Bear Lake Nutrient Study

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Grand Valley State University
Annis Water Resources Institute

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Executive Summary

Bear Lake is a moderate to highly eutrophic lake that has elevated concentrations of total phosphorus (TP) and heavy summer blooms of cyanobacteria (formerly blue green algae). The sources of the excessive nutrient levels and algal blooms are the result of combination of external and internal loading sources to Bear Lake. The water quality in the tributaries is relatively good during base flow as TP concentrations range from 20 to 32 ug/l for Bear Creek and Little Bear Creek. Daily base flow loadings of TSS and TP to Bear Lake from Bear Creek averaged 400 lbs and 2 lbs, respectively. In contrast, the storm event data demonstrate elevated loadings of suspended sediment and nutrients. A 0.95 inch rain event delivered an average daily load of 3836 lbs of TSS and 12 lbs of TP. Bear Creek contributes approximately four times the loading of total suspended solids (TSS) and six times the loading of TP as Little Bear Creek. Stream flow hydrographs show that peak flows, during the early spring, result in stream discharges that exceed the amounts observed during the rain event monitoring. These data suggest that even higher loadings of TSS and TP enter the system during the spring. TP and TSS transport in the tributaries is enhanced by the channelized stream and the highly modified wetlands near the inlet to Bear Lake. While an investigation of the effects of nonpoint source (NPS) inputs from the immediate drainage area around Bear Lake was not conducted, the results of the Long-Term Hydrologic Impact Assessment Model (L-THIA) estimated that TSS and TP from rain events > 1 inch would exceed estimated loadings from Little Bear Creek.

While storm events can accelerate the loading of TP to Bear Lake, the presence of heavy cyanobacteria blooms, elevated chlorophyll-*a* concentrations, and low Secchi disk depth readings throughout the summer are indicative of an internal sediment loading source. The concentration of iron in the sediment appears to be sufficient to limit phosphorus release. In addition, the shallow bathymetry of Bear Lake (8 to12 ft) prevents summer stratification and anaerobic conditions that enhance phosphorus release from the sediments. The moderate level of soluble reactive phosphorus (SRP) found in the sediments of Bear Lake is a function of the elevated iron concentrations and the lack of summer stratification. Because of the wind mixed water column, phosphorus can still be circulated up into the water column and become available to stimulate productivity. Since Bear Lake appears to be phosphorus limited, additional loading of this nutrient will stimulate primary productivity. The dominant phytoplankton organism, *Microcystis aeruginosa*, can take advantage of these conditions by adjusting its vertical position in the water column and accumulating phosphorus at the sediment/water interface. The shallow bathymetry of Bear Lake and the moderate level of phosphorus enrichment in the sediment are ideal conditions for *Microcystis aeruginosa* to form blooms.

To improve water quality in the watershed, a combination of NPS reduction strategies should be considered that involve the tributaries and the immediate drainage basin. With respect to the tributaries, the implementation of best management practices (BMPs) in the Bear Creek subwatershed is the first priority. The installation of effective buffer strips along the stream corridor plus creating more opportunities for runoff infiltration in developed areas will help reduce NPS pollution. In addition, returning some of the

natural sinuosity to the stream channel and restoring the wetlands at the mouth of Bear Creek will help promote settling and slow the transport of sediment and nutrients to the creek. With respect to Bear Lake, riparian buffers along the lakefront will help reduce the input of nutrients. The use of phosphate-free fertilizer for lawn maintenance and adding more opportunities for infiltration instead of runoff also will lower the NPS contribution for the immediate drainage basin. Many of the homes along the shore of Bear Lake in Laketon Township are serviced by septic systems. Municipal sewer recently has been extended to this area and where possible, home owners are encouraged to connect to the system and decommission their septic tank. Where connections are not possible, proper septic system maintenance and design are critical to limiting the leaching of nutrients into Bear Lake.

1.0 Introduction

The Bear Lake watershed Figure 1.1) is located in west-central Michigan and is approximately 11.5 miles long from its headwaters in Dalton Township to its mouth at Bear Lake channel at Muskegon Lake. The watershed covers approximately 19,058 acres (77.1 km^2) and lies entirely within Muskegon County. Five local governments share land within the watershed and include: Dalton Township, Laketon Township, Cedar Creek Township, Muskegon Township, and the City of North Muskegon. The tributaries in the watershed drain into Bear Lake, a 410 acre (1.66 km^2) drowned river mouth lake with a mean depth of 6.8 ft (2.1 m) and a maximum depth of 11.8 ft (3.6 m) (Wilson et al. 2005). Bear Lake is listed on the Michigan Department of Environmental Quality (MDEQ) 303(d) list for nuisance algal growths caused by elevated phosphorus levels. A Total Daily Maximum Load (TMDL) analysis is scheduled by the MDEQ for 2008.

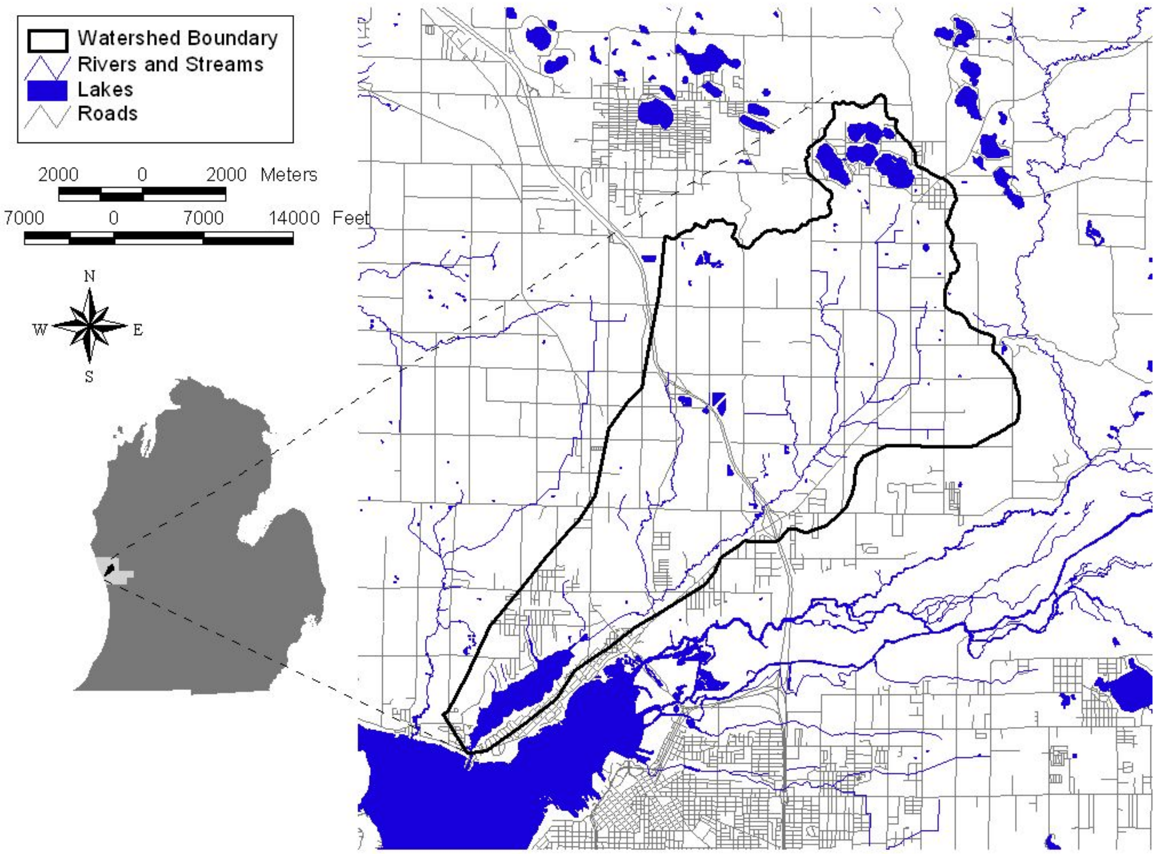

FIGURE 1.1. THE BEAR LAKE WATERSHED.

1.1 Project Objectives and Task Elements

The Cadmus Group, Inc. (Cadmus) and the Annis Water Resources Institute (AWRI) conducted a project requested by the MDEQ Water Bureau and funded by the U.S. Environmental Protection Agency (EPA) to determine the loading of nutrients from internal and external sources to Bear Lake. These data were used in conjunction with land use information to develop recommendations for best management practices and to determine the major sources of nutrient loading. Ultimately, the project data will be used by the MDEQ, in conjunction with other related studies, to develop a phosphorus TMDL for Bear Lake in 2008. Project tasks are described in more detail below.

Task 1: Bear Lake Water and Sediment Monitoring

- AWRI conducted a spring turnover assessment of Bear Lake on April 16, 2007. Field measurements included Secchi disk depth readings at each lake sampling location and the collection of vertical profiles of chlorophyll-*a*, pH, dissolved oxygen, temperature and conductivity readings at 1 ft intervals using a Hydrolab Datasonde. An additional sample for chlorophyll-*a* was collected at each location as an integrated composite to 2.5 times the Secchi disk reading. Samples for laboratory analysis were collected with a VanDorn bottle from the surface at a depth of 1.5 feet below the surface, at mid depth and just off the bottom near undisturbed sediments during a period of stable surface conditions. Laboratory parameters included total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrite/nitrate, total iron, and total copper. Data collected by AWRI and MDEQ during 2006 also was included in the assessment.
- Sediment samples were collected along the three transects. Three locations were selected along each transect (nine samples total). Five surficial sediment subsamples were collected with a piston core at each of the nine locations and composited into a single sample. The top five inches of sediment in the core was used for the composite. The samples were collected on April 20, 2007 during calm weather to obtain sediment from a relatively undisturbed lake bottom. Sediment samples were analyzed for total phosphorus, soluble reactive phosphorus, percent moisture, total organic carbon (TOC), ash free dry weight, total copper and total iron. In addition, a series of triplicate PONARs were collected at the same stations for the identification and enumeration of the benthic macroinvertebrate community.

Task 3: Wet and Dry Weather Sampling

- AWRI conducted dry weather sampling four times during the project monitoring period (October 2006 – August 2007). One grab sample was collected from Bear Creek at Giles Rd., Little Bear Creek at Giles Rd., Bear Creek at Witham Rd., and the unnamed tributary at Dykstra Rd. Water samples were analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), total Kjeldahl nitrogen (TKN), ammonia, nitrite/nitrate, and total suspended solids (TSS).

- Wet weather sampling was conducted by AWRI for four events during the above monitoring period at the above locations. The wet weather runoff events were in response to precipitation events of 0.5 or greater within 24 hours. Sampling was initiated at the start of precipitation. Single grab samples were collected manually during the rise and fall of the hydrograph. Water samples were analyzed for total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrite/nitrate, and total suspended solids.
- Flow was measured at each location using a Marsh-McBirney Flow Mate 2000 velocity meter. Transects were established at each location and water depth measurements were collected. The MDEQ provided a reference point to measure water elevation at each sampling location. Flow measurements were collected during each wet and dry weather sampling and used to develop rating curves for each tributary.
- Stream conditions at each location were recorded using the Michigan Single Site Watershed Survey Data Sheet (http://www.deq.state.mi.us/documents/deq-swq-gleas-singlesite.pdf).
- In addition to manual measurements of flow during dry and wet events, pressure transducers (PTs) were installed at three locations to obtain continuous flow and temperature data. Pressure transducers were contained in a rigid PVC enclosure and attached to a fixed object. A 10-minute recording time interval was set for all sites. The measured stream depths were converted to water discharges by using the developed rating curves. Hydrographs were generated for all sites.

Task 4: Discharge Measurements and the Calculation of Rating Curves

- The Microsoft Windows-based hydrologic software, HYDROL-INF (Chu 2006) was used for processing the measured stream data and computing stream discharge and other hydraulic parameters that were used for developing rating curves. Rating curves were developed for all monitoring sites based on the measured stream flow data from the project and data provided by MDEQ.

Task 5: Land Use/Cover Inventory and Vegetative Cover Analysis

- The 1998 land use and cover database was updated for the watershed tributaries to Bear Lake using the 2002 aerial imagery provided by the Muskegon County Equalization Department. Photo interpreters utilized the Michigan Land Cover/Use Classification System.
- In addition to the land use inventory, AWRI conducted a visual characterization of vegetative growth including algal blooms and rooted aquatic plants in the lake. This information was recorded with Global Positioning System (GPS) coordinates and included on map of Bear Lake.

Task 6 Assessment of internal and external nutrient loadings to Bear Lake

- AWRI conducted an assessment of internal and external phosphorus sources to determine sources contributing nutrients to Bear Lake and identify controllable sources and recommended best management practice (BMP) options to meet applicable water quality standards that would minimize nuisance algal blooms. Phosphorus loads contributed by tributaries were estimated using HYDROL-INF. Internal phosphorus load estimates were based on the phosphorus and iron concentrations measured in the sediment samples. Although not as rigorous as measuring actual flux from the sediments, significant relationships have been found between release rates and total sediment phosphorus (P) (cf. Nürnberg 1988). The relative contribution of each source was estimated for the period of record. In addition, the Long-Term Hydrologic Impact Assessment (L-THIA) analytical model was used to develop estimates of runoff and nonpoint source pollution resulting current land use. L-THIA estimated average nonpoint source pollutant loads for selected rain events scenarios (0.5", 1.0", 1.5", and 2.0") based on land use and precipitation data for the area. Data outputs (ESRI Arc/INFO file format) included Soil Conservation Service (SCS) Curve Number (composite derived from land use and cover and hydrologic soil type), runoff depth and volumes, and NPS estimates for nutrients and TSS. Based on these findings, recommendations were made for preferred management options.

1.2 References

Bhaduri, B., Minner, M., Tatalovich, S., Harbor, J., 2001. Long-term Hydrologic Impact of Urbanization: A Tale of Two Models. Journal of Water Resources Planning and Management 127, 13–19.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45: 453-462.

2.0 Bear Lake Watershed 2005 Land Use/Cover

2.1 Methods

The Bear Lake Watershed 2005 Land Use/Cover data were completed by updating 1998 MSU Land Use/Cover data using ESRI ™ ArcView GIS 3.3 and the National Agricultural Imagery Program's (NAIP) 2005 digital orthophotograph. Ancillary data also were used for the analysis including digital U.S. Geologic Survey (USGS) topographic maps, National Wetland Inventory data, Muskegon County Plat book and U.S. Forest Service (USFS) parcel level data received from the Muskegon County Equalization Department. Land use/cover changes were ground truthed with two separate field surveys and adjustments were made accordingly to the final product. The land use change analysis was completed using Geographic Information Systems (GIS) to intersect the original 1998 and the final 2005 land use/cover data to quantify the change. A review of this change data was conducted to eliminate minor change fragments around land use/cover polygons caused by differences in resolution and geographic registration of the 1998 color infrared photography and the 2005 orthophotography.

2.2 Land Use/Cover Data Analysis

The Bear Lake watershed covers 19,059 acres or 29.8 square miles. Significant water features include Bear Lake (410 acres) and 7 subbasins (Figure 2.1). Bear Creek and Little Bear Creek provide drainage for a majority of the watershed that is highly channelized. Several county drains and unnamed tributaries provide drainage for the remaining watershed area. Watershed soils and topography are presented in Figures 2.2 and 2.3, respectively. Most of the soils are sandy and classified as having high infiltration and low runoff or as intermediate (Figure 2.2). In consideration of the high permeability of the soils in the watershed, surface runoff would be minimal in undeveloped areas. Consequently, the tributaries appear to be driven largely by groundwater recharge based on soil type and slope. In contrast, sections of the riparian zone along Bear and Little Bear Creeks are classified as having low infiltration and high runoff. Both creeks cut into the native clay and expose heavier soils along the banks. Topographic slopes are relatively steep along the bank area and adjacent to Bear Lake (Figure 2.3). The remainder of the watershed exhibits a more gradual topographic relief. Most of the land in the watershed is publicly held (Figure 2.4). A small part of the Manistee National Forest is located in the northern most section of the watershed.

Land use and cover data for the watershed are summarized in Table 2.1 and presented in Figure 2.5. The watershed supports a significant amount of natural cover which accounts for 61% of the total area. Most natural area is classified as forested or grass and shrub land, with forest land predominating. Urban land is the second most common land use occupying 33% of the watershed. Approximately 75% of the urban land is classified as residential. Agricultural land use is relatively limited (15%) in the watershed. Natural land use and cover has decreased 10% (1252 acres) during the period between 1998 and

2005 (Table 2.2). Agricultural and grass/shrub land also declined by 6% (168 acres) and 4% (120 acres), respectively. During the same time period, urban land increased by 30% (1420 acres) due to additional residential development.

TABLE 2.1. LAND USE AND COVER FOR THE BEAR LAKE WATERSHED.

Cover Type	2005 Acres	% Prevalence
Urban and Built Up	6269	32.9%
Residential	4686	24.6%
Commercial, Services, Institutional	571	3.0%
Industrial	95	0.5%
Transportation, Communication, Utilities	364	1.9%
Extractive	264	1.4%
Open Land and Other	289	1.5%
Agricultural Land	1111	5.8%
Grass and Shrub Land	2984	15.7%
Forest Land	7624	40.0%
Water	825	4.3%
Wetland	245	1.3%

TABLE 2.2. NET CHANGE IN TOTAL ACRES AND PERCENT AREA OF THE BEAR LAKE WATERSHED BETWEEN 1998 AND 2005.

Cover Type	Net Change (Acres)	% Change
Urban and Built Up	1420	30.43%
Agricultural Land	-168	-15.12%
Grass and Shrub Land	-120	-4.02%
Forest Land	-1170	-15.35%
Water	1	0.12%
Wetland	37	15.10%

For the immediate watershed area surrounding Bear Lake (south of Whitehall Rd. and Giles Rd.), differences in land use patterns emerged (Table 2.3). Urban land use accounted for 52% of land use adjacent to Bear Lake, as compared to 33% over the entire watershed. Agricultural land was absent in the immediate area surrounding Bear Lake and 62% of the wetlands in the watershed were located in this area.

TABLE 2.3. LAND USE IN THE IMMEDIATE BEAR LAKE WATERSHED

Cover Type	Acres	% of Total*
Urban and Built Up	1436	52
Agricultural Land	0	0
Grass and Shrub Land	740	27
Forest Land	406	15
Water	33	2
Wetland	153	6

*area within the Laketon Township subwatershed (Figure 2.1)

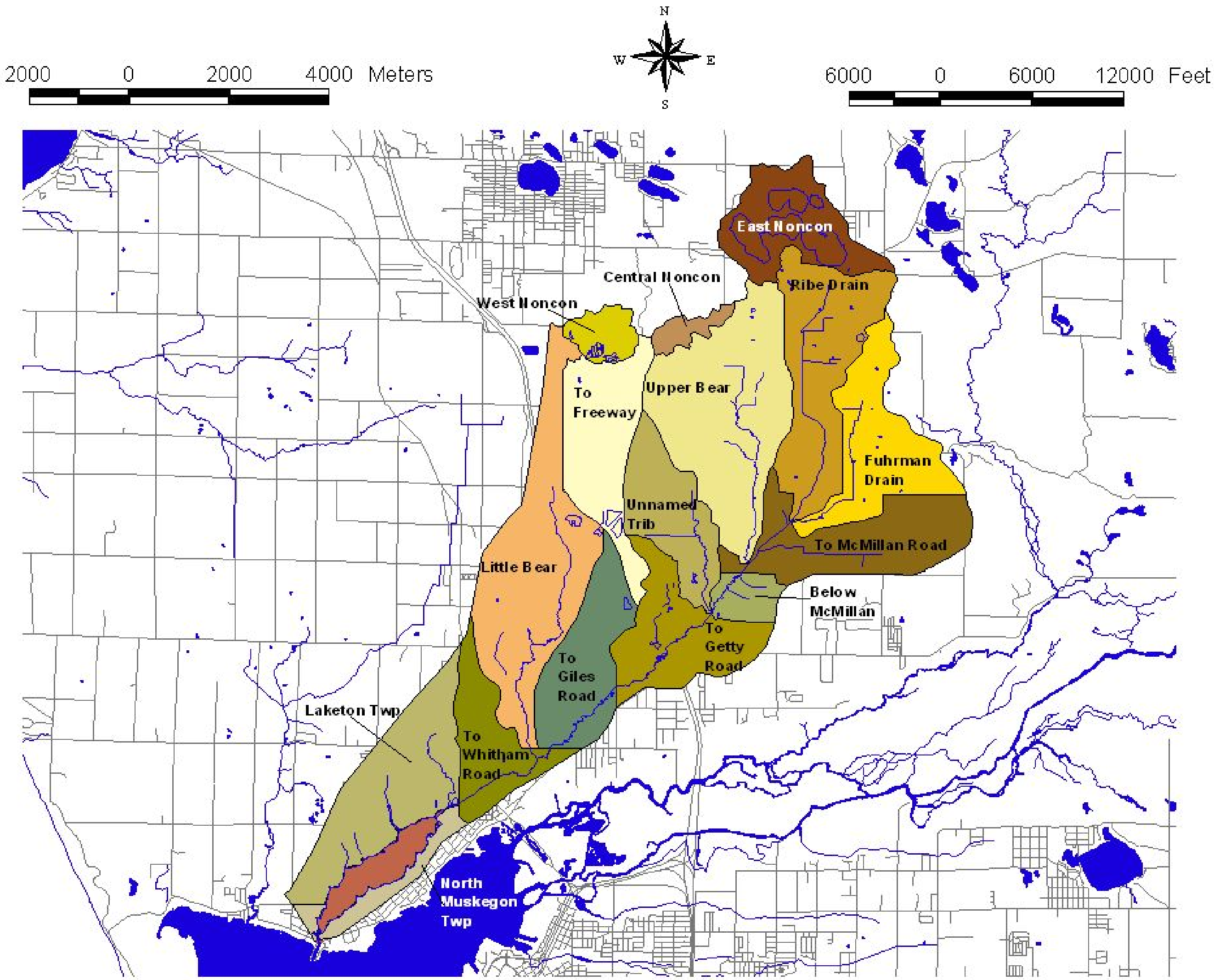

FIGURE 2.1. BEAR LAKE WATERSHED SUBBASINS.

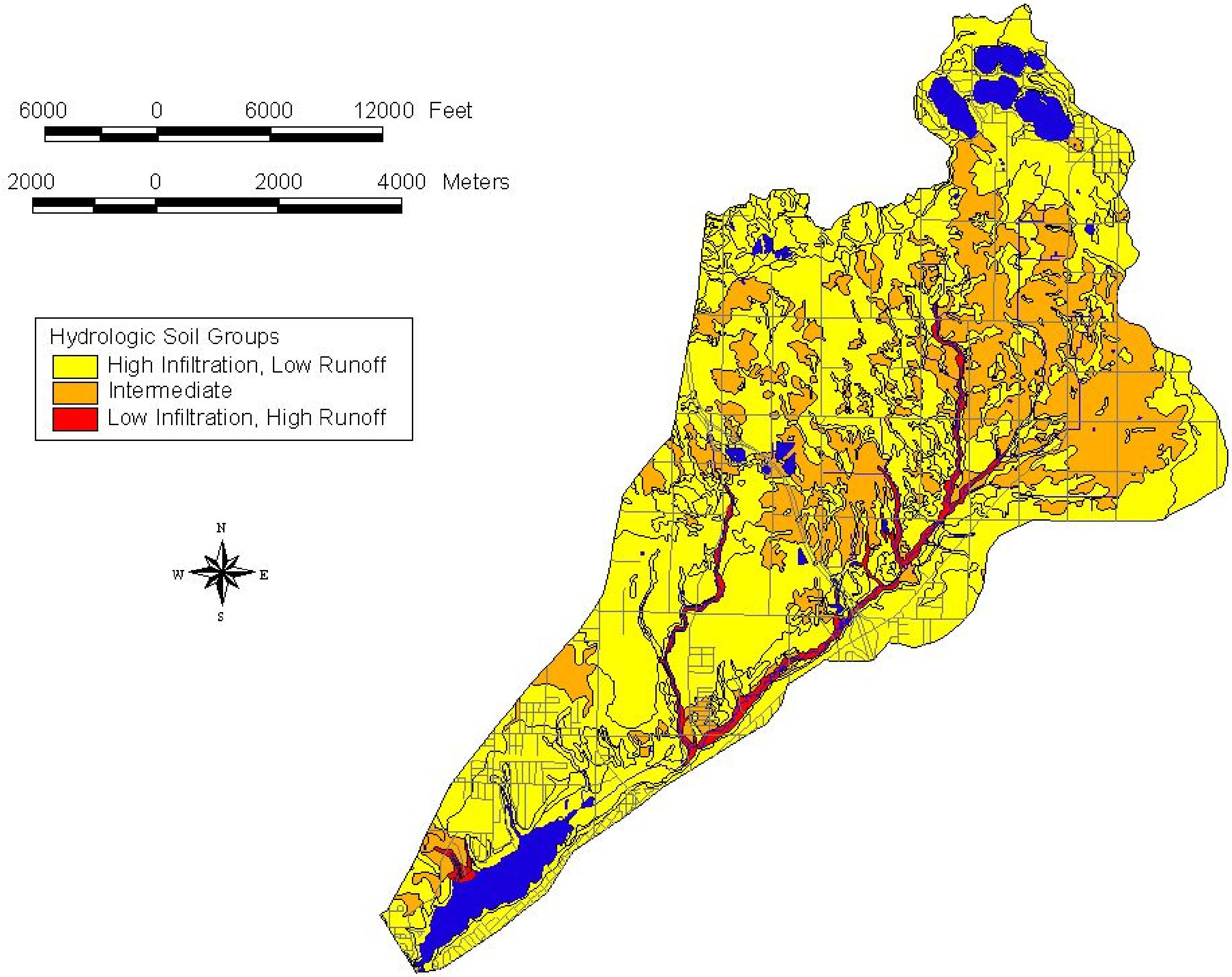

FIGURE 2.2. BEAR LAKE WATERSHED SOIL TYPES

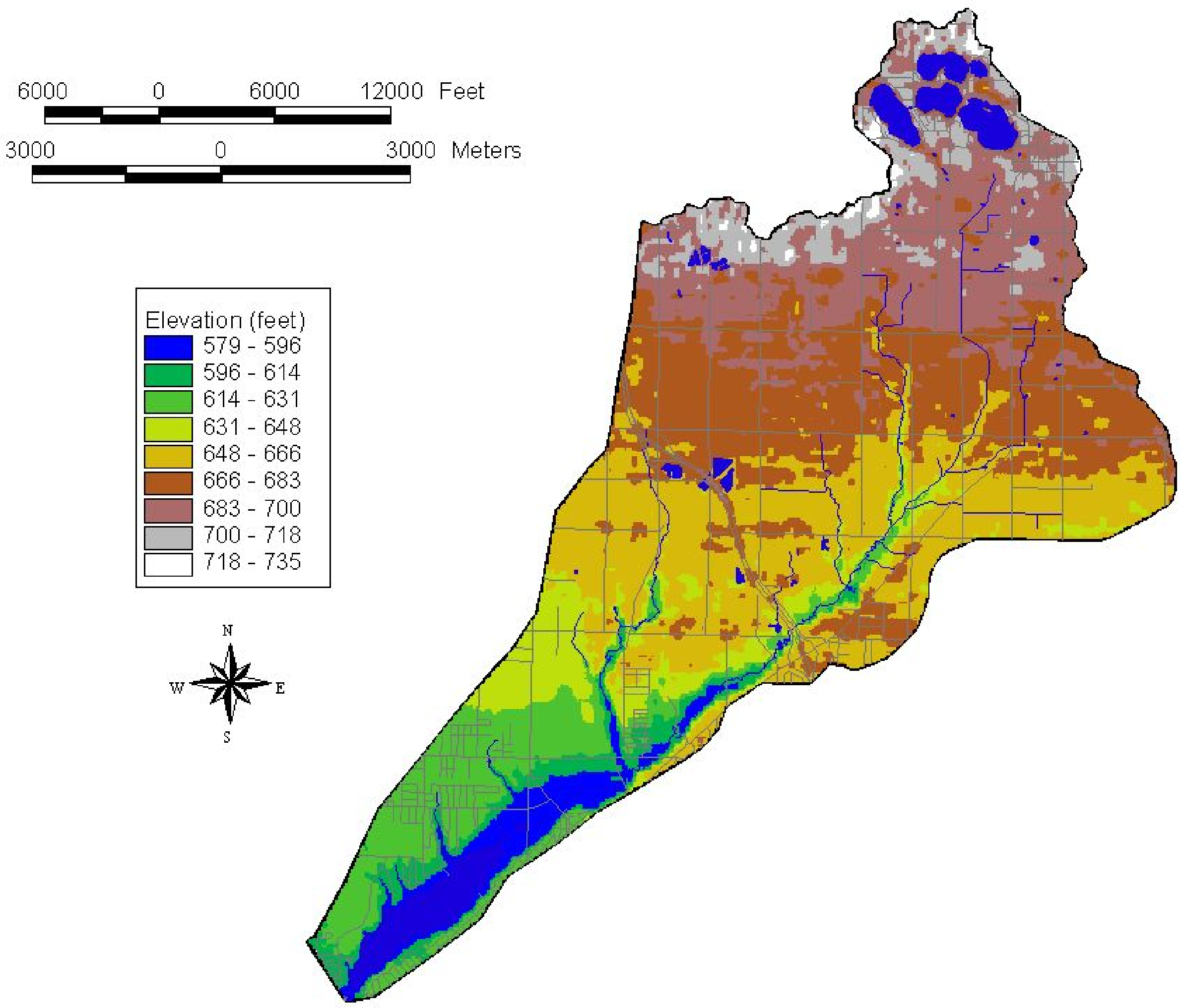

FIGURE 2.3. BEAR LAKE WATERSHED ELEVATIONS.

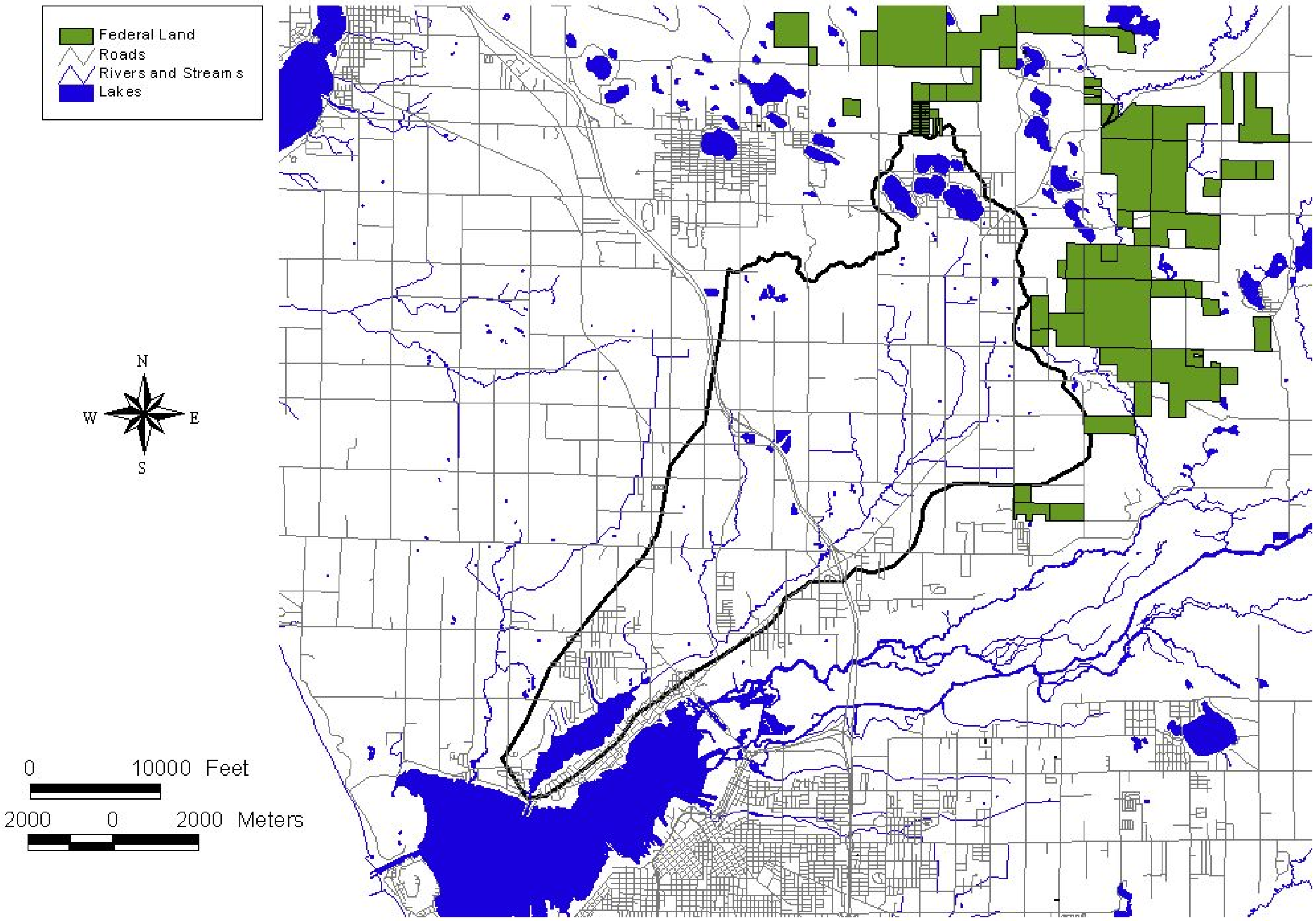

FIGURE 2.4. NATIONAL FOREST LAND IN THE BEAR LAKE WATERSHED.

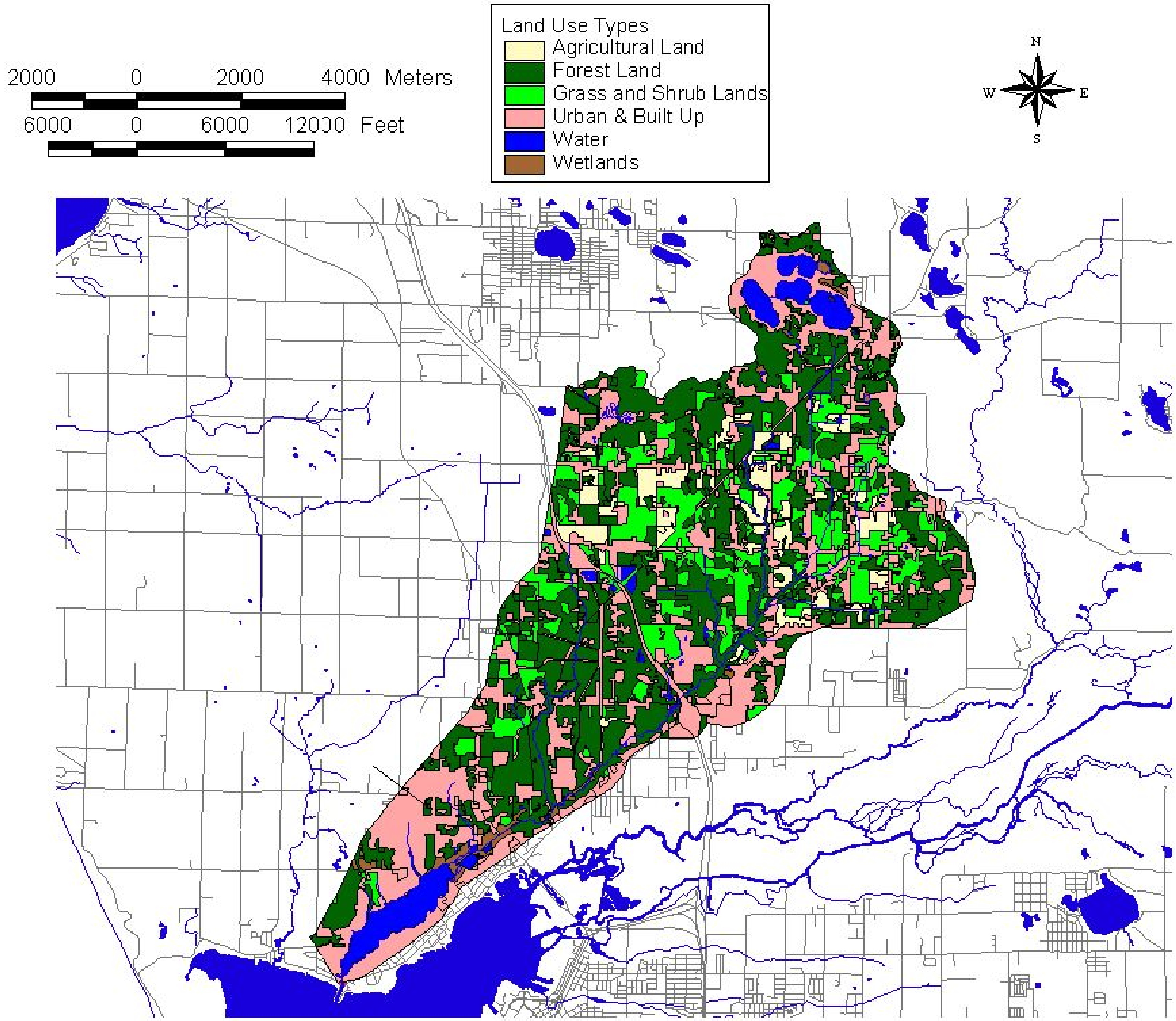

FIGURE 2.5. LAND USE SUMMARY FOR THE BEAR LAKE WATERSHED (2005).

3.0 Bear Lake Water and Sediment Monitoring

3.1 Description

Sampling locations for water and sediment in Bear Lake are shown in Figure 3.1. The GPS coordinates are provided in Table 3.1.

TABLE 3. 1 SEDIMENT SURVEY SAMPLING STATION COORDINATES FOR BEAR LAKE 2007.

Location	Latitude	Longitude
BL-1	43.2500	-86.2913
BL-1E	43.2481	-86.2910
BL-1W	43.2517	-86.2925
BL-2	43.2557	-86.2809
BL-2E	43.2539	-86.2799
BL-2W	43.2572	-86.2822
BL-3	43.2605	-86.2736
BL-3E	43.2585	-86.2730
BL-3W	43.2618	-86.2747

3.2 Methods

A spring turnover assessment of Bear Lake was conducted at the locations shown in Figure 3.1 on April 16, 2007. Field measurements include Secchi disk depth readings at each lake sampling location and the collection of vertical profiles for chlorophyll-*a*, pH, dissolved oxygen, temperature and conductivity readings at 1 foot intervals using a Hydrolab Datasonde. The chlorophyll-*a* samples were collected at each location as a vertical integrated composite based on a collection depth of 2.5 times the Secchi disk reading using a plexi glass tube. Water chemistry samples for laboratory analysis were collected with a VanDorn bottle from the surface at a depth of 1.5 feet below the surface, at mid depth and just off the bottom near undisturbed sediments during a period of stable surface conditions.

Sediment chemistry samples were collected at the nine locations shown in Figure 3.1. Each of the nine samples represented a composite of five surficial sediment subsamples (top five inches of sediment) collected with a piston core. The samples were collected during stable wind conditions at a minimum depth of three feet. The piston core samples were first extruded in a plastic pan and the top five inches of sediment were removed. This layer was transferred to a large plastic pan for compositing and mixing. After the five individual samples were collected, the composite was thoroughly mixed and transferred to the appropriate containers. An additional series of triplicate petite PONAR samples were collected at each station for benthic macroinvertebrate analysis. Samples were washed into a large tub and then into an elutriation device with a 0.5-mm, Nitex-mesh sleeve to remove silt and other fine particles. Retained material was preserved in 10% buffered formaldehyde with rose bengal stain. Benthic macroinvertebrates were identified to family level.

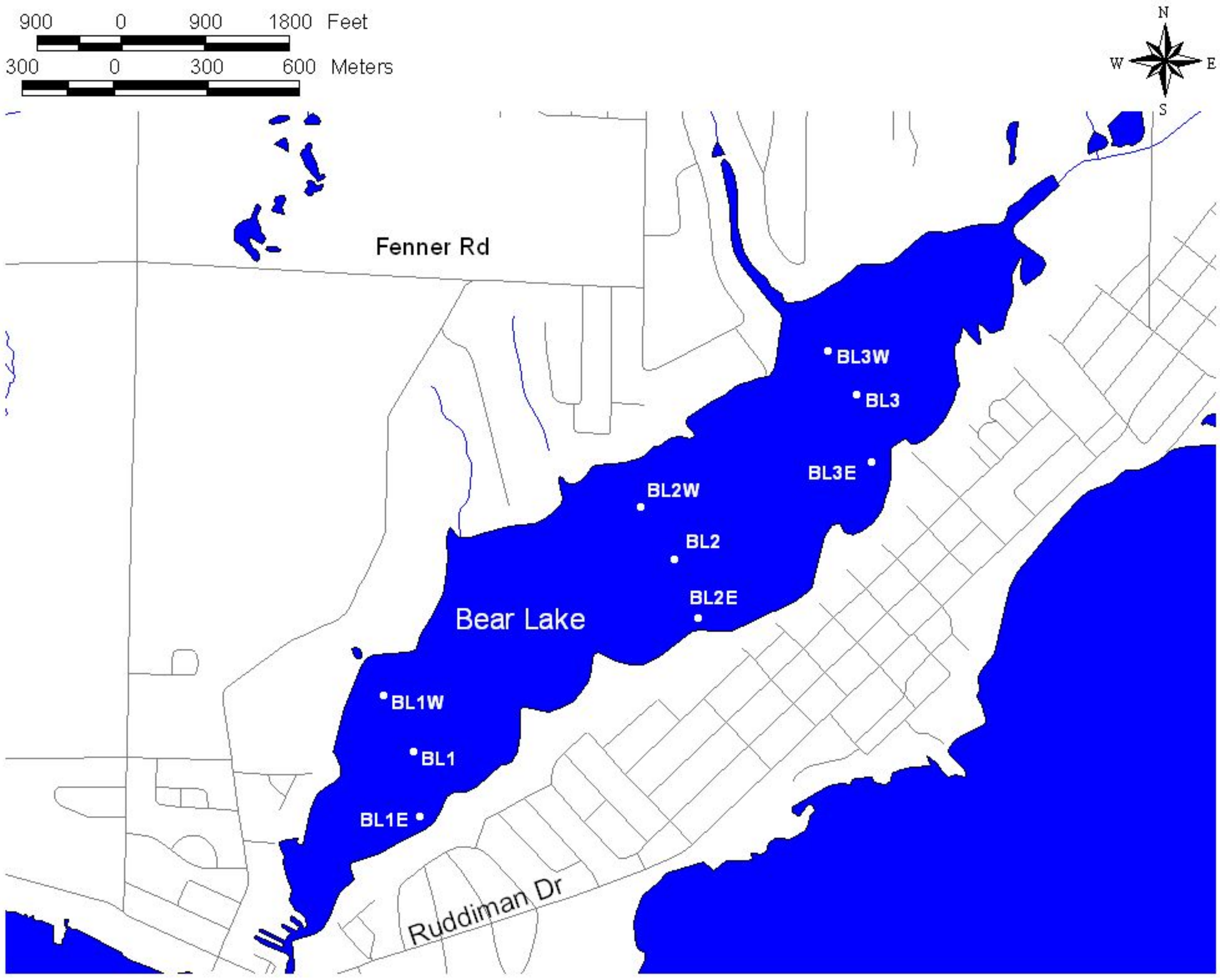

FIGURE 3.1. SEDIMENT SURVEY SAMPLING LOCATIONS IN LITTLE BLACK CREEK (2007).

Requirements for sample volumes, containers, and holding times are listed in Table 3.2. All sample containers for sediment chemistry and toxicity testing were purchased, precleaned, and certified as Level II by I-CHEM Inc.

TABLE 3. 2 SAMPLE CONTAINERS, PRESERVATIVES, AND HOLDING TIMES.

Parameter	Preparation	Bottle	Preservation	Holding Time
Benthos Identification and Enumeration	Elutriation	1 L Plastic	Refrigeration	1 Wk
Soluble Reactive Phosphorus	0.45 µm filter in field	10 mL plastic acid washed	Freeze -10°C	28 days
Total Phosphorus	Persulfate digestion	500 mL plastic acid washed	H_2SO_4, 4°C	28 days
Ammonia	-	500 mL plastic acid washed	H_2SO_4, 4°C	28 days
Total Kjeldahl Nitrogen	Digestion	500 mL plastic acid washed	H_2SO_4, 4°C	28 days
Nitrate/Nitrite	0.45 µm filter	10 mL plastic acid washed	Freeze -10°C	28 days
Color	Glass fiber filter	500 mL plastic acid washed	4°C	28 days
Chlorophyll-*a*	GF filter in field	25 mL amber vial	4°C	
Total Iron (water)	Digestion	500 mL plastic acid washed	HNO_3, 4°C	6 mo.
Total Copper (water)	Digestion	500 mL plastic acid washed	HNO_3, 4°C	6 mo.
Total Iron (sediment)	Digestion	1 L Plastic	4°C	6 mo.
Total Copper (sediment)	Digestion	1 L Plastic	4°C	6 mo.
Ash Free Dry Mass	Drying/ashing	1 L Plastic	4°C	6 mo.
Total Organic Carbon	Combustion	1 L Plastic	4°C	6 mo.
Soluble Reactive Phosphorus	Water extraction	1 L Plastic	4°C	6 mo.
Total Phosphorus	Digestion	1 L Plastic	4°C	6 mo.

A summary of analytical methods and detection limits is provided in Table 3.3. Instrument conditions and a summary of quality assurance procedures are provided in the following sections.

3.3 Sediment Chemistry Results and Discussion

The results of the Bear Lake sediment samples are presented in Table 3.4. Quality Control data are summarized in the Appendix. With the exception of BL-2E and BL-3E, the sediments can be classified as organic silts with total organic carbon (TOC) < 10% and percent solids < 15%. BL-2E and BL-3E were sandy in composition and contained less organic matter and moisture. Because of low organic content, phosphorus and metals content of these two samples, were less than the other

TABLE 3.3. ANALYTICAL METHODS AND DETECTION LIMITS.

Parameter	Preparation	Description	Methods Reference
Benthos Identification and Enumeration	Elutriation	Microscopic	EPA 1998 and 2001
Soluble Reactive Phosphorus	0.45 µm filter in field	Automated ascorbic acid	4500-P F*
Total Phosphorus	Persulfate digestion	Automated ascorbic acid	4500-P B.5 and F*
Ammonia	-	Automated phenate	4500-NH_3 H*
Total Kjeldahl Nitrogen	Digestion	Automated phenate	4500-N_{ORG} B*
Nitrate/Nitrite	0.45 µm filter	Ion Chromatography	4100 C*
Chlorophyll-*a*	GF filter in field	Fluorometric	10200*
Total Iron (water)	Digestion	Atomic absorption	7380**
Total Copper (water)	Digestion	Atomic absorption	7210**
Total Iron (sediment)	Digestion	Atomic absorption	7380**
Total Copper (sediment)	Digestion	Atomic absorption	7210**
Ash Free Dry Mass	Drying/ashing	Gravimetric	1130*
Total Organic Carbon	Combustion	IR	9060
Soluble Reactive Phosphorus (sediment)	Water extraction	Automated ascorbic acid	4500-P F*
Total Phosphorus (sediment)	Digestion	Automated ascorbic acid	4500-P B.5 and F*

* – Standard Methods (APHA 1999a).

stations. Overall, copper concentrations ranged from 25-62 mg/kg (dry wgt) with a median level of 50 mg/kg (dry wgt). The lake has a history of copper sulfate treatments for algal control and the sediments reflect a moderately elevated level of enrichment. Median total phosphorus and total iron concentrations were 1,091 mg/kg (dry wgt) and 4,100 mg/kg (dry wgt), respectively. The relationship between iron and total phosphorus concentrations can be used to predict the ability of sediments to release phosphorus and serve as a source of internal nutrient loading (Nürnberg 1988; Jensen et al. 1992). This relationship will be discussed in detail in Section 5. The median soluble reactive phosphorus (SRP) concentration for Bear Lake sediments was 100 mg/kg (dry wgt). SRP is released into the pore water of sediments from microbial decomposition. In a shallow system like Bear Lake, sediment resuspension by wave action can release the SRP to the water column (Jensen et al. 1992).

TABLE 3.4 RESULTS OF SEDIMENT SAMPLES COLLECTED FROM BEAR LAKE APRIL 16, 2007.

Sample #	Date	Station	AFDM		TOC	Total Copper	Total Iron	Sediment SRP	Sediment TP
			%Solids (w/w)	% Volatile Solids (w/w)	% (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)
22326	4/16/2007	BL-1	8	36	20	42	51000	98	1079
22327	4/16/2007	BL-1 E	9	29	16	46	41000	112	1126
22328	4/16/2007	BL-1 W	10	33	19	44	48000	105	1104
22329	4/16/2007	BL-2	9	37	20	55	61000	130	1146
22330	4/16/2007	BL-2 E	43	5	5	35	11000	55	388
22331	4/16/2007	BL-2 W	10	35	20	53	51000	87	1105
22332	4/16/2007	BL-3	13	34	19	62	41000	92	944
22333	4/16/2007	BL-3 E	78	1	2	25	1000	5	59
22334	4/16/2007	BL-3 W	13	35	19	53	36000	107	1172
22335	4/16/2007	BL-3 W DUP	12	34	19	60	32000	101	955
Median			11	34	19	50	41000	100	1091

3.4 Water Chemistry Results and Discussion

The results of the Bear Lake water samples collected on April 16, 2007 and historical data collected by MDEQ and AWRI in 2006 are presented in Table 3.5. Quality Control data are summarized in the Appendix. Median values and ranges for selected parameters are presented in Table 3.6. Dissolved nitrogen compounds (NO_3-N and NH_3-N) were low during the summer and showed a small increase during spring and fall. Median summer nitrate and ammonia concentrations were 0.01 mg/l and 0.003 mg/l, respectively. Dissolved phosphorus (SRP) was below the detection limit (5 ug/l) in all but one sample (8 ug/l). In contrast, the summer (June, July, and August) median total phosphorus (TP) and total Kjeldahl nitrogen (TKN) concentrations were 44 ug/l and 0.96 mg/l, respectively. TP concentrations ranged from 30-78 ug/l while TKN results ranged from 0.67-1.98 mg/l. The median summer chlorophyll-*a* was 30 ug/l and ranged from 18-74 ug/l. Total phosphorus and chlorophyll-*a* values found during this investigation were similar to those measured by Wilson et al. 2005 (66 ug/l and 39 ug/l, respectively). Limnological assessment methods utilize Secchi disk depth, chlorophyll-*a* and total phosphorus concentrations to determine lake trophic status. Thus, based on standard values of these parameters used to assess lake trophic status (Cooke et al. 2003), Secchi disk depth, chlorophyll-*a* and total phosphorus values would indicate upper eutrophic status for Bear Lake. Carlson (1977) developed a Trophic Status Index (TSI) that uses Secchi depth, chlorophyll-*a* and total phosphorus as indicators. The summer median TSI values for Secchi depth, TP and chlorophyll-*a* were 65, 59 and 64, respectively. These TSI values again indicate that Bear Lake is a highly eutrophic system.

Total nitrogen to total phosphorus ratios (TN:TP) are often used as a relative indicator of nitrogen or phosphorus limitation in aquatic ecosystems (Smith 1982, Downing and McCauley 1992). A number of studies have attempted to determine the ratio at which phytoplankton are most likely to be nitrogen or phosphorus limited (Sakamoto 1966, Smith 1982, 1983). In general, these studies suggest that for phytoplankton growing during the summer, N-limitation was most likely when the epilimnion TN:TP ratio (molar) was less than 22:1, whereas P-limitation was most likely when the epilimnion TN:TP ratio was greater than 37:1. The median molar TN:TP ratio for Bear Lake was 50, indicating that the system appears to be phosphorus limited.

Samples collected by MDEQ on July 12, 2006 and August 16, 2006 at Station BL-2 (Table 3.5) showed no accumulation of ammonia and SRP in the bottom samples. Temperature and dissolved oxygen (DO) data collected during these monitoring events are summarized in Figure 3.2. These data suggest that Bear Lake does not stratify and remains mixed during the summer. In stratified lakes, anaerobic conditions result in the release of SRP and ammonia from the sediments to the water column. The shallow bathymetry and high productivity of Bear Lake appear to limit chemical stratification. Samples were not collected at night and consequently, the effect of respiration on oxygen depletion is unknown. In a productive system like Bear Lake, respiration may be sufficient to deplete oxygen levels near the lake bottom. The presence of oxygen near saturation in the early morning samples collected by MDEQ suggest that oxygen depletion during the night may not be occurring to a significant level.

TABLE 3.5. SUMMARY OF WATER QUALITY DATA FOR BEAR LAKE (2006 AND 2007). TSI = CARLSON TROPHIC STATUS INDEX.

Source	Depth	Site	Date	Secchi Disk (m)	TSI Secchi Disk	NO3-N (mg/L)	NH3-N (mg/L)	TKN-N (mg/L)	SRP-P (ug/L)	TP-P (ug/L)	TSI TP	Ratio TKN:TP	Chl a (ug/L)	TSI Chl a
MDEQ	Surface	BL-1	4/11/06	1.1	59	0.27	0.02	0.59	< 5	35	55	17	17	58
MDEQ	Bottom	BL-1		na	na	0.28	0.03	1.06	< 5	83	68	13	NA	NA
MDEQ	Surface	BL-2		0.9	62	0.24	0.01	0.59	< 5	34	55	17	NA	NA
MDEQ	Bottom	BL-2		na	na	0.24	0.01	0.59	< 5	33	55	18	NA	NA
MDEQ	Surface	BL-3		1.1	59	0.24	0.01	0.61	< 5	31	54	20	26	63
MDEQ	Bottom	BL-3		na	na	0.24	0.01	0.63	< 5	39	57	16	NA	NA
MDEQ	Surface	BL-1	5/10/06	0.8	63	0.07	0.01	1.00	< 5	65	64	15	17	58
MDEQ	Bottom	BL-1		na	na	0.12	0.02	0.81	< 5	58	63	14	NA	NA
MDEQ	Surface	BL-2		0.8	63	0.07	0.01	0.84	< 5	50	61	17	NA	NA
MDEQ	Bottom	BL-2		na	na	0.06	0.02	0.79	< 5	49	60	16	NA	NA
MDEQ	Surface	BL-3		0.9	62	NA	<0.01	0.82	< 5	46	59	18	18	59
MDEQ	Bottom	BL-3		na	na	0.07	0.04	0.87	< 5	54	62	16	NA	NA
MDEQ	Surface	BL-1	6/14/06	0.9	62	<0.01	0.00	0.68	< 5	37	56	18	NA	NA
MDEQ	Surface	BL-2		0.9	62	<0.01	0.00	0.67	< 5	36	56	19	18	59
MDEQ	Surface	BL-3		0.9	62	<0.01	0.00	0.76	< 5	39	57	19	NA	NA
AWRI	Integrated 1 M	BL-1	7/6/06	na	na	<0.01	0.02	1.84	< 5	71	66	26	37	66
AWRI	Integrated 1 M	BL-2		na	na	<0.01	0.02	1.72	< 5	68	65	25	35	65
AWRI	Integrated 1 M	BL-3		na	na	0.05	0.05	1.98	< 5	61	63	32	33	65
AWRI	Integrated 1 M	BL-2 D		na	na	<0.01	0.02	1.60	< 5	63	64	25	29	64
MDEQ	Surface	BL-1	7/12/06	na	na	<0.01	0.01	1.27	< 5	78	67	16	NA	NA
MDEQ	Surface	BL-2		0.6	68	<0.01	0.01	1.24	< 5	77	67	16	42	67
MDEQ	Surface	BL-3		na	na	<0.01	0.01	1.26	< 5	75	66	17	NA	NA
AWRI	Integrated 1 M	BL-1	7/25/06	na	na	<0.01	<0.01	1.31	< 5	69	65	19	48	69
AWRI	Integrated 1 M	BL-2		na	na	<0.01	<0.01	1.27	< 5	68	65	19	45	68
AWRI	Integrated 1 M	BL-3		na	na	<0.01	<0.01	1.22	< 5	78	67	16	47	68
AWRI	Integrated 1 M	BL-2 D		na	na	<0.01	<0.01	1.04	< 5	69	65	15	39	67
AWRI	Integrated 1 M	BL-1	8/4/06	na	na	<0.01	0.04	0.76	< 5	48	60	16	22	61
AWRI	Integrated 1 M	BL-2		na	na	<0.01	0.02	0.92	< 5	42	58	22	24	62
AWRI	Integrated 1 M	BL-3		na	na	0.02	0.02	0.90	8	44	59	20	26	63
AWRI	Integrated 1 M	BL-2 D		na	na	<0.01	0.02	1.03	< 5	42	58	25	29	64
MDEQ	Surface	BL-1	8/16/06	0.6	67	0.01	0.01	0.94	< 5	42	58	22	NA	NA
MDEQ	Surface	BL-2		0.6	67	0.01	0.01	0.96	< 5	41	58	23	NA	NA
MDEQ	Bottom	BL-2		na	na	0.01	0.01	1.00	< 5	45	59	22	NA	NA
MDEQ	Surface	BL-3		0.6	67	<0.01	0.01	0.94	< 5	40	57	24	NA	NA
AWRI	Integrated 1 M	BL-1	8/24/06	na	na	<0.01	<0.01	0.78	< 5	33	55	24	24	62
AWRI	Integrated 1 M	BL-1 D		na	na	<0.01	0.01	0.76	< 5	31	54	25	28	63
AWRI	Integrated 1 M	BL-2		na	na	<0.01	<0.01	0.93	< 5	30	53	31	30	64
AWRI	Integrated 1 M	BL-3		na	na	<0.01	<0.01	0.86	< 5	32	54	27	28	63
MDEQ	Surface	BL-1	9/13/06	0.6	63	0.01	0.01	0.81	< 5	34	55	24	NA	NA
MDEQ	Surface	BL-2		0.8	63	<0.01	0.01	0.81	< 5	36	56	23	22	61
MDEQ	Bottom	BL-2		na	na	<0.01	0.01	0.86	< 5	38	57	23	NA	NA
MDEQ	Surface	BL-3		0.6	67	<0.01	<0.01	0.84	< 5	35	55	24	NA	NA
MDEQ	Surface	BL-1	10/11/06	0.8	63	0.03	0.01	0.84	< 5	38	57	22	NA	NA
MDEQ	Surface	BL-2		0.8	63	0.02	0.01	0.95	< 5	44	59	22	20	60
MDEQ	Bottom	BL-2		na	na	0.02	0.01	0.84	< 5	39	57	22	NA	NA
MDEQ	Surface	BL-3		1.0	60	0.01	0.01	0.84	< 5	37	56	23	NA	NA
MDEQ	Surface	BL-1	11/15/06	1.0	60	0.25	0.07	0.61	< 5	23	49	27	NA	NA
MDEQ	Surface	BL-2		1.0	60	0.24	0.07	0.65	< 5	26	51	25	9	52
MDEQ	Bottom	BL-2		na	na	0.24	0.07	0.72	< 5	33	55	22	NA	NA
MDEQ	Surface	BL-3		1.0	60	0.25	0.06	0.74	< 5	27	52	27	NA	NA
AWRI	0.1	BL-1	4/16/07	0.9	62	0.23	< 0.01	0.70	< 5	42	58	17	9	52
AWRI	8.0	BL-1		na		0.23	< 0.01	0.66	< 5	43	58	15		
AWRI	0.1	BL-2		0.9	61	0.25	< 0.01	0.66	< 5	32	54	21	10	53
AWRI	8.1	BL-2		na		0.26	0.02	0.67	< 5	31	54	22		
AWRI	0.1	BL-3		0.8	63	0.23	< 0.01	0.66	< 5	30	53	22	9	52
AWRI	0.1	BL-3 Dup		0.8		0.23	0.01	0.61	< 5	32	54	19		
AWRI	1.8	BL-3		na		0.24	< 0.01	0.69	< 5	31	54	22		

Table 3.6. Median Values and Ranges for Water Quality Parameters in Bear Lake (2006-2007). (TSI = Carlson Trophic Status Index. * Standard Error)

Measurement	NO3-N (mg/l)	NH3-N (mg/l)	TKN-N (mg/l)	Secchi Depth m	TSI Secchi Depth	TP-P (ug/L)	TSI TP	Ratio TN:TP	Chl a (ug/L)	TSI Chl *a*
Summer Surface Median (n=25)	0.01 (0.01)*	0.010 (0.003)*	0.96 (0.07)*	0.7 (0.1)*	65 (1)*	44 (3)*	59 (1)*	50 (2)*	30 (1)*	64 (1)*
Summer Minimum Surface (n=25)	<0.01	0.003	0.67	0.6	62	30	53	34	18	59
Summer Maximum Surface (n=25)	0.05	0.050	1.98	0.9	68	78	67	74	48	69
Grand Median Surface (n=34)	0.15 (0.03)*	0.012 (0.005)*	0.84 (0.07)*	0.8 (0.1)*	63 (1)*	41 (3)*	58 (1)*	49 (2)*	26 (3)*	63 (2)*
Grand Median Bottom (N=10)	0.23 (0.03)*	0.018 (0.01)*	0.79 (0.04)*	-	-	39 (4)*	57 (1)*	37 (2)*	-	-

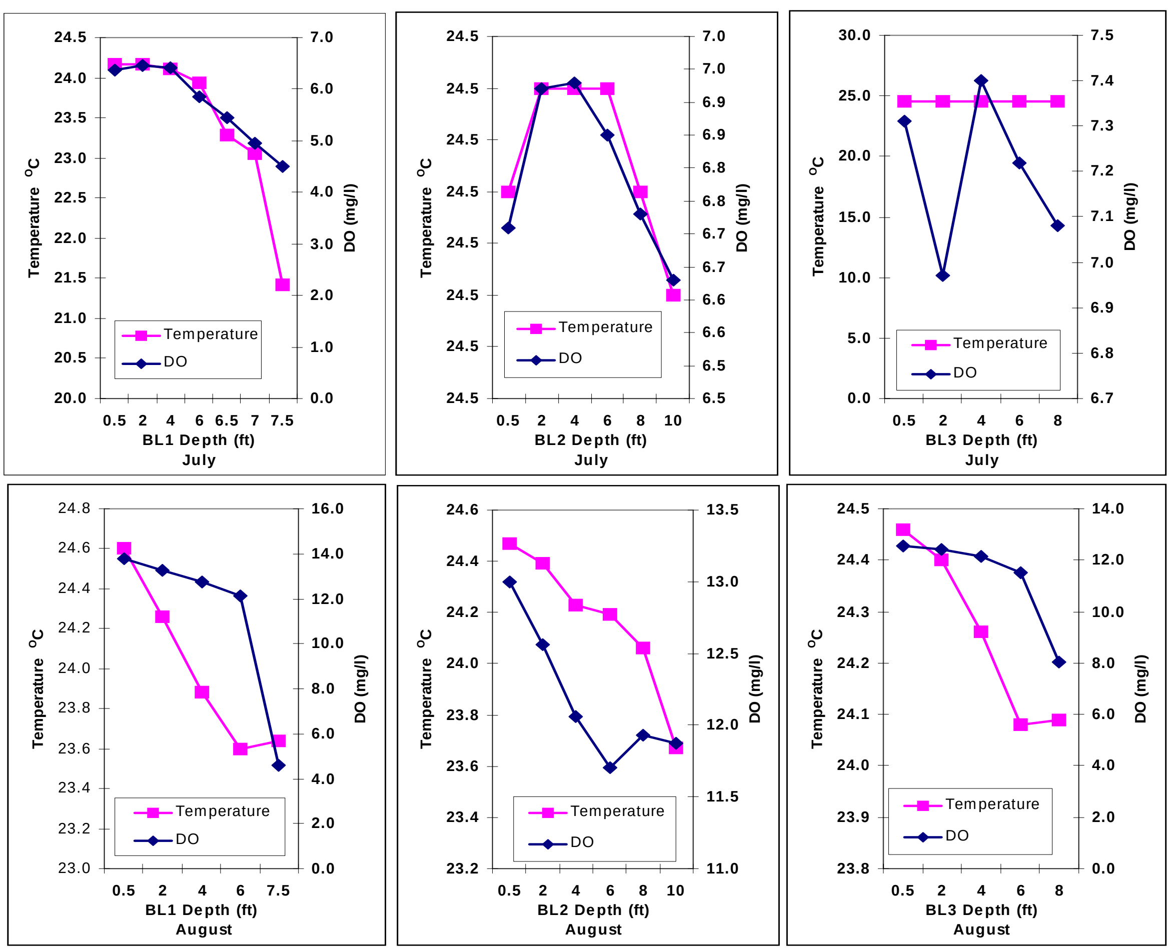

Figure 3.2. Summary of Temperature and Dissolved Oxygen Data for Bear Lake (MDEQ 2006).

3.5 Benthic Macroinvertebrate Results and Discussion

The results of the macroinvertebrate samples are presented in Table 3.7. The benthic macroinvertebrate community is comprised chironomids, oligochaetes, *Chaoborus*, and clams. Mean total organism densities range from 580-1610/m^2, with *Chaoborus* as the dominant organism. The distribution of benthic organisms is shown in Figure 3.2. Chironomid densities are greater than oligochaetes at all stations. Oligochaete:Chironomid ratios < 1 indicate moderate organic enrichment while ratios >1 are indicative of heavy organic pollution (Allen et al. 1999). The highest densities of clams are located along the eastern shore and appear to be related to substrate. Stations BL-2E and BL-3E had less organic matter (Table 3.4) and sandy texture. Benthic macroinvertebrate data from 1972 (Evans 1974) are presented in Figure 3.3. The sampling locations were different than the current investigation, but fall into the same general sections of the lake. When compared to current conditions, the 1972 data show fewer organisms per square meter, the dominance of oligochaetes at 2 stations, and the absence of clams. *Chaoborus* was present in reduced numbers at only one location. These data suggest that the benthic macroinvertebrate community in Bear Lake has improved since 1972 as both taxa richness and total numbers have increased. In 1972, the discharge from the Story/Ott Superfund Site was entering the lake and may have been the cause of the reduced taxa richness, lower organism densities, and changes in population composition. The current dominance of *Chaoborus*, oligochaetes, and chironomids is an indication of moderately eutrophic conditions (Nalepa 1987) and improved water/sediment quality compared to 1972.

TABLE 3.7. RESULTS OF MACROINVERTEBRATE SAMPLES COLLECTED FROM BEAR LAKE SEDIMENTS (4/16/2007).

Sample Number	Site	#/m^2	Mean #/m^2	Standard Error	#/m^2	Mean #/m^2	Standard Error	#/m^2	Mean #/m^2	Standard Error	#/m^2	Mean #/m^2	Standard Error	#/m^2	Mean #/m^2	Standard Error
22304	BL1 A	174			174			957			0			1305		
22306	BL1 B	218	232	38	261	276	63	1523	1102	214	0	0	0	2001	1610	206
22288	BL1 C	305			392			827			0			1523		
22298	BL1 EA	0			261			174			44			479		
22302	BL1 EB	44	29	15	348	261	50	261	276	63	0	15	15	653	580	52
22309	BL1 EC	44			174			392			0			609		
22287	BL1 WA	131			44			914			87			1175		
22310	BL1 WB	87	87	25	131	102	29	1001	899	63	131	102	15	1349	1189	88
22301	BL1 WC	44			131			783			87			1044		
22303	BL2 A	131			87			827			0			1045		
22305	BL2 B	44	116	38	131	160	52	914	914	50	87	29	29	1175	1218	115
22308	BL2 C	174			261			1001			0			1436		
22296	BL2 EA	131			87			174			827			1218		
22290	BL2 EB	131	116	15	131	131	25	609	740	370	1044	711	233	1914	1697	240
22307	BL2 EC	87			174			1436			261			1958		
22291	BL2 WA	44			174			870			44			1131		
22297	BL2 WB	0	15	15	87	160	38	609	754	77	0	15	15	696	943	129
22311	BL2 WC	0			218			783			0			1001		
22293	BL3 A	44			305			1305			131			1784		
22294	BL3 B	44	73	29	479	377	52	870	914	215	174	102	52	1566	1465	219
22286	BL3 C	131			348			566			0			1044		
22285	BL3 EA	44			44			218			305			609		
22299	BL3 EB	0	58	38	131	87	25	870	464	205	653	464	102	1653	1073	307
22300	BL3 EC	131			87			305			435			957		
22292	BL3 WA	87			305			1088			261			1740		
22289	BL3 WB	261	189	52	261	319	38	957	928	102	174	174	50	1653	1610	91
22295	BL3 WC	218			392			740			87			1436		

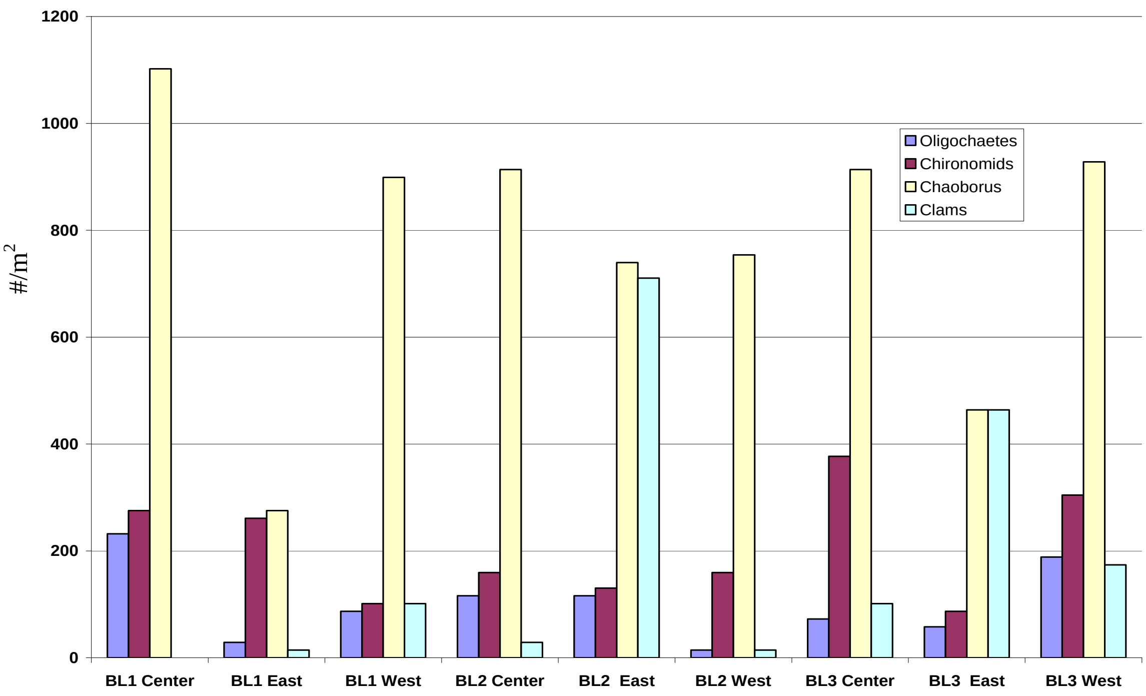

FIGURE 3.3. DISTRIBUTION OF BENTHIC MACROINVERTEBRATES IN BEAR LAKE SEDIMENTS (4/16/07).

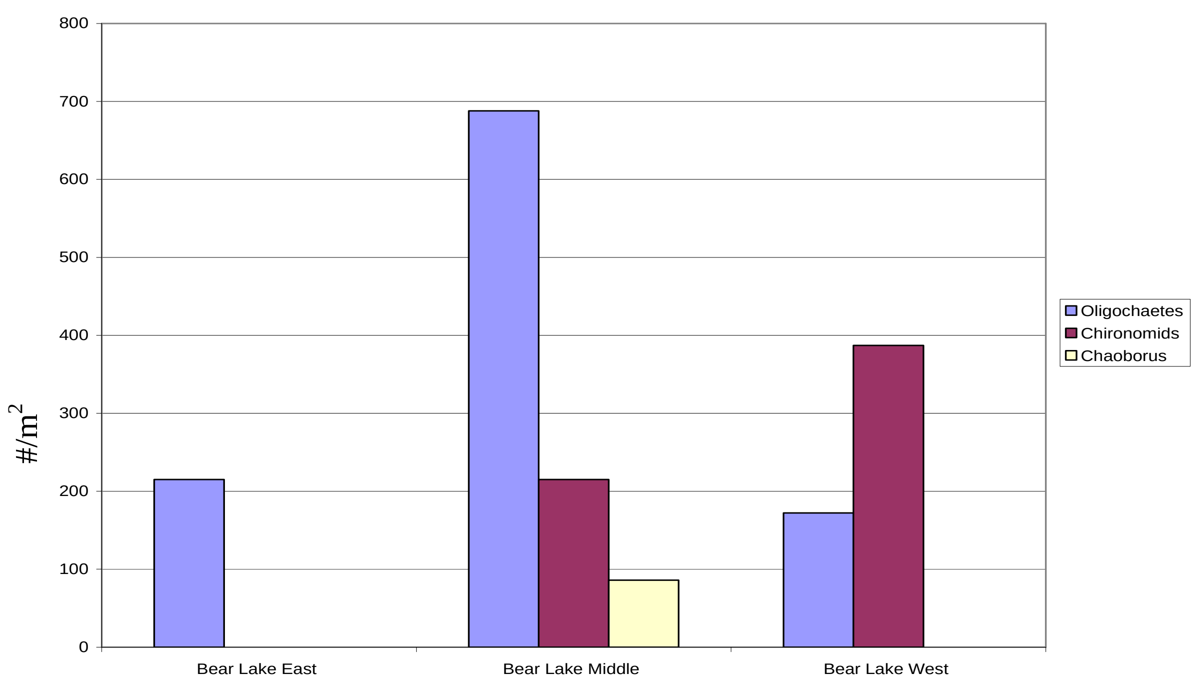

FIGURE 3.4. DISTRIBUTION OF BENTHIC MACROINVERTEBRATES IN BEAR LAKE SEDIMENTS (1972).

3.6 Phytoplankton Results and Discussion

Phytoplankton samples were collected from Bear Lake by AWRI in 2006 as part of an investigation of cyanobacteria and their associated toxins in west Michigan lakes. Three locations in Bear Lake were examined at a frequency of twice per month in July and August. The sampling locations were similar to the water quality stations BL-1, BL-2, and BL-3 in Figure 3.1. The distribution of phytoplankton organisms is shown in Figure 3.5. Bear Lake is dominated by cyanobacteria during the summer months with biovolumes > 1x 10^7 *u*m^3/ml. Diatoms, dinoflagellates, green algae are minor components of the phytoplankton community. The composition of the cyanobacteria population is given in Figure 3.6. *Microcystis aeruginosa, Microcystis viridis*, and *Microcystis wesenbergii* dominate the phytoplankton most of the summer months. *Aphanizomenon gracile* is present in July. *Microcystis* forms blooms in eutrophic lakes and is capable of adjusting its buoyancy in the water column (Paerl and Ustach 1982; Pearl et al. 2001). The organism also can accumulate phosphorus at the sediment/water interface through luxury consumption (Pearl 1996). The shallow bathymetry of Bear Lake and the high levels of phosphorus in the sediment (Section 3.3) are ideal conditions for *Microcystis aeruginosa* to move vertically from the sediment to the surface and form blooms.

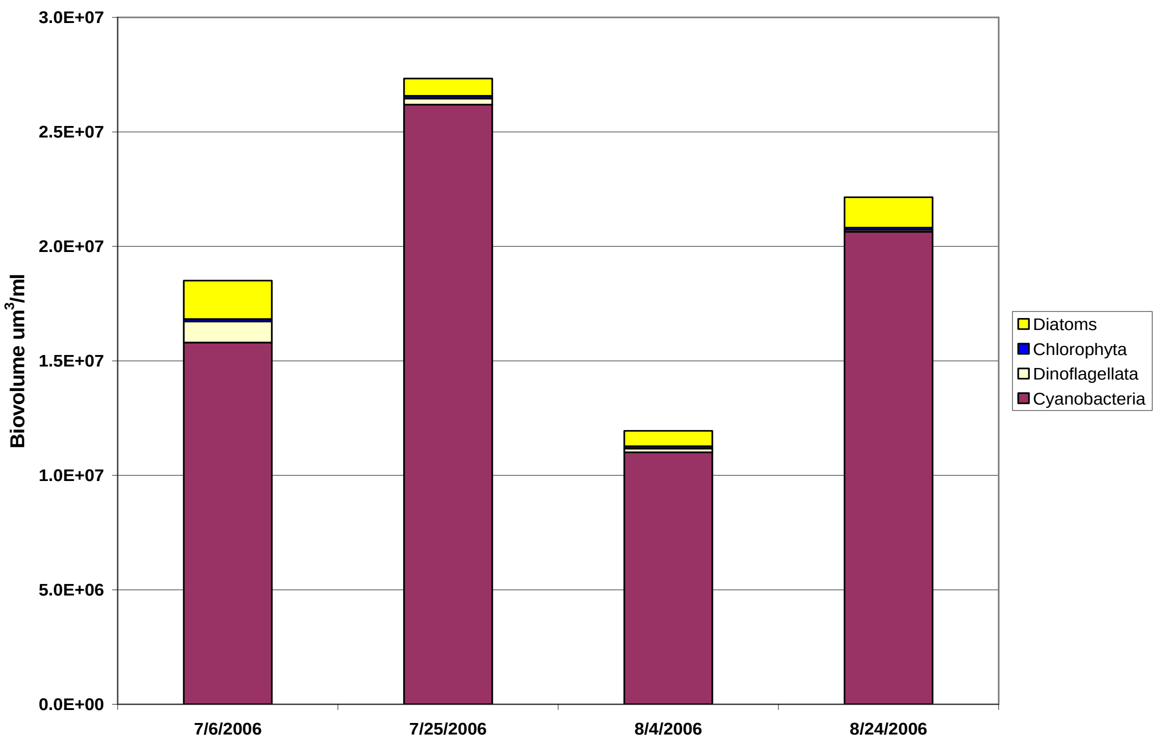

FIGURE 3.5. DISTRIBUTION OF PHYTOPLANKTON ORGANISMS IN BEAR LAKE (2006).

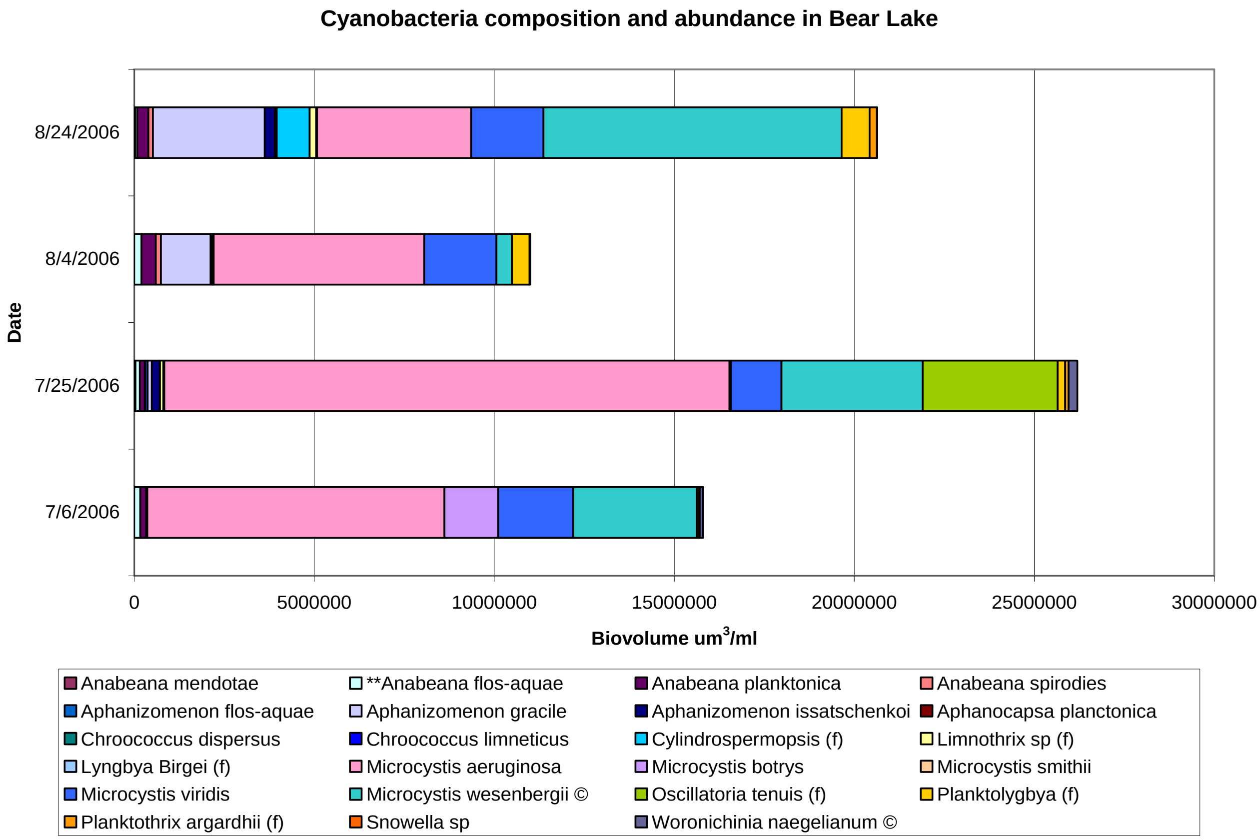

FIGURE 3.6. CYANOBACTERIA POPULATION COMPOSITION IN BEAR LAKE (2006).

3.7 Summary and Conclusions

Bear Lake is a highly eutrophic lake based on summer Secchi depth, total phosphorus and chlorophyll-*a* concentrations. Molar TN:P ratios suggest that the lake is phosphorus limited. The benthic macroinvertebrate and phytoplankton communities also are indicative of eutrophic conditions. Although the benthic macroinvertebrate community has improved in taxa richness since 1972, chironomid and oligochaete densities still support eutrophic classification. Similarly, the dominance of cyanobacteria in the phytoplankton community also indicates an advanced degree of cultural eutrophication or nutrient enrichment.

3.8 References

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4.0 Bear Lake Vegetative Cover Analysis

4.1 Methods

A survey of aquatic vegetation following the Tier I guidelines of the Indiana Department of Natural Resources' *Procedure Manual for Surveying Aquatic Vegetation* (IDNR 2004) was completed on August 10, 2007. Unique plant beds and algal blooms were identified and mapped using a Magellan ProMark 3 GPS receiver. Because water transparency was low, the extent of each plant bed was determined by using a combination of double-headed-rake throws and periodic depth measurements. With this method, we found that the littoral zone extended to a depth of approximately 3 feet (1 m), which aided in the determination of the lakeward extent of the plant beds. All plant species were identified within each bed and percent abundance was visually estimated for each species (Table 4.1). A double-headed rake was used both to collect vegetation and to estimate abundance. Voucher specimens were collected for any species whose identity was uncertain and later identified in the lab using taxonomic keys (Crow and Hellquist 2000). After a plant bed was surveyed in its entirety, overall abundance was visually estimated for each of the following vegetation types: submersed, non-rooted floating, rooted floating, and emergent. Using the Magellan GPS receiver's mobile mapping feature, the perimeter of each bed was traveled to accurately delineate its boundary. The geographic position data were post-processed in the lab using the nearest base station data (Muskegon MDOT station), resulting in sub-meter accuracy for the plant bed locations.

TABLE 4.1. VISUAL ABUNDANCE RATINGS USED FOR BEAR LAKE (AUGUST 2007).

Abundance (%)	Cover Rating
>60	4
21-60	3
2-20	2
<2	1

4.2 Results and Discussion

A total of 10 unique plant beds were identified in Bear Lake (Figure 4.1). These beds differed in community composition and abundance. Although the lake is relatively shallow, the littoral zone was narrow and extended to a depth of only 3 feet (1 m). Approximately 119 acres, or 32%, of the total area of the lake was vegetated (Table 4.2). The majority of plant beds were dominated by submersed vegetation, with the exception of Beds 4 and 7, which also had abundant floating (rooted) plants (Table 4.3). Macrophyte abundance was greatest in the northeast end of the lake, where water depths were approximately 3 feet (1 m; Figure 4.2). Eighteen total macrophyte species were identified, with species richness ranging from 5

FIGURE 4.1. VEGETATIVE COVER IN BEAR LAKE BY PLANT BED (AUGUST 2007).

FIGURE 4.2. MACROPHYTE ABUNDANCE IN BEAR LAKE BY PLANT BED (AUGUST 2007).

TABLE 4.2. VEGETATIVE COVER. IN BEAR LAKE (AUGUST 2007).

Plant Bed	Area (acres)
Bed 01	0.6
Bed 02	4.3
Bed 03	22.5
Bed 04	0.2
Bed 05	24.3
Bed 06	20.0
Bed 07	0.1
Bed 08	14.4
Bed 09	32.1
Bed 10	0.7
Open Water	256.0
Total Area	**375.1**
Vegetated Area	**119.2**
Percent Vegetated	**31.8%**

to 13 in the plant beds (Table 4.3). In general, the plant beds on the north and south shores tended to be dominated by *Najas* sp. and *Chara* sp., while the shallow northeastern beds were characterized by a dense community dominated by *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Vallisneria americana*, and *Zosterella dubia* (Table 4.3). *Najas* sp. and *Chara* sp. are typically found in hard water lakes (Wetzel 2001). Their presence in Bear Lake may indicate the venting of groundwater with elevated hardness in the littoral zone.

An extensive algal bloom covered the majority (94.7%) of the lake. The algal bloom contributed to low water transparency, with Secchi depth averaging 90 cm on the day of the vegetation survey (Figure 4.3). The bloom appeared to be dominated by the cyanobacteria *Microcystis aeruginosa* and was absent in the far northeastern portion of the lake (Bed 6; Figure 4.3). This same area had a moderate abundance of *Cladophora* sp., a filamentous benthic algae (Table 4.3). A very thick algal scum was present in a small area (Bed 4) that was characterized by dense floating (rooted) and submersed vegetation, and highly organic sediment (Table 4.3). It is not know whether a local source of nutrients was present to stimulate algal growth or if the wind caused scum accumulation that was retained by the macrophytes.

The presence of an extensive algal bloom is an indicator of eutrophic conditions. Macrophyte beds are limited to the shallow littoral zone around the lake and at the mouth of Bear Creek. The absence of macrophytes in the rest of the lake appears to be limited by light penetration caused by the excessive algal blooms. The elevated total phosphorus concentrations in the sediment (Table 3.4) and the shallow bathymetry of the lake should be able to support dense macropyte beds if light was not a limiting factor.

TABLE 4.3. AQUATIC MACROPHYTE COMMUNITY CHARACTERIZATION OF BEAR LAKE (AUGUST 2007). OVERALL ABUNDANCE RATED ACCORDING TO THE SCALE SHOWN IN TABLE 4.1.

	Plant Bed ID									
PLANT SPECIES	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Benthic algae - filamentous						3				
Ceratophyllum demersum	2		1	4	4		4	1		
Chara sp.		2	2					2	2	3
Elodea canadensis	1				2					
Lemna sp.						1				
Myriophyllum spicatum	2	1	2	3	4	3	3	1		
Najas flexilis	3	1	2		2			2	2	3
Najas guadalupensis		3			2	2				
Nuphar sp.				3			3			
Nymphaea odorata	3	1	1	3	1	1	3	1	1	2
Phragmites australis		1	1							1
Potamogeton pectinatus		1	1		1	2		1		
Potamogeton perfoliatus	1	1	1						1	
Potamogeton pusillus	1	2	1		2	3		1	1	
Potamogeton richardsonii		1	1		1	1		1		
Schoenplectus pungens	1	1						1		
Typha latifolia		1	1	2	1	1	2	1	1	1
Vallisneria americana	2	1	1		2	4		1	1	
Zosterella dubia	2					3				
OVERALL ABUNDANCE										
Submerged	3	3	2	4	4	4	4	3	2	4
Non-rooted Floating						1				
Rooted Floating	3	1	1	4	1	1	4	1	1	2
Emergent	1	1	1	2	1		2	1	1	1
Number of Species	9	13	12	5	11	10	5	11	7	5

FIGURE 4.3. ALGAL BLOOM EXTENT IN BEAR LAKE (AUGUST 2007).

4.3. References

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5.0 Internal Loading Analysis

5.1 Introduction:

Lake sediments can serve as a significant source of phosphorus (P) in shallow, eutrophic lakes (Welch and Cooke, 1995, 1999; Steinman et al., 1999; Søndergaard et al., 2001; Nürnberg and LaZerte, 2004). In most cases, the amount of sediment-released P is related to the degree to which the lake sediments are anoxic. During periods of anoxia, the oxidized form of iron becomes reduced in form, thus liberating P from its bound state. While measurement of P release rates is the most direct method to estimate internal loading in lakes, this analysis can be time-consuming and logistically challenging. Nürnberg (1988) found a statistically significant relationship between P release rates from sediments and sediment P; this relationship can serve as a possible surrogate for direct measurements of release rates from lake sediments. In this section, we present three different indirect approaches to evaluate internal loading potential in Bear Lake: 1) a comparison of sediment TP concentration among lakes in the region; 2) sediment Fe:TP ratio; and 3) application of Nürnberg's (1988) regressions to Bear Lake sediment TP concentration.

5.2 Results

5.2.1 TP Concentration

Lake sediments accumulate phosphorus over time. Sediments heavily loaded with P are suggestive of long-term eutrophic loading. However, the sediment TP concentrations do not necessarily correlate with P release rate because it is the *form* of P that controls how mobile it may be in the sediment. Fractionation is necessary to determine the various P forms, a process that was not done in this study. Rather, we use TP concentration here to provide a coarse index of internal loading potential, noting the very serious caveats above.

Sediment TP concentrations in Bear Lake ranged from a low of 59 (BL-3 E) to a high of 1172 (BL-3 W) mg/kg (dry wgt). As described in Section 3.3, the low value at BL-3 E was related to the low amount of organic carbon and the elevated sand content. There were no statistically significant differences measured among lake stations (i.e., stations 1-3; $F_{2,8}$ = 0.614, p = 0.572; Figure 5.1A). Among lake regions, mean TP sediment concentration was lowest in the east region, but because variance was high, no significant differences were detected among regions (Kruskal-Wallis 1-way ANOVA; H = 2.222, p = 0.382; Figure 5.1B). Two public beaches are located on the east side of the lake. Since most storm events travel from west to east, this side of the lake would be subject to more erosional forces from wave action.

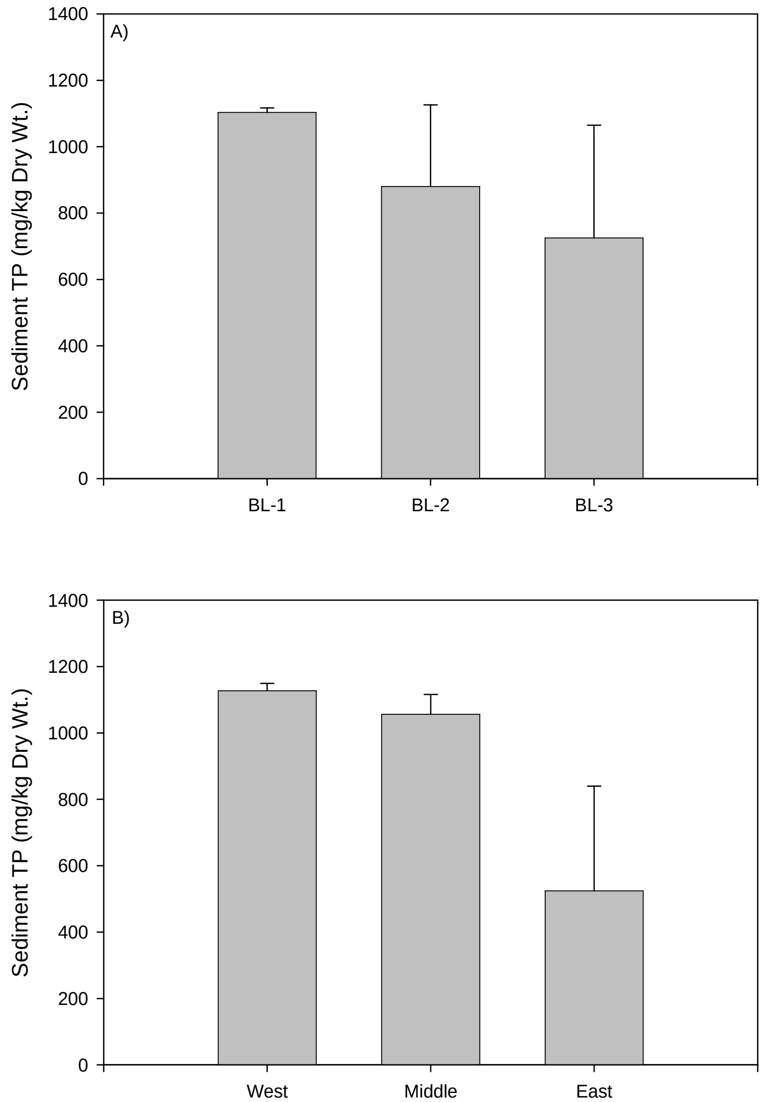

FIGURE 5.1. MEAN (± SE) SEDIMENT TP CONCENTRATIONS IN BEAR LAKE, DIFFERENTIATED BY STATION (A) AND GEOGRAPHIC REGION (B).

The sediment TP concentrations in Bear Lake were similar to what we have measured in other west Michigan drowned river mouth lakes (Figure5.2). Sediment TP concentrations from Bear Lake (this study), White Lake (sampled in summer 2006), Spring Lake (sampled in summer of 2004 and 2006; Steinman et al. 2006; Steinman and Ogdahl in press), and Mona Lake (sampled in summer of 2005) were marginally different from one another (Kruskal-Wallis 1-way ANOVA: H = 9.005; P = 0.061), but most of this difference is driven by a very high sediment TP concentration at one station in Mona Lake. When all outliers (both high and low) were removed from the analysis, there were no statistically significant differences (Kruskal-Wallis 1-way ANOVA: H = 7.084; P = 0.132).

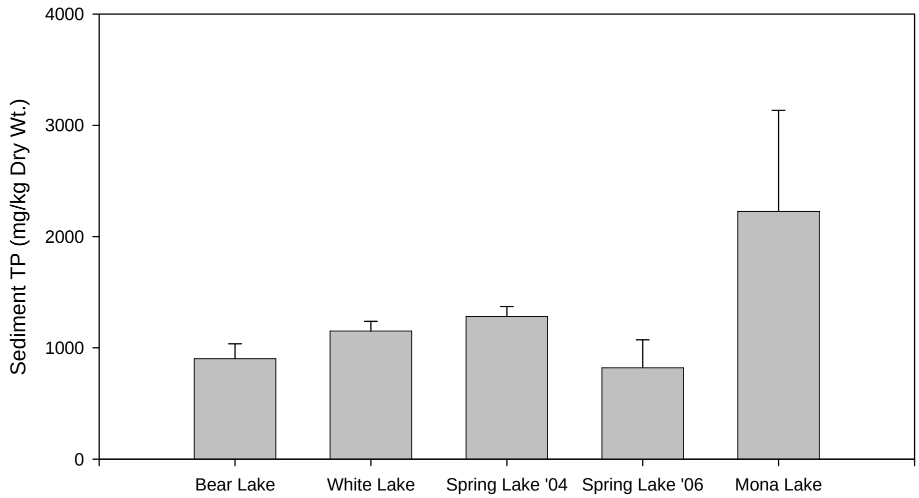

FIGURE 5.2. MEAN (± SE) SEDIMENT TP CONCENTRATIONS (MG/KG) FROM BEAR LAKE, SPRING LAKE (2004 AND 2006), MONA LAKE (2005), AND WHITE LAKE (2006).

5.2.2 Fe:TP Concentration

Jensen et al. (1992) found that the Fe:TP ratio (by weight) in surface sediments was a robust indicator of the adsorption capacity of oxidized sediments. These results are based on the principle that a high Fe:TP ratio allows for the formation of new sorption sites for P when ferrous iron is oxidized to ferric iron, thereby preventing orthophosphate flux or movement from the sediments into the overlying water column provided the sediment/water interface remains oxidized. They reported that SRP release from aerobic sediments was very low in lakes where the sediment Fe:TP ratio (by weight) was > 15. In Bear Lake, the Fe:TP ratio exceeded 15 at all sites, with ratios ranging from 16.9 to 53.2. There was no statistically significant difference in the Fe:TP ratio among stations ($F_{2,8}$ = 1.196, p = 0.366; Figure 5.3A). The relatively high ratios suggest there is sufficient iron in the Bear Lake sediments to deter P release. However, a statistically significant difference was detected among geographic locations ratios within the lake, with "east" sites having significantly lower ratios than the "middle" sites ($F_{2,8}$ = 5.23, p = 0.048). No other site-to-site contrasts were statistically different from one another (Figure 5.3B). This result suggests that the sites in the eastern part of the lake may be more vulnerable than other portions of the lake to internal loading if P continues to enter Bear Lake from external sources.

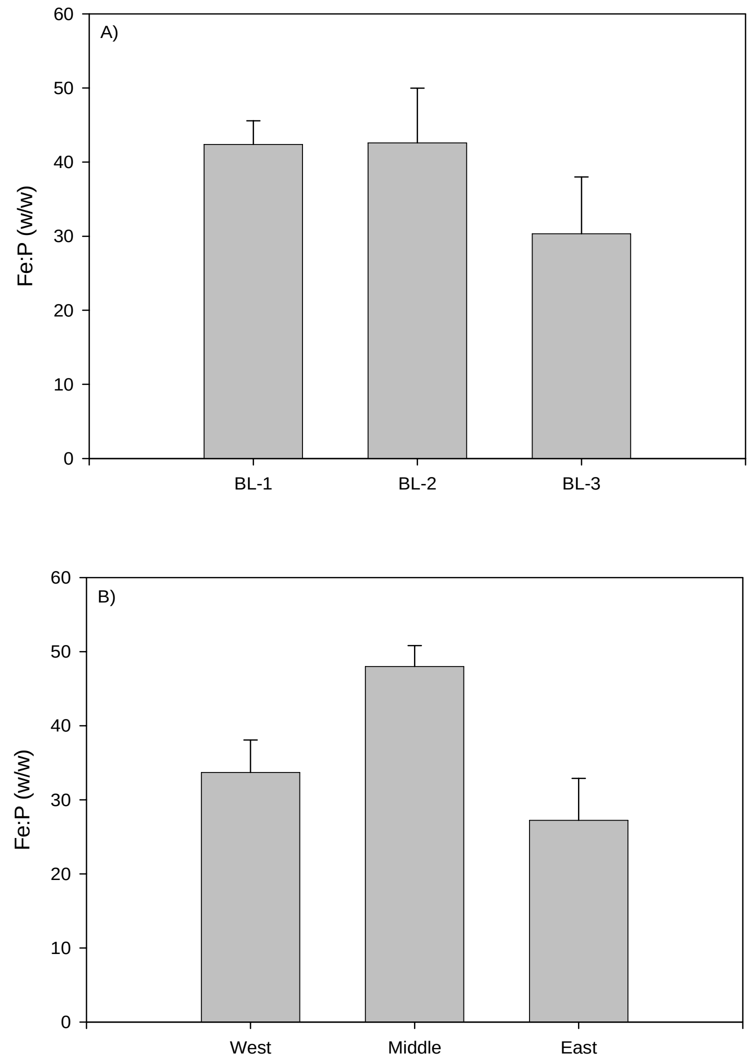

FIGURE 5.3. MEAN (± SE) SEDIMENT FE:TP RATIOS IN BEAR LAKE, DIFFERENTIATED BY STATION (A) AND GEOGRAPHIC REGION (B).

5.2.3 Nürnberg's Regressions

Nürnberg's study (1988) found the strongest relationship between sediment P release rate and the most releasable (mobile) form of P (i.e., bicarbonate dithionite extractable phosphorus: BD-P; r^2 = 0.71 for the 0 to 5 cm sediment core depth), but also found a significant although weaker relationship between release rate and TP (r^2 = 0.63 for the same core depth). We did not fractionate the different forms of sediment P in our study, so for this analysis we used the regressions based on TP.

The regression for dry sediment of 0-5 cm core depth was (Nürnberg 1988):

(i) TP release rate ($mg/m^2/d$) = -4.18 + 3.77(TP)

The sediment TP release rates measured in Bear Lake, based on the regression from Nürnberg 1988), range from 0.22 to 4.42 $mg/m^2/d$ (Table 5.1). The mean sediment TP release rate was estimated to be 3.40 $mg/m^2/d$ (Table 5.1).

TABLE 5.1. BEAR LAKE SEDIMENT TP (MG/KG) BASED ON SEDIMENT DRY WEIGHT AND CALCULATED SEDIMENT TP RELEASE RATE ($MG/M^2/D$) UNDER ANAEROBIC CONDITIONS BASED ON REGRESSION FROM NÜRNBERG (1988).

Station	Sediment TP (mg/kg) dry weight	Calculated TP release rate ($mg/m^2/d$)
BL-1 E	1079	4.06
BL-1	1126	4.24
BL-1 W	1104	4.16
BL-2 E	1146	4.31
BL-2	388	1.46
BL-2 W	1105	4.16
BL-3 E	944	3.56
BL-3	59	0.22
BL-3 W	1172	4.42
Grand Mean (± SD)	903 ± 399	3.40 ± 1.50

The mean rate for Bear Lake was lower than any of the TP release rates that we measured directly from other lakes in west Michigan (Table 5.2).

TABLE 5.2. MEAN SEDIMENT TP RELEASE RATES (± SD) MEASURED DIRECTLY USING SEDIMENT CORE INCUBATIONS FROM DROWNED RIVER MOUTH LAKES IN WEST MICHIGAN.

Lake	Measured Mean (± SD) TP Release Rate (mg P/m^2/d)
White Lake (2006)	3.75 ± 2.40*
Mona Lake (2004)	9.57 ± 3.68*
Mona Lake (2006)	4.44 ± 0.88*
Spring Lake (2003)	15.60 ± 6.91**

*Unpublished data (Steinman)
**Steinman et al. (2004)

5.3 Summary

Based on the available data collected from the Bear Lake sediments, and employing multiple lines of evidence, it appears that internal loading likely is not a significant source of P to the Bear Lake water column. Because these analyses are based on indirect lines of evidence and not based on direct measurements of P flux from the sediments, it is impossible to state with confidence how significant internal loading is in Bear Lake. However, based on our analyses from other west Michigan lakes, where internal loading can represent up to 65% of the total load to the lake (Steinman et al. 2004), it seems prudent to reduce external P loading to Bear Lake as quickly as possible to avoid the possibility of internal loading becoming a major source of P to this system.

5.4 References

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6.0 Dry and Wet Weather Tributary Data

6.1 Sampling Locations

Wet and dry weather sampling of Bear Lake tributaries was conducted during 2006 and 2007 do determine water quality characteristics and nutrient loading. The locations of the tributary monitoring stations are shown on Figure 6.1 and the GPS coordinates are summarized below:

1. Bear Creek (upstream of Little Bear Creek confluence) at Giles Road.
   Latitude: 43.278044
   Longitude: -86.239364
2. Little Bear Creek at Giles Road.
   Latitude: 43.278045
   Longitude: -86.244392
3. Bear Creek: Witham Road
   Latitude: 43.26769
   Longitude: -86.26172
4. Unnamed West Side Tributary: at Dykstra Road
   Latitude: 43.270879
   Longitude: -86.279475
5. Outlet Sampling: at Ruddiman Drive:
   Latitude: 43.243155
   Longitude: -86.295989

6.2 Sampling and Analytical Methods

Dry weather sampling was conducted four times during the project period. One grab sample was collected from each station. Dry weather sampling was preceded by at least 72 hours without precipitation. Wet weather sampling was conducted by AWRI for four events during the monitoring period. The wet weather runoff events were in response to precipitation events of 0.5 inches or greater within 24 hours as determined by a rain gages located at each station. Sampling was initiated when the precipitation began. Single grab samples were collected manually every hour during the rise and fall of the hydrograph. Typical wet weather sampling events were conducted over a 24 hour period. Water samples for wet and dry conditions were collected at the centroid of each transect where approximately 50% of cumulative flow occurs. Samples were collected by immersing two 1-liter polyethylene bottles at mid depth. Sample containers were placed in coolers with ice and kept at 4^oC. One field blank sample was collected for every 20 investigative samples. One duplicate sample was collected for every 10 investigative samples. Samples were analyzed for total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrite/nitrate, and total suspended solids by the methods outlined in Table 3.3. Quality Control data are summarized in the Appendix.

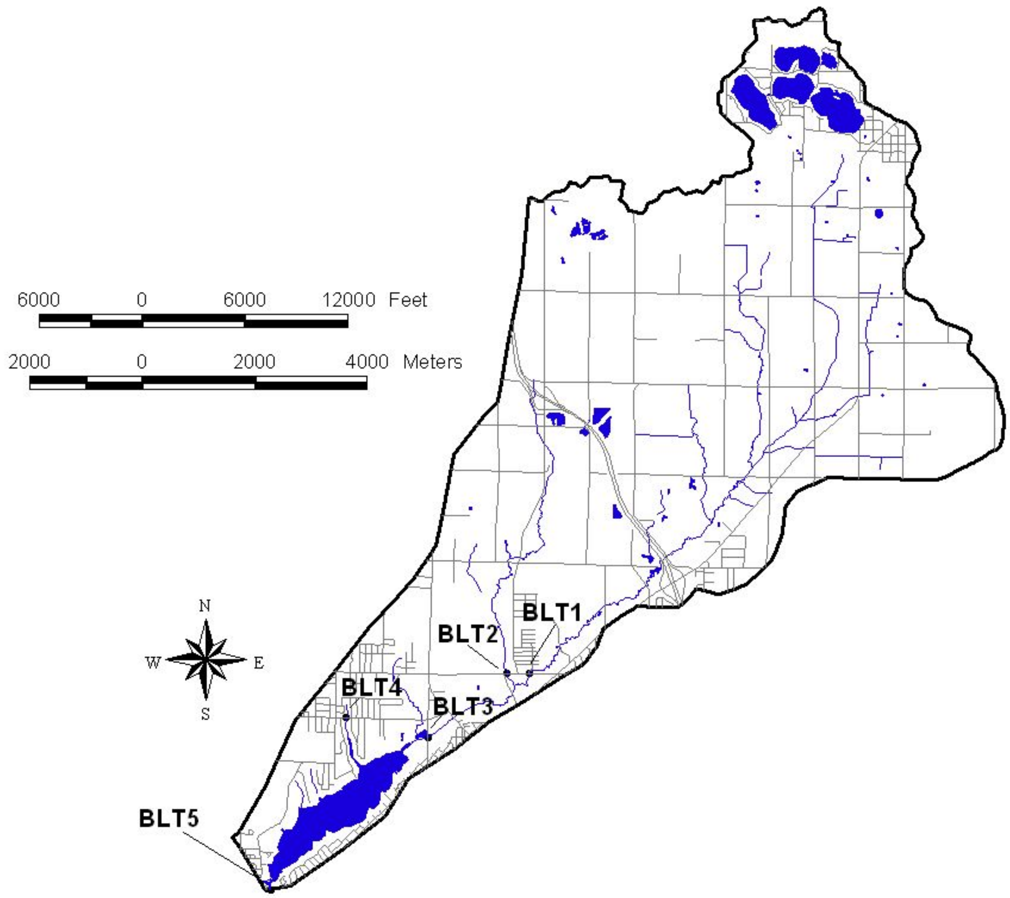

FIGURE 6.1. THE LOCATION OF TRIBUTARY MONITORING STATIONS IN THE BEAR CREEK WATERSHED (2006-2007).

At sites BLT-1, BLT-2, and BLT-3, an Odyssey pressure and temperature recording system was installed for continuously collecting the stream water level and temperature data. The recording time interval was 10 minutes for all sites. To ensure that the pressure and temperature sensors functioned properly and accurately, the monitoring equipment was tested and calibrated in the laboratory before field installation. In the field, the sensors were maintained on a bi-weekly or monthly basis and the recorded data were downloaded to a laptop computer for further processing.

Flow was measured at each location using a Marsh-McBirney Flow Mate 2000 velocity meter according to USGS protocols. Transects were established at each location and water depth measurements were collected by wading. The location of each transect were marked by stakes. Depending on stream width, depth and flow measurements were made at 4 to 10 equally spaced points along the transect. Transects were located so as to minimize interferences from structural anomalies such as debris jams, bridges, and highly eroded areas. Water elevations were measured at the MDEQ reference point located on each culvert or bridge. Flow measurements were collected during each wet and dry event weather sampling. If the stream depth was < 2.5 ft, flow measurements were taken at 0.6 the depth at each transect point. If depths were > 2.5 ft, flow measurements were taken at 0.2 and 0.8 the depth. The Microsoft®Windows-based hydrologic software, HYDROL-INF (Figure 6.2; Chu, 2006) was used for processing the measured stream data and computing stream discharges and hydraulic parameters. In the software, the midsection method was selected for calculating water discharge across a stream channel.

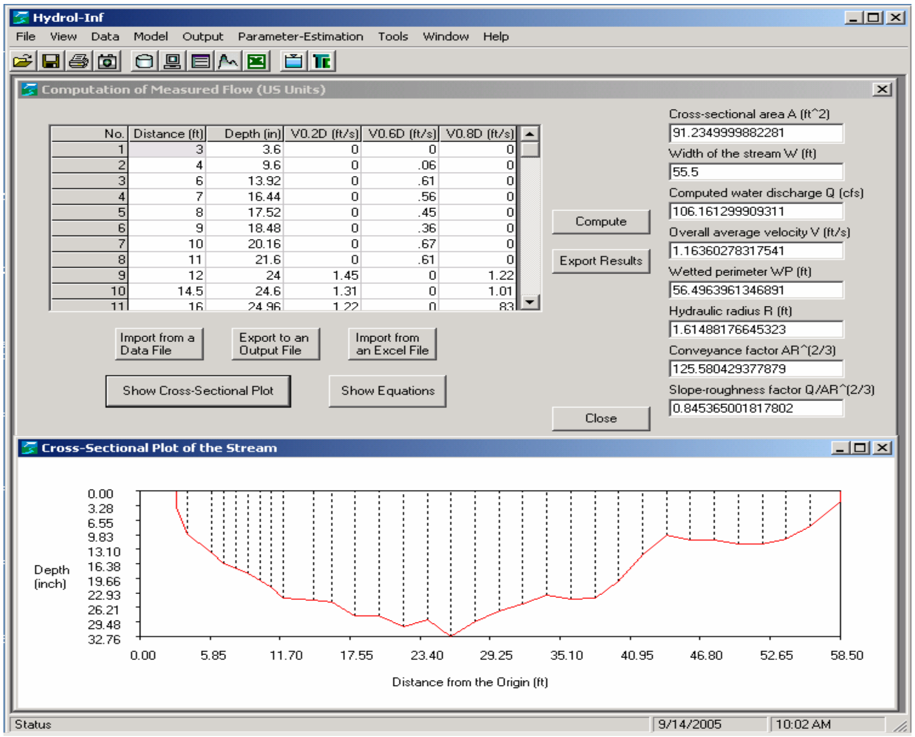

FIGURE 6.2. STREAM FLOW COMPUTATION TOOL IN THE HYDROL-INF SOFTWARE.

6.3 Bear Lake Tributaries Base Flow Data

The data for the four base flow events are shown in Table 6.1. TSS for all tributaries ranged from 1 to 6 mg/l, except for the Bear Lake Channel station on August 22, 2007. TKN and TP results for this sample were 1.23 mg/l and 63 ug/l, respectively. These results differ from the other measurements and probably reflect an algal bloom in Bear Lake. Water quality measurements were not conducted on November 7, 2006 due to backflow from Muskegon Lake. Nitrate-N concentrations at the Bear Creek and Little Bear Creek stations ranged from 0.15 to 0.33 mg/l. The unnamed tributary was higher in nitrate-N and ranged from 0.50 to 0.69 mg/l. SRP-P was above the detection limit only during the August 22, 2007 sampling and ranged from 7 to 11 ug/l. TP concentrations ranged from 20 to 32 ug/l.

TABLE 6.1. WATER QUALITY DATA FOR BEAR CREEK TRIBUTARIES DURING BASE FLOW CONDITIONS (2006-2007).

Sample ID	Site	Date	TSS mg/L	NO3-N (mg/L)	NH3-N (mg/L)	TKN-N (mg/L)	SRP-P (mg/L)	TP-P (ug/L)
21834	Bear Creek @ Giles Rd BLT-1	11/7/2006	1	0.27	0.04	0.31	<5	32
21835	Bear Creek @ Giles Rd (dup)		1	0.23	0.03	0.30	<5	29
21836	Little Bear Creek @ Giles Rd BLT-2		2	0.20	0.03	0.24	<5	28
21837	Bear Creek @ Witham Rd BLT-3		3	0.20	0.06	0.27	<5	26
21838	Unnamed Trib @ Dykstra Rd		5	0.56	0.04	0.29	<5	27
21848	Bear Creek @ Giles Rd BLT-1	11/16/2006	1	0.29	0.04	0.30	<5	23
21849	Little Bear Creek @ Giles Rd BLT-2		4	0.22	0.02	0.22	<5	22
21850	Bear Creek @ Witham Rd BLT-3		3	0.27	0.06	0.32	<5	20
21851	Unnamed Trib @ Dykstra Rd		3	0.69	0.06	0.20	<5	27
21852	Bear Lake Channel BLT-5 Dup		6	0.29	0.08	0.57	<5	20
21853	Bear Lake Channel BLT-5		6	0.26	0.08	0.68	<5	20
22665	Bear Creek @ Giles Rd BLT-1	5/24/2007	4	0.26	0.04	0.45	<5	26
22664	Little Bear Creek @ Giles Rd BLT-2		5	0.15	0.03	0.46	<5	28
22662	Bear Creek @ Witham Rd BLT-3		5	0.22	0.06	0.39	<5	26
22663	Unnamed Trib @ Dykstra Rd		6	0.52	0.04	0.35	<5	34
22661	Bear Lake Channel BLT-5		6	< 0.01	0.03	0.89	<5	47
24042	Bear Creek @ Giles Rd BLT-1	8/2/2007	3	0.33	0.06	0.52	11	30
24041	Little Bear Creek @ Giles Rd BLT-2		4	0.20	0.03	0.29	7	20
24039	Bear Creek @ Witham Rd BLT-3		4	0.29	0.08	0.35	7	26
24040	Unnamed Trib @ Dykstra Rd		5	0.50	0.03	0.30	14	34
24038	Bear Lake Channel BLT-5		17	< 0.01	< 0.01	1.23	<5	63

The loading and flow data are presented in Table 6.2. Loadings at the Bear Lake Channel (BLT-5) could not be calculated due to wind induced backflow from Muskegon Lake. Although the discharge of Bear Creek is greater than Little Black Creek, TSS loadings for the Little Black were higher during all base flow events. In contrast, TP loadings for Bear Creek were higher than Little Bear Creek. These data suggest that there is more erosion in the Little Bear Creek subwatershed which is reflected in greater TSS transport. This subwatershed has a steeper gradient than Bear Creek, which would result in greater erosional velocity. The Bear Creek watershed contributes a higher nutrient load. Bear Creek has more developed land and a greater potential for non-point source runoff. Since the two stations on Giles Rd. are approximately 0.6 miles (1 km) upstream from the Witham Rd. station, the TSS and TP loading at Witham Rd. should be similar or slightly exceed the sum of the loadings from the two Giles Rd. stations. This relationship is true for TP however TSS loadings at Witham are 1.5 to 2 times greater than the sum of the Giles Rd. stations for three of the four base flow events. These data suggest that there is a significant source of erosion between these locations.

TABLE 6.2. FLOW AND LOADING DATA FOR BEAR CREEK TRIBUTARIES DURING BASE FLOW CONDITIONS (2006-2007).

Site ID:	Name	Time	Discharge m^3/ sec	Discharge cfs	TSS mg/l	TSS Loading lb/d	TP mg/l	TP Loading lb/d	Surface feet
Location			**November 7, 2006**						
BLT-1	Bear Creek @ Giles Rd	11:00	0.278	9.82	1	53	0.032	1.7	8.43
BLT-2	Little Bear Creek @ Giles Rd	10:38	0.188	6.64	2	71	0.028	1.0	6.68
BLT-3	Bear Creek @ Witham Rd	9:55	0.525	18.54	3	299	0.026	2.6	9.25
BLT-4	Unnamed Trib @ Dykstra Rd	10:15	0.020	0.71	5	19	0.027	0.1	1.12
Location			**November 16, 2006**						
BLT-1	Bear Creek @ Giles Rd	12:30	0.331	11.69	1	63	0.023	1.4	8.30
BLT-2	Little Bear Creek @ Giles Rd	12:00	0.151	5.33	4	115	0.022	0.6	6.85
BLT-3	Bear Creek @ Witham Rd	10:55	0.563	19.88	3	321	0.020	2.1	9.22
BLT-4	Unnamed Trib @ Dykstra Rd	11:30	0.012	0.42	3	7	0.027	0	1.12
Location			**May 24, 2007**						
BLT-1	Bear Creek @ Giles Rd	12:14	0.269	9.50	4	205	0.026	1.3	8.33
BLT-2	Little Bear Creek @ Giles Rd	11:57	0.221	7.80	5	210	0.028	1.2	6.55
BLT-3	Bear Creek @ Witham Rd	11:23	0.539	19.03	6	615	0.026	2.7	9.16
BLT-4	Unnamed Trib @ Dykstra Rd	11:43	0.022	0.78	5	21	0.034	0.1	1.08
Location			**August 2, 2007**						
BLT-1	Bear Creek @ Giles Rd	11:58	0.164	5.79	3	94	0.030	0.9	8.46
BLT-2	Little Bear Creek @ Giles Rd	11:40	0.166	5.86	4	126	0.020	0.6	6.82
BLT-3	Bear Creek @ Witham Rd	10:55	0.356	12.57	4	271	0.026	1.8	9.35
BLT-4	Unnamed Trib @ Dykstra Rd	11:20	0.011	0.39	5	10	0.034	0.1	1.31

6.4 Bear Lake Tributaries Storm Event Data

The data for the four storm flow events are shown in Tables 6.3, 6.4, 6.5, and 6.6 for Bear Creek Giles Rd., Little Bear Creek Giles Rd., Bear Creek Witham Rd., and the Unnamed Tributary at Dykstra Rd., respectively. All stations show a rapid response to the rain event with increases in TSS, TP, and TKN. Nitrate and ammonia show a moderate increase during the storm event. These data suggest that most of the nutrients are transported with suspended solids and not as dissolved ions. Loading data are shown in Tables 6.7, 6.8, 6.9, and 6.10 for Bear Creek Giles Rd, Little Bear Creek Giles Rd, Bear Creek Witham Rd, and the Unnamed Tributary at Dykstra Rd., respectively. Average tributary loadings for each storm event are summarized in Table 6.11. The segment of Bear Creek upstream of Giles road contributes approximately 90% of the TSS and TP loading observed at Witham Rd. Little Bear Creek accounts of about 10% of the storm loading. For rain events in the 0.5 to 1.0 inch range, loadings of suspended sediment and TP exceed base flow amounts by an order of magnitude (Table 6.4).

TABLE 6.3. WATER QUALITY DATA FOR BEAR CREEK GILES RD. DURING STORM FLOW CONDITIONS (2007).

Bear Creek Giles Rd 5-1-2007 & 5-2-2007 0.85"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
22365	BLT-1	7:22	6	40	11	0.16	< 0.05	0.10	0.60	< 0.005	0.04	5/2/07
22344	BLT-1	10:50	18	39	10	0.16	< 0.05	0.07	0.64	< 0.005	0.05	5/1/07
22348	BLT-1	12:11	13	48	12	0.19	< 0.05	0.07	0.64	< 0.005	0.05	5/1/07
22349	BLT-1 DUP	12:11	13	42	12	0.20	< 0.05	0.08	0.92	< 0.005	0.04	5/1/07
22336	BLT-1	15:12	17	41	11	0.19	< 0.05	0.07	0.75	< 0.005	0.05	5/1/07
22352	BLT-1	21:08	7	36	10	0.17	< 0.05	0.06	0.90	< 0.005	0.07	5/1/07
22355	BLT-1	9:56	13	42	11	0.17	< 0.05	0.05	0.79	< 0.005	0.05	5/2/07
22356	BLT-1 DUP	9:56	8	44	11	0.17	< 0.05	0.04	0.98	< 0.005	0.05	5/2/07
Bear Creek Giles Rd 5-9-2007 & 5-10-2007 0.95"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
22322	BLT-1	4:12	7	49	12	0.15	< 0.05	0.03	0.56	< 0.005	0.03	5/9/07
22365	BLT-1	6:30	7	49	12	0.15	< 0.05	0.03	0.56	< 0.005	0.03	5/9/07
22385	BLT-1	9:30	45	58	12	0.20	< 0.05	0.05	0.75	< 0.005	0.08	5/9/07
22390	BLT-1	14:23	27	50	11	0.18	< 0.05	0.05	0.73	0.005	0.07	5/9/07
22395	BLT-1	17:55	30	27	7	0.11	< 0.05	0.03	0.56	< 0.005	0.06	5/9/07
22397	BLT-1	21:05	21	42	11	0.17	< 0.05	0.04	0.83	< 0.005	0.05	5/9/07
22404	BLT-1	9:47	6	46	12	0.17	< 0.05	0.03	0.68	< 0.005	0.03	5/10/07
Bear Creek Giles Rd 6-19-2007 0.55"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
22755	BLT-1	1:36	9	80	15	0.37	< 0.05	0.04	0.53	< 0.005	0.04	6/19/07
22756	BLT-1	5:16	65	116	14	0.42	< 0.05	0.10	1.61	< 0.005	0.13	6/19/07
22757	BLT-1	9:18	55	95	16	0.48	< 0.05	0.08	1.42	0.013	0.14	6/19/07
22758	BLT-1	13:19	27	69	14	0.37	< 0.05	0.09	1.01	0.020	0.08	6/19/07
22759	BLT-1	17:18	15	92	14	0.31	< 0.05	0.06	0.64	0.010	0.05	6/19/07
22760	BLT-1	21:33	9	79	15	0.33	< 0.05	0.04	0.59	0.010	0.04	6/19/07
Bear Creek Giles Rd 8-20 to 8-21-2007 0.75"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
24042	BLT-1	12:00	3	93	17	0.33	< 0.05	0.06	0.52	0.011	0.03	8/20/07
24011	BLT-1	13:22	75	24	6	0.06	< 0.05	0.06	1.39	0.011	0.22	8/20/07
24016	BLT-1	16:15	53	53	23	0.25	< 0.05	0.07	1.40	0.010	0.14	8/20/07
24020	BLT-1	19:23	24	44	19	0.19	< 0.05	0.07	0.70	0.010	0.08	8/20/07
24026	BLT-1	8:52	7	74	22	0.30	< 0.05	0.10	0.45	0.010	0.04	8/21/07
24030	BLT-1	11:38	5	63	18	0.25	< 0.05	0.09	0.45	0.009	0.03	8/21/07
24035	BLT-1	14:56	3	53	15	0.23	< 0.05	0.08	0.45	0.011	0.03	8/21/07

TABLE 6.4. WATER QUALITY DATA FOR LITTLE BEAR CREEK GILES RD. DURING STORM FLOW CONDITIONS (2007).

Little Bear Creek Giles Rd 5-1-2007 & 5-2-2007 0.85"												
Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
22343	BLT-2	10:38	4	57	11	0.12	< 0.05	0.07	0.55	< 0.005	0.03	5/1/07
22347	BLT-2	11:56	11	49	11	0.13	< 0.05	0.08	0.54	< 0.005	0.03	5/1/07
22337	BLT-2	14:58	8	55	11	0.12	< 0.05	0.04	0.43	< 0.005	0.03	5/1/07
22351	BLT-2	20:56	7	59	12	0.10	< 0.05	0.04	0.56	< 0.005	0.03	5/1/07
22357	BLT-2	9:42	4	54	12	0.11	< 0.05	0.10	0.66	< 0.005	0.02	5/2/07
22364	BLT-2 DUP	17:10	6	50	12	0.11	< 0.05	0.03	0.33	< 0.005	0.03	5/2/07
22363	BLT-2	17:10	6	59	12	0.11	< 0.05	0.02	0.50	< 0.005	0.02	5/2/07
Little Bear Creek Giles Rd 5-9-2007 & 5-10-2007 0.95"												
Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
22309	BLT-2	4:00	8	63	11	0.09	< 0.05	0.03	0.46	< 0.005	0.03	5/9/07
22384	BLT-2	9:16	35	53	11	0.14	< 0.05	0.06	0.89	< 0.005	0.07	5/9/07
22388	BLT-2	14:03	12	72	11	0.12	< 0.05	0.03	0.53	< 0.005	0.04	5/9/07
22389	BLT-2 DUP	14:03	12	61	11	0.12	< 0.05	0.03	0.44	< 0.005	0.04	5/9/07
22394	BLT-2	17:45	12	59	11	0.09	< 0.05	0.03	0.42	< 0.005	0.03	5/9/07
22396	BLT-2	20:55	11	50	11	0.09	< 0.05	0.03	0.58	< 0.005	0.03	5/9/07
22403	BLT-2	9:35	8	85	12	0.11	< 0.05	0.03	0.41	< 0.005	0.02	5/10/07
Little Bear Creek Giles Rd 6-19-2007 0.55"												
Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
22761	BLT-2	1:30	14	151	15	0.23	< 0.05	0.03	0.48	0.012	0.04	6/19/07
22762	BLT-2	5:10	62	51	12	0.25	< 0.05	0.06	1.53	0.005	0.11	6/19/07
22763	BLT-2	9:13	19	47	13	0.21	< 0.05	0.04	0.65	0.008	0.05	6/19/07
22764	BLT-2	13:12	14	50	13	0.16	< 0.05	0.02	0.51	0.007	0.03	6/19/07
22765	BLT-2	17:08	11	58	14	0.17	< 0.05	0.02	0.44	0.008	0.03	6/19/07
22767	BLT-2 DUP	17:08	12	60	13	0.15	< 0.05	0.02	0.44	< 0.005	0.04	6/19/07
22766	BLT-2	21:25	9	58	14	0.16	< 0.05	0.02	0.33	0.007	0.02	6/19/07
Little Bear Creek Giles Rd 8-20 to 8-21-2007 0.75"												
Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
24001	BLT-2	11:40	4	31	13	0.20	< 0.05	0.03	0.29	0.007	0.02	8/22/07
24010	BLT-2	13:18	14	38	15	0.14	< 0.05	0.02	0.68	0.008	0.05	8/20/07
24015	BLT-2	16:10	8	39	16	0.18	< 0.05	0.02	0.42	0.007	0.03	8/20/07
24019	BLT-2	19:16	6	39	14	0.18	< 0.05	0.02	0.51	0.007	0.02	8/20/07
24024	BLT-2	8:46	6	33	13	0.20	< 0.05	0.02	0.17	0.006	0.02	8/21/07
24025	BLT-2 DUP	8:46	4	33	13	0.21	< 0.05	0.02	0.18	0.008	0.02	8/21/07
24034	BLT-2	14:51	5	22	9	0.16	< 0.05	0.01	0.20	0.006	0.02	8/21/07

TABLE 6.5. WATER QUALITY DATA FOR BEAR CREEK WITHAM RD. DURING STORM FLOW CONDITIONS (2007).

Bear Creek Witham Rd 5-1-2007 & 5-2-2007 0.85"

Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
22341	BLT-3	10:02	3	51	11	0.17	< 0.05	0.08	0.64	< 0.005	0.04	5/1/07
22345	BLT-3	11:23	10	51	11	0.18	< 0.05	0.12	0.48	0.005	0.04	5/1/07
22338	BLT-3	14:27	14	71	10	0.18	< 0.05	0.10	0.64	< 0.005	0.05	5/1/07
22354	BLT-3	21:40	14	33	7	0.11	< 0.05	0.06	0.80	< 0.005	0.06	5/1/07
22358	BLT-3	9:06	8	47	11	0.15	< 0.05	0.06	0.75	0.005	0.05	5/2/07
22361	BLT-3	16:44	3	40	12	0.15	< 0.05	0.03	0.52	< 0.005	0.04	5/2/07

Bear Creek Witham Rd 5-9-2007 & 5-10-2007 0.95"

Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
22306	BLT-3	4:28	5	49	12	0.15	< 0.05	0.07	0.55	< 0.005	0.03	5/9/07
22382	BLT-3	8:45	21	55	12	0.18	< 0.05	0.07	0.59	< 0.005	0.06	5/9/07
22386	BLT-3	13:34	31	56	10	0.20	< 0.05	0.09	0.85	< 0.005	0.08	5/9/07
22391	BLT-3	17:19	20	49	10	0.15	< 0.05	0.06	0.76	< 0.005	0.06	5/9/07
22399	BLT-3	21:40	18	41	10	0.16	< 0.05	0.06	0.82	0.005	0.06	5/9/07
22400	BLT-3	9:05	9	46	12	0.15	< 0.05	0.06	0.79	< 0.005	0.04	5/10/07
22407	BLT-3 DUP	13:28	5	49	12	0.15	< 0.05	0.05	0.59	< 0.005	0.03	5/10/07

Bear Creek Witham Rd 6-19-2007 0.55"

Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
22768	BLT-3	1:16	9	75	14	0.24	< 0.05	0.04	0.41	0.005	0.03	6/19/07
22769	BLT-3	4:55	28	68	14	0.33	< 0.05	0.14	0.78	0.012	0.08	6/19/07
22773	BLT-3	8:55	37	76	14	0.32	< 0.05	0.07	0.99	0.011	0.09	6/19/07
22801	BLT-3 DUP	8:55	38	69	13	0.31	< 0.05	0.10	1.15	0.005	0.09	6/19/07
22775	BLT-3	16:53	15	58	14	0.28	< 0.05	0.12	0.72	0.010	0.05	6/19/07
22776	BLT-3	21:13	12	56	14	0.24	< 0.05	0.05	0.55	0.007	0.04	6/19/07

Bear Creek Witham Rd 8-20 to 8-21-2007 0.75"

Sample #	Station	Sampling Time	TSS	Cl	$S0_4$	$N0_3$-N	$N0_2$-N	NH_3-N	TKN-N	SRP-P	TP-P	Sampling Date
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
24398	BLT-3	10:57	4	63	16	0.29	< 0.05	0.08	0.35	0.007	0.03	8/20/07
24008	BLT-3	13:00	63	56	13	0.16	< 0.05	0.08	1.29	0.013	0.15	8/20/07
24012	BLT-3	15:56	40	65	16	0.21	< 0.05	0.07	0.97	0.012	0.12	8/20/07
24017	BLT-3	19:04	24	67	23	0.26	< 0.05	0.08	1.16	0.009	0.08	8/20/07
24022	BLT-3	8:33	8	64	19	0.26	< 0.05	0.10	0.40	0.007	0.03	8/21/07
24027	BLT-3	11:21	5	58	17	0.23	< 0.05	0.10	0.39	0.070	0.03	8/21/07
24031	BLT-3	14:38	3	59	17	0.24	< 0.05	0.09	0.29	0.009	0.03	8/21/07
24032	BLT-3 DUP	14:38	3	61	18	0.27	< 0.05	0.09	0.37	0.008	0.03	8/21/07

TABLE 6.6. WATER QUALITY DATA FOR THE UNNAMED TRIBUTARY DURING STORM FLOW CONDITIONS (2007).

Unnamed Tributary 5-1-2007 & 5-2-2007 0.85"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
22332	BLT-4	10:22	7	50	18	0.44	< 0.05	0.09	0.53	< 0.005	0.03	5/1/07
22346	BLT-4	11:42	12	44	18	0.47	< 0.05	0.15	0.73	< 0.005	0.04	5/1/07
22339	BLT-4	14:47	14	76	16	0.39	< 0.05	0.06	0.47	< 0.005	0.03	5/1/07
22353	BLT-4	21:30	15	57	18	0.46	< 0.05	0.05	0.64	< 0.005	0.05	5/1/07
22359	BLT-4	9:30	13	58	18	0.46	< 0.05	0.06	0.28	< 0.005	0.02	5/2/07
22362	BLT-4	17:00	4	52	18	0.42	< 0.05	0.04	0.32	< 0.005	0.02	5/2/07
Unnamed Tributary 5-9-2007 & 5-10-2007 0.95"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
22408	BLT-4	13:45	4	45	11	0.25	< 0.05	0.04	0.45	< 0.005	0.01	5/9/07
22387	BLT-4	13:44	14	63	16	0.40	< 0.05	0.12	0.59	0.005	0.04	5/9/07
22392	BLT-4	17:28	13	56	17	0.39	< 0.05	0.04	0.48	< 0.005	0.03	5/9/07
22393	BLT-4 DUP	17:28	12	47	16	0.34	< 0.05	0.04	0.57	< 0.005	0.03	5/9/07
22402	BLT-4	9:17	1	59	19	0.49	< 0.05	0.04	0.41	< 0.005	0.02	5/10/07
Unnamed Tributary 6-19-2007 0.55"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
22891	BLT-4	11:20	11	68	19	0.53	< 0.05	0.03	0.45	0.014	0.03	6/19/07
22802	BLT-4	1:23	20	59	19	0.53	< 0.05	0.04	0.60	0.020	0.05	6/19/07
22803	BLT-4	5:05	65	49	16	0.81	< 0.05	0.14	1.69	0.022	0.18	6/19/07
22804	BLT-4	8:05	16	57	18	0.50	< 0.05	0.05	0.63	0.007	0.05	6/19/07
22805	BLT-4	13:05	15	65	19	0.52	< 0.05	0.05	0.58	0.005	0.04	6/19/07
22806	BLT-4	17:02	12	77	18	0.50	< 0.05	0.04	0.47	0.009	0.04	6/19/07
Unnamed Tributary 8-20 to 8-21-2007 0.75"												
Sample #	Station	Sampling Time	TSS mg/l	Cl mg/l	$S0_4$ mg/l	$N0_3$-N mg/l	$N0_2$-N mg/l	NH_3-N mg/l	TKN-N mg/l	SRP-P mg/l	TP-P mg/l	Sampling Date
240890	BLT-4	11:20	5	52	20	0.50	< 0.05	0.03	0.30	0.014	0.03	8/20/07
24009	BLT-4	13:11	12	46	23	0.44	< 0.05	0.05	0.86	0.018	0.05	8/20/07
24013	BLT-4	16:05	10	39	15	0.30	< 0.05	0.04	0.55	0.010	0.04	8/20/07
24014	BLT-4 DUP	16:05	9	40	23	0.45	< 0.05	0.04	0.57	0.014	0.03	8/20/07
24018	BLT-4	19:12	22	53	22	0.50	< 0.05	0.04	0.64	0.013	0.05	8/20/07
24023	BLT-4	8:41	5	53	20	0.49	< 0.05	0.04	0.30	0.013	0.02	8/21/07
24028	BLT-4	11:28	4	57	20	0.49	< 0.05	0.03	0.28	0.011	0.03	8/21/07
24033	BLT-4	14:46	3	60	17	0.42	< 0.05	0.03	0.30	0.013	0.02	8/21/07

TABLE 6.7. BEAR LAKE TRIBUTARY LOADINGS DURING A 0.85” RAIN EVENT (2007).

AWRI #	Site ID:	Name	Time	Date	Discharge m^3/ sec	Discharge cfs	TSS mg/l	TSS Loading lb/d	TSS Loading lb/hr	TP mg/l	TP Loading lb/hr	Surface ft
22344	BLT-1	Bear Creek @ Giles Rd	10:30	5/1/07	0.910	32.13	6	1038	43	0.043	0.31	7.79
22348	BLT-1	Bear Creek @ Giles Rd	11:30	5/1/07	0.930	32.84	18	3182	133	0.048	0.35	7.75
22336	BLT-1	Bear Creek @ Giles Rd	12:11	5/1/07	1.040	36.72	13	2570	107	0.045	0.37	7.61
22352	BLT-1	Bear Creek @ Giles Rd	15:12	5/1/07	1.200	42.37	17	3878	162	0.048	0.46	7.38
22355	BLT-1	Bear Creek @ Giles Rd	9:10	5/2/07	1.320	46.61	13	3262	136	0.074	0.77	7.22
22365	BLT-1	Bear Creek @ Giles Rd	17:00	5/2/07	1.140	40.25	7	1517	63	0.050	0.45	7.55
22343	BLT-2	Little Bear Creek @ Giles Rd	10:38	5/1/07	0.417	14.72	4	317	13	0.027	0.09	6.56
22347	BLT-2	Little Bear Creek @ Giles Rd	11:56	5/1/07	0.439	15.50	11	918	38	0.033	0.11	6.50
22337	BLT-2	Little Bear Creek @ Giles Rd	14:58	5/1/07	0.449	15.85	8	683	28	0.027	0.10	6.50
22351	BLT-2	Little Bear Creek @ Giles Rd	20:56	5/1/07	0.456	16.10	7	607	25	0.032	0.12	6.50
22357	BLT-2	Little Bear Creek @ Giles Rd	9:42	5/2/07	0.459	16.21	4	349	15	0.024	0.09	6.56
22363	BLT-2	Little Bear Creek @ Giles Rd	17:10	5/2/07	0.386	13.63	6	440	18	0.017	0.05	6.58
22341	BLT-3	Bear Creek @ Witham Rd	10:02	5/1/07	1.460	51.55	3	833	35	0.037	0.43	8.66
22345	BLT-3	Bear Creek @ Witham Rd	11:23	5/1/07	1.580	55.79	10	3003	125	0.038	0.48	8.60
22338	BLT-3	Bear Creek @ Witham Rd	14:27	5/1/07	1.590	56.14	14	4231	176	0.048	0.60	8.53
22354	BLT-3	Bear Creek @ Witham Rd	21:40	5/1/07	1.990	70.27	14	5296	221	0.057	0.90	8.43
22358	BLT-3	Bear Creek @ Witham Rd	9:06	5/2/07	1.720	60.73	8	2616	109	0.046	0.63	8.53
22361	BLT-3	Bear Creek @ Witham Rd	16:44	5/2/07	1.456	51.41	3	830	35	0.039	0.45	8.69
22342	BLT-4	Unnamed Trib @ Dykstra Rd	10:22	5/1/07	0.040	1.41	7	53	2	0.030	0.01	1.15
22346	BLT-4	Unnamed Trib @ Dykstra Rd	11:42	5/1/07	0.050	1.77	12	114	5	0.037	0.01	1.08
22339	BLT-4	Unnamed Trib @ Dykstra Rd	14:47	5/1/07	0.040	1.41	14	106	4	0.025	0.01	1.15
22353	BLT-4	Unnamed Trib @ Dykstra Rd	21:30	5/1/07	0.030	1.06	15	86	4	0.046	0.01	1.18
22359	BLT-4	Unnamed Trib @ Dykstra Rd	9:30	5/2/07	0.030	1.06	13	74	3	0.019	0.00	1.21
22362	BLT-4	Unnamed Trib @ Dykstra Rd	17:00	5/2/07	0.028	0.99	4	21	1	0.023	0.01	1.21

TABLE 6.8. BEAR LAKE TRIBUTARY LOADINGS DURING A 0.95” RAIN EVENT (2007).

22385	BLT-1	Bear Creek @ Giles Rd	5:30	5/9/07	0.640	22.60	7	852	35	0.029	0.15	8.17
22390	BLT-1	Bear Creek @ Giles Rd	9:30	5/9/07	0.851	30.05	45	7279	303	0.081	0.55	7.68
22395	BLT-1	Bear Creek @ Giles Rd	14:23	5/9/07	0.808	28.53	27	4147	173	0.073	0.47	7.84
22397	BLT-1	Bear Creek @ Giles Rd	17:55	5/9/07	0.817	28.85	30	4659	194	0.062	0.40	7.94
22404	BLT-1	Bear Creek @ Giles Rd	21:05	5/9/07	0.689	24.33	21	2750	115	0.052	0.28	8.14
22410	BLT-1	Bear Creek @ Giles Rd	9:47	5/10/07	0.577	20.37	6	658	27	0.033	0.15	8.17
22384	BLT-2	Little Bear Creek @ Giles Rd	4:00	5/9/07	0.294	10.38	8	447	19	0.026	0.06	6.59
22388	BLT-2	Little Bear Creek @ Giles Rd	9:16	5/9/07	0.339	11.97	35	2255	94	0.071	0.19	6.56
22394	BLT-2	Little Bear Creek @ Giles Rd	14:03	5/9/07	0.442	15.61	12	1008	42	0.035	0.12	6.53
22396	BLT-2	Little Bear Creek @ Giles Rd	17:45	5/9/07	0.320	11.30	12	730	30	0.031	0.08	6.63
22403	BLT-2	Little Bear Creek @ Giles Rd	20:55	5/9/07	0.302	10.66	11	631	26	0.026	0.06	6.66
22409	BLT-2	Little Bear Creek @ Giles Rd	9:35	5/10/07	0.283	9.99	8	430	18	0.022	0.05	6.71
22382	BLT-3	Bear Creek @ Witham Rd	4:28	5/9/07	0.974	34.39	5	926	39	0.028	0.22	8.92
22386	BLT-3	Bear Creek @ Witham Rd	8:45	5/9/07	1.398	49.36	21	5580	233	0.060	0.66	8.63
22399	BLT-3	Bear Creek @ Witham Rd	13:34	5/9/07	1.222	43.15	31	7201	300	0.083	0.80	8.73
22400	BLT-3	Bear Creek @ Witham Rd	17:19	5/9/07	1.085	38.31	20	4125	172	0.059	0.51	8.66
22406	BLT-3	Bear Creek @ Witham Rd	21:40	5/9/07	1.043	36.83	18	3569	149	0.055	0.45	8.79
22391	BLT-3	Bear Creek @ Witham Rd	9:05	5/10/07	0.944	33.33	9	1615	67	0.035	0.26	8.83
22383	BLT-4	Unnamed Trib @ Dykstra Rd	4:22	5/9/07	0.035	1.24	4	27	1	0.116	0.03	1.12
22387	BLT-4	Unnamed Trib @ Dykstra Rd	9:42	5/9/07	0.062	2.19	52	613	26	0.041	0.02	0.98
22392	BLT-4	Unnamed Trib @ Dykstra Rd	14:47	5/9/07	0.027	0.95	14	72	3	0.033	0.01	1.18
22398	BLT-4	Unnamed Trib @ Dykstra Rd	17:30	5/9/07	0.026	0.92	13	64	3	0.048	0.01	1.21
22402	BLT-4	Unnamed Trib @ Dykstra Rd	21:30	5/9/07	0.028	0.99	1	5	0	0.015	0.00	1.21
22408	BLT-4	Unnamed Trib @ Dykstra Rd	9:00	5/10/07	0.024	0.85	4	18	1	0.012	0.00	1.21

TABLE 6.9. BEAR LAKE TRIBUTARY LOADINGS DURING A 0.55" RAIN EVENT (2007).

AWRI #	Site ID:	Name	Time	Date	Discharge m^3/ sec	Discharge cfs	TSS mg/l	TSS Loading lb/d	TSS Loading lb/hr	TP mg/l	TP Loading lb/hr	Surface ft
22759	BLT-1	Bear Creek @ Giles Rd	1:36	6/19/07	0.144	5.10	9	247	10	0.035	0.04	8.46
22763	BLT-1	Bear Creek @ Giles Rd	5:16	6/19/07	0.255	9.02	65	3155	131	0.132	0.27	8.43
22768	BLT-1	Bear Creek @ Giles Rd	9:18	6/19/07	0.255	9.02	55	2669	111	0.137	0.28	8.37
22776	BLT-1	Bear Creek @ Giles Rd	13:19	6/19/07	0.269	9.49	27	1380	57	0.078	0.17	8.40
22805	BLT-1	Bear Creek @ Giles Rd	17:18	6/19/07	0.241	8.51	15	687	29	0.053	0.10	8.46
22811	BLT-1	Bear Creek @ Giles Rd	21:33	6/19/07	0.208	7.33	9	355	15	0.043	0.07	8.50
22758	BLT-2	Little Bear Creek @ Giles Rd	1:30	6/19/07	0.185	6.54	14	493	21	0.035	0.05	6.73
22762	BLT-2	Little Bear Creek @ Giles Rd	5:10	6/19/07	0.219	7.72	62	2577	107	0.107	0.19	6.56
22767	BLT-2	Little Bear Creek @ Giles Rd	9:13	6/19/07	0.192	6.78	19	693	29	0.048	0.07	6.69
22775	BLT-2	Little Bear Creek @ Giles Rd	13:12	6/19/07	0.192	6.78	14	511	21	0.034	0.05	6.69
22803	BLT-2	Little Bear Creek @ Giles Rd	17:08	6/19/07	0.185	6.54	12	423	18	0.029	0.04	6.73
22810	BLT-2	Little Bear Creek @ Giles Rd	21:25	6/19/07	0.179	6.31	9	306	13	0.024	0.03	6.76
22756	BLT-3	Bear Creek @ Witham Rd	1:16	6/19/07	0.516	18.23	9	883	37	0.029	0.12	9.25
22760	BLT-3	Bear Creek @ Witham Rd	4:55	6/19/07	0.646	22.81	28	3438	143	0.075	0.38	9.12
22764	BLT-3	Bear Creek @ Witham Rd	8:55	6/19/07	0.544	19.20	37	3824	159	0.094	0.40	9.19
22773	BLT-3	Bear Creek @ Witham Rd	13:23	6/19/07	0.560	19.76	25	2660	111	0.069	0.31	9.22
22801	BLT-3	Bear Creek @ Witham Rd	16:53	6/19/07	0.489	17.28	15	1395	58	0.047	0.18	9.25
22808	BLT-3	Bear Creek @ Witham Rd	21:13	6/19/07	0.398	14.04	12	907	38	0.044	0.14	9.32
22757	BLT-4	Unnamed Trib @ Dykstra Rd	5:31	6/19/07	0.022	0.78	20	84	3	0.053	0.01	1.31
22761	BLT-4	Unnamed Trib @ Dykstra Rd	1:26	6/19/07	0.036	1.27	65	445	19	0.176	0.05	1.08
22766	BLT-4	Unnamed Trib @ Dykstra Rd	1:12	6/19/07	0.028	0.99	16	85	4	0.046	0.01	1.28
22774	BLT-4	Unnamed Trib @ Dykstra Rd	13:05	6/19/07	0.022	0.78	15	63	3	0.039	0.01	1.31
22802	BLT-4	Unnamed Trib @ Dykstra Rd	17:02	6/19/07	0.020	0.71	12	46	2	0.039	0.01	1.31
22809	BLT-4	Unnamed Trib @ Dykstra Rd	21:10	6/19/07	0.020	0.71	11	42	2	0.032	0.01	1.31

TABLE 6.10. BEAR LAKE TRIBUTARY LOADINGS DURING A 0.75" RAIN EVENT (2007).

AWRI #	Site ID:	Name	Time	Date	Discharge m^3/ sec	Discharge cfs	TSS mg/l	TSS Loading lb/d	TSS Loading lb/hr	TP mg/l	TP Loading lb/hr	Surface ft
24011	BLT-1	Bear Creek @ Giles Rd	6:50	8/20/07	0.159	5.61	3	91	4	0.030	0.04	8.46
24016	BLT-1	Bear Creek @ Giles Rd	12:00	8/20/07	0.433	15.28	75	6169	257	0.216	0.74	8.20
24020	BLT-1	Bear Creek @ Giles Rd	13:22	8/20/07	0.364	12.86	53	3670	153	0.144	0.42	8.27
24026	BLT-1	Bear Creek @ Giles Rd	16:15	8/20/07	0.296	10.44	24	1349	56	0.079	0.19	8.33
24030	BLT-1	Bear Creek @ Giles Rd	19:23	8/21/07	0.159	5.61	7	211	9	0.036	0.05	8.46
24035	BLT-1	Bear Creek @ Giles Rd	8:52	8/21/07	0.159	5.61	5	151	6	0.031	0.04	8.46
24010	BLT-2	Little Bear Creek @ Giles Rd	7:20	8/20/07	0.159	5.60	4	121	5	0.020	0.03	6.86
24015	BLT-2	Little Bear Creek @ Giles Rd	11:40	8/20/07	0.199	7.01	14	529	22	0.051	0.08	6.66
24019	BLT-2	Little Bear Creek @ Giles Rd	13:18	8/20/07	0.179	6.31	8	272	11	0.034	0.05	6.76
24025	BLT-2	Little Bear Creek @ Giles Rd	16:10	8/20/07	0.165	5.83	6	188	8	0.023	0.03	6.82
24029	BLT-2	Little Bear Creek @ Giles Rd	19:16	8/21/07	0.159	5.60	6	181	8	0.020	0.03	6.86
24034	BLT-2	Little Bear Creek @ Giles Rd	8:46	8/21/07	0.159	5.60	5	151	6	0.020	0.03	6.86
24008	BLT-3	Bear Creek @ Witham Rd	7:03	8/20/07	0.584	20.62	4	444	18	0.03	0.12	9.35
24012	BLT-3	Bear Creek @ Witham Rd	11:57	8/20/07	1.174	41.45	63	14056	586	0.15	1.35	8.86
24017	BLT-3	Bear Creek @ Witham Rd	13:00	8/20/07	1.050	37.08	40	7983	333	0.12	0.96	9.02
24022	BLT-3	Bear Creek @ Witham Rd	15:56	8/20/07	0.827	29.22	24	3775	157	0.08	0.50	9.15
24027	BLT-3	Bear Creek @ Witham Rd	19:04	8/21/07	0.659	23.26	8	1002	42	0.03	0.15	9.32
24031	BLT-3	Bear Creek @ Witham Rd	8:33	8/21/07	0.467	16.48	5	444	18	0.03	0.10	9.35
24009	BLT-4	Unnamed Trib @ Dykstra Rd	7:15	8/20/07	0.020	0.71	5	19	1	0.034	0.01	1.31
24013	BLT-4	Unnamed Trib @ Dykstra Rd	11:20	8/20/07	0.030	1.06	12	68	3	0.051	0.01	1.25
24018	BLT-4	Unnamed Trib @ Dykstra Rd	13:11	8/20/07	0.020	0.71	10	38	2	0.037	0.01	1.31
24023	BLT-4	Unnamed Trib @ Dykstra Rd	16:05	8/20/07	0.020	0.71	22	84	3	0.054	0.01	1.31
24028	BLT-4	Unnamed Trib @ Dykstra Rd	19:12	8/21/07	0.020	0.71	5	19	1	0.021	0.00	1.31
24033	BLT-4	Unnamed Trib @ Dykstra Rd	8:41	8/21/07	0.020	0.71	4	15	1	0.025	0.00	1.31

TABLE 6.11. SUMMARY OF MEAN TRIBUTARY LOADINGS FOR THE BEAR LAKE WATERSHED (2007)

Tributary	Rainfall inches	Date	Mean TSS Loading lb/d	Mean TP Loading lb/d
Bear Creek Giles Rd.	0.85	5/1-2/07	2574	11
Little Bear Creek Giles Rd.			552	2
Bear Creek Witham Rd.			2801	14
Unnamed Tributary Dykstra Rd.			76	0.2
Bear Creek Giles Rd.	0.95	5/9-10/07	3391	8
Little Bear Creek Giles Rd.			917	2
Bear Creek Witham Rd.			3836	12
Unnamed Tributary Dykstra Rd.			133	0.3
Bear Creek Giles Rd.	0.55	6/19/07	1204	3
Little Bear Creek Giles Rd.			834	2
Bear Creek Witham Rd.			1968	6
Unnamed Tributary Dykstra Rd.			127	0.4
Bear Creek Giles Rd.	0.75	8/20-21/07	1940	6
Little Bear Creek Giles Rd.			240	1
Bear Creek Witham Rd.			2072	8
Unnamed Tributary Dykstra Rd.			41	0

6.5 Reference

Chu, Xuefeng. 2006. Windows-Based Hydrol-Inf, User’s Manual, Version 2.03. Annis Water Resources Institute, Grand Valley State University.

7.0 Hydrology Data for Bear Lake Tributaries

7.1 Stream Flow Monitoring and Computation

Odyssey pressure and temperature recording systems were installed for continuously collecting stream water level and temperature data at Bear Creek (Giles Rd.), Little Bear Creek (Giles Rd.), and Bear Creek (Witham Rd.). The recording time interval was 10 minutes for all sites. In order to develop rating curves that relate the stream water stage recorded by the pressure sensor to discharge, stream flow also was manually measured at all sites by using a Marsh-McBirney flow meter (Flo-Mate Model 2000) for a number of selected time points. Basically, the measured stream stages covered the primary range of the sensor-recorded data. The Microsoft®Windows-based hydrologic software, HYDROL-INF (Chu, 2006) was used for processing the measured stream data, in which the velocity-area method was used for computing stream discharges. In addition, the HYDROL-INF software also provided other hydraulic parameters, such as wetted perimeter, hydraulic radius, conveyance factor, and slope-roughness factor.

7.2 Development of Rating Curves

Based on the USGS Techniques of Water Resources Investigations (TWRI), Chapter A10 of Book 3 (Kennedy, 1984), rating curves were developed for the three monitoring sites. The general relationship between the stream discharge Q and the stage D can be mathematically expressed as:

$$Q = \alpha(D - d_0)^{\beta}$$

i.e.,

$$Ln(Q) = Ln(\alpha) + \beta Ln(D - d_0)$$

or

$$y = y_0 + \beta Ln(D - d_0)$$

where α and β = parameters; d_0 = depth adjustment constant (zero-flow depth) or “scale offset” (Kennedy, 1984); $y = Ln(Q)$; and $y_0 = Ln(\alpha)$.

Nonlinear regression method was used in the analysis and a 3-parameter logarithm equation (y_0, β and d_0) was fitted to each set of the measured data [D-$Ln(Q)$]. Then, the final rating curve equations can be determined. The developed rating curves are summarized in Figures 7.1, 7.2, and 7.3 for Bear Creek at Giles Rd., Little Bear Creek at Giles Rd., and Bear Creek at Witham Rd., respectively.

Bear Creek at Giles Rd.:

$$Q = 0.1875(D - 3.5)^{1.4928}$$

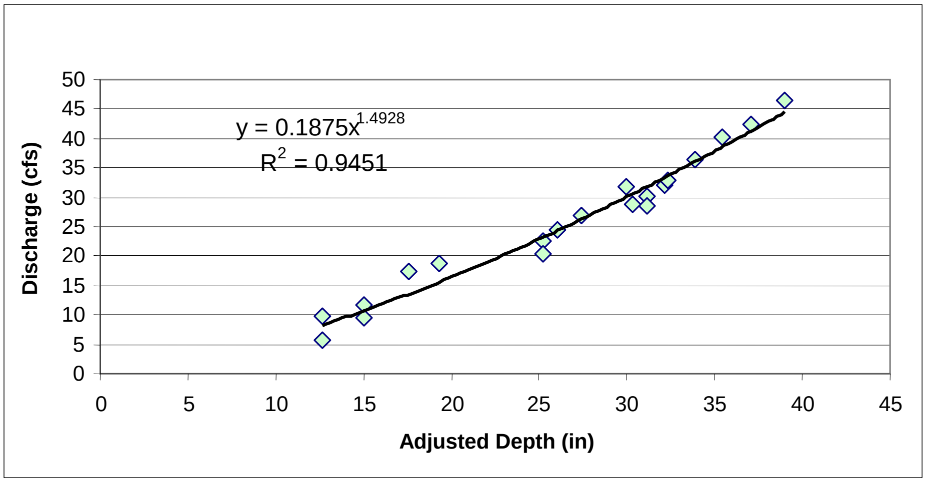

FIGURE 7.1. RATING CURVE FOR BEAR CREEK AT GILES RD. (2006-2007).

Little Bear Creek at Giles Rd.:

$$Q = 1.8031(D - 2.0)^{0.8469}$$

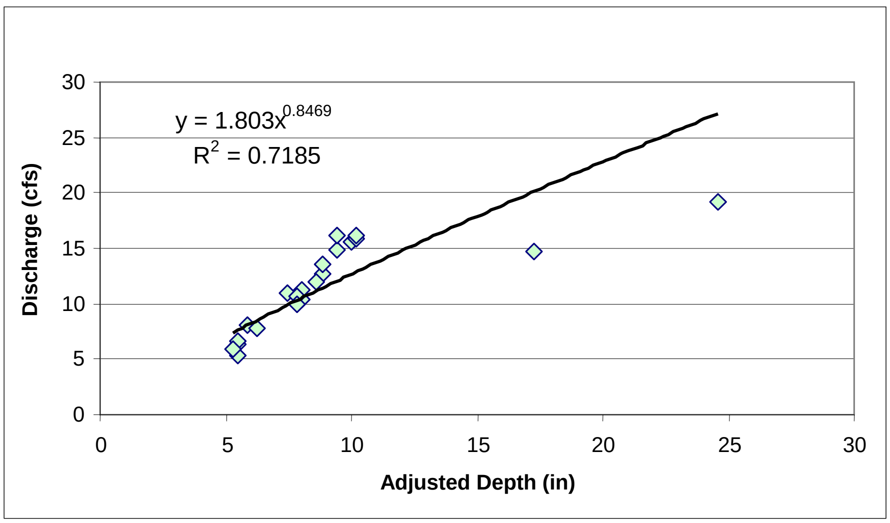

FIGURE 7.2. RATING CURVE FOR LITTLE BEAR CREEK AT GILES RD. (2006-2007).

Bear Creek at Witham Rd.:

$$Q = 0.6353(D - 2.29)^{1.5862}$$

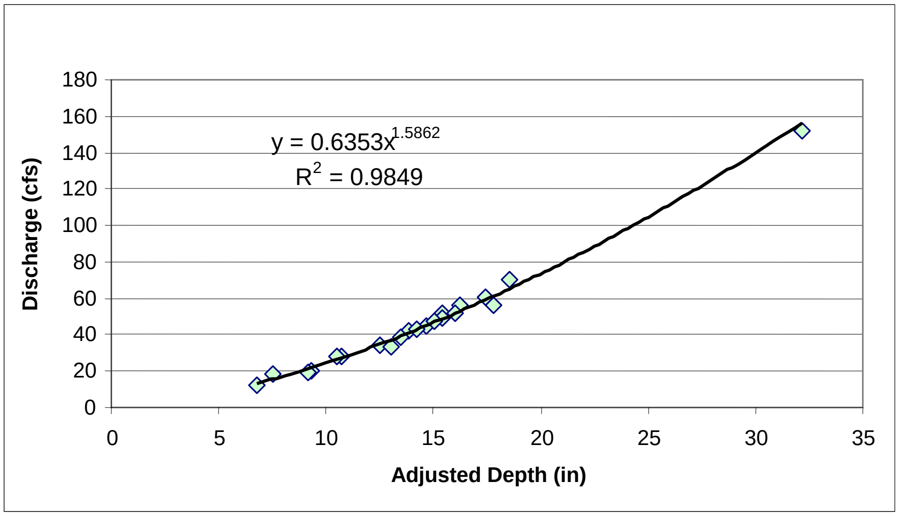

FIGURE 7.3. RATING CURVE FOR BEAR CREEK AT WITHAM RD. (2006-2007).

7.3 Rating Curves for the Bridge Reference Points

In addition to the Odyssey transducer reference point, rating curves also were developed from the MDEQ reference point on the bridges. The developed rating curves for the bridge reference points are summarized in Figures 7.4, 7.5, and 7.6 for Bear Creek at Giles Rd., Little Bear Creek at Giles Rd., and Bear Creek at Witham Rd., respectively.

Bear Creek at Giles Rd.:

$$Q = 39.362(8.5137 - L)^{0.6225} \quad (R^2=0.9656)$$

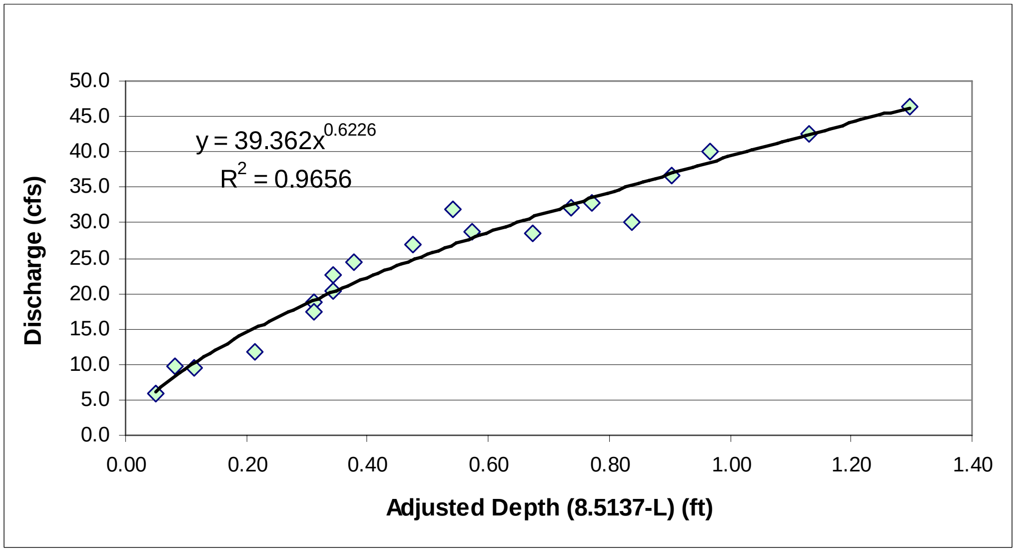

FIGURE 7.4. BRIDGE RATING CURVE FOR BEAR CREEK AT GILES RD. (2006-2007).

Little Bear Creek at Giles Rd.:

$Q = 20.8593(6.9802 - L)^{0.5780}$ (R^2=0.7526)

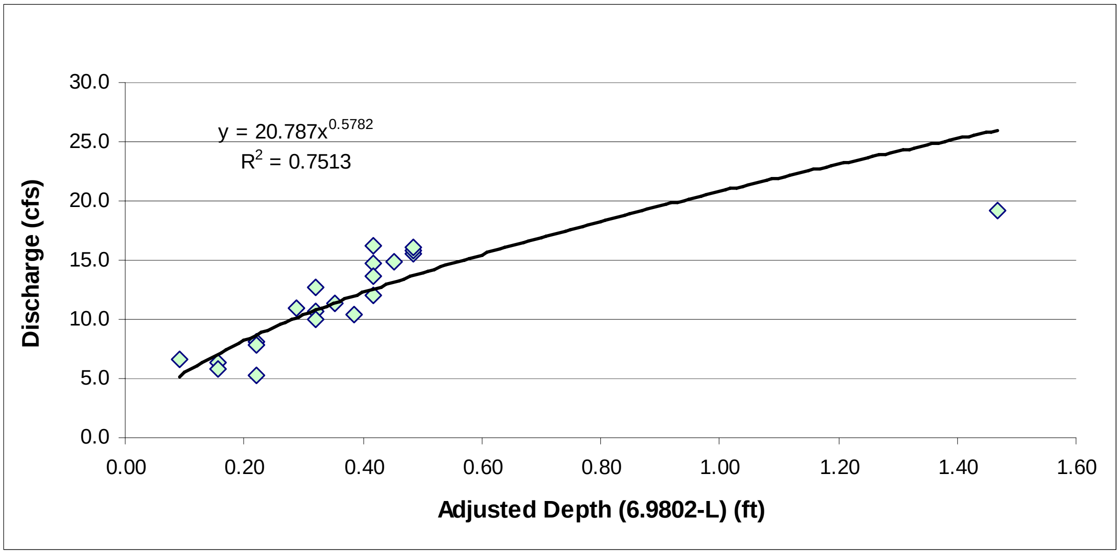

FIGURE 7.5. BRIDGE RATING CURVE FOR LITTLE BEAR CREEK AT GILES RD. (2006-2007).

Bear Creek at Witham Rd.:

$$Q = 28.537(9.9992 - L)^{1.7562} \quad (R^2=0.9663)$$

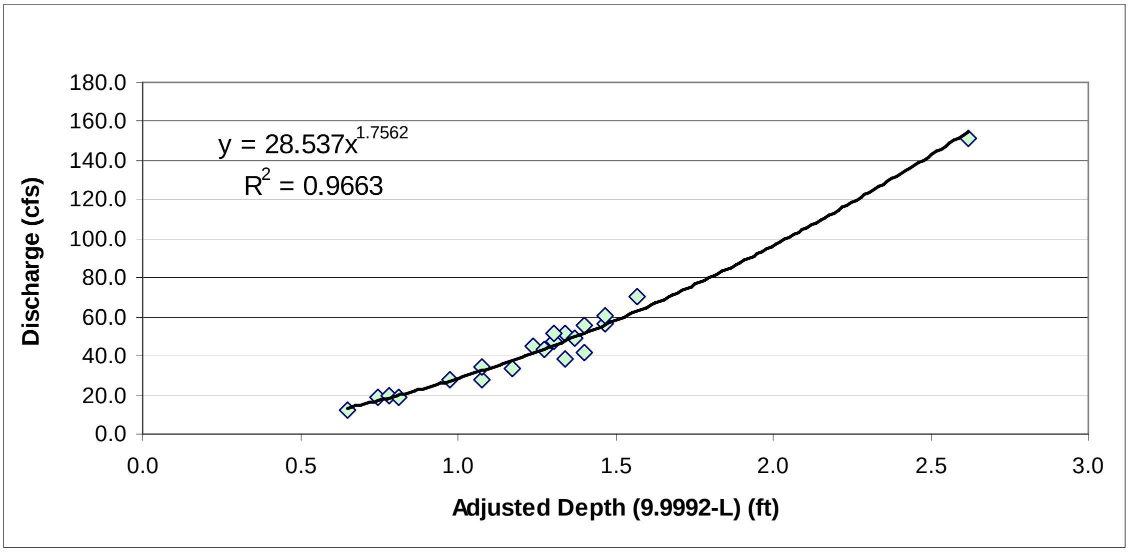

FIGURE 7.6. BRIDGE RATING CURVE FOR BEAR CREEK AT WITHAM RD. (2006-2007).

7.4 Computation of Observed Stream Flow

Using the developed rating curves and the sensor-recorded stage data, hydrographs were developed for each of the tributaries. The hydrograph for Bear Creek at Giles Rd. is shown inn Figure 7.7. The peak discharge measured at this site was 85 cfs on April 4, 2007 and the minimum discharger recorded was 2.1 cfs on August 4, 2007. The mean discharge for Bear Creek at Giles Rd. was 14.4 cfs. The hydrograph for Little Bear Creek at Giles Rd. is shown in Figure 7.8. The peak discharge measured at this site was 28 cfs on March 14, 2007 and the minimum discharger recorded was 4.1 cfs on August 4, 2007. The mean discharge for Little Bear Creek at Giles Rd. was 8.2 cfs. Little Bear Creek appears to have a more stable flow than Bear Creek as the difference between peak and base flow was 3.5 vs. 6.0. Although Bear Creek drains a larger segment of the watershed and has a higher average Q, Little Bear Creek was impacted less during the summer drought as its Q_{min} was 4.1 cfs as compared to 2.1 cfs for Bear Creek. These data suggest that Little Bear Creek has a more stable ground water recharge than Bear Creek. The hydrograph for Bear Creek at Witham Rd. is shown in Figure 7.9. The peak discharge measured at this site was 132 cfs on March 12, 2007 and the minimum discharger recorded was 8.4 cfs on August 4, 2007. The mean discharge for Little Bear Creek at Witham Rd. was 27 cfs.

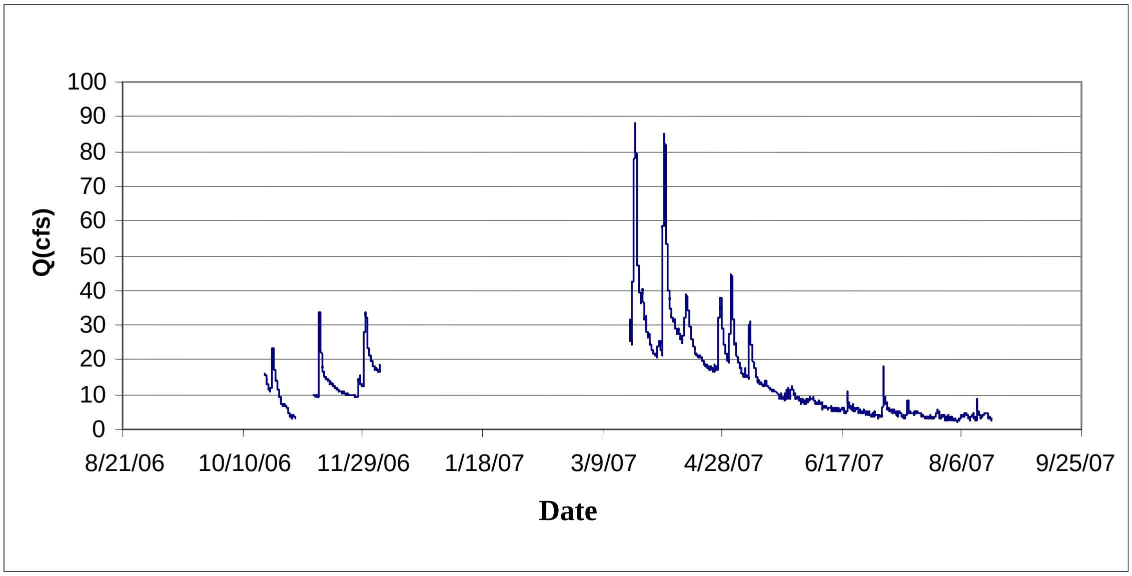

FIGURE 7.7. HYDROGRAPH FOR BEAR CREEK AT GILES RD. (2006-2007).

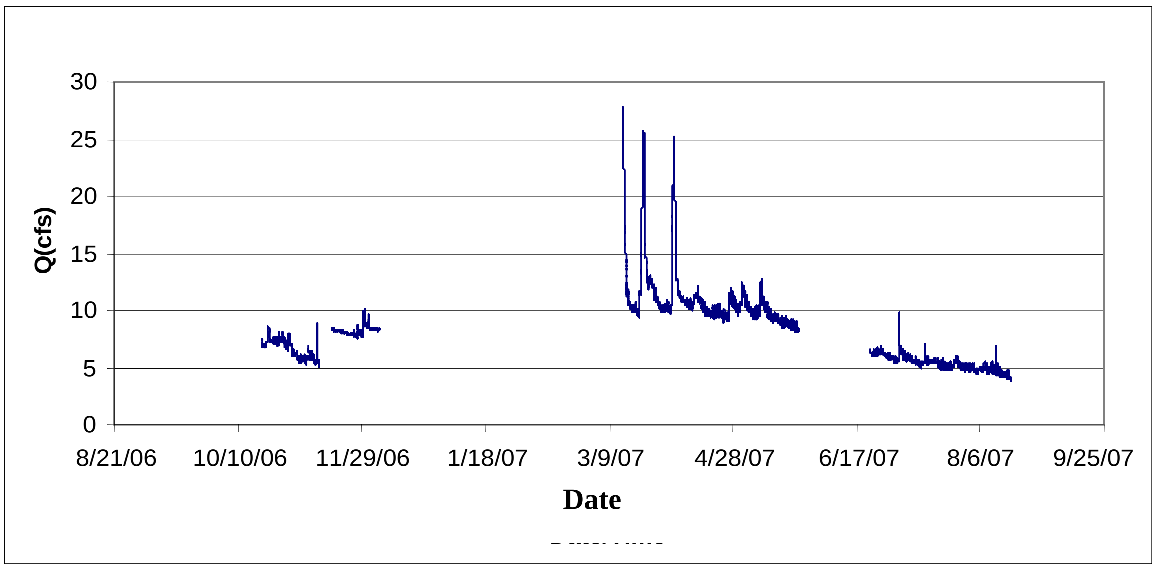

FIGURE 7.8. HYDROGRAPH FOR LITTLE BEAR CREEK AT GILES RD. (2006-2007).

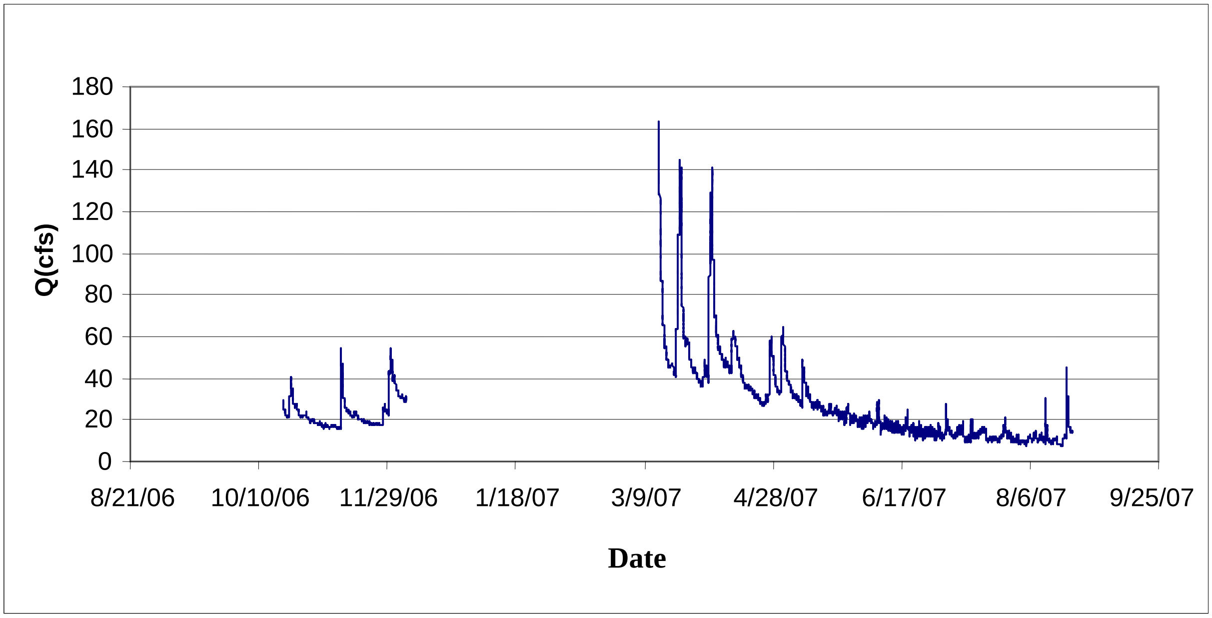

FIGURE 7.9. HYDROGRAPH FOR BEAR CREEK AT WITHAM RD. (2006-2007).

7.5 References

Chu, Xuefeng. 2006. Windows-Based Hydrol-Inf, User's Manual, Version 2.03. Annis Water Resources Institute, Grand Valley State University.

Kennedy, E.J. 1984. Discharge Ratings at Gaging Stations, Techniques of Water- Resources Investigations of the United States Geological Survey, Chapter A10, Book 3.

8.0 Nonpoint Source Estimates Using L-THIA

8.1 Data Analysis

The 2005 land use/cover data were input into the Long-Term Hydrologic Impact Assessment Model (L-THIA) (Bhaduri et al. 2001) to estimate nonpoint source contributions for simulated rain events. L-THIA is based on computations of daily runoff obtained from long-term climatic records, soil data, CN values and land use of the area. The results for 0.5 inch, 1.0 inch, and 1.5 inch rainfall events are summarized in Table 8.1. The model was run for the total watershed, the Bear Creek subwatershed, the Little Bear Creek subwatershed, and the drainage basin around Bear Lake. L-THIA predicts that the Bear Creek Tributary would contribute 10 times more loading of TSS and TP than Little Bear Creek. This estimate is consistent with the observed results (Section 6.4). The model also predicts that the loading of TSS and TP from the area surrounding Bear Lake would be greater than the contribution from the Little Bear Creek subwatershed when the rainfall exceeded 1 inch.

TABLE 8.1. RESULTS OF L-THIA MODELING FOR 0.5", 1.0", AND 1.5" RAIN FALL EVENTS IN THE BEAR LAKE WATERSHED USING 2005 GEOSPATIAL DATA.

0.5" Rain Event		
	TP Loading	TSS Loading
	lbs/d	lbs/d
Total Watershed	12	2066
Bear Lake	1	143
Little Bear Creek	1	156
Bear Creek	10	1767
1.0" Rain Event		
Total Watershed	123	19045
Bear Lake	18	3409
Little Bear Creek	12	2192
Bear Creek	94	13444
1.5" Rain Event		
Total Watershed	458	58679
Bear Lake	56	10370
Little Bear Creek	37	6452
Bear Creek	365	41856

A comparison of actual loadings from the rain events and the model results are shown in Table 8.2. The actual and predicted results are similar for the 0.5" rain event. The model however overestimates the loadings of TSS and TP for the 1.0" rain event. The 1.0" rain event occurred over a 4 hour period and the L-THIA model is based on duration of 1 hr. The slower rate of rainfall may account for a majority of the difference.

TABLE 8.2. COMPARISON OF L-THIA ESTIMATES AND OBSERVED RESULTS FOR 0.5" AND 1.0" RAIN FALL EVENTS IN THE BEAR LAKE WATERSHED USING 2005 GEOSPATIAL DATA.

0.5" Rain Event				
	L-THIA TP Loading	Measured TP Loading	L-THIA TSS Loading	Measured TSS Loading
	lbs/d	lbs/d	lbs/d	lbs/d
Little Bear Creek	1	2	156	834
Bear Creek	10	6	1767	1968
1.0" Rain Event				
Little Bear Creek	12	2	2192	917
Bear Creek	94	8	13444	3391

8.2 Reference

Bhaduri, B., Minner, M., Tatalovich, S., Harbor, J., 2001. Long-term Hydrologic Impact of Urbanization: A Tale of Two Models. Journal of Water Resources Planning and Management 127, 13–19.

9.0 Nutrient Loading Assessment

Bear Lake is a moderate to highly eutrophic lake that has elevated concentrations of total phosphorus and heavy summer blooms of cyanobacteria (formerly blue green algae). The sources of the excessive nutrient levels and algal blooms are the result of combination of external and internal factors to Bear Lake. The water quality in the tributaries to Bear Lake is relatively good during base flow conditions as TP concentrations range from 20 to 32 ug/l for Bear Creek and Little Bear Creek (Table 6.1). Daily base flow loadings of TSS and TP to Bear Lake from Bear Creek averaged 400 lbs and 2 lbs, respectively In contrast, the storm event data demonstrate elevated loadings of suspended sediment and nutrients (Table 6.3). A 0.95 inch rain event delivered an average daily load of 3836 lbs of TSS and 12 lbs of TP. Bear Creek contributes approximately four times the loading of TSS and six times the loading of TP as Little Bear Creek. Stream flow hydrographs (Figures 7.7-7.9) show that peak flows, during the early spring, result in stream discharges that exceed the amounts observed during the rain event monitoring. These data suggest that even higher loadings of TSS and TP enter the system during the spring. TP and TSS transport in the tributaries is enhanced by the channelized stream and the highly modified wetlands near the inlet of Bear Lake. A large part of the wetlands was converted to a muck farming operation with dyked borders along the stream channel. While an investigation of the effects of NPS inputs from the immediate drainage area around Bear Lake was not conducted, the results of L-THIA modeling estimated that TSS and TP from rain events > 1 inch would exceed the estimated loadings from Little Bear Creek.

While storm events can accelerate the loading of TP to Bear Lake, the presence of heavy cyanobacteria blooms, elevated chlorophyll-*a* concentrations, and low Secchi disk depth readings throughout the summer are indicative of an internal sediment loading source. The concentration of iron in the sediment appears to be sufficient to limit phosphorus release. In addition, the shallow bathymetry of Bear Lake (8-12 ft) prevents summer stratification and anaerobic conditions that enhance phosphorus release from the sediments. The moderate level of SRP found in the sediments of Bear Lake is a function of the elevated iron concentrations and the lack of summer stratification. Because of the wind mixed water column, some phosphorus can still be circulated up from the sediments into the water column and become available to stimulate productivity. Since Bear Lake appears to be phosphorus limited (Table 3.6), additional loading of this nutrient will stimulate primary productivity. The dominant phytoplankton organism, *Microcystis aeruginosa*, can take advantage of these conditions by adjusting its vertical position in the water column and accumulating phosphorus at the sediment/water interface. The shallow bathymetry of Bear Lake and the moderate levels of phosphorus in the sediment are ideal conditions for *Microcystis aeruginosa* to form blooms.

Bear Lake appears to be impacted by a combination of internal and external phosphorus loading. External loading of phosphorus from 0.5-1.0 inch rain events is six times greater than during base flow conditions. The dominant species of phytoplankton, *Microcystis aeruginosa*, can take advantage of the phosphorus in the sediment by adjusting their position in the water column and accumulating the nutrient from this environmental compartment.

10.0 Recommendations

Since there are no significant point sources of nutrients and suspended solids in the Bear Lake watershed, a combination of nonpoint source reduction strategies should be considered that involve the tributaries and the immediate drainage basin of the lake. With respect to the tributaries, the implementation of best management practices in the Bear Creek subwatershed is the first priority. The installation of buffer strips along the stream corridor plus creating more opportunities for runoff infiltration and detention in developed areas will help reduce direct NPS pollution inputs. In addition, returning some of the natural sinuosity back to the stream channel and restoring the wetlands at the mouth of Bear Creek and inlet of Bear Lake will help slow the transport of sediment and nutrients to the lake. With respect to adjacent upland areas of Bear Lake, attractive, vegetative riparian buffers along the lake front will help reduce the input of nutrients. In addition, using phosphate free fertilizer for lawn maintenance and adding more opportunities for runoff detention and infiltration will lower the nonpoint point source contribution of the immediate drainage basin. Because of the shallow nature of the lake, chemical treatments to limit phosphorus availability such as alum, will not be effective. Many of the homes along the shore of Bear Lake in Laketon Township are serviced by septic systems. Municipal sewer recently has been extended to this area and where possible, home owners are encouraged to connect to the system and decommission their septic tank. Where connections are not possible, proper septic system maintenance and design are critical to limiting the leaching of nutrients into Bear Lake.

Appendix

Quality Control Data

Table A.1. Field Blank Data

Sample #	Station	TSS	N03-N	NH3-N	TKN-N	SRP-P	TP-P	Sampling Date
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
21839	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	11/7/06
21854	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	11/16/06
22282	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	4/16/2007
22366	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	5/1/07
22367	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	5/2/07
22401	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	5/9/07
22411	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	5/10/07
22811	Field Blank	< 1	< 0.01	< 0.01	0.01	< 0.005	< 0.01	5/19/2007
22812	Field Blank	< 1	< 0.01	< 0.01	0.01	< 0.005	< 0.01	5/19/2007
22666	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	5/24/2007
24043	Field Blank	< 1	< 0.01	< 0.01	< 0.1	< 0.005	< 0.01	8/2/2007
24021	Field Blank	< 1	< 0.01	< 0.01	< 0.01	< 0.005	< 0.01	8/20/07
24037	Field Blank	< 1	< 0.01	< 0.01	< 0.01	< 0.005	< 0.01	8/21/07

Table A.2. Water Field Duplicate Data

Sample #	**Station**	**TSS**	**N03-N**	**NH3-N**	**TKN-N**	**SRP-P**	**TP-P**	**Sampling Date**
		mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
21834	BLT-1	1	0.27	0.04	0.31	< 0.005	0.03	11/7/2006
21835	BLT-1 DUP	1	0.23	0.03	0.30	< 0.005	0.03	11/7/2006
22279	BL-3 TOP	-	0.23	< 0.05	0.66	< 0.005	0.03	4/16/2007
22280	BL-3 TOP DUP	-	0.23	< 0.05	1.05	< 0.005	0.03	4/16/2007
22388	BLT-2	12	0.12	0.03	0.53	< 0.005	0.04	5/9/07
22389	BLT-2 DUP	12	0.12	0.03	0.44	< 0.005	0.04	5/9/07
22393	BLT-4 DUP	12	0.34	0.04	0.57	< 0.005	0.03	5/9/07
22400	BLT-3	9	0.15	0.06	0.79	< 0.005	0.04	5/10/07
22407	BLT-3 DUP	5	0.15	0.05	0.59	< 0.005	0.03	5/10/07
22402	BLT-4	1	0.49	0.04	0.41	< 0.005	0.02	5/10/07
22765	BLT-2	11	0.17	0.02	0.44	0.008	0.03	6/19/07
22767	BLT-2 DUP	12	0.15	0.02	0.44	< 0.005	0.04	6/19/07
22773	BLT-3	37	0.32	0.07	0.99	0.011	0.09	6/19/07
22801	BLT-3 DUP	38	0.31	0.10	1.15	0.005	0.09	6/19/07
24013	BLT-4	10	0.30	0.04	0.55	0.010	0.04	8/20/07
24014	BLT-4 DUP	9	0.45	0.04	0.57	0.014	0.03	8/20/07
24024	BLT-2	6	0.20	0.02	0.17	0.006	0.02	8/21/07
24025	BLT-2 DUP	4	0.21	0.02	0.18	0.008	0.02	8/21/07
24031	BLT-3	3	0.24	0.09	0.29	0.009	0.03	8/21/07
24032	BLT-3 DUP	3	0.27	0.09	0.37	0.008	0.03	8/21/07
21852	BLT-5	6	0.29	0.08	0.57	< 0.005	0.02	11/16/2007
21853	BLT-5 DUP	6	0.26	0.08	0.68	< 0.005	0.02	11/16/2007

TABLE A.3. SEDIMENT FIELD DUPLICATE DATA

Sample #	Date	Station	AFDM		TOC	Total Copper	Total Iron	Sediment SRP	Sediment TP
			%solids (w/w)	% volatile solids (w/w)	% (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)
22334	4/16/2007	BL-3 W	13	35	19	53	36000	107	1172
22335	4/16/2007	BL-3 DUP	12	34	19	60	32000	101	955

TABLE A.4. SEDIMENT MS/MSD DATA

Sample #	Date	Station	AFDM		TOC	Total Copper	Total Iron	Sediment SRP	Sediment TP
			%solids (w/w)	% volatile solids (w/w)	% (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)	mg/kg (Dry wt)
						20 mg/kg spk	10,000 mg/kg spk	100 mg/kg spk	1000 mg/kg spk
22326	4/16/2007	BL-1	8	36	20	42	51000	98	1079
22326 D	4/16/2007	BL-1	9	27	18	-	-	-	-
22326 MS	4/16/2007	BL-1	-	-	-	58	59000	210	1950
22326 MSD	4/16/2007	BL-1	-	-	-	55	57000	220	2058

TABLE A.5. WATER MS/MSD DATA

Sample #	Station	TSS	N03-N	NH3-N	TKN-N	SRP-P	TP-P	Sampling Date
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
			Spk amt 0.5 mg/l	Spk amt 0.5 mg/l	Spk amt 0.5 mg/l	Spk amt 0.05 mg/l	Spk amt 0.05 mg/l	
21834	BLT-1	1	0.27	0.04	0.31	< 0.005	0.03	11/7/2006
21834	BLT-1 DUP	2	-	-	-	-	-	11/7/2006
21834	BLT-1 MS	-	0.67	0.50	0.78	0.040	0.08	11/7/2006
21834	BLT-1 MSD	-	0.73	0.58	0.85	0.050	0.12	11/7/2006
22279	BL-3 TOP	-	0.23	< 0.05	0.66	< 0.005	0.23	4/16/2007
22279	BL-3 TOP DUP	-	-	-	-	-	-	4/16/2007
22279	BL-3 TOP MS	-	0.63	0.44	1.06	0.055	0.27	4/16/2007
22279	BL-3 TOP MSD	-	0.69	0.50	1.19	0.052	0.28	4/16/2007
22388	BLT-2	12	0.12	0.57	0.53	< 0.005	0.04	5/9/07
22388	BLT-2 DUP	14	-	-	-	-	-	5/9/07
22388	BLT-2 MS	-	0.54	0.53	0.98	0.046	0.09	5/9/07
22388	BLT-2 MSD	-	0.62	0.59	0.91	0.045	0.08	5/9/07
22392	BLT-4	13	0.39	0.04	0.48	< 0.005	0.03	5/9/07
22392	BLT-4 DUP	11	-	-	-	-	-	5/9/07
22392	BLT-4 MS	-	0.79	0.49	1.05	0.046	0.08	5/9/07
22392	BLT-4 MSD	-	0.76	0.44	1.12	0.054	0.09	5/9/07
22400	BLT-3	9	0.15	0.06	0.79	< 0.005	0.04	5/10/07
22400	BLT-3 DUP	6	-	-	-	-	-	5/10/07
22400	BLT-3 MS	-	0.55	0.50	1.35	0.042	0.09	5/10/07
22400	BLT-3 MSD	-	0.70	0.47	1.26	0.047	0.14	5/10/07
22765	BLT-2	11	0.17	0.02	0.44	0.008	0.13	6/19/07
22765	BLT-2 DUP	12	-	-	-	-	-	6/19/07
22765	BLT-2 MS	-	0.64	0.51	0.90	0.053	0.08	6/19/07
22765	BLT-2 MSD	-	0.62	0.44	88.00	0.055	0.07	6/19/07
22773	BLT-3	37	0.32	0.07	0.99	0.011	0.09	6/19/07
22773	BLT-3 DUP	38	-	-	-	-	-	6/19/07
22773	BLT-3 MS	-	0.84	0.51	1.33	0.041	0.12	6/19/07
22773	BLT-3 MSD	-	0.82	0.57	1.29	0.048	0.13	6/19/07
24013	BLT-4	10	0.30	0.04	0.55	0.010	0.04	8/20/07
24013	BLT-4 DUP	13	-	-	-	-	-	8/20/07
24013	BLT-4 MS	-	0.75	0.50	0.93	0.055	0.09	8/20/07
24013	BLT-4 MSD	-	0.72	0.16	0.89	0.053	0.14	8/20/07
24024	BLT-2	6	0.20	0.02	0.17	0.006	0.12	8/21/07
24024	BLT-2 DUP	4	-	-	-	-	-	8/21/07
24024	BLT-2 MS	-	0.62	0.52	0.57	0.051	0.07	8/21/07
24024	BLT-2 MSD	-	0.70	0.58	0.54	0.053	0.12	8/21/07
24031	BLT-3	3	0.24	0.09	0.29	0.009	0.13	8/21/07
24031	BLT-3 DUP	1	-	-	-	-	-	8/21/07
24031	BLT-3 MS	-	0.70	0.53	0.66	0.054	0.08	8/21/07
24031	BLT-3 MSD	-	0.72	0.51	0.61	0.055	0.11	8/21/07
21852	BLT-5	6	0.29	0.08	0.57	< 0.005	0.02	11/16/2007
21852	BLT-5 DUP	4	-	-	-	-	-	11/16/2007
21852	BLT-5 MS	-	0.73	0.54	1.21	0.045	0.06	11/16/2007
21852	BLT-5 MSD	-	0.71	0.51	1.13	0.041	0.06	11/16/2007