Lake Charlevoix Tributary Monitoring Study

By Tip of the Mitt Watershed Council

2013 - 2014

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SUMMARY

Stakeholder's concerns regarding nonpoint source pollution led to development of the Lake Charlevoix Watershed Management Plan. Per plan recommendation WQ.8, the Lake Charlevoix Tributary Monitoring Project (LCTMP) was implemented to help assess and control sediment and nutrient pollution. Water quality and discharge data were collected from thirteen sites on streams flowing into Lake Charlevoix during 12 sampling events in 2013 and 2014. Streams monitored included: Horton Creek, the Boyne River (3 sites), Porter Creek, the Jordan River (2 sites), Brown Creek, Birney Creek, Deer Creek, Monroe Creek, Loeb Creek, and Stover Creek. Discharge measurements and water quality parameter concentration data collected were used to calculate daily and annual pollutant loads at each sampling location.

Bacteriological monitoring results from discreet samples showed that the DEQ Part 4 Water Quality Standards (WQS) partial-body contact limit of 1000 *E. coli*/100mL was exceeded at several sample sites, including Horton Creek (42% of samples), Brown Creek (27%), Loeb Creek (25%), Monroe Creek (25%), Porter Creek (25%), and Boyne River South Branch (9%). The highest exceedance rates for the WQS full-body contact limit of 300 *E. coli*/100mL occurred in Loeb Creek (92% of samples), Birney Creek (75%), Stover Creek (75%), Horton Creek (50%), Monroe Creek (50%), and Porter Creek (42%). High bacteria concentrations are a threat to public health to those recreating in in the creeks, rivers, and in Lake Charlevoix.

Averaged total phosphorus concentrations were generally below the USEPA reference condition of 12 µg/L in the Lake Charlevoix tributaries, the highest levels occurring in Loeb Creek, Stover Creek, and Birney Creek. Conversely, averaged total nitrogen concentrations were above the USEPA reference condition of 440 µg/L at all but two sites, and highest in Horton Creek, Stover Creek, and the Jordan River. Averaged chloride concentrations in the Lake Charlevoix tributaries were far below the USEPA-recommended chronic toxicity level of 230 mg/L and highest in Loeb Creek, Birney Creek, and Stover Creek. Accordingly, conductivity levels were highest in Stover, Birney, and Loeb Creeks. Total suspended solid concentrations were highest in Birney, Brown, Stover, and Monroe Creeks. Dissolved oxygen concentrations at all LCTMP sites were consistently above the WQS minimum of 7 mg/L for sustaining a cold-water fishery. Averaged water temperatures were lowest in Horton Creek (9.60° Celsius) and highest in the Boyne River at Park Street (13.65° Celsius). WQS water temperature maximums for cold-water fish were exceeded four times in the Boyne River Park St and South Branch sites, three times in Deer Creek, two times in Loeb Creek, and one time in Birney, Porter, and Stover Creeks. All pH readings at LCTMP sites fell within the range of 6.5 to 9.0 required for all surface

waters according to DEQ WQS.

Averaged discharge from the Lake Charlevoix tributaries ranged from 2.78 cfs in Brown Creek to 318.3 cfs in the Jordan River. Combined (total) discharge into Lake Charlevoix from the LCTMP tributaries ranged from 287 cfs to 1760 cfs with an average of 532 cfs. On average, the Jordan River accounted for 60% of the discharge into Lake Charlevoix from the LCTMP tributaries, followed by the Boyne River at 25%. Relative to discharge, the percentage of the total phosphorus and dissolved organic carbon (DOC) loads were high in Loeb, Monroe, Porter, and Stover Creeks, while the percentage of the total nitrogen load was high in Horton Creek, the Jordan River, and Stover Creek. Chloride loads were high in the Boyne River, Loeb Creek, and Stover Creek, relative to discharge, and total suspended solid loads were high in the Jordan River, Monroe Creek, and Stover Creek.

Monitoring results show that most parameters monitored in the Boyne River met DEQ WQS. Water temperatures at the South Branch and Park Street sites were above WQS monthly temperature maximums for sustaining a cold water fishery during several monitoring events. In addition, averaged total nitrogen concentrations were above the USEPA reference condition at the South Branch and Park Street sites. The Boyne Falls Mill Pond and the Boyne City Mill Pond are the likely culprits for elevated water temperatures at the South Branch and Park Street sites, respectively. High nitrogen concentrations documented in the Boyne River in both archive and LCTMP data may be linked to agricultural activity in the Mancelona Plains.

There is little evidence of water quality problems on the main branch of the Jordan River. However, total nitrogen concentrations were far above the USEPA reference condition and among the highest in the LCTMP streams. Recent research attributes elevated nitrogen levels in the Jordan River to fertilizer application in agricultural operations in the Mancelona Plains. Deer Creek water temperatures exceeded WQS maximums for cold-water fish three times, which is likely caused by an impoundment located less than one mile upstream. A variety of sources, such as septic systems, wildlife, and roads, invariably contribute to high *E. coli*, total suspended solid, and nitrogen concentrations in Birney Creek, but agriculture is suspected to be the primary source of these pollutants. Monitoring results show that Brown Creek is minimally impacted despite flowing through the City of East Jordan, though high *E. coli* and moderately high chloride concentrations were documented.

Averaged nitrogen concentrations and loads in Horton Creek were higher than all other LCTMP streams. There are signs of eutrophication in Horton Creek as a result of nutrient pollution, including extensive algae growth and relatively low dissolved oxygen concentrations. High bacteria counts in Horton Creek are also a concern. Agriculture in the watershed is suspected as a primary source of pollution to the creek.

Results from the LCTMP show evidence of water quality problems in Stover Creek. Stover Creek had the highest averaged total phosphorus, total nitrogen, nitrate-nitrogen, dissolved organic carbon, chloride, and conductivity levels among LCTMP streams. Pollutant load percentages from Stover Creek were two to three times higher than would be expected based on discharge. Based on the recently completed Stover Creek Watershed Restoration and Management Plan, nutrient pollution and other water quality problems are occurring at upstream locations as well. Extensive agricultural (40%) and urban land cover (10%) in the watershed are probably responsible for the water quality issues in Stover Creek.

Loeb Creek was found to contribute large loads of total phosphorus, DOC, and chloride to Lake Charlevoix, relative to discharge. Runoff from residential and commercial areas is suspected of contributing chloride and phosphorus to Loeb Creek and the high DOC levels were attributed to extensive wetlands that comprise 36% of the watershed land cover. Archive and LCTMP data show little evidence of pollution in Monroe Creek and Porter Creeks. Relatively large DOC loads from these creeks are probably the result of riparian wetlands in their watersheds.

Annual contributions to Lake Charlevoix from the LCTMP streams are enormous, totaling nearly 10,000 pounds of phosphorus and 12,000,000 pounds of sediments. In spite of these loadings, high water transparency and low phosphorus levels show that high water quality persists in Lake Charlevoix. However, nitrogen concentrations in Lake Charlevoix, particularly in the South Arm, show high levels relative to other large lakes in Northern Michigan. Excessive nitrogen inputs can cause shifts in the aquatic food web and, in fact, there is evidence of algal community shifts occurring in neighboring lakes of similar size. Other research showing evidence that high nitrogen levels drive invasion by non-native species may be playing out in Lake Charlevoix.

INTRODUCTION

Background

Nonpoint source pollution has long been recognized by stakeholders in the Lake Charlevoix Watershed as a threat to the water quality and lake ecosystem of Lake Charlevoix. Concerns regarding nonpoint source pollution led to the formation of the Lake Charlevoix Watershed Advisory Committee (Committee) and subsequent development of the Lake Charlevoix Watershed Nonpoint Source Pollution Inventory and Watershed Management Plan (Plan) in 2001. The Plan, which was updated in 2012, includes results of resource inventories, such as road/stream crossings, streambank erosion, and agricultural practices as they relate to nonpoint source pollution as well as recommendations for addressing problems. Plan development identified sediments and nutrients as primary nonpoint source pollutants in the Lake Charlevoix Watershed. Per the following Plan recommendation, the Lake Charlevoix Tributary Monitoring Project (LCTMP) was proposed to help assess and control these pollutants.

- Monitor tributaries (includes the Jordan and Boyne Rivers, Stover, Horton, Porter/Dyer, Monroe, and Loeb Creeks) at mouths to calculate pollutant loadings to Lake Charlevoix.

Monitoring had been carried out to varying degrees in most of the major tributaries to Lake Charlevoix, though water quality data were not available for several streams. Furthermore, the Lake Charlevoix tributaries had never been monitored concurrently. Through LCTMP implementation, nonpoint source pollution could be assessed at the sub-watershed scale. Sub-watersheds found to contribute excessive pollutant loads to Lake Charlevoix could then be further assessed to determine pollution sources. Suspected water quality pollutants sources include agricultural practices, road/stream crossings, shoreline/streambank management, urban stormwater, and septic systems. The goals of the LCTMP are to:

- Collect accurate, reproducible water quality and discharge data from all major tributaries flowing into Lake Charlevoix during a variety of flow conditions throughout all seasons of the year.
- Calculate pollutant loadings for each monitoring site to assess relative impacts of individual sub-watersheds.
- Provide information gathered during this project to Watershed stakeholders, and water resource management organizations and agencies to assist with controlling and reducing nonpoint source pollution.

Ultimately, the LCTMP will improve the Committee's understanding of nonpoint source pollution in the watershed and provide valuable information for Plan updates, particularly in terms of modifying existing recommendations or developing new recommendations based on the study's results.

Study Area

The streams monitored in the LCTMP pertain to the Lake Charlevoix Watershed, which is located in the northwestern Lower Peninsula of Michigan. Lake Charlevoix is a large, deep oligotrophic lake with over 17,000 acres of surface area, a maximum depth of 122 feet, and approximately 60 miles of shoreline. The following tributaries, in counter clockwise order starting at the Pine River outlet on the northwest side of the lake, were included in the study: Stover Creek, Loeb Creek, Monroe Creek, the Jordan River, Porter Creek, the Boyne River, and Horton Creek (Figure 1). In addition, tributaries of the rivers, including Birney, Deer, and Brown Creeks in the Jordan River system, and the North and South Branches of the Boyne River, were monitored. These tributaries flow into and influence the water quality and ecosystem of Lake Charlevoix, which in turn empties into and affects Lake Michigan.

The Lake Charlevoix Watershed extends from headwaters in the southeast to the outlet in the northwest (Figure 1). The Lake Charlevoix Watershed covers 213,216 acres; primarily in Charlevoix County, but also extending into Antrim and Otsego Counties. The combined area of the LCTMP sub-watersheds is 162,228 acres, representing 76% of the Lake Charlevoix Watershed.

Land cover statistics were generated for the Lake Charlevoix Watershed using remote sensing data from the NOAA Coastal Great Lakes Land Cover project (Figure 2). The watershed is still predominantly forested, but development is occurring at a rapid pace, reducing the amount of forests, agricultural lands, and wetlands. According to land cover data from 2010, 16.3% of the Lake Charlevoix Watershed was classified as agricultural while 4.5% was urban (Table 1). During the 10-year period spanning from 2000 to 2010, urban and agricultural landcover combined increased by 2.4%. LCTMP streams that flow through, and are potentially impacted by, urban areas include Stover Creek, the Boyne River, the Jordan River, and Brown Creek. Agriculture likely affects most LCTMP streams to some degree, but is most prevalent in the Stover, Loeb, and Birney Creek Watersheds.

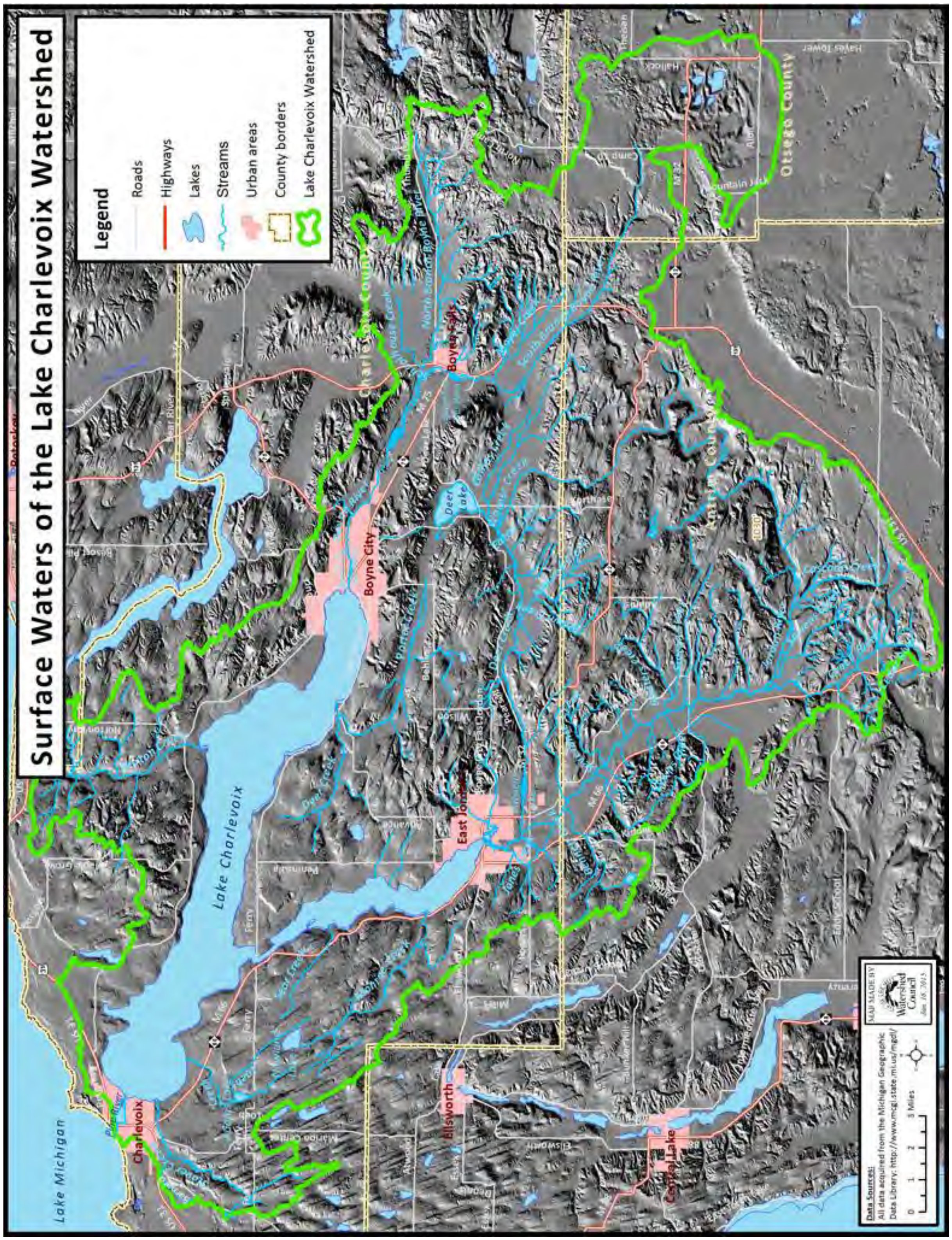

Figure 1. Surface waters of the Lake Charlevoix Watershed.

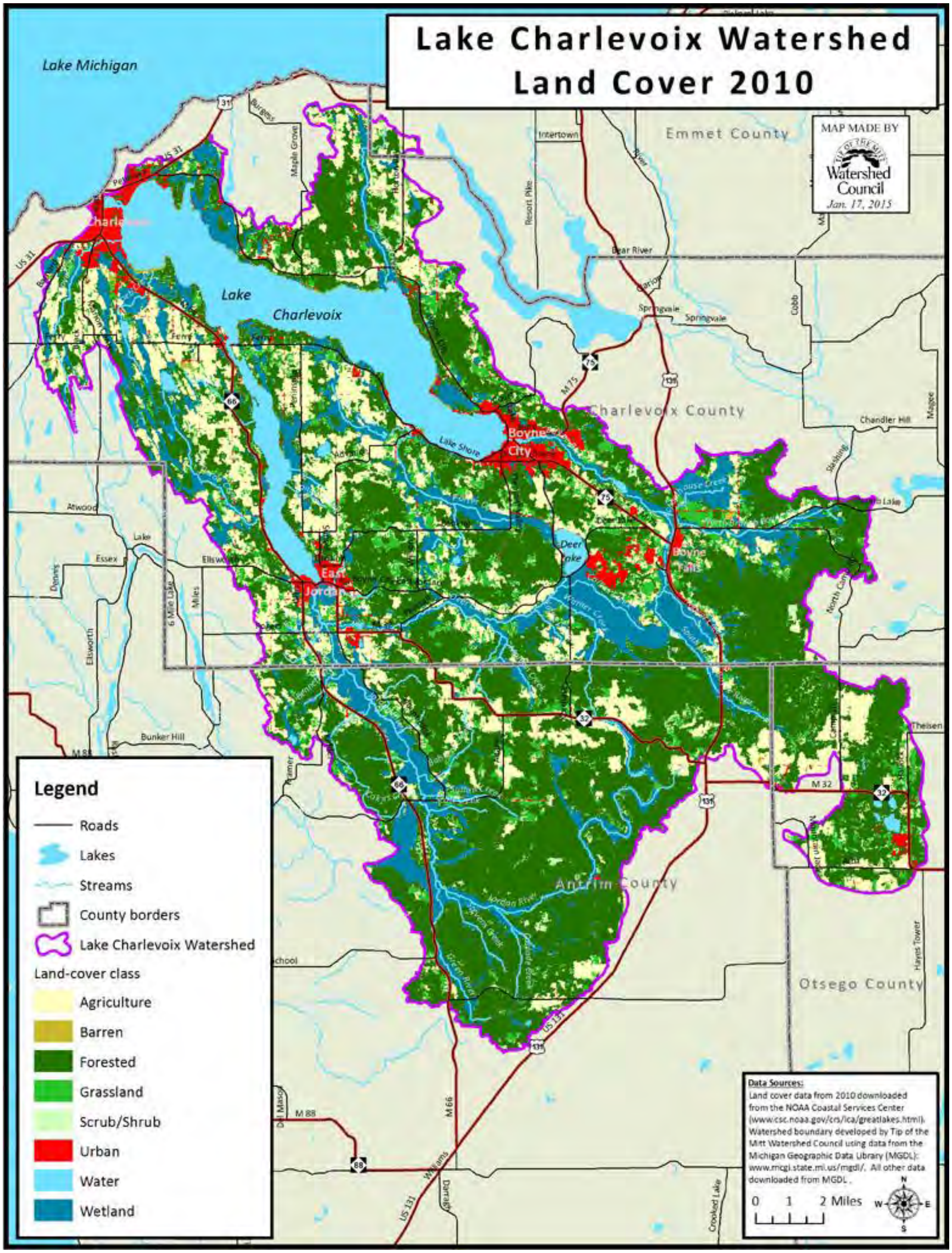

Figure 2. Lake Charlevoix Watershed Land Cover 2010.

Table 1. Lake Charlevoix Watershed land-cover statistics.

Land Cover Type	2000 Acreage	2000 Percent	2010 Acreage	2010 Percent	Change (%)
Agriculture	33,159	15.6	34,615	16.3	0.7
Barren	734	0.3	555	0.3	-0.1
Forested	100,032	47.0	97,739	46.0	-1.0
Grassland	24,029	11.3	15,470	7.3	-4.0
Scrub/shrub	4,883	2.3	5,921	2.8	0.5
Urban	6,097	2.9	9,660	4.5	1.7
Water	18,676	8.8	18,514	8.7	-0.1
Wetland	25,042	11.8	30,041	14.1	2.4
TOTAL	212,652	100.0	212,515	100.0	NA

The two primary inlet tributaries, the Boyne and Jordan Rivers, drain over 70% of the land in the Lake Charlevoix Watershed; 45,912 and 83,056 acres respectively (Table 2). The largest tributary, the Jordan River, flows nearly 26 miles from headwaters in Antrim County near the intersection of US131 and M32 to its outlet into the South Arm of Lake Charlevoix at the City of East Jordan (Figure 1). Throughout its course, the main channel of the Jordan River drops over 610 feet. A dense network of tributaries flow into the Jordan River, the largest being the Green River in headwaters to the south, and Deer Creek, which drains Deer Lake and much of the land area between East Jordan and Boyne Falls. Other tributaries include Balsters, Bartholomew, Bennett, Birney, Brown, Cascade, Cokris, Collins, Eaton, Jones, Landslide, Lilac, Nemecheck, Scott, Severance, Stevens, Sutton, Warner, and Webster Creeks. These tributaries comprise over 200 additional channel miles.

Table 2. Watershed and channel statistics for LCTMP streams.

Stream Name:	Boyne River	Jordan River	Horton Creek	Stover Creek	Loeb Creek	Monroe Creek	Porter Creek
Watershed Area (acres)	45,912	83,056	7,817	4,242	3,329	6,455	11,417
Channel Length (miles)	28.3	25.8	6.3	8.2	5.8	6.6	6.0
Vertical Drop (feet)	730	610	190	180	140	120	160
Stream Gradient (feet/mile)	25.8	23.6	30.2	22.0	24.1	18.2	26.7

The Jordan was the first to receive the State of Michigan's designation as "wild and scenic" under the state's Natural Rivers Act of 1970. In addition, sections of the river are considered high-quality Blue Ribbon Trout Streams by the Michigan Department of Natural Resources (MDNR). Of particular note is the Jordan River Spreads, a highly productive and diverse natural area covering several hundred acres adjacent to the City of East Jordan. Habitat in the Spreads transitions from the open waters of Lake Charlevoix through shallow submerged aquatic plant beds; emergent vegetation such as rushes, sedges, and cattails; wetlands dominated by shrubs (willow, alder, dogwood) and trees (cedar, balsam poplar, black ash, red maple); to uplands. Long-term data (1967 to 2015) from a USGS gauge station on the Jordan River at Webster Bridge Road show a daily mean range of 130 cubic feet per second (cfs) to 840 cfs, with an annual average of 185 cfs. The maximum individual measurement of discharge at Webster Bridge Road was 1360 cfs.

The second largest tributary is the Boyne River, which flows into the southeast end of Lake Charlevoix's main basin (Figure 1). The Main Branch drops 80 feet as it flows 6.5 miles from the confluence of the North and South Branches near Boyne Falls to the outlet into Lake Charlevoix at Boyne City (Table 2). The North Branch extends another 6.5 miles to its headwaters in the Thumb Lake area, with a vertical drop of 370 feet as it traverses its 11,647-acre watershed. The South Branch of the Boyne River starts in northwestern Otsego County and flows through northeastern Antrim County until merging with the North Branch in southern Charlevoix County. It drops 650 feet as it meanders 12 miles through its 26,553-acre watershed.

There are three impoundments on the Boyne River: the Boyne City Mill Pond near the mouth, the Boyne USA Power Plant and Dam on the Main Branch at Dam Road and the Boyne Falls Mill Pond on M75. Portions of the Main and North Branch are recognized as State Designated Blue Ribbon Trout Streams. Discharge measurements by the Little Traverse Bay Bands of Odawa at Park Street in Boyne City from 2004 to 2007 ranged from 75 cfs to 161 cfs, with an average of 102 cfs.

Horton, Stover, Loeb, Monroe, and Porter Creeks are the largest of the multitude of small inlet streams that flow into Lake Charlevoix. Horton Creek flows over 6 miles through its 7,817-acre watershed that extends from headwaters less than a mile from Little Traverse Bay to the north side of Lake Charlevoix where the creek flows into Horton Bay (Figure 1, Table 2). The main branch of Stover Creek flows over 8 miles through a 4,242–acre watershed until emptying into the west end of Lake Charlevoix at the City of Charlevoix. Loeb Creek flows nearly 6 miles from headwaters near Nowland Lake and passing through Adams Lake on it journey through a 3,329-acre watershed to Loeb Bay at the east end of Lake Charlevoix. Monroe Creek shares its headwater area with Loeb Creek, flowing from Nowland Lake 6.5 miles in a southeasterly direction through a 6,455-acre watershed before emptying into the west side of Lake Charlevoix's South Arm. Porter Creek drains a 11,417-acre watershed via two main branches: Dyer Creek, which flows 4 miles from north to south; and Porter Creek, which flows 6 miles from south to north.

Review of Existing Monitoring Data for the Lake Charlevoix Tributaries

Water quality data for Lake Charlevoix Watershed streams were obtained from the Michigan Department of Environmental Quality (DEQ), United States Environmental Protection Agency (USEPA), Tip of the Mitt Watershed Council (TOMWC), United States Fish and Wildlife Service (USFWS), United States Geological Survey (USGS), and the Little Traverse Bay Bands of Odawa Indians (LTBB). "Legacy" water quality data (prior to year 2000) from the USEPA STORET database was obtained from DEQ. Data from DEQ were available for 68 locations in the watershed and stretch back to 1960 at some sites. Watershed Council staff and volunteers have monitored water quality since 2004 at 14 sites in the Boyne River, Jordan River, Horton Creek, and Stover Creek. The USFWS has monitored 52 sites in the Jordan River system (1973-2014), 8 sites on the Boyne River (1977-2013), 12 sites on Horton Creek (1970-2013), and 8 sites in the Porter Creek system (1970-2013). The USGS monitored five sites on the Jordan River from 1966 to 1971 and the LTBB have monitored three sites on the Boyne River since 2004.

Water quality has been monitored in many of the rivers and streams in the Lake Charlevoix Watershed including: Bennett Creek, Birney Creek, the Boyne River, Brown Creek, Cascade Creek, Collins Creek, Covenant Creek, Deer Creek, Dyer Creek, Delilah Creek, Eaton Creek, Five-tile Creek, the Green River, Hog Creek, Horton Creek, Job Creek, Jones Creek, the Jordan River, Joshua Creek, Landslide Creek, Loeb Creek, Marvon Creek, Mill Creek, Monroe Creek, Moyer Creek, Porter Creek, Saul Creek, Schoolhouse Creek, Scott Creek, Severence Creek, Six-tile Creek, Stevens Creek, Stover Creek, Suttons Creek, Todd Creek, Unnamed Creek, Warner Creek, and Webster Creek (Figure 3). Most of these streams are part of the larger Boyne and Jordan River systems.

Water quality data types for streams include physical, chemical, biological, channel, and discharge (Table 3). Physical data include parameters such as dissolved oxygen and pH; chemical data include parameters such as nutrients and metals; biological data documents the aquatic macroinvertebrate community; channel data include parameters such as width, depth, and riparian vegetation; and discharge data measure volume per unit time (e.g., cubic feet per second). The types and amount of water quality data available vary from stream to stream; in general, more data are available for rivers and less for creeks.

The Boyne River

Water quality data available from DEQ, TOMWC, USFWS, and LTBB for the Boyne River and its tributaries indicate that the stream ecosystem is healthy. The DEQ has water quality data from

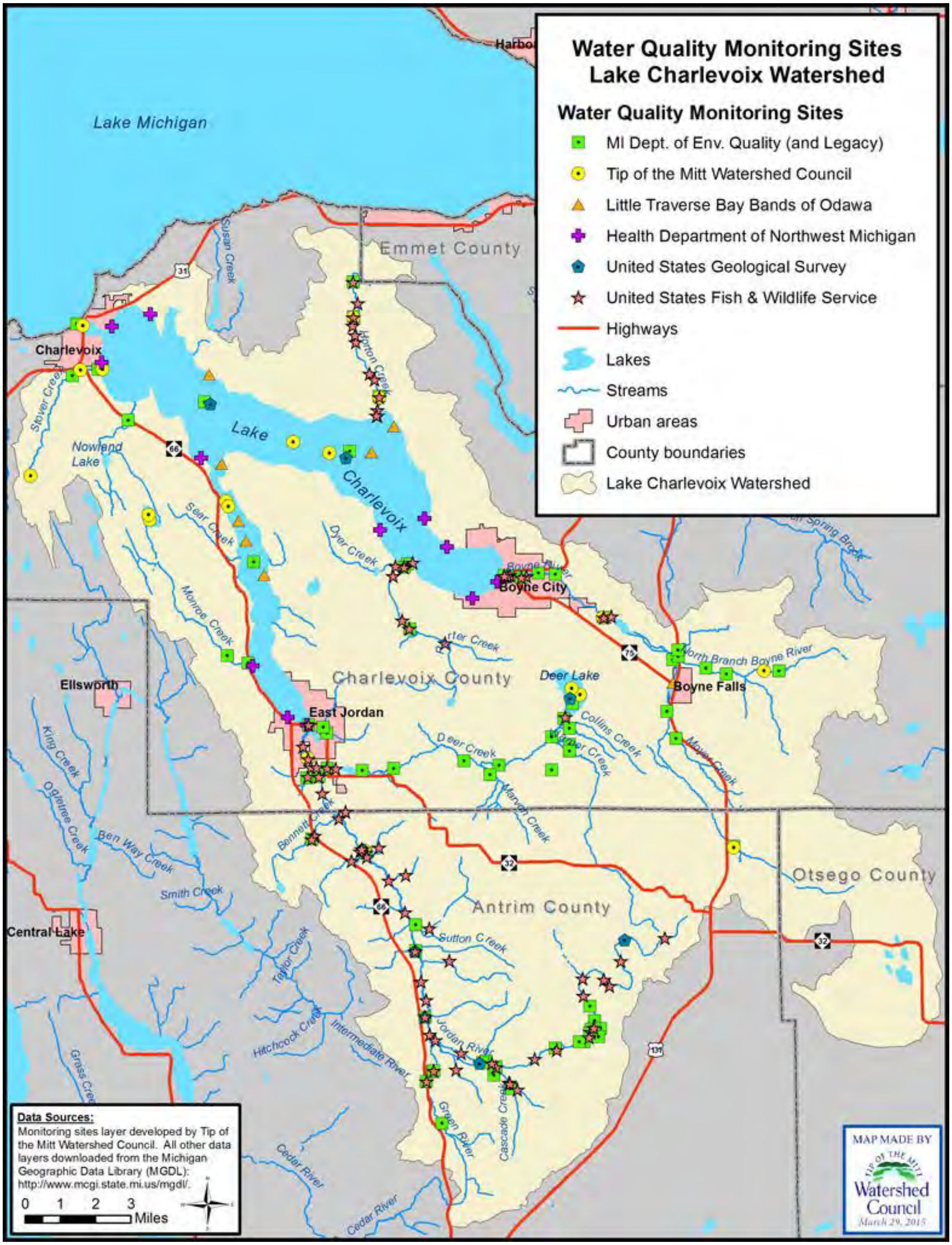

Figure 3. Water quality monitoring sites in the Lake Charlevoix Watershed.

Table 3. Archived water quality data for the LCTMP streams.

Tributary Name	River or Creek System	Water Quality Data Availability:*					Water Quality Data Types Available: †				
		DEQ	TOMWC	LTBB	USGS	USFWS	Physical	Chemi-cal	Biologi-cal	Channel	Dis-charge
Bennett Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Birney Creek	Jordan River	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
Boyne River	Boyne River	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Brown Creek	Jordan River	Yes	No	No	No	No	Yes	Yes	No	No	Yes
Cascade Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes
Collins Creek	Deer Creek	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
Covenant Creek	Jordan River	No	No	No	No	Yes	No	No	No	No	Yes
Deer Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Dyer Creek	Porter Creek	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Delilah Creek	Jordan River	No	No	No	No	Yes	No	No	No	No	Yes
Eaton Creek	Deer Creek	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
Five-tile Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes
Green River	Jordan River	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes
Hog Creek	Deer Creek	Yes	No	No	No	No	No	Yes	No	No	No
Horton Creek	Horton Creek	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Job Creek	Jordan River	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Jones Creek	Jordan River	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Jordan River	Jordan River	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Joshua Creek	Jordan River	No	No	No	No	Yes	No	No	No	No	Yes
Landslide Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Loeb Creek	Loeb Creek	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Marvon Creek	Deer Creek	Yes	No	No	No	No	No	Yes	No	No	No
Mill Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Monroe Creek	Monroe Creek	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Moyer Creek	Boyne River	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
Porter Creek	Porter Creek	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes
Saul Creek	Jordan River	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Schoolhouse Crk	Boyne River	Yes	No	No	No	No	No	Yes	No	Yes	Yes
Scott Creek	Jordan River	No	No	No	No	Yes	No	No	No	No	Yes
Severance Creek	Jordan River	No	No	No	No	Yes	No	No	No	No	Yes
Six-tile Creek	Jordan River	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes
Stevens Creek	Jordan River	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Stover Creek	Stover Creek	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes
Suttons Creek	Jordan River	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Todd Creek	Jordan River	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Unnamed Creek	Jordan River	Yes	No	No	No	No	No	Yes	No	No	No
Warner Creek	Deer Creek	Yes	No	No	No	No	No	No	Yes	Yes	Yes
Webster Creek	Jordan River	No	No	No	No	Yes	No	No	No	No	Yes

** DEQ=Michigan Department of Natural Resources and Environment, TOMWC=Tip of the Mitt Watershed Council, LTBB=Little Traverse Bay Bands of Odawa, USGS=United States Geological Survey.*
† Examples of types: physical: dissolved oxygen and pH; chemical: nutrients and metals; biological: macroinvertebrates; channel: width, depth, and riparian vegetation; discharge: cubic feet per second.

15 locations in the Boyne River Watershed (Figure 4) that span more than 45 years. Volunteers and staff from TOMWC have monitored water quality from 2004 to present at four locations on the Boyne River. The USFWS has monitored 8 sites with data going back to 1977. LTBB has monitored 3 locations on the river since 2004. Data collected show that all sites monitored in the Boyne River Watershed consistently meet Michigan WQS.

Dissolved Oxygen

Dissolved oxygen is one of the most important parameters monitored for assessing water quality. Oxygen is required by almost all organisms, including those that live in the water. Oxygen dissolves into the water from the atmosphere and through photosynthesis of aquatic plants and algae. State law requires that a minimum of seven parts per million (mg/L) be maintained in streams like the Boyne River designated as a cold-water fishery.

Water quality data from six locations on the Boyne River show dissolved oxygen concentrations to be consistently high. Dissolved oxygen has been monitored at two locations on the North Branch: Thumb Lake Rd and US131, one location on the South Branch: M75, and five locations on the main stem: Dam Road, Spring St, East St, Boyne City Park, and Lake St. Data at some sites go back to 1967; the most recent data are from 2013. All readings were above the state WQS of 7 mg/L, attesting to the high water quality of the Boyne River (Table 4).

Table 4. Archive dissolved oxygen data for the Boyne River.

River Section	Location	Data Sources	Low*	High*	Average	Time Period
North Branch	Thumb Lake Rd	DEQ†	11.8	11.8	11.8	1967
North Branch	US131, Boyne Falls	DEQ†	8.4	11.8	9.6	1967-1970
South Branch	M75, Boyne Falls	LTBB, USFWS	9.2	18.0	11.4	2004-2013
Main Branch	Dam Road	DEQ†, LTBB, USFWS	8.2	14.7	10.4	1977-2013
Main Branch	Spring St	USFWS	7.6	11.4	9.7	1997-2010
Main Branch	East St	USFWS	7.9	11.5	9.5	1990-2013
Main Branch	Boyne City Park	DEQ†, LTBB, TOMWC, USFWS	8.3	14.0	11.4	1977-2013
Main Branch	Lake St, mouth	DEQ†	7.5	13.7	10.0	1968-2006

**units: milligrams per liter or parts per million.*
†DEQ data include legacy data from USEPA.

Alkalinity, Hardness, and pH

Alkalinity, hardness, and pH data indicate that water of the Boyne River contains relatively high amounts of calcium carbonate ($CaCO_3$), which classify it as a moderately alkaline stream with a high buffering capacity (i.e., acid neutralizing), and with very hard water. Alkalinity data from the DEQ and USFWS for 19 locations in the Boyne River Watershed had an average value of 194 mg/L $CaCO_3$ (Table 5). Hardness data from DEQ and USFWS for three sites in the watershed

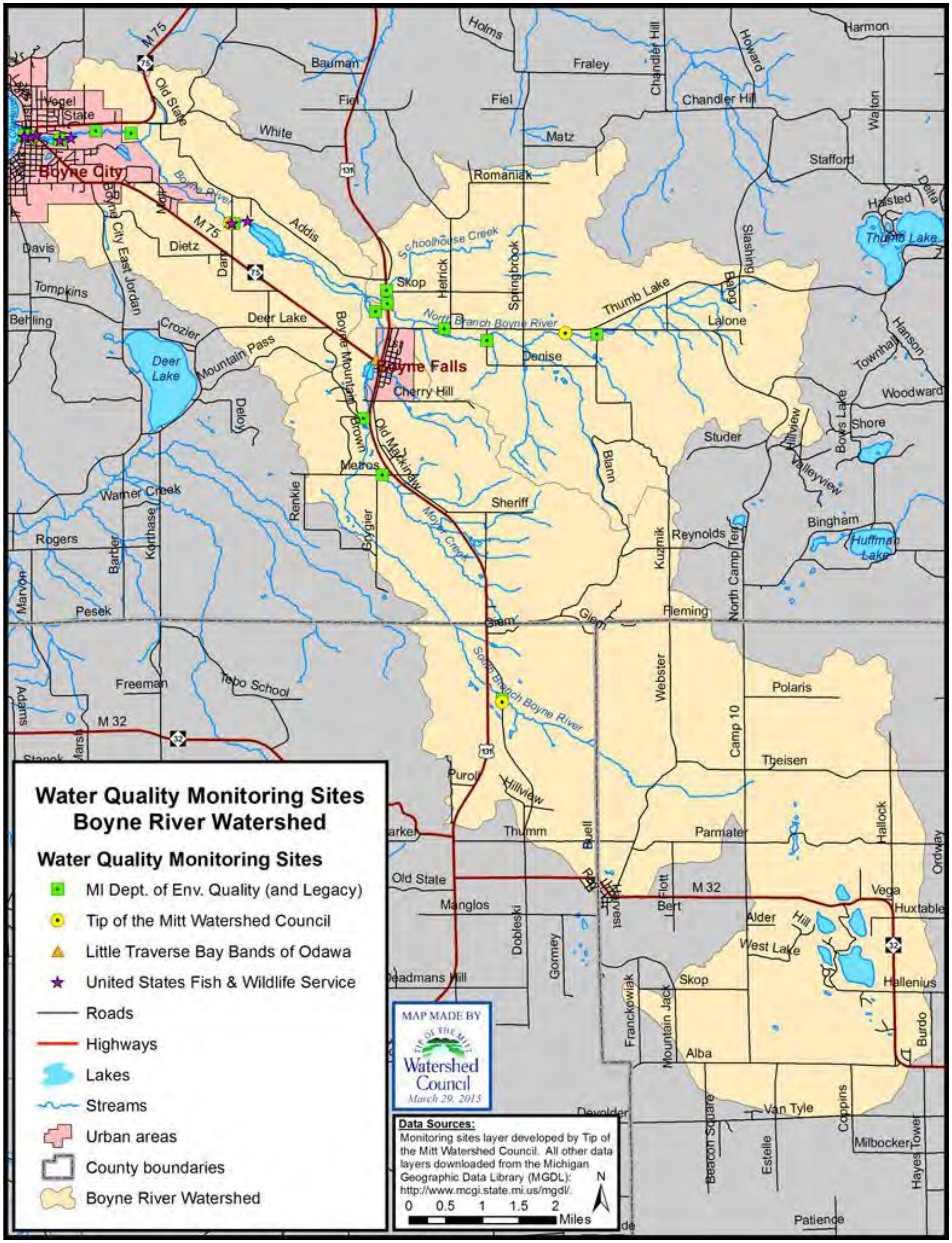

Figure 4. Water quality monitoring sites for Boyne River Watershed.

averaged 201 mg/L $CaCO_3$. The DEQ, LTBB, USFWS, and TOMWC pH data for 13 sites on the river averaged 8.3.

Table 5. Archive alkalinity, hardness, and pH data for the Boyne River.

Parameter	Low * (value)	Low (year)	Low (site)	High* (value)	High (year)	High (site)	Average Value*
Alkalinity	125	1973	Mouth	226	2003	North Branch US131	194
Hardness	166	2005	Spring St	254	2003	North Branch US131	201
pH	7.2	1974	Mouth	8.8	2010	M75	8.1

**alkalinity and hardness measured in milligrams per liter CaCO3 or parts per million.*

Conductivity and Chloride

Conductivity is a measure of the ability of water to conduct an electric current, which is dependent upon the concentration of charged particles (ions) dissolved in the water. Chloride, a component of salt, is a negatively charged particle that contributes to the conductivity of water. Chloride is a "mobile ion," meaning it is not removed by chemical or biological processes in soil or water. Many products associated with human activities contain chloride (e.g., de-icers, water softeners, fertilizers, and bleach). Conductivity and chloride levels in lakes and streams tend to increase as population and human activity in a watershed increase. Research shows that both conductivity and chloride levels in surface waters are good indicators of human disturbance in a watershed, particularly from urban land use (Jones and Clark 1987, Lenat and Crawford 1992, Herlihy et al. 1988).

Conductivity and chloride data from the Boyne River were available from DEQ, LTBB, and TOMWC (

Table 6). Specific conductivity in the Boyne River, measured in microSiemens (µS), has ranged from 305 µS (LTBB, Dam Rd, 2006) to 455 µS (LTBB, Boyne City Park, 2013). LTBB has the most extensive conductivity dataset, though limited to the years 2004 through 2013. Averaged data from LTBB show a slight increase in conductivity levels from the mid-stream site at Dam Road (387 µS) to the Boyne City Park site near the river mouth (404 µS). Legacy data from DEQ for the lower section of the river (near the river mouth on Lake St.) show lower conductivity levels in the 1970s (an average of 377µS) as compared with recent data. However, there were only 16 records from 1973 to 1975 versus 57 records from 2003 to 2013.

Chloride has been monitored in the Boyne River by DEQ, TOMWC, and LTBB (Table 7). The 45 records show a range of 0.0 mg/L (State Legacy data, 1967) to 17.2 mg/L (LTBB, 2013). Based on data collected at locations near the mouth of the river, chloride concentrations have increased from an average of 2.9 mg/L during the 1970s to 12.8 mg/L during recent years (2004 to 2013).

Table 6. Archive specific conductivity data for the Boyne River.

River Section	Location	Data sources	Low (µs)	High (µS)	Avg. (µS)	Time Period	Number of Samples
S. Branch	Dobleski Rd.	DEQ	394.0	394.0	394.0	2003	1
S. Branch	Moyer Creek	DEQ	385.0	385.0	385.0	2003	1
S. Branch	Boyne Mountain Rd	DEQ	394.0	394.0	394.0	2003	1
S. Branch	M75, Boyne Falls	LTBB	308.8	439.4	393.7	2004-2013	54
N. Branch	US131, N. Branch	DEQ	405.0	405.0	405.0	2003	1
Main	Dam Rd.	LTBB	304.8	429.0	386.6	2004-2010	40
Main	Boyne City Park	LTBB, DEQ, TOMWC	331.5	455.0	404.0	2003-2013	58
Main	Lake St.	DEQ*	345.0	408.0	378.4	1973-75, 1993	17

**includes Legacy data from USEPA obtained from DEQ.*

Table 7. Archive chloride data for the Boyne River.

River Section	Location	Data sources	Low (mg/L)	High (mg/L)	Avg. (mg/L)	Time Period	Number of Samples
S. Branch	Dobleski Rd.	DEQ	4.0	4.0	4.0	2003	1
S. Branch	Moyer Creek	DEQ	3.0	3	3	2003	1
S. Branch	Boyne Mountain Rd	DEQ	5.0	5.0	5.0	2003	1
S. Branch	M75 (Boyne Falls)	LTBB	8.7	12.0	10.3	2013	4
N. Branch	Thumb Lake Rd.	DEQ*	0.0	0.0	0.0	1967	1
N. Branch	US131, N. Branch	DEQ*	0.0	4.0	2.0	1968, 2003	2
Main	Park St.	LTBB, DEQ, TOMWC	6.1	17.2	12.3	2003-2013	9
Main	Lake St.	DEQ*	0.0	5.0	2.8	1968-75, 1993	21

**includes Legacy data from USEPA obtained from DEQ.*

The pattern of increasing chloride and conductivity corresponds with US Census data that show a steady population increase in counties in the Lake Charlevoix Watershed between 1970 and 2000. Nonpoint source pollution from urban areas in the watershed, particularly those located directly on tributaries, is the likely source of conductivity and chloride increases. These increases can be indicative of more harmful pollutants that are associated with human activity, but not regularly monitored, contaminating the watershed's surface waters (e.g., automotive fluids, metals, pesticides, etc.).

Nutrients: Phosphorus and Nitrogen

Nutrients are chemicals needed by organisms to live, grow, and reproduce. Nutrients occur naturally and can be found in soils, water, air, plants, and animals. Phosphorus and nitrogen are essential nutrients for plant growth and important for maintaining healthy, vibrant aquatic ecosystems. However, excess nutrients from sources such as fertilizers, faulty septic systems, and stormwater runoff lead to nutrient pollution, which can have negative impacts on the surface waters of the Lake Charlevoix Watershed. It has been estimated that one pound of phosphorus could stimulate 500 or more pounds of algae growth. Therefore, heavy phosphorus inputs into Lake Charlevoix from the tributaries could result in nuisance algae and plant growth, which could, in turn, degrade water quality and alter the natural lake ecosystem.

Due to the negative impacts that phosphorus can have on surface waters, legislation was first passed in Michigan to ban phosphorus in soaps and detergents and more recently, phosphorus use in fertilizers has been regulated. Michigan WQS do not include a numerical standard for nutrient concentration limits for surface waters. Regulation for surface waters is limited to the following narrative standard from Rule 60 (323.1060): "nutrients shall be limited to the extent necessary to prevent stimulation of growth of aquatic rooted, attached, suspended, and floating plants, fungi or bacteria which are or may become injurious to the designated uses of the waters of the state." However, a total phosphorus concentration of 12 micrograms per liter (µg/L) or less for streams in the Northern Michigan ecoregion is considered the reference condition by the USEPA "because it is likely associated with minimally impacted conditions, will be protective of designated uses, and provides management flexibility" (USEPA, 2001). The USEPA reference condition for total nitrogen in the same ecoregion is 440 µg/L or less. In addition, Michigan drinking water standards require that nitrate-nitrogen concentrations be less than 10 mg/L.

Phosphorus is one of several nutrients that have been monitored on the Boyne River by DEQ, TOMWC, and LTBB. Total phosphorus concentrations have ranged from 0.0 µg/L in the North Branch during the 1960s to 110.0 µg/L at the mouth in 1973 (Table 8). The averaged total phosphorus concentration from monitoring data collected between 1993 and 2013 is much lower than the average value of data collected between 1968 and 1978; 5.7 µg/L versus 18.4 µg/L, respectively. This decline over time could be explained by a variety of factors, including changes in analytical procedures that detect lower limits, improved regulations, and more widespread stewardship of water resources as a result of outreach and education. Changes to the river ecosystem brought on by invasive zebra mussels, which were documented at the Dam Road site by TOMWC volunteer stream monitors, may also play a role in the observed phosphorus declines. The averaged total phosphorus concentration from the recent time period are within the range of data from TOMWC's Comprehensive Water Quality Monitoring Program (CWQM) for rivers in this region (Table 9).

Total nitrogen, which includes all organic and inorganic forms and is important in determining whether a lake is nitrogen limited in relation to phosphorus, has been monitored by DEQ, LTBB, and TOMWC in the Boyne River. Total nitrogen concentrations have exceeded USEPA reference conditions consistently at sites on the South and Main Branches (Table 10). Of the 13 rivers monitored in the CWQM program, the Boyne River has the second highest nitrogen concentrations, surpassed only by the Jordan River (Table 9).

Table 8. Archive total phosphorus data for the Boyne River.

River Section	Location	Data sources	Time Period	Num. of Samples	Low (µg/L)	High (µg/L)	Avg. (µg/L)
S. Branch	Dobleski Rd.	DEQ	2003	1	8.0	8.0	8.0
S. Branch	Moyer Creek	DEQ	2003	1	7.0	7.0	7.0
S. Branch	Boyne Mountain Rd	DEQ	2003	1	12.0	12.0	12.0
S. Branch	M75 (Boyne Falls)	LTBB	2013	4	3.6	8.2	6.0
N. Branch	Kuzmick Rd.	DEQ	2003	1	10.0	10.0	10.0
N. Branch	Thumb Lake Rd.	DEQ*	1967	1	0.0†	0.0†	0.0†
N. Branch	Schoolhouse Creek	DEQ	2003	1	12.0	12.0	12.0
N. Branch	US131, N. Branch	DEQ*	1968-70, 2003	9	0.0†	100.0	36.3
Main	Dam Rd.	DEQ*	1977-78, 2003-05	17	3.0	26.0	8.1
Main	WWTP	DEQ	2005	4	8.0	27.0	14.3
Main	Spring Rd.	DEQ	2005	4	9.0	32.0	16.8
Main	Park St.	LTBB, DEQ*, TOMWC	1977-78, 2003-13	21	1.0	16.0	8.7
Main	Lake St.	DEQ*	1968-75, 1993	21	7.0	110.0	21.8

**includes Legacy data from USEPA obtained via DEQ.*

†Zero values are likely non-detect results due to analytical methods used in the past.

Table 9. Water quality data for rivers from the CWQM program.

River Name	Total Phosphorus* (µg/l)	Nitrate-Nitrogen* (µg/l)	Total Nitrogen* (µg/l)	Chloride* (mg/l)	Specific Conductivity* (µS/cm2)
Bear River	9.7	158	381	13.7	297.3
Black River	5.8	28	302	5.3	277.2
Boyne River	4.3	366	520	9.8	369.2
Cheboygan River	4.8	47	315	7.4	293.3
Crooked River	4.6	191	366	9.3	299.5
Elk River	4.5	224	342	8.4	272.1
Indian River	2.9	107	299	11.6	304.1
Jordan River	6.2	843	1052	8.4	341.3
Little Sturgeon River	5.9	63	241	12.5	309.4
Maple River	5.6	234	483	5.5	262.0
Pigeon River	7.1	51	298	6.0	311.8
Pine River	1.9	284	383	10.1	265.3
Sturgeon River	4.0	195	345	12.5	345.1
AVERAGE	**5.2**	**215**	**410**	**9.3**	**303.7**

Values in orange represent high values, whereas blue represent low values.

Table 10. Archive total nitrogen data for the Boyne River.

River Section	Location	Data Sources	Time Period	Num. of Samples	Low (µg/L)	High (µg/L)	Avg. (µg/L)
S. Branch	Dobleski Rd.	DEQ	2003	1	490	490	490
S. Branch	Moyer Creek	DEQ	2003	1	360	360	360
S. Branch	Boyne Mountain Rd	DEQ	2003	1	660	660	660
S. Branch	M75 (Boyne Falls)	LTBB	2013	4	410	790	595
N. Branch	Kuzmick Rd.	DEQ	2003	1	306	306	306
N. Branch	Schoolhouse Creek	DEQ	2003	1	304	304	304
N. Branch	US131, N. Branch	DEQ	2003	1	302	302	302
Main	Dam Rd.	DEQ*	1977-78, 2003-05	17	452	784	563
Main	WWTP	DEQ	2005	4	490	730	555
Main	Spring Rd.	DEQ	2005	4	490	800	578
Main	Park St.	LTBB, DEQ* TOMWC	1977-78, 2003-13	21	405	904	607
Main	Lake St.	DEQ*	1973-75, 1993	20	470	1,100	635

Biological Monitoring

Biological monitoring has been performed by DEQ and TOMWC at 12 sites on the Boyne River; three on the North Branch, four on the South Branch, and five on the Main Branch. DEQ biologists have monitored 11 sites in watershed. Volunteers, trained by TOMWC staff, monitor four sites as part of the Tip of the Mitt Volunteer Stream Monitoring (VSM) program. DEQ data are limited to one or two sampling events, whereas TOMWC data include up to 19 sampling events. DEQ biologists perform taxonomic identification to the family level in the field. Specimens collected by TOMWC volunteers are preserved in ethanol and identified to the family level by experienced aquatic macroinvertebrate taxonomists at a later date.

Biological data were assessed using three metrics: 1) total taxa = the total number of macroinvertebrate families found at a site; 2) EPT taxa = the number of families belonging to three insect orders that are largely intolerant of pollution (mayflies, stoneflies, and caddisflies); and 3) sensitive taxa = the number of macroinvertebrate families that are the most intolerant of pollution (those that rate 0, 1, or 2 in PhD William Hilsenhoff's family-level sensitivity classification system). At sites monitored by both DEQ and TOMWC, DEQ found higher numbers of total and EPT taxa, which is attributed to DEQ field biologists having more experience than TOMWC volunteers. However, numbers for sensitive taxa were quite similar among DEQ and TOMWC data, indicating that this metric is not as heavily influenced by collector(s) experience and therefore, the most reliable for making comparisons among datasets.

Biological data show strong diversity in the aquatic macroinvertebrate communities throughout the entire Boyne River. Of the 12 sites for which there are data, 30 or more total taxa were found at five sites, EPT taxa exceeded 10 families at nine sites, and five or more sensitive taxa were found at 11 sites (Table 11). In general, the lower section of the river, from Dam Road to Park Street, had higher total taxa diversity than the upper section (Figure 5). EPT diversity was also higher in the lower section on average, though not as pronounced. Sensitive taxa numbers were similar throughout the river system. The relatively high number of sensitive taxa found throughout the Boyne River, compared to other VSM program streams, is evidence of high water quality and a healthy ecosystem (Table 12).

Localized conditions may be contributing to the slightly lower sensitive taxa scores at Park Street on the lower section of the Boyne River. Urbanization in this lower section (Boyne City) results in stormwater inputs to the river laden with sediments, nutrients, metals and other pollutants commonly found in urban areas. Thermal pollution as a result of stormwater runoff flowing across pavement and other impervious surfaces may also have negative impacts on the water quality and aquatic macroinvertebrate populations in the Boyne City area.

Table 11: Archive biological monitoring data for the Boyne River.

Sample Site	River Section	Data Source	Time Period	Num. of samples	Total Taxa*	EPT Taxa*	Sensitive Taxa*
Dobleski Rd.	South Branch	DEQ	2003	1	21.0	13.0	6.0
Dobleski Rd.	South Branch	TOMWC	2005-2014	19	16.0	9.7	5.6
Moyer Creek	South Branch	DEQ	2003	1	19.0	9.0	6.0
Boyne Mountain Rd	South Branch	DEQ	1998-2003	2	21.5	10.5	6.0
Boyne Falls	South Branch	DEQ	2008	1	31.0	17.0	9.0
LTC Preserve	North Branch	TOMWC	2007-2014	14	16.6	8.6	4.6
Denise Rd.	North Branch	DEQ	2003	1	26.0	13.0	7.0
US131	North Branch	DEQ	1998-2003	2	19.5	9.0	5.5
Dam Rd.	Main	DEQ	2003-2004	2	32.5	12.5	5.5
Dam Rd.	Main	TOMWC	2007-2014	15	16.8	9.1	5.2
Lagoon	Main	DEQ	2004	1	30.0	12.0	5.0
Wastewater Plant	Main	DEQ	2004	1	34.0	14.0	6.0
Spring Rd.	Main	DEQ	2004	1	36.0	16.0	6.0
Park St.	Main	DEQ	2008	1	28.0	16.0	5.0
Park St.	Main	TOMWC	2005-2014	19	15.5	8.5	4.7

**Total taxa: total number of macroinvertebrate taxa; EPT taxa: taxa from pollution-sensitive insect orders (mayflies, stoneflies, and caddisflies); sensitive taxa: taxa most intolerant of pollution.*

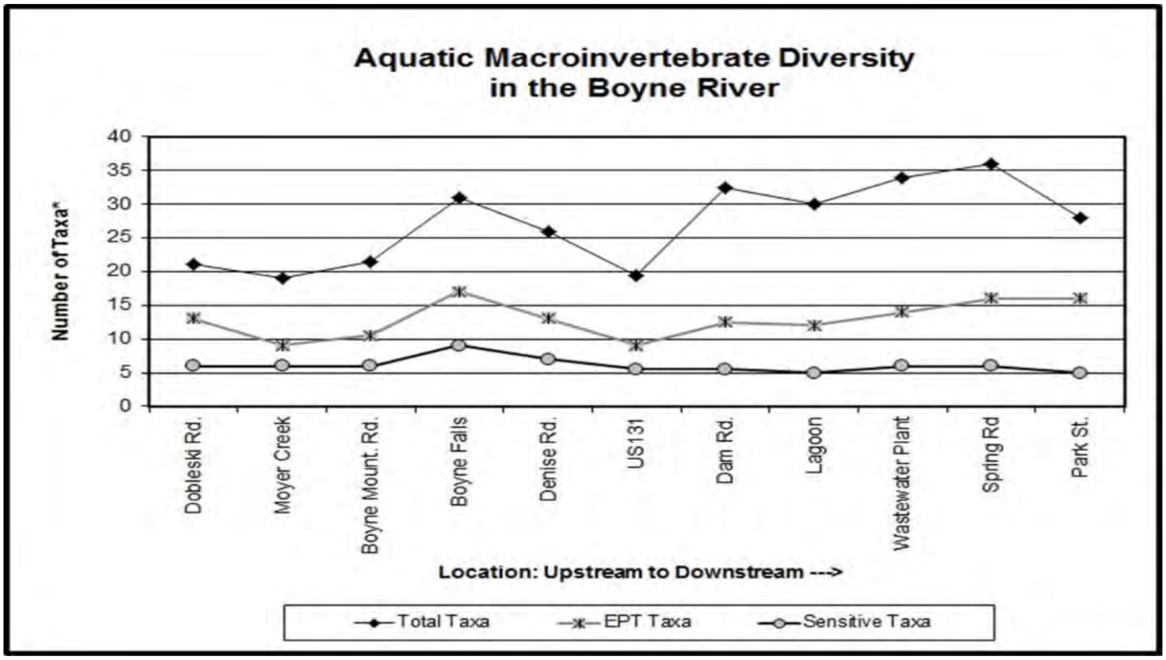

Figure 5. Macroinvertebrate diversity in the Boyne River.

Table 12. Sensitive Taxa from the TOMWC Volunteer Stream Monitoring Program.

River/Stream Name	Sensitive Taxa Low*	Sensitive Taxa High*	Sensitive Taxa Average*
Bear River	2.0	4.7	3.0
Boyne River	4.8	5.6	5.0
Eastport Creek	1.8	4.2	3.0
Horton Creek	0.9	6.4	3.6
Jordan River	5.2	9.0	7.0
Kimberly Creek	3.2	4.5	3.9
Maple River	1.3	5.5	3.8
Milligan Creek	6.1	6.4	5.5
Mullett Creek	0.8	5.3	3.8
Pigeon River	5.0	6.3	5.7
Stover Creek	0.3	3.3	1.8
Sturgeon River	5.0	9.0	6.6
Tannery Creek	0.6	2.7	1.7

**Sensitive taxa low and high values are averages for individual sites on stream systems. The averaged value is for data from all sites on the river system.*

The Jordan River

Data available from the DEQ, USGS, USFWS, and TOMWC for the Jordan River and its tributaries indicate that water quality is high and stream ecosystems are healthy. The DEQ dataset (including legacy data from USEPA) includes water quality monitoring data from 39 locations in the Jordan River Watershed; data spanning more than 40 years from 1967 to 2013. The USGS monitored water quality on the Jordan River from 1966 to 1971 at five sites. The USFWS dataset includes water quality data for 52 sites dating back to 1973. Volunteers and staff from TOMWC have monitored water quality from 2004 to present at four locations on the Jordan River (Figure 6). Data collected show that almost all sites monitored in the Jordan River Watershed maintain excellent water quality and that nearly all test results meet Michigan WQS.

Dissolved Oxygen

An average dissolved oxygen concentration of 10.1 mg/L from 760 records from DEQ, USFWS, and TOMWC show that dissolved oxygen is generally abundant (Table 13). Only four readings from the data collected between 1967 and 2013 were below the State water quality cold-water fishery standard of 7.0 mg/L; 6.1 mg/L at the discharge from the Jordan River National Fish Hatchery in 1977, 6.5 at Landslide Creek in 2012, 6.9 mg/L at the river mouth at Bridge Street in 1977, and 6.9 mg/L at Cascade Creek in 2012. The aerobic digestion by bacteria of organic compounds from the hatchery discharge and in the marshy area upstream of Bridge Street probably contributed to the lower readings at these sites.

Table 13. Archive dissolved oxygen data for the Jordan River.

Parameter	Low * (value)	Low (year)	Low (site)	High* (value)	High (year)	High (site)	Average Value*
Dissolved Oxygen	6.1	1977	Hatchery discharge	14.1	1978	Pinney Bridge	10.1

**dissolved oxygen units: milligrams per liter or parts per million.*

Alkalinity, Hardness, and pH

The DEQ, USGS, and USFWS datasets contain 1199 alkalinity records for the Jordan River system, collected between 1966 and 2014 at 77 different locations. Alkalinity ranged from 110 mg/L $CaCO_3$ to 235 mg/L $CaCO_3$, averaging 176 mg/L $CaCO_3$ (Table 14). Hardness data include 94 records from the DEQ and USGS, collected between 1966 and 2004 at 17 different locations. Hardness ranged from 130 mg/L $CaCO_3$ to 253 mg/L $CaCO_3$, averaging 177 mg/L $CaCO_3$. The DEQ, USGS, USFWS, and TOMWC have 1386 pH records for 68 sites on the river that range from 7.0 to 8.7 and average 8.3. Alkalinity, hardness, and pH data indicate that the Jordan River is a moderately alkaline stream with a high acid neutralizing capacity and very hard water.

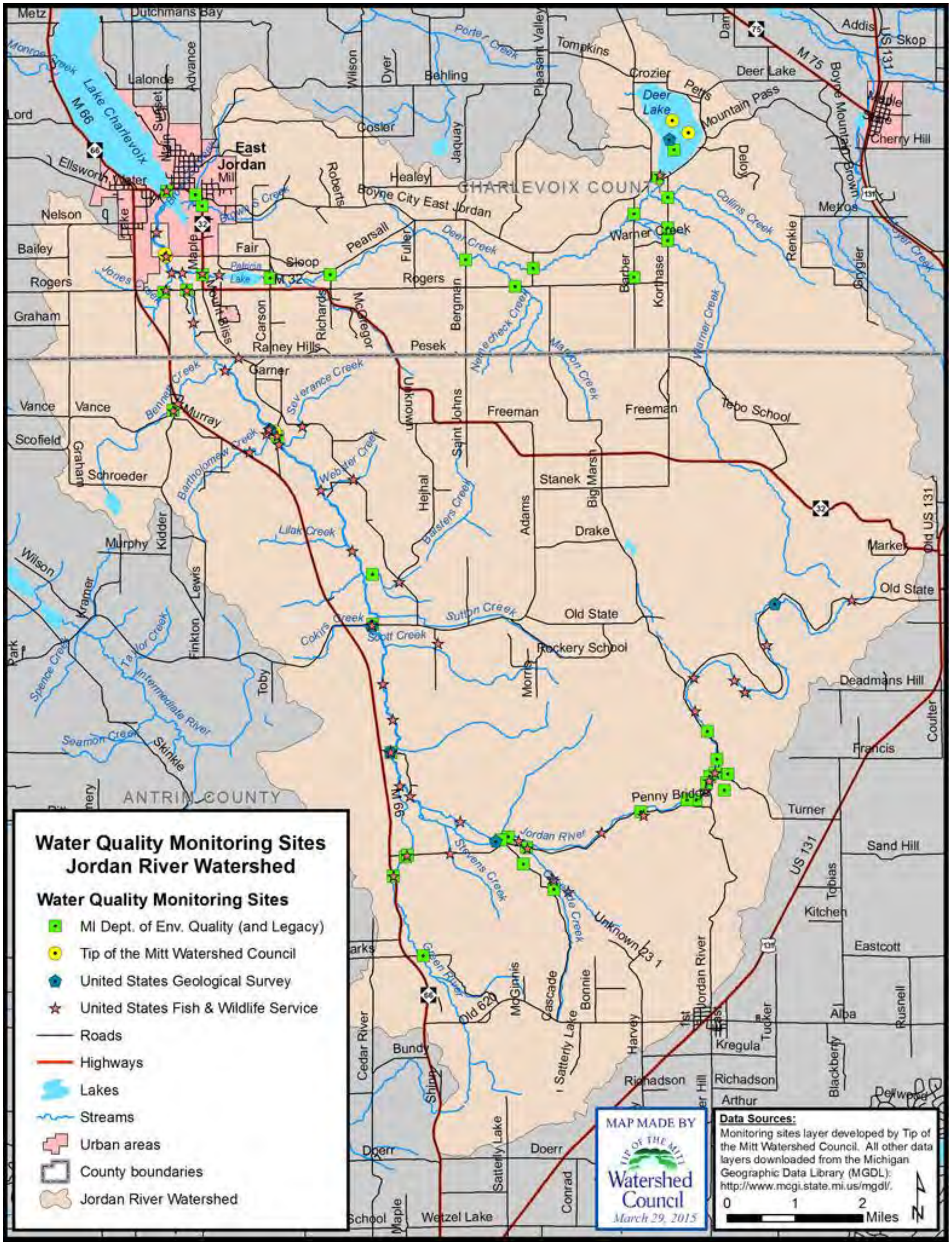

Figure 6. Water quality monitoring sites for the Jordan River Watershed.

Table 14. Archive alkalinity, hardness, and pH data for the Jordan River.

Parameter	Low * (value)	Low (year)	Low (site)	High* (value)	High (year)	High (site)	Average Value*
Alkalinity	110	1973	Old State Rd	235	2011	Jones Creek	176
Hardness	130	1966	Webster Rd	253	2003	Birney Creek	177
pH	7.0	1968	Rogers Rd	8.7	1977	Jordan River Mouth	8.3

**units: µg/L or parts per million.*

Conductivity and Chloride

Conductivity and chloride data for the Jordan River were available from DEQ, USGS, and TOMWC for 19 sites in the watershed. Conductivity levels in the river have ranged from 162 µS (USGS, Webster Rd, 1970) to 483 µS (DEQ, Birney Creek, 2003), with an average of 333 µS (Table 15). Conductivity levels throughout the Jordan River Watershed have been within the range of 150-500 µS/cm, which studies in inland freshwater streams have found to support good mixed fisheries (USEPA, 1997). There are no discernible trends in the conductivity data. The high conductivity value from Birney Creek in 2003 may be an indication of nonpoint source pollution occurring in the creek's watershed.

Table 15. Archive conductivity data from the Jordan River.

River Section	Location	Data sources	Time Period	Number of Samples	Low (µS)	High (µS)	Avg. (µS)
Upstream	Jordan River Rd.	USGS	1971	1	325.0	325.0	325.0
Upstream	Mill Creek	DEQ	2003	1	384.0	384.0	384.0
Upstream	Hatchery, upstream	DEQ	2003	1	353.0	353.0	353.0
Upstream	Hatchery, downstream	DEQ	2003	1	356.0	356.0	356.0
Upstream	Cascade Creek	DEQ	2003	1	335.0	335.0	335.0
Upstream	Landslide Creek, Cascade Rd.	DEQ	2003	1	361.0	361.0	361.0
Upstream	Landslide Creek, Pinney Bridge	DEQ	2003	1	355.0	355.0	355.0
Upstream	Pinney Bridge	DEQ*, USGS	1971, 2003	6	295.0	358.0	324.7
Upstream	Graves Crossing	DEQ*, USGS	1968-69, 2003	12	300.0	400.0	339.3
Downstream	Old State Rd.	DEQ*, USGS	1967-1975	19	295.0	355.0	333.4
Downstream	Webster Rd.	DEQ*, USGS	1966-71, 2003	32	162.0	380.0	314.5
Downstream	Birney Creek	DEQ	2003	1	483.0	483.0	483.0
Downstream	Rogers Rd.	DEQ*	1974-1975	12	320.0	360.0	343.3
Downstream	Deer Creek, CR 626	DEQ	2003	1	291.0	291.0	291.0
Downstream	Deer Creek, Marvon Rd.	DEQ	2003	1	389.0	389.0	389.0
Downstream	Deer Creek, Pearsall Rd.	DEQ	2003	1	388.0	388.0	388.0
Downstream	Deer Creek, M32	DEQ*	1974-1975	12	230.0	365.0	330.0
Downstream	Fair Rd.	TOMWC	2004-2013	4	279.2	359.0	325.1
Downstream	Bridge St.	DEQ*	1973, 1993	9	320.0	368.0	349.9

**includes Legacy data from USEPA obtained from DEQ.*

The data show a chloride concentration range of 0.0 mg/L (DEQ Legacy, Old State Rd, 1967) to

13.4 mg/L (TOMWC, Fair Rd, 2013), with an average of 2.9 mg/L (Table 16). Chloride concentrations increased from an average of 2.0 mg/L during the 1960s and 1970s to 4.0 mg/L in the 1990s to 7.6 mg/L during recent years (2003 to 2013). This trend of increasing chloride levels, documented in many Michigan surface waters (TOMWC 2013, DEQ 2013), is indicative of increased landscape development and human activity in the watershed. However, all archived Jordan River data show chloride to be far below levels that negatively impact aquatic life.

Table 16. Archive chloride data from the Jordan River.

River Section	Location	Data sources	Time Period	Num. of Samples	Low (mg/L)	High (mg/L)	Average (mg/L)
Upstream	Jordan River Rd.	USGS	1971	1	10.0	10.0	10.0
Upstream	Mill Creek	DEQ	2003	1	4.0	4.0	4.0
Upstream	Hatchery, upstream	DEQ	2003	1	3.0	3.0	3.0
Upstream	Hatchery, downstream	DEQ	2003	1	3.0	3.0	3.0
Upstream	Cascade Creek	DEQ	2003	1	3.0	3.0	3.0
Upstream	Landslide Creek, Cascade Rd.	DEQ	2003	1	Non-detectable		
Upstream	Landslide Creek, Pinney Bridge	DEQ	2003	1	4.0	4.0	4.0
Upstream	Pinney Bridge	DEQ*, USGS	1968-73, 2003	7	1.0	4.0	2.0
Upstream	Graves Crossing	DEQ	2003	1	4.0	4.0	4.0
Downstream	Old State Rd.	DEQ*, USGS	1967-1975	24	0.0†	3.7	1.7
Downstream	Webster Rd.	DEQ*, USGS	1966-67, 2003	3	2.0	4.0	3.3
Downstream	Birney Creek	DEQ	2003	1	10.0	10.0	10.0
Downstream	Rogers Rd.	DEQ*	1974-1975	12	1.0	3.4	2.1
Downstream	Deer Creek, CR 626	DEQ	2003	1	12.0	12.0	12.0
Downstream	Deer Creek, Marvon Rd.	DEQ	2003	1	6.0	6.0	6.0
Downstream	Deer Creek, Pearsall Rd.	DEQ	2003	1	6.0	6.0	6.0
Downstream	Deer Creek, M32	DEQ*	1974-1975	12	1.0	3.5	2.0
Downstream	Fair Rd.	TOMWC	2004-2013	4	6.0	13.4	8.4
Downstream	Bridge St.	DEQ*	1973, 1993	11	1.0	4.0	2.7

**includes Legacy data from USEPA obtained via DEQ.*
†Zero values are likely non-detect results due to analytical methods used in the past.

Nutrients: Phosphorus and Nitrogen

Phosphorus has been monitored on the Jordan River by DEQ, USGS, and TOMWC, with over 190 records available from 1967 to 2013 (Table 17). In addition, total phosphorus has been monitored regularly by USFWS at the National Fish Hatchery since 2005 per conditions of a National Pollution Discharge Elimination System permit issued by DEQ. Total phosphorus concentrations ranged from 0.0 µg/L (DEQ Legacy, Old State Rd, 1967) to 550.0 µg/L (DEQ Legacy, Hatchery discharge, 1977). Hatchery discharge phosphorus data since 2005 show a range of 10 µg/L to 310 µg/L, with an average of 64 µg/L. Similar to trends observed in the Boyne River, averaged total phosphorus concentrations from 1968 to 1978 were much higher than those collected between 1993 and 2013; 26.8 µg/L versus 11.0 µg/L respectively. This decrease could be the result of improved regulation, coupled with greater water resource stewardship by watershed residents.

Table 17. Archive total phosphorus data for the Jordan River.

River Section	Location	Data Sources	Time Period	Num. of Samples	Low (µg/L)	High (µg/L)	Average (µg/L)
Upstream	Mill Creek	DEQ	2003	1	13.0	13.0	13.0
Upstream	5 Tile Creek, River Rd.	DEQ	2003	1	7.0	7.0	7.0
Upstream	5 Tile Creek, Spring	DEQ*	1977-1978	12	2.0	7.0	3.5
Upstream	6 Tile Creek, Spring	DEQ*	1977-1978	12	1.0	6.0	3.2
Upstream	Hatchery, discharge	DEQ*	1977-1978	12	69.0	550.0	164.2
Upstream	Hatchery, downstream	DEQ	2003	1	14.0	14.0	14.0
Upstream	Hatchery, upstream	DEQ	2003	1	6.0	6.0	6.0
Upstream	Cascade Creek	DEQ	2003	1	8.0	8.0	8.0
Upstream	Landslide Creek, Cascade Rd.	DEQ	2003	1	17.0	17.0	17.0
Upstream	Landslide Creek, Pinney Bridge	DEQ	2003	1	12.0	12.0	12.0
Upstream	Green River, Green River Rd.	DEQ	2003	1	9.0	9.0	9.0
Upstream	Green River, Pinney Bridge Rd	DEQ	2003	1	8.0	8.0	8.0
Upstream	Pinney Bridge	DEQ*	1968-78, 2003	16	9.0	33.0	15.1
Upstream	Unnamed creek, Pinney Bridge	DEQ	2003	1	13.0	13.0	13.0
Upstream	Graves Crossing	DEQ	2003	1	120.0	120.0	120.0
N/A	Jordan River (Site 01)	DEQ*	1977-1978	12	2.0	18.0	6.7
Downstream	Old State Rd.	DEQ*	1967-1975	22	0.0†	100.0	29.5
Downstream	Webster Rd.	DEQ	2003	1	11.0	11.0	11.0
Downstream	Bennet Creek	DEQ	2003	1	10.0	10.0	10.0
Downstream	Birney Creek	DEQ	2003	1	22.0	22.0	22.0
Downstream	Marvon Creek, Rogers Rd.	DEQ	2003	1	17.0	17.0	17.0
Downstream	Rogers Rd.	DEQ	1968-78	31	0.0	70.0	17.2
Downstream	Collins Creek	DEQ	2003	1	13.0	13.0	13.0
Downstream	Deer Creek, Barber Rd.	DEQ	2003	1	10.0	10.0	10.0
Downstream	Deer Creek, Bergman Rd.	DEQ	2003	1	8.0	8.0	8.0
Downstream	Deer Creek, CR626	DEQ	2003	1	7.0	7.0	7.0
Downstream	Deer Creek, M32	DEQ*	1974-78, 2003	25	4.0	20.0	13.5
Downstream	Deer Creek, Marvon Rd.	DEQ	2003	1	8.0	8.0	8.0
Downstream	Deer Creek, Pearsall Rd.	DEQ	2003	1	8.0	8.0	8.0
Downstream	Eaton Creek, Deer Creek	DEQ	2003	1	12.0	12.0	12.0
Downstream	Hog Creek, Deer Creek	DEQ	2003	1	7.0	7.0	7.0
Downstream	Fair Rd.	TOMWC	2004-2013	4	5.3	8.3	6.2
Downstream	Bridge St.	DEQ*	1968-77, 1993	22	7.0	50.0	20.1

**includes Legacy data obtained from DEQ.*
†Zero values are likely non-detect results due to analytical methods used in the past.

Both DEQ and TOMWC data show high total nitrogen concentrations throughout most of the Jordan River Watershed, far above the USEPA reference condition of 440 µg/L (Table 18). The

DEQ report for 2003 survey data recognized that nitrate-nitrogen concentrations were atypically high and widespread, warranting investigation of potential sources (Walker 2008). Total nitrogen is highest in the headwaters of the main branch near, but both upstream and downstream of the Jordan River National Fish Hatchery. The 2003 DEQ survey noted that total nitrogen concentrations were lowest in the southernmost tributaries including Cascade Creek, Landslide Creek, and the Green River (Walker 2008). The 2003 DEQ data show nitrogen levels decreasing in a downstream direction between Pinney Bridge and the mouth at Bridge Street, which is probably a result of dilution from tributaries with lower nitrogen concentrations, such as the Green River. Total nitrogen and nitrate-nitrogen concentrations in the Jordan River are highest, at least double that of other rivers monitored in the CWQM program (Table 9).

Table 18. Archive total nitrogen data for the Jordan River.

River Section	Location	Data Sources	Time Period	Num. of Samples	Low (μg/L)	High (μg/L)	Avg. (μg/L)
Upstream	Mill Creek	DEQ	2003	1	1,540	1,540	1,540
Upstream	Jordan River Rd.	DEQ*	1977-78	12	952	1,252	1,095
Upstream	5 Tile Creek, River Rd.	DEQ	2003	1	2,900	2,900	2,900
Upstream	5 Tile Creek, Spring Pond	DEQ*	1977-1978	12	1,873	2,283	2,028
Upstream	6 Tile Creek, Spring Pond	DEQ*	1977-1978	12	2,042	2,205	2,106
Upstream	Hatchery, upstream	DEQ	2003	1	1,610	1,610	1,610
Upstream	Hatchery, discharge	DEQ*	1977-78	12	2,230	3,050	2,422
Upstream	Hatchery, downstream	DEQ	2003	1	1,920	1,920	1,920
Upstream	Cascade Creek	DEQ	2003	1	440	440	440
Upstream	Green River, Green River Rd.	DEQ	2003	1	460	460	460
Upstream	Green River, Pinney Bridge Rd.	DEQ	2003	1	460	460	460
Upstream	Landslide Creek, Cascade Rd.	DEQ	2003	1	325	325	325
Upstream	Landslide Creek, Pinney Bridge	DEQ	2003	1	650	650	650
Upstream	Pinney Bridge	DEQ*	1972-78, 2003	15	710	1,740	1,122
Upstream	Unnamed Creek, Pinney Bridge	DEQ	2003	1	2,800	2,800	2,800
Upstream	Graves Crossing	DEQ	2003	1	1,370	1,370	1,370
Downstream	Old State Rd.	DEQ*	1973-75	20	860	1,310	1,085
Downstream	Webster Rd.	DEQ	2003	1	1,270	1,270	1,270
Downstream	Bennet Creek	DEQ	2003	1	950	950	950
Downstream	Birney Creek	DEQ	2003	1	1,790	1,790	1,790
Downstream	Rogers Rd.	DEQ*	1974-1978	24	781	1,685	995
Downstream	Fair Rd.	TOMWC	2004-2013	4	745	1,567	1,052
Downstream	Bridge St.	DEQ*	1973-78, 1993	17	680	1,979	1,019

**includes Legacy data obtained from DEQ.*

Biological Monitoring

Biological monitoring data from DEQ and TOMWC are available for 22 sites in the Jordan River Watershed; seven on the main stem of the river and 15 on tributaries that flow into the river.

DEQ biologists monitored 21 sites while TOMWC VSM Program volunteers monitor four sites. DEQ data are generally limited to one or two sampling events, whereas TOMWC data include up to 12 sampling events. The same metrics used to assess biological data on the Boyne River are used to evaluate data from the Jordan River. Similar to the Boyne River, experienced DEQ biologists found higher numbers of total and EPT taxa on the Jordan River than TOMWC volunteers, but sensitive taxa numbers from DEQ and TOMWC are approximately the same.

Biological data show high aquatic macroinvertebrate diversity throughout most of the Jordan River Watershed. The number of total taxa per site ranged from 10 to 43 with an average of 25.1 (Table 19). EPT taxa diversity ranged from 3 to 19.6 taxa, with an average of 12.2. The number of sensitive taxa ranged from 2 to 11, averaging 6.6 among all sites. The high number of sensitive taxa found throughout the Jordan River, far above the TOMWC VSM Program average of 3.9 taxa for all streams, indicates a very healthy stream ecosystem.

Table 19. Archive biological monitoring data for the Jordan River and its tributaries.

Sample Site	**River Section**	**Data Source**	**Time Period**	**Num. of samples**	**Total Taxa***	**EPT Taxa***	**Sensitive Taxa***
Jordan River Rd	Upstream	DEQ	2008	5	40.8	19.6	9.0
Hatchery, upstream	Upstream	DEQ	1993-2003	2	23.0	11.0	7.5
Hatchery, downstream	Upstream	DEQ	1993	1	21.0	11.0	6.0
Landslide Creek	Tributary	DEQ	2003	1	21.0	11.0	5.0
Green River, Green River	Tributary	DEQ	2008	1	31.0	17.0	8.0
Green River, M66	Tributary	DEQ	2008	1	23.0	12.0	7.0
Green River, upstream	Tributary	DEQ	2008	1	20.0	11.0	7.0
Green River, Pinney Bridge	Tributary	DEQ	1992-2003	3	22.7	12.0	6.7
Pinney Bridge, upstream	Upstream	DEQ	2003	1	26.0	14.0	8.0
Pinney Bridge,	Upstream	DEQ	1992	2	26.0	10.0	7.0
Pinney Bridge, both	Upstream	TOMWC	2011-2013	4	23.3	14.3	9.0
Mill Creek	Tributary	DEQ	2003	1	20.0	11.0	6.0
Webster Rd	Downstream	DEQ	2003	1	29.0	14.0	7.0
Webster Rd	Downstream	TOMWC	2007-2014	12	21.1	11.8	7.1
Collin Creek (Deer Crk)	Tributary	DEQ	1990	1	26.0	9.0	3.0
Deer Creek, Barber Rd	Tributary	DEQ	1990	1	26.0	14.0	6.0
Warner Crk (Deer Crk)	Tributary	DEQ	2008	1	43.0	19.0	11.0
Eaton Creek (Deer Crk)	Tributary	DEQ	1990	1	15.0	6.0	4.0
Deer Creek, Marvon Rd	Tributary	DEQ	1990	1	21.0	7.0	2.0
Deer Creek, Pearsall Rd	Tributary	DEQ	1990	1	33.0	17.0	10.0
Deer Creek, Carson Rd	Tributary	DEQ	2008	5	37.4	19.4	9.2
Bennet Creek	Tributary	DEQ	2003	1	21.0	10.0	5.0
Birney Creek	Tributary	DEQ	2003	1	10.0	3.0	2.0
Rogers Rd	Downstream	TOMWC	2011-2013	4	23.0	11.5	6.8
Fair Rd	Downstream	TOMWC	2007-2014	12	20.9	10.6	5.3

**Total taxa: total number of macroinvertebrate taxa; EPT taxa: taxa from pollution-sensitive insect orders (mayflies, stoneflies, and caddisflies); sensitive taxa: taxa most intolerant of pollution.*

Remarkable macroinvertebrate diversity was documented at the Jordan River Road site in the uppermost headwaters of the main stem and at the site on Warner Creek in the Deer Creek Watershed. Conversely, macroinvertebrate diversity was quite poor in Birney Creek; providing further evidence of water quality problems in this creek. There were no clear patterns in the biological data between upstream and downstream sample sites (Figure 7).

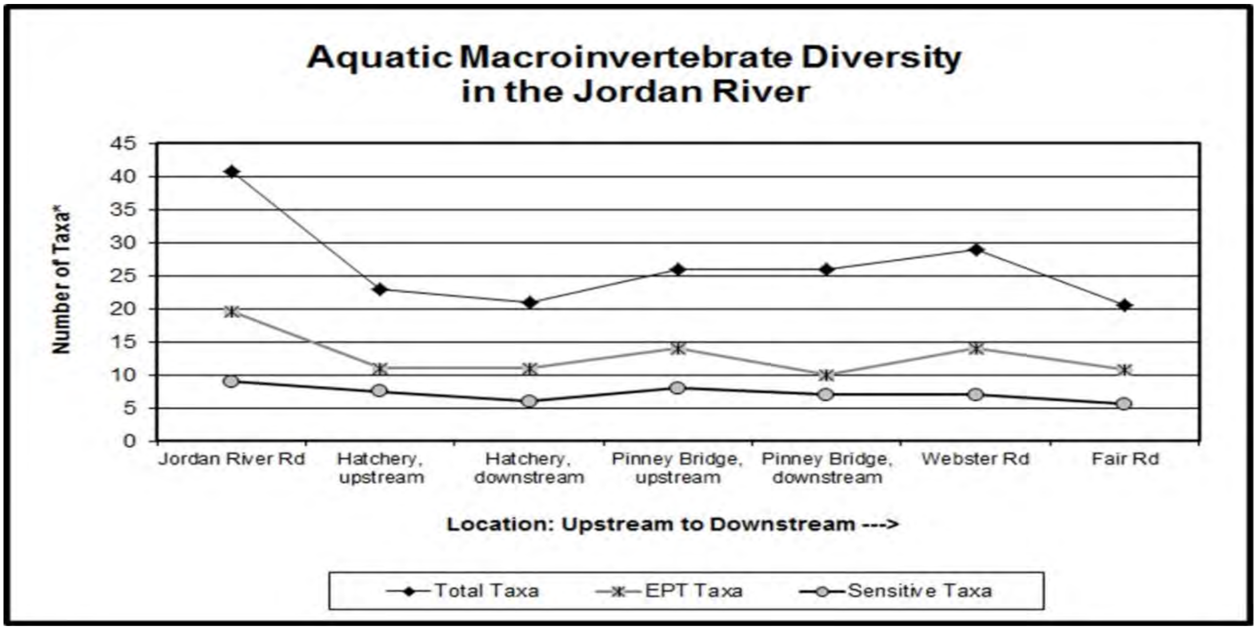

Figure 7. Macroinvertebrate diversity in the Jordan River

**Total taxa = total number of macroinvertebrate families; EPT taxa = number of families in three pollution-sensitive insect orders; and sensitive taxa = number of families most sensitive to non-point source pollution.*

Creeks: Horton, Stover, Loeb, Monroe, and Porter

Archived water quality data are available for the small LCTMP stream systems from the DEQ, USFWS, and TOMWC. Water quality at most sites in these creeks is comparable to that of the Boyne and Jordan Rivers; i.e., water quality is high and aquatic ecosystems appear to be healthy. There are cases of test results not meeting state standards and indications of water quality problems. However, most of these were isolated incidences or appear to be caused by natural phenomena.

Dissolved Oxygen

Dissolved oxygen levels in DEQ Legacy data from 1977 and 1978 were well above the State standard for all five creeks, ranging from 8.0 to 13.2 mg/L during 9 to 12 monitoring events in all seasons of the year (Table 20). USFWS data for Horton and Porter Creeks show levels consistently above 7 mg/L except for a reading of 6.4 mg/L in Horton Creek at Boyne City Road in 2013. Data collected by TOMWC from three sites on Horton Creek in 2004 show dissolved oxygen concentrations in the same range as Legacy and USFWS data. Concurrent with LCTMP monitoring, TOMWC collected additional data from three upstream sites on Stover Creek. All dissolved oxygen readings at these sites, except one on the West Branch of Stover Creek, were above 8.0 mg/L. The low dissolved oxygen reading of 4.2 mg/L occurred when the West Branch had become stagnant, which it typically does in the dry summer period.

Table 20. Archive dissolved oxygen data for LCTMP creeks.

Stream	Location	Data Sources	Time Period	Num. of Records	Low*	High*
Stover Creek	Stover Road	MDEQ†	1977-1978	9	8.0	13.2
Stover Creek	Brookside Cemetery	TOMWC	2013-2014	6	9.2	12.5
Stover Creek	Belvedere Golf Club, S. Branch	TOMWC	2013-2014	6	9.0	12.0
Stover Creek	Belvedere Golf Club, W. Branch	TOMWC	2013-2014	6	4.2	10.7
Horton Creek	Boyne City Road	MDEQ†, TOMWC, USFWS	1977-78, 1993-2005	29	6.4	12.7
Horton Creek	Church Road	USFWS	2004	2	9.6	11.0
Horton Creek	Horton Bay Footbridge	TOMWC	2004-2005	4	10.0	10.5
Horton Creek	Mouth	USFWS	2001	1	12.4	12.4
Horton Creek	Near Horton Bay Road	USFWS	2013	2	7.0	10.1
Horton Creek	Sand filter (downstream)	TOMWC	2004-2005	4	9.8	10.3
Horton Creek	Sand filter (upstream)	TOMWC	2004-2005	4	9.7	10.3
Horton Creek	Stolt Road (lower)	USFWS	2004	2	10.2	11.1
Horton Creek	Waterwheel Lane	USFWS	1993-2004	9	9.0	12.4
Monroe Creek	M-66	MDEQ†	1977-1978	12	8.7	13.0
Loeb Creek	M-66	MDEQ†	1977-1978	12	8.0	11.5
Porter Creek	Advance Road	USFWS	2013	2	7.2	8.4
Porter Creek	Anderson Road	USFWS	2009-2013	4	8.1	9.8
Porter Creek	Dyer Creek	USFWS	2009	2	8.7	8.9
Porter Creek	Ferry Road	MDEQ†, USFWS	1977-78, 1988-2013	27	7.0	13.2

**units: mg/L or parts per million.*
†DEQ data include legacy data from USEPA.

Alkalinity, Hardness, and pH

Alkalinity and hardness data for the LCTMP creeks include one monitoring event in all creeks by DEQ in 2003 and 546 alkalinity records from USFWS for Horton and Porter Creeks collected between 1970 and 2013. Alkalinity values ranged from a low of 155 mg/L $CaCO_3$ in Porter Creek to a high of 235 mg/L $CaCO_3$, also in Porter Creek (Table 21). Similarly, hardness values were lowest in Loeb Creek at 195 mg/L $CaCO_3$ and highest in Stover Creek at 254 mg/L $CaCO_3$. The pH measurements in LCTMP creeks from DEQ, USFWS, and TOMWC ranged from 6.8 to 8.5 (Table 22). Alkalinity, hardness, and pH data show that the LCTMP creeks are moderately alkaline streams with high buffering capacities (i.e., acid neutralizing), and with very hard water.

Table 21. Archive alkalinity and hardness data for LCTMP creeks.

Parameter*	Stream	Location	Data Sources	Low*	High*	Avg.*	Time Period
Total Alkalinity	Stover Creek	Marion Center Road	MDEQ	226	226	226	2003
Total Alkalinity	Horton Creek	Boyne City Road	MDEQ, USFWS	158	215	204	1985-2013
Total Alkalinity	Horton Creek	Church Road	MDEQ	193	222	214	2003-2009
Total Alkalinity	Horton Creek	Horton Creek, misc.	USFWS	188	206	197	1979
Total Alkalinity	Horton Creek	Mouth	USFWS	204	205	205	2001
Total Alkalinity	Horton Creek	Mouth (upstream)	USFWS	189	220	207	1970-1977
Total Alkalinity	Horton Creek	Near Horton Bay Road	USFWS	194	215	208	2013
Total Alkalinity	Horton Creek	Near Horton Creek Road	USFWS	185	211	206	2003-2004
Total Alkalinity	Horton Creek	Near Pincherry Road	USFWS	220	220	220	2004
Total Alkalinity	Horton Creek	Near Stevens Road	USFWS	211	211	211	2003
Total Alkalinity	Horton Creek	Stolt Road (lower)	USFWS	204	225	217	2003-2004
Total Alkalinity	Horton Creek	Waterwheel Lane	USFWS	160	219	205	1985-2013
Total Alkalinity	Loeb Creek	M-66	MDEQ	176	176	176	2003
Total Alkalinity	Monroe Creek	LaCroix Road	MDEQ	212	212	212	2003
Total Alkalinity	Porter Creek	Advance Road	MDEQ, USFWS	186	220	206	2003-2013
Total Alkalinity	Porter Creek	Anderson Road	USFWS	159	210	195	2009-2013
Total Alkalinity	Porter Creek	Dyer Creek	USFWS	184	235	223	2004-2013
Total Alkalinity	Porter Creek	Ferry Road	USFWS	164	220	200	1988-2013
Total Alkalinity	Porter Creek	Porter Creek, misc.	USFWS	185	185	185	2004
Total Alkalinity	Porter Creek	Mouth	USFWS	197	215	204	2000-2013
Total Alkalinity	Porter Creek	Mouth (upstream)	USFWS	171	215	198	1970-1973
Total Alkalinity	Porter Creek	Near Advance Road	USFWS	186	201	196	2004-2009
Total Alkalinity	Porter Creek	Near Snyder Road	USFWS	187	187	187	2004
Total Alkalinity	Porter Creek	Near Wilson Road	USFWS	204	210	209	2013
Total Alkalinity	Porter Creek	Wilson Road	MDEQ, USFWS	155	215	197	2003-2013
Hardness	Stover Creek	Marion Center Road	MDEQ	254	254	254	2003
Hardness	Horton Creek	Boyne City Road	MDEQ	211	211	211	2003
Hardness	Horton Creek	Church Road	MDEQ	232	232	232	2003
Hardness	Loeb Creek	M-66	MDEQ	195	195	195	2003
Hardness	Monroe Creek	LaCroix Road	MDEQ	225	225	225	2003
Hardness	Porter Creek	Advance Upstream	MDEQ	211	211	211	2003

**alkalinity and hardness measured in milligrams per liter CaCO3 or parts per million.*

Table 22. Archive pH data for LCTMP creeks.

Stream	Location	Data Sources	Low	High	Avg.	Time Period
Stover Creek	Stover Road	MDEQ†	7.8	8.2	8.0	1977-1978
Stover Creek	Brookside Cemetery	TOMWC	8.0	8.5	8.2	2013-2014
Stover Creek	Belvedere Golf Club, S. Branch	TOMWC	7.9	8.5	8.2	2013-2014
Stover Creek	Belvedere Golf Club, W. Branch	TOMWC	6.8	8.3	7.8	2013-2014
Horton Creek	Below Sec. 31-36 line	USFWS	8.3	8.3	8.3	2003
Horton Creek	Boyne City Road	MDEQ†, TOMWC, USFWS	7.8	8.5	8.1	1977-78, 1985-2013
Horton Creek	Church Road	USFWS	7.8	8.2	7.9	2003-2004
Horton Creek	Horton Bay Club	TOMWC	8.0	8.1	8.0	2004-2005
Horton Creek	Mouth	USFWS	8.2	8.3	8.2	2001-2003
Horton Creek	Mouth (upstream)	USFWS	8.2	8.3	8.3	1977
Horton Creek	Near Horton Bay Road	USFWS	7.8	8.3	8.0	2013
Horton Creek	Near Horton Creek Road	USFWS	7.9	8.2	8.0	2003-2004
Horton Creek	Near Pincherry Road	USFWS	7.7	7.8	7.8	2004
Horton Creek	Near Stevens Road	USFWS	8.1	8.1	8.1	2003
Horton Creek	Sand filter (downstream)	TOMWC	7.9	8.1	8.0	2004-2005
Horton Creek	Sand filter (upstream)	TOMWC	7.9	8.1	8.0	2004-2005
Horton Creek	Stolt Road (lower)	USFWS	7.8	8.2	8.0	2003-2004
Horton Creek	Waterwheel Lane	USFWS	7.7	8.3	8.1	1987-2013
Monroe Creek	M-66	MDEQ†	7.6	8.4	8.1	1977-1978
Loeb Creek	M-66	MDEQ†	7.6	8.3	8.0	1977-1978
Porter Creek	Advance Road	USFWS	8.1	8.5	8.3	2004-2013
Porter Creek	Anderson Road	USFWS	7.7	8.3	8.1	2009-2013
Porter Creek	Below Sec. 31-32 line	USFWS	8.2	8.2	8.2	2004
Porter Creek	Dyer Creek	USFWS	8.2	8.4	8.3	2004-2013
Porter Creek	Ferry Road	MDEQ†, USFWS	7.7	8.5	8.3	1977-87, 1988-2013
Porter Creek	Mouth	USFWS	8.2	8.4	8.3	2000-2013
Porter Creek	Near Advance Road	USFWS	8.1	8.4	8.2	2004-2009
Porter Creek	Near Snyder Road	USFWS	8.2	8.2	8.2	2004
Porter Creek	Near Wilson Road	USFWS	8.0	8.1	8.0	2013
Porter Creek	Wilson Road	USFWS	7.9	8.3	8.1	2009-2013

†DEQ data include legacy data from USEPA.

Conductivity and Chloride

Conductivity levels and chloride concentrations from archive data were generally low and within typical ranges for Northern Michigan streams. The highest chloride levels were documented in Stover and Loeb Creeks while conductivity readings were highest in Stover and Porter Creeks (Table 23). Likely sources of chloride and other charged particles that would elevate conductivity include agricultural and road runoff for all three creeks, as well as runoff from the Belvedere Golf Club for Stover Creek.

Table 23. Archive conductivity and chloride data for LCTMP creeks.

Stream	Parameter	Low * (value)	Low (year)	Low (site)	High* (value)	High (year)	High (site)	Avg. (value)*
Horton Creek	Chloride	4.0	2001	Boyne City Rd	10.0	2003	Church Rd	6.6
Loeb Creek	Chloride	14.0	2003	M66	14.0	2003	M66	14.0
Monroe Creek	Chloride	4.0	2003	LaCroix Road	4.0	2003	LaCroix Road	4.0
Porter Creek	Chloride	5.0	2003	Wilson Road	6.0	2003	Advance Upstream	5.5
Stover Creek	Chloride	5.7	2013	Golf Course, South	34.8	2013	Golf Course, South	14.1
Horton Creek	Conductivity	351.1	2004	Horton Bay Club	440.0	2003	Church Rd	395.1
Loeb Creek	Conductivity	395.0	2003	M66	395.0	2003	M66	395.0
Monroe Creek	Conductivity	421.0	2003	LaCroix Road	421.0	2003	LaCroix Road	421.0
Porter Creek	Conductivity	394.0	2003	Wilson Road	414.0	2003	Advance Upstream	437.5
Stover Creek	Conductivity	355.3	2013	Golf Course, South	541.2	2013	Golf Course, West	448.5

**units: chloride readings shown in mg/l; conducitivity readings shown in µS/cm2. Avg=average for all archive data from the stream.*

Nutrients: Phosphorus and Nitrogen

Total phosphorus and total nitrogen data have been collected from all the LCTMP creeks and at multiple sites for some of the creeks. Total phosphorus concentrations have ranged from 1.8 µg/L to 74.5 µg/L (Table 24). The highest phosphorus levels were found in Monroe and Loeb Creeks in the 1970s and in Stover Creek during the last two years. DEQ data from 2003 show that total phosphorus in Loeb Creek was still higher than the EPA reference condition of 12 µg/L, though Monroe Creek was below this threshold. Averaged values for the recent data from Stover Creek show total phosphorus concentrations approaching or just over the EPA reference condition for two of three sites. The other site on the West Branch has intermittent flow and was stagnant when the concentration of 74.5 µg/L was documented.

Most total nitrogen data from LCTMP creeks show concentrations above the EPA reference condition of 440 µg/L (Table 24). Nitrogen concentrations are particularly high in Horton and Stover Creeks. Runoff from agricultural lands in these watersheds and from a golf course in the case of Stover Creek are suspected of contributing nitrogen to the creeks.

Table 24. Archived nutrient data from LCTMP creeks.

Parameter	Stream	Location	Time Period*	Num. of Readings	Low (µg/L)	High (µg/L)	Average (µg/L)
Total Phosphorus	Horton Creek	Stolt Road	2003	1		8.0	
Total Phosphorus	Horton Creek	Church Road	2003	1		6.0	
Total Phosphorus	Horton Creek	Boyne City Road	1977 - 1978	12	2.0	22.0	8.6
Total Phosphorus	Horton Creek	Boyne City Road	2003	1		13.0	
Total Phosphorus	Horton Creek	Boyne City Road	2004 - 2005	4	2.4	5.2	4.0
Total Phosphorus	Horton Creek	Horton Bay Club†	2004 - 2005	12	1.9	5.8	3.6
Total Phosphorus	Monroe Creek	LaCroix Road	2003	1		8.0	
Total Phosphorus	Monroe Creek	M-66	1977 - 1978	12	7.0	38.0	13.8
Total Phosphorus	Loeb Creek	M-66	1977 - 1978	12	4.0	42.0	13.6
Total Phosphorus	Loeb Creek	M-66	2003	1		17.0	
Total Phosphorus	Porter Creek	Ferry Road	1977 - 1978	12	3.0	16.0	8.4
Total Phosphorus	Porter Creek	Wilson Road	2003	1		16.0	
Total Phosphorus	Porter Creek	Advance - East Jordan Rd	2003	1		10.0	
Total Phosphorus	Stover Creek	Golf Course (South Branch)	2013 - 2014	6	4.6	21.5	11.4
Total Phosphorus	Stover Creek	Golf Course (West Branch)	2013 - 2014	6	6.8	74.5	39.2
Total Phosphorus	Stover Creek	Marion Center Road	2003	1		15.0	
Total Phosphorus	Stover Creek	Cemetery	2013 - 2014	6	5.3	37.3	15.2
Total Phosphorus	Stover Creek	Stover Road	1977 - 1978	9	3.0	15.0	9.1
Total Nitrogen	Horton Creek	Stolt Road	2003	1		1730	
Total Nitrogen	Horton Creek	Church Road	2003	1		2230	
Total Nitrogen	Horton Creek	Boyne City Road	1977 - 1978	12	1137	2257	1518
Total Nitrogen	Horton Creek	Boyne City Road	2003	1		1840	
Total Nitrogen	Monroe Creek	LaCroix Road	2003	1		480	
Total Nitrogen	Monroe Creek	M-66	1977 - 1978	12	426	1053	607
Total Nitrogen	Loeb Creek	M-66	1977 - 1978	12	490	983	690
Total Nitrogen	Loeb Creek	M-66	2003	1		900	
Total Nitrogen	Porter Creek	Ferry Road	1977 - 1978	12	220	400	313
Total Nitrogen	Porter Creek	Wilson Road	2003	1		449	
Total Nitrogen	Porter Creek	Advance - East Jordan Rd	2003	1		520	
Total Nitrogen	Stover Creek	Golf Course (South Branch)	2013 - 2014	6	463	1504	991
Total Nitrogen	Stover Creek	Golf Course (West Branch)	2013 - 2014	6	630	1703	1189
Total Nitrogen	Stover Creek	Marion Center Road	2003	1		1680	
Total Nitrogen	Stover Creek	Cemetery	2013 - 2014	6	505	1609	1078
Total Nitrogen	Stover Creek	Stover Road	1977 - 1978	9	1021	1293	1194

**Data from 1977-78 are Legacy from USEPA, 2003 data collected by DEQ, all other data from TOMWC.*
†Horton Bay Club data combines all data from three monitoring sites in close proximity on the Club's property.

Biological Monitoring

Biological monitoring has been conducted by DEQ and TOMWC at 3 sites on Horton Creek, 1 site on Loeb and Monroe Creeks, 2 sites on Porter Creek, and 4 sites on Stover Creek (Table 25). DEQ biologists monitored 8 of the sites, while TOMWC volunteers monitored 5 sites. DEQ data were limited to one or two sampling events, whereas TOMWC data represents up to 18 sampling events. Total, EPT, and sensitive taxa indices were used to assess biological data from the creeks.

Data from upstream sites on Horton Creek show moderate to low aquatic macroinvertebrate diversity, but this lack of diversity is likely due to natural conditions. The upstream section of Horton Creek is low-gradient with sluggish flow through wetland areas where great amounts of silt and muck are deposited on the stream bottom. The resultant lack of habitat diversity and lower dissolved oxygen levels due to slower waters at the upstream sites do not support sensitive aquatic macroinvertebrate populations. The downstream site on Horton Creek at Boyne City Road, where flow is faster and habitat more varied, supports a diverse, healthy macroinvertebrate population.

Stover Creek shows an interesting pattern of moderately low diversity in the headwaters (Ferry Rd), moderate to high diversity in the middle section (Cemetery and Marion Center Rd), and very low diversity at the mouth. The low biological diversity in the headwaters at Ferry Rd are likely natural due to the minute and shallow nature of the creek at that site. Conversely, low diversity at the mouth is probably the result of urban land use in the lower watershed. Recent efforts by TOMWC to thoroughly assess the creek found that polluted runoff from commercial, residential, and recreational (golf course) areas, combined with poor in-stream habitat and riparian vegetation buffers all contribute to impairment in the lower creek section (TOMWC 2015).

Biological data from Loeb, Monroe, and Porter Creek show moderate to high diversity for at all sites monitored. However, the number of sample sites and monitoring events for these creeks is quite limited.

Table 25. Biological data from LCTMP creeks.

Stream	Sample Site	Data Source	Time Period	Num. of Samples	Total Taxa*	EPT Taxa*	Sensitive Taxa*
Horton Creek	Stolt Rd	DEQ	1990	1	13.0	3.0	0.0
Horton Creek	Church Rd	DEQ	1990	1	16.0	4.0	0.0
Horton Creek	Church Rd	TOMWC	2005-2014	16	14.7	5.1	0.8
Horton Creek	Boyne City Rd	DEQ	1990, 2003	2	20.5	10.0	4.5
Horton Creek	Boyne City Rd	TOMWC	2005-2014	16	20.2	10.8	6.3
Loeb Creek	M-66	DEQ	2003	1	20.0	9.0	4.0
Monroe Creek	LaCroix Rd	DEQ	1998, 2003	2	24.5	10.0	3.0
Porter Creek	Wilson Rd	DEQ	1998	1	21.0	8.0	3.0
Porter Creek	Advance Upstream	DEQ	2003	1	24.0	14.0	8.0
Stover Creek	Ferry Rd	TOMWC	2005-2008	8	12.1	2.7	1.4
Stover Creek	Marion Center Rd	DEQ	1998, 2003	2	19.5	8.5	3.0
Stover Creek	City Cemetery	TOMWC	2005-2014	18	18.2	6.6	3.1
Stover Creek	Irish Boat Shop	TOMWC	2005-2014	18	13.6	2.4	0.3

**Total taxa: total number of macroinvertebrate taxa; EPT taxa: taxa from pollution-sensitive insect orders (mayflies, stoneflies, and caddisflies); sensitive taxa: taxa most intolerant of pollution.*

METHODS

Methods used in data collection were designed to accomplish the following measurable objectives of the LCTMP:

- Obtain physical water quality parameter measurements at 13 sites during 12 events.
- Collect and analyze water samples for orthophosphate, total phosphorus, ammonium, nitrate, total nitrogen, dissolved organic carbon, total suspended solids, and chloride at 13 sites during 12 events. Collect and analyze water samples for *Escherichia coli* (*E. coli*) in triplicate at 13 sites during 4 sampling events.
- Record cross-sectional profile data (channel width, depth, and flow velocity) to calculate discharge at 13 sites during 12 events.
- Generate pollutant loading estimates for all sites during all events.
- Assess sub-watershed pollutant loadings, relative to discharge.

Field Data Collection

Water quality and discharge data were collected from thirteen sites on streams flowing into Lake Charlevoix. Streams monitored included: Horton Creek, the Boyne River (3 sites), Porter Creek, the Jordan River (2 sites), Brown Creek, Birney Creek, Deer Creek, Monroe Creek, Loeb Creek, and Stover Creek (Table 26). Monitoring was conducted at or near the mouths or confluences of the LCTMP tributaries (Figure 8).

Monitoring was conducted 12 times equally split between wet and dry conditions during the spring, summer, and fall of 2013 and 2014. In 2013, monitoring was performed twice in the spring, once in the summer, three times in the fall. In 2014, monitoring was performed twice in the spring, three times in the summer, and two times in the fall. Dry event monitoring was conducted after a period of dry weather, optimally at least one week with little to no precipitation. Wet event monitoring was conducted following large precipitation events, ideally within six hours after at least 0.25 inches of rain.

Water samples for chemical analyses were collected using the grab sample method. Small plastic bottles (250 mL) washed with 10% sulfuric acid were used to collect samples for analyses of orthophosphates ($PO4^-$), total phosphorus (TP), nitrate-nitrogen ($NO3^-$), total nitrogen (TN), dissolved organic carbon (DOC), and chloride (CL^-). Large plastic bottles (500 mL) rinsed thoroughly with tap water, were used to collect samples for total suspended solids (TSS) measurements. Label tape was affixed to all bottles and indelible marker used to write stream

Table 26. Sample site locations and watershed information.

Site ID	River System	Stream Name	Location	Watershed Size (acres)
CHXTRIB01	Horton Creek	Horton Creek	Boyne City Road, upstream	7817
CHXTRIB02	Boyne River	Boyne River	Old City Park, Boyne City	45912
CHXTRIB03	Boyne River	Boyne River N. Branch	US131 , upstream	11647
CHXTRIB04	Boyne River	Boyne River S. Branch	M75, downstream	26553
CHXTRIB05	Porter Creek	Porter Creek	Lake Shore Rd	11417
CHXTRIB06	Jordan River	Jordan River	Fair Road, Jordan River Preserve	82356
CHXTRIB07	Jordan River	Jordan River	Rogers Road, downstream	49518
CHXTRIB08	Jordan River	Brown Creek	Depot Street, East Jordan	948
CHXTRIB09	Jordan River	Birney Creek	Rogers Family Homestead Preserve	1723
CHXTRIB10	Jordan River	Deer Creek	M32, downstream	27404
CHXTRIB11	Monroe Creek	Monroe Creek	M66, downstream	6455
CHXTRIB12	Loeb Creek	Loeb Creek	Evergreen Lane, upstream	3329
CHXTRIB13	Stover Creek	Stover Creek	Mouth, Irish Boat Shop	4242

name, sample site location, and date. The bottles were rinsed three times at the site with water from the stream prior to collecting the sample. Water samples were collected at mid-stream and mid-depth. The water samples were stored in a cooler with ice and transported under chain of custody to laboratories at either the University of Michigan Biological Station (UMBS) or Lake Superior State University (LSSU). Due to staff turnover at UMBS, samples from the last monitoring event (October, 2014) were analyzed at the LSSU laboratory. If water samples could not be delivered immediately to the laboratory, then the small bottles for chemical analyses were frozen, whereas large bottles were stored in a refrigerator. For quality control, replicate water samples were collected at a rate of 10% and field blanks at a rate of 5%.

To assess bacteria levels in terms of partial and total body contact recreation designations, DEQ requires a minimum of 5 sampling events over a 30-day period. Sampling events are defined by Rule 323.1062 as “three or more samples taken during the same sampling event at representative locations within a defined sampling area.” In accordance with DEQ WQS, three water samples were collected from the LCTMP tributaries during each monitoring event. However, LCTMP monitoring did not comply with the minimum number of sampling events over a 30-day period; monitoring was limited to one event in the summer of 2013 and three events during the summer of 2014. Sampling was equally split between dry and wet weather conditions.

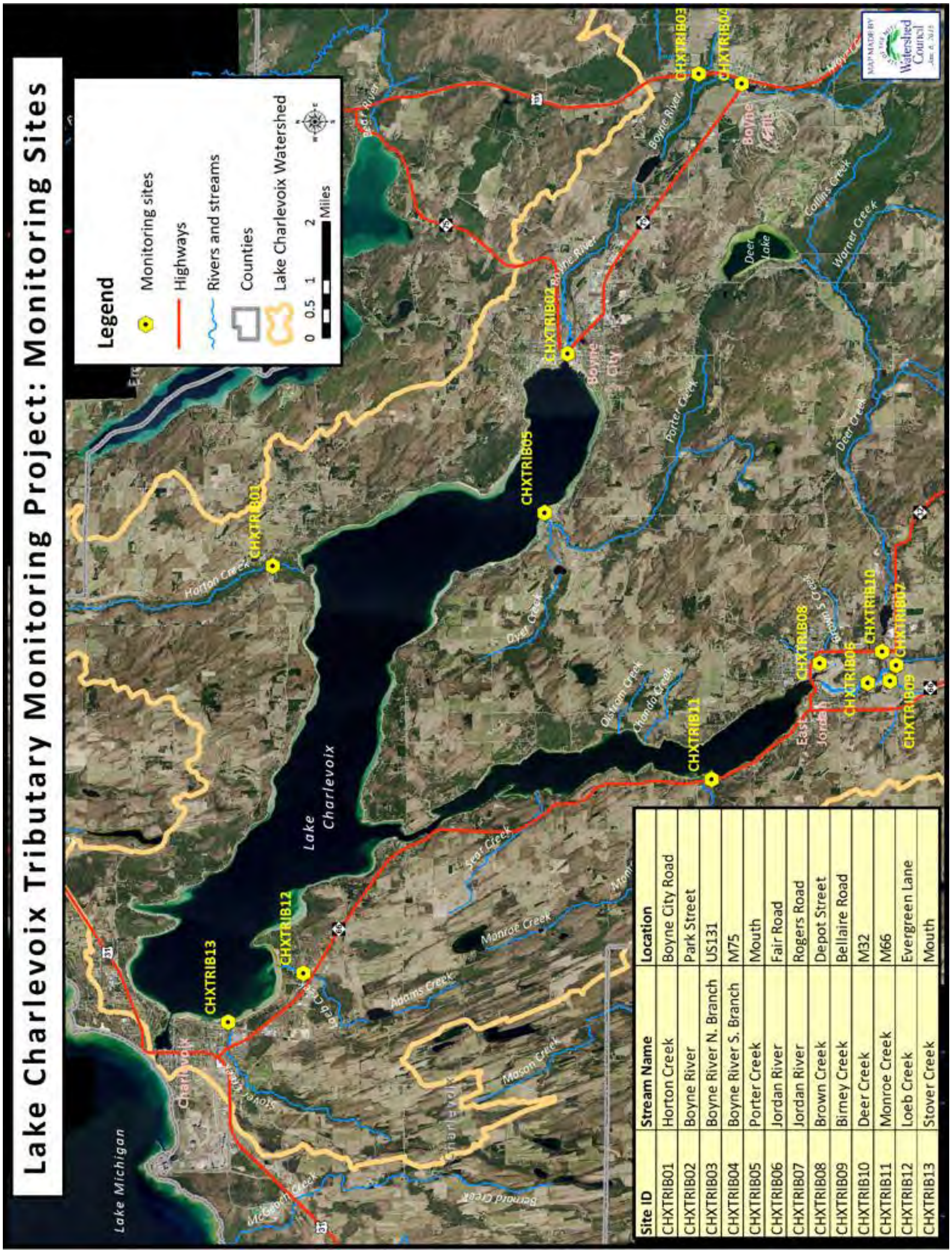

Figure 8. LCTMP sampling sites.

Sterilized 250mL plastic bottles provided by the Health Department of Northwest Michigan (HDNM) were used to collect three grab samples at each site for bacteriological analysis. Samples were collected left, right, and center across the channel approximately equidistant from one another and near the surface. Per HDNM protocols, *E. coli* sample bottles were not rinsed with stream water prior to sample collection. The water samples were stored in a cooler with ice and delivered under chain of custody to HDNM within the 6 hour hold time.

Physical parameters, including dissolved oxygen, specific conductivity, pH, and water temperature, were measured using a Hydrolab MiniSonde® water quality multiprobe. The MiniSonde was calibrated per user manual instructions in the TOMWC office prior to each monitoring event; dissolved oxygen was calibrated with the percent saturation method using current barometric pressure, specific conductivity was calibrated using a standard solution of 447 microSiemens/cm, and pH was calibrated using standard buffer solutions of 7 and 10 units pH. At each monitoring site the MiniSonde® was lowered into the water at mid-channel to approximately half the total depth, readings saved to memory in the Surveyor handheld unit and also recorded on a field datasheet.

Discharge was measured at all sites during all monitoring/sampling events immediately after water sample collection to allow for pollutant load calculations. Discharge was measured along a cross-sectional profile, recording channel width, water depth, and flow velocity at multiple locations in the cross section to calculate the volume of the water per unit time passing through the site. Cross-sectional profiles were located as close as possible to the mouth of the stream or point of confluence. Tools for discharge measurements included tape measure, anchoring pins, wading rod, and flow velocity meters (Marsh McBirney Flo-mate® flow velocity meter with an electromagnetic sensor and digital display reading to 0.01 ft/second and Global Water velocity probe with propeller and digital reading to 0.1 ft/second). Cross-sectional profiles were measured at each site and recorded on the field datasheet according to the following procedure:

1. Determine the best place for the cross-sectional profile at the site. To avoid error in flow velocity measurements, the profile should be located in an area of the stream that is a single channel (i.e., not braided and without islands), relatively free of debris, without undercut stream banks, and of sufficient depth across the majority of the profile such that the sensor on the flow velocity meter is completely submersed (>0.2 feet).
2. Extend the measuring tape across the stream perpendicular to the stream's flow and affix the tape tightly to unmoving structures (e.g., large trees) on both sides of the stream or use the anchoring pins if necessary.
3. Record the location on the measuring tape (i.e., width) where the water at the stream edge begins and ends (e.g., the wetted perimeter) on the field datasheet.

4. Record the profile width location, water depth, and flow velocity on the datasheet at intervals across the channel. Intervals should be selected based on changes in depth and flow velocity along the profile or at regular intervals for stream channels with relatively uniform depths and flow velocities. Using a top-setting wading rod, the Marsh McBirney flow meter is placed at six tenths of the depth below the water surface. In the case of the Global Water Flow Probe, the unit is raised and lowered at a steady rate throughout the water column for 20-40 seconds to collect an average reading. A minimum of 10 locations along the cross-section are measured and recorded for small streams (<20 feet wide) and 20 locations for large streams and rivers.
5. Calculate the discharge for each section or the profile using the equation: q = w*d*v, where: q = discharge, w = width of the section, d = average depth of the section, and v = average velocity of the section.
6. Calculate the total discharge at the site by summing the discharge of all sections across the profile.

Analytical Methods

Analytical chemistry for water samples were performed by chemists at the UMBS laboratory in Pellston, MI and at the LSSU laboratory in Sault Ste. Marie, MI. Chemists at UMBS and LSSU used the same USEPA-approved methods (Table 27). Bacteriological analyses were performed by HDNM staff at the laboratory in Gaylord, MI. Analytical procedures used by the laboratories are provided in Appendix A.

Table 27. USEPA-approved methods used and detection limits.

Parameter	Reporting Limit	Determinative Methods*	Holding Times
Ammonium (aqueous)	5 ug N/L	SM 4500-NH3 (G)	28 days, frozen
Nitrate (aqueous)	2 ug N/L	SM 4500-NO3 (F)	28 days, frozen
Total Nitrogen (aqueous)	45 ug N/L	digestion with basic persulfate, analyzed using SM 4500-NO3 (F)	28 days, frozen
Ortho-phosphate (aqueous)	2 ug P/L	SM 4500-P(F)	28 days, frozen
Total Phosphorus (aqueous)	5 ug P/L	digest with acidic persulfate, analyze using SM 4500-P(F)	28 days, frozen
Dissolved Organic Carbon	0.5 mg C/L	wet oxidation with nondispersive infrared detector SM 5310C	filter immediately (0.45 um), 28 days
Total Suspended Solids	1 mg/L	SM 2540-D	7 days at 4C, unpreserved
Chloride (aqueous)	0.5 mg/L	SM 4500-Cl (E)	28 days, frozen unpreserved
E. coli	1.0-2419.6 E.coli/100mL	Colilert-18/ Quantitray 2000	6 hours

**SM is Standard Methods for the Examination of Water and Wastewater, 21st edition.*

Data Management

Digital water quality data from the Hydrolab Surveyor units were downloaded onto a TOMWC computer following each monitoring/sampling event. Results of chemical and bacteriological analyses of water samples were delivered electronically to TOMWC by UMBS and HDNM via email. Discharge data and field notes were entered manually into a separate Microsoft Excel® workbook. All water quality data gathered during the project were compiled in Microsoft Excel® workbooks. All digital data associated with the project were stored on the TOMWC server and hard copies of field datasheets stored in a project file at the TOMWC office.

Discharge measurements and water quality parameter concentration data were used to calculate daily and annual pollutant loads at each sampling location. Pollutant loads were calculated by multiplying discharge (in cubic meters per second), the pollutant's measured concentration, and a conversion factor (190.48 for parameters measured in parts per million or 0.1905 for those in parts per billion). For each sample event, discharge and pollutant loads for tributaries were summed to produce a total for all tributaries that were monitored.

To determine the percentage of discharge and pollutant loads contributed by each stream to Lake Charlevoix, discharge and loadings from individual tributaries were divided by the sum total for all tributaries. Pollutant loads from other minor tributary watersheds that were not monitored or areas of direct drainage to Lake Charlevoix were estimated using loading data from adjacent and similarly sized LCTMP streams (i.e., loads per watershed acre for Horton, Loeb, Monroe, Porter, and Stover Creeks). Results of discharge and pollutant load percentages for individual tributaries were used to evaluate pollutant loadings to Lake Charlevoix for individual streams in relation to discharge. Pollutant loadings were also evaluated in relation to watershed area and land cover types.

RESULTS

In total, 170 water samples were collected from the Lake Charlevoix tributaries, which included 14 duplicates for quality control. In addition, 6 blank samples were collected for quality control. The UMBS laboratory performed 139 replicate or triplicate tests on water samples to verify precision, with results for individual replicates being within 15% of the mean result for the replicates.

Discharge was measured 156 times in the LCTMP tributaries. The monitoring site in the Lower Jordan River was moved from M32 to Fair Rd after the first monitoring event because the river was too deep at M32 to measure discharge. During the second monitoring event (5/23/2013), water was too deep to measure discharge with equipment on hand at the Fair Rd site on the Jordan River and the Park St. site on the Boyne River. Therefore, discharge was estimated for the Jordan River Fair Rd site for the first two monitoring events using discharge data from the Rogers Rd site to make a linear trend line (R^2 = 0.9963, Appendix D). Discharge was estimated for the Boyne River Park St site for the second monitoring event using discharge data from nearby Porter Creek to make a linear trend line (R^2 = 0.9656). Physical and chemical water quality data collected from the M32 Jordan River site during the first monitoring event were used for the Fair Rd site to determine average concentration values and pollutant loads.

Precipitation in study stream watersheds associated with wet weather monitoring events was determined using estimates generated by the National Oceanic and Atmospheric Administration Advanced Hydrologic Prediction Service model. Precipitation data produced by the model for the 24-hour period prior to the sampling date and the 24-hour period of the sampling date were summed for individual watersheds. Averaged precipitation during this 48-hour period for what were considered wet weather monitoring events ranged from 0.13" to 2.33" (Table 28). The variability in precipitation among the sub-watersheds of the Lake Charlevoix Watershed is exemplified by data from the 8/12/2014 monitoring event, which ranged from 0.38" in the South Branch of the Boyne River to 1.11" in Monroe Creek.

Data plotted from four study stream watersheds representing different areas of the greater Lake Charlevoix Watershed (north, south, east, and west) show moderate to strong relationships between precipitation and discharge in three of the four areas (Appendix B). The weak relationship in the Stover Creek data could indicate that it is a flashy stream, but could also be due to errors in the precipitation model or timing of discharge measurements. Discharge measured at the beginning or end of the hydrograph, as opposed to the peak, would result in a weaker relationship between precipitation and discharge.

Table 28. Precipitation data for the LCTMP watersheds (in inches for 48 hour period).

Monitoring Date	Rain Event	Stover Creek	Loeb Creek	Monroe Creek	Birney Creek	Jordan River	Deer Creek
4/9/2013	Yes	0.20	0.19	0.17	0.26	0.22	0.22
5/23/2013	Yes	0.89	0.81	0.82	0.74	1.09	1.04
7/17/2013	No	0.00	0.00	0.00	0.00	0.00	0.00
10/2/2013	No	0.00	0.00	0.00	0.00	0.00	0.00
11/14/2013	Yes	0.15	0.12	0.16	0.24	0.20	0.13
11/18/2013	Yes	2.47	2.47	2.29	2.51	2.19	2.26
5/7/2014	No	0.01	0.01	0.01	0.01	0.01	0.01
5/28/2014	No	0.00	0.00	0.02	0.03	0.01	0.01
6/23/2014	No	0.04	0.03	0.02	0.02	0.02	0.01
7/7/2014	Yes	0.69	0.64	0.51	0.56	0.51	0.59
8/12/2014	Yes	0.72	1.03	1.11	0.99	0.55	0.56
10/27/2014	No	0.10	0.09	0.08	0.09	0.08	0.07

Monitoring Date	Rain Event	Horton Creek	Brown Creek	Porter Creek	Boyne River North	Boyne River South	Boyne River All	Average for all watersheds
4/9/2013	Yes	0.24	0.18	0.19	0.20	0.18	0.19	0.20
5/23/2013	Yes	1.03	0.83	0.89	1.12	1.05	1.07	0.95
7/17/2013	No	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/2/2013	No	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11/14/2013	Yes	0.06	0.15	0.07	0.11	0.08	0.09	0.13
11/18/2013	Yes	2.52	2.50	2.51	2.07	2.06	2.13	2.33
5/7/2014	No	0.00	0.01	0.01	0.01	0.00	0.01	0.01
5/28/2014	No	0.00	0.02	0.00	0.01	0.01	0.00	0.01
6/23/2014	No	0.19	0.01	0.02	0.05	0.01	0.03	0.04
7/7/2014	Yes	1.00	0.45	0.53	0.48	0.59	0.53	0.59
8/12/2014	Yes	0.70	1.00	0.86	0.49	0.38	0.43	0.73
10/27/2014	No	0.07	0.08	0.07	0.05	0.05	0.05	0.07

Bacteria

Fecal contamination of surface waters in Michigan, due to human and animal sources, is typically assessed by measuring the number of *Escherichia coli (E. coli*) colonies in a given volume of sample water. *E. coli* bacteria usually do not pose a direct danger, but are rather indicators of the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that originate in human and animal digestive systems. Thus, their presence in surface waters indicates that pathogenic microorganisms might also be found and that there may be health risks associated with total body contact.

Bacteria in surface waters are regulated by the State of Michigan per Rule 62 (R 323.1062) of DEQ WQS. According to Rule 62, “At no time shall the waters of the state protected for total body contact recreation contain more than a maximum of 300 *E. coli* per 100 milliliters.” Rule 62 also states that: “All waters of the state protected for partial body contact recreation shall not contain more than a maximum of 1000 *E. coli* per 100 milliliters.” Note that total body contact limits apply to all Michigan streams from May to October. Although insufficient for DEQ listing purposes due to limited number of sample events, LCTMP data provide for a preliminary assessment of bacteriological contamination in the tributaries.

Daily mean bacteria concentrations exceeded WQS total body contact limits on at least one occasion at all sample sites, except for Deer Creek (Table 29). The highest rates of exceedance occurred in Birney Creek (3 events), Loeb Creek (4 events), and Stover Creek (3 events). Daily mean bacteria concentrations exceeded the WQS partial body contact standard one time in Birney, Brown, Loeb, Monroe, and Porter Creeks, and two times in Horton Creek. All partial body contact exceedances occurred during wet weather monitoring events.

Table 29. Bacteria (*E. coli*) concentrations at LCTMP sites.

Stream Name	Sample Site	7/17/2013 (Dry)*	6/23/2014 (Dry)*	7/7/2014 (Wet)*	8/12/2014 (Wet)*	Mean of All Events
Birney Creek	LTC Preserve	568.4	243.6	537.0	>2420	>944.1
Boyne River	Mouth	37.0	38.3	57.7	365.6	126.3
Boyne River	North	37.6	30.0	125.1	326.2	131.0
Boyne River	South	no data	84.6	180.4	806.8	321.7
Brown Creek	Depot St.	165.5	no data	66.6	>2420	>733.1
Deer Creek	M32	32.9	37.2	96.7	65.7	58.6
Horton Creek	Boyne City Rd	99.5	94.3	2027.1	1143.7	>853.9
Jordan River	Fair Rd	56.8	33.5	66.8	402.6	140.9
Jordan River	Rogers Rd	51.5	32.6	41.8	418.6	138.9
Loeb Creek	Evergreen Lane	358.7	338.7	537.2	>2420	915.8
Monroe Creek	M66	526.9	45.3	73.7	2265.6	731.1
Porter Creek	Mouth	103.1	194.4	332.2	1382.4	507.5
Stover Creek	Mouth	469.5	169.3	460.6	663.1	450.9

**Values presented by date are daily geometric means of threes samples collected at intervals across the stream. Bold values exceed the 1000 E. coli per 100mL partial body contact water quality standard and italicized values exceed the 300 E. coli per 100mL total body contact water quality standard.*

Mean *E. coli* concentrations from all events were less than the WQS partial body contact limit at all sites, but above the total body contact limit in Birney Creek, the Boyne River South Branch, Brown Creek, Horton Creek, Loeb Creek, Monroe Creek, Porter Creek, and Stover Creek (Table 29). Although total body contact by the public is likely limited in LCTMP creeks, high bacteria concentrations at mouth sites pose a threat to public health for those recreating in Lake Charlevoix.

Between 2001 and 2014, HDNM has collected and analyzed 1456 water samples from sites on Lake Charlevoix. The maximum of 300 was exceeded 19 times; seven times at the East Jordan Tourist Park, three times at Young State Park, two times at the East Jordan M32 Bridge, two times at Peninsula Beach, and once at the following locations: Elm Point, Ferry Beach, Hayes Township Park, Tannery Park, and Whiting Park (Table 30).

Table 30. Bacteriological monitoring results from HDNM exceeding standards.

Location	**Sample Date**	**Sample Type**	**Result Value***
East Jordan Bridge	7/26/2006	Daily Mean	649.9
East Jordan Bridge	8/28/2007	Daily Mean	368.1
East Jordan Tourist Park	7/31/2001	Daily Mean	308.5
East Jordan Tourist Park	8/3/2001	Daily Mean	320.8
East Jordan Tourist Park	8/10/2001	Daily Mean	338.8
East Jordan Tourist Park	8/31/2001	Daily Mean	435.6
East Jordan Tourist Park	8/30/2005	Daily Mean	468.4
East Jordan Tourist Park	8/7/2012	Daily Mean	515.5
East Jordan Tourist Park	8/27/2012	Daily Mean	753.3
Elm Point	8/28/2007	Daily Mean	1008.6
Ferry Beach	8/2/2006	Daily Mean	649.5
Hayes Township Park	7/27/2009	Daily Mean	318.5
Peninsula Beach	8/2/2006	Daily Mean	535.4
Peninsula Beach	6/12/2012	Daily Mean	463.6
Tannery Park	7/18/2011	Daily Mean	842.2
Whiting Park	8/31/2001	Daily Mean	302.3
Young State Park Beach	6/26/2003	Daily Mean	416.7
Young State Park Beach	7/18/2011	Daily Mean	314.8
Young State Park Beach	7/19/2011	Daily Mean	317.9

**Results reported in the number of E. coli bacteria per 100 milliliters.*

Based on results of the Health Departments bacteriological monitoring data, it appears there are occasional bacteria-related health concerns in the water at public beaches and access points on Lake Charlevoix. The most problematic site is the beach at East Jordan Tourist Park, which is located near the mouth of the Jordan River, but also near a large stormwater outfall that drains the commercial corridor along M66. Other HDNM monitoring sites near the mouths of LCTMP streams include Elm Point (Monroe Creek), Ferry Beach (Stover Creek), and Tannery Park (Boyne River). However, most samples not meeting WQS were isolated, occurring at the monitoring site on just one occasion.

Nutrients

Averaged total phosphorus concentrations were low in the Lake Charlevoix tributaries, generally below the USEPA reference condition of 12 µg/L (Table 31). Total phosphorus concentrations in individual samples ranged from 0.4 µg/L in the Jordan River at Rogers Rd to 58.3 µg/L in Birney Creek (Appendix C). Averaged concentrations were highest in Loeb Creek, Stover Creek, and Birney Creek.

Table 31. Averaged nutrient concentration data from LCTMP sites.

	Averaged Nutrient Concentration Data*					
Sample Site	**SRP (µg/L)**	**TP (µg/L)**	**NO3-N (µg/L)**	**NH4-N (µg/L)**	**TN (µg/L)**	**DOC (mg/L)**
Birney Creek - LTC Preserve	3.2	10.3	594	17.3	861	3.5
Boyne River - Park St.	2.0	6.0	300	20.2	448	3.3
Boyne River - North Branch US131	2.5	5.5	197	14.7	351	2.5
Boyne River - South Branch M75	2.0	5.6	396	14.8	551	2.7
Brown Creek - Depot St.	2.2	8.3	304	5.5	478	3.2
Deer Creek - M32	1.5	5.2	275	21.4	483	3.9
Horton Creek - Boyne City Rd.	2.6	7.3	1178	10.4	1408	2.4
Jordan River - Fair Rd.	1.8	7.5	824	15.2	1196	2.9
Jordan River - Rogers Rd.	1.8	6.7	957	10.5	1137	2.7
Loeb Creek - Evergreen Pointe Dr.	3.3	12.7	157	22.2	497	6.6
Monroe Creek - M66	2.4	6.0	171	8.1	462	5.7
Porter Creek - Lake Shore Dr.	2.0	8.3	168	12.8	391	4.5
Stover Creek - Mouth	3.1	10.8	853	18.8	1320	7.9

**SRP=soluble reactive phosphorus, TP=total phosphorus, NO3-N=nitrate nitrogen, NH4-N= ammonium, TN=total nitrogen, DOC=dissolved organic carbon.*

Conversely, averaged total nitrogen concentrations were high in the Lake Charlevoix tributaries, all but two sites above the USEPA reference condition of 440 µg/L (Table 31). Total nitrogen concentrations in individual samples ranged from 208 µg/L in the Boyne River, North Branch to 2852 µg/L in the Jordan River at Fair Rd (Appendix C). Averaged concentrations were highest in Horton Creek, Stover Creek, and the Jordan River.

DOC concentrations in the Lake Charlevoix tributaries ranged from 0.47 mg/L on the Jordan River at Rogers Rd to 17.53 at the Stover Creek mouth (Appendix C). Averaged DOC concentrations were highest in Stover and Loeb Creeks (Table 31). Averaged DOC concentrations documented in this study were within the range of 1-18 mg/L from studies of other Midwest streams (Royer and David 2003, and Volk et. al 2002).

Chloride, Conductivity, and Total Suspended Solids

Averaged chloride concentrations in the Lake Charlevoix tributaries were far below the USEPA-recommended chronic toxicity level of 230 mg/L (Table 32). Chloride concentrations in individual samples ranged from 4.3 mg/L in Monroe Creek to 59 mg/L in Stover Creek (Appendix C). Averaged concentrations were highest in Loeb Creek, Birney Creek, and Stover Creek.

Conductivity levels for individual measurements in the Lake Charlevoix tributaries ranged from 174.9 µS/cm in Monroe Creek to 690.5 µS/cm in Stover Creek (Appendix C). Averaged conductivity levels were highest in Stover, Birney, and Loeb Creeks (Table 32). Conductivity levels for all LCTMP streams were within the range of 150-500 µS/cm, which studies in inland freshwater streams have found to support good mixed fisheries (USEPA, 1997).

Measuring total suspended solids (TSS) is a way to determine the amount of sediment and other particles in water bodies. Michigan rules do not have numerical limits for TSS, but rather a narrative standard that states "that waters of the state shall not have any of the following unnatural physical properties in quantities which are or may become injurious to any designated use: turbidity, color, oil films, floating solids, foam, settleable solids, suspended solids, and deposits." Water is generally considered to be clear when TSS measures 20 mg/L or less, cloudy between 40 and 80 mg/L, and dirty when over 150 mg/L.

Averaged TSS concentrations in the Lake Charlevoix tributaries ranged from 3.4 mg/L in Deer Creek to 29.8 mg/L in Birney Creek (Table 32). Individual measurements of TSS concentration ranged from 0.9 mg/L in Deer Creek to 142.3 mg/L in Birney Creek (Appendix C). Although averaged concentrations were less than 30 mg/L for all the tributaries, there were nine measurements above 40 mg/L, two of which were above 100 mg/L. The highest TSS concentrations (>70 mg/L) were found in Birney, Brown, Stover, and Monroe Creeks. Most of the high TSS levels in these creeks occurred following precipitation, but half of the high levels in Birney Creek occurred during dry weather.

Table 32. Chloride, conductivity and total suspended solids at LCTMP sites.

	Averaged Conductivity, Chloride and Solids Data		
Sample Site	**Conductivity (uS/cm)**	**Chloride (mg/L)**	**Total Suspended Solids (mg/L)**
Birney Creek - LTC Preserve	415.07	13.7	29.8
Boyne River - Park St.	384.95	13.5	5.7
Boyne River - North Branch US131	373.69	7.0	17.2
Boyne River - South Branch M75	376.23	9.9	5.6
Brown Creek - Depot St.	373.43	16.7	19.0
Deer Creek - M32	333.94	11.0	3.4
Horton Creek - Boyne City Rd.	369.87	8.0	8.9
Jordan River - Fair Rd.	341.84	8.2	7.8
Jordan River - Rogers Rd.	332.94	6.8	11.1
Loeb Creek - Evergreen Pointe Dr.	405.68	22.1	7.2
Monroe Creek - M66	358.11	8.3	14.6
Porter Creek - Lake Shore Dr.	361.60	9.1	7.2
Stover Creek - Mouth	462.59	26.9	17.0

Dissolved Oxygen, Temperature, and pH

Averaged dissolved oxygen levels in the in the Lake Charlevoix tributaries ranged from 9.72 mg/L in Horton Creek to 10.89 mg/L in the South Branch of the Boyne River (Table 33). Dissolved oxygen measurements at sample sites ranged from 7.44 mg/L in Horton Creek to 15.96 mg/L in Porter Creek (Appendix C). All recorded levels were above the WQS minimum dissolved oxygen concentration of 7 mg/L for sustaining a cold-water fishery.

Averaged water temperatures were lowest in Horton Creek (9.60° Celsius) and highest in the Boyne River at Park Street (13.65° Celsius) (Table 33). The WQS established monthly maximum temperatures for streams naturally capable of supporting both cold and warm water fish for Northern Michigan (Table 34). State water temperature maximums for cold-water fish were exceeded four times in the Boyne River Park St and South Branch sites, three times in Deer Creek, two times in Loeb Creek, and one time in Birney, Porter, and Stover Creeks (Appendix C). Monitoring events when maximums were exceeded include: July and October of 2013 and May and July of 2014. None of the temperatures recorded exceeded State warm-water fish limits.

Table 33. Dissolved oxygen, temperature, and pH at LCTMP sites.

	Averaged Dissolved Oxygen, Temperature, and pH Data		
Sample Site	Dissolved Oxygen (mg/L)	Water Temperature (C°)	pH (units)
Birney Creek - LTC Preserve	10.21	11.69	8.14
Boyne River - Park St.	10.70	13.65	8.27
Boyne River - North Branch US131	10.63	10.74	8.25
Boyne River - South Branch M75	10.89	13.13	8.27
Brown Creek - Depot St.	10.79	10.51	8.32
Deer Creek - M32	10.38	12.99	8.24
Horton Creek - Boyne City Rd.	9.72	9.60	8.01
Jordan River - Fair Rd.	10.13	12.18	8.25
Jordan River - Rogers Rd.	10.35	10.94	8.25
Loeb Creek - Evergreen Pointe Dr.	9.93	11.55	8.11
Monroe Creek - M66	10.77	10.86	8.24
Porter Creek - Lake Shore Dr.	10.69	11.71	8.22
Stover Creek - Mouth	10.78	10.60	8.17

Averaged hydrogen ion concentration, expressed as pH, ranged from 8.01 in Horton Creek to 8.32 in Brown Creek (Table 33). All readings at sample sites fell within the range of 6.5 to 9.0 required for all Michigan surface waters according to WQS Rule 53 (323.1053) (Appendix C).

Table 34. DEQ maximum stream water temperatures by month.

Month/Temperature	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Cold Water Fish Maximum Temperature (Fahrenheit)	38.0	38.0	43.0	54.0	65.0	68.0	68.0	68.0	63.0	56.0	48.0	40.0
Cold Water Fish Maximum Temperature (Celsius)	3.3	3.3	6.1	12.2	18.3	20.0	20.0	20.0	17.2	13.3	8.9	4.4
Warm Water Fish Maximum Temperature (Fahrenheit)	38.0	38.0	41.0	56.0	70.0	80.0	83.0	81.0	74.0	64.0	49.0	39.0
Warm Water Fish Maximum Temperature (Celsius)	3.3	3.3	5.0	13.3	21.1	26.7	28.3	27.2	23.3	17.8	9.4	3.9

Discharge

Averaged discharge from the Lake Charlevoix tributaries ranged from 2.78 cfs in Brown Creek to 318.3 cfs in the Jordan River (Table 35). Natural breaks show four distinct groupings of sample sites based on averaged discharge data: 1) low: Birney Creek, Brown Creek, and Stover Creek; 2) moderately low: Boyne River North Branch, Horton Creek, Loeb Creek, Monroe Creek, and Porter Creek; 3) moderately high: Boyne River Park Street, Boyne River South Branch, and Deer Creek; and 4) high: Jordan River at Fair Road and Rogers Road (Figure 9). The relative range of discharge readings, which shows the range of discharge measurements at a site in relation to what the full range could be (zero to the maximum reading), shows that discharge readings at Brown Creek varied the least from the average, while Loeb Creek varied the most. The relative range statistic is not intended to be a flashiness index, but it does provide insight into natural flow regimes and discharge stability.

Combined (total) discharge into Lake Charlevoix from the LCTMP tributaries ranged from 287 cfs to 1760 cfs with an average of 532 cfs (Appendix B). On average, the Jordan River accounted for 60% of the discharge into Lake Charlevoix from the LCTMP tributaries, followed by the Boyne River at 25% (Figure 10, Appendix D). Considering that LCTMP tributary watersheds account for 76% of the Lake Charlevoix Watershed area, another 168 cfs (on average) could potentially be contributed from other tributaries and areas of direct drainage in the watershed.

Table 35. Low, high, and average discharge data for Lake Charlevoix tributaries.

Sample Site	**Low Discharge (cfs)***	**High Discharge (cfs)***	**Average Discharge (cfs)***	**Discharge Relative Range (%)†**
Birney Creek - LTC Preserve	1.11	8.54	3.54	87.00%
Boyne River - Park St.	66.31	331.56	125.24	80.00%
Boyne River - North Branch US131	19.38	66.16	34.31	70.71%
Boyne River - South Branch M75	39.14	190.66	72.85	79.47%
Brown Creek - Depot St.	1.69	4.35	2.78	61.15%
Deer Creek - M32	29.99	262.71	82.09	88.58%
Horton Creek - Boyne City Rd.	15.14	52.21	23.17	71.00%
Jordan River - Fair Rd.	179.92	1048.44	318.30	82.84%
Jordan River - Rogers Rd.	167.89	810.58	266.30	79.29%
Loeb Creek - Evergreen Pointe Dr.	0.68	89.19	14.53	99.24%
Monroe Creek - M66	3.59	92.73	21.93	96.13%
Porter Creek - Lake Shore Dr.	8.34	137.55	33.86	93.94%
Stover Creek - Mouth	0.73	17.49	5.63	95.83%

**Units: cfs = cubic feet per second and cms = cubic meters per second.*

† Higher percentage indicates a wider range in discharge measurements, relative to the full range.

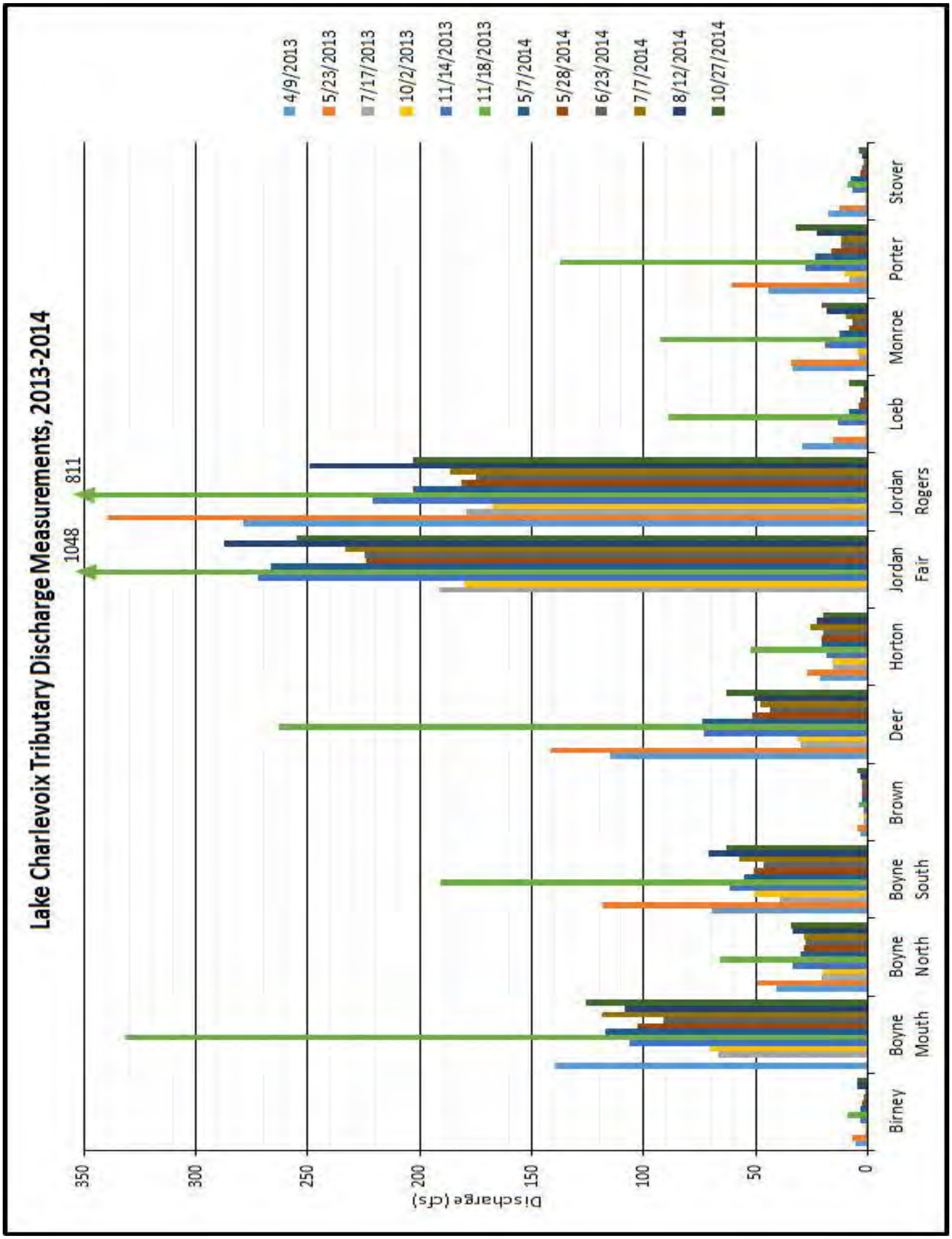

Figure 9. Lake Charlevoix tributary discharge measurements.

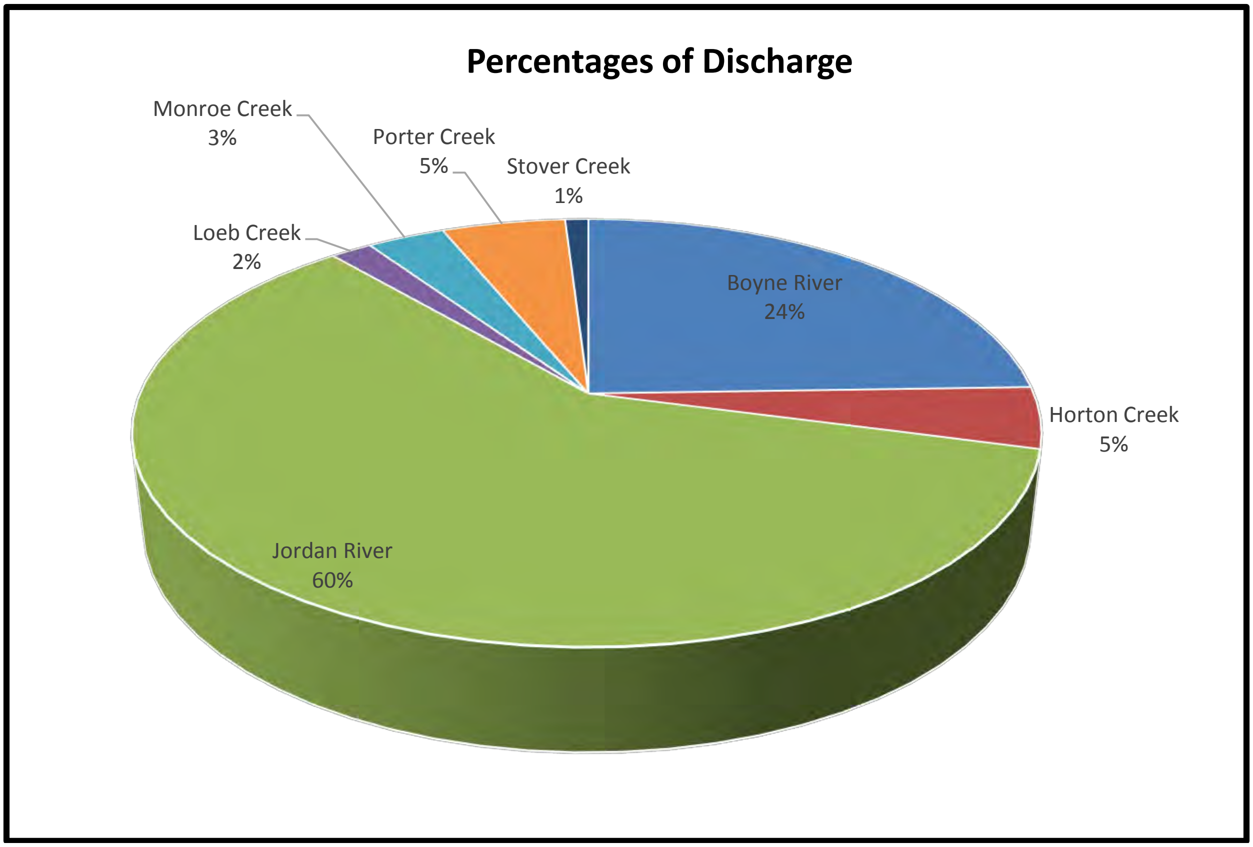

Figure 10. Averaged percentage of discharge into Lake Charlevoix from LCTMP tributaries.

Pollutant Loadings

Largely a function of discharge, averaged pollutant loads into Lake Charlevoix from the LCTMP streams were highest in the large rivers and lowest in the small creeks (Table 36). The North Branch of the Boyne River was found to have higher suspended solid loads than the South Branch despite having less than half the discharge, on average. Total suspended solid loads in the Jordan River were found to be higher at the upstream sample site at Rogers Road than at the lower site, which indicates that deposition occurs in this stream reach. High nitrogen loads in Stover Creek are exemplified by the fact that the averaged discharge from Stover Creek is less than half that of Loeb Creek, yet averaged total nitrogen loads from the creeks are the same. Although having lower averaged discharge, Monroe Creek was found to have higher total suspended solid loads than Porter Creek. Chloride loads in Loeb Creek were higher than the North Branch of the Boyne River, Horton Creek, Monroe Creek and Porter Creek in spite of lower averaged discharge in Loeb Creek.

Table 36. Nutrient loads in the Lake Charlevoix tributaries.

	Averaged Pollutant Loads (lbs/day)					
Sample Site	**Total Phosphorus**	**Total Nitrogen**	**Dissolved Organic Carbon**	**Total Suspended Solids**	**Chloride**	**Discharge (cfs)**
Birney Creek - LTC Preserve	0.2	15	84	482	252	3.54
Boyne River - Park St.	4.5	308	2,737	5,820	8,694	129.90
Boyne River - North Branch US131	1.8	68	524	4,048	1,310	34.31
Boyne River - South Branch M75	2.3	204	1,333	2,604	3,857	72.85
Brown Creek - Depot St.	0.2	7	57	319	247	2.78
Deer Creek - M32	2.4	204	1,823	2,871	4,519	82.09
Horton Creek - Boyne City Rd.	1.0	164	320	1,322	985	23.17
Jordan River - Fair Rd.	17.7	1,783	6,569	19,385	15,027	329.63
Jordan River - Rogers Rd.	10.5	1,461	5,034	20,512	9,443	266.30
Loeb Creek - Evergreen Pointe Dr.	0.6	31	467	850	1,560	14.53
Monroe Creek - M66	0.8	50	762	2,415	802	21.93
Porter Creek - Lake Shore Dr.	1.8	73	879	2,017	1,501	33.86
Stover Creek - Mouth	0.3	31	299	843	569	5.63
Total Input to Lake Charlevoix*	26.9	2,448	12,090	32,971	29,383	561.43
Annual Input to Lake Charlevoix†	9,820.3	893,455	4,412,777	12,034,338	10,724,872	NA

** Total input is the sum of loads or discharge from the stream sites in bold font.*
† Annual input is the sum of loads in pounds per year. NA=not applicable.

Similar to averaged pollutant load data, the percentage of pollutant loads was highest in the rivers and lowest in the small creeks (Table 37 and Appendix F). Relative to discharge, the percentage of the total phosphorus and dissolved organic carbon loads were high in Loeb, Monroe, Porter, and Stover Creeks, while the percentage of the total nitrogen load was high in Horton Creek, the Jordan River, and Stover Creek. Chloride loads were high in the Boyne River, Loeb Creek, and Stover Creek, relative to discharge, and total suspended solid loads were high in the Jordan River, Monroe Creek, and Stover Creek.

Table 37. Percent of averaged pollutant loads and discharge from Lake Charlevoix tributaries.

Sample Site	**Total Phosphorus**	**Total Nitrogen**	**Dissolved Organic Carbon**	**Chloride**	**Total Suspended Solids**	**Discharge**
Boyne River	23.7%	12.8%	24.4%	33.0%	14.9%	24.8%
Horton Creek	4.7%	7.3%	3.6%	3.7%	5.4%	4.9%
Jordan River	57.3%	73.1%	54.1%	50.9%	67.0%	60.4%
Loeb Creek	2.5%	1.0%	2.8%	3.3%	1.3%	1.4%
Monroe Creek	3.9%	1.8%	5.6%	2.5%	5.4%	3.0%
Porter Creek	6.0%	2.7%	7.1%	4.6%	4.0%	4.8%
Stover Creek	1.9%	1.3%	2.4%	2.0%	2.1%	0.7%

DISCUSSION

The LCTMP streams and their associated tributaries (e.g., Deer, Birney, and Brown Creek are included in the Jordan River section) are discussed individually to evaluate data and identify water quality problems in the context of each stream system and associated watershed. The last section of the discussion focuses on the collective influence of the LCTMP streams to the water quality and ecosystem of Lake Charlevoix.

Boyne River: North, South, and Main Branches

There is very little evidence of water quality problems in the Boyne River, whether the Main, North, or South Branch. Monitoring results show that most parameters met Michigan WQS. Water temperature was the exception, as some measurements were above the monthly temperature maximums for sustaining a cold water fishery. Water temperatures were higher at the South Branch and Park Street sites than at any other LCTMP sample site. Results for parameters that are not regulated were typical for streams monitored in the Northern Lower Peninsula as part of the CWQM Program (Appendix C, Table 9). However, total nitrogen levels were slightly above the USEPA reference condition (440 µg/L) at the South Branch and Park Street sites (Table 31).

Dams can elevate the stream water temperature due to the increased residence time of water in the impoundment coupled with solar radiation over a large surface area. Small surface-release dams, such as those on the Boyne River, have been shown to reduce the abundance of stream resident cold-water species, such as brook trout (Lessard and Hayes, 2003). The dam that forms the Boyne Falls Mill Pond is the likely culprit for elevated water temperatures at the South Branch monitoring site, which is located immediately downstream. The Boyne USA Power Plant and Dam, located mid-stream near Dam Road, likely only has subtle effects on water temperature at the Park Street site, which is located approximately 5 miles downstream. However, the Boyne City Mill Pond, a wide and shallow section of the river measuring up to 500’ across and just upstream of Boyne City, invariably affects water temperatures at the Park Street site. These dams are also a barrier to fish passage and movement of other aquatic fauna.

Agriculture is a well-documented source of nonpoint source pollution to surface waters, including nutrients (USEPA 1997a). Elevated nitrogen concentrations were documented in the Boyne River in both archive and LCTMP data (Table 10, Table 31). The elevated nitrogen could be linked to agricultural activity in the Mancelona Plains, which is also a suspected source of

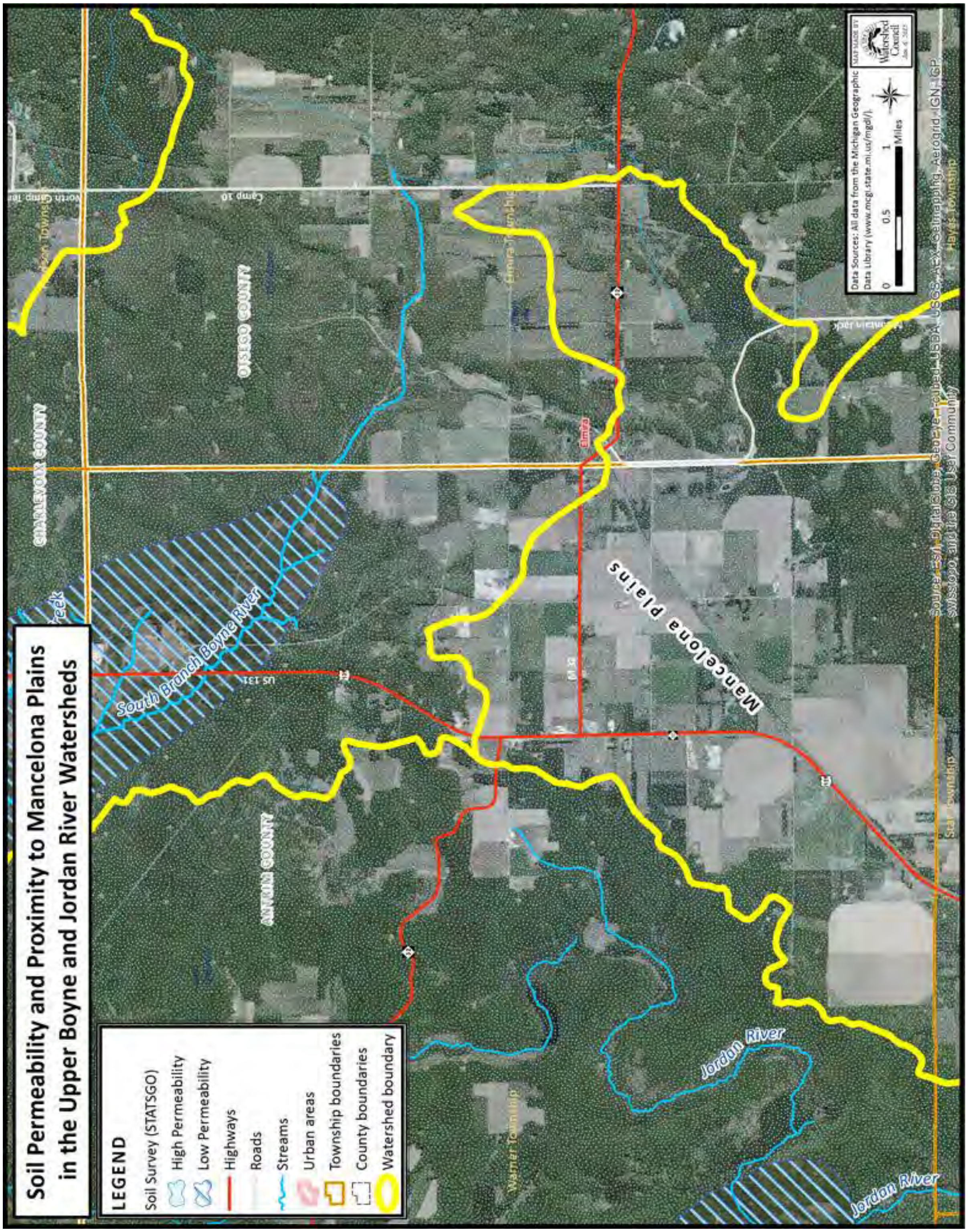

Figure 11. Soil and agriculture in headwaters of the Boyne and Jordan River Watersheds.

nutrient pollution to the Jordan River. Fertilizers, manure used for crops, and livestock wastes in agricultural areas are known sources of nitrogen in streams (USGS 1999). The headwaters of the South Branch extend into the Mancelona Plains where agriculture, particularly potato farming, is prevalent (Figure 11). Furthermore, the South Branch's groundwater watershed may extend into the Mancelona Plains beyond the topographical watershed, which could further increase nitrogen levels in the Boyne River via groundwater inputs. Based on the State Soil Geographic (STATSGO) dataset, the sandy soils prevalent in this headwater area are conducive to pollutant transport outside the topographical watershed via groundwater migration. Any nutrient pollution occurring in the river would be lessened by the dams, which have been shown to reduce nitrogen and phosphorus loads in river systems (Bosch et. al. 2009).

Although nitrogen concentrations were found to be relatively high in the Boyne River, as well as in several other LCTMP streams, phosphorus concentrations were generally low (Table 31). This incongruity is likely related to nitrate readily dissolving in water whereas phosphorus tends to attach to soil particles rather than dissolve into water. Research shows that nitrogen yields in streams are about one-half or less of total nitrogen inputs from the atmosphere, fertilizers, and manure, while phosphorus yields are roughly one-sixth or less of inputs from the same sources (USGS 1999). Furthermore, CWQM program data show that phosphorus is the limiting nutrient for most lakes and streams in the Northern Lower Peninsula (TOMWC 2013), which may contribute to the low concentrations found during the LCTMP due to utilization of phosphorus by plants in the stream ecosystem.

Jordan River and Tributaries

The Jordan River system was monitored at five different sites to evaluate inputs from discrete branches, effects of tributaries on the main branch, and impacts from sub-watersheds possessing relatively high agricultural or urban land cover. In general, data show that the main stem of the Jordan River boasts high water quality. Averaged data at both the Rogers Road and Fair Road sites show total phosphorus concentrations below the USEPA reference condition (12 µg/L), chloride concentrations far below the USEPA recommended chronic toxicity level (230 mg/L), low suspended solid concentrations, among the lowest dissolved organic carbon concentrations, consistently high dissolved oxygen levels, among the lowest conductivity levels, pH consistently within the range required by DEQ, and low *E. coli* concentrations (Table 31). However, in accordance with CWQM results, total nitrogen concentrations were far above the USEPA reference condition (440 µg/L) and among the highest in the LCTMP tributaries.

The high nitrogen levels in the Jordan River, documented in archive data and during the current study, were initially perplexing because there is relatively little agricultural and urban land cover in the watershed (Table 31, Table 18, Table 38) However, recent research by MSU hydrologists attributed elevated nitrogen levels in the Jordan River to agricultural operations (potato farming) in the Mancelona Plains (Kendall et. al 2011). Although outside the topographical watershed boundary, the Landscape Hydrology Model (LHM) developed at MSU shows that extensive areas in the Mancelona Plains are within the groundwater watershed of the Jordan River (Figure 12). This provides a plausible explanation for the high nitrogen concentrations observed in the Jordan River; nitrogen in fertilizers used in Mancelona Plains potato farming operations reach the river via groundwater channels. Furthermore, irrigation trends in the Mancelona Plains determined by the MSU researchers show a large increase in irrigated areas (Martin et. al. 2010), which likely accelerates the migration of nutrient-laden groundwater to the Jordan and Boyne Rivers (Figure 13).

Although not the limiting nutrient, excessive nitrogen in the ecosystem could cause shifts in the aquatic food web, beginning with changes in algal communities. The high nitrogen concentrations could cause the Jordan River to become more eutrophic. In addition, there is evidence that high nitrogen levels may encourage invasion by non-native species, such as *Phragmites australis* and *Typha angustifolia* (Currie et. al., 2014). Nitrogen concentrations were lower at the downstream location at Fair Road than at Rogers Road during 11 of 12 monitoring events (Appendix C), which is probably the result of dilution from Deer Creek, but may also be due to uptake, settling, and denitrification in the wetland complexes buffering both sides of the river (Figure 2).

Monitoring data collected from Deer Creek points toward high water quality and a healthy stream ecosystem, which validates DEQ surveys in the creek that showed remarkable aquatic macroinvertebrate diversity (Table 19). Nutrient concentrations, suspended solids, conductivity, and bacteria are low, while dissolved oxygen is high (Appendix C). The only issue that emerges from the Deer Creek data is elevated water temperatures, which exceeded State water temperature maximums for cold-water fish three times. The high water temperatures are likely caused by the impoundment called Patricia Lake that was created by the dam, which is located less than one mile upstream.

Monitoring data from this study (Table 19) support the biological assessment of Birney Creek in 2003 by DEQ indicating water quality impairment (Walker 2008). High nitrogen concentrations indicate that Birney Creek may be experiencing nutrient pollution (Table 31). Total suspended solids and *E. coli* concentrations were also high, and were in fact the highest averaged values in

Table 38. Land cover in LCTMP tributary watersheds (%).

Land-cover Type 2010	Boyne River	Brown Creek	Birney Creek	Deer Creek	Horton Creek	Jordan River	Loeb Creek	Monroe Creek	Porter Creek	Stover Creek
Agriculture	14.99	4.05	39.13	15.50	32.14	12.66	29.75	23.17	23.51	39.55
Barren	0.23	0.05	0.06	0.08	0.02	0.10	0.06	0.00	0.02	0.24
Forest	54.34	65.78	30.51	50.20	45.64	58.01	19.70	38.76	39.37	22.32
Grassland/Herbaceous	9.28	5.54	14.04	7.84	7.52	6.74	5.94	5.94	12.07	6.08
Scrub/Shrub	3.37	3.38	3.64	2.74	2.50	2.81	2.71	3.60	3.06	2.98
Urban	5.58	8.58	4.79	3.29	2.16	2.57	4.78	0.97	1.74	9.81
Water	0.67	0.00	0.00	2.04	0.02	0.76	1.48	2.30	0.45	0.01
Wetland	11.53	12.62	7.83	18.32	10.01	16.34	35.60	25.26	19.79	19.02

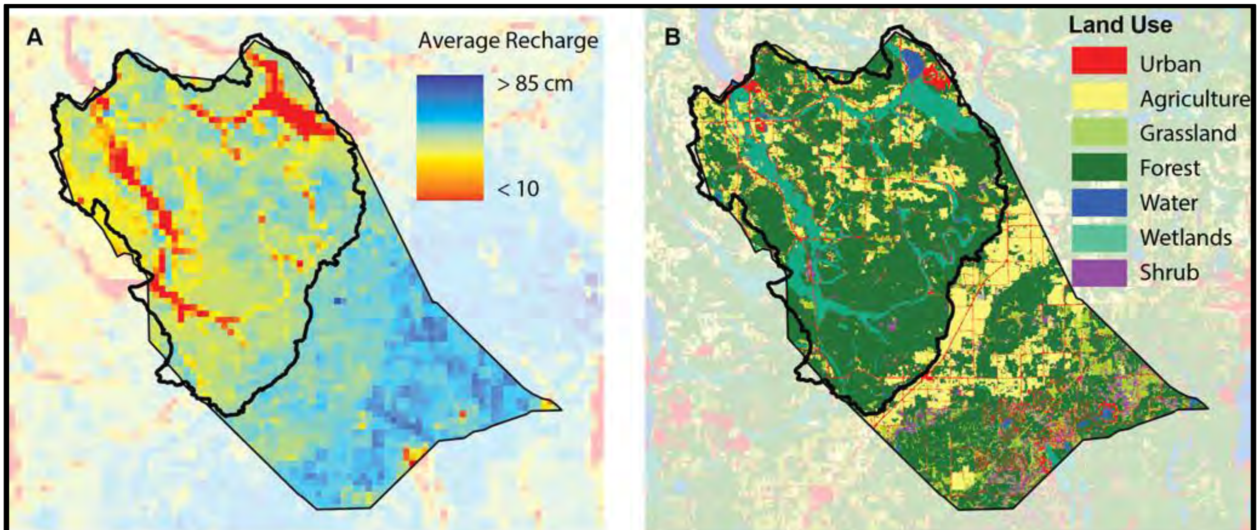

Figure 3e. Average annual groundwater recharge (A) and 2001 NLCD land use/cover (B). The inner black outline is the JRW, while the larger outlined area is the ILHM-calculated groundwatershed for the Jordan River.

The groundwatershed area (563 km²) is 69% greater than the surface watershed area (333 km²), and encompasses a region of significantly greater groundwater recharge than within the surface watershed.

Over the 10-year model period, 49.9% of the total simulated recharge to the Jordan River came from outside the surface watershed. This high-recharge region is heavily agricultural, with a significant expansion of irrigated area in the last two decades.

Figure 12. Jordan River groundwater watershed as determined by the Landscape Hydrology Model (Martin et. al. 2010).

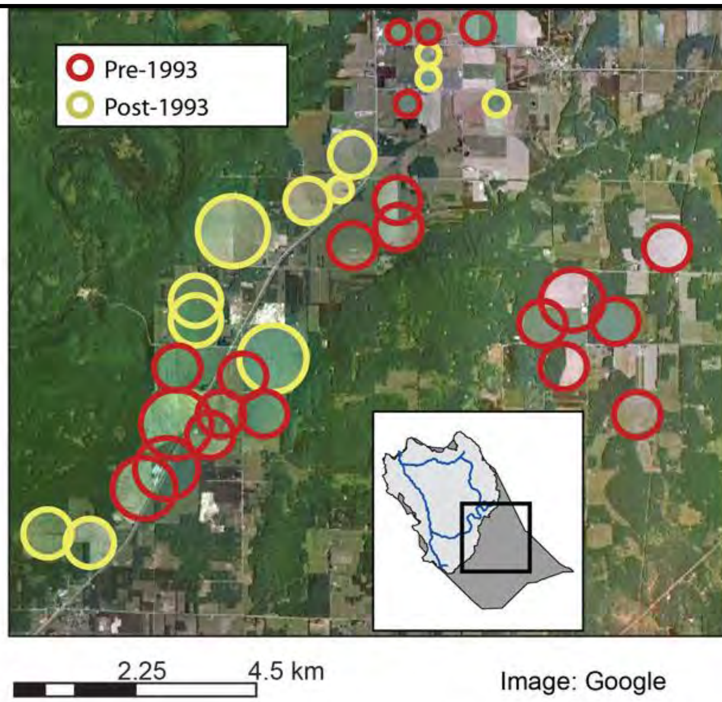

Figure 6a. Map of irrigated agricultural fields outside of the JRW (light grey) yet inside the Jordan River groundwatershed (dark grey), as shown in the inset map. Red circles outline irrigated fields present in both 1993 and 2005 imagery, while yellow circles outline fields only recently irrigated.

Figure 13. Irrigation trends in the Mancelona Plains (Martin et. al. 2010).

the study for these parameters (Table 29, Table 32). The water quality issues in Birney Creek may be the result of agricultural land use in the watershed. In 2010, land cover in the Birney Creek Watershed was nearly 40% agricultural, compared to 13% in the Jordan River Watershed (Table 38). Runoff from agricultural lands degrade stream water quality due to inputs of sediments, nutrients, pesticides, herbicides, and other pollutants.

In spite of flowing through the City of East Jordan, monitoring results show that Brown Creek is minimally impacted. Most parameters monitored were found to be within normal ranges or at low concentrations (Appendix C). Urban runoff in the Brown Creek Watershed likely contributed to the high *E. coli* counts and relatively high chloride concentrations found in the creek (Table 29, Table 32). Potential sources of bacteria in the urban setting include pet waste, leaking sewer lines, and wildlife (e.g., rodents, birds, etc.).

Horton Creek

Horton Creek is the fourth largest tributary to Lake Charlevoix, in terms of both watershed area and discharge (Table 37, Table 38). Over 30% of the Horton Creek Watershed was classified as having agricultural land cover in 2010, which provides an explanation for the high nitrogen levels in the creek. Averaged total nitrogen and nitrate-nitrogen concentrations in the creek were found to be higher than all other LCTMP streams (Table 31). Accordingly, pollutant loading figures show that Horton Creek contributed a high percentage of total nitrogen to Lake Charlevoix relative to discharge (Table 37). The cold water temperatures documented in Horton Creek indicate large groundwater inputs (Table 33), which could be a big source of nitrogen as nitrate-nitrogen readily dissolves in water and is transported via subsurface runoff.

Phosphorus concentrations and loads in Horton Creek were found to be roughly average for LCTMP streams despite the disproportionate nitrogen loading to Lake Charlevoix. Similar to other LCTMP streams experiencing nitrogen pollution, the low phosphorus levels in Horton Creek are probably a result of phosphorus adhering to particles as precipitation infiltrates the soil column, coupled with uptake by plants in the stream ecosystem. However, there are signs of eutrophication in Horton Creek as a result of nutrient pollution.

Extensive, dense *Cladophora* algae growth was noted at the Boyne City Road monitoring site. *Cladophora* is used as a biological indicator of nutrient pollution because, though occurring naturally, it tends to proliferate and grow densely in response to greater nutrient availability. Dissolved oxygen measurements also hint at eutrophication of the stream ecosystem. In spite of cold water temperatures, which allow water to hold more dissolved oxygen than warm water, Horton Creek had the lowest dissolved oxygen readings during the July and August 2014 sampling events (Appendix C). However, dissolved oxygen levels may have been influenced by low-oxygen waters from slower upstream areas or decomposition of the large quantities of organic material noted in the stream channel.

The high bacteria counts in Horton Creek documented in 2014 are a public safety concern, particularly for those recreating where the creek flows into Lake Charlevoix at Horton Bay (Appendix C). There are many potential sources of *E. coli* ranging from wildlife to failing septic systems. However, agricultural runoff is suspected as a likely source because of the high nitrogen levels documented in the creek.

Stover Creek

Results from the LCTMP show that nutrient pollution, and potentially other forms of pollution, is an issue in Stover Creek. Averaged data show that total phosphorus, total nitrogen, nitrate-nitrogen, dissolved organic carbon, chloride, and conductivity levels in Stover Creek were among the highest of the LCTMP streams (Table 31). Correspondingly, pollutant load percentages from Stover Creek were two to three times higher than would be expected based on discharge (Table 37). Based on the recently completed Stover Creek Watershed Restoration and Management Plan (SCWRMP), nutrient pollution and other water quality problems are occurring at upstream locations as well (TOMWC 2015). Water pollution and degradation of the stream ecosystem are attributed to high percentages of agricultural (40%) and urban land cover (10%) in the Stover Creek Watershed, which are highest among LCTMP streams (Table 38).

A variety of surveys and assessments performed during development of the SCWRMP help pinpoint nonpoint source pollution in the Stover Creek Watershed. Erosion at several road stream-crossings and 34 streambank sites contribute sediments and nutrients to the creek. Based on SCWRMP stormwater assessments, runoff from commercial, residential, and recreational (golf course) land use in the lower watershed is estimated to contribute over 90 lbs of phosphorus, 666 lbs of nitrogen, and nearly 19,000 lbs of sediments to the creek annually. The SCWRMP provides 25 recommendations for restoring and protecting Stover Creek that range from stabilizing streambank erosion to installation of stormwater BMPs to permanent land protection. TOMWC and partners from the Committee are expected to actively seek out funding to implement these recommendations during the next 10 years.

Loeb Creek

Loeb Creek was found to contribute large loads of total phosphorus, DOC, and chloride to Lake Charlevoix, relative to discharge (Table 37). Archive data from 2003 also showed relatively high chloride and total phosphorus concentrations (Table 23, Table 24). Runoff from residential and commercial areas upstream of the sample site near M66 is suspected of contributing chloride and phosphorus to the creek. The high DOC levels likely result from the extensive wetlands in the Loeb Creek Watershed, which make up a greater percentage (36%) of watershed land cover than all other LCTMP streams (Table 38).

Nitrogen concentrations and loads in Loeb Creek were found to be relatively low considering its watershed possesses nearly 30% agricultural land cover (Table 38). Averaged total nitrogen concentrations from LCTMP data were slightly above the reference condition of 440 µg/L recommended by USEPA, though archive data show much higher concentrations (Table 31, Table 24). Uptake, settling, and denitrification in the large wetland complexes throughout the creek's watershed probably reduce nitrogen loading from agricultural areas. The wetlands, as well as surrounding agricultural areas, could also be a source of the relatively high phosphorus load found in the creek.

Monroe Creek

Archive and LCTMP data show little evidence of pollution in Monroe Creek. The only pollutant concentration in Monroe Creek found to be greater than the average for LCTMP streams was DOC. Similar to Loeb Creek, ample wetlands in the Monroe Creek Watershed (>25%) are the likely source of DOC in the creek (Table 38). Total nitrogen concentrations in Monroe Creek were slightly above the USEPA reference condition (Table 31), which likely results from the moderately high percentage of agricultural land cover in the creek's watershed (~23%).

Porter Creek

Similar to Monroe Creek, archive and LCTMP data show Porter Creek to be minimally impacted. The averaged DOC load from Porter Creek was large relative to discharge, which is probably a result of the extensive wetlands bordering the creek throughout the watershed (Table 36, Table 38). The wetlands may also be the source of phosphorus load that was found to be slightly high in Porter Creek relative to discharge. The wetlands may also be protecting the creek from nitrogen pollution caused by agriculture (~24% of agricultural land cover in the watershed), considering the averaged total nitrogen concentration of 391 μg/L was lower than the USEPA reference condition (Table 31).

Lake Charlevoix

Annual contributions to Lake Charlevoix from the LCTMP streams are enormous, totaling nearly 10,000 pounds of phosphorus and 12,000,000 pounds of sediments (Table 39). Including estimates for areas in the Lake Charlevoix Watershed that were not monitored, which were based on LCTMP loads per acre in adjacent tributary watersheds, totals climb to over 11,000 pounds of phosphorus and nearly 15,000,000 pounds of sediments.

In spite of these loadings, CWQM data show that high water quality persists in Lake Charlevoix. TOMWC Volunteer Lake Monitoring program data show high water transparency, nearly 20' on average throughout summer months (TOMWC 2014). There is little phosphorus in the lake, with 1.2 µg/L of total phosphorus measured throughout the water column according to the latest CWQM program data (TOMWC 2013). However, CWQM data for total nitrogen and nitrate-nitrogen concentrations in Lake Charlevoix, particularly in the South Arm, show high levels relative to other large lakes in Northern Michigan (Table 40). This is not surprising considering the high nitrogen concentrations documented in several LCTMP streams.

Table 39. Pollutant loads from the entire Lake Charlevoix Watershed.

	Pollutant Loads into Lake Charlevoix (lbs/year)				
Sample Site	**Acreage**	**TP-Load**	**TN-Load**	**TSS-Load**	**Cl^--Load**
All LCTMP streams combined	162,228	9,763	890,790	11,917,797	10,634,697
Remaining watershed area*	33,743	1,692	129,298	2,757,509	2,005,506
Entire Lake Charlevoix Watershed†	195,971	11,454	1,020,088	14,675,306	12,640,203

**Remaining watershed area load estimated with LCTMP data from adjacent or similar-sized watersheds, including Stover, Loeb, Monroe, Porter, and Horton Creek.*
†Entire Lake Charlevoix Watershed acreage does not include Lake Charlevoix.

Nitrogen pollution is not as problematic as phosphorus pollution in freshwater systems, but there can be consequences. As previously mentioned, excessive nitrogen inputs can cause shifts in the aquatic food web. There are reports and evidence of algal community shifts occurring in neighboring large, deep, oligotrophic lakes. Concerned about a proliferation of diatoms on the lake bottom in nearshore areas, the Elk-Skegemog Association collected samples for analysis. The analysis revealed the presence of several algal species that thrive in nitrogen- rich environments. Phycologists from Michigan State University and the University of Michigan plan to undertake research in 2015 to examine a similar situation in Torch Lake and determine causes for the proliferation of this algal community type.

Table 40. CWQM program data for large, oligotrophic lakes in Northern Michigan.

	Average Pollutant Concentrations from CWQM Program Data*			
Lake	**Nitrate-Nitrogen (ug/L)**	**Total Nitrogen (ug/L)**	**Total Phosphorus (ug/L)**	**Chloride (mg/L)**
Lake Charlevoix (main)	327	477	4	9
Lake Charlevoix (South Arm)	441	579	5	8
Burt Lake	108	282	5	8
Mullett Lake	86	292	8	9
Torch Lake	329	442	4	6
Elk Lake	253	364	4	8
Little Traverse Bay	250	400	4	11
Grand Traverse Bay	248	318	7	9

**CWQM = Comprehensive Water Quality Monitoring Program 1992-2013.*

Other research showing evidence that high nitrogen levels may encourage invasion by non-native species may be playing out in Lake Charlevoix. Although invasive *Phragmites australis* still occurs rarely in inland lakes of the Northern Lower Peninsula, numerous infestations were discovered on Lake Charlevoix approximately five years ago. Invasion by this highly problematic species is probably a consequence of the direct connection of Lake Charlevoix to Lake Michigan via the Pine River in the City of Charlevoix. However, nitrogen pollution may be accelerating the spread of invasive Phragmites in the lake.

Recommendations

High Priority

1. Conduct additional monitoring and surveys in the Birney Creek system to identify and address sources of water quality problems, including sedimentation, nutrient pollution and public health risk from high bacteria concentrations. Develop a restoration and management plan for Birney Creek to address problems found.
2. Identify sources of nutrient pollution in Horton Creek and the Boyne River South Branch by surveying stream channels to document *Cladophora* algae growth and riparian activities that contribute excess nutrients.
3. Continue bacteriological monitoring at public beaches and include source tracking if possible. Support HDNM's efforts to monitor bacteria at public swimming beaches around Lake Charlevoix, particularly those near tributary mouths where high *E. coli* concentrations were documented (Horton, Stover, Loeb, Monroe, and Porter Creeks). Source track bacteria through DNA analysis or other methods to determine if human, livestock, or pet wastes are contributing to the problem.
4. Develop and implement a plan to reduce nutrient, sediment, and bacteria inputs to LCTMP streams by working with agricultural producers to implement BMPs. Extend outreach and education efforts to all agricultural producers and hobby farms, with a focus on the largest agricultural operations. Specifically, these producers could volunteer to be verified through the Michigan Agricultural Environmental Assurance Program, which is a comprehensive, voluntary, proactive program designed to reduce farmers' legal and environmental risks through a three-phase process: 1) education; 2) farm-specific risk assessment and practice implementation; and 3) on-farm verification that ensure the farmer has implemented environmentally sound practices.
5. Address erosion in the tributaries to reduce sedimentation in Lake Charlevoix. Data show disproportionate suspended solid inputs from the Jordan River, Horton Creek,

Monroe Creek, and Stover Creek. Conduct or update road-stream crossing and streambank erosion surveys in the tributaries to identify nonpoint source pollution problems. Develop a plan that prioritizes remedial actions and acquire support for implementation.

6. Monitor drinking water wells for nitrate in watersheds where nitrogen concentrations were high. These including watersheds of the Jordan River, Boyne River South Branch, Horton Creek, and Stover Creek. Drinking water wells in the Mancelona Plains should also be tested for nitrate levels.
7. Loeb Creek: Assess developed areas near M66 that are contributing polluted runoff and implement BMP installation to reduce nonpoint source pollution to the creek.
8. Stover Creek: Numerous detailed recommendations for restoration are already included in the SCWRMP. In terms of water quality monitoring, additional data are needed from sites upstream of golf course and monitoring should be conducted following implementation of SCWRMP recommendations (e.g., stormwater BMP installations) to assess effectiveness.
9. Collect more comprehensive water temperature data at Boyne River and Deer Creek sites downstream of dams/impoundments to evaluate impacts to organisms that depend on cool water. Temp loggers should be deployed to accurately assess the full range of water temperatures in the creeks and determine the number of days exceeding WQS maximums.
10. Preserve wetlands throughout the watershed as data provide evidence that riparian wetlands have afforded protections against nutrient pollution for Loeb, Monroe, and Porter Creeks.
11. Encourage riparian owners in all streams throughout the Lake Charlevoix Watershed to adopt best management practices that benefit the water quality. Fertilizers should be applied sparingly, if at all, in riparian areas. Stormwater should be held and treated on site, septic systems should be properly maintained, and eroded areas should be stabilized and replanted. Greenbelts are particularly important for protecting water quality and should be maintained at the greatest width possible. Greenbelts effectively absorb surface runoff and by doing so filter out pollutants, reduce peak stream discharge during rain events, provide shade to maintain water temperatures necessary for cold water fisheries and prevent erosion. Naturally vegetated stream banks also provide critical habitat and a food energy source for both aquatic and terrestrial organisms. Research has shown that optimal greenbelt width for stream protection to be 100 feet or more, but that greenbelts of 35 feet of width provide many benefits to stream water quality and biology (Wenger 1999).

Medium Priority

12. Monitor water quality of the southeastern Brown Creek to determine if there are negative impacts associated with urban runoff. There are two Brown Creeks that flow through the east side of the City of East Jordan and only the northern-most was monitored in the LCTMP.
13. Determine the proximity of invasive species infestations to inlet tributaries to determine if there is a spatial relationship.
14. Assess algal communities in Lake Charlevoix to determine if changes are occurring as a result of excessive nitrogen inputs from the tributaries.
15. Repeat this tributary monitoring project every five to ten years to evaluate changes in the sub-watersheds. Expand the monitoring to include additional tributaries, such as Sear and Chanda Creeks. Select monitoring sites in sub-watersheds up and downstream of BMP installations to accurately assess longitudinal changes in the streams.

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Appendix A. Analytical methods for chemical and biological parameters.

Aqueous Ammonium

Standards

Stock standard: weigh approximately 1.5 grams of previously dried ammonium chloride standard into a 500-mL volumetric flask. Record the exact weight in the lab notebook. Dissolve the standard in approximately 300 mL of DI water. When totally dissolved, finish diluting by adding additional water to the mark. This solution contains approximately 800 mg N/L (800 ppm N). This solution is stable for about two months if stored at 4 ºC. Bring to room temperature before using.

Intermediate standard: dilute the stock standard by pipetting exactly 5.0 mL of the stock standard into a 500-mL volumetric flask and diluting to the mark with DI water.   This solution contains approximately 8 mg N/L (8 ppm N).

Working standards: using the intermediate standard, pipette 0.2, 0.5, 1.0, and 1.5 mL into four separate 100-mL volumetric flasks. Add DI water to the mark, cap and mix well. To a fifth 100-mL volumetric, add DI water.

Sample preparation

Filter sample through an acid-washed 0.45 µm membrane filter fitted onto an acid-washed syringe filter holder. Typically 10 mL of filtered sample is required for the test. Samples need to be free of particulate matter. If they appear turbid, centrifuge them for 10 minutes at 750xg before filtering. Samples should be filtered immediately upon returning from the field. Filtered samples can be stored at 4 ºC for 24 hours.

QC sample

Dilute a sample of the simple nutrient QC standard to be run with the samples.

Sample analysis

Analyze samples, standards and QC samples using the ammonium SOP. Results are reported as µg N/L. Any sample higher than the highest standard should be repeated after making the appropriate dilution with DI water.

Aqueous Nitrate

Standards

Stock standard: dissolve approximately 2.0 g of previously dried potassium nitrate (dried at 90 ºC for 2 hours) in approximately 300 mL of DI water. Record the exact weight in the lab notebook. Dilute to exactly 500 mL and mix thoroughly. This solution contains approximately 650 mg N/L (650 ppm N). When kept in the refrigerator it is stable approximately 1 month.

Intermediate standard: dilute the stock standard by adding 5.0 mL of stock solution to a 500-mL volumetric flask and dilute to the mark with DI water. This solution is approximately 6.5 mg N/L (6.5 ppm N).

Working standards: to four separate 100-mL volumetric flasks, add 0.1, 0.2, 0.5 and 0.8 mL of intermediate standard. Dilute to the mark with DI water and mix thoroughly. To a fifth 100-mL volumetric flask, add DI water. The working standards need to be made fresh whenever the nitrate procedure is run.

Sample Preparation

Filter samples through an acid-washed 0.45 µm membrane filter fitted into an acid-washed syringe filter holder. Typically 10 mL of filtered sample is required for the test. Samples need to be free of particulate matter. If they appear turbid, centrifuge them for 10 minutes at 750xg before filtering. Samples should be filtered immediately upon returning from the field. Filtered samples can be stored at 4 ºC for 24 hours before analyzing.

QC sample

Dilute a sample of the simple nutrient QC standard to be run with the samples.

Sample analysis

Analyze samples, standards and QC samples using the nitrate SOP. Results are reported as µg N/L. Any sample higher than the highest standard should be diluted with DI water and rerun.

Total Nitrogen

Standards

Stock standard: dissolve approximately 2.0 g of previously dried potassium nitrate (dried at 90 ºC for 2 hours) in approximately 300 mL of DI water. Record the exact weight in the lab notebook. Dilute to exactly 500 mL and mix thoroughly. This solution contains approximately 650 mg N/L (650 ppm N). When kept in the refrigerator it is stable approximately 1 month.

Intermediate standard: dilute the stock standard by adding 5.0 mL of stock solution to a 500-mL volumetric flask and dilute to the mark with DI water. This solution is approximately 6.5 mg N/L (6.5 ppm N).

Working standards: to four separate 100-mL volumetric flasks, add 1.5, 2, 3, and 5 ml of intermediate standard. Dilute to the mark with DI water and mix thoroughly. To a fifth 100-mL volumetric flask, add DI water.

Basic potassium persulfate (low nitrogen)

The basic persulfate is prepared by adding 1.5 g boric acid (H_3BO_3), 4.0 g potassium persulfate (low nitrogen, $K_2S_2O_8$) and 1.5 g sodium hydroxide (low nitrogen, NaOH) to 100 mL of DI water and mixing until dissolved. Gentle heating may be necessary to aid dissolution.

Sample preparation

Add 8.0 mL of sample or standard to a culture tube fitted with a Teflon lined screw cap. Add 0.8 mL of the persulfate solution, loosely cap and place in an autoclave at 115° C for 45 minutes. The pH of the digest should be about 8. When the autoclave returns to ambient conditions, remove the samples, which will still be warm, and allow them to cool to room temperature before analyzing. Samples that aren't analyzed immediately can be stored at 4 ºC for 24 hours.

QC sample

Dilute an aliquot of the complex nutrient QC sample and run along with the samples.

Sample analysis

Analyze samples, standards and QC samples using the nitrate SOP. Results are reported as mg N/L. Any sample more concentrated than the highest standard should be diluted with blank solution and rerun. For optimal results, the pH of the diluted samples must not change.

Aqueous Ortho-phosphate

Standards

Stock standard: Dissolve approximately 0.2 g of previously dried potassium dihydrogen phosphate in about 300 mL of DI water. Record the exact weight in the lab notebook. Dilute to exactly 500 mL with DI water and mix thoroughly. This solution contains approximately 100 mg P/L (100 ppm P).

Intermediate standard: prepare a fresh intermediate standard by pipetting exactly 1.0 mL of stock standard into a 500-mL volumetric flask. Dilute to the mark with DI water and mix thoroughly. This solution is approximately 200 µg P/L (200 ppb P).

Working standards: whenever phosphate is to be determined, into four separate 100-mL volumetric flasks, add: 2, 5, 10 and 25 mL of the intermediate standard, dilute to the mark with DI water and mix thoroughly. Into a fifth 100-mL volumetric add DI water.

Sample preparation

Filter sample through an acid-washed 0.45 µm membrane filter fitted onto an acid-washed syringe filter holder. Typically 10 mL of filtered sample is required for the test. Samples need to be free of particulate matter. If they appear turbid, centrifuge them for 10 minutes at 750xg before filtering. Samples should be filtered immediately upon returning from the field. Filtered samples can be stored at 4 ºC for 24 hours. Do not freeze.

QC sample

Dilute a sample of the simple nutrient QC standard to be run with the samples.

Sample analysis

Analyze samples, standards and QC samples using the phosphate SOP. Results are reported as µg P/L. Any sample higher than the highest standard should be repeated after making the appropriate dilution with DI water.

Total phosphorus in Aqueous Samples

Standards

Stock standard: Dissolve approximately 0.2 g of previously dried potassium dihydrogen phosphate in about 300 mL of DI water. Record the exact weight in the lab notebook. Dilute to exactly 500 mL with DI water and mix thoroughly. This solution contains approximately 100 mg P/L (100 ppm P).

Intermediate standard: prepare a fresh intermediate standard by pipetting exactly 1.0 mL of stock standard into a 500-mL volumetric flask. Dilute to the mark with DI water and mix thoroughly. This solution is approximately 200 µg P/L (200 ppb P).

Working standards: whenever phosphate is to be determined, into four separate 100-mL volumetric flasks, add: 2, 5, 10 and 25 mL of the intermediate standard, dilute to the mark with DI water and mix thoroughly. Into a fifth 100-mL volumetric add DI water.

Acidic ammonium persulfate

Dissolve 4.0 g of ammonium persulfate in approximately 75 mL of DI water; carefully add 10.0 mL of 2.5 N sulfuric acid. Once the ammonium persulfate is dissolved, dilute the mixture to 100 mL with DI water.

Sample preparation

Add 8.0 mL of sample or standard to a clean culture tube fitted with a Teflon lined screw cap. Add 0.8 mL of persulfate digesting mixture, cap and heat in the autoclave at 115 ºC for 45 minutes. When the autoclave returns to ambient pressure, carefully remove the tubes, which will still be hot, and allow them to cool to room temperature before analyzing. Samples that aren't analyzed immediately can be stored at 4 ºC for 24 hours.

QC sample

Dilute an aliquot of the complex nutrient QC sample and run along with the samples.

Sample analysis

Analyze samples, standards and QC samples using the phosphate SOP. Results are reported as µg P/L. Any sample more concentrated than the highest standard should be diluted with blank solution and rerun. For optimal results, the pH of the diluted samples must not change.

Total Suspended Solids Dried at 103-105 °C

General Description

Total suspended solids consist of material retained on a glass-fiber filter (Fisher brand G8 or equivalent) after filtration of a well-mixed sample. The residue is dried at 103-105 °C.

Procedure

Place filter on membrane filter apparatus. Apply vacuum and wash filter with three successive 20-mL portions of DI water. Continue suction to remove all traces of water, discard washings. Remove filter from holder and transfer to an aluminum weighing pan. Dry to constant weight in forced air oven set at 103 °C. Store in a desiccator until needed. Weigh immediately before use.

Filter enough sample to yield no less than 2 mg of material retained on the filter. Wash filter with three successive 10-mL portions of DI water. Carefully remove filter and transfer to an aluminum weighing pan. Dry to a constant weight in a forced air oven set at 103 °C. Cool in a desiccator before weighing.

QC Sample

Filter an appropriate amount of Hardness QC sample to yield approximately 5 mg dried residue.

Calculation

mg Suspended Solids/L = ((A – B) x 1000)/Sample vol, (mL)

where:
A = weight of filter + residue (mg)
B = weight of filter (mg)

Chloride

General Description

This automated procedure for the determination of chloride depends on the liberation of thiocyanate ion from mercuric thiocyanate by the formation of unionized but soluble mercuric chloride. In the presence of ferric ion, the liberated thiocyanate forms a highly colored ferric thiocyanate proportional to the original chloride concentration.

Performance at 60 samples per hour using aqueous standards and AA2 colorimeter

Test conditions: standard range 0-10 mg/L, AA2 colorimeter with 10 mm flowcell.

Pump tube: red/red (0.8mL/min)
Sampling rate: 60/hr
Sampling:wash ratio: 4/1
Sensitivity at 5 mg/L: 0.3 au
Reagent absorbance: <0.1 au
Detection limit (see QA plan): <0.5mg/L

Reagents

Unless otherwise stated all chemicals should be of Analytical reagent grade or equivalent.

List of Raw Materials

Mercuric thiocyanate, $Hg(SCH)_2$
Ferric ammonium sulfate, $FeNH_4(SO_4)_2$
Sodium chloride, NaCl (dried at 100 ºC for 2 hours)

Reagent Make Up

Prepare reagents with deionized water.

System Wash Solution

Use deionized water containing about 0.5 gram of Brij-35/L

Special Wash Solution

Use 6% sodium hypoclorite diluted 1:5 with deionized water. After washing the system, rinse for about 30 minutes with deionized water to remove all traces of chloride.

Mercuric thiocyanate (forms unionized mercuric chloride)

Add 0.7 g of $Hg (SCN)_2$ to one liter of distilled water. Heat to a boil, cover and cool to room temperature. Filter it through a glass filter after cooling. This solution can be stored for up to one month if kept at room temperature and away from light. Replace with distilled water for blank runs.

Ferric ammonium sulfate (forms a red ferric thiocyanate $Fe (SCN)_3$ with the liberated thiocyanate)

Add 24 g of pulverized $FeNH_4(SO_4)_2 \cdot 12\ H_2O$ to 500 ml of deionized water containing 77 ml of concentrated HNO_3, dilute to 1 liter. Stir it for at least 30 minutes. Filter it through a glass filter. Add about 200 mg of Brij-35 as wetting agent. This solution is stable for several weeks if kept away from light and heat.

Operating Notes

The sample cups should be acid-washed just prior to use, followed by a thorough rinse with deionized water.
Where particulate matter is present, the solution must be filtered prior to the determination.
Alternate ranges may be obtained by utilization of the Std Cal control on the colorimeter.
Collect the effluent from the chloride channel in a separate waste container.

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Bacteriological Analysis of Potable & Non-potable Water by Presence/Absence (Colilert®)

1. Principle
2. Presence/absence testing based on the Defined Substrate Technology (DST) utilizes indicator-nutrients which cause target microbes contained in the sample and incubated in the DST reagent system to produce a color change or similar signal e.g. fluorescence, both indicating and confirming their presence. The Colilert system provides specific indicator nutrients: ONPG (O-Nitrophenyl-B-d-galactopyranoside) and MUG (4 Methylumbelliferyl-B-d-glucuranide), for the target organisms, total coliforms and Escherichia coli. Non-coliform organisms are suppressed since they cannot metabolize the indicator nutrients thus eliminating interference with the target microbes during the test incubation period.
3. Sample Collection & Handling
    - A. Collect sample as described in Standard Methods for the Examination of Water and Wastewater 20th Edition, 1998. Collection directions are also listed on the back of the laboratory requisition.
    - B. Transport the sample to the laboratory as soon as possible so that testing can be initiated on a timely basis. Adherence to Federal, State and local requirements for sample integrity is required.
    - C. Samples regulated by the Safe Drinking Water Act must be analyzed within 30 hours of collection. All other samples should be tested within 48 hours of collection.
    - D. If there is a delay in transport the sample should be refrigerated at 1-4°C whenever feasible.
4. Criteria for rejection
    - A. Samples submitted without paperwork will not be tested.
    - B. Samples submitted on a photocopied form will not be tested.
    - C. Samples whose holding time has expired will be tested but will have an appropriate disclaimer entered as part of the result.
5. Reagents, Supplies & Equipment
    - A. Colilert powder - single dose ampoules sufficient for testing 100 ml. of water (IDEXX Cat # WP 200).
    - B. Sterile borosilicate/polystyrene collection/culture vessel (low fluorescence) containing sodium thiosulfate (1 mg/L) (IDEXX Cat # WSV 20PS).
    - C. 35.0°C + 0.5°C air incubator.

D. Long wavelength (365 nm) ultraviolet lamp.
E. Color/Fluorescence comparator (IDEXX Cat # WP 102).
F. Consecutively numbered accession labels.
G. 10% sodium hypochlorite (bleach, Clorox).
H. H.. Stock cultures of *E. coli* (ATCC # 25922), K. pneumoniae (ATCC # 13883), and Ps. aeruginosa (ATCC # 10145) OR Quanti-Cult Kit (IDEXX Cat. WKIT-1001)
I. Sterile inoculating loops.
J. Sterile 10.0 ml pipettes.
K. UV-absorbing goggles.

6. Quality Control
   A. Reagent substrate (Colilert powder) using ATCC stock cultures
      i. Each new lot of Colilert® reagent must be tested for sterility and performance.
      ii. Fill four (4) collection vessels with 100 ml. of sterile deionized water and label as follows:
         1. E. coli
         2. K. pneumoniae
         3. Ps. aeruginosa
         4. Sterility
      iii. Add a Snap Pack of Colilert powder to each vessel and mix thoroughly to aid dissolution.
      iv. Touch a sterile inoculating loop to an 18-24 hr pure culture slant of the above-listed organisms and transfer to the appropriate test vessel. Repeat for all 3 test organisms.
      v. The "sterility" bottle will receive no inoculum.
      vi. Incubate bottles at 35.^{o}C + 0.5^{o} for 24 hrs.
      vii. Observe and record results.
      viii. Expected Results:

	ONPG	MUG
E. coli	+	+
K. pneumoniae	+	-
PS aeruginosa	-	-
Sterility	- *	-

*No turbidity (growth)

      ix. Reagent substrate using the Quanti-Cult® Method
      x. Discard blue cap from the rehydration fluid vial.
      xi. Remove organism vial from pouch.
      xii. Transfer colorless cap onto pre-warmed (35-37° C) rehydration vial. Discard vial containing desiccant.
      xiii. Insert fluid vial into foam rack.
      xiv. Invert foam rack and incubate 10 minutes at 35-37°C.
      xv. Remove vials from rack and tap gently to mix.
      xvi. Remove cap and look at inside surface of cap to be certain that no undissolved black particles are present. If present, reincubate another 10 minutes.
      xvii. Add entire contents of QUANTI-CULT vial to 100 mL of prewarmed (35-37°C) sterile distilled water.
      xviii. Add Colilert powder to sample, mix, and incubate at 35°C +/- 0.5°C. for a minimum of 24 hours. Read and record results on appropriate QC log.

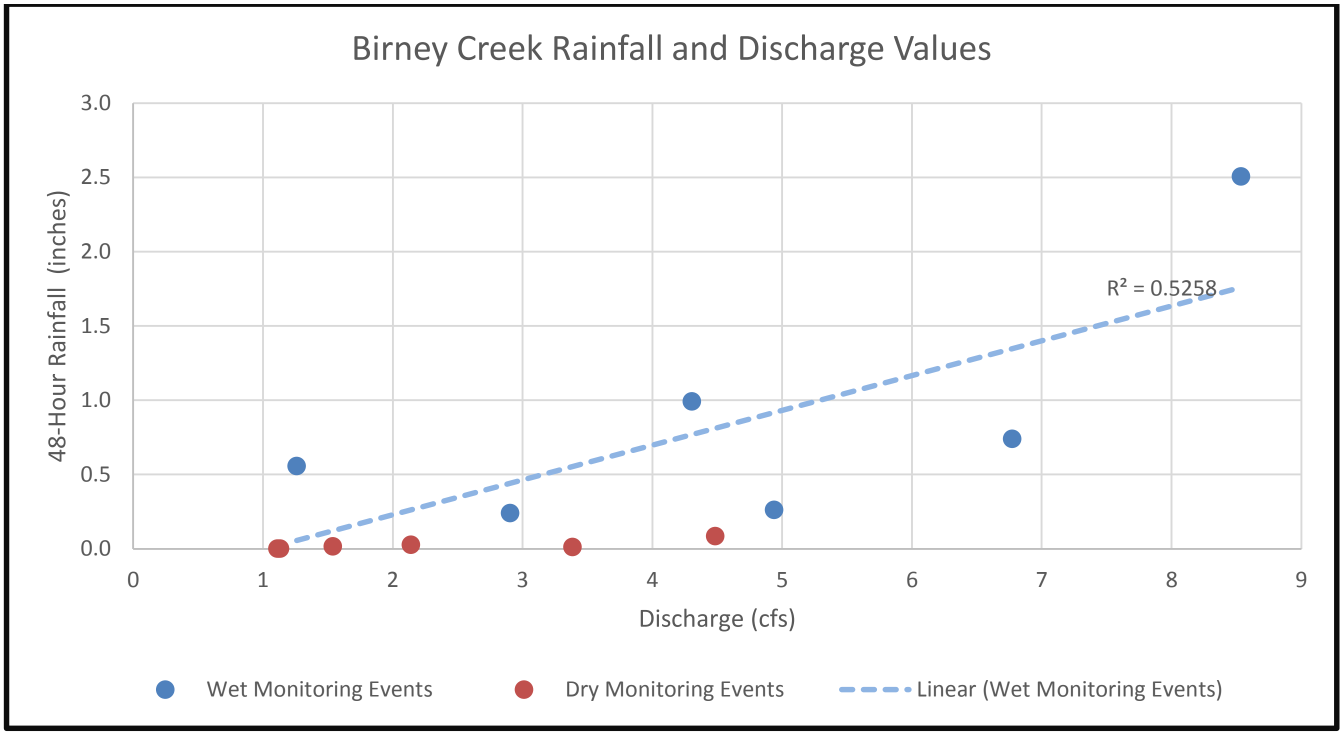
7. Procedure
   A. Accession samples by placing a unique accession number on the laboratory requisition and the corresponding numbered label on the specimen. A device such as a Bates numbering machine may be used for this purpose. The format for the accession number will be RBYYXXXXX where RB is the unique prefix for bacteriological drinking water samples, YY the last 2 digits of the current year and XXXXX the unique five-digit lab number.
   B. If sample is received in the Colilert vessel, verify volume. Decant samples that are greater than 100 mL and flag those that are less than 97.5 mL.
   C. Carefully remove one Colilert Snap Pack from the strip and gently tap it on the bench surface to ensure that the contents are in the bottom of the pack.

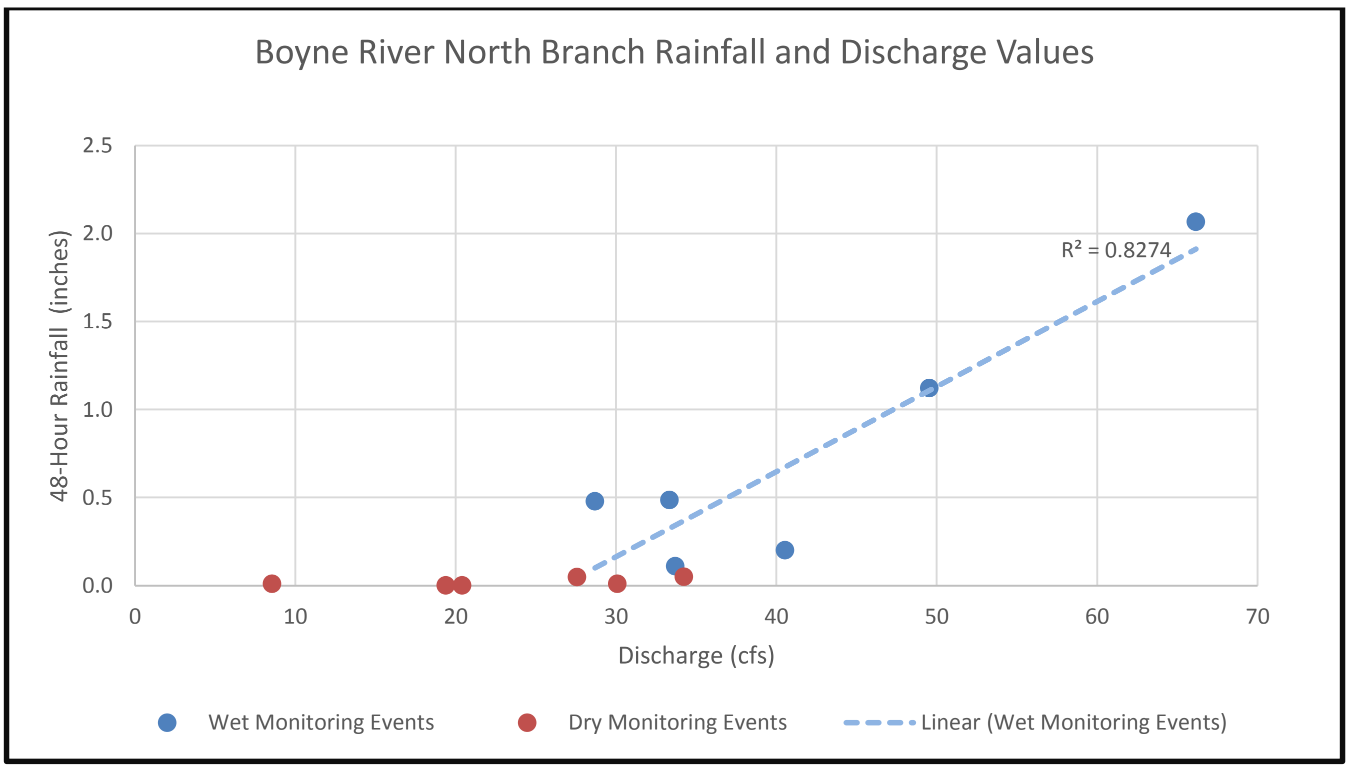
D. Aseptically open the pack by snapping back the top at the score line. Note: The top remains attached to the rest of the pack. Do not touch the opening of the pack.
E. Add the contents of the pack to the sample bottle.
F. Aseptically replace the vessel cap and shake vigorously by repeated inversion to aid dissolution of the reagent. Note: Some particles will remain undissolved.
G. Incubate sample at 35^{o}C + 0.5^{o}C for 24 hrs.
H. Observe bottles for development of a yellow color after 24 hrs. Color should be uniform throughout the vessel; if not, mix by inversion before reading. Use the comparator to gauge the intensity of color development.
I. All bottles showing yellow color equal to or greater in intensity to the comparator must be checked for fluorescence with the UV light. This should be done in a darkened room so as to detect low levels of fluorescence. Place the UV lamp three to five inches in front of the sample, making sure that it is facing away from your eyes and toward the vessel.
    i. Note: UV-absorbing goggles must be worn for this procedure.
J. Bottles showing yellow color at 24 hrs. whose intensity is less than the comparator, must be incubated an additional 4 hours (maximum of 28 hrs.) and observed again for color intensification.

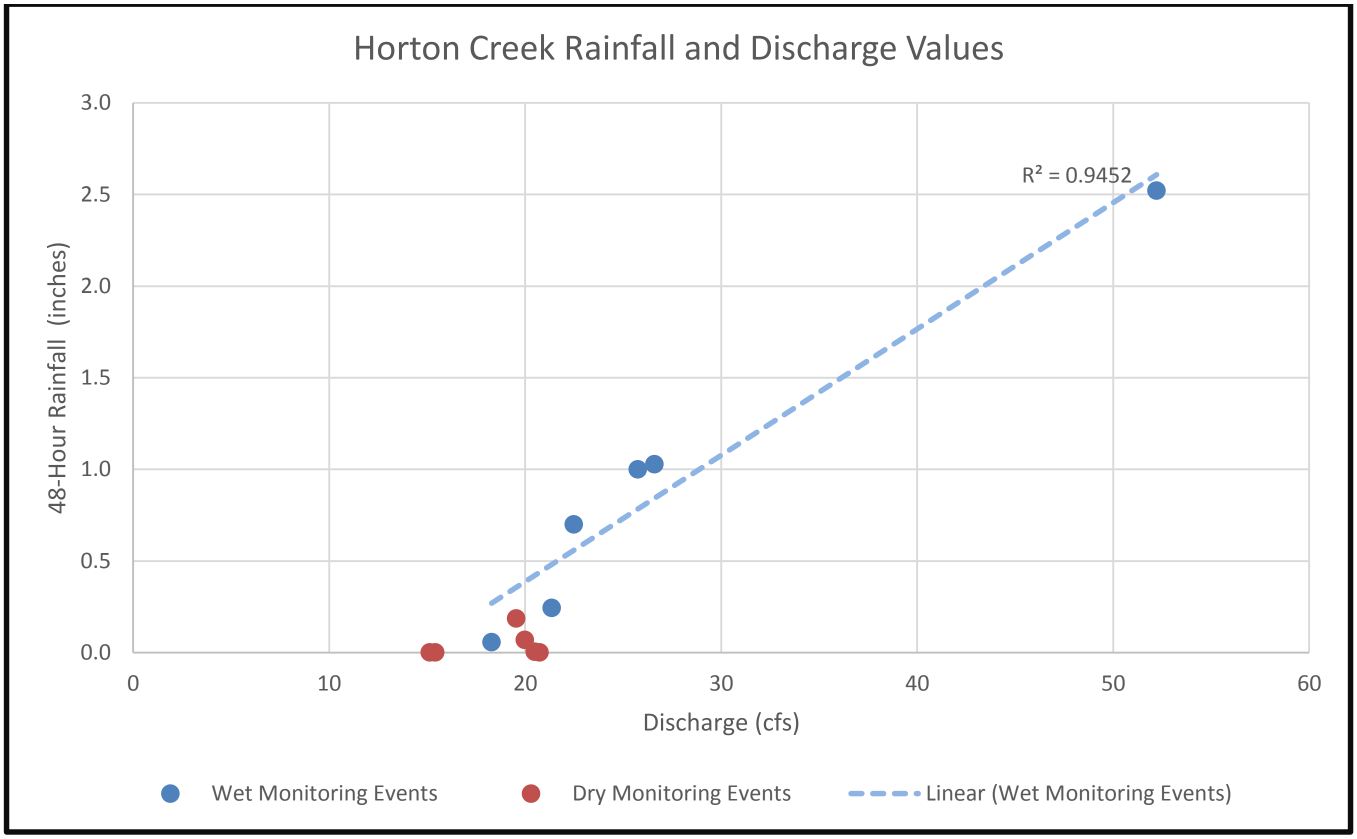
8. Interpretation
    A. If no yellow color develops after 24 hrs, the test is negative for total coliforms and *E. coli*.
    B. If sample is yellow at 24 hrs, but the intensity is less than the comparator after the additional 4 hr. incubation, the sample is negative for total coliforms and *E. coli*
    C. If sample is yellow after 24 (28) hrs. and the intensity is equal to or greater than the comparator, but demonstrates no fluorescence, the sample is positive for total coliforms only.
    D. If sample is yellow after 24 (28) hrs. and the intensity is equal to or greater than the comparator and also demonstrates fluorescence, the sample is positive for *E. coli*.
    E. If sample is inadvertently incubated over 28 hours, it can be considered negative if no yellow color develops. If yellow color develops, the results should be verified or the test repeated.
9. Reporting
    A. Report samples using the established guidelines for the EPIC LIS.
    B. Specific (embedded) / free-text messages must be added as required.
10. Procedure Notes:
    A. Samples must be thoroughly mixed prior to inoculation.
    B. Colilert powder must never be autoclaved prior to use.
    C. Incubation for greater than 28 hrs. will allow heterotrophic bacteria to express themselves and allow possible false positive readings.
    D. Colilert is to be used only as a primary water test. The characteristics of the test do not apply when pre-enrichment, concentration, or other culture procedures are incorporated.
    E. Sample must not be diluted or filtered prior to testing.
    F. Samples containing 40-50 times the amount of free-chlorine normally present in drinking, will produce a transient blue color when mixed with the Colilert powder. This constitutes an invalid sample and testing must be discontinued
    G. Samples with high calcium salt concentrations may cause a slight precipitate that does not affect results.
    H. If a large number of refrigerated samples are tested, they should be allowed to equilibrate to room temperature prior to incubation so as to avoid chilling of the incubator contents.
11. References

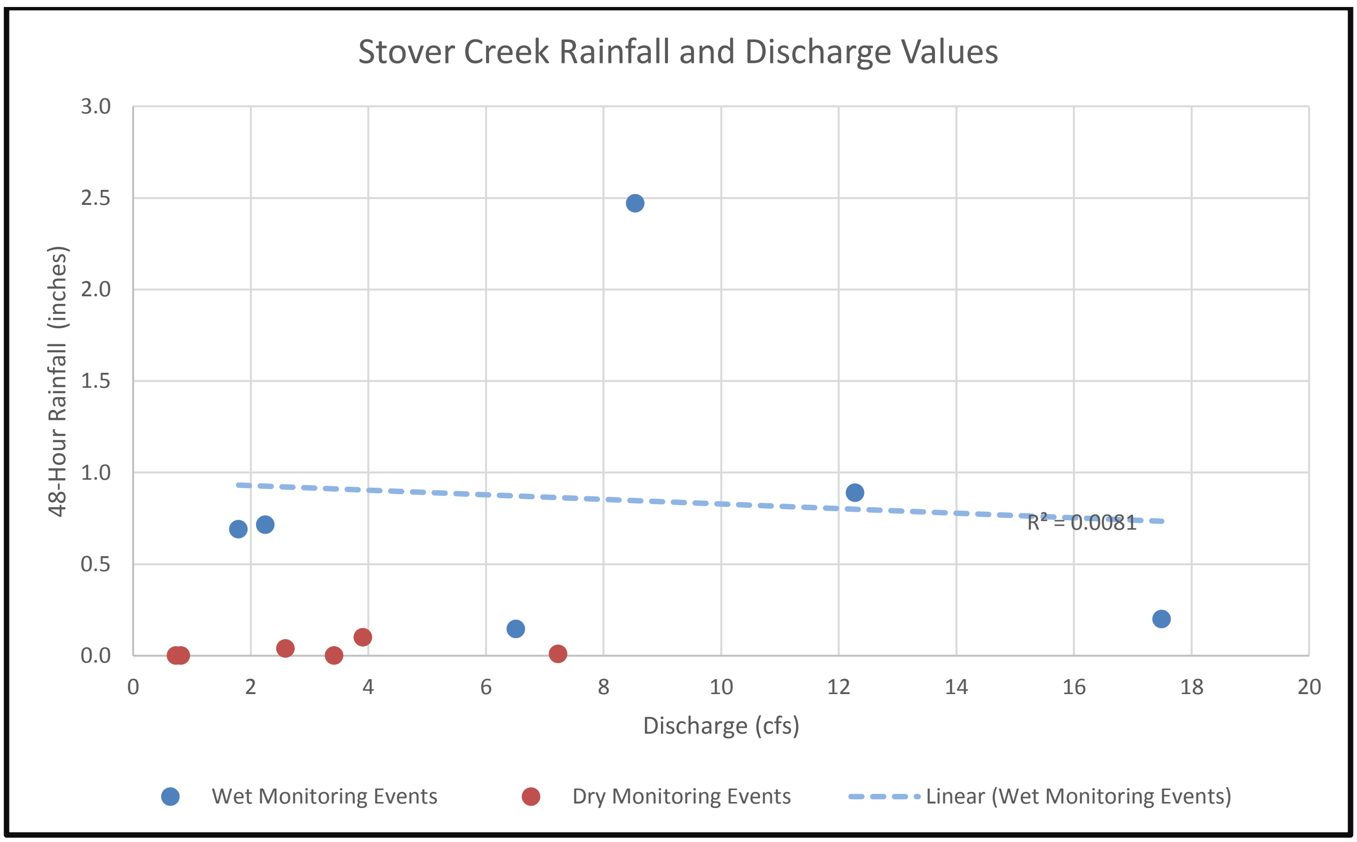
    A. Manual for the Certification of Laboratories Analyzing Drinking Water, Fourth Edition USEPA March , 1997.
    B. Standard Methods for the Examination of Water and Wastewater. 20th Edition, APHA, AWWA, WPCF, Washington DC, 1998.
    C. IDEXX Laboratories Inc. Westbrook, Main 04092.
    D. Federal Register, Wed. June 10, 1992, Part V Environmental Protection Agency.

Appendix B. Discharge in relation to precipitation for study stream watersheds.






Horton Creek Rainfall and Discharge Values
48-Hour Rainfall (inches)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
Discharge (cfs)
R² = 0.9452
Wet Monitoring Events
Dry Monitoring Events
Linear (Wet Monitoring Events)


Stover Creek Rainfall and Discharge Values
48-Hour Rainfall (inches)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
16
18
20
Discharge (cfs)
R² = 0.0081
Wet Monitoring Events
Dry Monitoring Events
Linear (Wet Monitoring Events)

Appendix C. Water quality data from the Lake Charlevoix Tributary Monitoring Project.

	Soluble Reactive Phosphorus (µg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	1.6	7.4	6.7	1.7	0.9	0.6	0.4	2.3	4.6	5.5	3.4	ND	3.2
Boyne River - Park St.	1.3	0.3	3.0	1.5	0.8	0.4	3.3	1.7	3.4	4.5	2.1	ND	2.0
Boyne River - North Branch US131	3.1	1.0	2.4	1.6	1.2	0.6	2.6	2.3	2.7	5.4	4.2	ND	2.5
Boyne River - South Branch M75	0.9	0.5	2.6	1.7	1.5	1.0	5.1	1.4	2.7	3.1	1.6	ND	2.0
Brown Creek - Depot St.	1.3	1.0	3.3	1.4	0.8	1.1	0.4	1.8	3.4	4.0	5.7	ND	2.2
Deer Creek - M32	1.2	0.2	3.0	1.6	0.6	0.9	-0.4	1.2	2.1	2.9	2.8	ND	1.5
Horton Creek - Boyne City Rd.	2.9	0.9	2.8	1.6	0.9	4.7	0.9	1.8	3.4	5.9	2.7	ND	2.6
Jordan River - Fair Rd.*	4.2	0.6	2.6	1.6	1.2	1.3	-0.1	2.3	2.4	3.6	2.7	ND	2.0
Jordan River - Rogers Rd.	1.8	0.4	2.4	1.7	1.1	0.7	0.5	0.9	3.1	5.0	2.6	ND	1.8
Loeb Creek - Evergreen Pointe Dr.	0.9	0.8	10.5	1.6	0.6	0.3	-0.8	1.7	7.8	7.3	5.5	ND	3.3
Monroe Creek - M66	1.7	1.9	7.1	1.8	0.6	0.0	-0.4	2.4	3.1	4.2	4.3	ND	2.4
Porter Creek - Lake Shore Dr.	1.7	0.6	2.9	1.7	0.8	0.5	-0.2	1.7	3.5	4.7	4.3	ND	2.0
Stover Creek - Mouth	1.6	3.6	8.3	2.4	0.8	1.8	-0.3	2.6	4.0	5.2	4.1	ND	3.1
	Total Phosphorus (µg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	9.6	4.7	8.6	1.0	2.9	5.9	1.4	2.9	9.7	5.7	12.3	58.3	10.3
Boyne River - Park St.	1.1	5.2	4.8	1.3	2.0	7.2	11.0	3.3	5.8	8.8	3.6	18.3	6.0
Boyne River - North Branch US131	3.1	1.0	2.4	1.6	1.2	0.6	2.6	2.3	2.7	5.4	4.2	39.3	5.5
Boyne River - South Branch M75	0.6	4.6	2.9	0.6	2.8	8.4	8.6	2.4	11.5	3.9	2.7	18.3	5.6
Brown Creek - Depot St.	1.7	25.1	3.4	1.8	1.1	4.0	6.9	1.2	11.1	4.7	11.4	27.3	8.3
Deer Creek - M32	2.8	5.4	5.9	2.3	3.6	7.2	2.9	6.3	5.0	3.5	4.8	12.3	5.2
Horton Creek - Boyne City Rd.	10.4	2.8	3.4	1.1	1.8	13.6	3.0	6.8	6.7	7.6	3.0	27.3	7.3
Jordan River - Fair Rd.*	5.3	4.3	4.0	2.1	1.4	20.9	2.3	3.0	17.3	5.8	3.6	18.3	7.4
Jordan River - Rogers Rd.	1.4	14.1	3.2	0.4	3.4	8.9	1.2	1.8	18.2	6.7	3.1	18.3	6.7
Loeb Creek - Evergreen Pointe Dr.	3.1	6.9	12.9	3.8	4.3	6.2	5.7	19.3	11.2	15.7	12.4	51.3	12.7
Monroe Creek - M66	1.6	8.2	7.5	1.8	3.8	8.3	8.8	7.9	4.7	6.4	8.6	4.7	6.0
Porter Creek - Lake Shore Dr.	4.3	6.5	4.7	1.7	2.0	13.1	3.1	5.0	8.6	14.8	5.4	30.3	8.3
Stover Creek - Mouth	8.0	14.0	8.8	2.2	6.1	11.9	5.9	6.9	18.6	8.4	11.5	27.3	10.8

*water quality data from M32 used for Fair Rd site for 4/9/13 sample date.

	Nitrate-Nitrogen (µg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	377	115	957	816	604	280	478	534	829	824	611	702	594
Boyne River - Park St.	349	138	267	370	199	228	318	252	336	375	335	434	300
Boyne River - North Branch US131	233	281	202	205	230	110	198	152	199	190	179	189	197
Boyne River - South Branch M75	345	97	478	515	503	137	433	374	424	385	489	575	396
Brown Creek - Depot St.	402	206	335	380	335	243	286	254	359	384	266	202	304
Deer Creek - M32	282	151	299	344	295	124	241	219	292	347	316	392	275
Horton Creek - Boyne City Rd.	1299	878	1434	1194	1615	508	1064	1111	1176	979	1153	1730	1178
Jordan River - Fair Rd.*	485	449	993	939	1094	343	744	680	869	921	996	1035	796
Jordan River - Rogers Rd.	845	554	1163	1060	1114	403	906	857	1016	1193	1095	1272	957
Loeb Creek - Evergreen Pointe Dr.	96	49	390	191	67	26	76	96	137	318	385	52	157
Monroe Creek - M66	144	66	347	259	114	18	136	128	224	295	228	94	171
Porter Creek - Lake Shore Dr.	199	63	228	239	199	52	173	113	209	212	164	167	168
Stover Creek - Mouth	385	311	1574	1385	727	261	561	605	997	1015	1157	1254	853

	Ammonium-Nitrogen (µg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	7.1	13.6	5.4	7.8	43.8	2.1	17.4	16.2	29.6	30.1	5.6	28.7	17.3
Boyne River - Park St.	16.8	25.1	18.1	11.5	29.1	4.2	21.7	12.1	31.8	21.0	8.3	42.8	20.2
Boyne River - North Branch US131	10.9	10.1	4.0	0.4	11.7	77.6	11.8	3.2	10.7	13.0	3.6	19.9	14.7
Boyne River - South Branch M75	6.2	5.2	17.0	7.3	22.2	12.9	21.6	11.0	33.2	16.7	5.8	18.8	14.8
Brown Creek - Depot St.	6.1	5.0	4.7	0.5	0.8	6.4	4.4	5.0	6.6	10.1	0.9	15.9	5.5
Deer Creek - M32	8.1	18.6	32.7	19.7	20.8	9.3	22.4	19.5	29.9	20.9	21.9	32.5	21.4
Horton Creek - Boyne City Rd.	8.2	6.5	5.2	1.8	13.4	9.7	22.4	4.9	20.3	5.2	4.4	22.7	10.4
Jordan River - Fair Rd.*	38.3	11.2	9.0	7.7	3.9	3.7	17.5	12.7	33.1	31.7	7.6	29.4	17.1
Jordan River - Rogers Rd.	3.6	7.2	5.1	3.1	12.7	3.5	7.2	7.5	32.3	20.6	6.7	16.4	10.5
Loeb Creek - Evergreen Pointe Dr.	4.1	22.3	17.6	11.4	19.3	17.1	23.9	21.8	53.8	27.5	31.3	16.8	22.2
Monroe Creek - M66	0.9	4.7	7.0	2.3	2.0	6.8	21.1	9.1	22.8	7.7	0.9	11.7	8.1
Porter Creek - Lake Shore Dr.	4.6	11.4	6.6	3.5	28.3	4.2	26.3	3.5	26.0	23.0	2.0	14.8	12.8
Stover Creek - Mouth	14.3	26.7	10.2	5.8	11.1	7.7	33.6	4.3	30.7	14.4	6.4	60.7	18.8

*water quality data from M32 used for Fair Rd site for 4/9/13 sample date.

	Total Nitrogen (µg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	742	418	1011	1060	779	499	838	660	922	981	805	1612	861
Boyne River - Park St.	496	440	429	493	469	385	477	301	469	484	455	477	448
Boyne River - North Branch US131	314	339	268	309	330	436	306	208	324	270	264	846	351
Boyne River - South Branch M75	503	387	540	653	623	402	566	491	563	487	559	839	551
Brown Creek - Depot St.	490	406	432	569	478	430	469	356	431	468	491	719	478
Deer Creek - M32	472	415	510	586	541	415	496	323	483	484	464	606	483
Horton Creek - Boyne City Rd.	1536	1199	1508	1583	1648	756	1552	1185	1435	1158	1190	2148	1408
Jordan River - Fair Rd.*	745	818	1065	1208	980	567	1018	876	2852	1270	1064	1441	1159
Jordan River - Rogers Rd.	978	836	1126	1343	1161	607	1324	896	1288	1305	1169	1607	1137
Loeb Creek - Evergreen Pointe Dr.	297	392	635	501	408	359	361	303	506	582	645	977	497
Monroe Creek - M66	351	374	522	455	386	294	415	275	422	269	401	1381	462
Porter Creek - Lake Shore Dr.	384	388	379	251	469	358	376	305	369	348	332	738	391
Stover Creek - Mouth	795	969	2086	1869	1024	658	980	944	1555	1379	1378	2206	1320

	Total Chloride (mg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	11.3	12.8	12.4	15.3	16.0	10.2	14.8	14.4	12.4	14.1	18.2	12.6	13.7
Boyne River - Park St.	12.0	12.1	13.5	16.2	10.6	6.8	15.0	15.2	14.2	14.8	17.8	14.0	13.5
Boyne River - North Branch US131	6.9	7.4	5.5	6.7	9.1	6.9	7.4	7.1	6.4	6.9	7.4	6.5	7.0
Boyne River - South Branch M75	9.3	9.0	8.5	11.2	11.8	9.7	10.8	10.2	8.5	10.3	10.1	9.1	9.9
Brown Creek - Depot St.	13.2	15.3	13.3	17.1	18.8	15.4	16.6	17.2	19.6	19.0	20.6	14.2	16.7
Deer Creek - M32	9.6	10.6	11.0	13.2	12.3	8.2	10.0	12.0	10.4	11.6	11.6	10.9	11.0
Horton Creek - Boyne City Rd.	8.0	7.2	6.6	7.6	9.6	6.7	9.1	8.4	7.8	7.8	8.3	9.3	8.0
Jordan River - Fair Rd.*	13.4	8.3	7.8	8.9	9.8	7.0	8.5	8.6	8.0	8.4	8.4	7.0	8.7
Jordan River - Rogers Rd.	5.8	6.3	6.3	7.5	8.1	5.7	7.1	7.4	6.8	6.6	7.7	6.5	6.8
Loeb Creek - Evergreen Pointe Dr.	9.3	13.8	32.1	38.4	15.9	25.3	14.0	16.5	17.4	34.2	30.6	17.2	22.1
Monroe Creek - M66	4.3	5.9	7.1	8.5	7.9	5.5	7.4	6.4	6.3	25.8	8.1	6.5	8.3
Porter Creek - Lake Shore Dr.	7.9	8.5	9.8	11.6	10.6	6.8	9.4	8.8	9.0	9.5	9.0	8.2	9.1
Stover Creek - Mouth	13.3	14.9	46.2	59.0	26.0	10.0	21.0	24.5	24.9	25.2	33.3	24.1	26.9

*water quality data from M32 used for Fair Rd site for 4/9/13 sample date.

	Total Suspended Solids (mg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	1.8	5.2	30.1	11.4	4.9	8.3	3.7	9.4	74.6	36.6	142.3	ND	29.8
Boyne River - Park St.	3.0	24.5	2.5	1.7	2.2	15.3	2.2	2.0	3.0	3.4	2.6	ND	5.7
Boyne River - North Branch US131	12.2	44.1	6.1	3.1	5.6	43.5	5.6	4.7	6.8	15.0	42.2	ND	17.2
Boyne River - South Branch M75	5.2	4.3	5.6	2.9	5.5	11.6	3.2	2.4	3.4	11.9	5.4	ND	5.6
Brown Creek - Depot St.	4.4	14.8	19.1	2.8	2.0	15.2	4.9	3.4	9.9	12.2	120.2	ND	19.0
Deer Creek - M32	2.1	3.5	2.0	2.7	0.9	16.9	1.1	2.1	1.5	2.2	2.1	ND	3.4
Horton Creek - Boyne City Rd.	20.2	21.0	1.6	10.8	4.2	19.1	8.4	4.1	1.6	2.9	3.6	ND	8.9
Jordan River - Fair Rd.*	11.5	18.5	4.3	3.9	4.8	16.3	5.2	4.4	4.4	7.1	9.5	ND	8.2
Jordan River - Rogers Rd.	9.4	29.8	6.1	4.4	4.8	20.2	8.0	6.2	7.8	9.4	15.9	ND	11.1
Loeb Creek - Evergreen Pointe Dr.	3.3	14.3	4.6	2.1	2.3	14.3	3.8	3.9	5.4	3.9	21.3	ND	7.2
Monroe Creek - M66	6.2	32.8	1.9	1.1	3.8	21.3	7.2	5.1	2.6	3.6	75.4	ND	14.6
Porter Creek - Lake Shore Dr.	5.6	14.4	1.7	1.5	2.2	15.3	3.2	1.6	1.8	2.8	28.7	ND	7.2
Stover Creek - Mouth	17.0	79.7	2.3	6.9	10.5	27.8	6.0	4.9	8.3	6.4	17.0	ND	17.0

	Dissolved Organic Carbon (mg/L)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	3.24	5.80	1.93	1.09	1.52	5.91	2.48	2.51	2.15	3.05	5.66	6.30	3.47
Boyne River - Park St.	2.75	5.87	1.93	0.97	3.87	5.98	3.17	2.47	3.39	2.74	2.92	3.80	3.32
Boyne River - North Branch US131	2.23	3.70	1.74	1.08	0.99	4.50	2.10	2.10	2.09	2.91	3.14	4.00	2.55
Boyne River - South Branch M75	2.47	7.51	1.79	0.55	1.29	4.76	1.74	1.76	1.55	3.29	2.46	3.10	2.69
Brown Creek - Depot St.	2.17	5.04	1.42	0.62	2.19	4.38	1.98	1.70	1.53	1.79	7.69	7.30	3.15
Deer Creek - M32	2.47	7.89	3.67	1.53	3.88	3.37	3.03	3.88	4.82	4.13	3.56	5.00	3.94
Horton Creek - Boyne City Rd.	2.48	3.81	1.52	0.73	1.63	2.87	1.28	1.89	2.03	4.47	3.05	2.80	2.38
Jordan River - Fair Rd.*	4.31	4.85	1.77	1.10	2.10	5.49	2.98	2.56	2.29	2.55	2.51	3.90	3.03
Jordan River - Rogers Rd.	3.09	6.32	1.50	0.47	1.79	5.78	2.37	1.95	1.57	2.07	2.40	3.30	2.72
Loeb Creek - Evergreen Pointe Dr.	5.00	1.02	5.50	7.05	4.69	6.63	6.09	7.07	8.11	9.34	7.43	11.00	6.58
Monroe Creek - M66	4.63	9.52	3.87	2.69	5.81	6.54	2.63	5.90	5.63	6.06	6.11	9.10	5.71
Porter Creek - Lake Shore Dr.	5.64	1.02	3.31	2.07	3.87	5.98	4.93	5.27	4.36	4.33	5.42	7.50	4.47
Stover Creek - Mouth	9.12	17.53	2.81	1.57	6.99	8.17	7.11	7.65	7.77	8.00	7.66	11.00	7.95

*water quality data from M32 used for Fair Rd site for 4/9/13 sample date.

	Water Temperature (C°)*												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	4.21	13.65	21.35	12.35	5.98	5.27	9.20	14.90	13.64	17.74	15.10	6.89	11.69
Boyne River - Park St.	3.70	13.34	24.92	16.48	3.76	6.44	10.40	19.86	17.91	21.04	17.37	8.59	13.65
Boyne River - North Branch US131	4.30	10.96	18.99	11.93	4.26	6.72	7.55	13.45	12.94	16.46	13.88	7.45	10.74
Boyne River - South Branch M75	5.04	14.40	25.74	13.89	3.17	6.16	9.57	18.97	15.58	21.78	15.39	7.82	13.13
Brown Creek - Depot St.	4.97	11.01	18.21	10.79	5.73	6.05	7.92	12.90	11.79	14.67	14.09	8.01	10.51
Deer Creek - M32	2.32	14.11	23.89	14.68	2.33	7.30	9.18	19.07	17.79	18.25	18.42	8.52	12.99
Horton Creek - Boyne City Rd.	4.23	9.59	15.21	12.60	4.04	7.07	6.82	9.91	12.00	14.29	13.49	6.00	9.60
Jordan River - Fair Rd.*	3.77	12.69	20.49	12.49	4.09	6.46	9.03	14.93	14.84	16.86	15.00	7.14	11.48
Jordan River - Rogers Rd.	3.98	11.51	19.93	11.98	4.35	6.52	8.86	13.41	13.98	16.02	14.31	6.41	10.94
Loeb Creek - Evergreen Pointe Dr.	1.63	12.52	20.86	14.75	3.18	4.72	8.55	15.23	16.19	17.17	16.63	7.15	11.55
Monroe Creek - M66	1.23	11.69	20.33	12.73	3.26	6.20	8.07	13.66	14.49	16.35	16.05	6.30	10.86
Porter Creek - Lake Shore Dr.	1.94	11.82	21.56	13.35	3.17	6.34	8.01	15.55	16.24	18.43	16.81	7.28	11.71
Stover Creek - Mouth	1.59	10.37	19.15	14.28	4.04	5.97	7.92	12.38	13.14	15.39	16.02	6.98	10.60

	Dissolved Oxygen (mg/L)*												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	12.01	10.31	7.97	9.92	11.46	11.26	11.03	9.64	9.11	8.57	8.49	12.81	10.21
Boyne River - Park St.	13.14	9.01	9.48	11.27	12.86	10.72	11.03	10.32	9.81	10.38	9.37	11.02	10.70
Boyne River - North Branch US131	12.24	10.30	9.27	10.69	12.26	10.69	11.40	10.32	9.45	9.57	9.59	11.79	10.63
Boyne River - South Branch M75	12.86	10.61	8.80	10.58	13.84	12.20	11.44	9.70	9.75	8.91	10.03	11.94	10.89
Brown Creek - Depot St.	12.65	10.67	9.34	10.69	12.01	11.43	11.86	10.80	10.15	9.79	9.60	10.49	10.79
Deer Creek - M32	13.47	9.75	7.63	10.06	13.57	11.56	11.24	9.33	8.87	9.40	9.05	10.56	10.38
Horton Creek - Boyne City Rd.	11.68	9.16	9.07	11.37	11.33	8.91	10.47	9.78	8.95	7.61	8.31	10.04	9.72
Jordan River - Fair Rd.*	12.41	9.89	9.87	9.88	12.48	10.17	10.79	9.92	8.63	9.84	9.23	10.73	10.32
Jordan River - Rogers Rd.	12.08	9.28	9.90	10.15	12.43	9.77	10.89	10.23	9.39	10.00	9.31	10.81	10.35
Loeb Creek - Evergreen Pointe Dr.	12.83	9.44	7.44	8.61	12.44	13.43	10.94	9.33	8.53	8.16	7.61	10.39	9.93
Monroe Creek - M66	13.32	10.01	8.91	10.31	12.83	11.18	11.46	10.20	9.30	9.42	9.18	13.08	10.77
Porter Creek - Lake Shore Dr.	15.96	9.92	8.41	10.21	13.33	11.13	11.45	10.25	8.69	9.20	9.10	10.63	10.69
Stover Creek - Mouth	13.56	9.43	8.46	9.44	12.50	14.91	11.48	10.68	9.98	9.24	8.61	11.02	10.78

*water quality data from M32 used for Fair Rd site for 4/9/13 sample date.

	Specific Conductance (uS/cm)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	319.8	381.3	507.7	449.9	410.5	301.0	409.9	445.3	464.6	476.5	417.6	396.7	415.1
Boyne River - Park St.	346.3	358.2	438.2	399.1	374.7	260.0	373.0	400.3	409.7	422.3	438.5	399.2	385.0
Boyne River - North Branch US131	336.8	346.4	430.1	383.7	365.6	293.9	361.3	382.9	395.7	406.0	407.7	374.3	373.7
Boyne River - South Branch M75	336.6	355.9	427.6	385.4	374.7	275.6	370.6	389.8	400.4	407.8	405.3	385.0	376.2
Brown Creek - Depot St.	328.6	350.5	433.4	385.5	365.9	297.1	358.0	383.4	403.3	413.6	414.7	347.1	373.4
Deer Creek - M32	271.4	317.0	424.5	366.6	291.4	200.7	294.2	349.7	362.8	384.7	393.9	350.3	333.9
Horton Creek - Boyne City Rd.	332.9	350.8	442.8	391.4	372.0	206.0	369.5	389.2	401.0	392.0	411.3	379.5	369.9
Jordan River - Fair Rd.	279.2	322.7	403.7	357.7	321.2	214.0	323.1	352.8	357.3	377.3	378.1	352.3	336.6
Jordan River - Rogers Rd.	276.2	300.7	391.8	353.9	325.4	210.6	330.2	351.2	358.8	372.1	374.3	350.2	332.9
Loeb Creek - Evergreen Pointe Dr.	268.9	370.4	548.3	517.5	334.1	301.3	342.5	385.9	402.7	500.9	522.6	373.2	405.7
Monroe Creek - M66	242.3	320.2	475.2	419.1	302.2	174.9	323.3	372.1	414.3	475.0	434.1	344.7	358.1
Porter Creek - Lake Shore Dr.	267.5	298.5	472.5	415.2	331.8	209.2	330.7	370.9	421.9	434.3	415.4	370.8	361.6
Stover Creek - Mouth	286.5	338.5	690.5	618.4	411.6	209.5	407.7	493.0	531.0	562.0	505.6	496.8	462.6

	pH (units)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	8.20	8.19	8.08	8.28	8.17	7.93	8.28	8.11	8.13	8.34	8.17	7.79	8.14
Boyne River - Park St.	8.25	8.34	8.24	8.39	8.44	7.87	8.46	8.27	8.28	8.37	8.29	8.00	8.27
Boyne River - North Branch US131	8.27	8.25	8.21	8.33	7.98	7.95	8.33	8.38	8.25	8.53	8.46	8.01	8.25
Boyne River - South Branch M75	8.33	8.34	8.25	8.35	8.06	8.11	8.44	8.28	8.27	8.33	8.42	8.06	8.27
Brown Creek - Depot St.	8.41	8.31	8.29	8.37	8.18	8.12	8.48	8.46	8.23	8.78	8.33	7.91	8.32
Deer Creek - M32	8.20	8.42	8.22	8.28	8.13	8.14	8.33	8.19	8.31	8.33	8.21	8.06	8.24
Horton Creek - Boyne City Rd.	8.05	8.04	7.97	8.21	8.20	7.65	8.35	8.13	7.89	7.94	7.83	7.80	8.01
Jordan River - Fair Rd.*	8.13	8.14	8.19	8.35	8.25	8.02	8.30	8.30	8.24	8.59	8.45	7.95	8.24
Jordan River - Rogers Rd.	8.22	8.40	8.17	8.36	8.29	7.93	8.37	8.31	8.21	8.43	8.40	7.94	8.25
Loeb Creek - Evergreen Pointe Dr.	8.20	8.22	7.91	8.05	8.21	7.85	8.40	8.13	8.07	8.22	8.16	7.88	8.11
Monroe Creek - M66	8.30	8.25	8.25	8.27	8.21	7.95	8.43	8.31	8.19	8.52	8.39	7.88	8.24
Porter Creek - Lake Shore Dr.	8.27	8.40	8.13	8.24	8.04	7.98	8.34	8.35	8.24	8.50	8.31	7.88	8.22
Stover Creek - Mouth	8.30	8.26	7.96	8.19	8.27	7.84	8.42	8.29	8.07	8.33	8.19	7.95	8.17

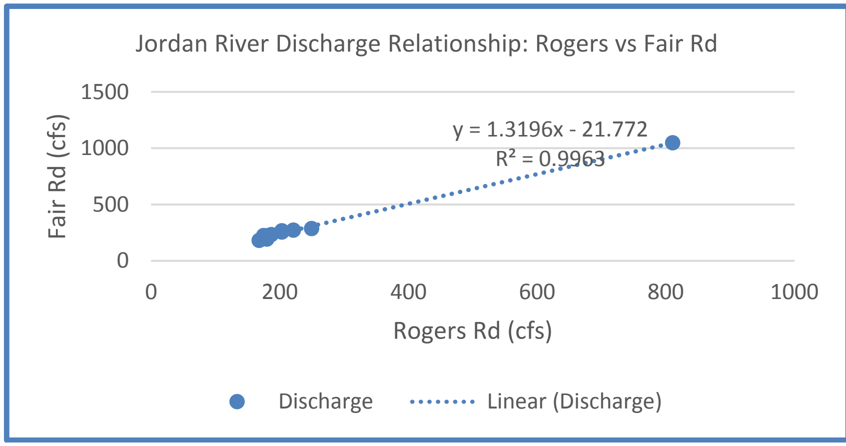
*water quality data from M32 used for Fair Rd site for 4/9/13 sample date.

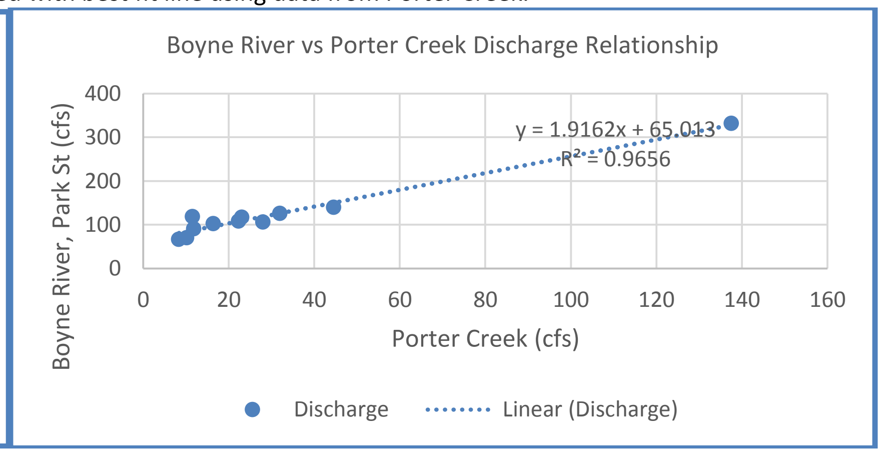
Appendix D. Discharge data.

Discharge measured in field at sample sites in cubic feet per second.

Date	Birney	Boyne Mouth	Boyne North	Boyne South	Brown	Deer	Horton	Jordan Fair	Jordan Rogers	Loeb	Monroe	Porter	Stover
4/9/2013	4.94	139.53	40.53	69.47	3.02	115.22	21.35	346.62*	279.17	28.87	33.79	44.53	17.49
5/23/2013	6.77	181.16*	49.55	118.77	4.27	141.42	26.60	425.90*	339.24	15.47	33.88	60.61	12.28
7/17/2013	1.13	66.31	20.41	39.14	1.72	29.99	15.42	191.79	179.57	0.68	3.59	8.34	0.81
10/2/2013	1.11	70.55	19.38	50.77	1.69	31.56	15.14	179.92	167.89	0.71	4.43	10.22	0.73
11/14/2013	2.90	106.31	33.69	61.23	1.92	73.44	18.30	272.03	221.06	13.25	19.11	27.99	6.51
11/18/2013	8.54	331.56	66.16	190.66	3.70	262.71	52.21	1048.44	810.58	89.19	92.73	137.55	8.54
5/7/2014	3.39	116.84	30.08	55.03	2.61	73.85	20.50	266.46	203.08	7.92	12.80	23.08	7.23
5/28/2014	2.14	102.65	28.07	50.46	2.32	51.51	20.74	223.94	181.56	3.49	8.05	16.42	3.42
6/23/2014	1.54	91.06	27.58	46.74	2.32	43.41	19.55	224.57	174.65	2.97	6.84	11.80	2.59
7/7/2014	1.26	118.38	28.68	57.45	2.07	48.13	25.76	233.48	186.51	1.36	9.58	11.52	1.79
8/12/2014	4.31	108.48	33.33	71.17	3.40	50.67	22.49	287.32	249.32	1.93	18.02	22.34	2.25
10/27/2014	4.48	126.02	34.23	63.28	4.35	63.15	19.99	255.09	203.00	8.46	20.31	31.96	3.91
Average	3.54	129.90	34.31	72.85	2.78	82.09	23.17	329.63	266.30	14.53	21.93	33.86	5.63

*No discharge measurements at Jordan River Fair Road for the 4/9/13 and 5/23/13 events, discharge estimated with best fit line using data from Rogers Rd. No discharge measurements from Boyne River at Park St on 5/23/13, so discharge estimated with best fit line using data from Porter Creek.





Discharge in cubic feet per second from tributary watersheds to Lake Charlevoix.

Tributary	4/9/13	5/23/13	7/17/13	10/2/13	11/14/13	11/18/13	5/7/14	5/28/14	6/23/14	7/7/14	8/12/14	10/27/14	Avg.
Boyne River	139.53	181.16*	66.31	70.55	106.31	331.56	116.84	102.65	91.06	118.38	108.48	126.02	129.90
Horton Creek	21.35	26.60	15.42	15.14	18.30	52.21	20.50	20.74	19.55	25.76	22.49	19.99	23.17
Jordan River	346.62*	425.90*	191.79	179.92	272.03	1048.44	266.46	223.94	224.57	233.48	287.32	255.09	329.63
Loeb Creek	28.87	15.47	0.68	0.71	13.25	89.19	7.92	3.49	2.97	1.36	1.93	8.46	14.53
Monroe Creek	33.79	33.88	3.59	4.43	19.11	92.73	12.80	8.05	6.84	9.58	18.02	20.31	21.93
Porter Creek	44.53	60.61	8.34	10.22	27.99	137.55	23.08	16.42	11.80	11.52	22.34	31.96	33.86
Stover Creek	17.49	12.28	0.81	0.73	6.51	8.54	7.23	3.42	2.59	1.79	2.25	3.91	5.63
TOTAL	632.17	755.91	286.95	281.70	463.50	1760.22	454.83	378.71	359.38	401.86	462.83	465.73	531.57

*No discharge measurements at Jordan River Fair Road for the 4/9/13 and 5/23/13 events, discharge estimated with best fit line using data from Rogers Rd. No discharge measurements from Boyne River at Park St on 5/23/13, so discharge estimated with best fit line using data from Porter Creek.

Percentage of total discharge contributed by individual tributaries.

	Discharge Percentage (%)												
Tributary	4/9/13	5/23/13	7/17/13	10/2/13	11/14/13	11/18/13	5/7/14	5/28/14	6/23/14	7/7/14	8/12/14	10/27/14	Avg.
Boyne River	22.1	24.0*	23.1	25.0	22.9	18.8	25.7	27.1	25.3	29.5	23.4	27.1	24.5
Horton Creek	3.4	3.5	5.4	5.4	3.9	3.0	4.5	5.5	5.4	6.4	4.9	4.3	4.6
Jordan River	54.8*	56.3*	66.8	63.9	58.7	59.6	58.6	59.1	62.5	58.1	62.1	54.8	59.6
Loeb Creek	4.6	2.0	0.2	0.3	2.9	5.1	1.7	0.9	0.8	0.3	0.4	1.8	1.8
Monroe Creek	5.3	4.5	1.3	1.6	4.1	5.3	2.8	2.1	1.9	2.4	3.9	4.4	3.3
Porter Creek	7.0	8.0	2.9	3.6	6.0	7.8	5.1	4.3	3.3	2.9	4.8	6.9	5.2
Stover Creek	2.8	1.6	0.3	0.3	1.4	0.5	1.6	0.9	0.7	0.4	0.5	0.8	1.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*No discharge measurements at Jordan River Fair Road for the 4/9/13 and 5/23/13 events, discharge estimated with best fit line using data from Rogers Rd. No discharge measurements from Boyne River at Park St on 5/23/13, so discharge estimated with best fit line using data from Porter Creek.

Appendix E. Pollutant loads at sample sites and total inputs to Lake Charlevoix by monitoring date.

	Total Phosphorus Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	0.26	0.17	0.05	0.01	0.05	0.27	0.03	0.03	0.08	0.04	0.29	1.41	0.22
Boyne River - Park St.	0.83	5.08	1.72	0.49	1.15	12.88	6.93	1.83	2.85	5.62	2.11	12.46	4.49
Boyne River - North Branch US131	0.33	0.88	0.23	0.30	0.29	2.43	1.01	0.70	2.19	4.83	0.86	7.26	1.78
Boyne River - South Branch M75	0.22	2.95	0.61	0.16	0.92	8.64	2.55	0.65	2.90	1.21	1.04	6.26	2.34
Brown Creek - Depot St.	0.03	0.58	0.03	0.02	0.01	0.08	0.10	0.02	0.14	0.05	0.21	0.64	0.16
Deer Creek - M32	1.74	4.12	0.95	0.39	1.43	10.20	1.16	1.75	1.17	0.91	1.31	4.20	2.44
Horton Creek - Boyne City Rd.	1.20	0.40	0.28	0.09	0.18	3.83	0.33	0.76	0.71	1.06	0.36	2.95	1.01
Jordan River - Fair Rd.	9.91	9.88	4.14	2.04	2.05	118.19	3.31	3.62	20.96	7.30	5.58	25.22	17.68
Jordan River - Rogers Rd.	2.11	25.80	3.10	0.36	4.05	38.91	1.31	1.76	17.14	6.74	4.17	20.07	10.46
Loeb Creek - Evergreen Pointe Dr.	0.48	0.58	0.05	0.01	0.31	2.98	0.24	0.36	0.18	0.11	0.13	2.34	0.65
Monroe Creek - M66	0.29	1.50	0.15	0.04	0.39	4.15	0.61	0.34	0.17	0.33	0.84	0.52	0.78
Porter Creek - Lake Shore Dr.	1.03	2.13	0.21	0.09	0.30	9.72	0.39	0.44	0.55	0.92	0.65	5.23	1.80
Stover Creek - Mouth	0.75	0.93	0.04	0.01	0.21	0.55	0.23	0.13	0.26	0.08	0.14	0.58	0.33
Total Inputs to Lake Charlevoix*	14.52	21.07	6.61	2.80	4.61	152.38	12.13	7.50	25.81	15.48	10.01	49.94	26.91

* Total input is the sum of discharge from the Boyne and Jordan Rivers, and Brown, Horton, Loeb, Monroe, Porter, and Stover Creeks.

	Soluble Reactive Phosphorus Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	0.04	0.27	0.04	0.01	0.01	0.03	0.01	0.03	0.04	0.04	0.08	ND	0.05
Boyne River - Park St.	0.98	0.29	1.07	0.57	0.46	0.72	2.08	0.94	1.68	2.87	1.23	ND	1.17
Boyne River - North Branch US131	0.68	0.27	0.26	0.17	0.22	0.21	0.42	0.35	0.40	0.84	0.76	ND	0.42
Boyne River - South Branch M75	0.34	0.32	0.55	0.47	0.50	1.03	1.51	0.38	0.69	0.96	0.61	ND	0.67
Brown Creek - Depot St.	0.02	0.02	0.03	0.01	0.01	0.02	0.01	0.02	0.04	0.04	0.10	ND	0.03
Deer Creek - M32	0.75	0.15	0.49	0.27	0.24	1.28	-0.16	0.33	0.50	0.75	0.77	ND	0.49
Horton Creek - Boyne City Rd.	0.33	0.13	0.23	0.13	0.09	1.32	0.10	0.20	0.35	0.82	0.33	ND	0.37
Jordan River - Fair Rd.	7.85	1.38	2.69	1.55	1.76	7.35	-0.14	2.78	2.86	4.53	4.18	ND	3.35
Jordan River - Rogers Rd.	2.71	0.73	2.32	1.54	1.31	3.06	0.55	0.88	2.94	5.03	3.50	ND	2.23
Loeb Creek - Evergreen Pointe Dr.	0.14	0.07	0.04	0.01	0.04	0.14	-0.03	0.03	0.13	0.05	0.06	ND	0.06
Monroe Creek - M66	0.31	0.35	0.14	0.04	0.06	0.00	-0.03	0.10	0.12	0.22	0.42	ND	0.16
Porter Creek - Lake Shore Dr.	0.41	0.20	0.13	0.09	0.12	0.37	-0.02	0.15	0.22	0.29	0.52	ND	0.23
Stover Creek - Mouth	0.15	0.24	0.04	0.01	0.03	0.08	-0.01	0.05	0.06	0.05	0.05	ND	0.07
Total Inputs to Lake Charlevoix*	10.19	2.67	4.37	2.42	2.57	10.01	1.94	4.28	5.46	8.88	6.89	0.00	4.97

	Total Nitrogen Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	19.8	15.3	6.2	6.4	12.2	23.0	15.3	7.6	7.7	6.7	18.7	39.0	14.8
Boyne River - Park St.	373.3	429.9	153.4	187.6	268.9	688.5	300.6	166.6	230.4	309.0	266.2	324.1	308.2
Boyne River - North Branch US131	68.6	90.6	29.5	32.3	60.0	155.6	49.6	31.5	48.2	41.8	47.5	156.2	67.6
Boyne River - South Branch M75	188.5	247.9	114.0	178.8	205.8	413.4	168.0	133.6	141.9	150.9	214.6	286.3	203.6
Brown Creek - Depot St.	8.0	9.4	4.0	5.2	4.9	8.6	6.6	4.5	5.4	5.2	9.0	16.9	7.3
Deer Creek - M32	293.3	316.6	82.5	99.8	214.3	588.1	197.6	89.7	113.1	125.7	126.8	206.3	204.5
Horton Creek - Boyne City Rd.	176.9	172.0	125.4	129.3	162.6	212.9	171.6	132.6	151.3	160.9	144.4	231.5	164.3
Jordan River - Fair Rd.	1392.8	1879.1	1101.7	1172.3	1437.9	3206.4	1463.1	1058.1	3454.6	1599.3	1648.9	1983.2	1783.1
Jordan River - Rogers Rd.	1472.6	1529.7	1090.6	1216.1	1384.3	2653.9	1450.2	877.5	1213.3	1312.9	1572.0	1760.0	1461.1
Loeb Creek - Evergreen Pointe Dr.	46.2	32.7	2.3	1.9	29.2	172.7	15.4	5.7	8.1	4.3	6.7	44.6	30.8
Monroe Creek - M66	64.0	68.4	10.1	10.9	39.8	147.1	28.6	11.9	15.6	13.9	39.0	151.3	50.0
Porter Creek - Lake Shore Dr.	92.2	126.8	17.1	13.8	70.8	265.6	46.8	27.0	23.5	21.6	40.0	127.2	72.7
Stover Creek - Mouth	75.0	64.2	9.1	7.4	36.0	30.3	38.2	17.4	21.7	13.3	16.7	46.5	31.3
Total Inputs to Lake Charlevoix*	2228.4	2782.5	1423.2	1528.4	2050.1	4732.1	2071.0	1423.9	3910.5	2127.6	2170.9	2925.2	2447.8

	Ammonium Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	0.19	0.50	0.03	0.05	0.69	0.10	0.32	0.19	0.25	0.20	0.13	0.69	0.28
Boyne River - Park St.	12.64	24.53	6.47	4.38	16.69	7.51	13.68	6.70	15.62	13.39	4.86	29.09	12.96
Boyne River - North Branch US131	2.38	2.70	0.44	0.04	2.13	27.69	1.91	0.48	1.59	2.00	0.65	3.67	3.81
Boyne River - South Branch M75	2.32	3.33	3.59	2.00	7.33	13.27	6.40	2.99	8.37	5.16	2.23	6.42	5.28
Brown Creek - Depot St.	0.10	0.12	0.04	0.00	0.01	0.13	0.06	0.06	0.08	0.11	0.02	0.37	0.09
Deer Creek - M32	5.03	14.19	5.29	3.35	8.24	13.18	8.94	5.42	7.00	5.41	5.99	11.07	7.76
Horton Creek - Boyne City Rd.	0.94	0.93	0.43	0.15	1.32	2.73	2.47	0.55	2.14	0.72	0.53	2.45	1.28
Jordan River - Fair Rd.	71.60	25.73	9.31	7.47	5.72	20.92	25.13	15.34	40.09	39.92	11.78	40.45	26.12
Jordan River - Rogers Rd.	5.42	13.17	4.94	2.81	15.14	15.30	7.93	7.34	30.43	20.67	9.01	17.96	12.51
Loeb Creek - Evergreen Pointe Dr.	0.64	1.86	0.06	0.04	1.38	8.23	1.02	0.41	0.86	0.20	0.33	0.77	1.32
Monroe Creek - M66	0.16	0.86	0.14	0.05	0.21	3.40	1.46	0.40	0.84	0.40	0.09	1.28	0.77
Porter Creek - Lake Shore Dr.	1.10	3.73	0.30	0.19	4.27	3.12	3.27	0.31	1.66	1.43	0.24	2.55	1.85
Stover Creek - Mouth	1.35	1.77	0.04	0.02	0.39	0.35	1.31	0.08	0.43	0.14	0.08	1.28	0.60
Total Inputs to Lake Charlevoix*	88.55	59.52	16.80	12.31	29.99	46.39	48.41	23.85	61.72	56.31	17.92	78.24	45.00

* Total input is the sum of discharge from the Boyne and Jordan Rivers, and Brown, Horton, Loeb, Monroe, Porter, and Stover Creeks.

	Nitrate-Nitrogen Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	10.0	4.2	5.8	4.9	9.5	12.9	8.7	6.2	6.9	5.6	14.2	17.0	8.8
Boyne River - Park St.	262.4	134.8	95.4	140.9	114.1	407.9	200.1	139.7	164.9	239.4	195.8	295.0	199.2
Boyne River - North Branch US131	51.0	75.1	22.3	21.4	41.8	39.1	32.1	23.0	29.6	29.4	32.2	34.9	36.0
Boyne River - South Branch M75	129.1	61.9	100.8	141.1	166.1	140.7	128.4	101.7	107.0	119.4	187.8	196.3	131.7
Brown Creek - Depot St.	6.5	4.7	3.1	3.5	3.5	4.8	4.0	3.2	4.5	4.3	4.9	4.7	4.3
Deer Creek - M32	175.2	115.2	48.4	58.6	116.8	176.1	95.8	60.8	68.3	90.1	86.3	133.5	102.1
Horton Creek - Boyne City Rd.	149.6	125.9	119.2	97.5	159.4	143.1	117.6	124.3	124.0	136.1	139.9	186.5	135.3
Jordan River - Fair Rd.	907.1	1031.0	1026.8	910.9	1605.2	1938.5	1069.3	821.8	1052.0	1159.6	1544.2	1424.1	1207.5
Jordan River - Rogers Rd.	1272.8	1013.7	1126.4	960.0	1328.3	1761.9	992.0	839.5	957.4	1200.2	1472.1	1392.8	1193.1
Loeb Creek - Evergreen Pointe Dr.	14.9	4.1	1.4	0.7	4.8	12.3	3.2	1.8	2.2	2.3	4.0	2.4	4.5
Monroe Creek - M66	26.3	12.0	6.7	6.2	11.8	8.9	9.4	5.6	8.3	15.3	22.1	10.3	11.9
Porter Creek - Lake Shore Dr.	47.8	20.4	10.3	13.2	30.0	38.7	21.5	10.0	13.3	13.2	19.8	28.8	22.2
Stover Creek - Mouth	36.3	20.6	6.9	5.5	25.5	12.0	21.9	11.2	13.9	9.8	14.0	26.4	17.0
Total Inputs to Lake Charlevoix*	1450.86	1353.59	1269.87	1178.30	1954.23	2566.28	1447.10	1117.49	1383.02	1579.93	1944.66	1978.18	1601.96

	Chloride Load (lbs/day)*												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	301	468	76	92	251	470	270	166	103	96	423	304	252
Boyne River - Park St.	9031	11823	4829	6164	6078	12161	9453	8415	6975	9450	10416	9529	8694
Boyne River - North Branch US131	1509	1978	605	700	1654	2462	1201	1075	952	1067	1330	1192	1310
Boyne River - South Branch M75	3485	5766	1794	3067	3897	9975	3206	2776	2143	3192	3877	3106	3857
Brown Creek - Depot St.	215	353	123	156	194	308	233	215	245	212	377	333	247
Deer Creek - M32	5966	8085	1779	2247	4872	11620	3983	3334	2435	3012	3170	3724	4519
Horton Creek - Boyne City Rd.	921	1033	549	621	947	1887	1006	940	822	1084	1007	999	985
Jordan River - Fair Rd.	25052	19067	8069	8637	14379	39585	12217	10388	9690	10578	13018	9640	15027
Jordan River - Rogers Rd.	8733	11528	6102	6792	9658	24921	7777	7247	6406	6640	10355	7160	9443
Loeb Creek - Evergreen Pointe Dr.	1448	1152	118	148	1137	12172	598	311	278	250	318	786	1560
Monroe Creek - M66	784	1078	138	203	814	2751	511	278	232	1333	787	717	802
Porter Creek - Lake Shore Dr.	1898	2779	441	640	1600	5045	1170	779	573	590	1084	1409	1501
Stover Creek - Mouth	1255	987	202	232	913	461	819	452	348	243	404	508	569
Total Inputs to Lake Charlevoix*	40603	38271	14468	16801	26063	74369	26008	21778	19164	23741	27411	23921	29383

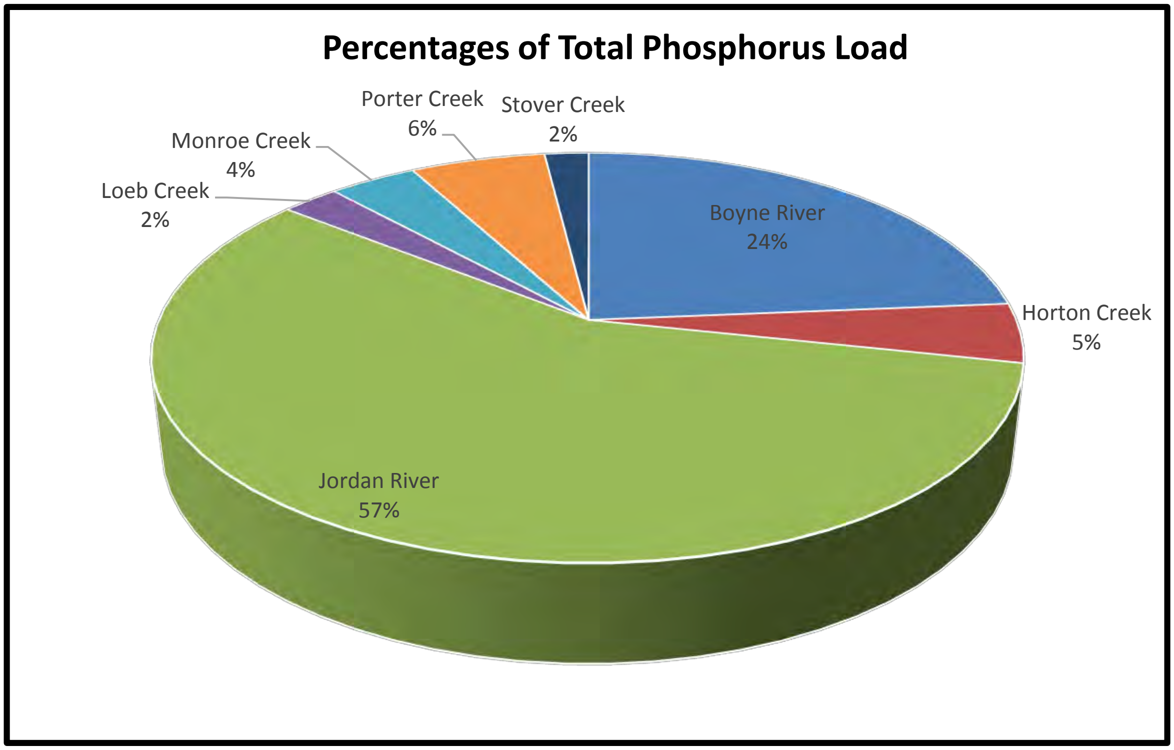
* Total input is the sum of discharge from the Boyne and Jordan Rivers, and Brown, Horton, Loeb, Monroe, Porter, and Stover Creeks.

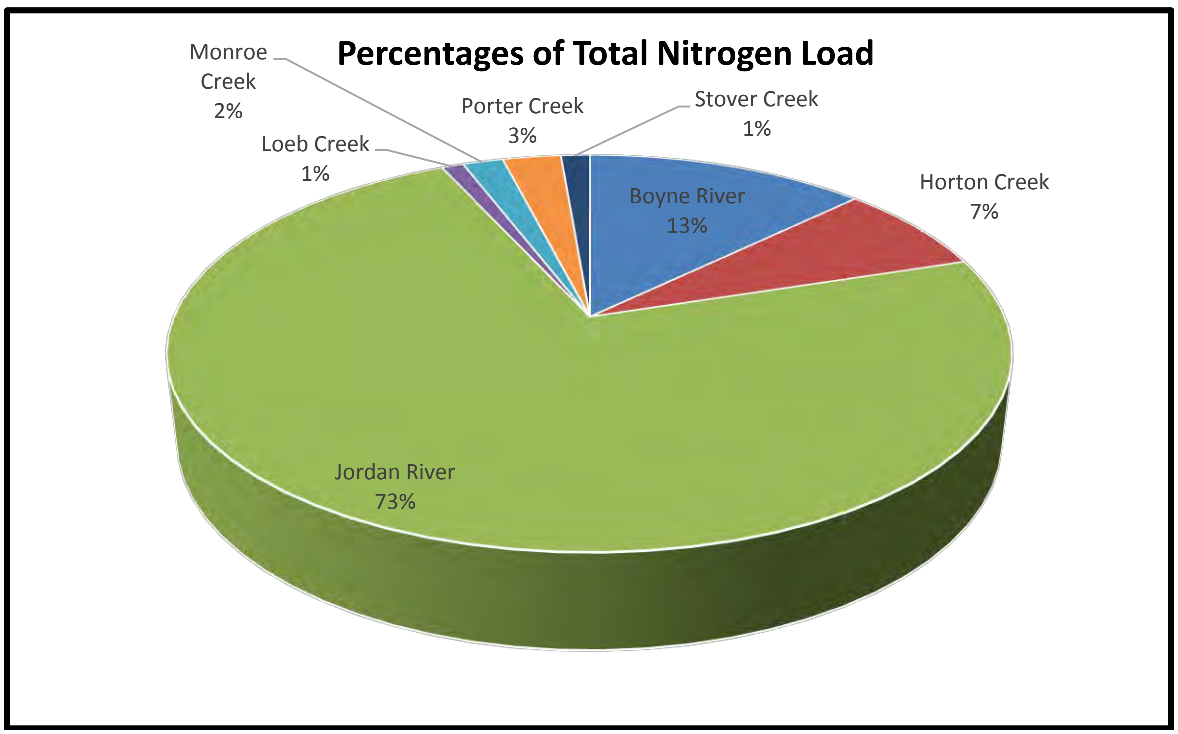
	Total Suspended Solids Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	48	190	184	68	77	382	68	109	619	249	3304	ND	482
Boyne River - Park St.	2258	23939	894	647	1262	27362	1386	1107	1474	2171	1521	ND	5820
Boyne River - North Branch US131	2667	11786	671	324	1018	15524	909	712	1011	2320	7587	ND	4048
Boyne River - South Branch M75	1948	2755	1182	794	1816	11929	950	653	857	3688	2073	ND	2604
Brown Creek - Depot St.	72	341	177	26	21	304	69	43	124	136	2201	ND	319
Deer Creek - M32	1305	2670	324	460	357	23948	438	583	351	571	574	ND	2871
Horton Creek - Boyne City Rd.	2326	3013	133	882	414	5379	929	459	169	403	437	ND	1322
Jordan River - Fair Rd.	21500	42498	4448	3785	7043	92177	7474	5315	5330	8941	14723	ND	19385
Jordan River - Rogers Rd.	14154	54528	5908	3984	5723	88316	8763	6072	7348	9457	21382	ND	20512
Loeb Creek - Evergreen Pointe Dr.	514	1193	17	8	164	6880	162	73	86	29	221	ND	850
Monroe Creek - M66	1130	5995	37	26	392	10654	497	221	96	186	7328	ND	2415
Porter Creek - Lake Shore Dr.	1345	4708	76	83	332	11352	398	142	115	174	3458	ND	2017
Stover Creek - Mouth	1604	5279	10	27	369	1281	234	90	116	62	206	ND	843
Total Inputs to Lake Charlevoix*	30748	86967	5793	5484	9996	155386	11150	7450	7509	12102	30095	0	32971

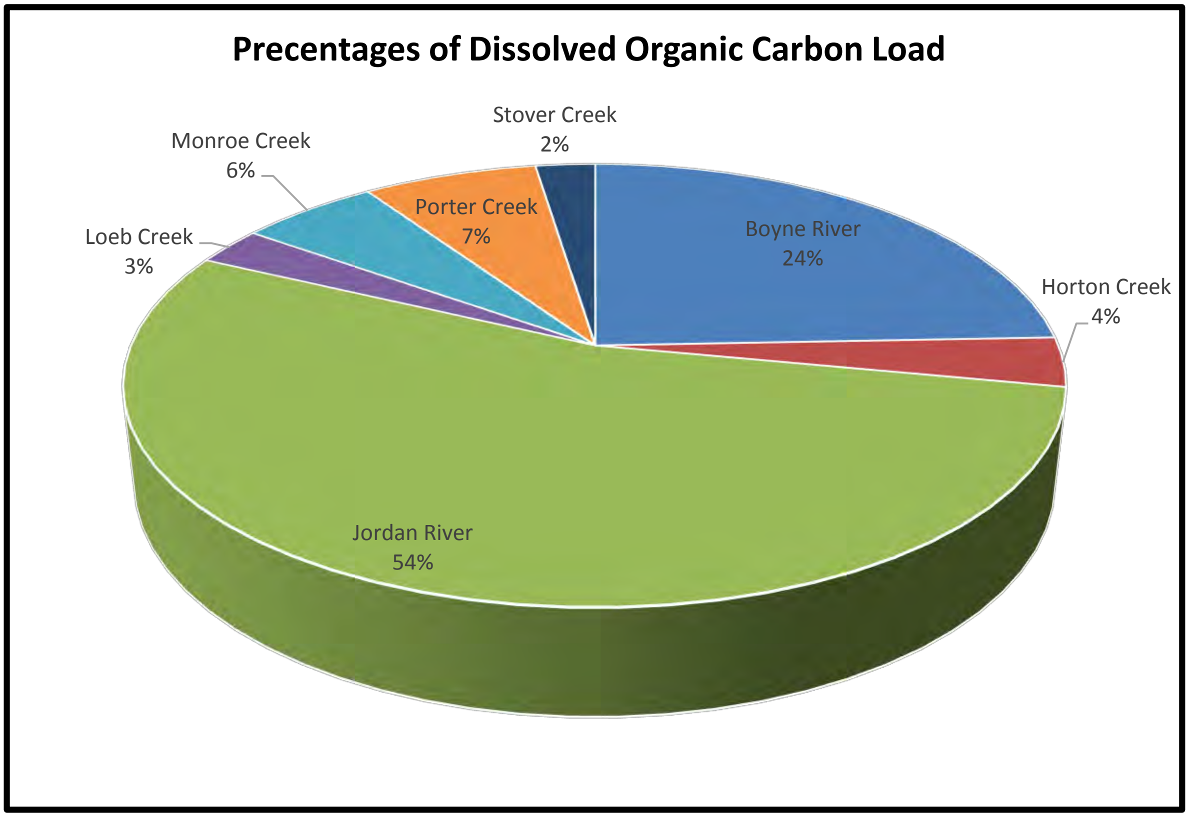
	Dissolved Organic Carbon Load (lbs/day)												
Sample Site	**4/9/13**	**5/23/13**	**7/17/13**	**10/2/13**	**11/14/13**	**11/18/13**	**5/7/14**	**5/28/14**	**6/23/14**	**7/7/14**	**8/12/14**	**10/27/14**	**Avg.**
Birney Creek - LTC Preserve	86.2	211.7	11.8	6.5	23.8	272.1	45.2	29.0	17.8	20.7	131.4	152.4	84.1
Boyne River - Park St.	2071.2	5731.8	689.6	369.1	2219.1	10694.3	1997.8	1365.3	1666.1	1748.9	1706.9	2582.9	2736.9
Boyne River - North Branch US131	488.0	987.5	191.0	112.9	179.9	1605.9	340.9	317.5	310.9	450.3	564.0	738.5	523.9
Boyne River - South Branch M75	925.5	4810.6	376.8	150.6	426.0	4895.2	517.4	479.0	391.5	1019.5	942.4	1058.1	1332.7
Brown Creek - Depot St.	35.3	116.2	13.2	5.7	22.6	87.5	27.8	21.2	19.1	20.1	140.9	171.4	56.7
Deer Creek - M32	1536.3	6016.0	593.2	260.5	1536.9	4775.4	1207.7	1078.0	1128.9	1072.5	973.5	1703.2	1823.5
Horton Creek - Boyne City Rd.	285.4	546.6	126.3	59.6	160.8	808.2	141.1	211.4	213.9	620.7	369.7	301.8	320.5
Jordan River - Fair Rd.	8063.5	11132.2	1831.0	1067.5	3081.2	31046.1	4278.7	3094.6	2770.2	3205.0	3888.3	5366.0	6568.7
Jordan River - Rogers Rd.	4655.8	11560.7	1456.8	425.6	2134.3	25270.6	2596.0	1912.6	1475.2	2085.5	3224.7	3613.3	5034.3
Loeb Creek - Evergreen Pointe Dr.	779.0	85.4	20.2	27.1	335.3	3189.6	260.3	133.2	129.7	68.3	77.1	502.0	467.3
Monroe Creek - M66	844.1	1739.5	75.1	64.2	598.9	3271.1	181.4	256.2	207.7	313.3	594.1	996.9	761.9
Porter Creek - Lake Shore Dr.	1354.2	333.3	148.9	114.2	584.3	4436.8	614.1	466.2	277.6	268.9	652.4	1292.8	878.6
Stover Creek - Mouth	860.4	1161.4	12.3	6.2	245.4	376.1	277.2	141.1	108.6	77.2	93.0	232.0	299.2
Total Inputs to Lake Charlevoix*	14293.0	20846.2	2916.5	1713.5	7247.8	53909.7	7778.3	5689.2	5392.9	6322.2	7522.5	11445.7	12089.8

* Total input is the sum of discharge from the Boyne and Jordan Rivers, and Brown, Horton, Loeb, Monroe, Porter, and Stover Creeks.

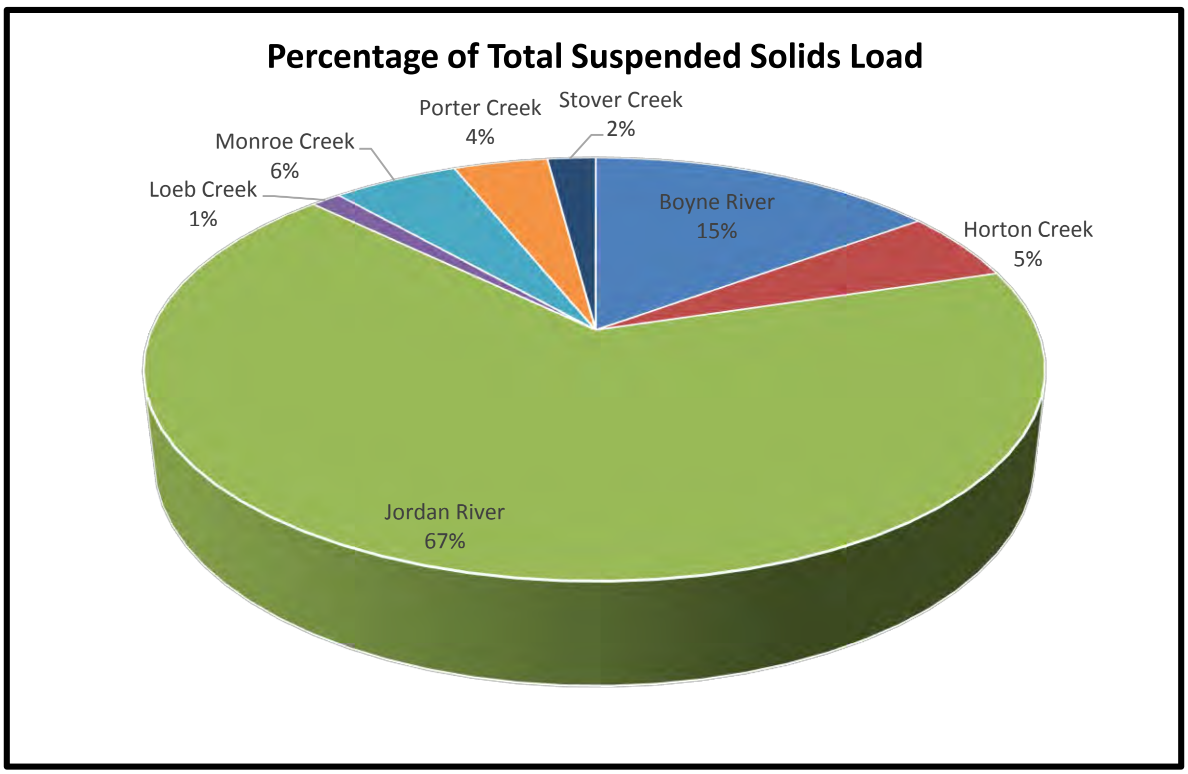
Appendix F. Charts of pollutant loads percentages into Lake Charlevoix from LCTMP tributaries.



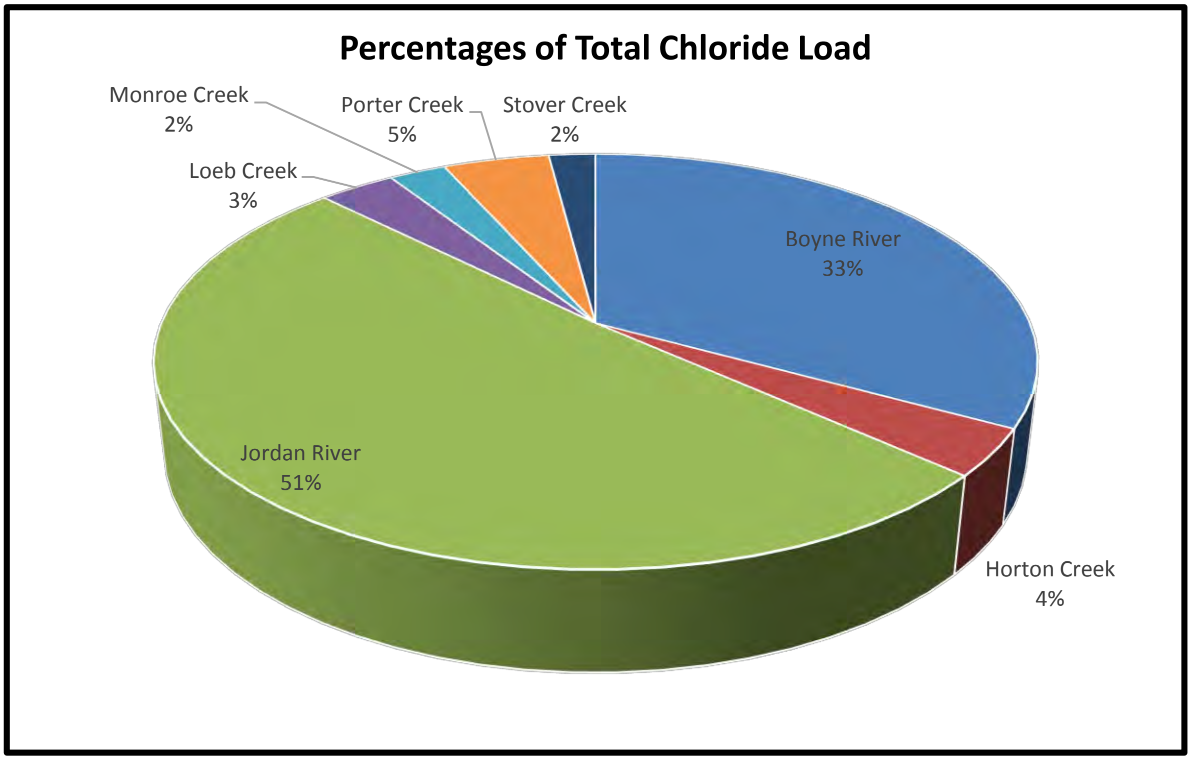




Precentages of Dissolved Organic Carbon Load
Stover Creek
2%
Monroe Creek
6%
Porter Creek
7%
Boyne River
24%
Loeb Creek
3%
Horton Creek
4%
Jordan River
54%



Percentage of Total Suspended Solids Load
Porter Creek
4%
Stover Creek
2%
Monroe Creek
6%
Loeb Creek
1%
Boyne River
15%
Horton Creek
5%
Jordan River
67%


Percentages of Total Chloride Load
Monroe Creek
2%
Porter Creek
5%
Stover Creek
2%
Loeb Creek
3%
Boyne River
33%
Jordan River
51%
Horton Creek
4%