Estimates of groundwater entering Torch Lake
plus
Cedar River watershed and land-use

Fig 1. Aerial view of Torch Lake (Ref 1)

Fig 2. Emily Lowery and Jessica Arnold learning how to use Secchi disk

by

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Abstract

In order to develop a computer model of nutrient flow in Torch Lake and predict its future, one needs to know the input and output sources of water and the nutrients it contains. All of these sources and sinks can be measured directly except groundwater. This paper will develop and compare three different methods that can be used to find the total groundwater flow into Torch Lake:

* Difference method
* Watershed method
* Piezometer method

The first method estimates the flow as a difference between all the other sources of flows in and out of torch. The second method is less accurate than the first. The idea with this method is that all groundwater comes from a fraction of the rainfall in the Torch watershed. The third method was created using information from a number of sample wells located around the lakeshore. For the **difference method** we found that there was a groundwater flow into Torch to be approximately **48 cubic feet per second** with an uncertainty around 20-60 cfs. For the **Watershed method** we found that there was a groundwater flow into Torch of approximately **28 cubic feet per second** with an uncertainty from 14-56 cfs. For the **Piezometer method** we found that there was a groundwater flow into Torch to be approximately **95 cubic feet per second** with an uncertainty from 20-140 cfs.

Introduction

As part of Three Lakes Association's (TLA's) ongoing efforts to protect the quality of water in Torch Lake, Clam Lake, and Lake Bellaire, Michigan Department of Environmental Quality (MDEQ) awarded TLA $62,000 grant on June 1, 2004. Seven townships (Helena, Milton, Kearney, Torch Lake, Custer, Forest Home, and Clearwater) contributed $8,000 and special donations from TLA members for this project totaled $5,000. The remaining $75,000 "funds" to build a predictive water quality model for Torch Lake corresponded to the in-kind volunteer's time associated with the field work, including the summer intern's community service time.

A second grant was received on July 1, 2005 to build a similar model for Lake Bellaire and Clam Lake in 2006. Eventually TLA would like to add the rest of the Chain-of-Lakes including the upper chain above Bellaire and the lower chain below Torch Lake. The Great Lakes Environmental Center (GLEC) has also made tremendous contributions. They provide the testing facilities for all our sampling and the development of the computer based model. The Three Lakes Association contributed money for supplies, equipment, and volunteers. Many of the volunteers are people who live on Lake Bellaire, Torch Lake, and many others. Other volunteers such as myself are high school students with an interest in science.

The Three Lakes Association has chosen to study phosphorous because it is the primary nutrient for our lakes and is an important factor in water clarity. The purpose of this study is to characterize the phosphorus levels in Torch Lake at the present time. A computer model for predicting phosphorus levels in the future with various estimates future development and population growth of doing this by monitoring and predicting population growth in the Torch Lake water shed. TLA is also estimating the amount phosphorus per person entering Torch Lake from septic systems. With this information the TLA will work with an Environmental Engineer from Great Lakes Environmental Center in Traverse City to build a nutrient-based predictive water quality model for Torch Lake. This will help our local township decision makers to evaluate future economic development projects that may change the amount of phosphorus entering Torch Lake resulting in a change in water quality.

In order to follow the transport of phosphorus through Torch Lake, one has to measure all the phosphorus inputs and outputs in Torch Lake. The inputs are Clam River, some small tributaries, rainfall, and groundwater. The outputs are Torch River and accumulation of phosphorus in the sediment at the bottom of the lake. Three Lakes Association volunteers and interns measured all of these components. They have measured the water flows in Torch and Clam and the phosphorus concentration in each, the total amount and phosphorus concentration in the rainfall, and the water flow and phosphorus concentration in groundwater. The part that will be discussed in this report involves estimating the water flow and phosphorus from shallow groundwater. To do this TLA installed 15 groundwater wells at 13 sites on the shoreline of Torch Lake. These wells were sampled three times, on a monthly schedule during the summer months. Measurements of the water level in the wells compared to the lake's level and the rate of change can be used to estimate the water flow into the lake. Phosphorus concentrations were measured from well samples (ref) from the TLA Groundwater Project Protocol.

The purpose of our project was to cross check the water-flow estimates from these wells compared to two other methods of estimating the same thing. One estimate is to calculate the total water available for groundwater from all the other water inputs and outputs, which is the "difference method". The other two methods involve an estimate of rainfall entering Torch Lake (precipitation method) and an estimate of groundwater entering Torch Lake (piezometeric method).

Body

Method One:

The first method of estimating ground water flow is described as the difference between all the sources of flow in and out of Torch. The data points we used for the inflow came from Clam River 233 cfs (Cubic Feet per Second) , minor tributaries 12.9 cfs, Precipitation 43 cfs(ref. 5) and groundwater flow in was currently unknown. Adding all the numbers together yields 289 cfs + groundwater cfs to get total inflow. The data points we used for outflow are Torch River 198 cfs, evaporation 34 cfs, and groundwater out 0 cfs. The total outflow of torch is 232 cfs. Subtracting the total outflow from the total inflow yields (289 – 232 = 57 cfs) you get the total groundwater entering Torch Lake. These measurements were taken by the Three Lakes Association 2005 summer volunteers every Thursday. There were two different types of probes we used to measure the flow. The first one is the Global Water flow probe and the second one is the Gurley type flow meter. Below is a reference section to show where all the numbers came from.

- Precipitation water entering Torch Lake = 43 cfs, based on….
  → Area of Torch Lake = 8.1×10^8 square feet ref (to the TLA Goundwater Project Report for a 1991 Antrim County watershed report, also this information is on the popular Chain of Lakes watershed map by Michigan Maps of Elk Rapids.
  → Precipitation in 2005 = 19.85 (ref.5)
  → Seconds per year = 3.14×10^7 seconds per year

- Evaporation water leaving Torch Lake = 34 cfs, based on…
  → 80% of total annual precipitation ref (to GLEC Lake2K model)

- Minor tributary water entering Torch Lake = 12.9 cfs, based on…. Ref Three Lakes Association volunteers, summer 2005)
  → The tributary flow was measured by the time it took a floating object to travel a certain distance such as a culvert
  → Spencer Creek = 9.44 cfs
  → Eastport Creek = 0.11 cfs
  → Wilkenson Creek = 0.33 cfs
  → A-Ga-Ming Creek = 1.36 cfs
  → Meggison Creek = 0.45 cfs
  → No-Name Creek = 0.61 cfs

Total = 12.9

- Inflow from Clam River = 233 cfs, based on….

  → Three independent measurements of flow ref TLS volunteers, summer of 2004 & 2005.

  → Each flow measurement was based on the width of the river (60ft) being divided in to 6 ft intervals and measured (Global Water flow probe and Ben Meadows, Gurley type flow meter) at 0.2 and 0.8 of the river depth

Fig 3. TLA Interns learning how to use Gurley Type flow meter

Fig 4. TLA Interns and volunteers measuring minor tributaries' flow

Method Two:

All the groundwater comes from rainfall. Only rainfall on the Torch watershed contributes to the groundwater flowing in at the edges minus the rainwater coming in from minor tributaries. If we assume that the topographic watershed and the underground watershed are the same and that minor tributaries we know about are the most significant ones, then we can just figure out the equivalent flow from the rainwater on the watershed to figure out the groundwater flow. Not all the water makes it to the water table because of evaporation. Because of evaporation, the amount of rainfall that reaches the water table is reduced. The watershed area of Torch Lake is approximately 1.6 times greater than the actual area of Torch Lake. We figured out the yearly average rainwater flow contribution directly into Torch was 43 cubic feet per second taking a yearly average rainfall for Aug. 2004 to Aug. 2005. If we multiply 1.6 to 43 cubic feet per and subtract 13 cubic feet per second, which is the minor tributaries, we end up with 56 cubic feet per second. We then have to include the evaporation rate. We couldn't find an exact evaporation rate for water on land around the Torch lake area so we used 50%, which is an educated guess. The evaporation rate can vary do to plant cover, temperature, humidity and other changes in the atmosphere. If the temperature is high then the evaporation rate is going to be higher and if the humidity is high then there will be less evaporation. So we then take 56 cubic feet per second and multiply by 50%. Doing this our estimate for the total groundwater flow from the rain on the watershed is 28 cubic feet per second.

Watershed Method			
	Torch's watershed is 1.6 times larger than the area of Torch Lake		
	43 cfs = The amount of rainfall from August 1, 2004 - August 31, 2005		
	13 cfs = Minor tributaries		
	50 % = equals evaporation rate		
1.6 * 43 cfs -13cfs = 56 cfs			
50%* 56 =	28 cfs	=	Groundwater flow in

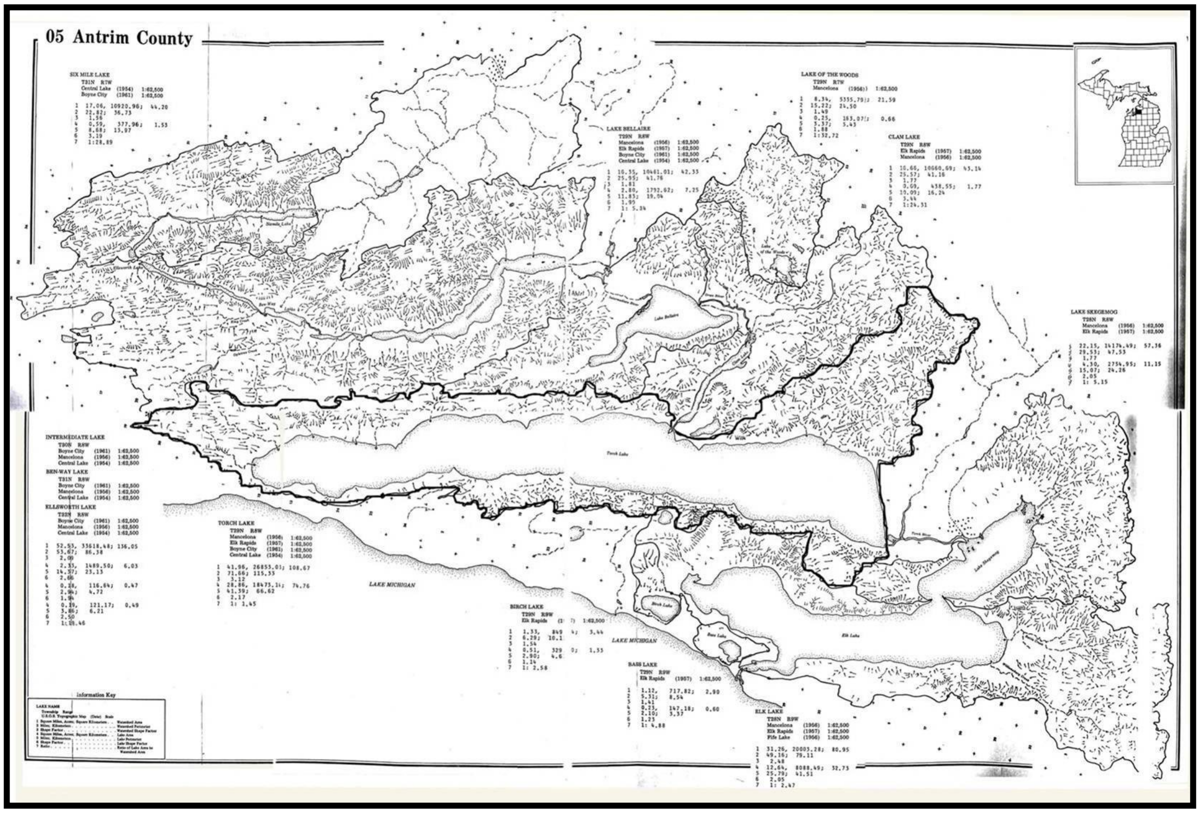


Fig. 5 Torch Lake watershed region (ref 4)

Method Three:

The third method uses measurements of the vertical flow of groundwater into the lake bed using an array of single piezometers (simple well tubes) inserted a small distance into the aquifer. In order to interpret the information from the peizometer measurements we assume that the flow field has no horizontal components and that the material in the soil surrounding the piezometer is uniform both vertically and horizontally. We further assume that our peizometer measurements are typical of the region between elements of the array. In this case one can obtain a simple estimate of both the hydraulic vertical gradient, dh/dl, and the hydraulic conductivity, K_h. Then using Darcy's equation one can estimate the total flow rate if one can estimate the area over which this flow takes place. Fig 1 shows an idealized picture of the piezometer and the variables that need to be measured. We assume that the groundwater flow is vertical, into the lake and therefore the hydraulic head, dh, is positive, that is, the water in the piezometer tube will rise above the water surface. This is commonly known as an artesian system. The gradient length, dl, is the depth of the piezometer sampling region below the water surface, so that dh/dl is a unitless number. We further assume that the hydraulic conductivity is isotropic, that is the horizontal and vertical components are the same (K_v = K_h) as would be expected in a uniform medium. As long as the tube is transparent the hydraulic head can be measured with a ruler. The well depth, dl, must be measured in the same units. Darcy's equation relates the flow to the hydraulic gradient, dh/dl, and the hydraulic conductivity as follows:

$$Q = A(dh/dl)K_v.$$

where Q is the groundwater flux or flow rate (cubic feet per second)
A is the area over which the flow takes place (square feet)
dh/dl is unitless
K_v is the vertical hydraulic conductivity (feet/second)

The groundwater flux can be determined if one can estimate A and measure K_v. To measure K_v one fills the piezometer with water to a height, H. If nothing further is done, the water level will return to its equilibrium level, dh. The lower the groundwater conductivity, the slower the return to equilibrium.

The point is made of steel and has a shoulder that fits loosely in the bottom end of the well pipe. The screen is made of polyester mesh with a pore diameter of about 0.1-0.3 mm, otherwise known as no-see-um mosquito netting. The plastic tubing is perforated and anchored to the point. About 3" of mesh is wrapped three times around the tubing and secured with stainless steel wire (Fig. 2) resulting in an effective pore size of about 0.1 mm. The polyester mesh with some typical beach sand is shown in Fig. 8. The point assembly is thoroughly rinsed in alcohol and distilled water and wrapped in a plastic bag before being deployed.

Fig. 6 - Well point, mesh screen, and sampling tube (Ref 7)

The groundwater hydraulic conductivity, K, can be determined in two equivalent ways: the constant head method or the falling head method. In the falling head technique the piezometer tube is filled to a height H_2 and allowed to fall to H_1 in time t_2-t_1. The valve X remains closed or this part eliminated. The following formula then gives the conductivity. (ref 7, 8)

$$K_h = [D^2/8L(t_2-t_1)]\ln\{(L/D) + [1+(L/D)^2)]^{1/2}\}\ln(H_2/H_1)$$

If $L/D > 4$ $$K_h = [D^2/8L(t_2-t_1)]\ln[2(L/D)]\ln(H_2/H_1)$$

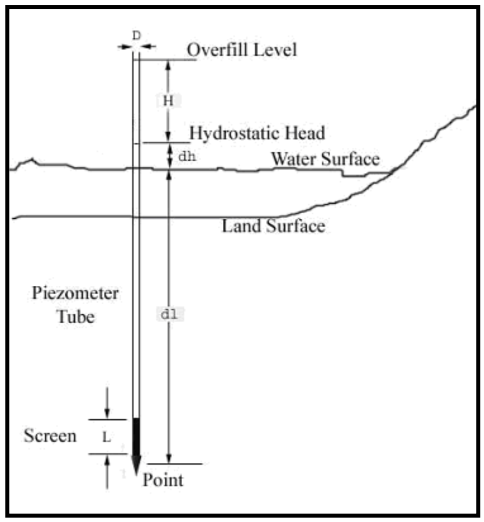


Fig 7. Variables used in piezometer calculation (Ref 7)

For the falling head method

Piezometer method WELL #		Well Depth (in)	Head Depth (in)	Time (sec)	H1 (in)	H2 (in)	Conductivity (in/s)	Area (ft^2)	Flow (cfs)
1		84	0.3	3.6	12	36	0.00072	1,155,264	0.2
1		84	1	6	12	36	0.00043	1,155,264	0.5
1		84	0.25	6.5	12	24	0.00025	1,155,264	0.1
2		24	1	1	12	36	0.00258	990,000	8.9
6									
4									
5									
7		24	3.5	5	12	36	0.00052	2,673,264	16.8
8		36	0.5	1	12	36	0.00258	2,475,264	7.4
10		24	3	1.5	16	40	0.00143	1,650,000	24.6
11		24	2	1	12	24	0.00163	1,155,264	13.1
12		36	0.3	2	12	24	0.00081	1,023,264	0.6
13		36	2	1	12	24	0.00163	1,122,000	8.5
15								1,254,000	
16								660,000	
17								264,000	
18								924,000	
19.5		72	3	2	12	24	0.00081	30,000	0.1
19.5		108	4	25	12	24	0.00007	30,000	0.0
20								759,264	
21								1,155,264	
24		30	5	2.5	12	24	0.00065	1,452,000	13.1
23		48	0.5	1.8	12	36	0.00143	1,155,264	1.4
								Total Groundwater flow	**95**

table 2 results using falling head method

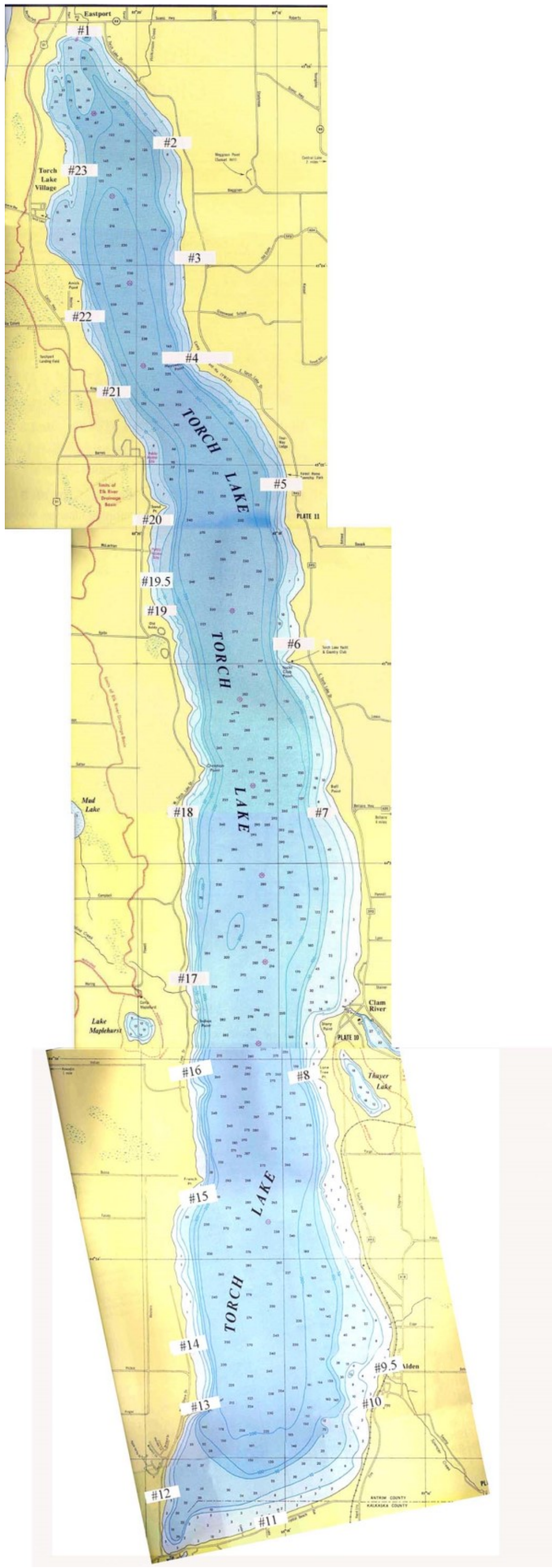


Fig. 8 Torch Well Locations

Assuming that we have made our best guess for each there is a variation in the values of 28 to 95 cfs. One of the reasons for trying all three methods is to find this range. The methods use techniques which are independent of each other. Multiple measurements of the flows in Torch and Clam have yielded a significant variation in the magnitude (and even the sign) of the flow difference. Variations in the level of Torch have not been monitored and could lead to significant errors. Past measurements of the Torch and Clam flows have given consistently positive and at least twice the values for groundwater flows. Further, one might expect that deep wells contribute to the groundwater in Torch which are not included in our shallow groundwater estimate. Thus, we expect our estimates from the difference method to be in the range of 20 – 60 cfs. Errors from the watershed method are less than the piezometer but greater than the difference method. The estimated error would mean that there is a range from about 16-64 cfs. Errors from the piezometer method come mainly from our lack of knowledge of the fraction of rainwater which evaporates before reaching the water table. The correct answer probably lies in the range 20-50%. Using this we estimate the real range of this number to be 11-28 cfs. Finally, the piezometer method suffers from a significant variation in the soil types and soil permeability around the lake. Our assumptions about isotropy are compensated only partly by leaving out regions of the shoreline that have clay or are otherwise not porous to water flow. In additions we have made these measurements only in the summer and do not know the seasonal variation of the piezometer measurements. We do not have a good estimate of the dimension of the area into the lake that we are using. All of these could lead to errors of a factor of two in the outcome. Again we must estimate conservatively that we could be wrong by a factor of at least four in magnitude putting the piezometer range as 20 – 140 cfs. This uncertainty is also because of we chose 100 ft. as the dimension perpendicular to the shoreline and have very little to base this on. Our only measurement perpendicular to the shore is with wells 20 ft., 150 ft., and 400 ft. They all showed similar flows. An upper limit might be the average distance between the drop-off at about 12 ft and the shoreline. I estimate the average of this to be about 1,000 ft. This is a lot bigger than 100 ft. Anyway, it's a major source of uncertainty. Increasing 100 to 1,000 ft obviously increases the flow estimate a lot.

How do these estimates come in to the nutrient based water quality model? The model tracks phosphorus flow, not water flow. If the phosphorus contribution to Torch from groundwater dominates all other sources then our estimate is critical. If the phosphorus contribution from groundwater is small compared to all other flows, then knowing the water flow exactly is not so important. In fact we know the other flows and phosphorus levels relatively accurately and we know the phosphorus level in the groundwater to a good accuracy (+/- 30% in most cases). So, using our median estimate for groundwater flows and our more accurate estimates for other phosphorus inputs, we find that the three main sources of phosphorus (rain, Clam, minor tributaries, and groundwater) are roughly 30:30:10:30. Thus, the groundwater contributes about one third of the phosphorus. Thus, the estimate of groundwater flow is important but not dominant in the nutrient budget. The computer model will have to take the range of groundwater uncertainty into account in estimating phosphorus flows and phosphorus predictions.

Conclusion

With method 1, the difference method, we came up with 43 cfs of flow in from groundwater, with an uncertainty from 20-60 cfs. Then with method 2, the watershed method, we came up with 32 cfs of flow in from groundwater, with an uncertainty from 16-64 cfs. From method 3, the piezometer method, we came up with 95 cfs of groundwater flow into Torch Lake, with an uncertainty of 40-120 cfs. These numbers are better than no information at all which was the state of our knowledge until this summer. We now have our first estimate of the fraction phosphorus into Torch from groundwater, namely 30%. Of the three methods to estimate groundwater flow, the one with the most promise of accuracy is the difference method supplemented with estimates of the level of Torch Lake taken at the same time to reduce the uncertainty of variations from day to day.

Appendix A

Cedar River Watershed

Appendix A consist of pictures, graphs and information relating to Cedar River watershed. The watershed for Cedar River covers about 26.5 square miles, a large majority is forest land (about 74%). The next largest land use is about 15% which is grass and shrub land. There are lower percentages of urban building areas (6%), agricultural land (3%), wetlands (1%), and water (.2%). This information is important because it can determine what effects human activities or lack thereof have on the water quality of the creek due to its watershed.

Cedar River Watershed

Approx. Watershed Area: 26.5 Sq Mi
Groundwater Recharge Area: 13 Sq Mi

Lake Bellaire-Clam Lake
Water Quality Modeling Project

Scale: 1:100,000

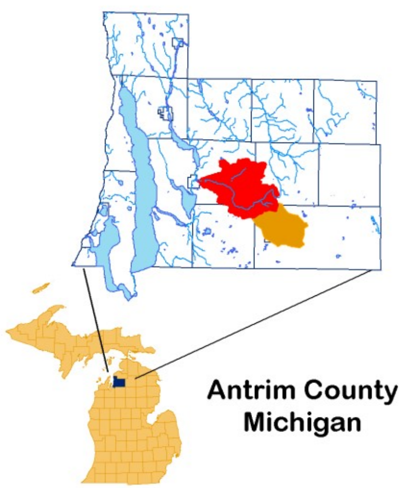
N W E S

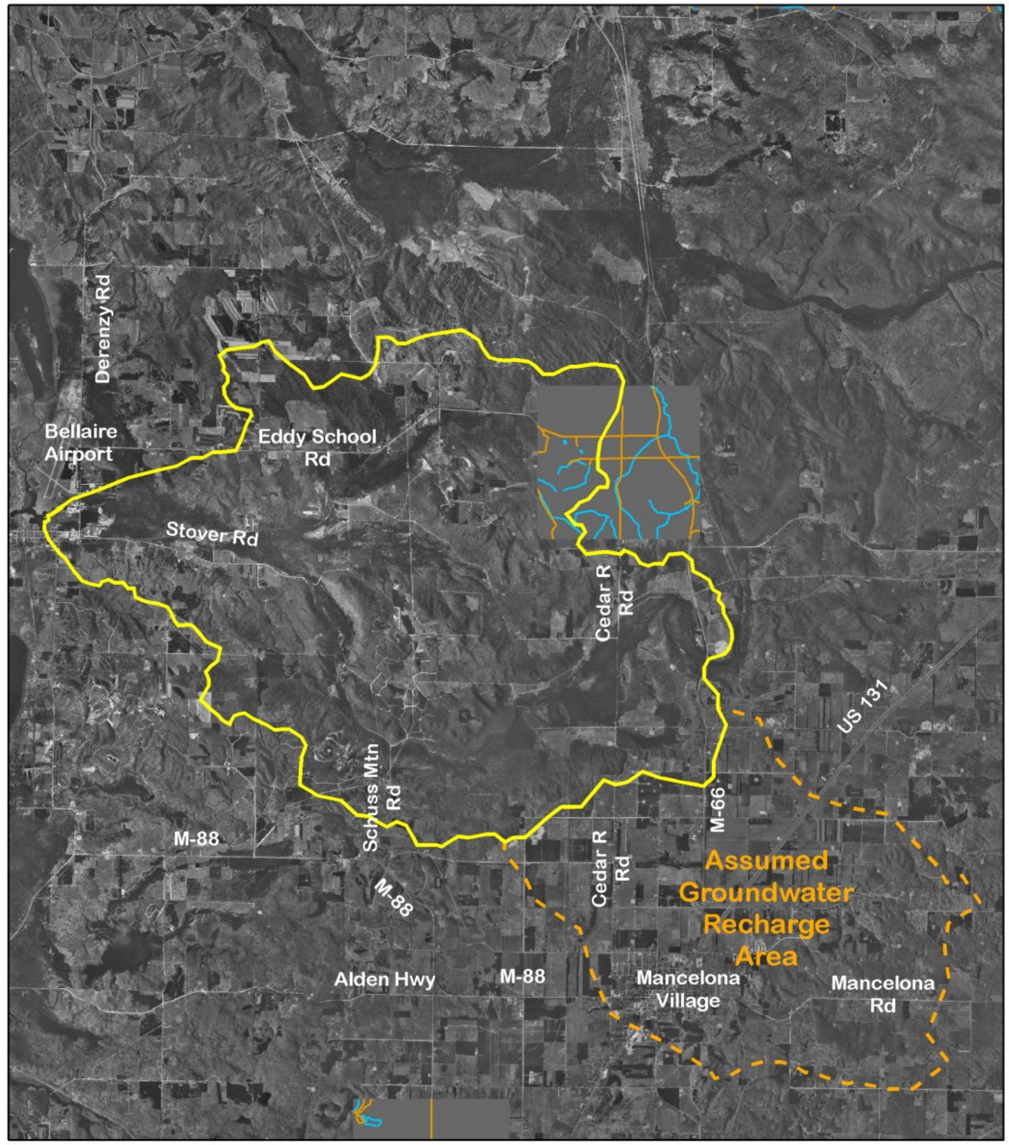
0 0.5 1 2 3 4 Miles

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





Cedar River Watershed

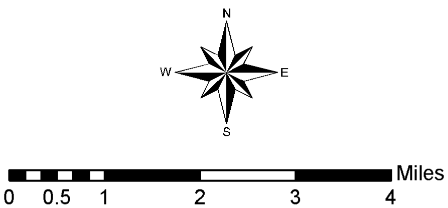
Approx. Watershed Area: 26.5 Sq Mi
Groundwater Recharge Area: 13 Sq Mi

Land Cover Map

Scale: 1:100,000

**Lake Bellaire-Clam Lake
Water Quality Modeling Project**

Source: Data from Antrim County 1978-1998 Land Use Atlas
Original Study by Anrtrim County
and Land Information Access Association
using 1998 MichCon digital orthophotos
Land Use Classification System: MIRIS-2000
(level 1 categories shown on map)
Base GIS Data: Michigan Framework Data
Michigan GeoRef, NAD 83

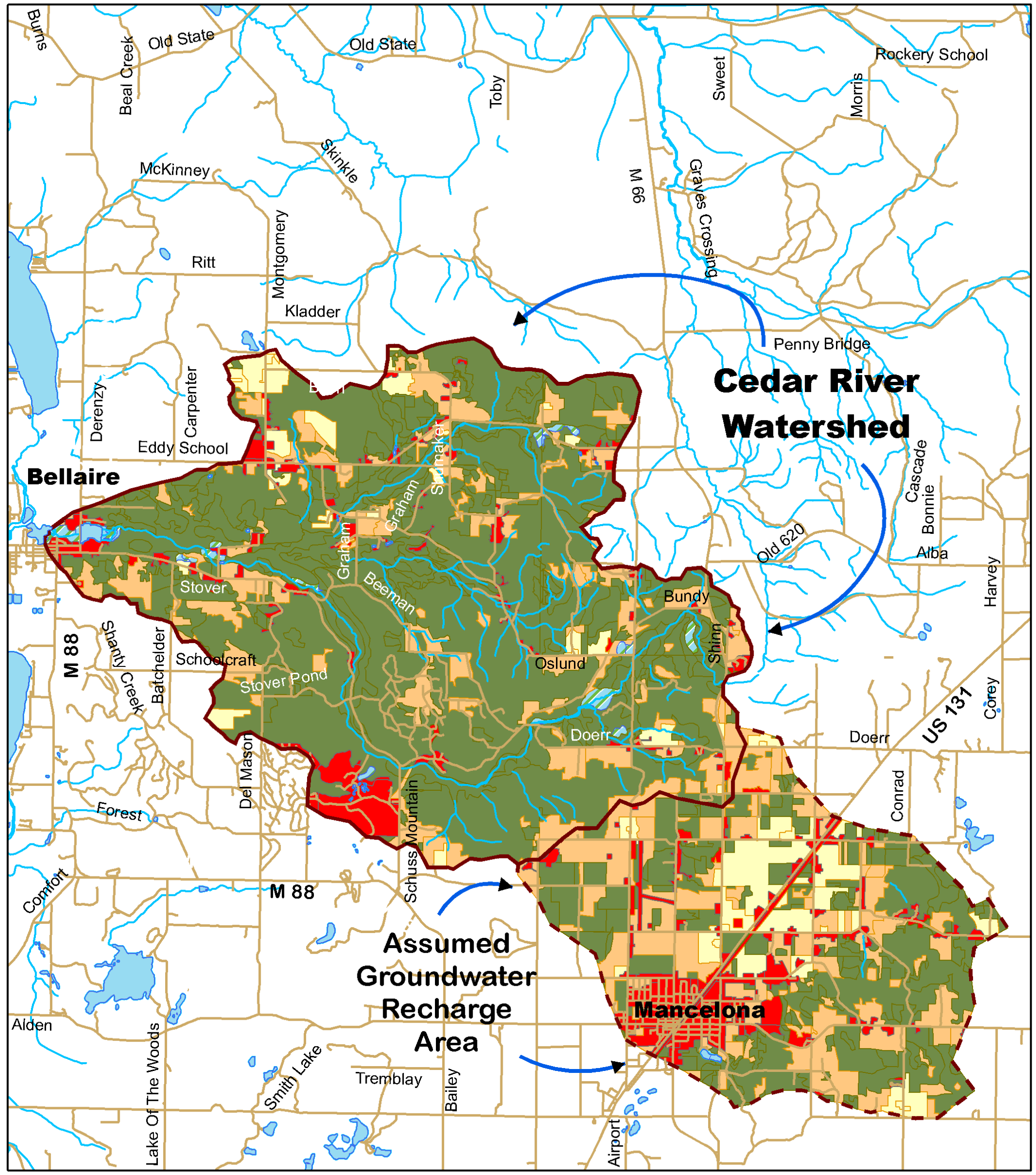


Legend

Watershed Boundary
Assumed Recharge Area

Major Land Use Categories

Urban and Built-up
Agriculture
Grass and Shrubs
Forest
Water
Wetland



Cedar River Watershed

Approx. Watershed Area: 26.5 Sq Mi
Groundwater Recharge Area: 13 Sq Mi

Topographic Map

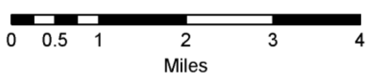
Scale: 1:100,000

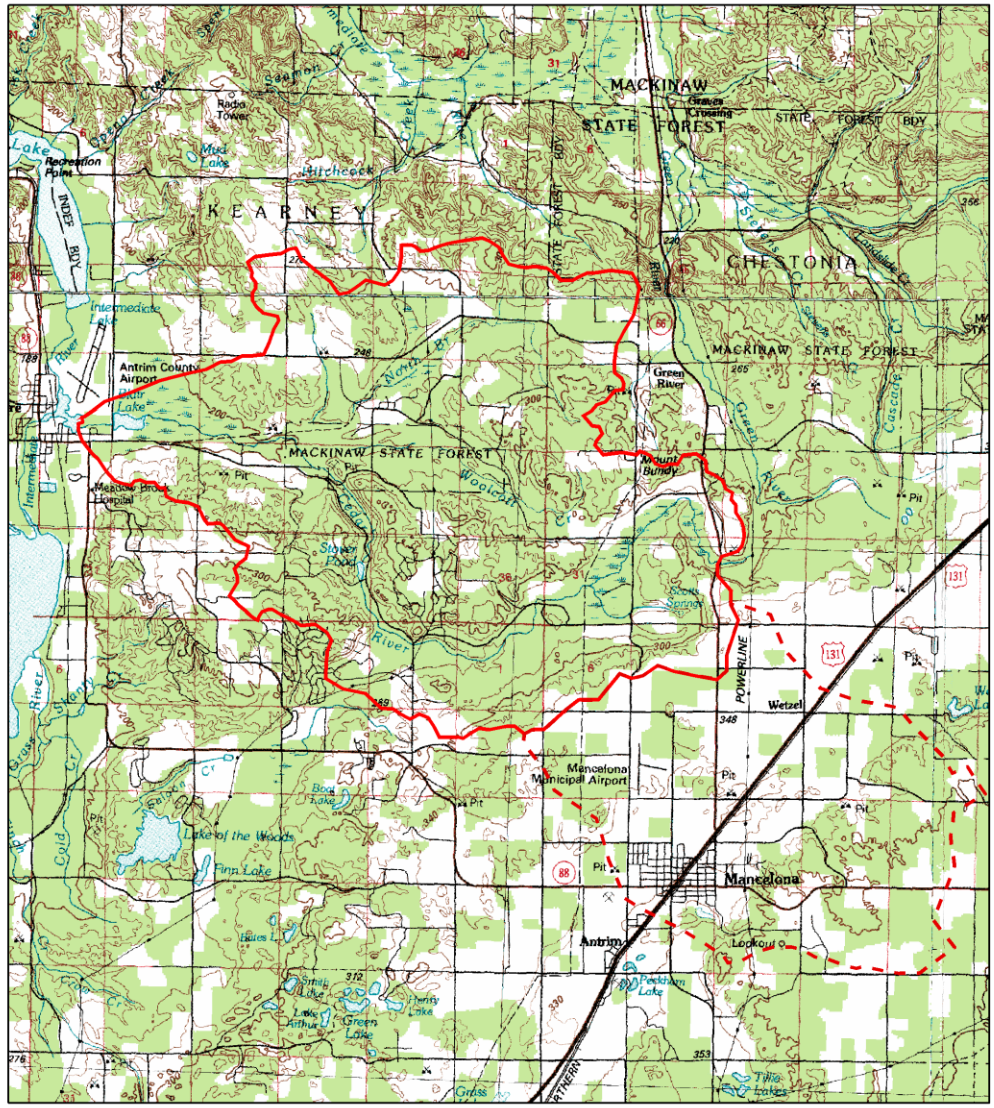
Lake Bellaire-Clam Lake
Water Quality Modeling Project

Source: USGS 1:100,000 Topo Maps
Digitized and made available by the
Center for Geographic Information
Dept. of Information Technology
State of Michigan

(Watershed delineation was performed using USGS 1:24,000 scale topo maps from the Center for Geographic Information. The resulting polygon was superimposed on the 1:100,000 scale USGS map shown on the figure at right.)

Base GIS Data: Michigan Framework Data
Michigan GeoRef, NAD 83





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