Total Phosphorus Input and Output of Torch Lake plus the Watershed Boundary of Shanty Creek

2005 Summer Internship Report

By

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And

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DEQ Grant Number 761P40021

Abstract

The primary concern of Three Lakes Association (TLA) during the summer or 2005 was the creation of a predictive water quality model based mainly on phosphorus levels in the water of Torch Lake. Volunteers and interns collected water samples from the lake and from the places that water entered and exited the lake, such as tributaries, rainwater, and groundwater. Samples were taken from each of the deep basins in Torch Lake, from many of the tributaries, large and small, that feed and flush the lake, and from the rainwater that falls on the lake by way of rain collection bottles. These water samples were analyzed by the Great Lakes Environmental Center (GLEC) for phosphorus content and were repeated numerous times over the summer to increase the accuracy of the data. Once the levels of phosphorus were known, they were combined with data on the amount of water entering and leaving the lake to figure the input and output of phosphorus. Phosphorus concentrations in Torch Lake have remained around 2 ppb for some time, but the concentrations in the sources and outlets vary considerably. It was found that about a total of 3910 kg of phosphorus entered Torch Lake this year (1930 kg from rainwater, 980 kg from tributaries, and 1000 kg from groundwater). This total input nearly quadruples the output of phosphorus by Torch River (988 kg/yr). TLA found that Torch Lake retained 75% of its phosphorus, but thought that it settled out as sediment over a period of time. This theory was confirmed by the high concentrations of phosphorus found in the sediment that drifted to the bottom of the lake. In addition, TLA concluded that it would take 2.2 years for the levels of phosphorus in Torch to drop by half if inputs and outputs ceased, 1.6 years for levels to double if sedimentation ceased, and 6.5 years to double if groundwater phosphorus content doubled.

Introduction

During the summer of 2005, Dean Branson and Tim Hannert of Three Lakes Association (Three Lakes Association (TLA), PO Box 689, Bellaire, MI 49615), along with Doug Endicott of the Great Lakes Environmental Center (Great Lakes Environmental Center (GLEC), 739 Hastings St., Traverse City, MI 49686) began constructing a predictive water quality model for Torch Lake. The primary responsibility of TLA was to collect lake data and deliver it to GLEC for analysis. Once analysis was finished, GLEC was responsible for input the relevant data from Torch Lake into the model. The ultimate goal of this model would be to provide a data-supported program that would be able to accurately foretell the environmental impact of the development that continues to take place within the Torch Lake watershed.

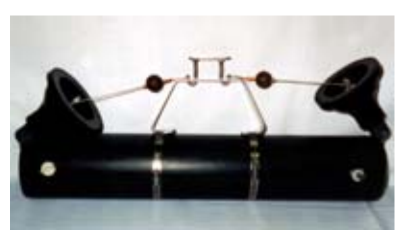
Beginning in the spring of 2002, TLA began offering internship positions to local high school students to assist TLA in their data collection and to give science-savvy students an opportunity to participate in an actual environmental study. This year TLA accepted five interns from Elk Rapids and Bellaire high schools. Toward the end of the school year, the interns began actually working on the project.

The development of the predictive model began in 2004, so the interns of 2005 began collecting data where the previous students had left off. The primary concern of the work to be done in 2005 was to collect data on phosphorus levels entering and leaving Torch lake, and the concentration already present in it. Phosphorus became the keystone nutrient of the 2005 report because it is the rate-determining reactant in the growth of algae and other plant life. Throughout the summer, they collected data about the input of phosphorus from tributaries, precipitation on the watershed, and groundwater flowing into the lake. When all of this data was compiled, a mass balance was done for the phosphorus content of the lake, that is, the total input mass of phosphorus to the lake was compared to the total amount leaving by way of Torch River each year. From here, it was easy to figure out what percentage of the phosphorus remained in the lake. This value is called the retention fraction, and it is calculated by dividing the difference of the total phosphorus input and output and dividing it by the total phosphorus input, yielding a total retention of around 75% (ref. Appendix G, #4). But wait, if the total retention of phosphorus within the lake is three-quarters, and the levels of the nutrient present in the actual lake water are, and have, remained quite low, then the phosphorus must have some alternative destination. This discrepancy will be discussed later.

In addition to calculating a retention fraction, a definite timescale was calculated for the phosphorus change-over. This was found by dividing the total amount of phosphorus in Torch Lake by the difference in the total input and output. This calculation produces a value of 2.2 years, and what this data means is that if all phosphorus inputs and outputs to the lake ceased, it would take about 2.2 years for half of the phosphorus in the lake to dissipate (ref. Appendix G, #5).

Lake Water Sampling Methodology

To be able to make any real comparisons between the water entering Torch Lake and that which was already there, it was necessary to make definitive measurements of the phosphorus levels in the lake water itself. Sampling of the water in the lake was done from a surface craft over either of the two deepest



Van Dorn water sampling device

points in Torch Lake: the North Deep Basin and the South Deep Basin. Measurements at the locations were made with the help of a Van Dorn device (pictured above).

Coordinates of Deep Basins in Torch Lake:

Torch south basin (~300 ft):	N -	44 deg.,	57 min.,	47.2 sec.
	W -	85 deg.,	18 min.,	36.2 sec.
Torch north basin (~260 ft):	N -	45 deg.,	2 min.,	24.2 sec.
	W -	85 deg.,	19 min.,	25.9 sec

Input Sampling Methodology

The three inputs of water to Torch Lake are tributaries, precipitation, and groundwater flow (ref. Appendix I). To measure the flow rates from each of these sources, different techniques had to be utilized. The local flow rates of tributaries including Clam River were determined using a Gurley probe or "balanced bucket wheel meter." This apparatus provided a digital readout of the rate of rotation of the wheel and was calibrated to the velocity of the water flowing about it. According to the manufacturer, the probe has a two percent margin of error if properly maintained. Prior to each use, the probe was lubricated and checked according to the instructions. Measurements were made at twenty and eighty percent of the total depth of the river, and at equidistant increments across the width. For large streams (i.e. Clam and Torch rivers) having significant variation in flow across the channel, each section of the river was measured using the Gurley probe and the results were summed to obtain a total flow rate. The depths gauged during flow measurement along with the determined width of the stream were used to create a cross-sectional profile. Once this was established, the profile was separated into sections according to the flow in each area. These sections were called flow panels. The flows from each panel were summed to produce a total flow for the tributary (ft^3/s or cfs).

The total flow of the smaller tributaries was measured by first estimating the area of the cross section, then assuming that the flow across the waterway was uniform, and finally measuring the flow velocity by finding the rate of travel of a sample floating in the water. Once measurements were completed for all of the tributaries, the flows could be added up to produce the total flow of water into Torch Lake from rivers and creeks.

Aside from visible tributary flow, groundwater represents another significant portion of the water that enters the lake. Groundwater comes from rainwater that falls on the lake watershed and percolates though the subsoil eventually reaching the lake near the shoreline. By the time that the water reaches the lake it contains some initial phosphorus from the atmosphere (particulate and dissolved), as well as whatever phosphorus and other solutes it happens to accumulate as it passes through the soil. On the way, a portion of this phosphorus is absorbed by the roots of plants and is used in the growth process. The non-initial phosphorus that enters the groundwater comes from naturally occurring deposits, as well as man-made sources including farm and lawn fertilizers and septic runoff. Acquiring samples from the water that is entering the lake at the shoreline required putting in sampling wells at numerous sites around the lake. After gaining permission from the property owner, a steel pipe was used to pound a well point into the subsoil. The point is connected to the surface with a flexible polyethylene tube after the steel pipe is removed. The tube was tipped with a tempered steel point and had a screen near the end to allow water, but prevent sand, from entering the tube. After the well was placed, it was allowed to settle for approximately a week. Once properly settled, the well can be used to accurately estimate the groundwater flow and to sample the phosphorus content of said water. The flow of the groundwater at a given point can be determined from the pressure of the water there, as well as the resistance to flow. The pressure is found by examining the height of the water in the tube above the level of the lake. This height is a measure of the pressure that the groundwater was exerting on the subsoil near the well point. The higher the water level in the tube was, the more pressure was being put on the soil, and thus more water was moving into the lake in that area. No areas of negative water pressure were found on the Torch Lake shoreline, and thus we infer that no water is *leaving* the lake via shallow groundwater flow. The subsoil resistance, or conductivity, is measured by timing the fall of water in the well tube. To do this, the entire length of exposed tubing is submerged to remove all of the air pockets. The tube was then brought back up and marked at one and two feet off of the lake level, while simultaneously retaining the vacuum in the tube. From here the water level was slowly allowed to decline until it reached the two-foot mark. The next step was to time the fall of the water from the two-foot mark to the one-foot mark accurate to a tenth of a second. This information, known as the fall time, can be used to estimate the flow resistance of the material into which the well was placed. The groundwater flow is the product of the pressure, the subsoil conductivity, and the area over which the flow takes place (the length of the area of the shoreline where groundwater flow enters the lake multiplied by the distance that that area protrudes into the lake).

Finally, data was collected on the magnitude of the precipitation that was falling on the lake. This was another critical figure in the calculation of the water input because, though the rainwater may not remain in the lake for a long period of time due to evaporation, the water that does reenter the atmosphere leaves behind whatever nutrients and/or dissolved particles that it may have contained. Obtaining this data consisted of allowing the day-to-day precipitation to accumulate in an acid-washed flask in an open area, so as to collect the maximum amount of precipitation and minimize contamination by the surrounding environment. The water in this flask was periodically measured for volume and removed for sampling by GLEC. Determining the total flow into Torch Lake from precipitation was not a task that TLA could complete with its own instruments. Thus, to determine a yearly flow for rainwater, it was necessary to access the Michigan Automated Weather Network (MAWN) database provided by Michigan State University. This site provided the total amount of precipitation over a one year period in the area of Torch Lake, which from November, 2004 to November, 2005 was roughly twenty-five inches. To turn this number into an actual flow, the number of inches of rain was converted to feet and multiplied by the area of the lake in square feet. This calculation provides us with both an annual average flow (cfs) and a total volume (ft^3) of rainwater entering the lake, depending on the time scale (ref. #1, Appendix E). As far as volume of water goes, the rate at which water evaporates off of the surface of the lake nearly equals the rate at which it falls onto the lake, so the actual volume of the body remains relatively constant (ref. Lake 2K model).

Output Sampling Methodology

The major pathway for water departing Torch Lake is Torch River, and all other flow out of the lake is presumed to take place by evaporation. Torch River also represents the only source of nutrients leaving the lake because, as mentioned earlier, there is no groundwater flow out of the lake and the precipitation leaves the nutrients that it contained behind when it evaporates.

Phosphorus Level Analysis Methodology

As the predictive water-quality model was mainly concerned with phosphorus, each input and output to Torch Lake had to be analyzed for the nutrient's presence. Obtaining water samples from each water source required varying techniques so as to prevent contamination, and thus incorrect results. The actual phosphorus analysis procedure, however, remained identical.

Once the information required to calculate the flow of a tributary was collected, it was necessary to acquire a sample of the water for phosphorus analysis. The procedure that we followed to do this was relatively simple, but critically important. It consisted of using one acid-washed (to minimize phosphorus contamination) glass bottle. This bottle was completely submerged in the water, preferable near the area with the greatest flow. While beneath the surface, the cap of the bottle was carefully unscrewed to allow water to enter. When the water level in the bottle was sufficient for use by the lab, the cap was re-tightened and the bottle was removed from the water. Once this was done, the sample was placed on ice until it could be delivered to GLEC.

Perhaps the most interesting phosphorus data came from the groundwater. Until the installation of the shore-side wells by TLA, there was no good way of sampling groundwater. The only wells were those found at residences and were typically 50 to 150 feet deep; frequently below a layer of clay which separates shallow groundwater from deep groundwater. The water from wells sampled from other lakes with similar soil types has showed low phosphorus (~ 4-6 ppb). Once the sampling wells were put in place by volunteers and interns, it made the collection of said water much more feasible. To do this, a small, electric pump had to be connected to the polyethylene tube protruding from the sand. This pump was usually powered by a length of cord either attached at the corresponding residence or a nearby surface craft. Once the pump was in operation, a process which involved priming the pump with lake water and submerging the tubes to remove air, it was attached to the well tube. At first, the water that exits the tube is warm and filled with sediment, because it is filled with surrounding lake water. The pump is allowed to operate for one to three minutes so as to cause the pump to begin drawing water near the imbedded well point. Recall that the well point had a screen near the end to prevent any solid particles from entering. The water that finally emerged is cold and clear, and this is what the sample is taken from. As in sampling tributary water, the well water pumped into an acid-washed glass bottle in a volume satisfactory for testing and placed on ice. These samples, too, were delivered to GLEC.

Another vital component of the total phosphorus input came from rainwater. As discussed previously, the collection of rainwater was completed by placing a sterilized flask in an open area and allowing rainwater to accumulate within it. This water was collected after storm events, chilled, and also taken to GLEC.

GLEC analyzed all of the water samples collected, as TLA did not have the means to do so effectively, and returned the results complete with margins of error. The process by which the analysis occurred is explained in the GLEC Standard Operating Procedure (S.O.P.), and is summarized in Appendix H.

The results that were received from GLEC were used to calculate the phosphorus input from each of the tributaries feeding Torch Lake. This calculation is made much simpler by the conversion of all water inputs and outputs to flows in cubic feet per second (cfs). Actually determining the phosphorus input from each source proceeded as follows: the previously determined flows were converted from cfs to cubic feet per year (ft^3/yr), and then to liters per year (L/yr). These conversions allow the cancellation of units at the end. From this point, the GLEC data for each water source or destination was referenced, and converted to a more manageable unit: ug/L (ppb). This value was then multiplied by the corresponding flow (L/yr), the units cancel, grams are converted to kilograms, and what was left was the total input of phosphorus from that source over the last one year period. Approximately ten percent of the total water samples submitted to GLEC for analysis were blank or replicate samples in order to provide constant accuracy assurance on our results. Before tributary sampling began, all of the glass bottles were acid washed and blank samples were taken to ensure minimal contamination of their contents; samples were collected multiple times throughout the summer to achieve consistent results. Before any samples of groundwater were taken, blanks were drawn from the same sampling apparatus before the well was driven. Additionally, samples of lake water from the same location as each well site were collected in order to establish a comparison and to be certain that lake water was not simply being drawn from the well. As with the other water sources, the flasks used in the collection of the rainwater samples were filled with samples of distilled water and checked for contaminants before any real samples were collected. The instruments used in sampling the water from all sources were checked for the presence of contaminants and pre-existing phosphorus before their use. As well, nearly every data point that was collected was a duplicate so as to increase the likelihood of acquiring untainted samples and the chance of recognizing errors.

Results

Once the inflows of phosphorus from tributaries, rainwater, and groundwater, and the outflow from Torch River were calculated, the sum of the inflows and the outflow were compared. The total inflow was 3910 kilograms per year and the outflow was about 988 kilograms per year. However, this created a problem: the total inflow of phosphorus to Torch Lake was almost four times larger than the total outflow. If these numbers were the only factors acting on the lake, the levels of phosphorus in the lake would be increasing rapidly. However, this was not the case. So where was all of this excess phosphorus going?

For some time, it has been the opinion of TLA that a major percentage of the phosphorus entering Torch Lake was being deposited to the bottom in the sediment, but what evidence was there to support this theory?

The first piece of evidence was the difference in the inputs and outputs. To precisely determine how much phosphorus was remaining in the lake, a retention fraction was used. By dividing the difference of the input and output by the total input, it becomes clear that 75% of all of the phosphorus entering Torch Lake remains there (ref. Appendix G, #4). If the level of phosphorus is not changing and the input and output do not balance, then the phosphorus must be going somewhere else.

The second piece of evidence that lead TLA to believe the sedimentation theory was the actual sampling of the sediment. To collect samples of this sediment, two different techniques were used, the first being to take a core sample of the bottom. To do this, a heavy, metal cylinder (pictured right) was lowered over the side of a surface

Core sampler

craft and allowed to descend quickly to the bottom of the lake where it became lodged in the sediment. This device was then pulled up and the sediment core removed. The different layers of sediment in the core were analyzed for phosphorus content. The second method of sediment collection was the use of a Ponar dredge (pictured right). This mechanism is essentially a pair or open jaws held by a spring. The device is lowered to the bottom and imbeds itself there due to its own momentum. The slack created on the rope triggers the trap and it snaps shut with sediment inside. These samples, too, were taken to GLEC for analysis of the phosphorus content of the collected sediment, the results of which are summarized below.

Ponar dredge

Total Phosphorus Leaving Torch Lake From Sediment Settling

Date	Trap	Phosphorus Concentration (mg/kg or ppm)
5/28/2005	Top (of core sample)	**467**
5/28/2005	2nd Down (" " ")	**216**
5/28/2005	3rd Down " "	**431**
5/28/2005	Bottom " "	**301**
Average Concentration Of Phosphorus =		**353**

This data shows us that the concentration of phosphorus found in the sediment at the bottom of Torch Lake contains over *70,000 times more* phosphorus that does the water that is entering from Clam River or leaving by Torch River. In addition, the water that is a mere centimeter above the sediment on the lake floor has a concentration 70,000 times less than that of the actual sediment itself. Data acquired from year-round testing reveals that the concentration of phosphorus in this water never seems to change despite its close proximity to the nutrient-laden sediment.

Though a great deal of phosphorus is settling out of the water in Torch Lake each year, the mechanism by which this process takes place is not well understood. Some of the nutrient undoubtedly returns to the sediment when dead organisms drift to the bottom of the lake and decompose there. More yet may be deposited by a reaction with $CaCO_3$ whereby phosphorus is precipitated. Detailed sediment analysis and sediment traps placed by TLA at intermediate depths in the lake should eventually provide the data needed to properly digest these processes, but until then, the details are clear.

Useful Derived Data

Water Source	Water Flow [cfs]	Phosphorus Concentration [ppb]	Phosphorus Flow [kg/yr]
Clam River	198	4	766
Tributaries	16	12	214
Rainwater	54	40	1.93x10^3
Groundwater	30	30	1000
Evaporation	-40	0	0
Torch River	-230	4	-988
TOTAL	**28**	~	**2922**

Several important figures can be derived from the data collected thus far. First and foremost is the universal timescale for the phosphorus in Torch Lake (ref. Appendix G,

#5). This is calculated by dividing the total phosphorus in Torch Lake by the flow of the phosphorus to the bottom, which is the same as the difference of the input and output. This number tells us that the time that it would take for half of the total amount of phosphorus in Torch Lake to leave by Torch River or settle out of the water would be about 2.2 years. Next, we can determine doubling times, that is the amount of time that it would take for the concentration of the phosphorus in Torch Lake water to double (ref. Appendix G, #2,3). Two different figures were calculated, the first being for the cessation of the sedimentation. This value is found by dividing the total mass of phosphorus in Torch Lake by the total input of phosphorus, revealing a time period of 1.6 years, meaning that in less than two years, phosphorus concentrations in the lake water would double if the nutrients quit settling to the bottom. Second, and perhaps most pertinent to the water quality model itself, is the doubling time for the doubling of groundwater input. This value is found by dividing the total mass of phosphorus in Torch by the phosphorus input from groundwater, yielding 6.6 years. This means that, were some large environmental event to occur and double the phosphorus input, it would take a mere six and a half years for the concentration of phosphorus in the lake water to increase twofold.

Conclusion

From all of the research performed during this study, a great deal of valuable knowledge was gained. The water flowing into Torch Lake comes from three major sources: tributaries, precipitation, and groundwater flow. Of these sources, rain makes the greatest contribution of phosphorus (about 50%), with tributary and groundwater flow each inputting about 25%. By comparing the outflow of Torch River to these inputs and calculating a retention fraction it becomes clear that most of the phosphorus remains in the lake (about 75%). This represents the first major conclusion made through the research that took place this year. Second was the average time for phosphorus to reach the bottom or the settling time. This is the total phosphorus in the lake divided by the rate of flow to the bottom (the difference in the input and output per year). This time is about 2.2 years and also represents the universal timescale for phosphorus in Torch Lake (ref. Appendix G, #5). When this time is compared to that for of the residence time or flushing time in Torch Lake some interesting conclusions can be drawn. The residence time is the total volume of the water in Torch Lake divided by the output flow rate, and the result is about 15 years. Thus, water enters Torch and stays for a long period of time while it processes its phosphorus. Beyond this, the distribution of phosphorus in Torch is so uniform that differences between the top and bottom, as well as all other areas are practically nonexistent. Because of this, it can be asserted that the phosphorus mixing time must be fairly short and, in all likelihood, less that the settling. Overall, one has the impression that there is a lot of chemistry occurring in Torch that happens much faster than water flows through it, causing the lake to act as a sort of natural filter for phosphorus.

Summary

Constraints on the study conducted this summer due to time, resources, and methodology undoubtedly produced some results of an uncertain nature. While measuring input and output water flows, the use of two different probes increased the chance of erroneous data being collected along with the frequency of estimation in data summary. As well, a limited amount of information was collected on the storm events and their impact on flows and phosphorus levels. Data collected on the flows of Clam and Torch Rivers were probably the most influential variables to the accuracy of this report. To offset the range of flows determined from these tributaries, the readings were frequently taken on the same day and under the same weather conditions. Even so, the flow difference of 30 cfs remains uncertain by 30 cfs in either direction and this potential difference heavily impacts the calculation of other values including the retention fraction and settling time. Sedimentation could not be measured directly with any real frequency, so the data there is also limited. These errors and many more may have created gaps or flaws in the information that was collected this summer. These inaccuracies would far extend beyond the reporting limits of the analysis facility. The uncertainty on all laboratory phosphorus samples (tributary, rain, and ground water) was about one part per billion, and the range of solid samples (sediment) was between ten and forty milligrams per kilogram.

Even though mistakes in the collection and analysis of data may make the water quality model less accurate, without making attempts at such data collection no progress would be made and decisions would have to be based on ever less reliable information. The work that took place during the past summer will contribute to the creation of the water quality model described earlier as well as reveal possible methods in which to make future studies more effective.

Shanty Creek Watershed

Shanty Creek watershed is an area of land located in Kearney Township and to the southeast of Lake Bellaire. The precipitation and corresponding runoff from this region drain west into Grass River, eventually flowing into Clam River and Torch Lake. The area is approximately 2.6 square miles and is primarily composed of forested area (about 66%). Other than forests, grass and shrubs, urban areas, agricultural land, and wetlands that make up 15%, 13%, 4%, and 1% of the remaining land use, respectively. A chart displaying this data can be found in Appendix D.

Acknowledgements

The internship opportunity provided to us this summer has been an invaluable experience in my educational career. Three Lakes Association has built a program that serves many purposes by not only preserving the environment, but also educating the community about what they can do to help.

The internship program could not exist without dedicated individuals like Norton Bretz and Dean Branson. These two spent countless hours of their own lives assisting we interns with our reports, and twice that much time helping us to comprehend why the data we were collecting was so important and what sort of an impact it would have in the future. These two were truly the life blood of what we did this summer.

Howard Yamaguchi also deserves a special “thank you” for all of the time that he put in creating the different maps and graphs to properly explain our watersheds. His skill with a computer remains unparalleled.

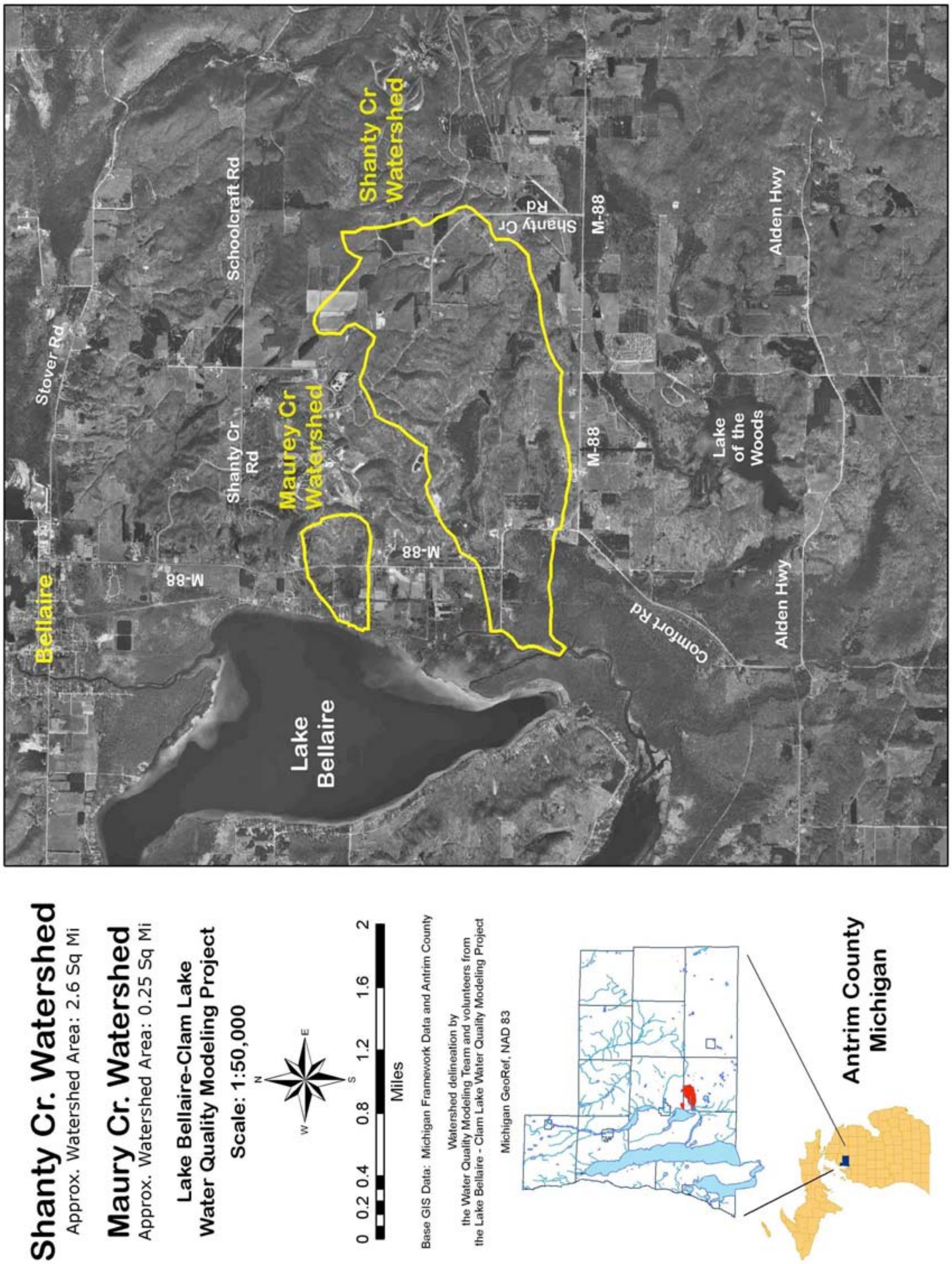
Last, but certainly not least, I would like to thank the team of interns and volunteer that assisted in our work this summer. Each Thursday, a dozen or more environmentally-conscious men and women drove from all over the area to participate and support our endeavors.

The opportunity provided to me this past summer is one unmatched in any other facet of my education. The experiences that we had gave us an enlightening view the realm of environmental work I hope that this program will continue to take on interns in the future. In my opinion, every student should be able to be a part of such an eye-opening project.

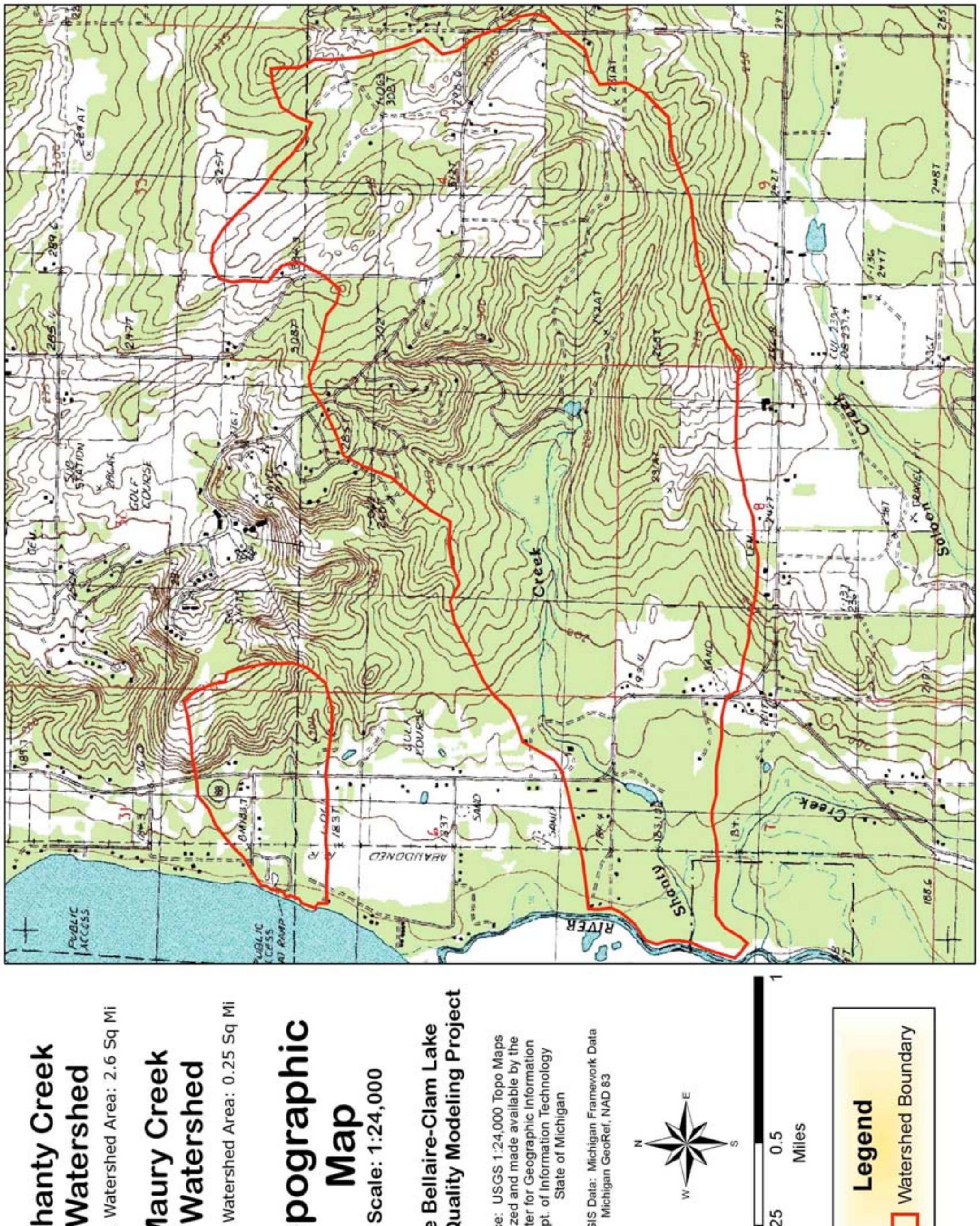
References

[1] Development of a Predictive Nutrient-Based Water Quality Model for the Three Lakes System Year 1: Torch Lake, T. Hannert, D. Branson, M. DeGraeve and D. Endicott, Three Lakes Association and Great Lakes Environmental Center, 04 MDEQ grant PO# 761P40021 (June, 2004).
[2] Torch Lake - Flow Rates of Rivers and Tributaries, 2004 Internship Report, Keenan Bailey, Anna Ash, Dec. 30, 2004.
[3] GLEC SOP Number: CHM 2001: STANDARD OPERATING PROCEDURE FOR THE DETERMINATION OF TOTAL PHOSPHORUS IN SURFACE WATER SAMPLES.
[4] Seasonal Profiles of Temperature, 2005 Internship Report, Samantha Fox, Lauren Elbert, Oct. 30, 2005
[5] Gurley flow probe, Gurley Precision Instruments, 514 Fulton St., Troy, NY 12180-3315
[6] Van Dorn water sampling device, Geneq Inc., http://www.geneq.com.html
[7] Michigan Automated Weather Network, Michigan State University, [http://www.agweather.geo.msu.edu/mawn/]
[8] Standard Procedure for Estimating Stream Flow, West Virginia University Extension Service, [http://www.caf.wvu.edu/~forage/streamflow/estimat.htm]
[9] *Soil Mechanics* by T. W. Lambe and R.V. Whitman, MIT, John Wiley & Sons, Inc. NY (1969), pp. 281-294
[10] *Surface Water Quality Modeling,* S. C. Chapra, McGraw-Hill International Editions, NY (1997), pp. 283-285
[11] *Characterization of Groundwater Phosphorus Input to Torch Lake Version. 5*, N. Bretz, D. Branson, T. Hannert, P. Roush, and D. Endicott TLA Report, May16, 2005.

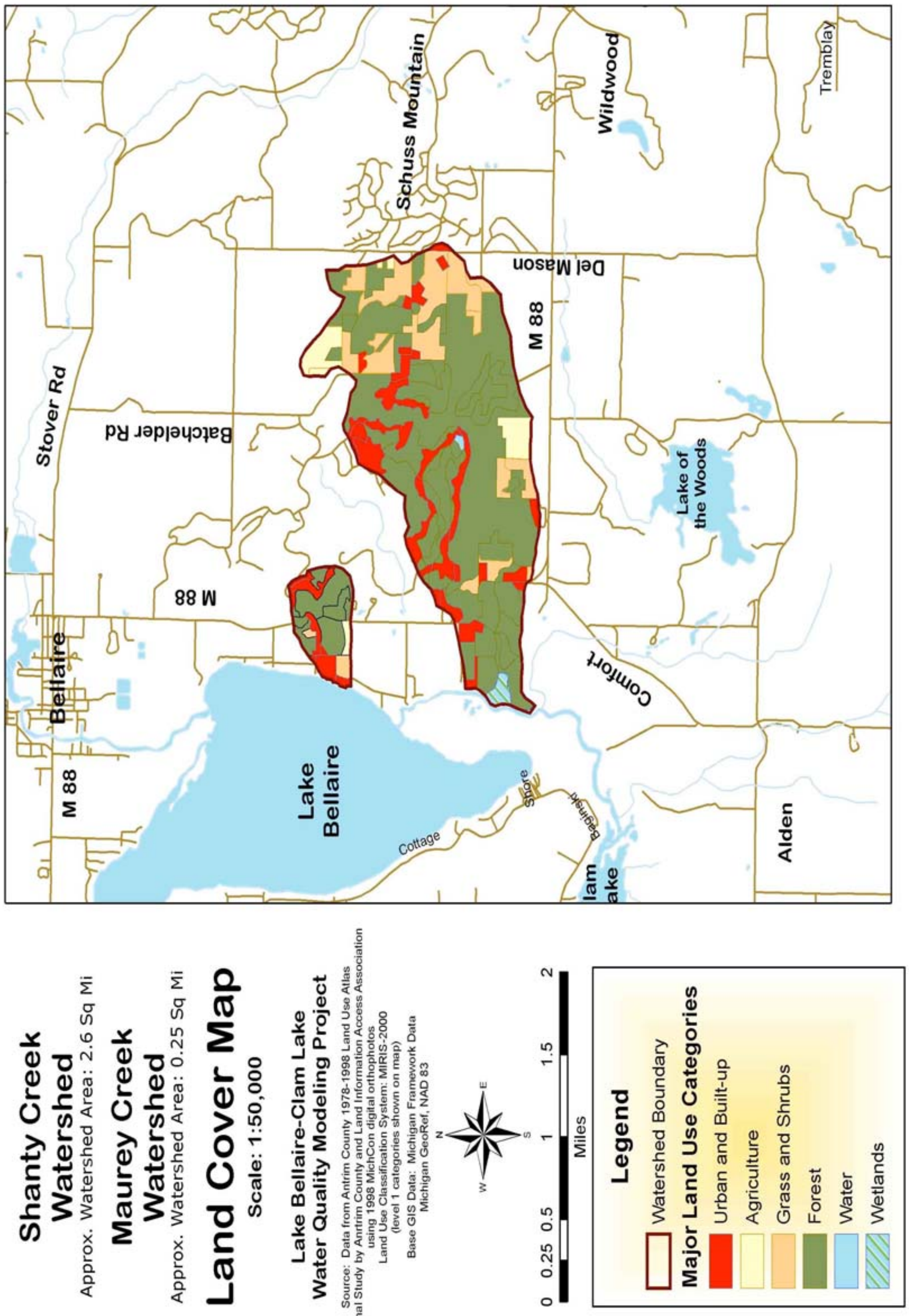
Appendix A


Shanty Cr. Watershed
Approx. Watershed Area: 2.6 Sq Mi
Maury Cr. Watershed
Approx. Watershed Area: 0.25 Sq Mi
Lake Bellaire-Clam Lake
Water Quality Modeling Project
Scale: 1:50,000
N
E
S
W
0 0.2 0.4 0.8 1.2 1.6 2
Miles
Base GIS Data: Michigan Framework Data and Antrim County
Watershed delineation by
the Water Quality Modeling Team and volunteers from
the Lake Bellaire - Clam Lake Water Quality Modeling Project
Michigan GeoRef, NAD 83
Antrim County
Michigan
Stover Rd
Schoolcraft Rd
Shanty Cr Rd
Shanty Cr Watershed
Maurey Cr Watershed
Bellaire
M-88
Shanty Cr Rd
Alden Hwy
Lake of the Woods
Comfort Rd
Lake Bellaire

Appendix B

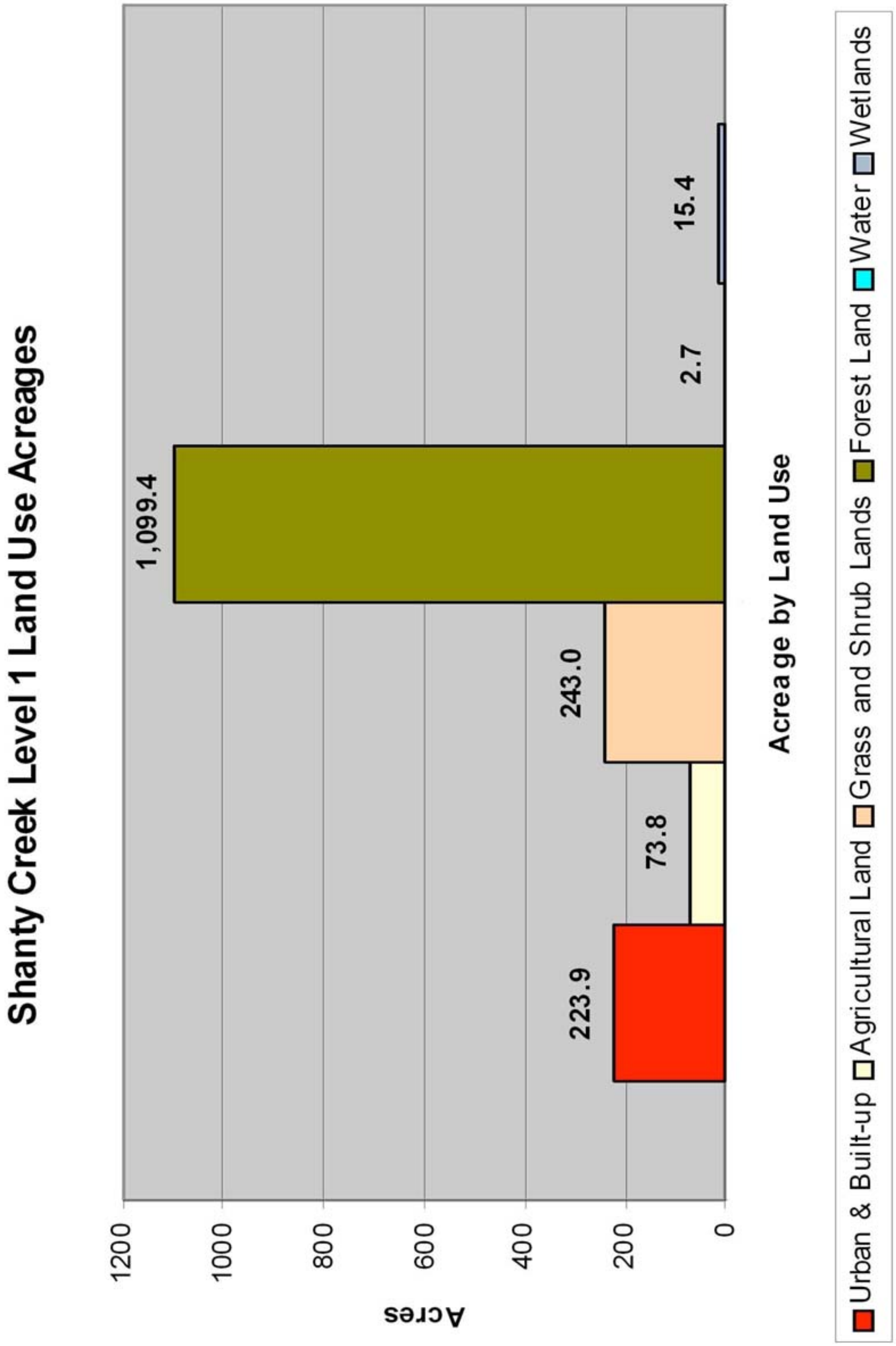

Shanty Creek Watershed
Approx. Watershed Area: 2.6 Sq Mi
Maury Creek Watershed
Approx. Watershed Area: 0.25 Sq Mi
Topographic Map
Scale: 1:24,000
Lake Bellaire-Clam Lake
Water Quality Modeling Project
Source: USGS 1:24,000 Topo Maps
Digitized and made available by the
Center for Geographic Information
Dept. of Information Technology
State of Michigan
Base GIS Data: Michigan Framework Data
Michigan GeoRef, NAD 83
N
E
S
W
0
0.25
0.5
1
Miles
Legend
Watershed Boundary
Shanty
Creek
RIVER

Appendix C



Land use within the Shanty Creek Watershed.

Appendix D



Shanty Creek Level 1 Land Use Acreages
Acres
1200
1000
800
600
400
200
0
223.9
73.8
243.0
1,099.4
2.7
15.4
Acreage by Land Use
Urban & Built-up
Agricultural Land
Grass and Shrub Lands
Forest Land
Water
Wetlands

Appendix E

Calculations

Input Phosphorus Flow

1. Rainwater

Total precipitation from 11/09/2004 – 11/09/2005 (ref. MAWN – MSU): 25.05 inches

Format: Rainfall in Area (in.) x area of lake (m^2) / Time Period (yr) = Liters per Year (L/yr)

Calculation: 2.09 ft. (25.05 in.) x 8.18x10^8 ft^2 / 1 year = 1.71x10^9 ft^3/yr or **4.84x10^10 L/yr**

Phosphorus: Because of the variation of the phosphorus content in the rainwater, half of the water was assumed to contain 20 ug/L or 20 parts per billion (ppb), and the other half was assumed to contain 60 ug/L (60 ppb).

Format: Flow (L/yr (1/2 of total)) x Concentration (ug/L or ppb) = Kg. Phosphorus per Year (kg/yr)

Calculation (1): 2.42x10^10 L/yr (1/2 of total flow) x 20 ug/L = **4.84x10^2 kg phosphorus per year**

Calculation (2): 2.42x10^10 L/yr (1/2 of total flow) x 60 ug/L = **1.45x10^3 kg phosphorus per year**

So: 4.84x10^2 kg phosphorus per year + 1.45x10^3 kg phosphorus per year = **<u>1.93x10^3 kg phosphorus entering Torch Lake from rainwater this year</u>**

2. Groundwater

Total averaged flow of groundwater into Torch Lake: 30.00 cfs

Format: Flow (cfs) x 3.15x10^7 seconds/year = ft^3/yr → L/yr

Calculation: 30 cfs x 3.15x10^7 sec/yr = 9.45x10^8 ft^3/yr = **2.68x10^10 L/yr**

Phosphorus: Because of the variation of the phosphorus content in the groundwater samples, half of the water was assumed to contain 25 ug/L (25 ppb), and the other half was assumed to contain 50 ug/L (50 ppb).

Calculation (1): 1.34x10^10 L/yr (1/2 of total flow) x 25 ug/L = **3.35x10^2 kg phosphorus per year**

Calculation (2): 1.34x10^10 L/yr (1/2 of total flow) x 50 ug/L = **6.70x10^2 kg phosphorus per year**

So: 3.35x10^2 kg phosphorus per year + 6.70x10^2 kg phosphorus per year = **<u>1.00x10^3 kg phosphorus entering Torch Lake from groundwater each year</u>**

Appendix E (cont.)

3. Tributaries

Primary tributaries feeding Torch Lake: Clam River, Spencer Creek, A-Ga-Ming Creek, Wilkenson Creek, Meggison Creek, Eastport Creek

Format: Flow (cfs) x 3.15x10^7 seconds/year = ft^3/yr → L/yr

Calculation (Clam River): 198 cfs x 3.15x10^7 sec/yr = 6.24x10^9 ft^3/yr = **1.77x10^11 L/yr**

Phosphorus: The phosphorus input from each tributary (kg/yr) is calculated by multiplying the ug/L (ppb) averaged from the water samples by the total flow of water into Torch from that tributary each year (L/yr).

Calculation: 1.77x10^11 L/yr x 4.33 ug/L = **7.66x10^2 kg phosphorus per year from Clam River**

The phosphorus inputs/outputs for all tributaries feeding/draining Torch Lake are calculated in the same fashion. A summary of these values is contained in Appendix G.

4. Total Input

Format: Total phosphorus input from rainwater (kg/yr) + Total phosphorus input from groundwater (kg/yr) + Total phosphorus input from tributaries (kg/yr) = Total phosphorus flow into Torch Lake

Calculation: 1.93x10^3 kg/yr + 1.00x10^3 kg/yr + 9.80x10^2 kg/yr = **<u>3.91x10^3 kg phosphorus entering Torch Lake this year</u>**

Appendix F

Calculations

Output Phosphorus Flow

1. Torch River

Total Phosphorus Output of Torch River: **9.88x10^2 kg phosphorus per year**

2. Sedimentation (Mass Balance)

Theory: Since the levels of phosphorus in Torch Lake have seen no significant changes in recent history, the amount of phosphorus entering Torch Lake and the amount leaving Torch Lake must be equal. When water evaporates from the surface of the lake, the phosphorus that it contained is left behind. As well, no groundwater is leaving the lake (deduced by groundwater sampling techniques), and so the phosphorus must be going elsewhere. When we compare the total inflow of phosphorus to that of the outflow out Torch River, a problem arises: the inflow nearly quadruples the outflow. Thus, we can deduce that the phosphorus must be depositing itself as sediment that makes its way to the lake floor.

Format: Total inflow of phosphorus (kg/yr) - Phosphorus flow out Torch River (kg/yr) = Total amount of phosphorus deposited as sediment (kg/yr)

Calculation: 3.91x10^3 kg phosphorus entering Torch - 9.88x10^2 kg phosphorus leaving Torch by Torch River = **<u>2.92x10^3 kg phosphorus being deposited as sediment</u>**

Appendix G
Calculations

Derived Calculations

1. Total Phosphorus in Torch Lake

Format: Volume of Torch Lake (L) x Concentration of phosphorus in lake (ug/L or ppb)

Calculation: 3.23x10^12 L x 2.0 ug/L = **6.46x10^3 kg phosphorus in Torch Lake**

2. Doubling Time for Phosphorus Concentration if Sedimentation Ceased

Format: [Amount of phosphorus in the lake (kg)] / [Total Inflow of Phosphorus (kg/yr)] = Time to double (years)

Calculation: [6.46x10^3 kg phosphorus in lake] / [3.91x10^3 kg/yr flowing into the lake] = **1.65 years for the phosphorus to double if sedimentation ceased**

Conclusion: The sedimentation represents the single greatest destination for phosphorus entering Torch Lake (ref. #2, Appendix F). Thus, were this sink to cease, it would take the least amount of time for the concentration of the phosphorus in Torch Lake to double. The calculations above reveal the time period over which this event were to occur: 1.65 years.

3. Doubling Time for Phosphorus Concentration if Groundwater Input Doubled

Format: [Amount of Phosphorus in Torch Lake (kg)] / [Inflow of phosphorus from groundwater (kg/yr)] = Time to double (years)

Calculation: [6.46x10^3 kg phosphorus in lake] / [1.00x10^3 kg/yr entering Torch Lake from groundwater] = **6.46 years for the phosphorus concentration to double**

Conclusion: Groundwater represents a major source of phosphorus that flows into Torch Lake each year. Development (i.e. new houses, lawns, drainage fields, and waste management structures) will cause the concentration of water entering the lake from above- and below-ground runoff to increase. Were this concentration to double, the time period over which the phosphorus concentration in the lake doubled would be approximately 6.46 years.

Appendix G (cont.)

4. Retention Fraction - Phosphorus

Format: [Total Phosphorus Entering Torch Lake (kg) - Total Phosphorus Leaving Out Torch River] / [Total Phosphorus Entering Torch Lake (kg)] = Percent of Phosphorus Remaining in Lake

Calculation: [3.91x10^3 kg phosphorus entering lake - 9.88x10^2 kg phosphorus leaving the lake by Torch River] / [3.91x10^3 kg phosphorus entering lake] = **75% of phosphorus remains in the Lake**

Conclusion: A certain amount of phosphorus enters Torch Lake each year, and we know by the high sedimentation figures (ref. #2, Appendix F) that most of that remains in the lake. By this calculation it is evident that three-quarters of all of the phosphorus that enters Torch Lake remains there, primarily as sediment.

5. Phosphorus Timescale

Format: [Total Phosphorus in Torch lake] / [Phosphorus Flow to the Bottom of the Lake (Inputs – Outputs)] = Timescale (years) for phosphorus half-life if inputs and outputs ceased

Calculation: [6.46x10^3 kg phosphorus in Torch] / [3.91x10^3 kg/yr phosphorus into Torch – 9.88x10^2 kg/yr phosphorus out of Torch] = **2.21 years for ½ of the total phosphorus to disappear after cessation of inputs and outputs**

Conclusion: This represents the universal timescale for the settling of phosphorus in Torch Lake.

Appendix H

GLEC Phosphorus Analysis S.O.P

Surface water samples that need to be analyzed for total phosphorus are tested using GLEC's standard operating procedure for the analysis of total phosphorus. This process identifies dissolved, organic, and solid phosphorus by digestion to easily identifiable orthophosphates. These molecules are then treated with ammonium molybdate and potassium antimony tartrate in acidic solution to yield a complex. This complex, once reduced with ascorbic acid produces a blue aqueous solution that is measured for transmittance/absorbance by a spectrophotometer (GLEC SOP Number: CHM 2001: Standard Operating Procedure for the Determination of Total Phosphorus in Surface Water Samples) This experimentation reveals the total amount of phosphorus present in each sample, which is the sum of dissolved and particulate phosphorus, and was reported by GLEC in mg/L (ppm).

Appendix I

Standard Procedure for Estimating Stream Flow

For the determination of the flow of deeper water channels, it is necessary to find the flow of each section of the channel and then sum these numbers to produce a total flow because the rate of the flow of the water is not uniform at different widths and depths. To do this, a flow meter with an impeller was used. The probe was submerged at several equidistant points across the width of the river. At each location, the depth of the river was determined using an incremented pole. The flow probe was then submerged and allowed to collect two readings; one reading was taken at twenty percent of the total depth of the river and the second at eighty percent of the total depth. When all of the measurements were completed, flows were determined for individual sections of the river and these values were summed to produce the total flow of the channel.

Appendix J

Total Phosphorus Entering Torch Lake From Rainwater

Sampling Date	Location	Actual Phosphorus Concentrations (ppb)
7/3/2005	Blank Rain Collector	4
~	~	~
6/16/2005	Alden	28
7/25/2005	Alden	116
8/4/2005	Alden	3
6/16/2005	Eastport	80
7/4/2005	Eastport	15
7/27/2005	Eastport	3
8/4/2005	Eastport	27
8/1/2005	Bellaire	15
8/3/2005	Bellaire	20
8/4/2005	Bellaire	7

Total Rainwater flow: 54.27 cfs (11/04-11/05)

Concentrations of phosphorus in rainwater:

1/2 of total flow at 20 ug/L = **480 kg phos/yr**

1/2 of total flow at 60 ug/L = + **1450 kg phos/yr**

TOTAL: 1930 kg phos/yr from rainwater

Total Phosphorus Entering Torch Lake From Groundwater

Averaged total flow of Groundwater: 30 cfs

Concentrations of phosphorus in rainwater:

1/2 of total flow at 25ug/L = **330 kg/yr**

1/2 of total flow at 50 ug/L = **+ 670 kg/yr**

TOTAL: 1000 kg phos/yr from groundwater

Appendix J (cont.)

Total Phosphorus Entering Torch Lake From Tributaries

Date	Tributary	Phosphorus Concentration (ppb)
7/29/2005	Clam River	4
7/29/2005	Clam River	8 **(Ne)**
7/29/2005	Clam River	5
8/11/2005	Clam River	4
7/7/2005	Eastport Creek	15
7/7/2005	Eastport Creek	15
7/7/2005	Eastport Creek	16
5/5/2005	Spencer Creek	18
7/7/2005	Spencer Creek	6 **(Ne)**
7/29/2005	Spencer Creek	16 **(SE)**
7/7/2005	Wilkinson Creek	6

(Ne) = Negated Value, (SE) = Storm Event

	Conc (Phos)	Flow (cfs)	Flow of Phos.
Clam River:	4.333333	198	**762 kg/yr**
Eastport Creek:	15.33333	0.17	**2 kg/yr**
Spencer Creek:	17	12.14	**184 kg/yr**
Wilkenson Creek:	6	0.66	**4 kg/yr**
Meggison Creek:	10	0.45	**4 kg/yr**
A-Ga-Ming Creek (north):	10	2.66	**+ 24 kg/yr**
TOTAL:		**980 kg phos/yr from tributaries**	

Total Inflow of Phosphorus to Torch Lake

Source	Phosphorus Contribution
Rainwater	**1930 kg phos/yr**
Tributaries	**980 kg phos/yr**
Groundwater	**+ 1000 kg phos/yr**

3910 kilograms of phosphorus entering Torch Lake each year

Total Phosphorus Leaving Torch Lake From Torch River

Date	Phosphorus Concentration (ppb)
6/23/2005	6
6/23/2005	8
6/30/2005	3
7/29/2005	2

	Conc (Phos)	Flow (cfs)	Flow of Phos.
Phosphorus Out Torch River:	4.75	233	**988 kg/yr**