertheless an integrated analysis of existing

data should provide an opportunity to let us achieve following objectives. First, statistical analysis of past water quality data will enable us to identify suspected progression of Chocorua lake eutrophication process. For instance, a significant change in water quality indicators over past 15 years would be interpreted as a strong evidence of cultural eutrophication because such process often take thousands of years in nature. Second, analysis of phosphorus data from various locations of the lake will help us estimate contribution of different nonpoint sources. For instance, higher phosphorus concentration level from a certain inlet would suggest us to focus future study on human activities that take place near that specific inlet. Finally, a close analysis of watershed map and aerial photograph will help us visually identify precise location of weed blooms and each nonpoint pollution sources. Overall, integrated analysis of existing data would help us understand contribution of each pollution sources in the Chocorua lake more thoroughly and suggest what need to be done for mitigation. This study focuses on such analysis of the existing data with respect to findings from previous nonpoint pollution study results.

## Chapter 1 Water quality indicators and their interpretation

Water quality of a lake is usually determined by how productive the lake is as whole, how much plant and algae population it supports in its water. Some water quality indicators are known to effectively indicate overall productivity of a lake. Chlorophyll a concentration level and Secchi Disk Index (SDI) are the two such water quality indicators. For example, Chlorophyll a concentration effectively indicate plant population density of a lake because it measures how much Chlorophyll a pigment, the main plant pigment that exist in every plant tissue, exist in 1 liter of water. [ Craycraft C-1 ] [ Craycraft pg. 11 ] Similarly, SDI also effectively indicate water quality since water is clearer when there is less algae and suspended organisms such as plankton. [ Craycraft pg. 10 ] Water quality can be classified into several trophic states depending on Chlorophyll a concentration level and Secchi Disk Index level. [ Craycraft pg. 19 ]

Indicators	Secchi Disk Index	Chlorophyll a
Trophic states		
Oligotrophic	4m or deeper	3 ppb and lower
Mesotrophic	Between 4m and 2.5m	Between 3ppb and 7ppb
Eutrophic	2.5m and lower	Above 7 ppb

Trophic states [ U.S. EPA < <http://www.epa.gov/owowwtrl/305b/trophic.html> >

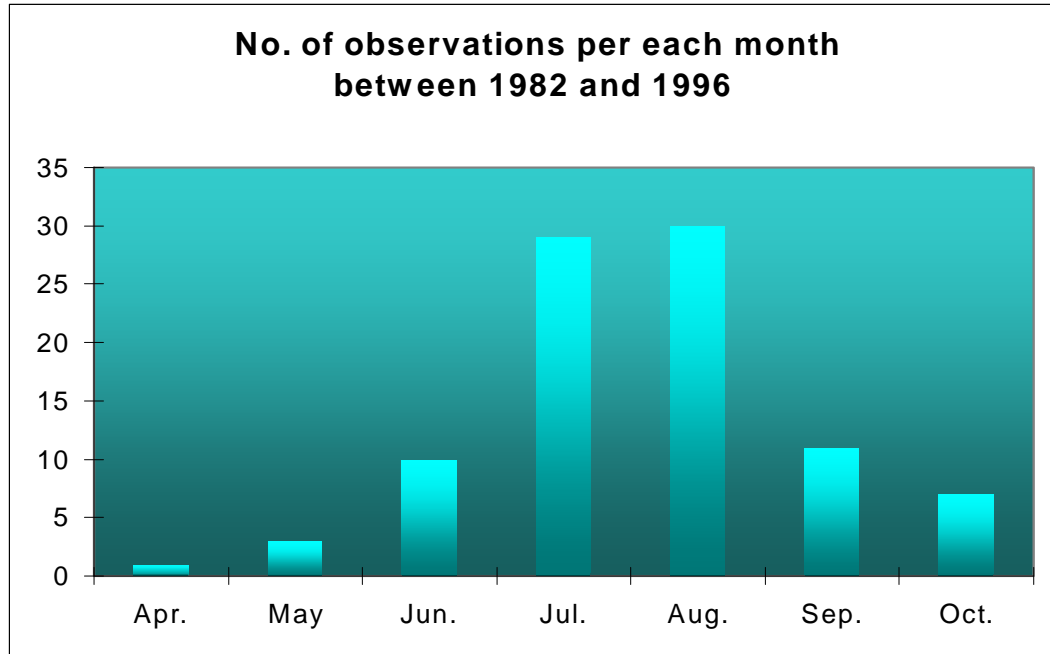
Waters show following characteristics in each trophic states:

- Oligotrophic - Clear waters with little organic matter or sediment and minimum biological activity.

- Mesotrophic - Waters with more nutrients and, therefore, more biological productivity.
- Eutrophic - Waters extremely rich in nutrients, with high biological productivity. Some species may be choked out.
- Hypereutrophic - Murky, highly productive waters, closest to the wetlands status. Many clearwater species cannot survive.
- Dystrophic - Low in nutrients, highly colored with dissolved humic organic matter. (Not necessarily a part of the natural trophic progression.)

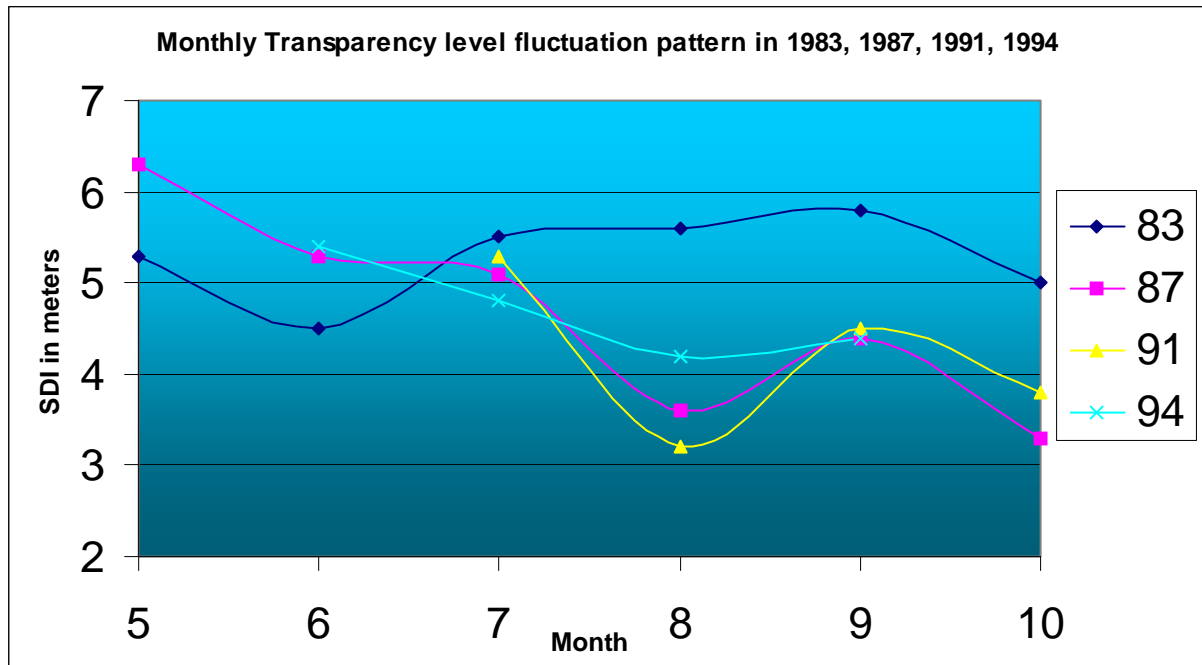
A. Chocorua lake Secchi Disk Index Data Trend Analysis : Transparency level can be measured by dipping a shaded disk called 'Secchi disk' into a lake and measuring how far down it can go before it becomes invisible to the observer. Water transparency level decrease as a lake become less clear with more algae, plankton and various other suspended particles. [ 4. Craycraft, pg.10 ] Thus, decreased transparency can effectively indicate increased biological activity in a lake. Therefore, a sharp decline in transparency level over a relative short period of time can be interpreted as a sign of cultural eutrophication. SDI data has been collected at Chocorua lake for past 17 years by volunteers. Currently available data of 1982 – 1996 was analyzed with various methods in order to identify any trend in water quality and signs of eutrophication.

## 1. Data characteristics



Volunteers made 92 Secchi Disk Index ( SDI ) measurements over 15 years between 1982 and 1996. Number of observations varied from year to year from minimal of 1 observation per year in 1992 to maximum of 11 per year in 1983. Average number of measurements per year was 6.1. Measurements were taken at various time point of a year ranging from April to October. Most measurements, 64% of measurement (59 out of 92) were taken during summer months of July and August.

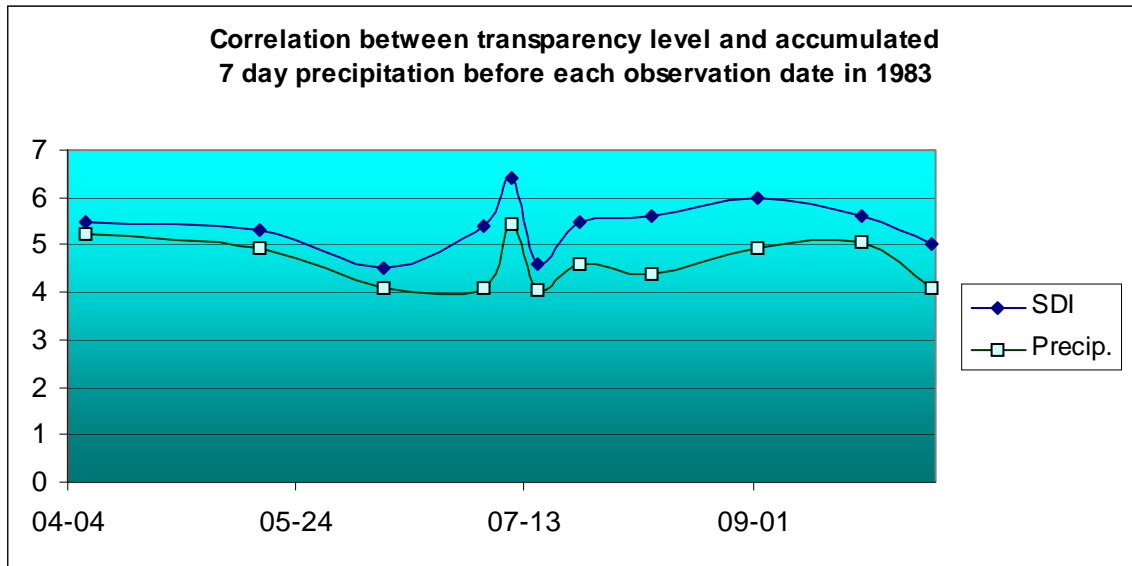
## 2. Trend in transparency level of a typical year



Transparency level in a typical lake tend to decrease toward summer because a lake become more productive during summer as temperature rise and more sunlight become available. Monthly SDI averages of several years show above transparency level fluctuation characteristic at Chocorua lake. It should be noted that fluctuation magnitude became much greater in past years such as 1983 compared to a more recent year of 1991. Assuming there is no significant temperature change between 1983 and 1991, this intensified transparency level fluctuation suggests increased availability of limiting nutrient, phosphorus in the lake. Otherwise, the fluctuation magnitude would have stayed the same in each year since limited supply of phosphorus should effectively limit lake productivity even in a productive warm summer season.

This particular graph shows very low transparency level in October every year. This seemingly unusual sign of high productivity in cooler October seems to be related to characteristics of a particular algae specie called diatoms that thrive in lower temperature of early fall than hot summer. [ Craycraft pg. 15 ] In fact, Diatoms and blue green algae are two main constituents of a typical NH lake aquatic plant community [ Likens pg. 176]

### 3. Precipitation related short term SDI fluctuation



*\* Precipitation data was shifted by 4 inches for better visual comparison.*

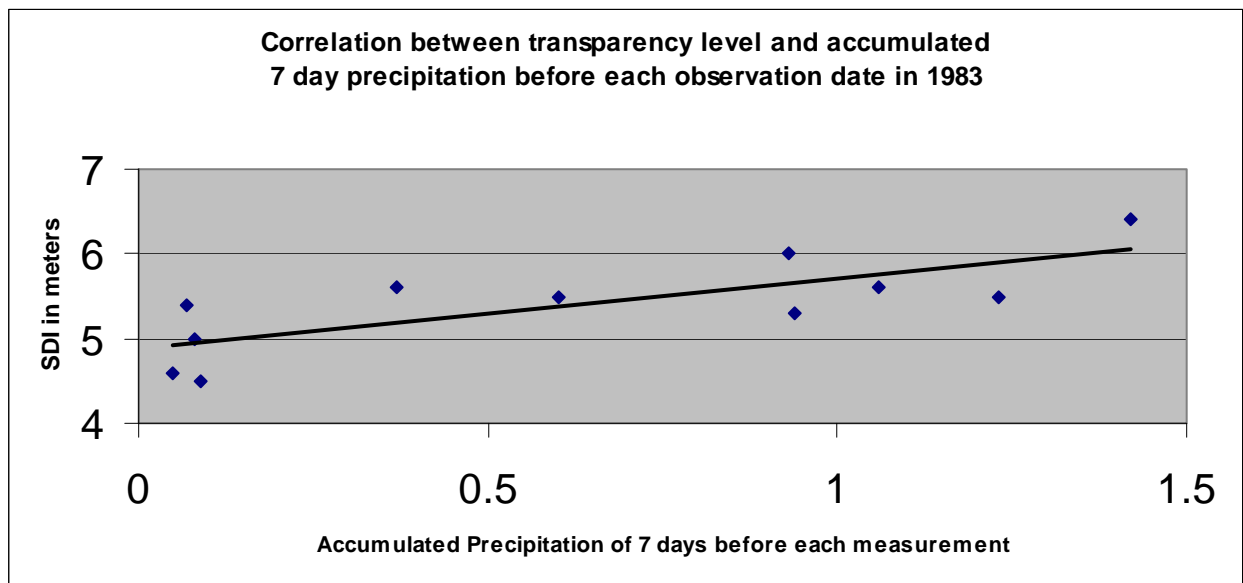
The seasonal transparency level fluctuation can be explained by change in temperature, sunlight availability as well as characteristics of certain algae. In summary, transparency level usually decrease during productive season of summer and increase during other seasons as algae and plankton population decrease. However, it can also fluctuate largely in relatively short period of time as short as a week. For instance, this portion of 1983 SDI data shows a dramatic change in transparency level of Chocorua lake between every week of July.

7-4	7-10	7-16	7-25
5.4	6.4	4.6	5.5

This high magnitude fluctuation seems to be related to precipitation amounts. In fact, above graph shows a strong correlation between accumulated precipitation of 7 days

before the day of each transparency data measurement (AP7BM) and each transparency data point in 1983.

Transparency level seems to increase temporarily after rainy days as precipitation supply clear water to lake and reduce its plant population by dilution and flushing. This indicator data characteristic suggests that some transparency measurements can be unnaturally high if they were taken only several days after a significant amount of precipitation. Consequently, monthly average of only one or two data points per month

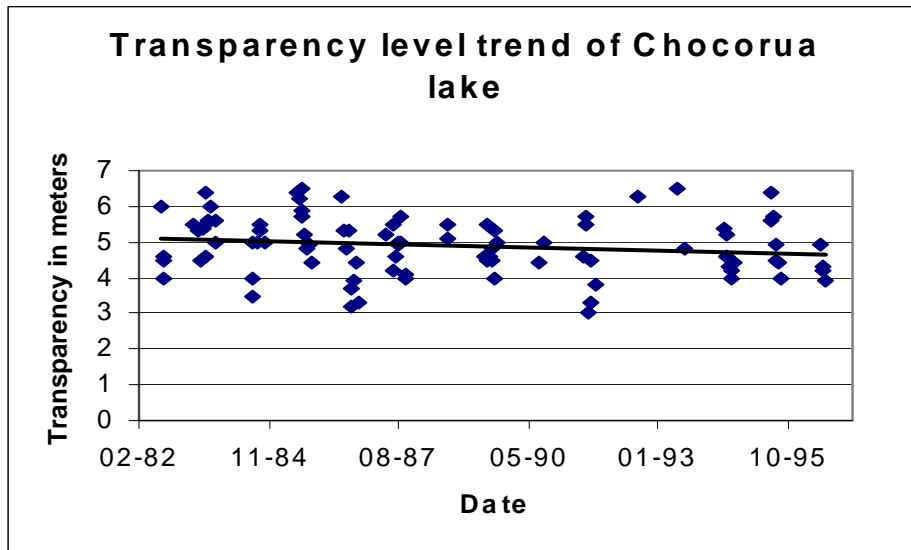


should be interpreted differently since the measurements might be artificially high.

In fact, correlation between AP7BM and SDI data has correlation coefficient of 0.77 as shown on the graph above.

- Note: Correlation analysis between 3, 15, 30, 45, 75 days accumulated precipitation and SDI measurements showed a much weaker correlation.

#### 4. Analysis of SDI data



Chocorua SDI data shows a slight downward trend when all the data points are plotted for analysis. The transparency level shows a decrease by approximately 0.5m over past 15 years.

Chocorua Lake Water Quality Monitoring: 1996 Summary and Recommendation suggests that whole data should be plotted in order to avoid misrepresentation. [Craycraft pg. 3 ] However, I decided to use averages of each year's July + August data for water transparency trend analysis for following reasons.

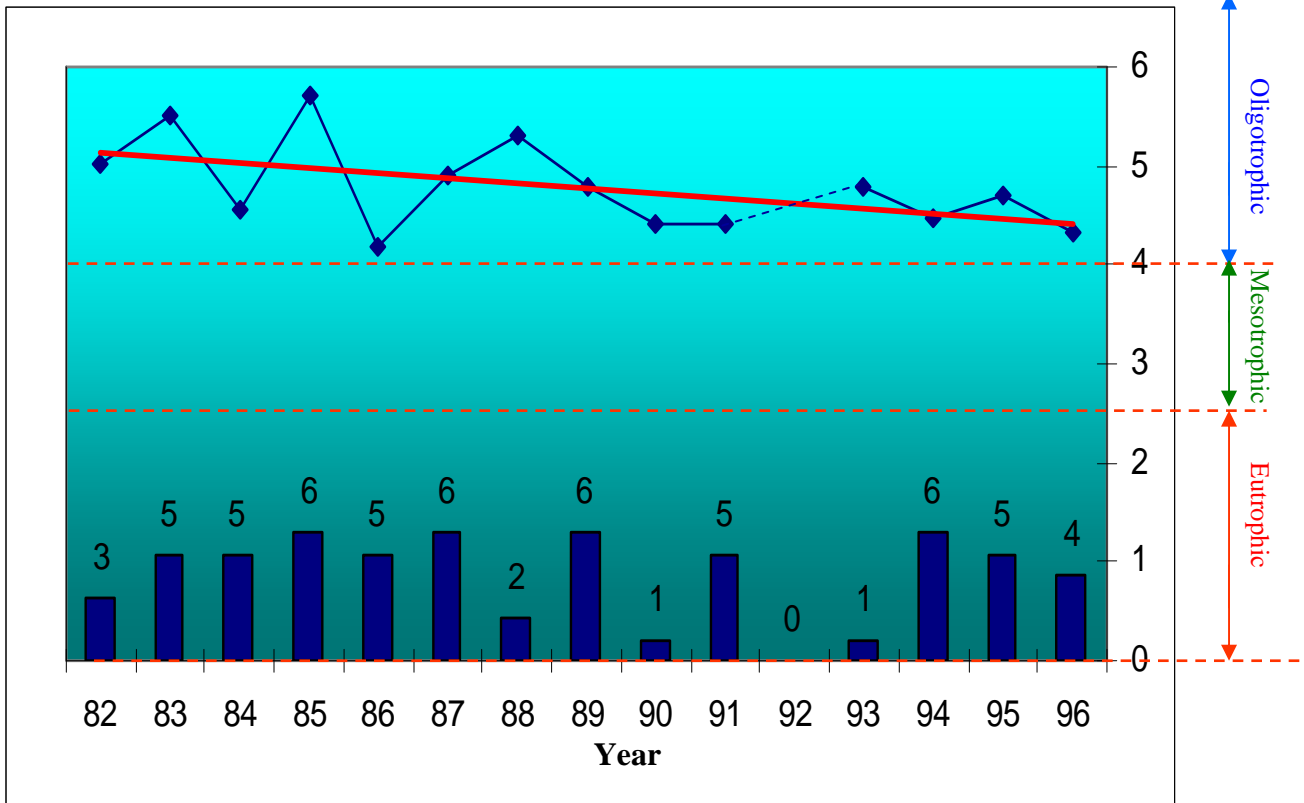
- a. A typical lake productivity is phosphorus limited only during summer. ( In other seasons sunlight and temperature are limiting component for lake productivity. [Likens pg. 88 ]
- b. Number of measurement per non summer month is below 1 per each month.
- c. If one year's data set contains higher number of transparency measurement in non summer season that particular year can be misrepresented as a clean year

even if it contained a very low transparency measurement during the summer season.)

- d. Only summer months have significant number of observation that can offset dilution and flushing effect of precipitation events that temporarily raises transparency level.

Annual average of July + August data trend analysis result shows a slightly sharper decrease in transparency level by 0.7m from 1982 to 1996.

### July & August Average Transparency Level Trend and Number of Observations

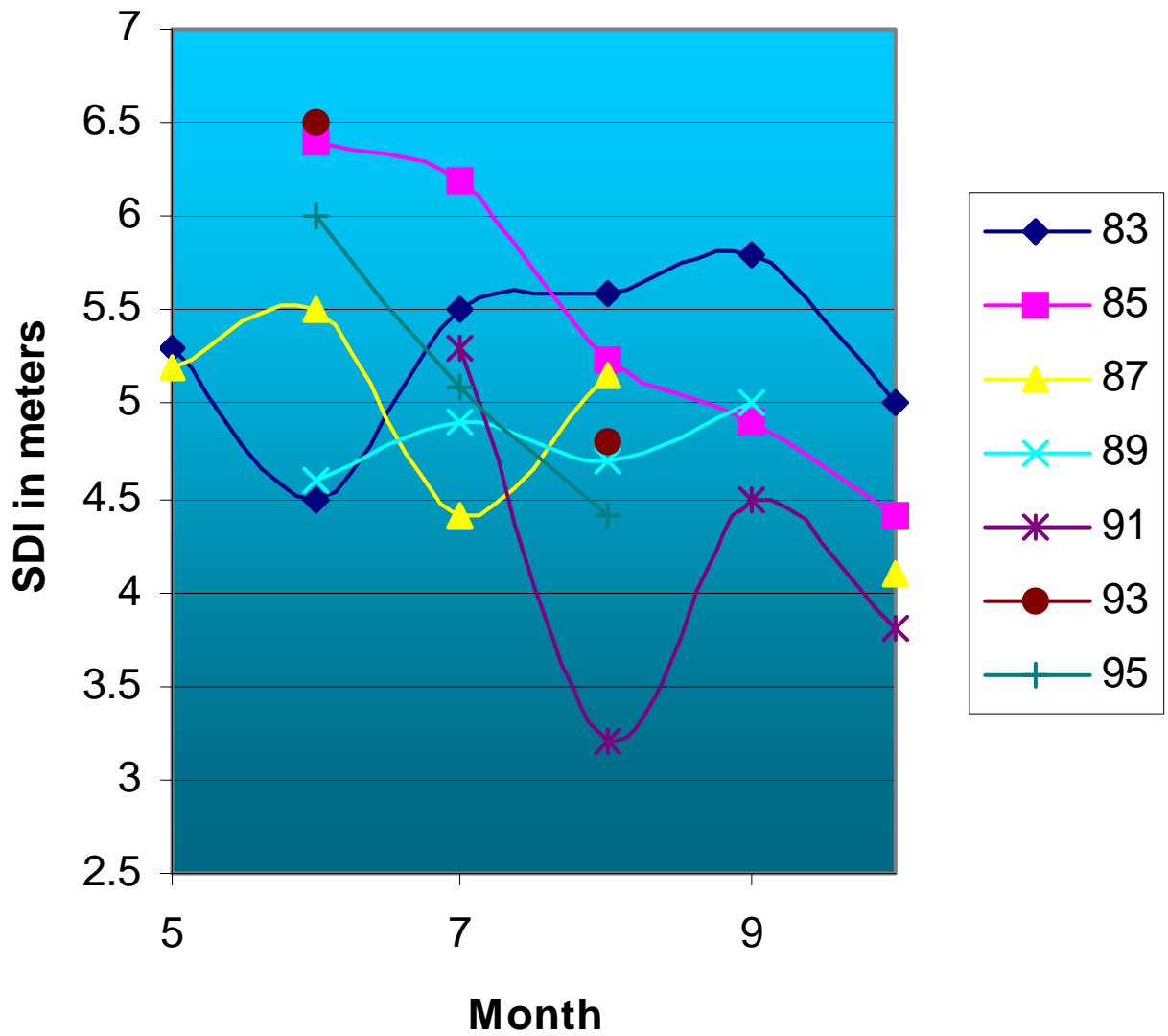


Identical analysis of August data shows a even stronger trend of approximately 1m decrease in transparency level between 1982 and 1996. Moreover, August data trend analysis result shows that Chocorua lake has entered mesotrophic state with transparency level of less than 4m as of 1996. Jeff Schloss of New Hampshire concluded that Chocorua lake water is in a transitional state as of 1996. [ Craycraft pg. 6 ]

\* Certain presentation method of data seem to be more effective in identifying trend.

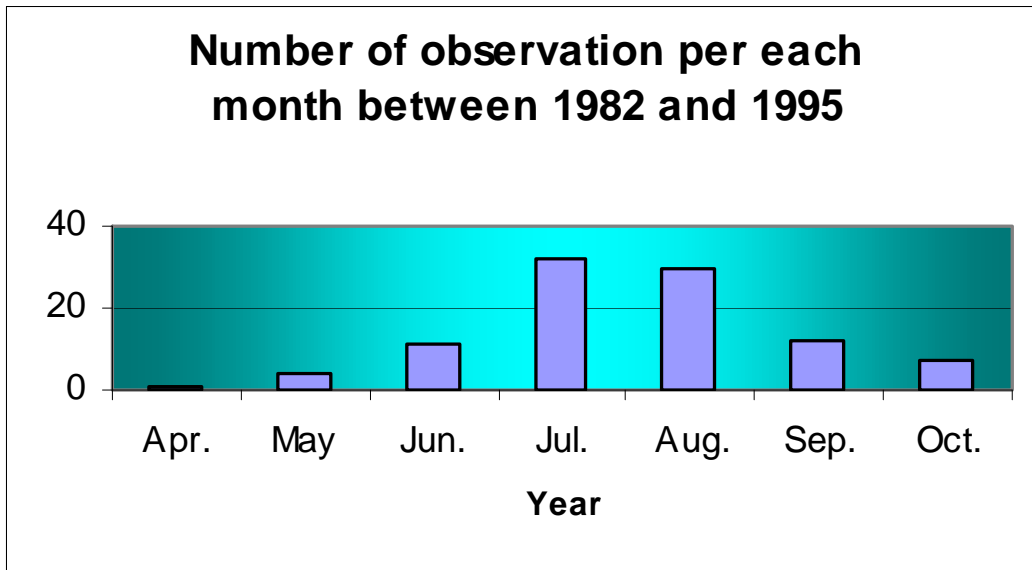
Following graph seem to show an interesting trend. It can be easily seen that transparency in any given month has declined between 1983 and 1995.

# SDI monthly average in 1983-1995



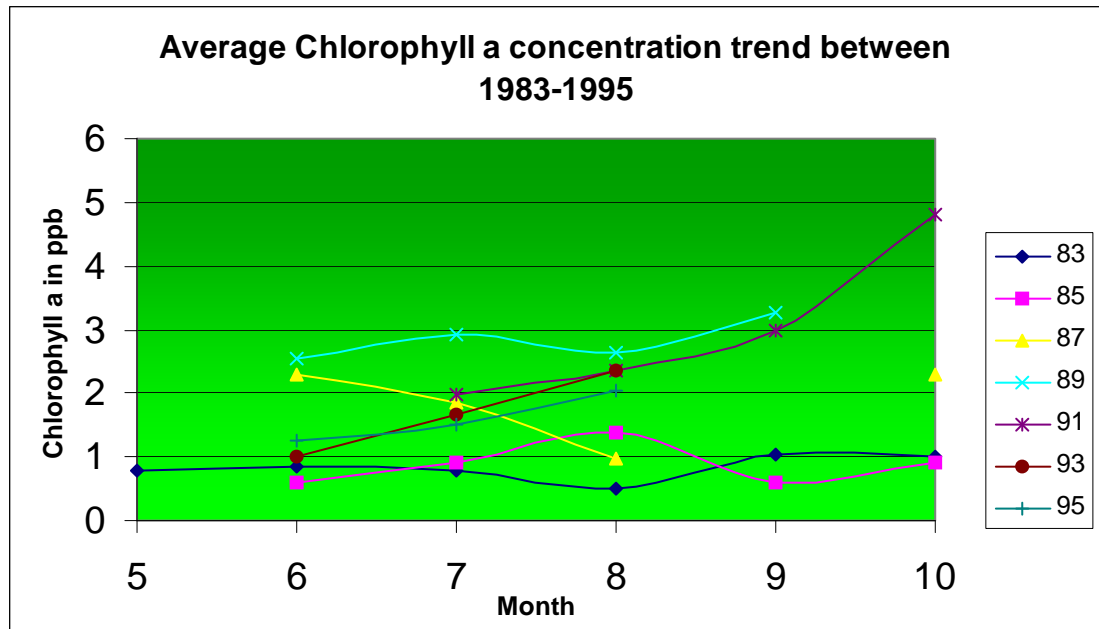
## B. Chlorophyll a index analysis

### 1. Data characteristics



Volunteers collected 97 chlorophyll a concentration measurement data over 15 years between 1982 and 1996. Number of measurements varied from maximum of 14 measurements in 1983 to minimum of 1 in 1992. On the average, 6.5 measurements were made in a typical year. Each measurement was taken between the month of April and October. 62 % of measurements were made in the summer months of July and August.

2. Chlorophyll a concentration level trend in a typical year.

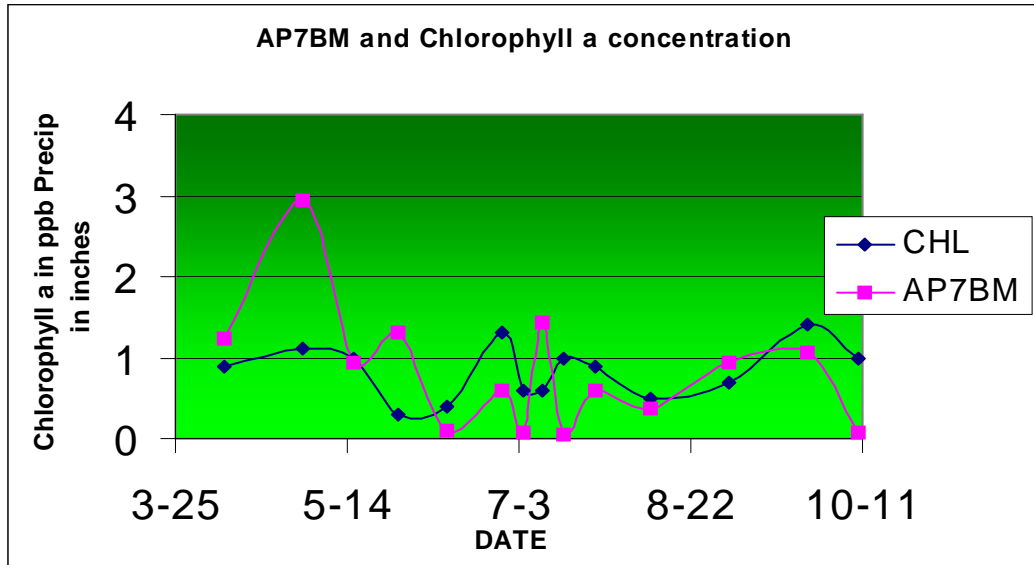


In a typical year, chlorophyll a concentration steadily rise from April to early October. This pattern reflects increasing primary (plant) productivity of a typical lake in a typical year due to increasing temperature and sunlight availability. However this monthly increase pattern from 1.0 ppb in May to 2.2 ppb in October might have been less dramatic if the lake was phosphorus limited. In fact, the increase has been very small in earlier years such as 1983 and 1985.

October Chlorophyll a concentration level is the highest in any given year although average temperature drops from low 70's F down to low 50's F between August and early October. This retained high plant population might be explained by a fact that some algae species, diatoms thrive at lower temperature of early fall.

[ Craycraft pg. 15 ]

### 3. Precipitation related fluctuation



Date	6-28-83	7-4-83	7-10-83	7-16-83	7-25-83
CHL	1.3	0.6	0.6	1	0.9

In 1983 Chlorophyll a concentration fluctuated with a great magnitude in as little time as a week. For instance it dropped by 0.7 ppb between June 28<sup>th</sup> and July 4<sup>th</sup>. This particular decrease in chlorophyll a concentration level seems to be related to a large precipitation event that took place several days before the a measurement was taken on July 4<sup>th</sup>. In fact, Chlorophyll a concentration data shows a strong correlation with AP7BM<sup>2</sup> just as transparency data does. In summary, precipitation events seem to reduce algae and plankton population significantly by dilution and flushing.

Visual correlation between Chlorophyll a and AP7BM seem significant. CHL a rise and fall as AP7BM increase and decrease. However, the magnitude of their change differ by a magnitude. As a result, mathematical correlation coefficient was

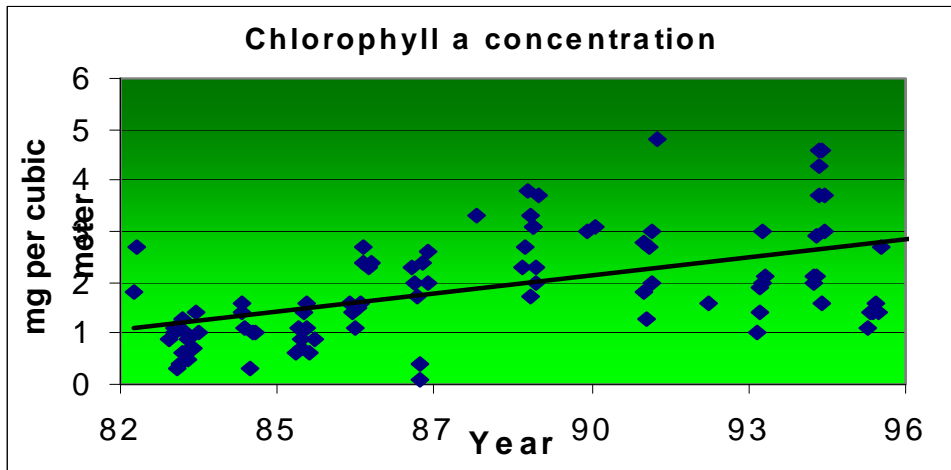
<sup>2</sup> accumulated precipitation of 7 days before the day of each data measurement

extremely low, 0.18. By contrast, the correlation coefficient between AP3BM and Chlorophyll a level was much higher, 0.54. Correlation coefficient with other AP#BM were all below 0.2. This result suggests that the correlation between Chlorophyll a and precipitation should be analyzed more in detail since a collection of light rain events in total of 3 inch over 7 days must have different effect on the lake compared to a heavy rain of 3 inch in just one day. However, such detailed analysis could not be performed in the given time frame.

Close analysis of the data suggests that Chlorophyll a data of a month with low number of measurements can be artificially low. For example, July average of 1983 chlorophyll a concentration could have been calculated as 0.4 ppb if only one measurement was taken on June although the actual average was 0.85 ppb. In fact, the average might have been much higher if more measurements were made in that month.

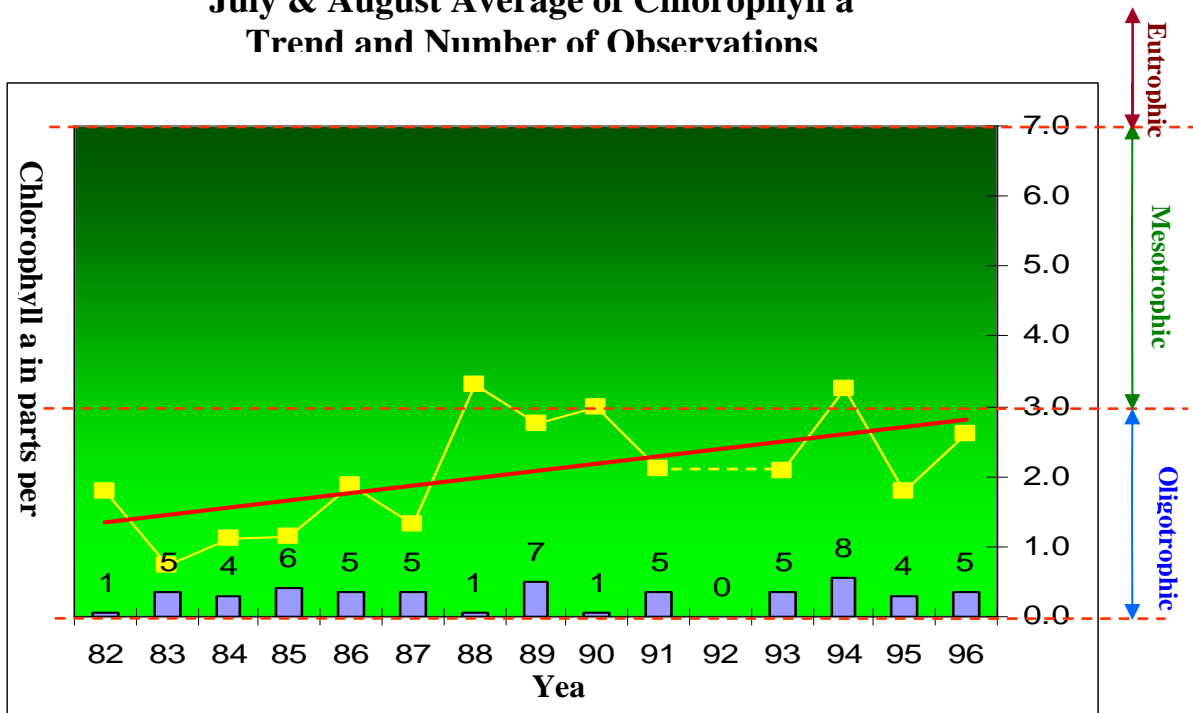
4. Analysis of Chlorophyll a concentration level data

For identical set of reasons used for analysis method selection of SDI data analysis, Chlorophyll a level data was analyzed in three different ways.

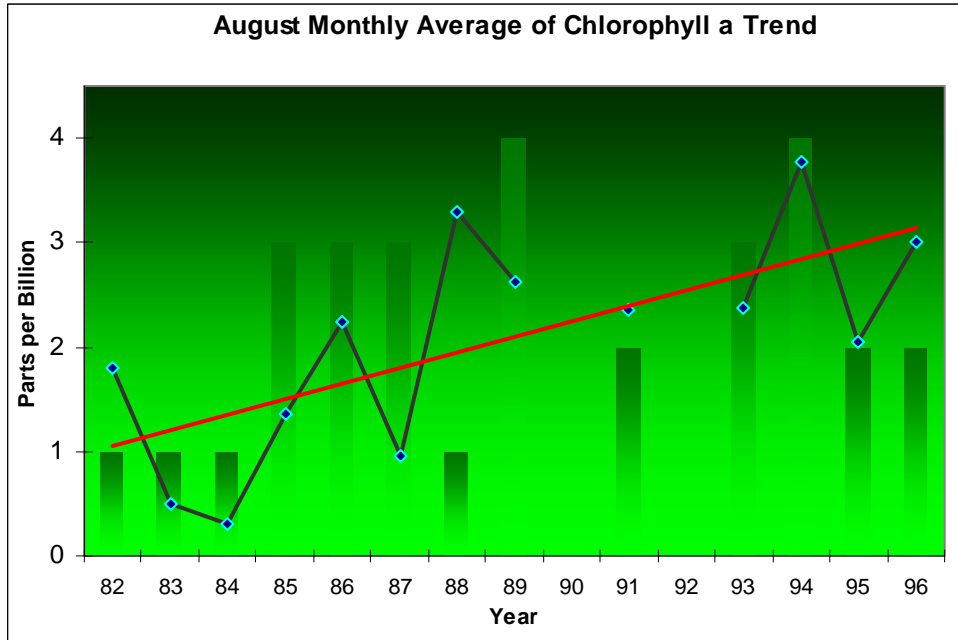


Unmodified data set shows an increase of 1.7 ppb over 15 years.

**July & August Average of Chlorophyll a  
Trend and Number of Observations**



July + August average data analysis shows a similar result.



August data shows a slightly greater increase of 2.1 ppb over 15 years.

Chocorua lake water has become mesotrophic as of 1996 according to the analysis result.

## Summary

Overall, both water quality indicator data shows a strong sign of rapid lake water quality degradation. Chlorophyll a concentration level rose by 200% from oligotrophic level of 1 ppb in 1982 to mesotrophic level of 3 ppb in 1996. Transparency data trend also shows 0.8 m decrease from 5.2 m in 1982 to 4.4m in 1996. However decrease in transparency could have been greater than 0.8m since lake depth at measurement site is only around 6m and many measurements in the 80's shows transparency level greater than 6m. In other words, transparency level measurements could have been limited by the lake depth in earlier years not by suspended plants in the water column.

Note: Analysis of average of aggregated two summer months, July and August data, was emphasized in my study because a typical lake is phosphorus limited only during summers. ( Chocorua lake productivity is limited by other factors such as sunlight availability and temperature in non-summer seasons. )

## **Recommendation for future data collection**

It has been demonstrated that water quality can significantly vary temporarily depending on the precipitation amount before each measurement and what time of year the measurement is taken. I attempted to perform a seasonal adjustment analysis for the past data yet I could not find adequate data and enough time to do so. Such analysis requires close analysis of each precipitation event before each measurement and I found it rather difficult to clarify relationship between different pattern of rainfall before each measurement and water quality.

I believe that my finding of relationship between precipitation and water quality data is much more important in its future application. In short, the volunteers would be able to collect much better water quality indicator data if they take it after several dry day. For example, they should wait many days after a heavy rainfall event so algae population can recover from the flushing effect of a rainfall. Otherwise, their water sample would contain waters that has been recently flushed of Chlorophyll a. Consequently, the indicators would show a very low Chlorophyll a level although the lake may have a usually high concentration of Chlorophyll a in its water. Transparency level should be measured after several dry day for the identical reason. Data collection should be concentrated between June and October. And multiple measurements should be made in each month.

## **Chapter 2 Key nutrients: Phosphorus & Nitrogen**

Balanced diet is recommended to young children since a wide variety of nutrients need to be supplied in order to promote their healthy growth. A balanced diet is also recommended to adults since it contains various vitamins and minerals that are necessary for maintaining their health. Similarly, plants also need to be supplied with balanced nutrients in order to grow. Therefore, lack of single key nutrient can limit plant growth even if all other necessary nutrients and elements were already supplied.

Plant productivity is often limited by phosphorus and nitrogen availability. In the late 20<sup>th</sup> century, plant productivity has increased dramatically because invention of chemical fertilizer enabled humans to supply a great quantity of phosphorus and nitrogen to agricultural lands. Aquatic plant productivity such as weed & algae growth is also limited by phosphorus and nitrogen availability. However human activities are supplying excess amount of nutrients to many water-bodies, removing the sole productivity limiting factor of a water-body and cause algae bloom and rapid water quality degradation.

### **A. Nitrogen**

In Korea, farmers experienced a sudden decline in crop productivity several years after introduction of chemical fertilizer. They tried to maintain soil productivity by supplying more chemical fertilizer however it kept on declining. Few years later, agricultural researchers discovered that Korean farm lands were nitrogen limited because intensive farming had drained natural nitrogen supply in the soil. Today, farmers are

recommended to plant soybeans and other legumes on cropland occasionally because these crops are capable of fixing gaseous nitrogen from the atmosphere to the soil.

Supplied with a large amount of phosphorus only, lake productivity can only rise up to a limited level because nitrogen is also vital for plant growth. For instance, mirror lake experiment showed that plant productivity can not rise infinitely unless adequate amount of nitrogen is supplied. [ Likens pg. 254 ] However, blue green algae, a major constituent of aquatic plant in a typical NH lake, are capable of fixing nitrogen from the atmosphere to a lake ecosystem and it is thus impossible for humans to regulate nitrogen supply. [Likens pg.255 ]

## **B. Phosphorus**

Phosphorus is also a vital component of animal tissues and bones. Phosphorus exist in fertile natural soil and rocks. [ 10. MS Encarta “Phosphorus” ] Phosphorus molecules are inherently sticky. Consequently, phosphorus often enter a water-body, attached to sediments and other debris in runoff. These phosphorus can stay in the lake for a prolonged period of time in the bottom sediments. However dissolved phosphorus can leave a water-body almost instantly especially during low productivity seasons since there is no plant to assimilate them. [ Likens pg. 344 ] In other words, dissolved phosphorus can flush right out of a lake when there is no vegetation to assimilate them or provide attachment.

Phosphorus usually enters a lake attached to a certain sediment because phosphorus is inherently sticky. Therefore, Phosphorus usually stay in a lake for a long period of time.

These phosphorus may not seem harmful to lake water quality. However studies suggest that this phosphorus can also contribute to eutrophication process because they can be released from the sediments during productive seasons in several ways. [ 3. Likens pg. 359 ] First, top 10-20cm of lakes' bottom sediment in shallow littoral zone (0-5m depth) can release phosphorus through biological and bacterial activities, especially during summer. [ 3. Likens pg. 343 ] In addition, sediment in deeper region can also release phosphorus when the lake water become stratified and make the bottom deprived of oxygen during summer. [ U.S. EPA < <http://www.epa.gov/owow/wtr/monitoring/volunteer/spring94/ppresfl9.htm> >] Phosphorus release by both mechanisms can be especially harmful to water quality because they release phosphorus during the most productive season of a year when algae growth is limited only by phosphorus availability.

In Mirror Lake, no element including phosphorus and nitrogen showed a significant net loss. Moreover, net phosphorus balance showed a statistically significant increase over the year the study was conducted. [ Likens pg. 147 ] Lakes retain some amount of phosphorus each year ranging from 32%-84% of the total input. [ Likens pg. 154 ] Thus relatively low phosphorus inflow from inlets over many years should be able to cause eutrophication since they get accumulated in lake sediment over time increasing in concentration. Phosphorus and other nutrients always flow into a lake since a lake often functions as a pollution sink of its watershed. In other words, everything in a watershed flows into its lake and it keeps on accumulating pollutant and nutrients every year. No lakes can physically reverse the flow pattern. However, there are few ways for nutrients to move out of a lake back to its watershed. For example, The Mirror lake study

researchers discovered that some insect larvae can take as much as 11% of total phosphorus of a lake out of the lake when the adult insects fly out at maturity. [ Likens pg. 154 ] Precipitation events also seem to remove phosphorus from a lake by removing algae which store phosphorus in their tissue. [ Likens pg. 324 ] However, overall effect of precipitation event is not very clear since it also brings a significant amount of phosphorus from the watershed and atmosphere.

Some phosphorus can stay in a lake without playing a significant role in its eutrophication process. For instance, as much as 9% of phosphorus can be stored in fish tissues and stay in the fish as long as the fishes live. Similarly phosphorus can be stored in deeper sediment of littoral zone and do not get reintroduced back to the lake ecosystem because much of bacterial and biological activities take place on top 10-20cm of the sediment. However, this does not apply to the Chocorua Lake since established macrophytes such as lily pads roots are capable of assimilating phosphorus from the deep sediments and make it available to other organisms in the lake. [ Likens pg. 315 ]

The majority of cultural eutrophication studies have focused on urban sewage and agricultural pollution sources because pollution from these sources tend to contain a rich amount of phosphorus. In essence, any activity related to crop production, food consumption and organic material can be interpreted as phosphorus sources contributing to eutrophication problems. Any food waste, fertilization, pet waste, phosphorus, sedimentation are the most common examples of phosphorus source.

## **Chapter 3 Impact Assessment of each nonpoint phosphorus source in Chocorua lake watershed**

### **A. Route 16 as phosphorus source**

EPA published a table of road runoff pollutants which identified Roadside fertilizer application as the prime source of phosphorus in road runoff. [ U.S. EPA < [www.epa.gov/OWOW/NPS/MMGI/Chapter4/table431.gif](http://www.epa.gov/OWOW/NPS/MMGI/Chapter4/table431.gif) > The same study suggested that there exist trace amount of phosphorus in runoff from a heavily traveled road with over 30,000 average daily traffic. Average daily traffic on Rt. 16 is approximately 10,000 according to a NH DOT official. ADT of 10,000 is relatively high for a narrow road in rural area of Tamworth, NH. However, estimated phosphorus deposit from the road usage seem quite small according to previous study results. In fact, only one study identified road salt application and road deposit as a phosphorus source. Instead, Mirror Lake study identified terrestrial litter (roadside trash) as source of about 5% of total phosphorus to a lake. [ Likens, pg 154 ]

Phosphorus concentration in road deposit is likely to be very low for Rt. 16. EPA identified road-size fertilizer application as a phosphorus source yet only a very shallow vegetative buffer strip exist along the roadside suggesting minimal amount of fertilizer application around the road. [ U.S. EPA < [www.epa.gov/OWOW/NPS/MMGI/Chapter4/table431.gif](http://www.epa.gov/OWOW/NPS/MMGI/Chapter4/table431.gif) > In addition, the strip looked heavily eroded and did not appear to have been fertilized at all in my inspection. However, this shallow vegetative strip seems to be adding phosphorus to the lake

through erosion and sedimentation of its own soil. The erosion seem to have been caused by a fast surface runoff flow created by smooth impervious surface of Rt. 16.

A study by Barrett concluded that 95% of solids on the roadway come from sources other than cars. [ NPS ( vehicle fluid / runoff ) <http://Chebucto.ns.ca/Science/SWCS/INFO/env07-highways> ] In other words, vehicles bring various debris to the road which did not originate from the car itself. Therefore, spilled gas, oil and tire-wear seem to constitute a very small percentage of road deposit materials. Furthermore, it is not clear how much nutrient exist in substances such as motor oil, gas and tires. Some phosphorus may exist in gasoline and gasoline additives since phosphorus is extremely flammable. However, motor oil and tires are not likely to contain flammable phosphorus as their component. Further research might be necessary but the lack of research on such topic seem to suggest that phosphorus in gasoline, motor oil and tire might be insignificant.

Rt. 16 seems to be accumulating a relatively large amount of soil particles from its many nearby unpaved local roads. Some cars may never touch one of the dirt roads before passing Chocorua Lake section of Rt.16. However, some cars such as ones that belong to the local residents must bring some soil particles to the Rt. 16 from numerous unpaved roads and parking lots. For instance, roadside snow stacks showed a visibly significant amount of soil on top of them. These soil particles are bound to get washed into the lake during a precipitation event. It seems plausible that those soil particles came from the Rt. 16 surface deposits brought by local traffics. Some photographs show a large amount of soil in the spring runoff from Rt. 16. This can be

a problem to the Chocorua Lake since soil particles naturally contain phosphorus and phosphorus molecules naturally attach themselves on debris such as soil particles.

Phosphorus reading from Rt. 16 runoff shows a very high phosphorus concentration level ranging from 1000 to 30 ppb. These unusually high concentration level are almost certainly influenced by presence of sediments and suspended particles in the runoff. Some people may argue that reading with sediments and suspended particles should not be accounted in a phosphorus budget study because attached phosphorus can not be assimilated by plankton. And it is certainly true that these particles with attached phosphorus do not provide nutrients to aquatic plants immediately. However, those phosphorus can become available to plankton and other organisms in a long term by bacterial activities and chemical reactions. Therefore, high phosphorus concentration measurement of a water sample with sediments from the culverts should be considered as important as dissolved phosphorus to a lake eutrophication problem.

U.S. DOT estimated in 1986 that highway runoff contain total phosphate of 0.5 to 0.9 mg/liter. [ NPS (vehicle fluid / runoff ) <<http://chebucto.ns.ca/science/swcs/INFO/Env07-highways> >] And approximately one mile of Rt.16 runs adjacent to the eastern shoreline. Assuming 0.7 mg/liter of phosphate in Rt. 16 runoff, phosphorus input from Rt. 16 surface runoff can be estimated as following.

- road area = 1 mile \* (1600m/mile)\*9m(estimated road width)
- phosphate = 0.7 mg/liter \* 144,000,000cm<sup>2</sup> \* 37 inch (precipitation) \* (2.5cm/inch)\*(1liter/1000cm<sup>3</sup>) = 9324000mg= 9324g= 9.3kg

This estimate is very crude and slightly less than 9.3kg seem to be entering the lake since some buffer zone exist on the most part of the eastern lake shore. It is unclear how large the effect of estimated 9.3kg of phosphorus is to the Chocorua lake.

In summary, road with 10,000 average daily traffic may not be considered as a prominent source of phosphorus. However, its close location to the lake and its rural surrounding seem to have made Rt. 16 a non-negligible source of other pollutants and some phosphorus, combined with the road's complete lack of runoff control. [ 11. U.S. EPA < 13. <http://www.epa.gov/OWOW/NPS/roads.html> > A study by U.S. DOT emphasized that concentration of heavy metal pollutant such as copper and lead is much higher because of highway fallout accumulated on the road. Yet it did not mention if highway runoff contains a particularly high concentration of phosphorus in it. Nevertheless, Rt. 16 runoff may contain some phosphorus in its runoff since it seems to have been collecting a large amount of sediments from local traffic and numerous near-by dirt roads & parking lots. In conclusion, route 16 may not be contributing a large amount of phosphorus to the Chocorua lake. However it might still be playing a major role in the eutrophication process because Chocorua lake is a such a small lake. Anyhow, this complete lack of runoff control of Rt. 16 does not comply with EPA's recommended road runoff control standard titled "Best Management Program." Therefore, its structure should be improved in order to control its runoff with heavy metal and various other toxic pollutant. In fact, Rt. 16 Corridor Protection Study made a similar recommendation. [ Rt. 16 Corridor Study Group NH pg. 59 ]

## **B. Chocorua lake road as Phosphorus source**

Temporary roads built for logging operations have been identified as a significant source of erosion for several reasons. First, its unpaved and un-vegetated surface can be easily eroded and its smooth surface are capable of creating fast runoff flows which can cause erosion of adjacent land area. [ Chester pg. 98 ] Heavy machinery usage on the road are also known to accelerate erosion by mobilizing surface soil of these roads as well. [Chester pg. 98 ] In other words, temporary roads can increase transportation of nutrient such as phosphorus to a nearby waterbody because poorly designed and operated roads cause erosion. [ Likens pg. 440 ] Some roads in the Chocorua lake watershed share a few similar characteristics of temporary road built for logging operations. Chocorua Lake Road is one such unpaved road that is built along the western shoreline.

Chocorua Lake Road is a private road that branches off from Rt. 16. It also has several branch roads of its own. One branch runs from 200 to 400 yards from the entire western shore and three others stretch away from the western shore. Several driveways stretch toward the western shore from one of the branch that lies along the shoreline. That particular branch of the Chocorua Lake Road is about a mile long and one and half lane wide.

Chocorua lake road branches, especially one that is built along the western shoreline may be adding nutritious fresh soil to western shore of the lake. During the snow-melting season of 1998, the road becomes extremely loosely-bounded and

unstable. In fact, its lack of stability caused difficulty in driving at a low speed of 15 miles per hour. According to my personal observation on March 27<sup>th</sup> 98, Stratton brook, was receiving muddy runoff directly from the road. Roadside snow stacks on Chocorua lake road showed a significant amount of sand + mud. Snow removal operations remove some surface dirt and soil from the road along with the snow, increasing sediment mobilization.

Numerous pot holes were formed on the road by local traffic. Disturbed surface sand + soil from the potholes are susceptible to erosion. On the day of observation, local government trucks were pouring sand + soil onto the road for repairing road damages accumulated over the winter. This suggests surface soil + sand loss from the road in the spring melt. The road repair operation left a very thick layer of loose soil on the road surface. I believe that surface runoff can carry sediment from the dirt roads into the lake over a year.

In summary, Chocorua lake road is only a narrow road with a very little traffic. It is only used by residents of 22 houses on the western watershed and their guests. However, it shares a few characteristics with a temporary logging operation (TLO) road. This similarity suggest that Chocorua lake road might be doing things that most TLO roads do, adding nutritious soils to a water-body. The 'fill-adding' road maintenance operation provides evidence that soil has been eroded from the road in the past. In fact, some photographs show muddy runoff flowing into the one of the lake's inlet, the Stratton brook. A significant weed growth on the Western shore of Chocorua lake seems to support this speculation of road erosion. Furthermore, a high

phosphorus concentration of 51ppb was detected at Stratton brook near Chocorua lake road after a large precipitation event of 4.71 inch on October 21<sup>st</sup> 1996. In conclusion, Chocorua lake road seem to be playing a larger role in Chocorua lake eutrophication problem than previously assessed.

Note: Most part of the dirt road is located couple hundred yards away from the western shoreline. However, it still seems like a source of problem because a large amount of muddy runoff can flow into a water inlets such as Stratton brook and enter the lake without much filtration. Dirt road built for logging operations are also known to be especially problematic to a waterbody when it crosses a water inlet such as a stream. [ Chester pg.98 ] Similarly, Chocorua Lake Road might be a problem to Chocorua lake because it crosses a couple of water inlets of the lake. A more detailed assessment and observation will be necessary to determine the full impact of Chocorua Lake Road erosion to the eutrophication problem.

### **C. Human settlement as phosphorus source ( septic tanks )**

The Flint Pond Study estimated that 56.4 Kg, 72% of total phosphorus was originated from the human settlement in the area. [ Flint Pond Study pg. 16 ]

Although there might be more than 52 houses in the Flint Pond watershed, researchers concluded that those 52 houses were the main source of phosphorus. Chocorua lake also has several houses near the shoreline and has total of approximately 90 houses in its watershed. However phosphorus loading patterns and their contribution from these approximately 90 houses are likely to be different from that of 52 houses in the Flint Pond area for several reasons. First of all, the houses on the Chocorua lake watershed are dispersed over a relatively large area compared to the house on the Flint Pond area. In addition, most Chocorua lake area houses are built at least a few hundred feet away from the Chocorua lake shoreline while all 52 Flint Pond area houses are located right on the shoreline. Overall, houses on Chocorua lake watershed are located further away from the lake shores and it also seem to have a larger leach field per house, which is essential for filtering phosphorus from septic discharges.

One third of the 52 Flint Pond residents responded that they apply fertilizer to their lawns. In addition, they also responded that they have cloth washers and garbage disposals in their houses which can add more nutrient to the septic tanks. It is not clear if the houses in Chocorua Lake watershed have garbage disposal or dish washers. The difference between the ownership of such appliance and fertilizer application pattern between Flint Pond residents and Chocorua Lake resident are

crucial in determining difference between the impact of residents of each watershed in their eutrophication problems. Assuming a minimal difference in such characteristics, the dispersed human settlement in Chocorua lake seem to be reducing phosphorus input to the lake since each houses are endowed with larger leach fields compared to that of Flint Pond houses. Nevertheless, even a dispersed human settlement seem to have a potential to aggravate a lake eutrophication problem. For instance, Mirror lake researchers concluded that Mirror lake was receiving 39% of phosphorus from only 5 year-round residences, 3 camp ground, 2 mobile home, and a tiny farm [ 3. Likens pg. 443 ]

Dispersed human settlement might be contributing a significant amount of phosphorus to the Chocorua lake for several reasons. First of all, although the majority of houses are built more than 1 mile from the Chocorua lake, approximately 20 houses are located within 0.5 mile from the shoreline. These houses seem to have a good sized leach fields with a far greater phosphorus filtering capacity compared to the houses on the Flint Pond area. However, some of the houses are located near water inlets of the Chocorua lake and appear capable of carrying septic discharge directly into the inlets and the lake. For instance one house is built on the northern shore of Chocorua lake right adjacent to one of the inlets, Chocorua brook. The houses on northern portion of Chocorua watershed are also located near the same inlet. ( The phosphorus contribution from such house would not almost impossible to detect since Chocorua river is a very large inlet and a single house will need to add a gigantic amount of phosphorus to the inlet in order to increase its phosphorus concentration level. )

Flint Pond Study concluded that septic tanks were contributing approximately 72% of total phosphorus to the lake. [ 7. Flint Pond Study pg. 16 ] According to the studies' assessment, septic tanks' contribution of 72% of total phosphorus is 6 times greater than the contribution of second largest phosphorus source, Forest. [ 7. Flint Pond Study pg. 16 ] However, the study also suggested that previous contribution of the septic tanks might have been even greater because a septic tank discharge much less phosphorus when properly maintained by pumping. [ Flint Pond Study pg. 10 ] and Flint Pond residents had pumped out their septic tanks once or even twice shortly before the Flint Pond study was conducted. Thus, Flint Pond Study researchers believed that their measurement of phosphorus concentration could have been much higher if the septic tanks were not pumped before the year of study. Consistent pumping of septic tanks are recommend and septic tanks are known to lose their functionality if they are not pumped regularly.

The conclusion of Flint Pond researchers suggests that phosphorus discharge per individual septic tank in Chocorua lake area might be higher than that of Flint pond area if they have not been properly maintained in the past. The result also showed that proper maintenance of septic tanks can reduce nutrient and other pollutant loading to the lake. [ Flint Pond Study pg. 10 ] Overall, phosphorus discharge of approximately 20 house near Chocorua lake might be comparable to that of Flint Pond houses although there are fewer houses with larger leach fields in the Chocorua lake area.

y concluded that large phosphorus outflow of septic tanks of the area was largely accountable to the fact that most of houses and their septic tanks were well over 20-30 years old. [ Flint Pond Study pg. 4 ] Most houses in the Chocorua lake watershed are also more than 20-30 years old. Casual interviews of local residents suggest that maintenance + pumping may have been irregular. Besides, some Chocorua lake residents have lawns and some animals which could be adding more phosphorus to the lake. Yet the houses also have larger buffer zone. An expert such as Jeff Schloss of University of New Hampshire concluded that septic tanks may not be a major phosphorus source. However, I still believe, because of these evidences, that septic tanks of these 22 houses in Chocorua lake watershed could be discharging phosphorus amount comparable to that of Flint Pond house septic tanks.

The majority of previous eutrophication studies concluded that human waste from septic tanks were the largest source of phosphorus to for most waters. In fact, phosphorus and nitrogen contribution from the west watershed of Mirror lake increased dramatically after 3 year-round residences and several tourist cottages were built. [ Likens pg. 147 ] Overall, human settlements seem to be a prominent contributor of phosphorus to the Chocorua lake for following reasons.

1. Majority of researches including Flint Pond study concluded that septic tanks were a prominent phosphorus source.
2. Chocorua watershed has more than 90 houses and some of them are located relatively close to the lake than other houses. Few houses are also located

close to one of its water inlets. However, Chocorua lake settlement are not directly comparable to the Flint Pond houses.

3. The septic tanks do not seem to have been properly maintained. ( It should be noted that although phosphorus discharge of Flint Pond area septic tanks was very high it could have been even higher if they were not pumped at least once, less than two years before the study was conducted.
4. The septic tanks are over 20-30 years old. ( Flint Pond study concluded that old septic tanks are poorly designed and do not filter phosphorus efficiently. )  
[ Flint Pond Study pg. 4 ]
5. Some houses have lawns and animals which are known to be significant phosphorus sources.
6. Some houses are built relatively close to water inlets although houses are supposed to be built at least 75 feet away from an inlet. [ Craycraft pg. B-2]

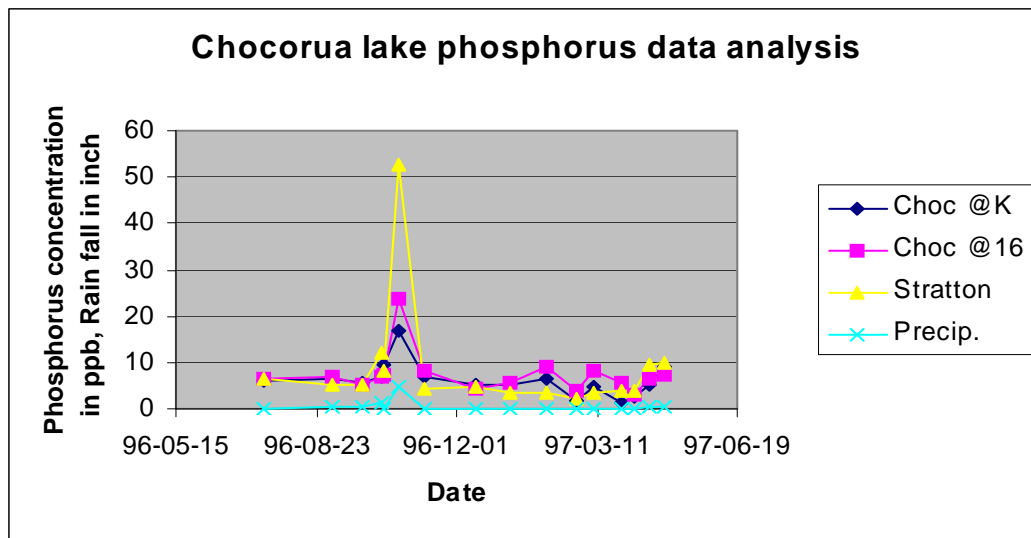
#### D. Summary

This study did not focus on phosphorus in septic discharge and other household activities of residents in the area. However the focus had inevitably shifted because only few researches found small amount of phosphorus from road deposits and many literatures pointed out that septic tank discharge was the one of the more prominent phosphorus source. Excessive weed growth on the western and northern shore of the Chocorua lake seem to indicate that septic tanks and human settlement could be playing a major role in the Chocorua lake eutrophication problem.

Note: It is extremely difficult to assess impact of human settlement in the Chocorua lake houses on the eutrophication process. Settlement is very dispersed and I could not find any research that discussed the effect of human settlement comparable to that of Chocorua lake watershed. Many houses seem to have a large leach field per their septic tank. However, I wonder if leach field can be overly saturated with septic discharge over a prolonged period of time. Close observation and survey of each houses seem necessary for further research.

## Chapter 4 Phosphorus data analysis

Over 200 phosphorus measurements were taken at various locations around the Chocorua lake including its inlets and outlet between 1996 and 1997. Preliminary analysis result of phosphorus data show varying patterns of phosphorus concentration level at various inlets depending on following weather conditions.



- Large rain fall event: Phosphorus concentration level has been measured to be below 10 ppb on dry days after a little precipitation at most inlets. However, phosphorus concentration jumped sharply from below 10 ppb level to 51 ppb at the Stratton brook on the Oct.-21-1996 after a large precipitation of over 4.7 inches. The water sample must contained some sediment in the sample. Phosphorus concentration level rose up to 25ppb at Chocorua brook as well. This kind of sudden jump in pollutant concentration level is referred as ‘shock loading’ by nonpoint pollution researchers. A shock loading event is often caused by erosion of nearby land or washed-off pollutant from septic leach field, fertilizer application or animal manure. In this case,

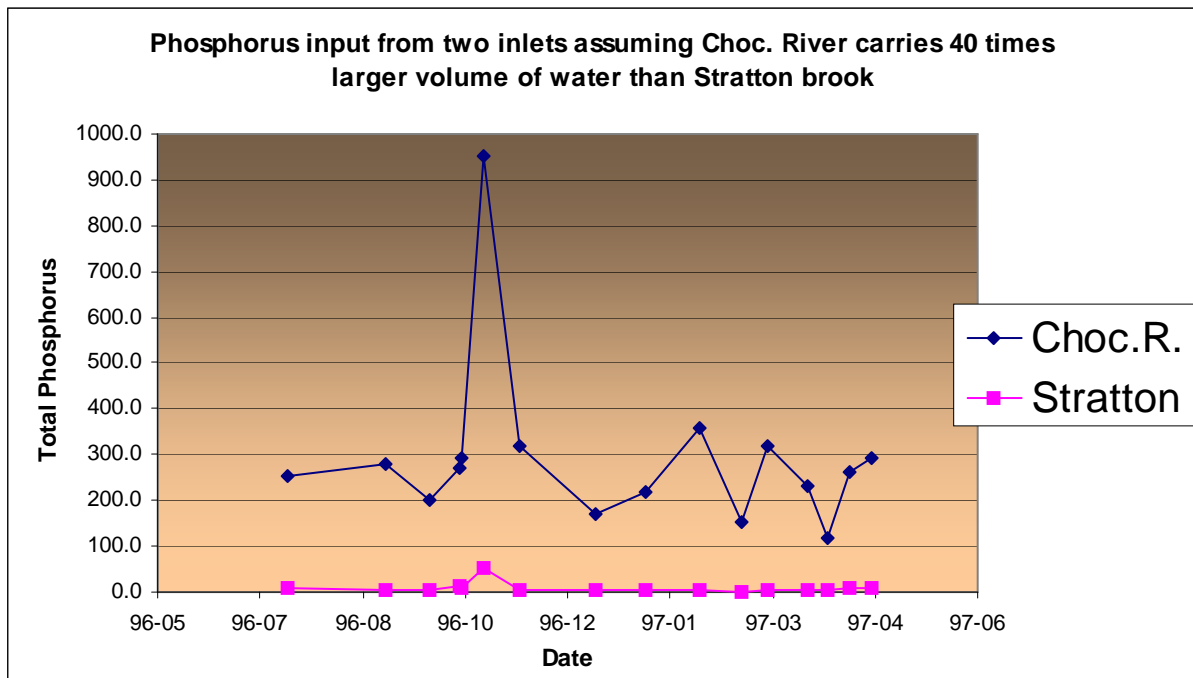
shock loading at Stratton brook may have been caused by both Chocorua Lake Road erosion and runoff from nearby septic leach fields. In fact, phosphorus level also jumped up by 6 ppb from 4ppb to 10ppb during the spring melting season of 1996 at Stratton brook, suggesting road erosion and stream bank erosion as well.

Furthermore, the result suggests that some of the leach field could be contributing much of phosphorus during the shock loading events as rain wash phosphorus off from the leach fields.

- Relatively Dry days: Phosphorus concentration level is usually higher at the Chocorua brook than at Stratton brook. This higher phosphorus concentration level might be related to septic tank discharges from relatively concentrated human settlement of approximately 50 houses located along the Rt. 16 and Chocorua brook. This moderately high concentration level of Chocorua river could be contributing a significant amount of phosphorus to the lake since the river carries a much greater amount of water to the lake. The most prominent weed growth appear on the northern shore. However, it is not very clear whether human settlement in the northern watershed caused such weed growth since the lily pads existed in that region for a long period of time.
- @ Culvert on a rainy day: Shock loading of extremely high phosphorus concentration as high as 1000 ppb has been measured at Rt. 16 culverts. The culverts seem to be carrying a large amount of sediment and phosphorus during precipitation events from the Rt. 16 surface. Significant weed growth recently began appearing on

some sections of the eastern shore where Rt. 16 is located only few feet away from the lake water.

- Note: Phosphorus concentration at Stratton brook can be higher than Chocorua river during large precipitation event. However, the phosphorus input from Chocorua river seem to be much more important than the Chocorua because it carries much greater amount of water to the lake.
- Stratton brook has higher concentration of phosphorus in the runoff. However, Chocorua river is carrying far more phosphorus than Stratton brook because of its size. Following graph shows how much phosphorus Chocorua river is carrying to the Chocorua lake compared to the Stratton brook.



\* Phosphorus reading at culvert has been extremely high, ranging from 280ppb to 1000ppb. However, these measurement could not be compared with inlet data.

Note: I could not analyze phosphorus reading at culvert for a few reasons. First, I could not locate culverts on the map and I only had several measurement data. I also wanted find out how water samples were taken at culverts before performing an analysis since a volunteer might have collected some extra amount of sediment if he held sampling tube on the culvert longer than a split second. Overall, it is not so clear how I should interpret the data at culvert.

#### Recommendation for future phosphorus data collection

It might be helpful to collect water samples from various sites on a given day within a short time interval. Such data collection should make it easier for future researchers to compare each phosphorus sources better. Volunteers should also try to collect phosphorus data away from the watershed at the same time. For instance, it would be interesting to know how much phosphorus exist in the water of Chocorua river in upstream before it flows by houses on the northern watershed. For instance, even a slight increase in phosphorus concentration may indicate a problem since Chocorua river is a relatively large inlet and a lot of extra phosphorus is required to raise its concentration level. ( Phosphorus concentration of pure rain would be also interesting to know. )

## **Chapter 5 An overview and conclusion**

### **A. Overview**

A lake is a complex ecosystem. Hundreds of organisms live and die within the system and each plays its role in the lake nutrient cycle. Thus, it is not possible to fully understand how Chocorua Lake works nor find out how much each nonpoint pollution sources is contributing to the current problem. However I believe researchers have accumulated enough knowledge on cultural eutrophication which can be combined to help us understand origin of the problems better.

Following paragraphs summarize my assessment of each nonpoint sources to the Chocorua lake based on previous study results and my data analysis.

1. Route 16 does not have any of runoff control devices recommended by the EPA except a thin roadside vegetative strip that looks rather heavily eroded (the steep slope of the vegetative strip seem to make it impossible for it to function as a pollution filtering device). Consequently, Rt. 16 drains its runoff directly into the lake without filtering any pollutants such as lead, and phosphorus containing soil particles. Phosphorus data and photographic evidences show a large amount of sediment and phosphorus in its run-off. The Rt. 16 may not be the sole most significant source of phosphorus. However, its structure should be improved in order to control its runoff that contains heavy metals and other harmful pollutants as well as phosphorus-rich sediments.

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ture should be improved in order to prevent future erosion problem. Paving might reduce erosion of the road itself yet it has a potential to increase erosion from adjacent land and also cost a lot of money. Instead, runoff diversion at small sections of roads where it crosses water inlets might be more cost-effective. The road would not be such a problem if it did not cross any water inlets.

3. Human settlement on the eastern shore: The Flint Pond Nutrition Study identified septic tank discharge as the most prominent source of phosphorus of over 75 % of total phosphorus although many of them had been inspected and pumped out just a year or two before the study was conducted. On the Chocorua lake watershed, only approximately 20 houses are located relatively close to the shore line compared to over 50 houses on the Flint Pond shoreline. However Chocorua lake

izer application on the lawns of the Chocorua lake houses also could be adding phosphorus to the lake. Some Chocorua lake houses are only used intensively during summer seasons. However, septic tank discharge from the summer houses can be particularly harmful to the water quality since septic discharge contains dissolved phosphorus which can be immediately assimilated by lake organisms during productive summer seasons. An aerial photograph of Chocorua lake shows significant weed growth along the western shore line where these 22 houses are located. Consequently, I believe the residents should inspect their septic tanks and pump them out immediately if they have not done so in past few years. Irregular maintenance are known to damage septic tanks permanently.

4. Human settlement on the northern watershed: Over 50 houses are located on northern watershed of the Chocorua lake. Six of them are located relatively close to the northern shore where Chocorua river drains into the lake. Some houses are located as far as 1.5 mile to 2 mile away from the lake. However the majority of the houses are located relatively close to Chocorua River, the largest inlet to the Chocorua Lake. Consequently, I believe septic discharge from over-used leach field of these houses could be entering the lake through the Chocorua River, especially if the residents have not maintained their septic tanks properly. Septic tanks of these houses should be inspected and properly maintained. Overall, more attention should be paid to houses on the northern watershed. ( Even a slight increase in phosphorus concentration can be very important since a lot of extra

ilar contribution of roadside litter to the Chocorua

Lake phosphorus loading.

- c. Increased temperature caused by global warming could be accelerating eutrophication problems by slowing down water renewal rate which increases nutrient concentration in a lake. [ Schindler pg. 967 ]
- d. Cropped soil and farmed soil tend to contain more phosphorus because of fertilizer application and animal manure in them. [ 3. Likens pg. 434 ] According to local logging representatives northern region of Chocorua lake watershed had been used for farming in the past. If this proves to be true, proposed logging operation on the northern watershed should be more carefully managed since eroded soil from that particular region might be especially rich in phosphorus. Anyhow, logging should be done during the winter in order to reduce its impact on the eutrophication problem.
- e. 32-84% of total phosphorus input and 59-87% of total nitrogen input can be retained in a lake. [ 3. Likens pg. 152 ] In fact, lake sediments often function as a nutrient sink [ 3. Likens pg. 152, 341 ] The top 10-20cm of sediments in littoral

zone can release phosphorus via biological activity and chemical reaction. [ 3. Likens pg. 359 ] In addition, nutrients in deeper sediment can be released by macro-phyte such as lily-pads because their roots can reach down the sediment and assimilate nutrients. [ 3. Likens pg. 177 ] In fact, the Mirror Lake study concluded that primary productivity of a lake is ultimately dependent on recycled nutrients in the sediment. [ Likens pg. 314 ] In summary, accumulated sediments is the largest source of phosphorus. Therefore, septic tank maintenance and road erosion control is likely to bring a gradual change in eutrophication trend than an immediate change.

- f. Lily-pads: Mirror lake study concluded that appearance of large macro-phytes such as lily pads were signs of sediment accumulation in the area. [ Likens, pg. 315 ] Lily-pads can grow in a lake when enough sediment accumulate on the lake bottom to provide a large amount of nutrients to support them. Lily pads can be harmful to a lake because they reintroduce inactive nutrients from deep sediment to lake plankton and algae. However they can also protect rest of the lake from becoming eutrophied in short term because its large leaves can trap phosphorus for a short period of time.

Note: It might be beneficial to let lily-pads grow during the summer and localize eutrophication to the northern watershed. Then careful removal of its leaves before the winter might remove a good amount of phosphorus from the lake since its tissue contain much phosphorus in them.

## **B. Conclusion & Recommendations**

Both indicators of water quality, Secchi Disk Index and Chlorophyll a concentration clearly shows a strong trend of the Chocorua lake water quality heading toward more productive mesotrophic state from 1982 to 1996. The transparency level decreased by 2 feet and Chlorophyll a concentration level increased by 200% from 1ppb to 3 ppb. Phosphorus data shows a moderate phosphorus concentration level under 10ppb at two inlets except during heavy precipitation events. However the lake's bottom sediment seem to be gradually accumulating nutrients and supplying them to weeds and algae during summers via bacterial activity and chemical reaction. Therefore moderate phosphorus concentration level from the inlets should not be interpreted as an evidence of no impact.

I concentrated on compilation and analysis of existing literature on road runoff and various other Chocorua Lake data in this project. I also aimed to construct a more holistic picture of the Chocorua Lake cultural eutrophication problem through my research. In conclusion, I believe Rt. 16 should be improved in order to control its runoff because the runoff contains heavy metal as well as some phosphorus. Septic tanks of human settlement on the western shore as well as unpaved Chocorua lake road also seem to be significant sources of phosphorus. However specific evidence could not be gathered in this study to concretely support my conclusion. Lastly, the impact of houses on the northern shore of Chocorua lake should also be studied since they are located near Chocorua river inlet and their septic tank discharge might be adding a significant amount of extra phosphorus to the lake through leaching.

Overall, every nonpoint sources seem to be contributing phosphorus quite evenly. And it could not be determined whether a certain source is contributing more phosphorus to the Chocorua lake.

Chocorua lake is unfortunate to be losing its pristine water quality. However it is also lucky to be receiving much attention from the volunteers who kept a record of its water quality history that revealed an emerging sign of eutrophication. I hope my analysis results provide useful information that can be used to mitigate rapidly progressing Chocorua lake eutrophication. As a next step, I recommend a septic tank study to be conducted. Even a simple survey of residents in the watershed would be helpful since septic tanks are known as one of the largest phosphorus sources in other lake studies. The number of septic tanks in the Chocorua lake watershed may not be very large compared to size of the watersheds however they seem old and old septic tanks do not filter out phosphorus and other pollutants very effectively. Consequently, inspection of the septic tanks and dye-testing might provide crucial information on the impact of human settlement on current eutrophication problem of Chocorua lake.

**Final Remark:** Historically, it has been extremely difficult for humans to co-exist with nature without harming it. We always seem to disrupt the delicate balance of nature whenever we build a road or few houses. Similarly, I believe septic tanks could be aggravating Chocorua lake eutrophication problem although there are not too many of them. I believe that residents have responsibility to clean their septic tank and always try to minimize their impact on the current eutrophication problem. In this study, I tried to analyze every nonpoint pollution sources in the watershed. However, a big piece of puzzle seem to be missing because I did not have any data on septic tanks in the area. I hope volunteers carry out a septic tank study similar to that of Flint Pond study and complete the puzzle. Only then we shall know what need to be done to each phosphorus sources in order to prevent further eutrophication and preserve Chocorua Lake.

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