

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY  
SURFACE WATER QUALITY DIVISION  
NOVEMBER 1999

STAFF REPORT

LOADING ASSESSMENTS OF PHOSPHORUS INPUTS TO LAKE ALLEGAN, 1998

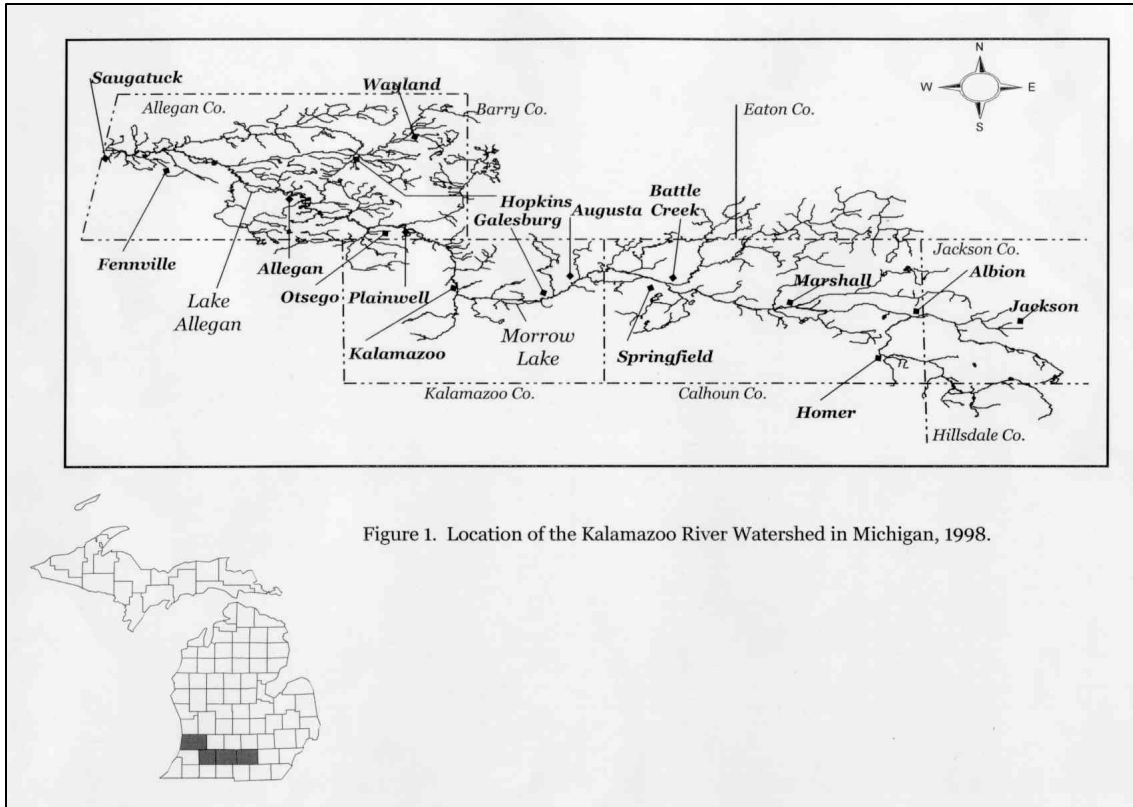
**INTRODUCTION**

This report summarizes the Michigan Department of Environmental Quality's (MDEQ's) monitoring efforts from 1996 to 1999 for Lake Allegan. The purpose of the sampling was to obtain monthly phosphorus concentration data and related measurements to support development of a phosphorus Total Maximum Daily Load (TMDL) that will result in Lake Allegan meeting water quality standards.

**Background**

**Kalamazoo River**

The Kalamazoo River Basin (Figure 1), located in the southwestern part of Michigan's Lower Peninsula, drains approximately 2,020 square miles, approximately 1.3 million acres, from ten counties: Calhoun, Kalamazoo, Allegan, Barry, Eaton, Hillsdale, Jackson, and Van Buren Counties.

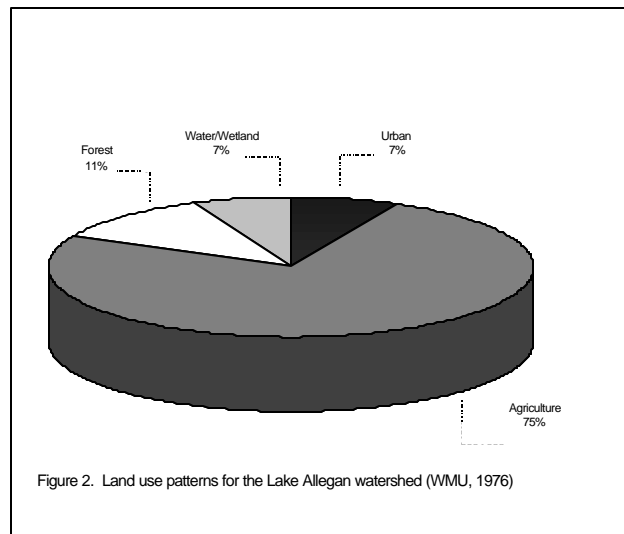


Portions of the Kalamazoo River have had a history of severe water quality degradation due to excessive waste being discharged to the river. The most severe cases of degradation have occurred between Kalamazoo and Plainwell. In the 1940s, 1950s, and 1960s, extremely poor water quality existed in the Kalamazoo River. Conditions were so poor at times, that the river ran multicolored and was considered a “dead, odiferous sewer” (WRC, September 1951). In 1953, four acres of dying carp in Dumont Creek appeared as a photograph in Life Magazine (Life Magazine, October 1953). Fish in the Kalamazoo River were forced to move into tributaries because of oxygen depletion in the Kalamazoo River caused by organic wastes discharged to the river from near-by paper mills. In 1982, the Kalamazoo River was listed as a Site of Environmental Contamination by Michigan; in 1983 an Area of Concern (AOC) by the International Joint Commission, and in 1990 a Superfund Site by the United States Environmental Protection Agency (USEPA). In 1984, a study was conducted by the Michigan Department of Natural Resources (MDNR) to determine the loadings of nutrients to the Kalamazoo River (Supnick and Creal, 1986). As a result of the study, phosphorus limitations were recommended for the Kalamazoo WWTP. In 1986, the WWTP upgraded its facility and implemented advanced waste treatment and better phosphorus removal. Biological surveys conducted in 1988, 1989, and 1994 showed a dramatic improvement in the biological communities (fish and aquatic insects), as well as absence of the nuisance growths of algae that were present prior to the phosphorus reductions (Oemke, 1988; Heaton, 1990 and 1997). The dramatic improvements were a direct result of the reductions in phosphorus made in the watershed in the late 1980s.

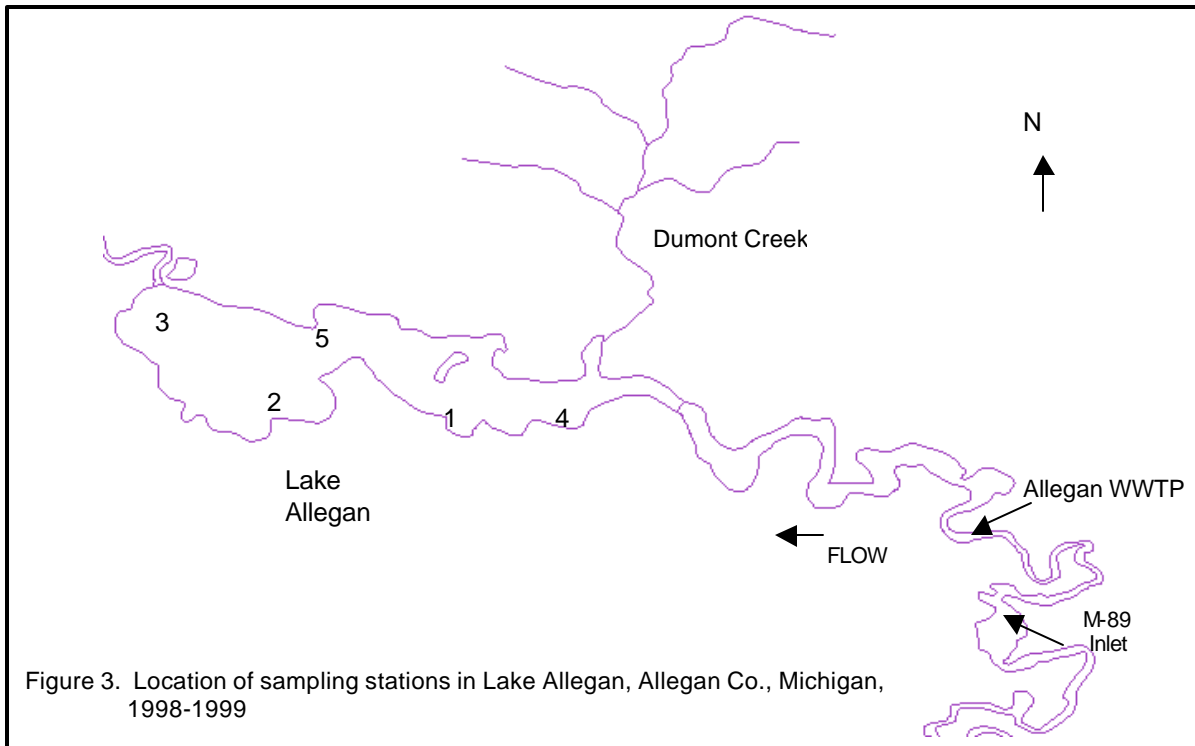
### Lake Allegan

Within the Kalamazoo River watershed lies Lake Allegan. The Lake Allegan watershed has an area of approximately 992,000 acres or 1,550 square miles. Land use in the Lake Allegan watershed (Figure 2) consists of agriculture (75%), forested land (11%), urban areas (7%), and wetlands and open water (7%) (WMU, 1976).

Lake Allegan is a 1,587 acre impoundment on the Kalamazoo River and is located in Allegan County in southwestern Michigan (Figure 3). Major tributaries discharging to Lake Allegan are the Kalamazoo River and Dumont Creek. Several small perennial and ephemeral streams also discharge directly to the lake. Six dams (Trowbridge, Plainwell, Otsego, Otsego City, Allegan City, and Lake Allegan) were originally constructed on the stretch of river from Plainwell to Allegan (three have been partially removed-Trowbridge, Otsego, and Plainwell). Lake Allegan was created in 1936 as a result of the Caulkins Dam built on the Kalamazoo River for providing hydroelectric power.



Lake Allegan has a volume of 17,200 acre-feet, and a mean hydraulic retention time of 7 days. In 1972, depths in the lake ranged from 3 to 20 feet, with a mean depth of 10 feet (USEPA, 1975). Maximum depths measured in 1998 were 20.5 feet, suggesting that filling of the lake is not significant. Natural areas of upland forest dominate the shoreline of Lake Allegan. Much of the immediate surrounding land is designated as the Allegan State Game Area. Currently, residential areas are a small portion of the lake’s shoreline.



Lake Allegan is protected for warmwater fish, other aquatic life and wildlife, agriculture, navigation, industrial water supply, public water supply at the point of intake, partial body contact recreation, and total body contact recreation. There are 77 individual National Pollutant Discharge Elimination System (NPDES) permitted point source discharges within the Lake Allegan watershed. Nonpoint sources of nutrient input from urban sources include, but are not limited to, industrial storm water runoff from impervious and semi-impervious surfaces as a result of urban development, commercial and residential areas, transportation and construction activities, and septic systems throughout the watershed. Nonpoint sources of nutrient input from agricultural activities include runoff from barnyard areas, manure holding areas, and cropland.

The USEPA conducted a National Eutrophication Survey of Lake Allegan in 1972 (USEPA, 1975). The lake was classified as hypereutrophic. The results of the survey indicated that the limiting nutrient contributing pollutant to the eutrophication of Lake Allegan was phosphorus. Additional monitoring data collected by the MDNR in 1988, 1994, 1996, and 1997 indicated that the lake had improved since the early 1970s, but was still considered extremely nutrient enriched. Lake Allegan is currently classified as a hypereutrophic lake (Wuycheck, 1998) with extremely high nutrient and chlorophyll *a* levels, low transparency, periodic nuisance algal blooms, low dissolved oxygen levels with occasional exceedance of the 5 mg/l dissolved oxygen standard, and an unbalanced fish community dominated by carp and channel catfish.

The high phosphorus levels in Lake Allegan have resulted in undesirable growths of algae. The undesirable algae blooms have caused high dissolved oxygen levels in the daytime when plants are releasing oxygen during photosynthesis, and likely low dissolved oxygen levels at night when no photosynthesis is occurring, but plant respiration is high. This increase in plant growth and lower dissolved oxygen has caused a shift in the fish and invertebrate communities to species that can tolerate these more stressful conditions, such as the dominant fish species in Lake Allegan of carp and channel catfish. The increased plant growth, especially of algae, has also dramatically lowered the transparency of the water column. Average secchi depth in Lake Allegan is approximately two feet. These conditions have caused a violation of Rule 60(2) of the Michigan Water Quality Standards (WQS) which states ..."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."

Section 305(b) of the 1972 Federal Clean Water Act (CWA) requires the MDEQ to biennially develop and submit to the USEPA a list of waterbodies that do not attain Michigan WQS. Section 303(d) of the CWA requires the submittal of a list of water quality limited or threatened waters needing established pollutant TMDLs. The MDEQ received a 104(b)(3) grant from the USEPA in July 1998 to develop a phosphorus TMDL for Lake Allegan. Lake Allegan was identified as an impaired waterbody not meeting WQS due to nutrient enrichment in the 1996 and 1998 305(b) reports (Kosek, 1997 and Wuycheck, 1998) and included on the 1996 and 1998 303(d) TMDL lists. In a department memorandum (March 1999) the MDNR, Fisheries Division, stated its support of the development of a phosphorus TMDL for Lake Allegan. Both the MDEQ and MDNR believe that improving water quality in Lake Allegan will lead to an improvement of the fishery.

## **METHODS**

### **Water Chemistry**

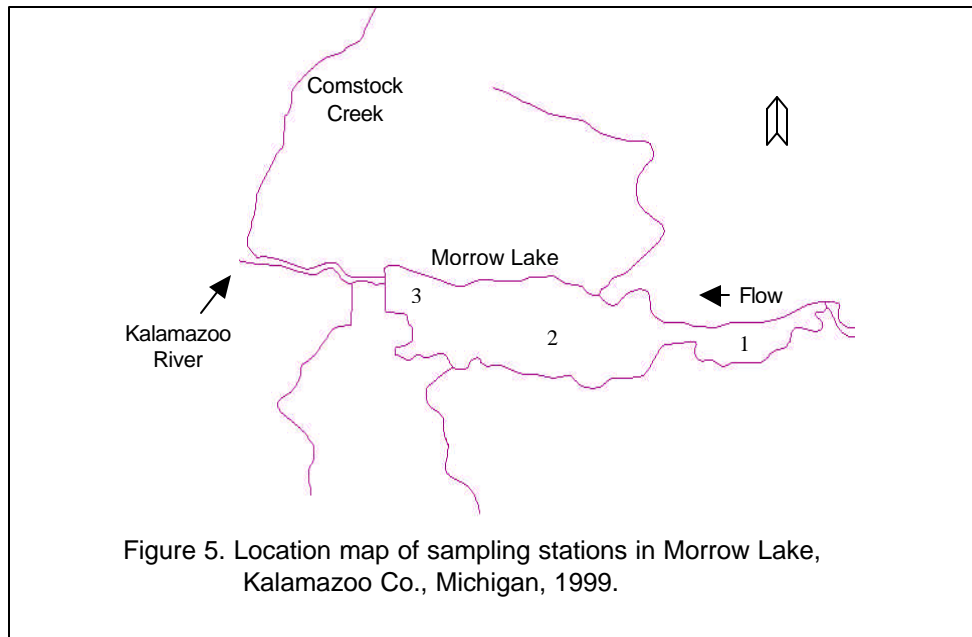
#### **Lake Sampling**

As part of the effort to develop a TMDL for phosphorus for Lake Allegan, extensive sampling was conducted on Lake Allegan and tributaries. Due to the short (seven day) retention time in Lake Allegan, sampling was conducted during the growing season. The critical season for excessive plant growth occurs during the spring and summer months with the growing period beginning in May. Therefore, allowing for time of passage and cycling of phosphorus through the system, it was determined that the critical period for phosphorus load is from April to September. As a result, monitoring of Lake Allegan and the Kalamazoo River tributaries occurred during the spring and summer period (April to September).

Lake sampling was conducted once per month from April 1998 through October 1998 at five stations in Lake Allegan (Figure 3). Monthly sampling in the lake resumed in April 1999 and continued through September 1999. In addition to the sampling of Lake Allegan, Morrow Lake was also sampled monthly at three stations from April 1999 through September 1999 (Figure 5). Monitoring at Morrow Lake was initiated for comparison of water quality conditions with Lake Allegan. Grab samples were collected at the surface, middle and bottom of the water column. Samples were analyzed for total and ortho-phosphorus, nitrites, nitrates, ammonia, suspended solids, and total dissolved solids. Additional sampling at each station included a measurement of secchi transparency and a vertical profile at two-foot increments, of temperature, dissolved oxygen, conductivity, and pH from the surface to the lake bottom. Chlorophyll *a* samples were collected using a vertical composite sampler. Samples were taken to a depth equal to twice the secchi depth. The phytoplankton communities in Lake Allegan and Morrow Lake were sampled in August and September 1999. Sediment samples were collected at each of the sites, where possible, on three occasions. The samples were analyzed for phosphorus for comparison of phosphorus levels in Lake Allegan sediments with levels in other Michigan lakes and to aid in determining the contribution of phosphorus from in-lake sediments.

#### **Tributary Sampling**

A total of 29 stations were selected throughout the watershed for water quality monitoring and to quantify phosphorus loading to Lake Allegan from various geographical areas (Figures 4a and 4b). The list of 29 stations and their locations are provided in Appendix A. The 29 stations were selected from a screening analysis of the watershed conducted in November and December



1997, prior to project initiation. A total of 64 stations were sampled for water quality parameters during the initial screening analysis. Based on the levels of total phosphorus found in the samples and known areas where significant loads of phosphorus were expected to occur from point and nonpoint sources, the list of 29 stations to be included in the study was compiled. Sampling of the 29 stations began April 1, 1998, and continued through October 31, 1998. The 29 stations were divided into two sample groups, 13 primary stations and 15 secondary stations. The 13 primary stations were sampled 3 times a month from April to mid-May (during snow melt and spring rains), and twice a month thereafter, due to the expectance of large phosphorus loads from these locations. The 15 secondary stations were sampled twice a month from April to mid-May (during snow melt and spring rains), and once a month from mid-May to October. In addition to the 1998 sampling, four stations on the Kalamazoo River were sampled monthly from April to September 1999. These included the Kalamazoo River at: (1) 35<sup>th</sup> Street in Galesburg; (2) River Street in Comstock; (3) M-89 in Allegan; and (4) the outlet to Lake Allegan. The rationale for sampling these stations is included in the section describing “Lake Sampling.”

In addition to the grab sampling, three of the upstream sampling locations were equipped with automatic samplers to determine flow and phosphorus loads from elevated runoff conditions (Figure 4a and 4b). The automatic samplers were deployed at the United States Geological Survey (USGS) gage station (04106000) located on the Kalamazoo River at Comstock, Michigan, and on the Gun River and Portage Creek. The Gun River represented an agriculturally dominated sub-watershed, while Portage Creek was representative of an urban dominated system. The automatic samplers were connected to stage recorders permitting the determination of a continuous flow record at these sites. The samplers were programmed to begin collecting samples when storm events produced a rise in the water level at each site greater than 6 inches.

All of the samples collected during the grab sampling runs and with the automatic samplers were collected, preserved (if necessary), stored at 4°C and transported to the MDEQ, Environmental Laboratory, for chemical analysis using standard protocols (MDNR, 1994). The samples were analyzed for total and ortho-phosphorus, nitrates, nitrites, ammonia, suspended solids, and total dissolved solids.

Figure 4a

Figure 4b

## Flow Monitoring

Records of average daily flow were obtained from the USGS for the gage stations located on the Kalamazoo River at Comstock (04106000) and Battle Creek (4105500), Michigan. Stream gages placed on the Gun River and Portage Creek in 1998 allowed for the development of stage discharge curves for these tributaries. The stage discharge curves were used along with the data obtained from the automatic samplers to develop annual hydrographs of average daily flow. When the automatic samplers were not working, which resulted in gaps in the annual hydrographs, equations were developed using the gage flow data and the available automatic sampler flow data. Missing daily flow values were then calculated using the equations and known flow at the USGS gage stations. Drainage areas were delineated and estimates made for each of the sampling stations. Average daily flows were computed for the remaining tributaries using the equations and drainage area ratio estimates.

## Phosphorus Load Estimations

To determine nutrient loading inputs from the watershed, phosphorus loads to Lake Allegan were calculated as the sum of the tributary loads, surface runoff loads from direct drainage areas immediately surrounding the lake, atmospheric loads and direct point source loads from the Allegan POTW. Tributary phosphorus loadings were estimated with a computer program developed by Dr. R. Peter Richards, Heidelberg College, entitled the "AutoBeale: An Implementation of the Beale Ratio Estimator Load Calculation" (Peter et al., 1996). The Beale Ratio Estimator estimates mean daily loads in a time-stratified mode. The mean daily load is calculated for the days of the year for which chemical observations were made, adjusted for differences in average flow between days on which chemical observations were made and the sample period as a whole, and corrected for bias which results from the correlation between flow and load. Flow and phosphorus data collected during storm events are factored into the estimates. The computer program contains an algorithm, which seeks to identify the optimal stratification. The criterion used is that the optimal stratification is the one which has the smallest pooled mean square error. The resulting value is an unbiased estimate of phosphorus load reported in grams per day. Loads in pounds per day for each of the sampling stations were calculated by dividing grams per day by 1,000 to obtain values in kg per day, and multiplying this value by a conversion factor, 2.205.

Estimated loads for phosphorus that are expected to occur were calculated using flows for the historical period of record (1931-1997) and the actual loads measured in 1998. The actual measured daily phosphorus loads and flows for 1998 were plotted, and a line of linear regression was computed (Figure 6). Based on the line equation, the expected phosphorus loads could be estimated for the months of April to September. The resulting expected loads were considered as being representative of the current loading of phosphorus to Lake Allegan to account for annual and seasonal variation in flows.

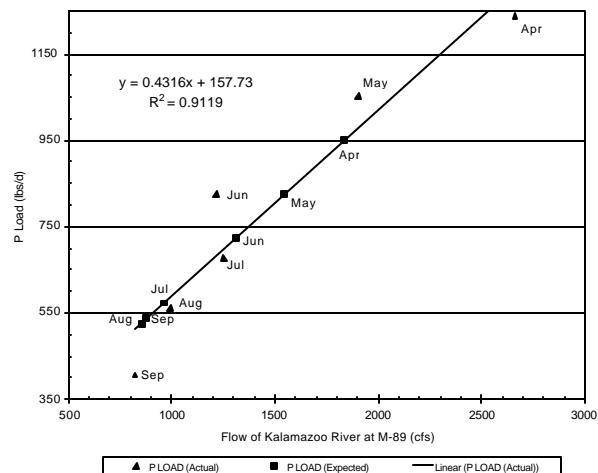


Figure 6. Actual and Expected Daily Phosphorus Loads (lbs/day) for the Inlet of Lake Allegan, 1998.

## **Point Source Phosphorus Load Estimates**

The monthly contribution of phosphorus from point source discharges with authorization to discharge phosphorus was determined from questionnaires submitted by the facilities. The facilities were asked to complete a form which reported the average daily and monthly loads of total phosphorus from each of their outfalls. An example of the form is provided in Appendix B. Each facility's NPDES permit specifies the frequency of monitoring flow and phosphorus concentration. The facilities are required to submit Discharge Monitoring Report (DMRs) forms to the MDEQ on a monthly basis. For those facilities where the forms were not submitted, Surface Water Quality Division staff computed the point source loads of phosphorus from the facility DMR form. Several non-contact cooling water discharges (NCCW) in the Kalamazoo River basin (excluding Calhoun) use potable water containing phosphate additives to reduce levels of copper and lead in the discharge. Point source estimates of phosphorus loads for NCCW were made based on an average phosphorus concentration of 0.7 mg/l and the average flows of the discharges.

## **RESULTS AND DISCUSSION**

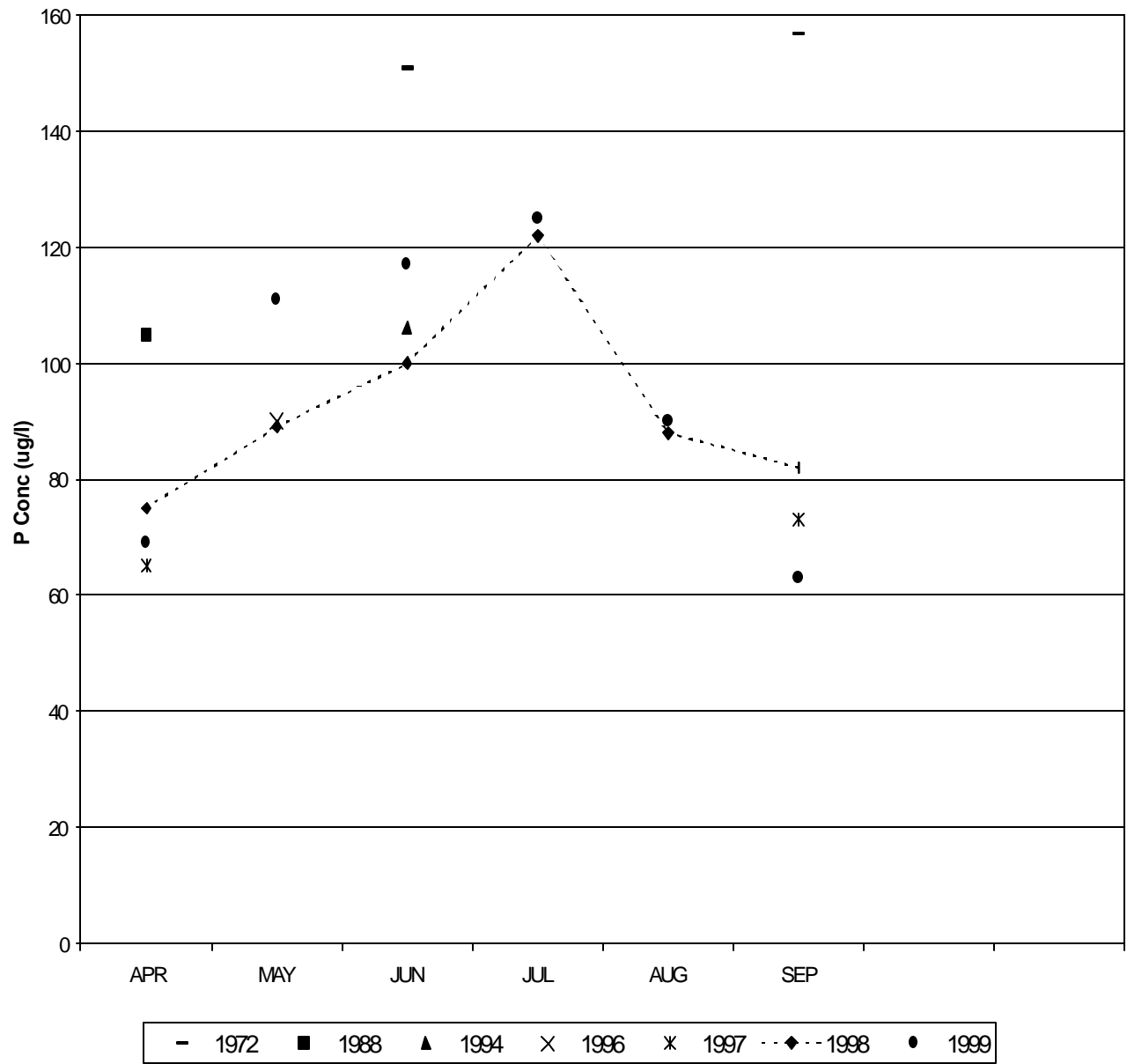
### **Lake Sampling**

A summary of the water quality sampling results for Lake Allegan and Morrow Lake in 1998 and 1999 are presented in Table 1. The recommended laboratory holding times for the nitrogen and phosphorus samples were exceeded for the samples collected in August and September 1998. However, the laboratory conducted a holding time trial and determined that concentrations of nitrogen and phosphorus did not significantly differ when the holding times were exceeded. The historic monthly sampling results of phosphorus for the period of record for Lake Allegan are displayed in Figure 7. Total phosphorus levels in the lake in 1972 averaged 150 ug/l and ranged from 92-303 ug/l. The reduction in point source phosphorus loading in the 1980s resulted in a decline of phosphorus levels in Lake Allegan. Current levels of total phosphorus in Lake Allegan average 96 ug/l.

Table 1. Lakewide Water Quality Sampling Summary for Lake Allegan (1998 and 1999) and Morrow Lake (1999), April - September.

Units	Total Phosphorus (ug/l)	Ortho Phosphorus (ug/l)	Secchi Depth (feet)	Chlor. A (ug/l)	NO <sub>2</sub> <sup>-</sup> (mg/l)	NO <sub>2</sub> <sup>-</sup> + NO <sub>3</sub> <sup>-</sup> (mg/l)	NH <sub>4</sub> <sup>+</sup> (mg/l)	Total Sus. Solids (mg/l)	Total Dis. Solids (mg/l)
Lake Allegan (1998)									
April	74	10.5	2.4	13	0.014	0.91	0.031	20	351
May	90	16	2.2	25	0.019	0.74	0.03	29	407
June	100	27.5	2	41.5	0.024	0.67	0.057	15	399
July	122	26.3	1.5	45.4	0.022	0.71	0.077	23	353
August	88	14	2.5	26.4	0.016	0.71	0.059	13	356
September	86	21	2.5	23.8	0.017	0.89	0.044	11	400
Average	95	19	2.2	29	0.019	0.748	0.0508	20	373.2
Lake Allegan (1999)									
April	69	7.6	2.4	43.2	0.02	1.05	0.043	10	387
May	111	5.9	1.7	80.6	0.022	0.87	0.016	27	441
June	117	20	1.9	82.2	0.024	0.78	0.066	25	437
July	125	6.3	2	86.8	0.02	0.47	0.05	26	411
August	90	13.6	2.9	41.2	0.02	0.7	0.03	18	426
September	63	10.3	2.5	N/A	0.015	N/A	N/A	12	415
Average	96	11	2.2	66.8	0.018	0.77	0.041	17	418
Morrow Lake (1999)									
April	50	11	4	10.7	0.013	1.06	0.036	6	339
May	60	17	3	11.3	0.021	1.05	0.138	12	438
June	78	23	3.5	33.7	0.022	0.7	0.101	12	424
July	83	11	3.3	30.3	0.014	0.65	0.017	15	397
August	79	9.1	3.8	32	0.012	0.71	0.017	21	440
September	47	5.4	3.1	N/A	0.008	N/A	N/A	20	426
Average	66	13	3.5	23.6	0.012	0.83	0.062	17	417

Figure 7. Historic phosphorus sampling results for Lake Allegan.



Excessive inputs of nutrients to lakes and reservoirs have been one of the most significant causes of water quality deterioration in these types of waterbodies (Rast and Lee, 1983). Responses to nutrient inputs in lentic systems include increased algal productivity and chlorophyll *a* levels causing nuisance plant growths, oxygen depletion in the hypolimnion, decreased water clarity, and changes in fish productivity (Jones and Bachmann, 1976; Larsen and Mercier, 1976).

Chlorophyll *a* concentrations in Lake Allegan in 1998 and 1999 increased as total phosphorus concentrations increased (Figures 8 and 9). The highest levels of total phosphorus and chlorophyll *a* in Lake Allegan were reported in the month of July in both 1998 and 1999. Algal blooms observed during these same time periods give evidence to the fact that high phosphorus levels are resulting in elevated chlorophyll *a* levels during the hot summer months. As a result, the average secchi depth in Lake Allegan measured only 2.0 feet in 1998 and 1999 due to the decrease in water transparency. Comparison of total phosphorus and chlorophyll *a* levels in Morrow Lake are shown in Figure 10.

The data from 1994, 1996, and 1997 are previously unpublished results of MDEQ sampling conducted to define existing conditions. The sampling results for Morrow Lake are also presented in Table 1. As part of the process in evaluating site-specific characteristics in the Kalamazoo River watershed, an analysis of the conditions in Morrow Lake, an impoundment on the Kalamazoo River upstream of the city of Kalamazoo was conducted. Morrow Lake is of similar size (1,000 acres) and depth (5-10 foot depth) as Lake Allegan, but has better water quality. In 1999, chlorophyll *a* levels averaged 23  $\mu\text{g/l}$ ,

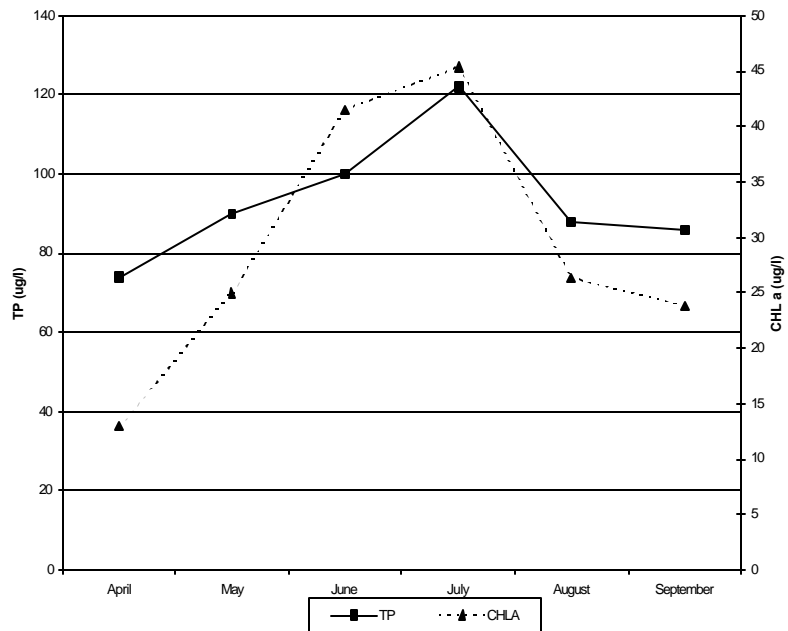


Figure 8. Comparison of total phosphorus and chlorophyll *a* levels in Lake Allegan, 1998.

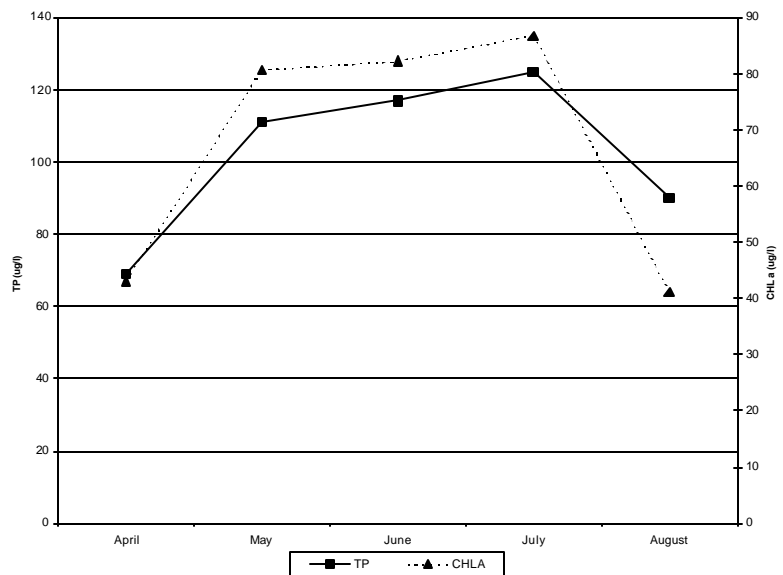


Figure 9. Comparison of total phosphorus and chlorophyll *a* levels in Lake Allegan, 1999.

secchi depth averaged 3.5 feet, and total phosphorus concentrations averaged 66 ug/l in Morrow Lake. The entire set of lake sampling results from 1996, 1997, 1998, and 1999 for Lakes Allegan and Morrow are provided in Appendix B.

Total phosphorus concentrations observed on the same day in Lake Allegan that were comparable to concentrations at the inlet (M-89) are shown graphically in Figure 11. Lake versus inlet concentrations indicated that there was a decrease in phosphorus concentrations of approximately 20% from the inlet through the lake.

### Tributary Sampling

Average monthly flows for 1998 at the Comstock USGS gage station (04106000) are shown in Figure 12. The historical flows for the Kalamazoo River at the USGS gage at Comstock, Michigan, for the period of record (1931-1997) are also presented. The flows for 1998 were approximately 10% greater than those for the period of record. Average daily flows at the Comstock USGS gage station, and for the Gun River and Portage Creek during the study period are portrayed in Figures 13-15.

Highest flows were observed during the spring run off period. Stage discharge relationships for the Gun River and Portage Creek are presented in Appendix C.

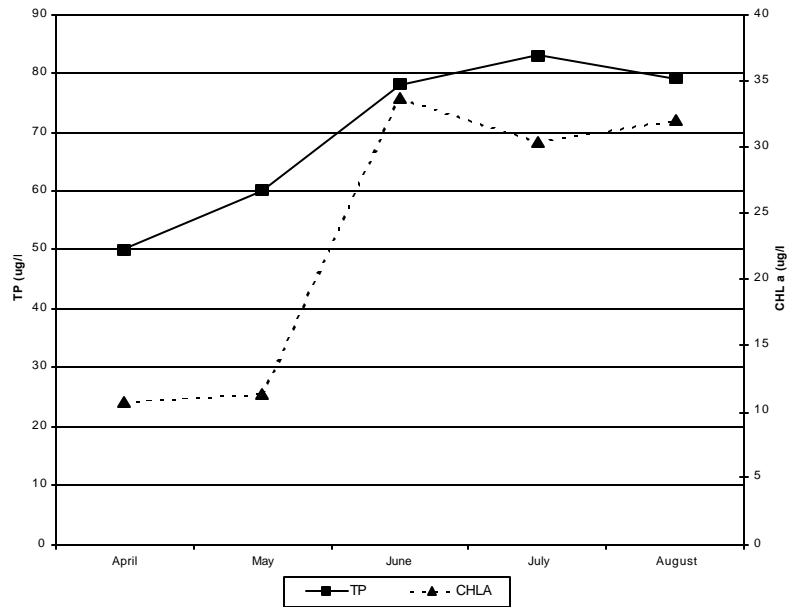


Figure 10. Comparison of total phosphorus and chlorophyll a levels in Morrow Lake, 1999.

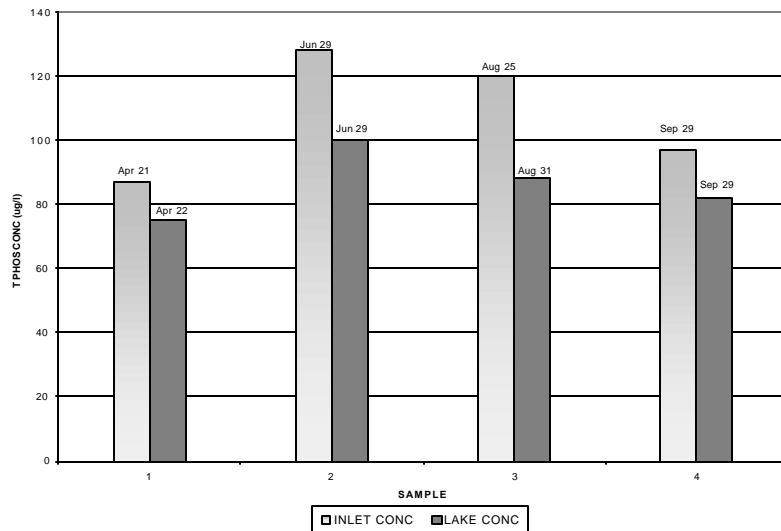


Figure 11. Lake Allegan inlet and in-lake concentrations of total phosphorus.

Figure 13

Figure 14

Figure 15

The concentrations of phosphorus, ortho-phosphorus, total nitrogen, nitrates, nitrates + nitrites, ammonia, suspended solids, and total dissolved solids for the 29 stations sampled in 1998 throughout the watershed are included in Appendix D. Total phosphorus concentrations in the Kalamazoo River increased as one moved downstream as depicted in Figure 16. Highest concentrations were seen at the M-89 inlet prior to entering Lake Allegan.

Samples collected in 1999 showed that total phosphorus was still highest at the M-89 station. The data showed that a 10% increase in phosphorus occurs from Morrow Lake to Comstock due to nutrient inputs from Comstock Creek and several small tributaries. The data collected in 1999 from the Kalamazoo River can be found in Appendix E. Flow data and drainage area estimates for the 29 stations are available upon request.

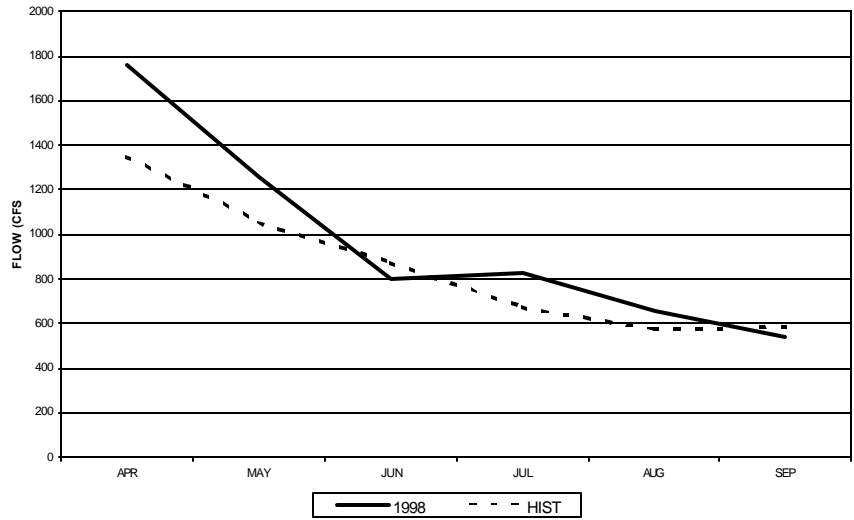


Figure 12. Average monthly flows for the Kalamazoo River at Comstock, MI (Gage 04106000) in 1998 and the historical period of record, 1931-1997.

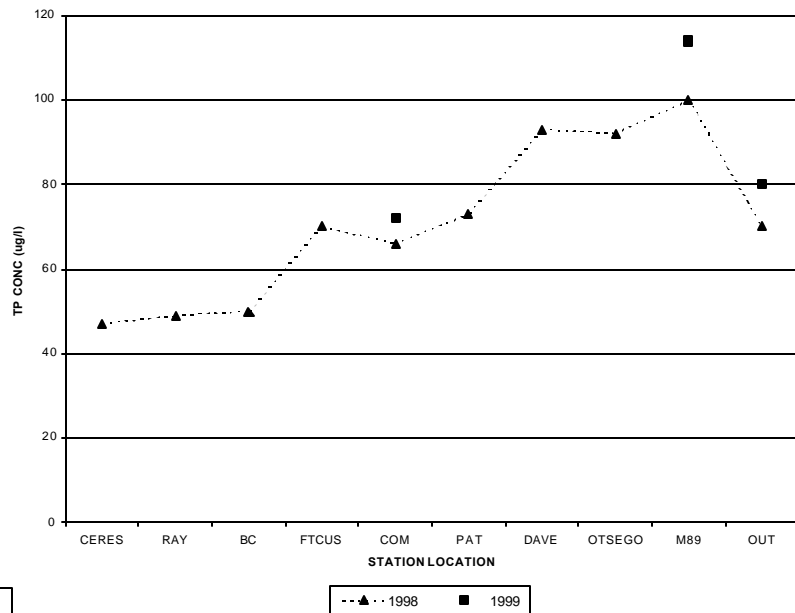


Figure 16. Total phosphorus concentrations (ug/l) measured in the Kalamazoo River from Ceresco to Lake Allegan, April to September, 1998 and 1999. The coded locations for the primary stations are listed in the location legend to the left.

Locations	
CERES	= Ceresco
RAY	= Raymond Road
BC	= Battle Creek Gage
FTCUS	= Fort Custer
COM	= Comstock
PAT	= Patterson Road
DAVE	= D Avenue
OTSEGO	= Otsego Dam
M-89	= M-89 in Allegan
OUT	= Lake Outlet

## Point and Nonpoint Source Phosphorus Load Estimates

The total and monthly phosphorus loads (pounds/month) estimated for the major tributaries sampled in 1998 are presented in Table 2.

The highest tributary loads were for the Kalamazoo River proper at M-89 as would be expected. Those measured tributaries with total loads of over 1,000 pounds of phosphorus were as follows (descending order): Battle Creek River, Portage Creek, Gun River, Schnable Brook, Pine Creek (Baseline Creek), Minges Brook/Harper Creek, Arcadia Creek, and Davis Creek. It should be noted that the Arcadia Creek loads are most likely an underestimate of actual loadings. Sampling of Arcadia Creek did not commence until the end of September. In addition, this tributary receives high volumes of storm water from the city of Kalamazoo during rain events which would most likely result in large loadings of phosphorus in the spring.

Table 2. Tributary phosphorus loads (pounds) for selected tributaries throughout the Lake Allegan Watershed, April to September, 1998.

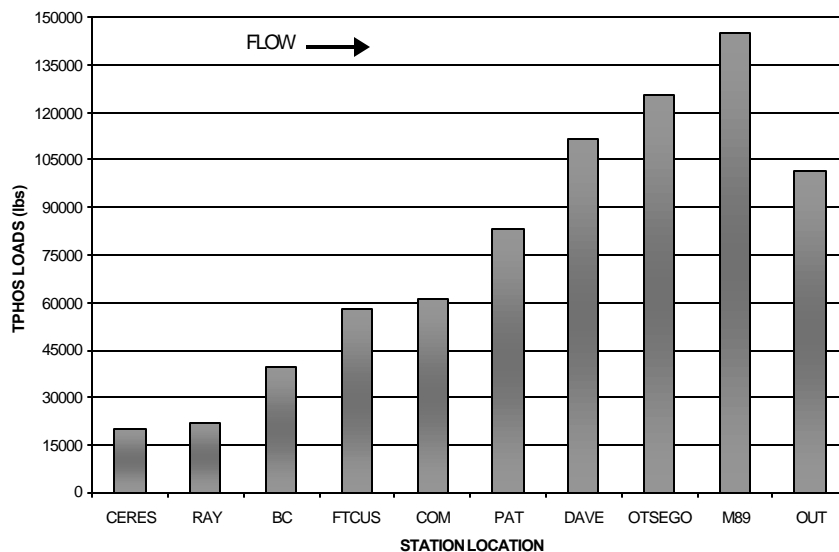
Month	April	May	June	July	August	September	Total	%Total
Station Load							Trib.	To Lake
Willow Creek	6	35	5	5	5	5	62	0.04
Minges Brook/Harper Creek	277	286	277	286	286	277	1689	1.14
Battle Creek River	4336	2162	4774	2183	1416	1143	16014	10.83
Seven Mile Creek	91	94	91	94	94	91	555	0.38
Gull Lake Creek	123	127	123	127	127	123	750	0.51
South Trib @ Fransis Rd	55	56	55	56	56	55	333	0.23
Comstock Creek	78	80	78	80	80	78	474	0.31
Davis Creek	180	186	180	186	186	180	1098	0.74
Portage Creek	1618	1023	593	612	612	593	5051	3.42
Arcadia Creek	215	223	215	223	223	215	1314	0.89
Spring Valley Creek (ARCA)	129	133	129	133	133	129	786	0.53
Chart Creek	8	8.3	8	8.3	8.3	8	48.9	0.03
Gun River	729	760	736	724	387	249	3585	2.42
Pine Creek (Baseline Creek)	323	333	323	333	333	323	1968	1.33
North Trib of Kalamazoo River	20	20	20	20	20	20	120	0.08
Schnable Brook	416	430	416	430	430	416	2538	1.72
110th Trib to Kalamazoo River	32	33	32	33	33	32	195	0.13
Kalamazoo River @ M-89 (inlet)	37153	32691	24723	21055	17343	12191	145156	98.15
Dumont Creek	400	90	88	90	80	36	784	0.53
LAST (immediate drainage)	122	126	122	126	126	122	744	0.5
Lake Allegan Outlet	16643	17198	16643	17198	17198	16643	101523	68.65

Various tributaries can be characterized in regards to the type of nonpoint sources they receive. The Portage River, Arcadia Creek, and Davis Creek watersheds are dominated by industrial/residential urban nonpoint sources. The remaining watersheds are dominated by inputs from agricultural nonpoint sources. The Gun River, Pine Creek, and Schnable Brook subwatersheds are examples of agriculturally dominated areas. In regards to loading rates (pounds per square mile) of phosphorus, the highest rates were observed for the small tributary to the Kalamazoo River at Francis Road in Comstock. However, this stream is ephemeral in nature, and therefore, does not contribute a significant load to the lake. Based on "pounds of phosphorus per square mile," the small tributary to the north side of the Kalamazoo River at 27<sup>th</sup> Street had the largest load rate, while Gull Lake Creek had the smallest load rate.

The phosphorus loads (pounds) to the Kalamazoo River proper, estimated for 1998, increase as one moves downstream (Figures 17). The greatest increase in phosphorus loads to the river occur at points where point source discharges and large nonpoint source (urban and agricultural) loads enter the river. The first increase in phosphorus can be seen between the Battle Creek gage and Fort Custer stations, where the Battle Creek WWTP discharge is expressed in the river. The second increase comes at Patterson Avenue, after inputs from the Portage River (urban sources). A third large increase is seen between Patterson and D-Avenues, where the discharges from Crown Paper and the Kalamazoo River WWTP occur. As one moves downstream, a slight increase in phosphorus occurs between D-Avenue and the Otsego Impoundment. Otsego WWTP and Menasha discharge at this point. In addition, loads from the Gun River and Pine Creek also enter at this point. Discharges from Plainwell Paper, Plainwell WWTP, Allegan Metal Finishing and Rock-Ten occur between the Otsego Impoundment and M-89.

Tributary loads based on loading rate (pounds/square mile) are presented in Table 3. The point source and nonpoint source total phosphorus loads to Lake Allegan measured in 1998 are presented in Table 4. The actual and permitted point source discharges and associated loads for 1998 are presented in Table 5. The point source load in 1998 was 45% of the load permitted in NPDES permits. The load estimates adjusted to account for variability of flows are presented in Table 6 for the inlet to Lake Allegan at M-89.

Figure 17. Total phosphorus loads (lbs) measured in the Kalamazoo River from Ceresco to Lake Allegan, April - September, 1998.



The estimated total phosphorus load to Lake Allegan measured in 1998 is 147,887 pounds for the six-month period. Actual phosphorus loads in 1998 measured from 36 of the 77 point source discharges (including some NCCW) totaled 51,663 pounds for the April to September period. Actual phosphorus loading from nonpoint sources totaled 96,224 pounds. Point source loading in 1998 accounted for 35% of the total load for the six-month period, while nonpoint source loads accounted for 65% of the total load entering the lake (Table 4). To obtain the nonpoint source contribution of phosphorus to the lake, monthly 1998 actual point source loads were subtracted from the corresponding monthly total loads entering the lake.

Table 3. Tributary loads for nonpoint and point sources in the Lake Allegan watershed, April - September, 1998.

Station Location	Total Phosphorus Load (lbs)	Point Source Load (lbs)	Nonpoint Spource Load (lbs)	Drainage Area (sq. mile)	Loading Rate (lbs/sq. mi)
Willow Creek	62	0	62	1	62
Minges Brook/Harper Creek	1689	0	1689	49	35
Battle Creek River	16014	1169	14845	279	57
Seven Mile Creek	555	0	555	12	46
Gull Lake Creek	750	0	750	40	19
South Trib @ Fransis Rd	333	0	333	2	*167
Comstock Creek	474	0	474	13	37
Davis Creek	1098	0	1098	13	85
Portage Creek	5051	295	4756	79	64
Arcadia Creek	1314	0	1314	14	94
Spring Valley Creek	786	0	786	19	41
Chart Creek	49	0	49	0.9	49
Gun River	3585	63	3522	88	41
Pine Creek (Baseline Creek)	1968	0	1968	76	26
North Trib of Kalamazoo River	120	0	120	1	120
Schnable Brook	2538	0	2538	37	69
110th Trib to Kalamazoo River	195	0	195	3.3	*59.1
Kalamazoo River @ M-89 (inlet)	145156	50711	94445	1523	95.3
Dumont Creek	784	0	784	14	56
*Intermittent waterbody					

Table 4. Total phosphorus loads (pounds) discharged to Lake Allegan in 1998.

Monitoring Location	April	May	June	July	August	September	Total	%Total
KR-89 (Kalamazoo River)	37,153	32,691	24,723	21,055	17,343	12,191	145,156	98.2
Dumont Creek	400	90	88	90	80	36	784	0.5
Immediate Drainage	122	126	122	126	126	122	744	0.5
Allegan WWTP	130	173	146	160	206	136	951	0.6
Precipitation	42	42	42	42	42	42	252	0.2
<b>Total</b>	<b>37,847</b>	<b>33,122</b>	<b>25,121</b>	<b>21,473</b>	<b>17,797</b>	<b>12,527</b>	<b>147,887</b>	<b>100</b>
Point Source Discharges	7427	8565	9159	9222	8303	8987	51663	35
Nonpoint Source Discharges	30420	24557	15962	12251	9494	3541	96224	65
							147887	100

Table 5. Actual and permitted point source loads (pounds) to the Lake Allegan watershed, 1998.

FACILITY NAME	MONTH						ACTUAL LOADS(lbs)	PERMITTED LOADS (lbs)
	APR	MAY	JUN	JUL	AUG	SEPT		
ALBION POTW	242	347	182	359	352	342	1824	6112
ALLEGAN METAL FINISHING	5	6	5	6	6	6	34	201
ALLEGAN WWTP	130	173	146	159	206	136	950	1830
AM TODD	49	51	43	46	45	39	273	763
BATTLE CREEK WWTP	623	790	1927	**4235	1981	2747	12303	27450
BELLVUE WWTP*	9	9	9	9	9	9	54	54
BENCHMARK COATERS	1	0	5	5	5	3	19	24
BOSTIK INC*	0	0	0	0	0	0	1	1
CHARLOTTE WWTP	165	192	120	121	155	138	891	1830
CROWN PAPER (008)	1140	992	660	719	961	1020	5492	8784
GUN LAKE WWTP	11	11	12	9	11	9	63	915
HOMER WWSL	39	48	0	0	0	0	87	87
KALAMAZOO WWTP	3120	4030	4560	1922	2914	3420	19966	41175
MARSHALL WWTP	123	130	146	115	129	132	775	4575
MENASHA (OUTFALL 001)	1	0	1	0	1	2	4	4
MENASHA (OUTFALL 003)	916	909	599	748	728	252	4152	4152
MURCO (actual T-P unknown)	0	0	0	0	0	0	0	1530
OLIVET WWSL*	112	112	0	0	0	0	224	224
OTSEGO WWTP	45	45	45	45	45	45	270	1153
PARKER HANNIFIN/PUMP	1	0	1	0	6	1	9	88
PARKER-HANNIFIN/BRASS	1	1	1	1	4	1	9	384
PERRIGO #1 (002 & 003)	25	26	25	26	26	25	153	153
PERRIGO #4&5* (001)	2	1	1	0	1	1	6	5
PHARMACIA & UPJOHN (001)	35	35	35	35	35	35	210	210
PLAINWELL PAPER	60	59	63	99	127	60	468	6105
PLAINWELL WWTP	123	112	105	109	105	99	653	1976
ROCK TENN CO	74	111	94	80	79	93	531	3056
NCCW <sup>(1)</sup>	374	374	374	374	373	373	2242	2242
<b>TOTALS</b>	<b>7427</b>	<b>8565</b>	<b>9159</b>	<b>9222</b>	<b>8303</b>	<b>8987</b>	<b>51663</b>	<b>115083</b>
								115083

\* Estimated actual loads  
\*\* Violation in month of July  
<sup>(1)</sup> NCCW discharges are those not already included under an individual permit.

Comparisons of the total phosphorus and orthophosphorus fractions in monthly samples measured in 1998 for the inlet and Lake Allegan outlet are shown in Figure 18. Total phosphorus is composed of particulate and dissolved phases. Particulate phosphorus includes: (1) phosphorus in organisms; (2) phosphorus in mineral rock; and (3) phosphorus adsorbed onto dead particulate organic matter (Wetzel, 1983). In contrast, dissolved phosphorus is composed of: (1) orthophosphate; (2) polyphosphates found in detergents; and (3) organic colloid and phosphate esters. The dissolved or soluble fraction of phosphorus is usually small relative to the amount of particulate phosphorus. The soluble fraction is considered reactive and is that portion that is rapidly used by algae. Most of the phosphorus data for freshwater refers to total phosphorus and inorganic soluble phosphorus (orthophosphorus). During the early season starting in April, orthophosphorus in the inlet and outlet of Lake Allegan are relatively equal. The growing season has not yet begun and algae are not rapidly using the bioavailable phosphorus entering the lake. However, as the season progresses, the orthophosphorus entering the lake is being used by the algae as seen in the lower concentrations observed at the outlet of the lake compared to the inlet as depicted in Figure 18.

Concerns have been raised regarding the release of phosphorus from the sediments to the overlying water. There are typically two types of phosphorus release from the sediments - diffusive release and resuspended release. According to Wetzel (1983), two important factors determining the diffusive release of phosphorus from the sediments are: (1) the ability of sediments to retain phosphorus, and (2) the conditions of the overlying water. The oxygen content at the mud-water interface determines the rate of transfer at which phosphorus is released from the sediments. The release of phosphorus from in-lake sediments typically is most likely to occur during anaerobic (no oxygen) conditions. Classic temperature stratification within Lake Allegan does not occur due to its shallow morphometry. Therefore, the oxygen content throughout the lake stays relatively mixed at high enough levels to prevent anoxic conditions. However, several samples from the bottom layer of the water column have higher phosphorus levels. Particulate phosphorus associated with the sediment may be a long term source of phosphorus in the lake (Sharpley, et al. 1992). Additional monitoring is necessary to determine if phosphorus release from sediments plays a significant part in the recycling of phosphorus in Lake Allegan.

Comparison of phosphorus levels in Lake Allegan and Morrow Lake sediments are made in Table 9. Concentrations of phosphorus in Morrow Lake sediments are similar to those levels found in Lake Allegan, even though total phosphorus entering the Morrow Lake system is less than that entering Lake Allegan.

Figure 16. Total phosphorus and soluble reactive phosphorus at the M-89 inlet and Lake Allegan outlet April to September, 1998.

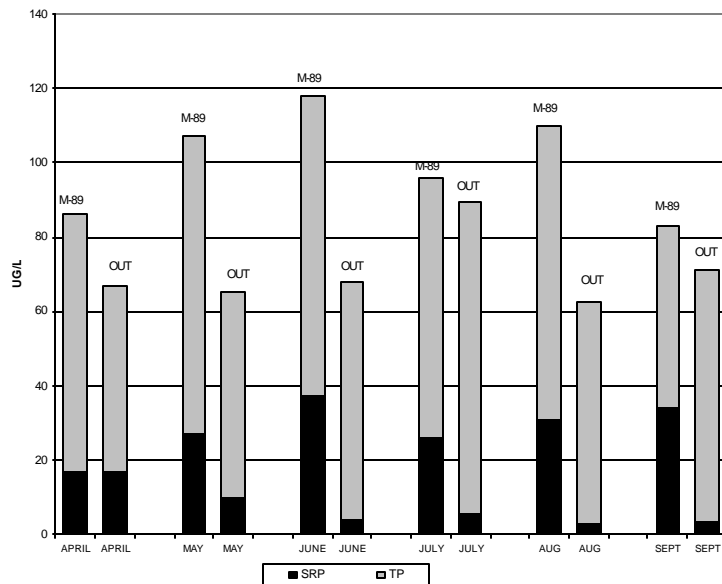


Table 9. Lake Allegan (LA) and Morrow Lake (ML) sediment sampling results, September 25, 1998, October 29, 1998 and April 15, 1999.

Parameter	Units	LA #1	LA #2	LA #3	LA #4	LA #5	ML #1
September 25, 1998							
Kjeldahl Nitrogen in Sediment	mg/kg (dry)	4300	4400	5200	5100	5500	----
Total Phosphorus in Sediment	mg/kg (dry)	1530	1400	1560	1770	1690	----
Total Solids - Inorganic	%TSS	32	27	23	32	28	----
October 29, 1998							
Kjeldahl Nitrogen in Sediment	mg/kg (dry)	4800	6900	----	----	----	----
Total Phosphorus in Sediment	mg/kg (dry)	1650	5700	----	----	----	----
Total Solids - Inorganic	%TSS	27	21	----	----	----	----
April 15, 1999							
Kjeldahl Nitrogen in Sediment	mg/kg (dry)	1000	----	----	----	5800	7400
Total Phosphorus in Sediment	mg/kg (dry)	400	----	----	----	2000	1600
Total Solids - Inorganic	%TSS	61	----	----	----	30	24

Comparisons of the types of algae collected from Lake Allegan and Morrow Lake are listed below. A more diverse group of algae were found in Morrow Lake than in Lake Allegan. The Lake Allegan phytoplankton community was primarily made up of the blue-green algae, *Oscillatoria*, and the diatom, *Melosira*.

Lake Allegan	Algal group	Morrow Lake	Algal Group
<i>Amphipleura</i>	Diatom	<i>Amphipleura</i>	Diatom
<i>Asterococcus</i>	Green	<i>Asterococcus</i>	Green
<i>Dinobryon</i>	Flagellate	<i>Dinobryon</i>	Flagellate
<i>Euglena</i>	Flagellate	<i>Euglena</i>	Flagellate
<i>Melosira</i>	Diatom	<i>Fragilaria</i>	Diatom
<i>Oscillatoria</i>	Blue-Green	<i>Mastogloia</i>	Diatom
<i>Tetrastrum</i>	Green	<i>Melosira</i>	Diatom
		<i>Nitzschia</i>	Diatom
		<i>Oscillatoria</i>	Blue-Green
		<i>Pediastrum</i>	Green
		<i>Pinnularia</i>	Diatom
		<i>Scenedesmus</i>	Green
		<i>Surirella</i>	Diatom

Report by: Sylvia Heaton, Aquatic Biologist

Field Work by: Scot Hanshue, Mike Alexander, Mike Walterhouse, Sara Bonnette, Jeff Cooper, Christine Thelen, William Creal, Jenny Molloy, Brenda Sayles, Joe Rathbun, Doyle Brunsen, Rick Lundgren, Hillary Flower, and Christine Aeillo

## REFERENCES

- Bohr, J. and C. Liston. 1987. A survey of the fish and benthic communities of Morrow Lake on the Kalamazoo River, Michigan, 1985 and 1986. Report to STS Consultants, Ltd., 33 pp.
- Heaton, S. 1990. Biological survey of the Kalamazoo River between Kalamazoo and Allegan, August, 1989. MDNR, Surface Water Quality Division, Report No. MI/DNR/SWQ-90/032.
- Heaton, S. 1997. A biological survey of the Kalamazoo River watershed, Allegan and Kalamazoo Counties, July-August, 1994. MDEQ, Surface Water Quality Division, Report No. MI/DEQ/SWQ-94/109.
- Jones, J.R. and R. W. Bachmann. 1976. Prediction of phosphorus and chlorophyll levels in lakes. *J. Water Poll. Control Fed.* 48 (9): 2176-2182.
- Kosek, S. 1996. A phosphorus loading analysis and proposed TMDL for Ford and Belleville Lakes, Washtenaw and Wayne Counties, December 1994- November 1995. MDEQ Report No. MI/DEQ/SWQ-96/005.
- Kosek, S. 1996. A nutrient chemistry survey of Kent, Brighton, Ore, Limekiln, and Sandy Bottom Lakes, Livingston and Oakland Counties, April 13, 1994 and April 24, 1996. MDEQ Report No. MI/DEQ/SWQ-96/044.
- Kosek, S. 1997. Water Quality and Pollution Control in Michigan, 1996 Report. Michigan 305(b) Report: Volume 14. MDEQ Report No. MI/DEQ/SWQ-97/040.
- Larsen, D. P. and H.T. Mercier. 1976. Phosphorus retention capacity of lakes. *J. Fish. Res. Board Can.* 33: 1742-1750.
- Limnotech. 1999. Updated water quality and phosphorus loading analysis of the Coldwater Chain of Lakes-Final Report, April 28, 1999. Prepared for: Coldwater Board of Public Utilities, Limno-Tech, Inc.
- Lundgren, R. 1994. Reference site monitoring report, 1992-1993. MDNR, Surface Water Quality Division. Report No. MI/DNR/SWQ-94/048.
- MDNR. 1994. Quality assurance for water and sediment sampling. Environmental Protection Bureau, Lansing, Michigan.
- Rast and Lee. 1983. Nutrient loading estimates for lakes. *J. Env. Eng.* 109(2): 502-517.
- Oemke, M.P. 1988. Biological survey of the Kalamazoo River between Comstock and Plainwell, July 1988. Report No. MI/DNR/SWQ-88/088.
- Peter, R.R., D.B. Baker, J.W. Kramer, and D.E. Ewing. 1996. Annual loads of herbicides in Lake Erie tributaries in Ohio and Michigan. *Journal of Great Lakes Research* 22:414-428.
- Sharpley, A.S., S. Smith, O. Jones, W. Berg, and G. Coleman. The transport of bioavailable phosphorus in agricultural runoff. *J. Environ. Qual.* 21:30-35.

- Suppnick, J. and W. Creal. 1986. Physical, chemical, and biological monitoring results from the Kalamazoo River, Comstock to Plainwell, 1984. MDNR, Surface Water Quality Division, Report No. 04990.
- USEPA. 1975. Report on Lake Allegan, Allegan County Michigan. EPA Region V, Working Paper Series No. 182. EPA National Eutrophication Studies. 1975. Report on Lake Allegan, Allegan County Michigan. EPA Region V, Working Paper Series No. 182. EPA National Eutrophication Studies.
- Wetzel, R.J. 1983. The phosphorus Cycle. *In* S. Fitz-Hugh, ed. LIMNOLOGY, second edition. Philadelphia, Saunders College Publ., pp. 255-297.
- WMU. 1976. Kalamazoo River AOC 1996 Land Cover Developed by Western Michigan University.
- WRC. 1951. Minutes from the Michigan Water Resource Commission, September 1951.
- Wuycheck, J. 1998. Water Quality and Pollution Control in Michigan. Michigan 305(b) Report, MDEQ, Surface Water Quality Division, Report No. MI/DEQ/SWQ-98/030.

## Appendix A

### Monitoring Locations for Stations in the Lake Allegan Study

1998

### **GRAB SAMPLES PRIMARY (2X/Month)**

1. Kalamazoo River d/s Ceresco Impoundment, R7W, T2S, sec 25 (Calhoun Co.)
2. Kalamazoo River @ Raymond Rd, R7 W, T2S, sec 8 (Calhoun Co.)
3. Battle Creek River @ Gage Station, R7W, T1S, sec 21 (Calhoun Co.)
4. Kalamazoo River @ Fort Custer, R9W, T1S, sec 34 (Kalamazoo Co.)
5. Kalamazoo River @ Comstock, R10W, T2S, sec 19 (Kalamazoo Co.)
6. Portage Creek @ BL-194, R11W, T2S, sec 15 (Kalamazoo Co.)
7. Kalamazoo River @ Patterson Drive, R11W, T2S, (Kalamazoo Co.)
8. Kalamazoo River @ D Avenue, R11W, T1S, sec 22 (Kalamazoo Co.)
9. Gun River @ 106th Avenue, R12W, T1N, sec 24 (Allegan Co.)
10. Kalamazoo River @ River Road (Otsego Dam), R12W, T1N, sec 20 (Allegan Co.)
11. Kalamazoo River @ M-89, R13W, T2N, sec 28 (Allegan Co.)
12. Lake Allegan Outlet @ Lake Allegan Dam Road, R14W, T2N, sec 16 (Allegan Co.)
13. Dumont Creek @ M-40, R13W, T2N, sec 18 (Allegan Co.)

### **GRAB SAMPLES SECONDARY (1X/MONTH)**

- A. Willow Creek @ E. River Road, R7W, T2S, sec 16, (Calhoun Co.)
- B. Minges/Harper Creek @ Minges Road, R9W, T2S, sec 19 (Calhoun Co.)
- C. Seven Mile Creek @ Augusta Drive, R6W, T1S, sec 19 (Calhoun Co.)
- D. Gull Lake Outlet @ Augusta Drive, R9W, T2S, sec 18 (Kalamazoo Co.)
- E. South Trib, Kalamazoo River @ St. Francis Rd., R10W, T2S, sec 20 (Kalamazoo Co.)
- F. Comstock Creek @ King Highway, R10W, T2S, sec 19 (Kalamazoo Co.)
- G. Davis Creek @ Olmstead/Lake Street, RR11W, T2S, sec 18 (Kalamazoo Co.)
- H. Arcadia Creek @ Mouth, R11W, T2S, sec 15 (Kalamazoo Co.)
- I. Spring Valley Creek @ EE Avenue, R11W, T1S, sec 34 (Kalamazoo Co.)
- J. Chart Creek @ 11th Avenue, R11W, T1N, sec 31 (Allegan Co.)
- K. Pine Creek @ River Road, R12W, T1N, sec 21 (Allegan Co.)
- L. Schnable Brook @ M-89, R12W, T1N, sec 7 (Allegan Co.)
- M. North Trib, Kalamazoo River @ 27th Street, R13W, T1N, sec 2 (Allegan Co.)
- N. South Trib, Kalamazoo River @ 110th Avenue, R13W, T1N, sec 9 (Allegan co.)
- O. South Trib, Lake Allegan @ Monroe Road, R13W, T2N, sec 19 (Allegan Co.)

### **AUTOMATIC SAMPLER STATIONS**

1. Gun River (@106th Avenue) P9
2. Portage Creek (@BL-194) P6
3. Kalamazoo River (@ Comstock) P5

### **LAKE SAMPLING STATIONS**

1. Lake Allegan mouth (channel inlet)
2. Lake Allegan mouth (channel outlet)
3. Lake Allegan Basin (east)
4. Lake Allegan Basin (south)
5. Lake Allegan Basin (west)

## **Appendix B**

Water Quality Results for  
Lake Allegan and Morrow Lake

1996 - 1999

## Appendix C

Gun River and Portage Creek  
Rating Curves, 1998

## Appendix D

Water Quality Results for  
Grab Samples of Tributaries in the  
Lake Allegan Watershed

April - September  
1998

## Appendix E

Water Quality Results for  
Grab Samples of Tributaries in the  
Lake Allegan Watershed

April - September  
1999