Mullett Lake Tributary Water Quality Monitoring Project

By Tip of the Mitt Watershed Council

Completed by Kevin L. Cronk
April 21, 2008

Table of Contents

Page

List of Tables

Page

List of Figures

Page

SUMMARY

The water quality of Mullett Lake, located in northern Cheboygan County, Michigan, has been monitored for several decades, but little data exists for tributaries flowing into Mullett Lake. At the request of the Mullett Lake Area Preservation Society, the Tip of the Mitt Watershed Council monitored water quality in the Cheboygan River, Indian River, Little Sturgeon River, Pigeon River, and Mullett Creek two times per year from 2005 to 2007. Water samples were collected for bacteriological and chemical analyses, physical water quality parameters were measured, and discharge data collected on the tributaries in the spring and fall of each year. Parameters monitored include: dissolved oxygen, pH, conductivity, temperature, total phosphorus, orthophosphates, total nitrogen, nitrate-nitrogen, chloride, fecal coliform bacteria and E. coli bacteria. Using chemical constituent concentrations and discharge data, pollutant loadings and relative percentage contributions were calculated for Indian River, Pigeon River, and Mullett Creek. Tributary pollutant loads were used to estimate nutrient load contributions from non-monitored watershed areas and combined with Cheboygan River load data to develop a nutrient budget. There is strong evidence that nutrient and bacteriological contamination are occurring in the upper Mullett Creek watershed; probably a result of agricultural activity. Despite flowing through an urban area, this study did not detect any water quality problems in the Indian River. Surprisingly, relatively high nutrient loads and bacteria levels were documented in the Pigeon River, which may be due to natural or human factors in its watershed. Results of this study make clear the need to adopt agricultural best management practices to protect and improve stream water quality, particularly in the Mullett Creek watershed. Groundwater nitrate concentrations in the Mullett Creek watershed should be monitored to safeguard public health. Beaver activity in Mullett Creek should be investigated to determine impacts and control options. Stormwater should be monitored to further assess urban impacts on the water quality of the Indian River. Encouraging good riparian property management practices throughout the watershed will benefit the water quality of Mullet Lake and its tributaries. Additional monitoring would provide a more representative and comprehensive data set to improve the reliability of the nutrient budget and determine water quality impacts from inlet streams that have not been monitored.

INTRODUCTION

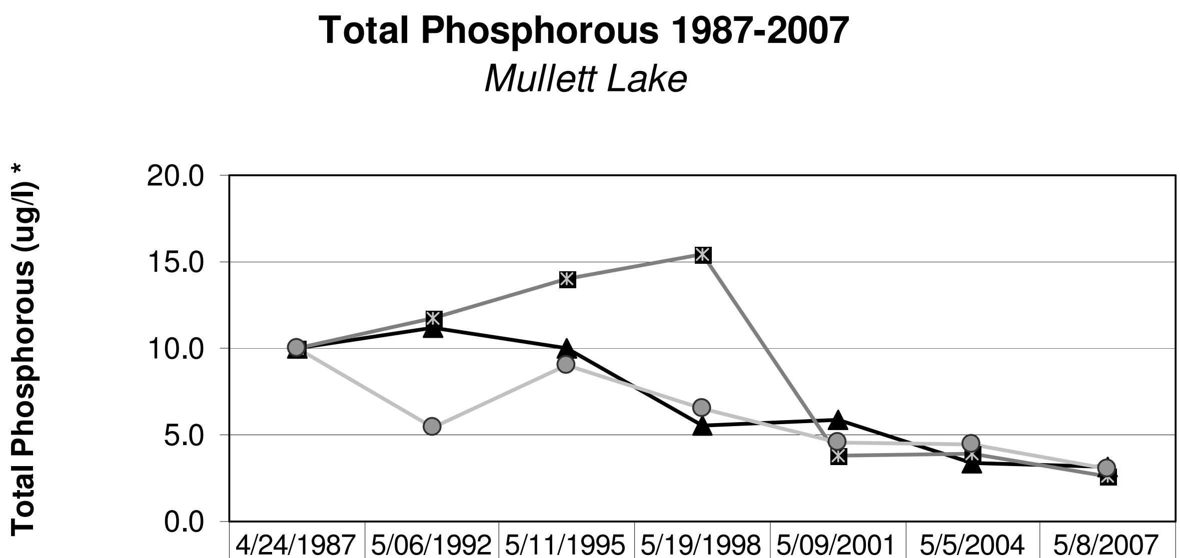
Background:

Mullett Lake, located in the northern tip of the Lower Peninsula of Michigan, sits at the bottom of a large watershed that includes Burt Lake, Douglas Lake, Crooked Lake, Pickerel Lake, the Maple River, the Sturgeon River and the Pigeon River. The water from all of these water bodies and more flows into and potentially impacts the water quality of Mullett Lake. A considerable amount of data has been collected on Mullett Lake attesting to its excellent water quality, but relatively little is known about the water flowing in from its tributaries. To learn more about water quality and impacts of major tributaries flowing into Mullett Lake, the Mullett Lake Area Preservation Society (MAPS) contracted with Tip of the Mitt Watershed Council to monitor physical, chemical, and biological water quality parameters on the Indian River, the Cheboygan River, the Pigeon River, the Little Sturgeon River and Mullett Creek.

The water quality of Mullett Lake has been monitored consistently for many years. The Mullett Lake Area Preservation Society (MAPS) has actively supported water quality monitoring programs on Mullet Lake, providing volunteers for the volunteer water quality monitoring programs coordinated by the Watershed Council and the Michigan Lakes and Streams Association. In addition, Watershed Council staff monitor Mullett Lake water quality as part of the Comprehensive Water Quality Monitoring program (CWQM). Watershed Council databases contain volunteer lake monitoring and CWQM data that date back to 1986 and 1987 respectively. Data collected through these programs indicate that water quality remains high. Total phosphorus data collected as part of the CWQM program show that levels have dropped throughout the last 20 years and are now consistently below 10 parts per billion (PPB), which is typical for high quality lakes of northern Michigan (Figure 1). Based on trophic status index values generated from volunteer lake monitoring data, Mullett Lake falls in the oligotrophic category, which is typical for pristine, large, deep lakes (Figure 2).

Lake Association (MAPS) members were particularly concerned about contaminants originating from urban areas along the Indian River and agricultural activity in the Mullett Creek watershed. The Indian River flows out of Burt Lake

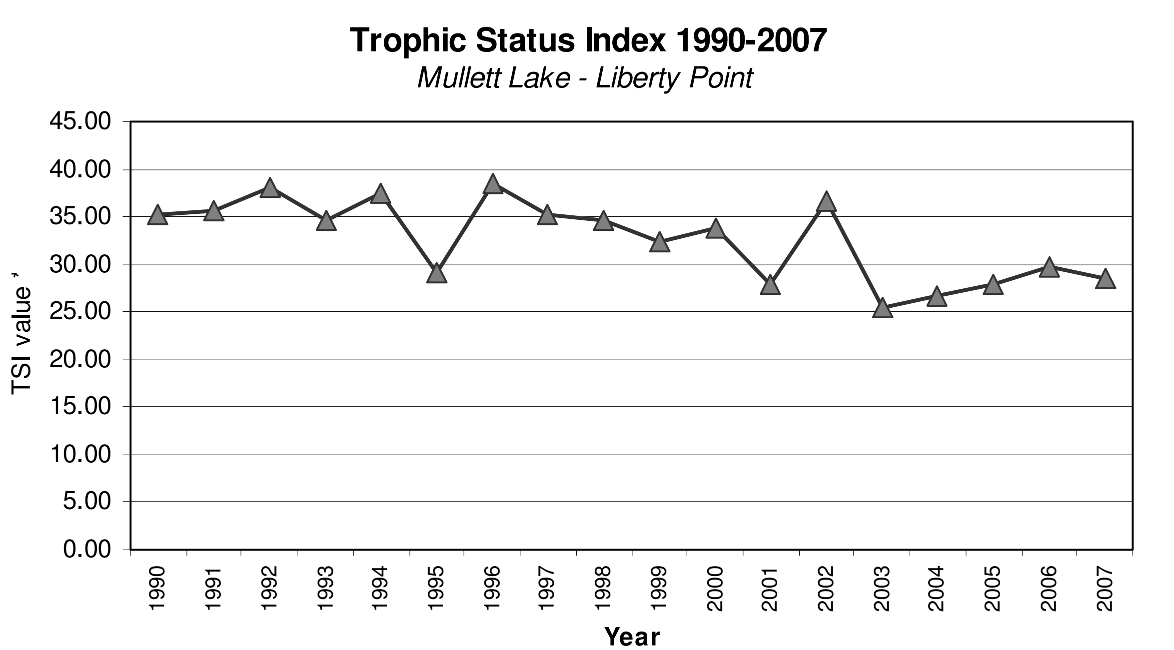
Figure 1. Phosphorus data collected on Mullett Lake from the CWQM program.



	4/24/1987	5/06/1992	5/11/1995	5/19/1998	5/09/2001	5/5/2004	5/8/2007
Surface	10.0	11.2	10.0	5.5	5.9	3.4	3.1
Middle	10.0	11.7	14.0	15.4	3.8	3.9	2.6
Bottom	10.0	5.4	9.0	6.5	4.6	4.5	3

**Total phosphorus measured in ug/l, which is milligrams per liter or parts per billion.*

Figure 2. Trophic status index data from volunteer monitoring on Mullett Lake.



**TSI determines trophic status of lake: 0-38 = oligotrophic (low productive system), 39-49 = mesotrophic (moderately productive system), and 50+ = eutrophic (highly productive system).*

and through the town of Indian River before reaching Mullett Lake. Pollutants associated with roads, such as leaking fluids from automobiles, and those associated with houses, such as septic leachate, are among some of the potential sources of pollution that could be reaching the Indian River. Mullett Creek flows through agricultural areas that may contribute pollutants to the stream, such as nutrients from fertilizers and animal waste or sediments from soil erosion.

Considering the importance of the Inland Waterway to local economies and the proximity to a major research facility (the University of Michigan Biological Station), surprisingly little water quality data has been collected from the Indian and Cheboygan Rivers. Although more water quality information probably exists, only one source was uncovered in the Watershed Council library. According to the Mullett Lake Watershed Nonpoint Source Management Plan (NEMCOG 1989), water quality testing performed by the Surface Water Quality Division of the Michigan Department of Natural Resources (DNR) in 1988 showed water quality in the Indian River to be high, with impacts limited to nitrogen increases downstream of the community.

Much more water quality data has been collected from the Pigeon River and Mullett Creek. Due to the Pigeon River's importance as a cold-water fishery, its designation as a Natural River, and being a natural and recreational resource in the DNR's Pigeon River Country special management unit, extensive water quality and biological data have been collected by regulatory agencies and others. Although less water quality data exists for Mullett Creek, several studies have been conducted to collect both biological and physico-chemical information.

The DEQ (Michigan Department of Environmental Quality) and the DNR have both conducted surveys on the Pigeon River and Mullett Creek. Two of these surveys are relevant to this study. In 1994, DEQ conducted a biological survey on the Pigeon River and Mullett Creek to assess land-use impacts on the fish and macroinvertebrate communities and on physical habitat conditions. The fish communities were rated as "good" at all stations and macroinvertebrate communities were rated as "good" at upstream stations and "fair" at all other stations. The DNR has collected water temperature data from the Pigeon and Little Sturgeon Rivers, but the most relevant data to this study was from Mullett Creek, which showed pronounced differences between upstream and downstream stations (Table 1).

Table 1. Water temperatures at two sites on Mullett Creek in 2004.

Month	Burt-Mullett Lake Rd Average Temperature (˚F)	S. Extension Rd. Average Temperature (˚F)
May	56.6	50.0
June	64.8	53.7
July	67.8	55.9
August	64.2	54.7
September	62.6	54.3
October	48.8	47.3
November	44.0	44.2
All Data	61.1	52.9

As part of a project conducted by the Watershed Council, water quality data were collected from multiple sites on the Pigeon River and Mullett Creek from 1995 to 1997. Water quality data were collected at 4-6 sites on each stream, 1-2 times per year, and included the following parameters: water temperature, dissolved oxygen, pH, conductivity, suspended solids, chloride, total phosphorus, nitrate, and nitrite. Discharge data were not collected. Results from the 1995-1997 monitoring consistently show relatively high levels of nutrients, chloride, conductivity and suspended solids in Mullett Creek (Appendix A).

Mullett Creek was included in the Watershed Council's Volunteer Stream Monitoring Program and has been monitored five times since 2005. Results from this program show that bio-diversity in Mullett Creek is high and comparable to other streams in the program (Table 2). In general, there is higher diversity at the upstream site (Crump Rd). It is uncertain whether the difference between sites is due to natural factors (e.g., habitat types at sample sites, beaver dams, etc.), anthropogenic impacts (e.g., increased impervious surface, agricultural activity, etc.), or a combination of both.

Table 2. Results from Volunteer Stream Monitoring program activities: total taxa.

Stream Name	Site Location	Total Taxa* 9-2005	Total Taxa* 5-2006	Total Taxa* 9-2006	Total Taxa* 5-2007	Total Taxa* 9-2007	Total Taxa* Avg.
Bear River	Bear River Rd	ND	25	26	13	20	21.0
Bear River	Mineral Well	ND	19	13	11	14	14.3
Bear River	Springbrook	ND	ND	ND	25	16	20.5
Bear River	Walloon Lake	ND	ND	ND	18	17	17.5
Boyne River	North Branch	ND	ND	ND	ND	17	17.0
Boyne River	Dobleski Rd	15	19	14	16	12	15.2
Boyne River	Dam Rd	ND	ND	ND	ND	19	19.0
Boyne River	City Park	19	20	10	12	11	14.4
Eastport Creek	Farrell Rd	23	25	ND	26	29	25.8
Eastport Creek	Eastport	19	22	ND	18	15	18.5
Horton Creek	Church Rd	15	18	13	18	21	17.0
Horton Creek	Boyne City Rd	18	18	25	18	20	19.8
Jordan River	Webster Rd	ND	ND	ND	17	28	22.5
Jordan River	Fair Rd	ND	ND	ND	18	23	20.5
Kimberly Creek	Montgomery Rd	20	18	19	31	20	21.6
Kimberly Creek	Quarry Rd	18	24	23	28	15	21.6
Mullett Creek	**Crump Rd**	**17**	**21**	**25**	**14**	**19**	**19.2**
Mullett Creek	**M27**	**21**	**14**	**20**	**23**	**22**	**20.0**
Spencer Creek	McPherson Rd	4	20	22	19	22	17.4
Spencer Creek	Coy St.	10	21	19	12	19	16.2
Stover Creek	Ferry Rd	16	11	15	21	11	14.8
Stover Creek	Cemetery	18	18	17	21	25	19.8
Stover Creek	Irish Boat	14	15	15	15	18	15.4

** Diversity expressed as the total number of macroinvertebrate families found at the site. ND = no data.*

Table 3. Results from Volunteer Stream Monitoring program activities: sensitive taxa.

Stream Name	Site Location	Sens. Taxa† 9-2005	Sens. Taxa† 5-2006	Sens. Taxa† 9-2006	Sens. Taxa† 5-2007	Sens. Taxa† 9-2007	Sens. Taxa† Avg.
Bear River	Bear River Rd	ND	5	4	1	5	3.8
Bear River	Mineral Well	ND	4	2	3	4	3.3
Bear River	Springbrook	ND	ND	ND	6	2	4.0
Bear River	Walloon Lake	ND	ND	ND	3	1	2.0
Boyne River	North Branch	ND	ND	ND	ND	3	3.0
Boyne River	Dobleski Rd	5	7	4	5	5	5.2
Boyne River	Dam Rd	ND	ND	ND	ND	6	6.0
Boyne River	City Park	5	6	4	3	4	4.4
Eastport Creek	Farrell Rd	3	5	ND	5	5	4.5
Eastport Creek	Eastport	1	2	ND	2	0	1.3
Horton Creek	Church Rd	0	1	0	2	1	0.8
Horton Creek	Boyne City Rd	6	9	7	7	5	6.8
Jordan River	Webster Rd	ND	ND	ND	5	8	6.5
Jordan River	Fair Rd	ND	ND	ND	6	6	6.0
Kimberly Creek	Montgomery Rd	3	4	3	7	3	4.0
Kimberly Creek	Quarry Rd	3	5	4	5	4	4.2
Mullett Creek	**Crump Rd**	**7**	**5**	**5**	**3**	**4**	**4.8**
Mullett Creek	**M27**	**0**	**0**	**0**	**1**	**0**	**0.2**
Spencer Creek	McPherson Rd	0	7	4	6	5	4.4
Spencer Creek	Coy St.	2	5	6	4	2	3.8
Stover Creek	Ferry Rd	0	2	0	2	2	1.2
Stover Creek	Cemetery	3	3	3	4	3	3.2
Stover Creek	Irish Boat	0	0	0	0	0	0.0

† Diversity expressed as the number of sensitive macroinvertebrate families found at the site. ND = no data.

Following meetings between Tip of the Mitt Watershed Council and MAPS, a plan was developed to monitor water quality on the Indian River, the Cheboygan River, the Pigeon River, the Little Sturgeon River and Mullett Creek. Watershed Council staff monitored water quality at seven locations in the tributaries of Mullett Lake two times per year from 2005 to 2007. Water samples were collected for chemical and bacteriological analyses, physical parameters were measured, and discharge data collected at each site in the spring and fall of each year. Sampling in the spring is important for gauging impacts from contaminants accumulated on the landscape during winter months that are carried into streams by surface runoff during snowmelt or large storm events. Fall sampling potentially reveals impacts from accumulated pollutants during the typically dry late summer period and is also more likely to expose contamination from septic systems as many systems in Northern Michigan experience heavier seasonal use during summer months. Data gathered in this study were used to calculate pollutant loadings to determine the relative amounts of pollutants flowing into Mullett Lake from each major tributary, and develop a simple nutrient budget.

Study Area:

Mullett Lake is located in the townships of Inverness, Benton, Mullett, Aloha, Tuscarora and Koehler in northern Cheboygan County, Michigan (Figure 3). The surface area of Mullett Lake measures approximately 17,000 acres. The lake's deepest point, ~144 feet, is located near the center of the lake, directly out from Long Point. Major inlets include the Indian and Pigeon Rivers, which both flow into the lake in the southwestern end. There are many minor inlets; the largest being Mullett Creek, which flows into the center of the lake from the northwest. Water flows out of Mullett Lake through the Cheboygan River in the northeastern end.

Mullett Lake is considered an oligotrophic lake. Oligotrophic lakes are characteristically deep, clear, nutrient poor, and with abundant oxygen throughout the water column. A general fish survey from 1988 documented the following types: brown trout, brown bullhead, carp, minnows, northern pike, pumpkin sunfish, redhorse suckers, rock bass, smallmouth bass, splake, walleye, white bass, white sucker and yellow perch (Sportsman's Connection 2002). From 1995 to 2001, splake, lake trout and walleye were stocked and lake sturgeon were stocked from 2005 to 2007.

The Mullett Lake Watershed encompasses approximately 560,000 acres of land and water, stretching nearly from the City of Gaylord in the south to the City of Cheboygan to the north (Figure 3). As determined by land cover data from the year 2000 (NOAA 2003), the watershed remains largely undeveloped with less than 3% urbanized and 8% agricultural (Table 4).

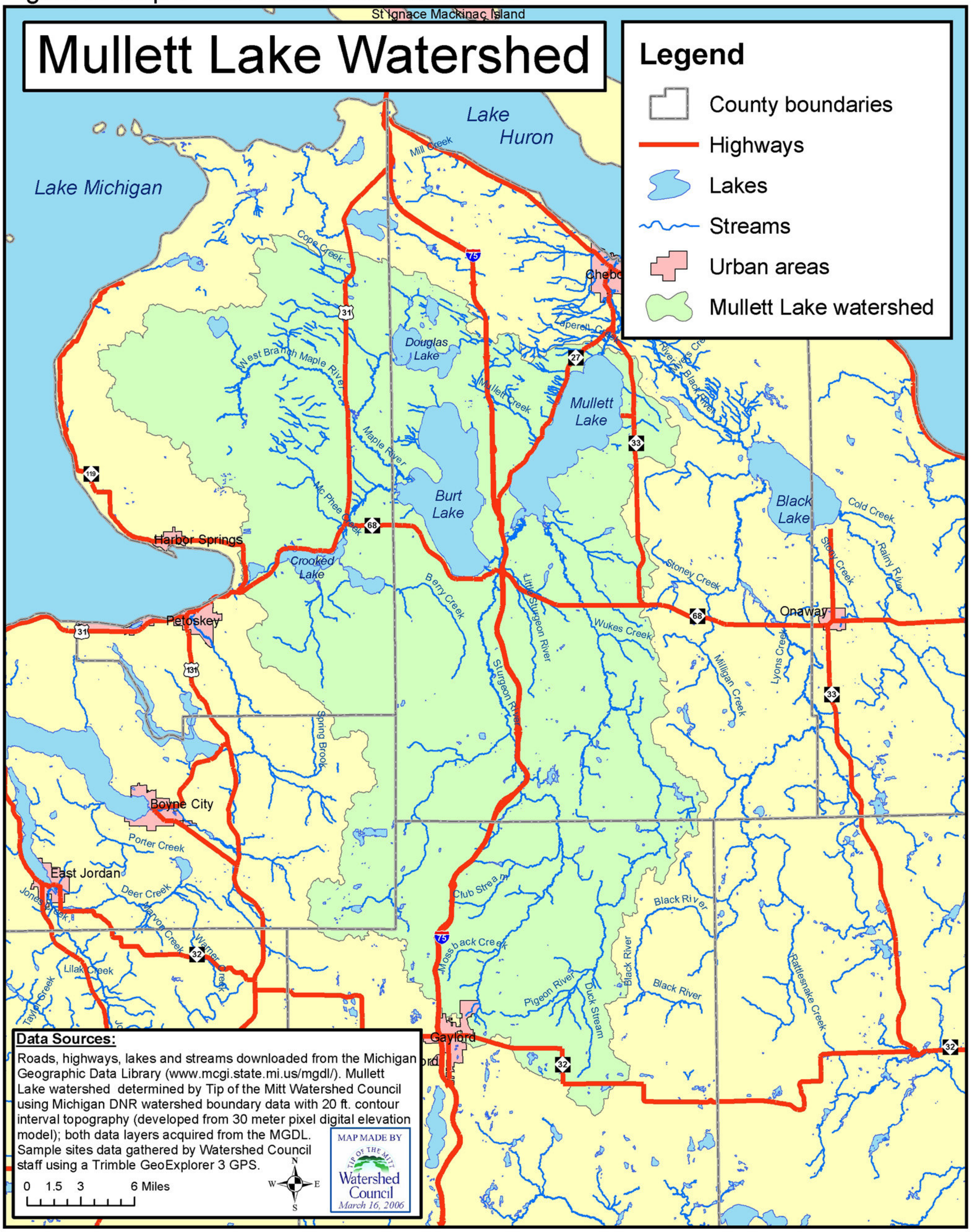
Table 4. Mullett Lake watershed 2000 land cover statistics.

Land Cover Type	Entire Watershed Acreage	Entire Watershed Percentage	Indian River Percentage	L. Sturgeon River Percentage	Pigeon River Percentage	Mullett Creek Percentage
Urban	13,153	2.35	2.57	2.45	1.23	3.43
Agricultural	45,102	8.06	8.13	3.33	6.26	26.79
Grassland	82,856	14.82	15.09	17.59	15.04	18.02
Forested	276,088	49.37	50.57	57.26	55.12	30.70
Scrub/Shrub	18,273	3.27	3.27	6.25	3.79	2.06
Wetland	76,005	13.59	12.87	12.24	17.56	18.46
Barren/Shore	1,223	0.22	0.25	0.18	0.13	0.33
Water	46,544	8.32	7.27	0.70	0.87	0.21
Total	559,245	100.00	100.00	100.00	100.00	100.00

Over 70% of the Mullett Lake watershed land area drains into the lake through the Inland Waterway, arriving at the lake through the Indian River. The Indian River is the conduit for this water, beginning in the southeast corner of Burt Lake, flowing through the town of Indian River, and converging with the Little Sturgeon River before emptying into Mullett Lake. Land cover for the year 2000 in the 394,000-acre watershed draining into the Indian River was quite similar to that of the entire watershed with just over 10% covered with urban and agricultural (Table 4). Land cover in the Little Sturgeon River watershed, a subset of the Indian River data, consisted of much less agriculture and more forest, grassland and scrub/shrub.

The watershed area drained by the Pigeon River is 107,880 acres and accounts for about 20% of the total for Mullett Lake. Land cover in the Pigeon River watershed in 2000 was predominantly forest, followed by wetlands and grasslands (Table 4). The Pigeon River watershed had the smallest percentage of urbanized land cover of the sub-watersheds of Mullett Lake at 1.2%.

Figure 3. Map of the Mullett Lake watershed.



Mullett Creek is the third largest tributary of Mullett Lake with a watershed area of 11,874 acres. Land cover data from the year 2000 show that the percentage of agriculture in the Mullett Creek watershed was three times greater than any other tributary watershed in this study at 26% (Table 4). Furthermore, the Mullett Creek watershed had a greater percentage of urban land cover than the other tributary watersheds.

Remaining watershed areas drain either directly into Mullett Lake or into minor inlet tributaries. These areas total 28,840 acres, which is approximately 5.25% of the Mullett Lake watershed. In 2000, agricultural lands covered 11.1% and urban or residential areas covered 4.6 % of these direct-drainage watersheds.

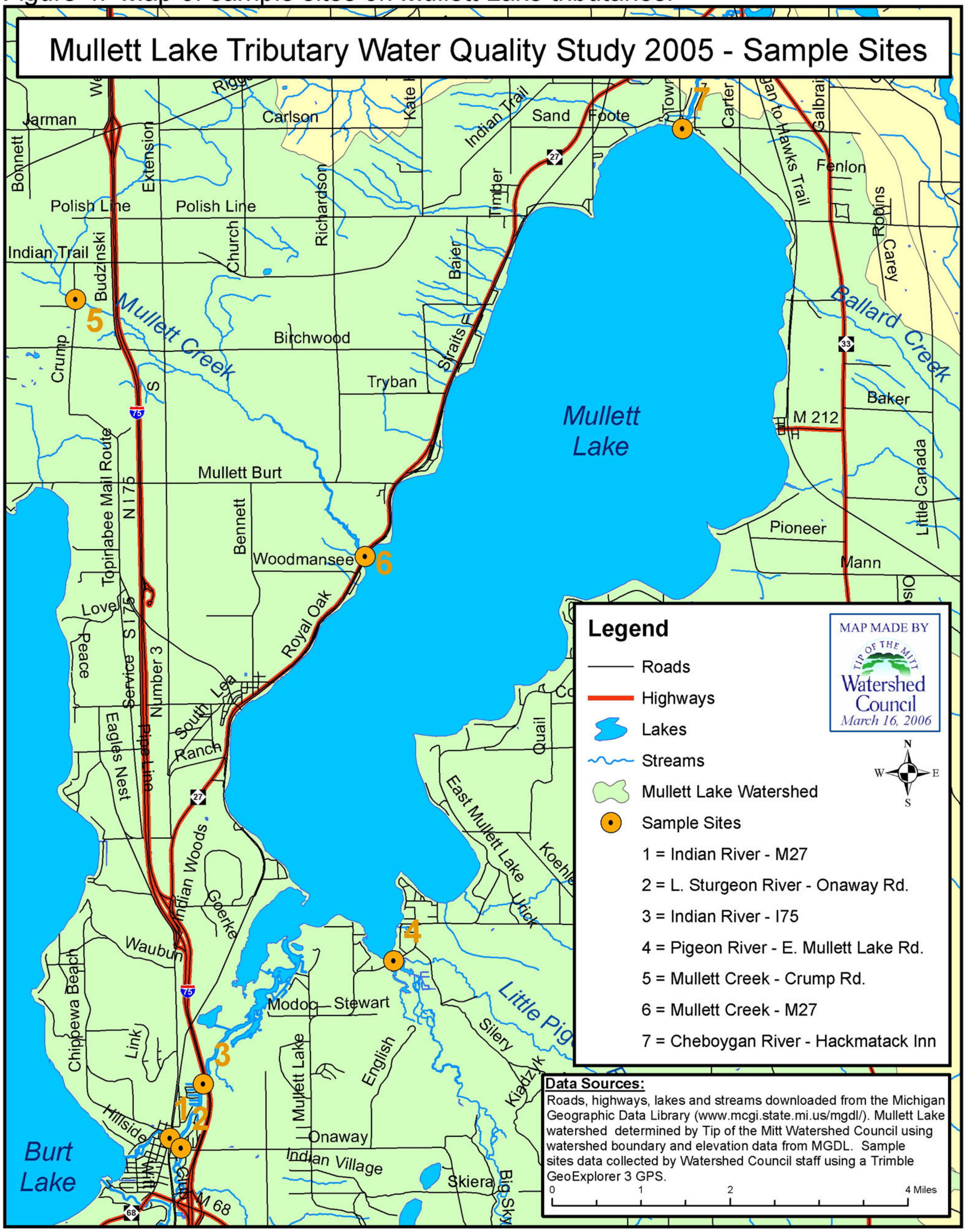
METHODS

Field Data Collection:

Water quality and discharge data were collected from seven sites on streams flowing into or out of Mullett Lake (Figure 4). Field data were collected in April and September of 2005, in May and September of 2006, and in May and November of 2007. Monitoring during 2005 and 2006 was carried out immediately following precipitation events with the objective of determining maximum pollutant concentrations in streams as a result of stormwater runoff. Conversely, monitoring in 2007 was performed during dry periods to measure base flow levels. Chemical and bacteriological analyses were conducted in laboratories on water samples collected in the field. Physical and discharge data were directly measured in the field. Discharge data were collected by measuring flow velocity and depth across stream transects. Due to weather conditions, only bacteriological data were collected from the Indian and Cheboygan River sites in the fall of 2007.

At each site, water samples were collected in separate containers for chemical and bacteriological analysis. During both 2006 monitoring events and in the spring of 2007, duplicate samples were collected for chemical analysis. Water samples were collected at sites on the Little Sturgeon River and Mullett Creek by wading and on the Indian River, Pigeon River, and Cheboygan River using a Kemmerer sampling device. The Kemmerer was rinsed three times prior to collecting the water sample by lowering the device into the water, withdrawing, and lowering it again. All sample water was collected in the middle of the stream and at approximately mid-depth. Acid-rinsed containers used to collect samples for chemical analysis were rinsed three times with stream water (both bottle and cap) prior to collecting the sample. Sterilized containers, acquired from the Michigan Department of Environmental Quality (DEQ) in April, 2005 and from the Emmet County Health Department in all other monitoring events, were used to collect water samples for bacteriological analysis. These samples were not rinsed with stream water per instructions provided by DEQ and the Health Department, but instead filled only once.

Figure 4. Map of sample sites on Mullett Lake tributaries.



All water samples were immediately placed in a cooler containing ice. Water samples collected for bacteriological analysis in April of 2005 were shipped overnight to the DEQ Drinking Water Laboratory in Lansing, exceeding the eight hour time limit set by DEQ for quality assurance. Those collected in September 2005 and thereafter were delivered directly to the Health Department Laboratory in Gaylord within six hours of sample collection. Water samples collected for chemical analysis were delivered directly to the University of Michigan Bio-station.

Bacteriological analysis for water samples collected in the spring of 2005 measured fecal coliform organisms per 100 milliliters and those collected in all subsequent sampling measured E. coli organisms per 100 milliliters. Water samples collected for chemical analysis were analyzed for orthophosphates ($PO4^-$), total phosphorus (TP), nitrate-nitrogen ($NO3^-$), total nitrogen (TN), and chloride (CL^-). Orthophosphates were not measured during the 2007 sampling events due to a misunderstanding with the laboratory performing the analyses.

Following water sample collection, physical water quality data were collected using a Hydrolab MiniSonde®. The MiniSonde® was calibrated each morning prior to field work, using methods detailed in the Hydrolab manual. Dissolved oxygen was calibrated with the percent saturation method, using actual barometric pressure as measured by a sensor contained in the Surveyor4a Data Display unit. Conductivity was calibrated using a standard solution of 447 microSiemens/cm and pH was calibrated using standard buffer solutions of 7 and 10 units pH.

At each sample site the MiniSonde® was lowered into the water at mid-channel to approximately half the total depth and then measurements were saved to memory in the Surveyor4a and also written on a paper field data collection sheet. Upon returning to the office, data was transferred from the Surveyor4a to a computer and all data consolidated in a Microsoft Excel® workbook.

After physico-chemical data collection, discharge data were collected at each site. A nylon measuring tape was tied across the stream channel perpendicular to flow. Current velocity, water depth, and stream width (location along the transect) were recorded at irregular intervals across the transect. Locations along the transect were selected based upon changes in depth and current velocity. Using a Marsh McBirney digital current meter and an adjustable wading rod, depth placement of the current velocity sensor was adjusted at each location along the transect using the 0.6 depth method. All data, including total channel width were recorded on a field data sheet and later inputted into a Microsoft Excel® spreadsheet.

Water quality monitoring could be improved during future efforts by employing additional staff during field data collection. According to EPA guidelines, water samples must be delivered to the laboratory performing bacteriological analysis within six hours of collection. It was difficult to meet this six-hour deadline when collecting physical, chemical, bacteriological and discharge data from multiple sites around a large water body. Another field hand would improve field data collection efficiency and help ensure that water samples are delivered to the laboratory (in Gaylord) within time limits. In addition, measuring discharge would be easier with extra field hands.

More suitable, as well as safer, alternatives for measuring discharge could have improved the accuracy of the data. The equipment used by the Watershed Council for this study was not the most appropriate for the large rivers and caused boater safety concerns. Extending a measuring tape across the Indian and Cheboygan Rivers and collecting discharge data was technically challenging and posed a danger to passing boaters. Thus, during future monitoring alternate methods should be considered. At some sites, a bridge board system would facilitate field data collection, though such a system would not be appropriate for use on the interstate bridge due to traffic hazards. More advanced technologies such as Doppler sonar would be more suitable for the circumstances, albeit expensive.

<u>Data Processing:</u>

Upon completing field data collection and data input, stream discharge and loads were calculated for each sample event at every sample site. Nutrient and chloride loadings were calculated for all sites using discharge and chemical concentration values. Subsequently, the percentage of discharge and load contributed by individual tributaries flowing into Mullett Lake were calculated.

Discharge was calculated for each section along the transect, i.e., between data collection points. The volume passing through each section per unit of time was calculated by multiplying the width, average depth and average current velocity. The current velocity was multiplied by a substrate friction coefficient that ranged from 0.8 to 0.9 depending upon substrate type observed in the field. Discharge figures for individual sections were summed to calculate total stream discharge. The percentage of discharge contributed by Indian River, Pigeon River and Mullett Creek were calculated by dividing discharge data from the most downstream site into the summed total discharge of all three sites and multiplying by 100.

Loads were calculated by multiplying the nutrient concentration, discharge in cubic meters per second and a conversion factor of 190.48 for parameters measured in parts per million or 0.1905 for those in parts per billion. Loads were calculated and reported in pounds per day. As with discharge calculations, the percentage of load was calculated using data from the most downstream point of tributaries flowing into Mullett Lake. Load figures calculated at individual sites were divided into the summed load of the three tributaries and multiplied by 100. Final results show the percentage of the total load that is contributed by each tributary to Mullett Lake for individual chemical constituents.

<u>Lake Nutrient Budget:</u>

A simple lake nutrient budget was developed by using the nutrient loading inputs and outputs. Total inputs were subtracted from total outputs to determine the quantity of nutrients that were utilized, removed or deposited in the Mullett Lake ecosystem. Other inputs, such as groundwater and atmospheric deposition were not included in the nutrient budget due to lack of data.

Although most nutrient inputs from the Mullett Lake watershed were accounted for through this project's monitoring efforts, estimates for non-monitored watershed areas were needed to calculate the nutrient budget. Nutrient load inputs calculated from water quality monitoring data collected from the Indian River, Pigeon River and Mullett Creek, accounted for 91.87% of the Mullett Lake watershed. Using nutrient load data from these inlet tributaries and watershed area data, a weighted load-per-acre statistic was generated to estimate nutrient loadings from the remaining 8.13% of the watershed. Then, outputs from the Cheboygan River were subtracted from the sum of all inputs to determine the nutrient load reduction occurring in the Mullett Lake ecosystem. This procedure was carried out for all four nutrient parameters monitored during each sampling event. A nutrient budget could not be calculated for the fall, 2005 and the fall, 2007 sampling events and orthophosphate budgets could not be calculated for spring, 2007 because of incomplete data.

There were a variety of factors that undermined the quality of the nutrient budget developed for this study. The majority of watershed inputs were accounted for by streams included in this study, but there were a number of minor inlet tributaries that were not monitored and thus, required estimations. Data used to develop the nutrient budget were limited to four of the six sampling events (for which there were complete data sets) and most of these data were collected under high-flow conditions. By collecting during high flow periods, considerable hydrologic variability was present in the system. A storm passing through the area would cause peak flow conditions much earlier in a small stream like Mullett Creek than in a large stream like the Indian River. Therefore, hydrologic conditions probably varied considerably among sites while monitoring. Important nutrient input (and potentially output) sources, such as groundwater and rainwater, were not monitored and loads from these were not included in the nutrient budget.

Statistics:

Most information gathered during this study is presented using descriptive statistics, though some analyses were performed on data using parametric statistical methods. Means were calculated for chemical constituent concentrations, discharge measurements, and loads in order to make comparisons between sample sites. The student t-test was used to determine significant differences in means of specific parameters between sample sites. Paired t-tests were used to determine significant seasonal changes in nutrient loads and discharge.

RESULTS

Bacteriological:

During the first sampling event, water samples collected for bacteriological analysis were tested for fecal coliforms. Test results ranged from less than 10 to 60,000 fecal coliform organisms per 100 milliliters (Table 5). Although there are no DEQ water quality standards for fecal coliforms in surface waters, Rule 323.1062 of Part 4 Water Quality Standards states that "discharges containing treated or untreated human sewage shall not contain more than 200 fecal coliform bacteria per 100 milliliters." The threshold of 200 fecal coliform bacteria per 100 milliliters was only exceeded at Crump Road on Mullett Creek.

Table 5. Bacteria concentrations in Mullett Lake tributaries.

Sample Site	April 2005*	Sept. 2005†	May 2006†	Sept. 2006†	May 2007†	Nov. 2007†
Indian River - M27	<10	14.4	3.1	4.1	1	<1
L. Sturgeon River – Onaway Rd.	100	88.2	240	121.1	10.9	33.2
Indian River - I75	20	20.1	90.9	162.4	6.3	3.1
Pigeon River – E. Mullett Lake Rd.	ND‡	105	365.4	204.6	ND‡	14.5
Mullett Creek – Crump Rd.	60000	727	>2419.6	>2419.6	20.1	517.2
Mullett Creek – M27	140	61.3	143.9	68.9	42	204.6
Cheboygan River – Hackmatack Inn	<10	2	3.1	6.3	<1	<1

*Reported in units of fecal coliform bacteria per 100 milliliters.
†Reported in units of E. coli bacteria per 100 milliliters.
‡ND = no data collected due to time constraints in 2005 and contamination in 2007.

Water samples collected for bacteriological analysis from September, 2005 onward were analyzed for E. coli. Test results ranged from less than 1 to greater than 2419.6 E. coli bacteria per 100 milliliters (Table 5). The upper end of the range is unknown as the method used had a maximum countable level of 2419.6. Rule 62 (R 323.1062) of DEQ Part 4 Water Quality Standards does have a provision for E. coli concentrations in surface water: "All waters of the state protected for total body contact recreation shall not contain more than 130 Escherichia coli (E. coli) per 100 milliliters, as a 30-day geometric mean." Rule 62 also states: "At no time shall the waters of the state protected for total body contact recreation contain more than a maximum of 300 E. coli per 100 milliliters." The maximum of 300 was exceeded during four times at Crump Road on Mullett Creek and once on the Pigeon River (Table 5).

There appeared to be marked differences in bacteria concentrations between upstream and downstream sample sites on both Mullett Creek and the Indian River. Statistical analyses show a significant difference in bacteria levels between Crump Road and M27 sample sites on Mullett Creek ($t(4) = 2.27$, $p < 0.05$). However, statistical analysis of bacteria data from the Indian River sample sites did not show a significant difference ($t(4) = -1.66$, $p > 0.05$).

Chemical:

Nutrient analyses of water samples show levels within typical ranges for all sites except those on Mullett Creek. Typical ranges were determined using nutrient concentration values contained in the Watershed Council Comprehensive Water Quality Monitoring (CWQM) program database. Comparisons were made using high, low and average concentration values in CWQM data collected from 1992 to 2007 on Mullett Lake and from all rivers monitored in the CWQM program (Table 6).

Table 6. Typical nutrient and chloride concentrations from CWQM program data.

	TP*	$NO3^{-*}$	TN*	CL^{-} *
Mullett Lake – Low	2.6	40	197	5.4
Mullett Lake – High	15.4	110	430	12.9
Mullett Lake – Average	6.9	87	300	7.9
All rivers – Low	1.0	21	202	2.9
All rivers – High	18.3	982	1021	13.2
All rivers – Average	6.6	210	429	7.6

**TP = total phosphorus, $NO3^{-}$ = nitrate-nitrogen, TN = total nitrogen, CL^{-} = Chloride. Chloride reported as mg/l (parts per million), all other units in ug/l (parts per billion).*

Total phosphorus concentrations were highest in Mullett Creek; above CWQM program data river monitoring averages on all but one occasion and, at the Crump Road site, often above CWQM river data highs (Table 7). Although total phosphorus in other tributaries exceeded CWQM river data averages on numerous occasions, concentrations never rose above 20 parts per billion (PPB). Total nitrogen and nitrate-nitrogen concentrations were above CWQM program river data averages during all sample events in Mullett Creek at Crump Road and during most sample events at M27 (Table 8). Total nitrogen and nitrate-nitrogen concentrations in the other tributaries were never found to be above CWQM river data averages.

Table 7. Phosphorus concentrations in Mullett Lake tributaries.

Total Phosphorus (µg/l)							
Sample Site	**Apr-05**	**Sep-05**	**Apr-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	4.5	4.7	7.9	3.3	3.6	ND	4.9
L. Sturgeon River	14.4	5.9	19.1	4.7	8.1	2.2	9.1
Indian River - I75	6.4	4.3	8.2	4	3.6	ND	5.4
Pigeon River	15.1	3.5	12.8	6.9	7.8	1.5	7.9
Mullett Creek – Crump	143.4	28.7	106.4	355.4	11.1	5	108.3
Mullett Creek – M27	25.9	18.2	57.1	13.4	17.1	8.9	23.4
Cheboygan River	3.7	3.8	6.4	2.8	3.2	ND	4.0
Soluble Reactive Phosphorus (µg/l)							
Sample Site	**Apr-05**	**Sep-05**	**Apr-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	2.3	2.5	4.4	0.8	ND	ND	2.5
L. Sturgeon River	2.3	4.5	4.7	1.1	ND	ND	3.2
Indian River - I75	1.8	2.7	4.6	0.3	ND	ND	2.4
Pigeon River	2	2.9	5.3	1.2	ND	ND	2.9
Mullett Creek – Crump	82	20.1	42.9	240.5	ND	ND	96.4
Mullett Creek – M27	13.9	10.5	8	5.1	ND	ND	9.4
Cheboygan River	2.2	2.4	4	0.5	ND	ND	2.3

**all units in ug/l (parts per billion). Avg. = average, ND = no data.*

Table 8. Nitrogen concentrations in Mullett Lake tributaries.

Total Nitrogen (µg/l)							
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	336	186	294	204	317	ND	267.4
L. Sturgeon River	361	209	266	209	202	224	245.2
Indian River - I75	299	159	212	191	319	ND	236.0
Pigeon River	292	210	293	290	247	287	269.8
Mullett Creek – Crump	1645	1260	1386	2897	1778	1456	1737.0
Mullett Creek – M27	653	444	488	611	691	990	646.2
Cheboygan River	266	175	219	184	266	ND	222.0
Nitrate-Nitrogen (µg/l)							
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	154.4	19.2	144.1	33.6	105.2	ND	91.3
L. Sturgeon River	132.1	54.9	72	59.5	57.5	131.5	84.6
Indian River - I75	156.8	17.6	118.7	15.8	111.6	ND	84.1
Pigeon River	104.5	38.9	90.6	43.2	28.0	149.6	75.8
Mullett Creek – Crump	871.8	789.1	725.3	1218.3	1532.1	1230.2	1061.1
Mullett Creek – M27	384.7	117.3	300.4	185.9	356.2	731.9	346.1
Cheboygan River	109.3	26.4	75	13.1	50.6	ND	54.9

**all units in ug/l (parts per billion), Avg. = average, ND = no data.*

DEQ Part 4 Water Quality Standards do not include nutrient concentration limits for surface waters. Regulation for surface waters is limited to the following passage from Rule 60 (323.1060): "nutrients shall be limited to the extent necessary to prevent stimulation of growths of aquatic rooted, attached, suspended, and floating plants, fungi or bacteria which are or may become injurious to the designated uses of the waters of the state." The United States Environmental Protection Agency (EPA) recommends that total phosphorus concentrations in streams discharging into lakes not surpass 50 PPB (Muller and Helsel, 1999). This value was exceeded only on Mullett Creek; three times at Crump Road and once at M27 (Table 7).

Chloride concentrations were commonly above averages and high values reported in the CWQM program data, but well within DEQ Water Quality Standards. The highest chloride concentrations occurred in Mullett Creek and the lowest levels were found in the Pigeon River (Table 9). Only the Pigeon River had chloride levels lower than averages reported from the CWQM program. According to Rule 51 (323.1051) in DEQ Part 4 Water Quality Standards chloride concentrations in public water supply sources are regulated as follows: "The waters of the state designated as a public water supply source shall not exceed 125 milligrams per liter of chlorides as a monthly average, except for the Great Lakes and connecting waters, where chlorides shall not exceed 50 milligrams per liter as a monthly average." Regardless of whether monitored tributaries were public water supply sources, measured concentrations did not exceed State standards at any site.

Table 9. Chloride concentrations in Mullett Lake tributaries.

Sample Site	Apr-05	Sep-05	May-06	Sep-06	May-07	Nov-07	Avg.
Indian River - M27	9.7	9.4	10.2	11.3	10.4	ND	10.2
L. Sturgeon River	14.2	9.8	11.9	16.0	13.2	15.2	13.4
Indian River - I75	10.2	9.3	10.3	11.1	11.2	ND	10.4
Pigeon River	7.3	5.3	5.2	5.7	6.8	6.2	6.1
Mullett Creek – Crump	16.5	21.3	14.7	31.2	29.7	23.0	22.7
Mullett Creek – M27	19.9	23.2	25.3	27.3	27.9	25.4	24.8
Cheboygan River	10.7	9.3	10.0	11.2	10.9	ND	10.4

**All units in mg/l (parts per million), Avg. = average, ND = no data..*

Physical:

Results from physical water quality measurements were typical for surface waters in the northern Lower Peninsula. Average values from the CWQM program were again used as reference for comparisons (Table 10). Most data recorded during tributary monitoring fell within ranges of data from the CWQM program.

Table 10. Typical physical parameter values from CWQM program data.

	Dissolved Oxygen*	Conductivity*	pH
Mullett Lake – Low	9.50	273	7.43
Mullett Lake – High	12.52	357	8.36
Mullett Lake – Average	11.47	299	7.97
All Rivers – Low	8.33	222	7.39
All Rivers – High	14.41	405	8.47
All Rivers – Average	10.73	308	8.16

**Units for dissolved oxygen in mg/l (or parts per million) and conductivity in microSiemens/cm.*

Water temperatures ranged from 6.17° to 14.05° Celsius in the spring and from 1.91° to 16.55° Celsius in the fall (Table 11). According to DEQ Part 4 Water Quality Standards, monthly maximum temperatures for streams capable of supporting cold water fish are set at 54° Fahrenheit (12.22° Celsius) for April, 65° (18.33° Celsius) for May, and 63° (17.22° Celsius) Fahrenheit for September. None of the temperatures recorded exceeded state limits. Average water temperatures were lowest in the Pigeon River, Little Sturgeon River and Mullett Creek at Crump Road. Mullett Creek water temperatures were significantly higher at the downstream site when excluding the fall 2007 data ($t(4) = -3.20$, $p < 0.05$).

Dissolved oxygen concentrations in the Mullett Lake tributaries ranged from 7.59 to 12.22 parts per million (PPM) (Table 11). Dependent upon the aquatic ecosystem type, DEQ Part 4 Water Quality Standards minimum dissolved oxygen concentrations for inland streams range from 5 to 7 PPM (Rule 64). All dissolved oxygen levels recorded in this study were above these minimums. Mullett Creek at M27 had the lowest dissolved oxygen levels during the first two years of this study, when monitoring was performed immediately following storm events. Dissolved oxygen levels were significantly different between upstream and downstream sites on Mullett Creek ($t(5) = 3.90$, $p < 0.05$).

Table 11. Temperature and dissolved oxygen data from Mullett Lake tributaries.

	Temperature*						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	6.17	16.55	12.24	15.45	12.79	ND	12.64
L. Sturgeon River	9.25	11.40	10.80	10.37	10.60	4.26	9.45
Indian River - I75	6.25	15.83	11.99	14.82	12.62	ND	12.30
Pigeon River	8.56	10.85	12.09	11.43	13.86	1.91	9.78
Mullett Creek – Crump	6.92	9.83	9.43	10.53	7.21	4.59	8.09
Mullett Creek – M27	11.86	11.26	13.58	11.26	14.05	1.97	10.66
Cheboygan River	8.62	14.79	12.17	15.15	12.48	ND	12.64
	Dissolved Oxygen*						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	11.97	9.34	10.06	9.22	10.04	ND	10.13
L. Sturgeon River	10.41	10.71	9.51	9.55	9.82	11.00	10.17
Indian River - I75	12.11	10.06	10.28	8.99	10.13	ND	10.31
Pigeon River	9.89	9.28	9.20	9.35	9.75	12.22	9.95
Mullett Creek – Crump	10.45	9.83	9.33	9.36	10.32	11.64	10.16
Mullett Creek – M27	7.59	7.68	7.70	7.65	10.48	10.23	8.55
Cheboygan River	11.98	10.04	10.23	9.34	10.87	ND	10.40

**Temperature in °Celsius, dissolved oxygen in mg/l or parts per million, Avg. = average, ND = no data.*

Specific conductivity in the Mullett Lake tributaries ranged from 257.4 to 441.8 microSiemens/cm (Table 12). Most conductivity levels recorded during this project are within the range of the CWQM program river data. On average, conductivity levels were highest at the Mullett Creek sites. Conductivity is not specifically addressed in DEQ Part 4 Water Quality Standards, though Rule 51 (323.1051) provides a framework for regulating total dissolved solid (TDS) concentrations from point source discharge. TDS in mg/l can be estimated from specific conductivity readings by using the widely applied multiplication factor of 0.67. All conductivity measurements and therefore, estimated TDS concentrations, from Mullett Lake tributaries were well below the Rule 51 TDS maximum of 750 PPM. However, the higher conductivity readings in Mullett Creek are probably the result of human activity in the watershed and indicative of potential water quality impairment.

Hydrogen ion concentration, expressed as pH, ranged from 7.60 to 8.44 in the Mullett Lake tributaries (Table 12). All values fell within the range of data collected in the CWQM program and also within the range of 6.5 to 9.0 required for all Michigan surface waters according to DEQ Part 4 Water Quality Standards, Rule 53 (323.1053).

Table 12. Conductivity and pH data from Mullett Lake tributaries.

	Conductivity*						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	282.1	277.8	275.8	265.6	285.3	ND	277.3
L. Sturgeon River	282.8	290.8	290.0	328.9	293.3	257.4	290.5
Indian River - I75	283.1	278.8	276.8	268.7	284.7	ND	278.4
Pigeon River	317.8	322.8	316.8	335.8	316.0	276.5	314.3
Mullett Creek – Crump	299.9	366.3	311.3	441.8	376.6	302.8	349.8
Mullett Creek – M27	345.9	387.4	380.3	342.8	353.2	302.6	352.0
Cheboygan River	291.1	264.4	274.3	258.5	276.0	ND	272.9
	pH*						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	8.15	8.42	8.25	8.44	8.21	ND	8.29
L. Sturgeon River	7.96	8.09	7.76	8.02	8.30	8.21	8.06
Indian River - I75	8.06	8.44	8.24	8.36	8.25	ND	8.27
Pigeon River	8.11	8.11	8.08	8.07	8.37	8.28	8.17
Mullett Creek – Crump	7.85	8.00	7.60	7.78	8.08	8.09	7.90
Mullett Creek – M27	7.84	7.65	7.73	7.72	8.26	8.04	7.87
Cheboygan River	8.26	8.36	8.35	8.43	8.33	ND	8.35

**Conductivity in microSiemens/cm, pH in units, Avg. = average, ND = no data.*

Discharge and Pollutant Loadings:

The average discharge from inlet streams into Mullett Lake was 13.80 cubic meters per second (cms) for the Indian River, 3.97 cms for the Pigeon River, and 0.40 cms for Mullett Creek (Table 13). The average discharge out of Mullett Lake through the Cheboygan River was 15.06 cms. In three of four sampling events for which there is a complete dataset, combined discharge inputs (Indian River, Pigeon River, and Mullett Creek) are greater than the output discharge measured on the Cheboygan River. During all sampling events, Indian River contributed the greatest volume of water per unit time into Mullett Lake, while Mullett Creek contributed the least. On average, discharge from Indian River accounted for 74.5% of the total, Pigeon River contributed 23.2% and Mullett Creek contributed 2.3% (Table 14, Figure 5).

Phosphorus loads in the Mullett Lake tributaries ranged from 0.1 lbs/day to 28 lbs/day (Table 15). On average, combined input phosphorus loads (from Indian River I75, Pigeon River, and Mullett Creek M27) exceeded the output load (Cheboygan River). Despite average discharge being greater in the Cheboygan River, average phosphorus loads in the Cheboygan River were less than those in the Indian River at I75. Similarly, phosphorus loads in Mullett Creek were greater than those of the Little

Table 13. Discharge measurements from Mullett Lake tributaries.

	Discharge (cms)*						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	15.22	9.55	14.33	7.93	13.02	ND	12.01
L. Sturgeon River	1.19	0.59	1.32	0.53	0.52	0.45	0.77
Indian River - I75	16.92	11.56	16.88	9.21	14.44	ND	13.80
Pigeon River	5.28	4.17	4.99	3.92	3.02	2.42	3.97
Mullett Creek - Crump	0.20	0.11	0.25	0.06	0.08	0.07	0.13
Mullett Creek - M27	0.59	0.28	0.60	0.48	0.16	0.28	0.40
Cheboygan River	9.51	ND	22.95	12.97	14.80	ND	15.06
TOTAL INPUT*	22.79	16.01	22.46	13.62	17.62	ND	
	Discharge (cfs)*						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	537.4	337.4	505.9	280.0	459.9	ND	424.1
L. Sturgeon River	42.1	21.0	46.6	18.6	18.2	15.9	27.1
Indian River - I75	597.4	408.2	596.0	325.2	510.1	ND	487.4
Pigeon River	186.6	147.3	176.1	138.6	106.5	85.5	140.1
Mullett Creek - Crump	7.2	3.7	8.9	2.3	2.8	2.6	4.6
Mullett Creek - M27	21.0	9.8	21.2	17.1	5.6	10.0	14.1
Cheboygan River	335.7	ND	810.4	458.0	522.6	ND	534.7
TOTAL INPUT*	805.0	565.2	793.3	480.9	622.2	ND	

**Units: cms = cubic meters per second and cfs = cubic feet per second. Avg. = average. ND = no data. Total input is the sum of discharge calculations from three sites: Indian River (I75), Pigeon River, and Mullett Creek (M27).*

Table 14. Percent of discharge from major Mullett Lake tributaries.

	Discharge Percentage						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River	75.24	72.22	75.2	67.6	82.0	ND	74.5
Pigeon River	22.12	26.05	22.1	28.8	17.1	ND	23.2
Mullett Creek	2.64	1.73	2.6	3.6	0.9	ND	2.3

Sturgeon River even though discharge in the Little Sturgeon River was nearly twice that of Mullett Creek.

Nitrogen loads in the Mullett Lake tributaries ranged from 5.7 lbs/day to 974 lbs/day (Table 16). On average, combined input loads (from Indian River I75, Pigeon River, and Mullett Creek M27) exceeded the output load (Cheboygan River). The Cheboygan River had the highest average total nitrogen load, mirroring its high discharge values. However, nitrate-nitrogen loads were highest at sites on the Indian River. As was the case with phosphorus loads, average nitrogen loads were greater in Mullett Creek than in the Little Sturgeon River, despite discharge being greater in the Little Sturgeon River. Surprisingly, the averaged total nitrogen load at the M27 site on the Indian River was greater than that at the downstream Indian River site at I75.

Table 15. Phosphorus loads in Mullett Lake tributaries.

	Total Phosphorus Load* (lbs/day)						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	13.0	8.6	21.4	5.0	9.6	ND	11.5
L. Sturgeon River	3.3	0.7	4.8	0.5	0.8	0.2	1.7
Indian River - I75	20.6	9.5	26.2	6.9	10.6	ND	14.8
Pigeon River	15.2	2.8	12.1	5.1	4.5	0.7	6.7
Mullett Creek – Crump	5.6	0.6	5.1	4.4	0.2	0.1	2.7
Mullett Creek – M27	2.9	1.0	6.5	1.2	0.5	0.5	2.1
Cheboygan River	6.7	ND	28.0	6.8	8.9	ND	12.6
TOTAL LOAD*	38.7	13.2	44.8	13.3	15.6	ND	
	Orthophosphate Load* (lbs/day)						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	6.7	4.5	11.9	1.1	ND	ND	6.1
L. Sturgeon River	0.5	0.5	1.2	0.1	ND	ND	0.6
Indian River - I75	5.8	5.9	14.6	0.5	ND	ND	6.7
Pigeon River	2.0	2.3	5.0	0.9	ND	ND	2.5
Mullett Creek – Crump	3.2	0.4	2.1	3.0	ND	ND	2.2
Mullett Creek – M27	1.6	0.6	0.9	0.5	ND	ND	0.9
Cheboygan River	4.0	ND	17.5	1.2	ND	ND	7.6
TOTAL LOAD*	9.4	8.8	20.5	1.9	ND	ND	

Units reported in pounds per day. ND = no data. Total load is the sum of loads from mouths of three inlet streams: Indian River (I75), Pigeon River, and Mullett Creek (M27).

Table 16. Nitrogen loads in Mullett Lake tributaries.

	Total Nitrogen Load* (lbs/day)						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	974.0	338.5	800.9	308.1	785.1	ND	641.3
L. Sturgeon River	81.9	23.6	66.8	20.9	19.9	19.3	38.7
Indian River - I75	963.4	350.1	679.9	334.1	876.2	ND	640.8
Pigeon River	293.9	166.8	277.8	216.4	141.9	132.4	204.9
Mullett Creek – Crump	63.9	25.4	66.8	35.8	26.7	20.4	39.8
Mullett Creek – M27	73.9	23.4	55.8	56.4	20.9	53.5	47.3
Cheboygan River	481.6	ND	955.1	454.5	748.3	ND	659.9
TOTAL LOAD*	1331.2	540.3	1013.5	606.9	1039.1	ND	
	Nitrate-Nitrogen Load* (lbs/day)						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River - M27	447.6	34.9	393.1	50.7	261.0	ND	237.5
L. Sturgeon River	30.0	6.2	18.1	6.0	5.7	11.3	12.9
Indian River - I75	505.2	38.8	381.4	27.6	307.0	ND	252.0
Pigeon River	105.2	30.9	86.0	32.3	16.1	69.0	56.6
Mullett Creek – Crump	33.8	15.9	35.0	15.1	23.0	17.3	23.3
Mullett Creek – M27	43.5	6.2	34.4	17.1	10.8	39.6	25.3
Cheboygan River	197.9	ND	327.8	32.4	142.5	ND	175.1
TOTAL LOAD*	653.9	75.8	501.8	77.1	333.9	ND	

Units reported in pounds per day. ND = no data. Total load is the sum of loads from mouths of three inlet streams: Indian River (I75), Pigeon River, and Mullett Creek (M27).

Pollutant load calculations show what one would expect: tributaries with greater discharge contributed more nitrogen, phosphorus and chloride. The Indian River contributed the highest discharge and was accordingly responsible for the greatest percent of nutrient and chloride loadings into Mullett Lake; followed by the Pigeon River and then, Mullett Creek (Tables 17, 18). However, the tributaries generally did not contribute the same proportion of pollutants as discharge. The Indian River contributed an average of 75.5% of discharge to Mullett Lake, but only 59.9% of the total phosphorus and 70% of the total nitrogen (Figures 5, 6, 7). Conversely, the Pigeon River and Mullett Creek contributed a disproportionately high amount of nutrients to the lake. On average, the Pigeon River contributed 23.2% of the total discharge while contributing 33.1% of total phosphorus and 24.7% of total nitrogen loads into Mullett Lake. Mullett Creek contributed only 2.3% of the total discharge, but 7.0% of total phosphorus and 5.4% of total nitrogen loads. Relative to discharge, chloride loads were higher in the Indian River and Mullett Creek and lower in the Pigeon River.

Table 17. Percent of nutrient loads from major Mullett Lake tributaries.

	Total Phosphorus Percentage						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River	53.22	71.69	54.5	52.1	67.9	ND	59.9
Pigeon River	39.22	21.05	37.8	38.5	28.8	ND	33.1
Mullett Creek	7.56	7.27	7.7	9.3	3.3	ND	7.0
	Total Nitrogen Percentage						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River	72.37	64.8	73.3	55.1	84.3	ND	70.0
Pigeon River	22.08	30.87	21.1	35.7	13.7	ND	24.7
Mullett Creek	5.55	4.33	5.6	9.3	2.0	ND	5.4

Table 18. Percent of chloride loads from major Mullett Lake tributaries.

	Chloride Percentage						
Sample Site	**Apr-05**	**Sep-05**	**May-06**	**Sep-06**	**May-07**	**Nov-07**	**Avg.**
Indian River	77.31	79.03	80.9	74.2	86.6	ND	79.6
Pigeon River	17.38	16.25	12.0	16.2	11.0	ND	14.6
Mullett Creek	5.31	4.72	7.1	9.6	2.4	ND	5.8

Figure 5. Chart of Mullett Lake tributaries' discharge percentages.

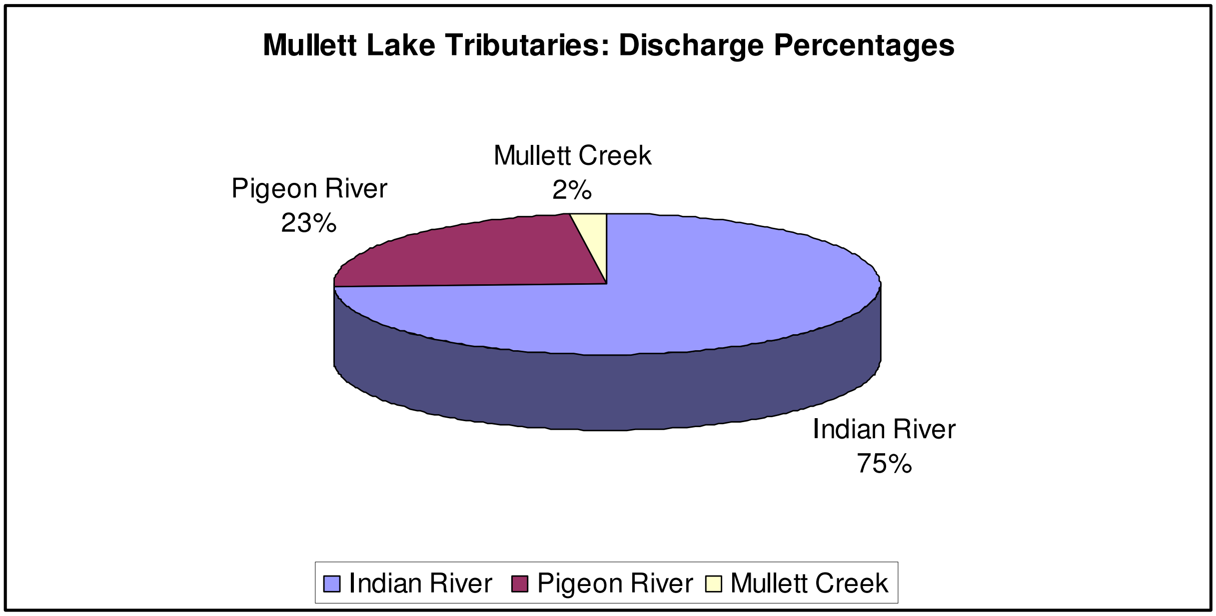


Figure 6. Chart of Mullett Lake tributaries' total phosphorus load percentages.

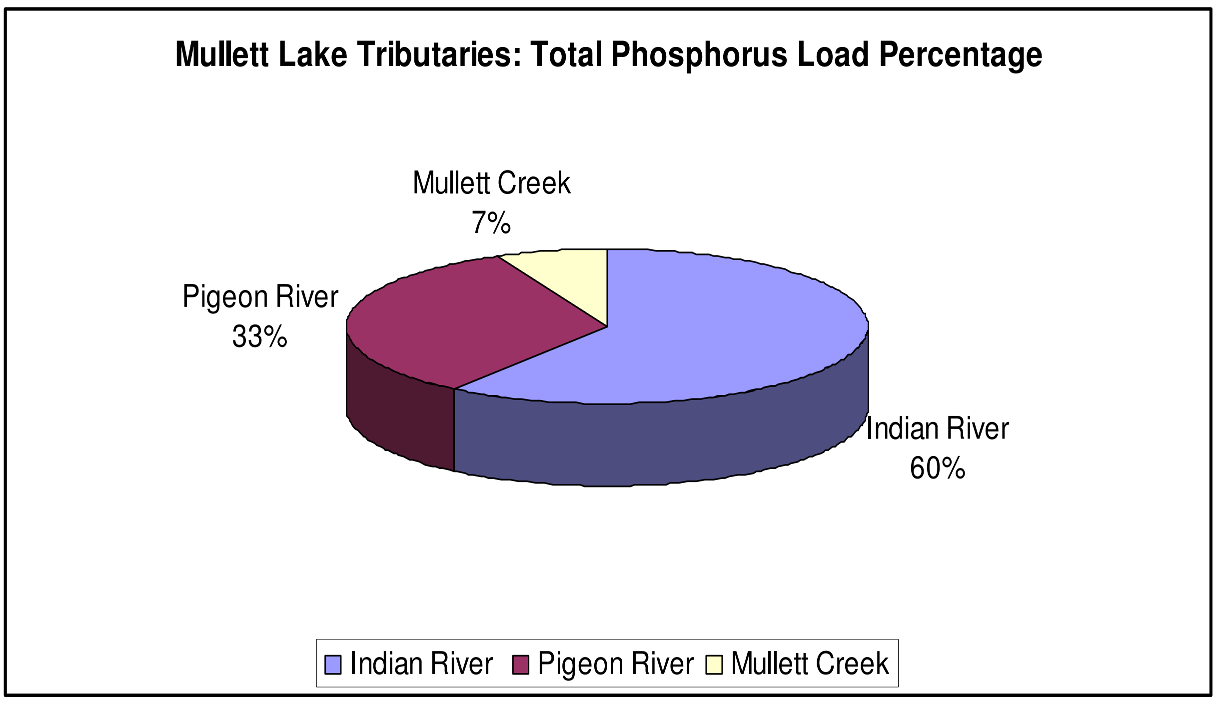


Figure 7. Chart of Mullett Lake tributaries' total nitrogen load percentages.

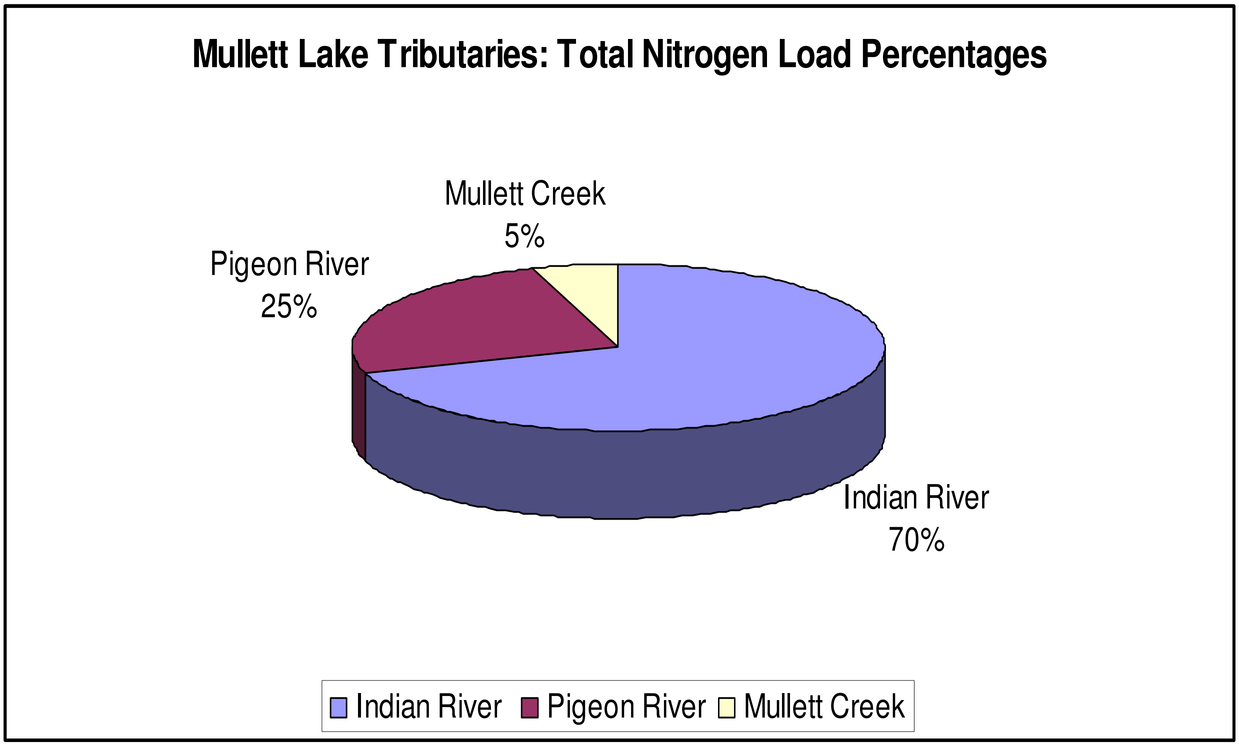
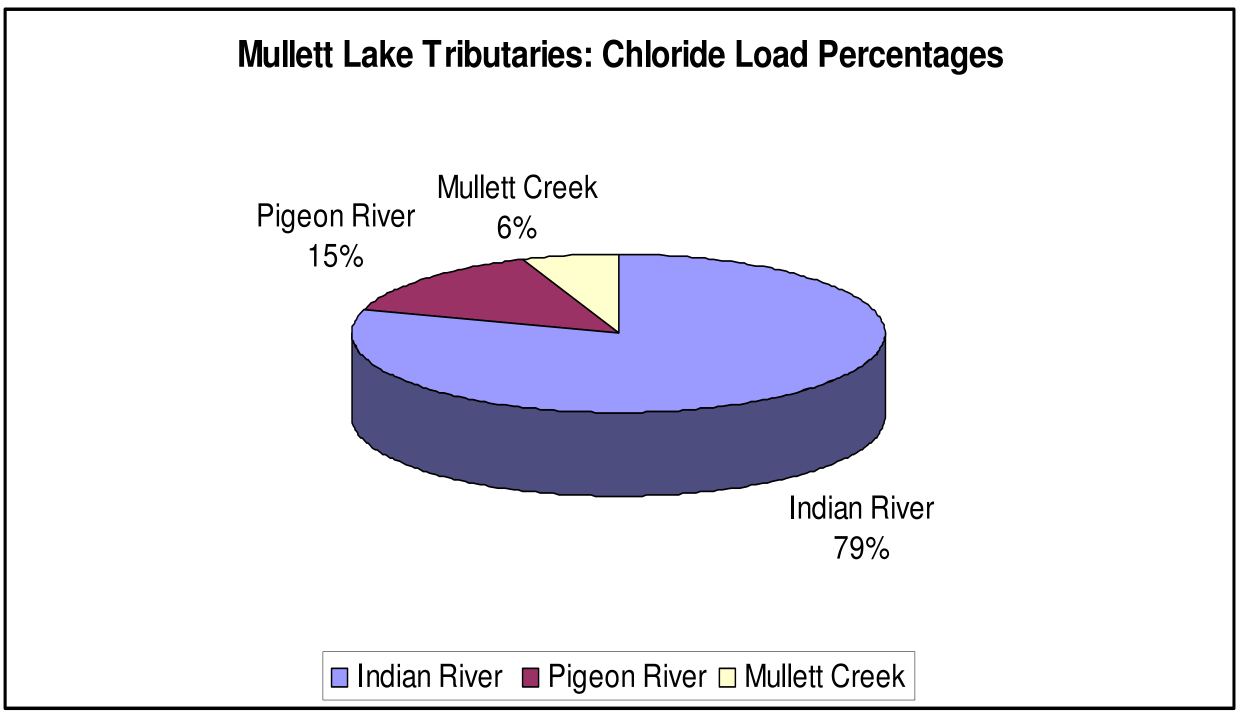


Figure 8. Chart of Mullett Lake tributaries' chloride load percentages.



Monitoring results from upstream and downstream locations on the Indian River and Mullett Creek provided data for determining longitudinal changes in the stream system. The distance between sample sites on the Indian River is approximately 0.85 miles, with an additional 0.13 mile stream reach between the sample site on the Little Sturgeon River and the confluence with the Indian River. Distance between sample sites on Mullett Creek totals approximately 5.2 miles.

Expectedly, all measurements show that the sum of discharge from Indian River at M27 and Little Sturgeon River was less than the discharge measured at the I75 Bridge on Indian River (Table 13). On average, discharge at M27 on the Indian River accounted for 87% of the total measured at the I75 Bridge while Little Sturgeon contributed less than 6%. The majority of the remaining ~7% must have originated from sources downstream of the confluence of the Indian and Little Sturgeon Rivers.

Phosphorus data from sample sites on the Indian and Little Sturgeon Rivers show that the load increased slightly or did not change moving downstream (Table 15). On average, over 10% of the total phosphorus load calculated for Indian River at the I75 bridge originated from sources between the bridge and upstream sites (approximately one mile channel distance), which is disproportionately high relative to discharge additions in this reach. However, combined orthophosphate loads at upstream sites exceeded the downstream load on two occasions and, on average, did not change from upstream to downstream sites (Table 15).

The sum of total nitrogen loads from the upstream Indian River and Little Sturgeon River sites were greater than the load of the downstream Indian River site during three of five sampling events for which there are data (Table 16). This was also the case for the sum of nitrate-nitrogen loads, though not during the same three events. On average, there was a load reduction for total nitrogen and a slight load increase for nitrate-nitrogen moving downstream.

Loading results from Mullett Creek painted a different picture than those from Indian River. On average, data from Mullett Creek show that phosphorus loads decreased while nitrogen loads increased moving downstream (Table 15). However, data from discreet sampling events show that total phosphorus loads were actually higher at the downstream (M27) site during four of six events. Similarly, although data show an average increase in nitrogen loads in a downstream direction, there were reductions in the total nitrogen load during three of six sampling events between upstream and downstream sites (Table 16). Storm events and discharge levels probably exerted a strong influence on the nutrient loads measured in the field, but there were no clear patterns distinguishing data collected following storm events versus data collected during base flow periods. Additional base-flow data is needed to determine base-flow patterns and the influence of storm events on longitudinal changes in nutrient loads in the stream system.

Noticeable seasonal patterns in the data prompted further examination. Results from statistical analyses of nutrient load data using the paired t-test showed significant differences between spring and fall loads ($t(16) = 2.44\text{-}4.15$, $p < 0.05$). Nutrient loads (total phosphorus, orthophosphates, total nitrogen, and nitrate nitrogen) were higher in spring monitoring events as compared with fall monitoring events of the same year for all total phosphorus data, 10 of 13 events for orthophosphates, 15 of 17 events for total nitrogen, and 14 of 17 events for nitrate-nitrogen. At three of four sample sites for which there were complete base-flow data in 2007, nitrate-nitrogen loads were higher in the fall than in the spring. The seasonal difference in nutrient loading corresponds with significant seasonal differences in discharge measurements ($t(16) = 2.97$, $p < 0.05$), which were higher during spring monitoring events all but one time (Mullett Creek, M27, 2007).

Lake Nutrient Budget:

For the four sampling events for which a comprehensive data set was collected, nutrient budgets show a consistent reduction in the nutrient load, i.e., nutrient inputs into Mullett Lake exceed outputs (Tables 19 & 20). This reduction occurred even when the discharge output was greater than the input (May, 2006 sampling event). Based on average nutrient load reductions, 6,993 pounds of total phosphorus and 158,757 pounds of total nitrogen are utilized, removed, or deposited in the Mullett Lake ecosystem on an annual basis.

Table 19. Phosphorus budgets for Mullett Lake.

	TP Load* Apr-05	TP Load* May-06	TP Load* Sep-06	TP Load* May-07	PO4 Load* Apr-05	PO4 Load* May-06	PO4 Load* Sep-06	PO4 Load* May-07
Indian River	20.62	26.20	6.93	10.59	5.80	14.63	0.53	No data
Pigeon River	15.20	12.11	5.12	4.48	2.01	4.99	0.86	No data
Mullett Creek	2.93	6.53	1.24	0.52	1.57	0.91	0.47	No data
Other areas	4.62	6.79	1.69	1.44	1.60	1.87	0.64	No data
Total Inputs	43.37	51.63	14.97	17.03	10.99	22.39	2.50	No data
Outputs	6.70	27.98	6.79	8.88	3.98	17.49	1.24	No data
Load reduction	36.68	23.65	8.18	8.15	7.01	4.91	1.26	No data
Percent reduction†	84.56	45.81	54.63	47.86	63.75	21.91	50.54	No data

**TP = total phosphorus, PO4 = orthophosphates, Load units = pounds per day.*
†Percent reduction is the load reduction as a percentage of total inputs.

Table 20. Nitrogen budgets for Mullett Lake.

	TN Load* Apr-05	TN Load* May-06	TN Load* Sep-06	TN Load* May-07	NO3 Load* Apr-05	NO3 Load* May-06	NO3 Load* Sep-06	NO3 Load* May-07
Indian River	963.43	679.91	334.11	876.24	505.23	381.43	27.62	307.03
Pigeon River	293.88	277.75	216.40	141.93	105.17	85.98	32.29	16.09
Mullett Creek	73.88	55.83	56.37	20.94	43.53	34.40	17.15	10.80
Other areas	123.48	96.46	73.76	95.04	63.25	48.68	21.44	34.24
Total Inputs	1454.66	1109.96	680.64	1134.15	717.19	550.49	98.50	368.16
Outputs	481.61	955.13	454.55	748.32	197.89	327.85	32.36	142.48
Load reduction	973.05	154.82	226.09	385.83	519.29	222.64	66.14	225.68
Percent reduction†	66.89	13.95	33.22	34.02	72.41	40.44	67.15	61.30

**TN = total nitrogen, NO3 = nitrate nitrogen, Load units = pounds per day.*
†Percent reduction is the load reduction as a percentage of total inputs.

The percent reduction of nutrient loads in Mullett Lake was highest in April of 2005, which is when the discharge out of the Cheboygan River was lowest. Conversely, the sample event with the lowest percent reduction of nutrients (in May of 2006) coincided with the highest discharge output. On average, nitrate-nitrogen experienced the greatest percent reduction at 60.32%, closely followed by total phosphorus at 58.21%, then orthophosphate at 45.40% and total nitrogen at 37.02%. Data were insufficient to determine if there was a seasonal pattern in percent reductions of nutrient loads.

DISCUSSION

Bacteriological Monitoring:

Clear evidence of bacteriological contamination was found at one sample site in the Mullett Lake tributaries. Monitoring results from Mullett Creek at Crump Road show high bacteria levels that far surpass State of Michigan surface water quality standards (Table 5). Due to the sampling objective during the first two years of this study of catching first flush of a large storm event, the high bacteria levels at this sample site, which is immediately downstream of an agricultural operation with livestock, were not surprising. The problem appeared to be localized as bacteria levels downstream at the M27 road crossing were significantly lower than the Crump Road site and consistently within State total body contact limits for discreet sampling events.

Bacteriological analyses of samples collected from Mullett Creek sites during the base-flow monitoring events of 2007 suggest that high bacteria counts are associated with runoff from precipitation. E. coli levels exceeded State limits for total body contact during the fall sampling event, but there had been some rain in the Mullett Creek watershed prior to collecting the fall, so it was not an accurate representation of base-flow levels. During the May 2007 sampling of Mullett Creek, bacteria levels were well under State limits; indicating that bacteria may not be a problem during base-flow periods (i.e., when there is no stormwater runoff).

The Pigeon River sample site on East Mullett Lake Road was the only other site where bacteria were found above the State's total body recreation limit of 300 organisms per 100 milliliters (Table 5). Although the level detected in May, 2006 was not far above the limit (365 organisms/100mL), it should be noted that bacteria levels at the Pigeon River were usually higher than all other sites except Crump Road on Mullett Creek. Thus, there is some evidence of bacteriological contamination occurring in the Pigeon River.

Although flowing through an urban area, Indian River displayed some of the lowest bacteria levels (Table 5). Mullett Lake residents have voiced concerns regarding contamination of the Indian River from urban sources as it flows through the community of Indian River. Research has repeatedly shown that urbanization has negative impacts on water quality (Klein 1979, Jones and Clark 1987, and Steedman 1988). However, the high volume of clean water in the Indian River that originates from Burt Lake appears to effectively absorb and dilute the impacts of the small urbanized area that it passes through.

During every monitoring event, bacteria levels at the downstream site on Indian River (I75) were higher than the upstream site (M27), indicating that there were bacteria input sources in this stream reach. The Little Sturgeon River is believed to be one source of the observed increase because bacteria levels were consistently higher at the monitoring site on the Little Sturgeon than at the upstream Indian River site. Storm sewers, shoreline properties and other streams are also probable sources contributing to the increase in bacteria in this stream reach.

Physical and Chemical Monitoring:

Physical measurements taken in the field did not reveal any pressing water quality problems. All temperatures recorded were low enough to sustain cold water fisheries. Both conductivity and pH in all tributaries were found to be at typical levels and dissolved oxygen concentrations were consistently above minimums established by the State of Michigan.

Relatively high water temperatures and low dissolved oxygen levels recorded in Mullett Creek at the downstream sample site (M27) were approaching the threshold for sustaining viable cold-water fisheries. During most sample events, water temperatures were higher and dissolved oxygen levels lower at M27 than at the upstream Crump Road site. Data from the DNR support the results of this study, showing the same trend of increasing water temperatures from upstream to downstream stations. In April of 2005, the water temperature measurement of 11.86 °C at the M27 sample site was just below the State water quality standard maximum of 12.22 °C (Table 10). Dissolved oxygen concentrations recorded at M27 on Mullett Creek during the first two years of this study were approaching the State water quality standard minimum of 7 PPM for sustaining cold-water fisheries (Table 11). Base-flow dissolved oxygen measurements during the third year of monitoring showed higher levels that were similar to other sites. Thus, data suggest that runoff following precipitation events causes changes in the stream ecosystem that lower dissolved oxygen levels; essentially degrading water quality at the M27 sample site.

There are several factors that potentially contribute to the lower dissolved oxygen levels and higher water temperatures at the mouth of Mullett Creek. In the lower section of the creek, the stream channel widens, the gradient lessens, and there appear to be more extensive riparian wetland areas. These physical characteristics result in greater sun exposure and slower flow velocities. Sun exposure raises the water temperature, which results in lower dissolved oxygen levels as warm water holds less dissolved oxygen than cold water. Slow or stagnant waters have lower atmospheric diffusion rates than that of fast turbulent waters and therefore, typically have lower dissolved oxygen concentrations. Further slowing and warming of the water may be occurring as a result of beaver activity upstream of the M27 sample site, which was observed by DNR staff during aerial reconnaissance (T. Cwalinski, DNR Fisheries, personal communication). Perhaps the most important factor contributing to low dissolved oxygen levels at the M27 site is the addition and decomposition of excess organic matter from agricultural operations in the watershed. The decomposition of organic matter within a stream lowers dissolved oxygen concentrations, which would explain the marked differences observed at the M27 site between dissolved oxygen data collected after precipitation events versus data collected during base-flow periods.

Results of chemical analyses of water samples showed concentrations typical of northern Michigan aquatic ecosystems at most sample sites. Nutrient (phosphorus and nitrogen) and chloride levels were higher in Mullett Creek than in other tributaries and highest at the Crump Road site. As with bacteria, elevated phosphorus and nitrogen concentrations were not unexpected at Crump Road due to nearby agricultural operations. Runoff from agricultural areas often contains high nutrient concentrations, particularly nitrogen (Sullivan 1999), which originate from farm field fertilizer application and livestock waste. Elevated nutrient and chloride concentrations in Mullett Creek appear to be a long-standing problem as similar conditions were observed during water quality monitoring activities performed by Tip of the Mitt Watershed Council on Mullett Creek from 1995 to 1997 (Appendix A).

Excessive nutrient inputs have the potential to negatively impact aquatic ecosystems and even pose a danger to human health. Aquatic plants and algae require both phosphorus and nitrogen for survival and will thrive if excess is available. A stream overloaded with plant and algae growth could alter in-stream habitat availability and therefore impact other aquatic organisms. In addition, excessive plant growth in slow-flowing stream reaches, ponds, and small lakes are susceptible to dissolved oxygen deficits, particularly at night when plants respire and consume oxygen. Furthermore, algae blooms as a result of nutrient enrichment may become a nuisance and potentially dangerous as some types are toxic to animals, including humans.

Pollutant Loadings and Nutrient Budgets:

Pollutant loading calculations provide a greater understanding of impacts of inlet tributaries upon the water quality of Mullett Lake. By viewing the data in terms of percentage contributions, inlet tributaries contributing more than their share of nutrients and chlorides were discernable. Both the Pigeon River and Mullett Creek contributed disproportionately high amounts of nutrients. The Indian River and Mullett Creek contributed disproportionately high amounts of chloride.

The disproportionately high nutrient loadings were expected from Mullett Creek, but not from the Pigeon River. Mullett Creek flows through and is impacted by agricultural activity, whereas much of the Pigeon River flows through largely undeveloped State lands including Pigeon River Country. There are branches of the Pigeon River that flow through agricultural, residential and even some commercial/industrial areas, which may be responsible for the high nutrient loads. Alternatively, nutrient loads may be the result of natural sources of phosphorus and nitrogen, such as decaying organic matter and atmospheric deposition that falls or washes into the stream ecosystem. Another factor to consider is that nutrient loading numbers are heavily influenced by the Indian River, which conveys large quantities of relatively nutrient-poor waters from the oligotrophic Burt Lake to Mullett Lake. On average, concentrations of total phosphorus, orthophosphates, and total nitrogen from inlet tributaries were lowest at sites on the Indian River (Tables 6 and 7). This high discharge of nutrient-poor water coming from the Indian River distorts the nutrient loading picture to some extent. Nutrient loads, relative to discharge, from a river like the Pigeon with a typical watershed drainage pattern will invariably be higher than a large river draining an oligotrophic lake.

Chloride may be the best indicator of human activity in the Mullett Lake watershed. Research by Herlihy et al. (1998) found that "chloride concentration is a good surrogate indicator for general human disturbance in the watershed". In relation to discharge, chloride loads were highest from Mullett Creek and the Indian River, which is likely due to impacts from agriculture and urbanization in those watersheds. The Pigeon River, on the other hand, contributed a small percentage of chloride to Mullett Lake in relation to its discharge, which is evidence of the pristine state of its watershed.

Seasonal differences in nutrient loads from tributaries into Mullett Lake corresponded to differences in discharge rates, but spring nutrient input increases were much greater than spring discharge increases. Data from the first two years of the study showed that both nutrient loads and discharge were consistently higher during spring monitoring events (data from the third year was incomplete and therefore, not used). However, the springtime average loading rate for the combined inlet tributaries was 320% greater for total phosphorus and 220% greater for total nitrogen, whereas average discharge was only 150% greater. The greater springtime nutrient loads, as compared to discharge, were probably a result of snowmelt and precipitation runoff scouring the landscape and washing in materials that had accumulated during the winter.

Averaged nutrient loading data from the Indian River showed increases in total phosphorus and decreases in total nitrogen from upstream to downstream sites. Phosphorus accrual in the Indian River must have originated from sources in the approximately one mile of stream channel between upstream and downstream sites. Riparian areas throughout the majority of this stream reach are heavily developed with both commercial and residential landcover. Fertilizers, septic leachate, and stormwater are among the key sources of nutrient pollution from urban areas. In addition, urbanized areas behind riparian properties likely contribute nutrients through drainage systems conveying stormwater to the river. Although the total phosphorus load was shown to increase in this stretch of river, orthophosphate (the form readily available for uptake by plants) loads stayed the same.

There is uncertainty as to why nitrogen loads in the Indian River tended to decrease in the stream reach between the M27 and I75 bridges while phosphorus loads increased (Table 16). Nitrogen reductions are typically the result of in-stream ecosystem processes, such as deposition, uptake by plants, and denitrification. Deposition and plant uptake undoubtedly occur in this section of the river, though there is probably little denitrification as it requires an anaerobic environment. Another possible explanation is that dilution occurred from low-nitrogen water inputs in the stream reach, though it is doubtful that inputs in this limited section of the river would be sufficient to alter the nitrogen concentration of the entire river. Furthermore, water inputs would more likely increase the river's nitrogen load due to nutrient pollution from adjacent urban areas.

The changes in total phosphorus loads between sample sites on Mullett Creek were undoubtedly influenced by ecosystem processes and watershed landuse, but were also probably impacted by stormwater runoff. The total phosphorus load reductions that occurred during two of six sampling events between upstream and downstream sites may be partially attributable to normal in-stream ecosystem processes, such as deposition and uptake by plants. However, the relatively high total phosphorus loads at the Crump Road site were probably caused by stormwater runoff from agricultural operations upstream of the sample site washing into the stream, laden with nutrient-rich materials.

There were not any clear patterns in the changes in nitrogen loads between upstream and downstream sample sites on Mullett Creek. Nitrogen loads increased between sites during half of the sample events and decreased during the other half. These changes in nitrogen loads did not appear to be related to season. Biological and physical in-stream processes likely explain the decreases in the nitrogen load whereas increases were probably due to a combination of inputs from natural sources and agricultural land-use in the watershed. The stream ecosystem has a limited capacity for nitrogen uptake, particularly considering the relatively low discharge. Thus, excessive nitrogen inputs originating from agricultural landuse could overwhelm the streams ability to utilize or store nitrogen and result in the increases that were observed.

Nutrient budget results imply that Mullett Lake is a large nutrient sink that removes substantial amounts of nutrients from the Inland Waterway system. As water in large drainage systems moves through lakes and reservoirs, nutrient loads typically decrease as a result of physical and biological processes, such as deposition and biological uptake. A recent study of the balance of all phosphorus entering and leaving Torch Lake, Antrim County indicated that 90% of the input phosphorus ends up as sediment at the bottom of the lake and is not recycled (Endicott et al. 2006). In Mullett Lake, total phosphorus and nitrate-nitrogen experienced the greatest load reductions, both decreasing by approximately 60%. Considering that groundwater and atmospheric inputs were not monitored and thus, not included in the nutrient budget, the actual nutrient load reduction must have been much greater.

CONCLUSION

The Mullett Lake Tributary Water Quality Monitoring Project was carried out to fill a gap in water quality data by monitoring streams for which little data existed and to better understand the impacts of these streams on the water quality of Mullett Lake. Results of the study supported suspicions that nutrient pollution and bacterial contamination were occurring in Mullett Creek, yet showed less contamination than expected from the Indian River. Surprisingly, data revealed potential water quality problems in the Pigeon River watershed. With this comprehensive water quality data set in hand, the Mullett Lake Area Preservation Society will be able to more effectively manage Mullett Lake and its watershed.

Particular attention should be given to nutrient contamination occurring in the Mullett Creek watershed. Nutrient enrichment could lead to dissolved oxygen deficits and the occurrence of nuisance or harmful algae blooms in the stream and conceivably in a localized area of Mullett Lake. Furthermore, nitrate contamination of ground water poses a direct threat to human health as nitrate in drinking water is known to cause "blue-baby" syndrome. Nitrate-nitrogen in drinking water is regulated by the State and should not exceed 10 PPM (MDEQ 1994). Testing of groundwater was not undertaken in this study and was not researched to determine if data already exists. More information should be gathered on nitrate levels in drinking water supplies in the Mullett Creek watershed. If little or no data exists or if data are not current, then ground water nitrate concentrations should be monitored.

In agricultural areas, livestock should not be allowed access to streams. In addition to bacteriological and nutrient contamination from waste, livestock accelerate streambank erosion. Eroding stream banks expose soils and contribute excess sediments, which can have many negative impacts on the aquatic ecosystem, including: smothering habitat and clogging gills of fish and macroinvertebrates, increasing stream temperature as suspended solids absorb sunlight energy, and reducing stream-edge greenbelts. In situations where a stream crossing is needed to allow livestock movement, impacts can be minimized by using fencing to limit stream access and building concrete, broken rock or gravel approaches to reduce erosion.

Beaver activity in Mullett Creek should be further investigated as it may be impacting physical water quality parameters and cold-water fisheries in the lower section of the stream. Reported beaver damming probably contributes to the relatively high water temperatures documented at the mouth of the creek, which could also result in lower dissolved oxygen concentrations. These conditions pose a danger to the cold-water fisheries, including the native brook trout, as they are approaching the limits that these fish can tolerate. MAPS should consider consulting with the DNR to gather more information and learn more about impacts from and control of beavers.

Riparian owners in all streams throughout the Mullett Lake watershed should be encouraged to adopt best management practices that benefit the water quality of Mullett Lake and its tributaries. Fertilizers should be applied sparingly, if at all, in riparian areas. Stormwater should be held and treated on site, septic systems should be properly maintained, and eroded areas should be stabilized and replanted. Greenbelts are particularly important for protecting water quality and should be maintained at the greatest width possible. Greenbelts effectively absorb surface runoff and by doing so filter out pollutants, reduce peak stream discharge during rain events, provide shade to maintain water temperatures necessary for cold water fisheries and prevent erosion. Naturally vegetated stream banks also provide critical habitat and a food energy source for both aquatic and terrestrial organisms. Research has shown that optimal greenbelt width for stream protection to be 100 feet or more, but that greenbelts of 35 feet of width provide many benefits to stream water quality and biology (Wenger 1999). .

Additional tributary water quality monitoring should be conducted in the future to monitor changes over time and to collect a more representative data set, which would allow for the development of a more accurate nutrient budget. The initial objective set out in this study to collect data during peak discharge conditions has succeeded in determining stormwater runoff impacts, but has not been conducive to development of a reliable nutrient budget. Ideally, data should be collected over a period of several years, sampling throughout all seasons and hydrologic conditions (i.e., low, normal and high discharge). Monitoring in other seasons and under a variety of discharge conditions would provide the necessary data to determine whether there are harmful bacteria levels during all flow stages on Mullett Creek, whether nutrient inputs vary substantially among rivers during differing flow regimes, and would provide a stronger foundation for quantifying nutrient utilization and deposition in Mullett Lake.

As many minor inlet tributaries as possible should be monitored during future tributary monitoring projects to fill data gaps. Although the inlet tributaries monitored during this survey accounted for a majority of the Mullett Lake watershed, some were missed and have possibly never been monitored. Of the minor inlet streams, the largest include Mullett Lake Creek on the northwest side of the lake and Ballard and Hatt Creeks on the northeast side. Monitoring additional inlet streams would provide a more comprehensive nutrient loading data set and would help determine if there are any specific water quality issues in these streams that are impacting the water quality of Mullett Lake.

Due to indications of phosphorus load increases in the Indian River, stormwater should be monitored to determine water quality impacts from the community of Indian River. Data collected in this study showed a substantial increase in total phosphorus between upstream and downstream sites on the Indian River. This increase may be due to a variety of factors, including stormwater runoff. Although impossible to monitor all stormwater inputs, a substantial portion could be monitored by collecting water samples and discharge data from storm-sewer outlet pipes. Collecting storm-sewer water quality data from would allow for a more thorough assessment of the impacts of urban landuse on the water quality of Indian River.

More in-depth monitoring of the Pigeon River may be required to determine if nutrient and bacteriological contamination are occurring in its watershed. Relatively high nutrient loads and bacteria counts were documented at the mouth of the Pigeon River. Monitoring water quality at upstream sites would help determine if human activity in the watershed is polluting the river. In particular, locations on branches of the Little Pigeon River toward Afton and Legrand should be monitored as there are known agricultural and mining operations in the area. Monitoring should also be carried out on the main branch of the Pigeon River at M68 to determine if there are problems occurring upstream of the highway.

This study was not intended to produce a comprehensive, all-inclusive water quality data set for every tributary of Mullett Lake, but rather provide a base of information that can be used to determine the best course of action for protecting and improving water quality. Despite some limitations, a unique set of valuable data was collected and is available to MAPS to guide lake management decisions and to strategize future monitoring efforts. Lake users and the lake ecosystem will ultimately benefit from MAPS taking the initiative to better understand and therefore, better manage Mullett Lake and its tributaries.

LITERATURE AND DATA REFERENCED

Endicott, D, and D. Branson, N. Bretz, and T. Hannert. 2006. Development of a Predictive Nutrient-Based Water Quality Model for Torch Lake. Antrim County, MI. http://www.3lakes.com

Jones, R.C., and C. Clark. 1987. Impact of watershed urbanization on stream insect communities. Water Resources Bulletin 15:1047-1055.

Herlihy, A.T., J.L. Stoddard, and C. B. Johnson. 1998. The relationship between stream chemistry and watershed land cover data in the Mid-Atlantic Region. Water, Air, and Soil Pollution 105:377-386.

Klein, R. 1979. Urbanization and stream quality impairment. Water Resources Bulletin 15:948-963.

Michigan Department of Environmental Quality. 1996. Part 4. A Biological Survey of The Pigeon River and Mullett Creek, Cheboygan County, August 15-16, 1994. MI/DEQ/SWQ-94/032. Lansing, MI.

Michigan Department of Environmental Quality Water Bureau. 1994. Part 4. Water Quality Standards. Sections 3103 and 3106 of 1994 PA 451. Lansing, MI. http://www.state.mi.us/orr/emi/admincode.asp?AdminCode=Single&Admin_Num=32301041&Dpt=EQ&RngHigh

Michigan Department of Information Technology, Center for Geographic Information. 2006. Michigan Geographic Data Library. Lansing, MI. http://www.mcgi.state.mi.us/mgdl/

Michigan Department of Natural Resources, Fisheries Division. 2004. Unpublished Water Temperature Data. Gaylord, MI.

Mueller, D. and D. Helsel. 1996. Nutrients in the Nation's Waters--Too Much of a Good Thing? U.S. Geological Survey Circular 1136. USGS, Reston, VA. http://water.usgs.gov/nawqa/circ-1136/circ-1136main.html

National Oceanic and Atmospheric Administration, Coastal Services Center. 2003. Coastal Great Lakes Land Cover Project. Charleston, SC. http://www.csc.noaa.gov/crs/lca/greatlakes.html

Northeast Michigan Council of Governments and Tip of the Mitt Watershed Council. 1989. Mullett Lake Watershed Nonpoint Source Management Plan. Petoskey, MI.

Sportsman's Connection. 2002. Northwestern Michigan Fishing Map Guide. Superior, WI. http://www.sportsmansconnection.com/

Sullivan, D.J. 1999. Nutrients and Suspended Solids in Surface Waters of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin, 1978-97. U.S. Geological Survey Water-Resources Investigations Report 99-4275. USGS. Reston, VA.

Steedman, R. J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Canadian Journal of Fisheries and Aquatic Science 45:492-501.

Tip of the Mitt Watershed Council. 2005. Volunteer Lake Monitoring and Comprehensive Water Quality Monitoring Programs. Petoskey, MI. http://www.watershedcouncil.org/inlandlakes.html

Wenger, S. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. Institute of Ecology, University of Georgia. Athens, GA.

Appendix A. Data from 1995-97 monitoring of Pigeon River and Mullett Creek.

Sample site	Date	Time	Tem	DO	Cond	pH	SS	TP	Cl	NO3-NO2
			˚C	mg/l	µS	units	mg/l	µg/l	mg/l	mg/l
Pigeon River #1	4/26/1995	9:35:00	6.0	12.1	210	8.2	5	14	4	0.083
Pigeon River #2	4/26/1995	10:50:00	6.5	11.9	250	8.0	4	15	5	0.074
Pigeon River #3	4/26/1995	11:30:00	6.5	10.5	225	8.1	15	16	5	0.077
Pigeon River #4	4/26/1995	12:30:00	6.0	12.0	230	7.9	3	13	8	0.043
Mullett Creek #1	4/26/1995	14:30:00	5.0	10.2	200	7.8	7	40	16	1.500
Mullett Creek #2	4/26/1995	14:05:00	5.0	12.2	230	7.9	17	43	27	2.200
Mullett Creek #3	4/26/1995	13:40:00	5.0	11.4	240	7.8	13	55	38	1.300
Mullett Creek #4	4/26/1995	13:15:00	8.0	12.2	220	8.0	2	21	18	0.450
Pigeon River #1	8/1/1995	10:15:00	22.0	6.8	355	9.1	17	22	5	0.017
Pigeon River #2	8/1/1995	11:00:00	21.0	7.1	350	8.3	7	11	5	0.014
Pigeon River #3	8/1/1995	11:30:00	22.0	7.0	350	9.0	7	10	5	0.019
Pigeon River #4	8/1/1995	12:00:00	22.0	6.8	355	8.7	3	21	6	0.020
Mullett Creek #1	8/1/1995	13:50:00	14.0	9.1	410	8.7	10	33	19	1.800
Mullett Creek #2	8/1/1995	14:05:00	14.0	9.2	430	8.3	13	36	25	2.200
Mullett Creek #3	8/1/1995	14:15:00	16.0	8.9	430	8.4	19	48	26	2.100
Mullett Creek #4	8/1/1995	14:40:00	25.0	8.1	380	8.3	4	40	13	0.010
Mullett Creek #5	8/1/1995	13:20:00	13.0	10.6	440	8.8	33	15	25	2.700
Mullett Creek #6	8/1/1995	14:30:00	23.0	5.1	400	8.4	ND	64	15	0.056
Pigeon River #1	5/24/1996	10:15:00	ND	ND	ND	ND	5	8	4	0.052
Pigeon River #2	5/24/1996	11:00:00	ND	ND	ND	ND	4	6	5	0.047
Pigeon River #3	5/24/1996	11:30:00	ND	ND	ND	ND	11	14	4	0.038
Pigeon River #4	5/24/1996	12:00:00	ND	ND	ND	ND	7	8	7	0.031
Mullett Creek #1	5/24/1996	13:50:00	ND	ND	ND	ND	1	12	17	1.900
Mullett Creek #2	5/24/1996	14:05:00	ND	ND	ND	ND	28	14	29	2.300
Mullett Creek #3	5/24/1996	14:15:00	ND	ND	ND	ND	3	44	34	2.000
Mullett Creek #4	5/24/1996	14:40:00	ND	ND	ND	ND	1	26	15	0.042
Mullett Creek #5	5/24/1996	13:20:00	ND	ND	ND	ND	2	4	27	3.000
Mullett Creek #6	5/24/1996	14:30:00	ND	ND	ND	ND	1	20	17	0.180
Pigeon River #1	10/1/1996	10:15:00	12.0	11.2	270	7.5	2	7	5	0.077
Pigeon River #2	10/1/1996	11:00:00	12.0	11.4	270	7.8	2	8	5	0.082
Pigeon River #3	10/1/1996	11:30:00	13.0	11.0	270	8.0	4	13	5	0.077
Pigeon River #4	10/1/1996	12:00:00	15.0	10.6	281	8.0	2	10	6	0.060
Mullett Creek #1	10/1/1996	12:48:00	9.0	10.2	338	7.5	9	14	30	2.400
Mullett Creek #2	10/1/1996	11:55:00	10.0	9.7	280	8.0	30	467	20	1.900
Mullett Creek #3	10/1/1996	14:15:00	10.5	10.2	330	7.0	3	74	18	1.600
Mullett Creek #4	10/1/1996	13:21:00	12.0	7.8	282	7.5	1	55	34	1.600
Mullett Creek #5	10/1/1996	13:35:00	14.0	7.4	285	7.5	ND	30	19	0.250
Mullett Creek #6	10/1/1996	14:30:00	ND	ND	ND	ND	ND	22	17	0.130
Pigeon River #1	5/30/1997	10:00:00	12.0	10.2	290	8.5	6	8	5	0.074
Pigeon River #2	5/30/1997	10:30:00	12.0	11.1	285	8.0	3	8	5	0.072
Pigeon River #3	5/30/1997	10:45:00	12.0	10.4	285	8.0	4	8	5	0.061
Pigeon River #4	5/30/1997	11:15:00	13.0	9.5	290	8.1	1	10	7	0.023
Mullett Creek #1	5/30/1997	12:00:00	9.5	10.8	320	8.0	9	10	27	1.900
Mullett Creek #2	5/30/1997	11:45:00	9.5	10.9	275	8.0	9	37	17	1.400

Sample site	Date	Time	Tem	DO	Cond	pH	SS	TP	Cl	NO3-NO2
			˚C	mg/l	µS	units	mg/l	µg/l	mg/l	mg/l
Mullett Creek #3	5/30/1997	12:30:00	10.5	11.1	305	8.2	7	33	28	1.100
Mullett Creek #4	5/30/1997	13:05:00	13.5	9.0	300	8.2	1	22	19	0.280
Mullett Creek #5	5/30/1997	12:20:00	9.5	11.2	295	8.1	4	25	24	1.400
Mullett Creek #6	5/30/1997	12:50:00	12.0	8.6	290	8.2	ND	26	19	0.500

**Tem=temperature, DO=dissolved oxygen, Cond=conductivity, SS=suspended solids, TP = total phosphorus, CL=Chloride, NO3-NO2=nitrate and nitrite, ˚C = degrees celcius, µS = microSiemens, mg/l=milligrams per liter or parts per million, µg/l=micrograms per liter or parts per billion, ND=no data.*

Sample sites:

Pigeon River #1 = Englewood Ln. T.34N R.2W Sec.13
Pigeon River #2 = M-68 T.35N R.2W Sec. 35
Pigeon River #3 = Eddy Rd. T.35N R.2W Sec.22
Pigeon River #4 = East Mullett Lake Rd. T.35N R.2W Sec.9
Mullett Creek #1 = Crump Rd. T.37N R.3W Sec.36
Mullett Creek #2 = Budzinski Rd. T.37N R.3E Sec.1
Mullett Creek #3 = South Extension Rd. T.36N R.2W Sec.6
Mullett Creek #4 = M-27 T.36N R.2W Sec.16
Mullett Creek #5 = Indian Trail Rd. T.37N R.3W Sec.35
Mullett Creek #6 = Mullett-Burt Rd. T.36N R.2W Sec.8