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The Impact of Rochester Storm Sewers on the Water Quality of the Lower Genesee River: A Modeling Approach Using PCSWMM

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The impact of Rochester storm sewers on the water quality of the lower Genesee River: a modeling approach using PCSWMM

by

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Abstract

The lower Genesee River suffers from beneficial use impairments from the mouth of the river at Lake Ontario to the New York State Barge Canal due to industrial and municipal sources, storm sewers, and urban runoff. In urban areas, nonpoint source pollution from stormwater runoff is known to be a dominant factor in water quality. An assessment of the lower Genesee River was initiated to determine impacts from the canal, storm sewers, combined sewer overflows, and a wastewater treatment plant. To accomplish this, an integrated approach combining water quality sampling, statistical analysis, and modeling was employed. A cluster analysis was performed on samples taken during hydrometeorologic events to determine natural groupings in storm sewer sites based on water quality. These events and results of the cluster analysis were used to calibrate and validate a model of the Rochester storm sewer network (ROCSWMM) using hydrologic modeling tool PCSWMM (Storm Water Management Model). Model-predicted flows, total phosphorus (TP) loads, and total suspended solid (TSS) loads to the Genesee River for 2012 were 19,197,116 m^3, 2,277 kg P, and 625,694 kg, respectively. More than 50% of the total flow and 27% of the TP load discharged to the Genesee River from the storm sewer network came from the Merrill sewershed. The Irondequoit sewershed was the second largest contributor of stormwater (2,659,179 m^3) and TP load (481 kg), and over half of the TSS load was contributed by the Merrill (29%) and KenElm (24%) sewersheds. Precipitation events resulted in four combined sewer overflows (CSOs) in 2012. Water from these discharges have extremely high concentrations of nutrients (727 μg P/L to 4,180 μg P/L), sediment (156 mg/L to 810 mg/L), and *E. coli* (282,720 MPN/100 mL to 483,920 MPN/100 mL). Kodak King's Landing Wastewater Treatment Plant (WWTP) was a large point source of water and pollutant loads to the Genesee River accounting for 0.5% of the total flow and 1.3% of the TP load of the Genesee River. Low impact developments (LIDs) were simulated in ROCSWMM to determine theoretical reductions in flows and loads to the Genesee River from the storm sewer network. Converting 25% of subcatchment impervious area to porous pavement reduced flow and TP and TSS loads by up to 15% and treating ten percent of impervious roof runoff with rain barrels could reduce flows and loads up to eight percent. Further research should be conducted to determine the placement of LIDs within subcatchments that will achieve the greatest reduction of inputs into the sewer system.

Introduction

The Environmental Protection Agency indicates that approximately 468,000 km (291,000 miles) of assessed rivers and streams across the country do not meet water quality standards (USEPA, 1998). Poor water quality affects aquatic life, fish consumption, swimming, and drinking water. Primary sources of pollution include urban runoff, storm sewers, land disposal of wastes, agricultural activities, and hydrologic modifications (USEPA, 2002). As a result, the United States adopted the Clean Water Act in 1972 to restore and maintain the integrity of the nation's waters (USEPA, 1998). Through the Clean Water Act, states are granted authority and responsibility for establishing water quality standards, for assessing the health of their waters, and the extent to which the waters support the water quality standards. Under the Clean Water Act section 305(b), states, territories, and tribes are required to submit reports on their water quality to the EPA every two years. States, territories, and tribes under section 305(d) are also required to develop lists of impaired waters, which are waters that do not meet water quality standards (USEPA, 1998). The list of impaired waters is also used to calculate discharge limits for permits issued under the National Pollutant Discharge Elimination System (NPDES) (USEPA, 1998). Total Maximum Daily Load (TMDL), which specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, must be designated for these waters. A TMDL is the sum of all available loads of a single pollutant from all contributing point and nonpoint sources (USEPA, 2002).

Pollutants such as oxygen-depleting substances, nutrients (phosphorus and nitrogen), sediment, silt, bacteria, and toxic organic chemicals are the major contributors to water quality impairments (USEPA, 1998). States face challenges detecting and ranking sources of pollutants. Point sources discharge pollutants directly into surface waters from a single point, and pollutants that discharge into surface waters from diffuse origins are considered nonpoint sources (USEPA, 1998)

Point sources of pollution to waterbodies are easily identifiable. Municipal water-treatment plants and factories are examples of point sources. Point sources are commonly a major source of nitrogen to streams near large urban land areas while areas dominated by agriculture have high nitrogen loads due to nonpoint sources (Puckett, 1994). However, phosphorus is the key limiting nutrient in eutrophication of freshwater waterbodies. Major point sources of phosphorus to waterbodies are wastewater treatment plants and industrial effluents, while agricultural runoff is an important nonpoint source of phosphorus (Jarvie *et al*., 2006). The proportion of pollution stemming from point and nonpoint sources varies by land use and geographic location (Puckett, 1994). Many of the pollution control measures since the Clean Water Act have focused on reducing point sources, but control on nonpoint pollution has been difficult to achieve because of its ephemeral and diffuse character.

Nonpoint pollution is the major source of water quality issues in the United States. Agriculture, urban activities, and hydrologic modification lead to increased levels of sediment and are the primary causes of nonpoint nutrient pollution (Carpenter *et al*., 1998; USEPA, 1998). Nonpoint sources are often harder to identify, isolate, and control than point sources. Section 319 of the Clean Water Act established a program focused on the control of nonpoint sources of pollution, involving assessment reports and the adoption and implementation of management programs (USEPA, 1998). Section 305(b) of the Clean Water Act requires states to identify the contribution of nonpoint sources to water quality impairment. Pollutant TMDLs are developed for impaired and threatened waterways under Section 303(d) of the Clean Water Act (USEPA, 2002).

Nonpoint pollution, especially urban runoff from wet weather periods, is listed as a leading source for lakes and river systems (McCarthy, 2009). During and after precipitation events, stormwater runoff can transport nutrients, sediments, and pathogens to receiving surface waters (Koehn *et al.,* 2011). Many cities are served by combined sewer systems, which combine sanitary wastewater and stormwater runoff in the same network and transport it to a wastewater treatment plant. During and after precipitation events, combined sewers overflow, discharging untreated waste into receiving waterbodies. The discharge of this untreated wastewater can lead to elevated concentrations of bacteria and nutrients in receiving waters. This issue is important in the Great Lakes region of the United States, which frequently has combined sewer systems (Phillips and Chalmers, 2009).

Genesee River Basin

The Genesee River Basin originates in the Allegany Plateau of northern Pennsylvania and expands northward across western New York State to Lake Ontario (Fig. 1) (NYSDEC, 2003). It encompasses 6,563 km^2 in New York and 246 km^2 in northern Pennsylvania (Eckhardt *et al*. 2007). The watershed is roughly rectangular in shape. Running south to north, the main stem reach of the Genesee River is about 247 km. Long-term mean flow of the Genesee River at Lake Ontario is 77 m^3/second. Mean annual precipitation for the watershed is 86.4 cm, which ranges from 106.7 cm in the upper basin to 71.1 cm in the lowlands (USEPA, 1991). The climate of the basin is humid with cold winters and mild summers; mean annual temperatures range from 7°C in the upper basin to 13°C in the lower basin (USEPA, 1991).

The Genesee River Basin includes large sections of Livingston, Allegany, Monroe, Genesee, and Wyoming Counties, along with portions of Orleans, Ontario, Steuben, and Cattaraugus Counties (NYSDEC, 2003). The basin contains four of the western Finger Lakes (Conesus, Hemlock, Canadice, and Honeyoe Lake), and the New York State Barge Canal crosses the Genesee River south of Rochester. The major tributaries to the Genesee River are Black Creek, Oatka Creek, Canaseraga Creek, and Honeyoe Creek (Eckhardt *et al*., 2007). The Genesee River Basin is split into two primary hydrologic units, the upper and lower Genesee with the dividing point being the Mount Morris Dam (GFLRPC, 2004) (Fig. 1), although Makarewicz *et al*. (2013) use Portageville, NY, as the northern limit of the Upper Genesee subwatershed.

The area drained by the Genesee River Basin has a wide range of land uses; it includes highly urbanized Rochester, commercial and industrialized areas, suburban residential areas, heavy agricultural areas, and lightly populated forested areas. Approximately 52 percent of land use for the basin is agriculture, and 40 percent is forested (GFLRPC, 2004). About 4.6 percent of land cover in the watershed is developed land, residential, commercial, industrial, transportation/utilities, or mixed urban categories. Wetlands comprise the final land use, with less than 2 percent of the watershed area (GFLRPC, 2004). Wyoming, Genesee, Livingston, and Allegany Counties are predominantly agricultural (GFLRPC, 2004). Traveling from south to north in the basin, the land use changes from predominantly rural and agricultural to more urbanized and commercial uses (GFLRPC, 2004). Monroe County, located in the Lower Genesee River Basin, contains the majority of populated, developed areas of Rochester and its surrounding suburbs (Eckhardt *et al*., 2007). The population of the Genesee River Basin within New York State was 401,000 in 2000 (NYSDEC, 2003). The City of Rochester alone has a population of 210,565, in addition to considerable populations in the surrounding suburbs (U.S. Census Bureau, 2011).

The Genesee River Basin suffers from multiple sources of pollution. Nonpoint runoff and pollutants from industrial, municipal, and commercial sources have significant impacts on the Lower Genesee River (NYSDEC, 2003). Urban nonpoint pollution sources include precipitation, soil erosion, accumulation and wash-off of atmospheric dust and street dirt, fertilizers, pesticides, and direct discharge of pollutants into storm sewers (Brezonik and Stadelmann, 2001). Agriculture is known to be a major source of water quality issues. Poor agricultural practices can lead to organic enrichment, nutrient loadings, and streambank erosion. Streambank erosion occurs naturally, is enhanced by removal of vegetative cover, and alters land use when higher stormwater runoff velocities during high flow events occur. It leads to increased sedimentation and turbidity in downstream areas (GFLRPC, 2004). Anthropogenic sources, especially agriculture and municipal sewage system, accounted for 70% of the phosphorus loads from the Black Creek and Oatka Creek Watersheds, which are both subwatersheds of the Genesee River Watershed, while natural inputs accounted for only 26% and 30% of the total phosphorus load, respectively (Makarewicz *et al*., 2013). Approximately 75% of phosphorus loads from Canaseraga Creek Watershed, another subwatershed of the Genesee River Watershed, was attributed to anthropogenic sources (Makarewicz *et al*., 2013). In rivers and streams in or near large urban areas, point sources are a major nutrient source (Puckett, 1995). Atmospheric deposition of nitrogen is a major nonpoint source in large urban areas, though it is often ignored because it originates from a point source, especially in the Northeast United States (Puckett, 1995).

Lower Genesee River Basin

The portion of the Genesee River Basin (Fig. 1), north of the Portageville to the mouth of the Genesee River at Lake Ontario, has a gently rolling topography, with an average slope between Mount Morris Dam and the City of Rochester of 0.15 m/km (GFLPRC, 2004). The main stem of the Lower Genesee River passes through the center of the City of Rochester, located in Monroe County, and has significant beneficial use impairments in the highly urbanized Rochester metropolitan area, which borders the south shore of Lake Ontario. Pollutants from the industrial, municipal, downstream agriculture, and other sources restrict aquatic life support, fish consumption, public bathing, recreational activities, and general aesthetics (NYSDEC, 2003).

The New York State Barge Canal, or the Erie Canal, crosses the Genesee River in the Lower Basin. The canal crosses the river at nearly right angles, south of Rochester, approximately 16 km from the mouth at Lake Ontario (Moffa *et al*., 1975). In the winter months, canal gates on either side of the Genesee River are closed, and the canal is drained so water from the Genesee River flows through the intersection unaffected (Bode and Novak, 2005). During the navigation season, usually May through November when the canal gates are open, water in the canal flows eastward (Coon and Johnson, 2005). The New York State Department of Environmental Conservation lists the New York State Barge Canal as suffering from minor water quality impacts (NYSDEC, 2003). The water quality issues in the canal are suspected to be from industrial sources, urban runoff, storm sewers, and boat traffic. There are concerns that the canal suffers from use impairments due to water quality, and discharge from the canal may impact other streams and tributaries (NYSDEC, 2003).

The Eastman Kodak King's Landing Wastewater Treatment Plant (WWTP) discharges into the Genesee River (Fig. 2) under a National Discharge Pollutant Elimination Systems (NPDES) permit and is considered to be a prominent point source of contaminants within the lower Genesee River (NYSDEC, 2003). Toxicity testing downstream of the King's Landing WWTP indicated sediments with highly elevated concentrations of metals and contamination from fuel oil (NYSDEC, 2003).

Sewer Networks

Three different sewer networks serve the City of Rochester (Appendix A): a combined sewer system, separate sanitary sewers, and separate storm sewers. The sewer network in the City of Rochester is owned and operated by Monroe County (personal communication: A. Sansone, Monroe County Environmental Services). The separate storm sewers collect storm water and urban runoff. The water is not treated before it is discharged into the Genesee River, New York State Barge Canal, or small stream networks. The sanitary sewer system collects only sanitary waste, which is then transported to the Van Lare Wastewater Treatment Plant. The combined sewer system (CSO) collects sanitary sewage, industrial wastes, and stormwater runoff in the same network and transports the water to the Van Lare Wastewater Treatment Facility for treatment, except for times when the volume of water overwhelms the combined sewer network infrastructure and the excess water overflows through relief points along the Genesee River and Irondequoit Bay.

During times of heavy precipitation, large amounts of water enter the combined sewer drains and overflow the capacity of the storage system and treatment facility. The excess water overwhelm through relief points, discharging pollutants including raw sewage, floatables, industrial waste, nutrients, and other contaminants in stormwater into the Genesee River (Lyandres and Welch, 2012). These pollutants including toxicants, heavy metals, and coliform bacteria (USEPA, 1991), released from periodic overflow of untreated sewage including bacteria and other pathogens, can cause health risks and are a cause of beach closings and health advisories across the Great Lakes (Lyandres and Welch, 2012).

A CSO Abatement Program (CSOAP), developed and implemented for the City of Rochester, was completed in 1993 (Lyandres and Welch, 2012). It involved a new network of deep storage tunnels with a 175-million gallon (approximately 662,000 m^3) capacity and has been effective at minimizing discharge into the Genesee River (Lyandres and Welch, 2012). Prior to the CSOAP, combined sewer overflow discharge had imposed heavy nutrient and chemical loads on the Genesee River and Irondequoit Bay and also caused bacterial contamination of public bathing beaches along Lake Ontario. The projected loads for a 2.54-cm storm from all overflows in 1980 included approximately 47 MT of total suspended solids, 126 kg total inorganic phosphorus, and fecal coliform concentrations of 28.3×10^{13} MPN (Murphy *et al*., 1981).

Even with the CSOAP infrastructure improvements, some CSO structures still exceed capacity during storm events and discharge into the river. Prior to the abatement program, the CSOs exceeded capacity an average of 66 days annually, with an estimated discharge of 7 million m^3 (1900 million gallons) per year (Murphy *et al*., 1981). Discharges into the Genesee River and Irondequoit Bay, both tributaries to Lake Ontario, have been reduced to 41.8 million gallons (158,000 m^3) in 2010 and 106.1 million gallons (402,000 m^3) in 2011 (Lyandres and Welch, 2012). From January 2011 through October 2011, a total of five structures overflowed due to three different storm events: control structure 44 (CS-44), control structure 45 (CS-45), control structure 243 (CS-243), Front Street Diversion Structure, and Densmore Control Structure (Fig. 2). Front Street Control Structure and structures 44, 45, and

243 discharge to the Genesee River; Densmore structure discharges into Irondequoit Bay. During the 14 August 2011 storm event, CSO structure 243 overflowed, discharging approximately 48.1 million gallons (182,000 m^3) into the Genesee. Water samples taken from that overflow had a fecal coliform level of 541,000 CFUs/100 mL, total phosphorus of 1.68 mg P/L, and total suspended solids of 396 mg/L (personal communication: A. Sansone, Monroe County Environmental Services).

Along with combined sewers, there are separate sanitary sewer networks that service Monroe County. These sewers are responsible for carrying only sanitary waste to the wastewater treatment plants. In the City of Rochester, cross-connections have been found between the separate storm sewers and the separate sanitary sewers (personal communication: A. Sansone, Monroe County Environmental Services). When these cross-connections occur, untreated sanitary waste flows through the storm sewers and discharges into receiving waters, including the Genesee River. The number and location of cross-connections is currently being investigated by Monroe County Environmental Services.

A third major sewer network in the City of Rochester is the separate storm sewer system. This system removes stormwater runoff from a sewershed, which is a land area drained by a specific network of sewers. Each sewershed has multiple outfalls, many of which discharge into the Genesee River (Fig. 3). There are 63 storm water outfalls that discharge into the Genesee River between Ballantyne Road and the mouth of the Genesee (Fig. 3). An additional 53 stormwater sewer outfalls discharge into the Canal west of the Genesee River. Stormwater from the storm sewer networks does not receive any treatment before discharging into receiving waterbodies. The New York State Department of Environmental Conservation lists nutrients, PCBs, pesticides, pathogens, and sediment and major pollutants to the Lower Genesee River, with major sources of pollutants listed as industrial, municipal, storm sewers, urban runoff, and combined sewer overflows (NYSDEC, 2003). The effect of the City of Rochester storm sewer outfalls on the Genesee River has not yet been quantified, but they are known as a source of pollutants in the Genesee River (NYSDEC, 2003).

The effects of urbanization can be enormous on basin hydrology and water quality. Urbanization results in an increase of pollutant loads by at least one order of magnitude over natural catchment conditions. These pollutants include suspended solids, nutrients, biochemical oxygen demand, pathogenic organisms, and trace metals (Tsihrintzis and Hamid, 1998) Impervious surfaces are increased, which decreases infiltration and increases runoff, and it is widely recognized that urban areas are a dominant factor in nonpoint source pollution from storm water runoff (Lee *et al*., 2010). Due to these impacts on receiving waters, predictive models have been developed to estimate water quantity and quality for nonpoint source pollution, storm sewers, and combined sewer systems and to estimate effectiveness of low impact developments (LIDs) on reducing pollutant concentrations and loads.

Modeling: PCSWMM

The EPA Storm Water Management Model (SWMM) is a popular model for use in urban areas. The SWMM model is a comprehensive model for simulation of urban runoff quantities and quality in storm and combined sewer systems (Lee *et al*., 2010). It was developed to simulate storm events, based on rainfall, other meteorologic inputs, and site characteristics. SWMM simulates aspects of urban hydrologic and water quality cycles, watershed characteristics, conveyance, storage, and treatment to predict both the quantity and quality of stormwater runoff (Smith *et al*., 2005). Single event and continuous simulation can be performed on storm drains, combined sewers, and natural drainage features, and hourly runoff can be generated from the model using daily precipitation data (Barco *et al*., 2008). Computational Hydraulics Incorporated developed PCSWMM, is a more user-friendly version of EPA's model. It is a spatially distributed rainfall model that incorporates all the hydrologic parameters that affect runoff.

Objectives

1. Develop and calibrate a hydrological model (PCSWMM) to determine the total load of total phosphorus and total suspended solids entering the Genesee River from separate storm sewers.
2. Using PCSWMM, develop scenarios using low impact developments (LIDs) to reduce pollutants loads from separate storm sewers.
3. Determine the difference, if any, in the pollutant (nitrates, total nitrogen, soluble reactive phosphorus, total phosphorus, sodium, total suspended solids, and total coliforms) concentration in water collected from separate storm sewers between event and nonevent times.
4. Determine loads from CSO and Kodak King's Landing Water Treatment Plant to the Genesee River.

5. Investigate the interaction between the Genesee River and the New York State Barge Canal at their intersection.

Methods

Site Selection

The storm sewer sample sites were selected under advisement from Andy Sansone, (Senior Industrial Waste Technician, Monroe County Environmental Services) based on accessibility, land use of the sewersheds, and location. The site located near Scottsville Road is the most upstream site of the storm sewer sites (Fig. 2) and is located on the west side of the Genesee River. It drains a predominantly commercial area west of the Genesee River, including runoff from the Greater Rochester International Airport. The sewershed (area of land that drains to a specific section of the sewer network) that the Kendrick Road and Elmwood Avenue sites drain is comprised of an area approximately 3.5 km^2 at the northeast corner of the intersection of the Genesee River and the New York State Barge Canal (Fig. 2). The sewershed encompasses a section of the University of Rochester and residential and commercial areas (personal communication: A. Sansone, Monroe County Environmental Services). The sewershed that the Court Street site drains is located on the west side of the Genesee River (Fig. 2). It drains approximately 1.2 km^2 of high-density residential and commercial land (personal communication: A. Sansone, Monroe County Environmental Services). The St. Paul Street outfall is located in a sewershed on the east side of the Genesee River and drains an area about 2.5 km^2.

The area drained by this sewershed is primarily residential and commercial (personal communication: A. Sansone, Monroe County Environmental Services). The Merrill Street outfall drains a large area, approximately 10 km^2, of residential, commercial, and industrial facilities west of the Genesee River. The sites at Maplehurst Road, Chapel Hill Drive, and Beaconview Court all are east of the river and all drain a primarily suburban residential area (personal communication: A. Sansone, Monroe County Environmental Services). The sewershed that all three are located within drains approximately 8 km^2 (Fig. 2).

Storm Sewers and Outfalls

Water quality samples were collected weekly, beginning 17 January 2012, at seven storm sewer sites for the period of one year and during 17 hydrometeorologic events, which were defined as snowmelt or rainstorms greater than 0.64 cm. Two additional sites on Chapel Hill Drive and Beaconview Court were added on 18 June 2012 (Table 1). Eight of the nine sites discharged into the Genesee River (Fig. 2). Of those eight sites, the storm sewers on Scottsville Road, Court Street, and Merrill Street drain areas west of the Genesee River; sites on Elmwood Avenue, St. Paul Street, Maplehurst Road, Chapel Hill Drive, and Beaconview Court drain areas east of the Genesee River. The site located near Kendrick Road drains an area east of the Genesee River and discharges into the New York State Barge Canal, east of the Genesee River (Fig. 2).

At the storm sewer sites, a bucket with a rope attached at the handle was lowered to the water level of the outfall until enough water had collected in the bucket for a sample. Velocity was measured using a Gurly meter (Model D625) or a sonar Doppler, digital current meter (OTT ADC 10M model). A Marsh McBirney Flo-mate 2000 was used when there were malfunctions with the sonar Doppler. Depth measurements and respective discharge calculations were used to develop a rating curve (discharge versus stage) based on a second order polynomial regression. At sites with depths too low to measure velocity with the current meter, discharge was calculated by measuring the amount of water flowing from the outfall over a period of time into a container. The method used was determined by accessibility to the site, depth of water, and flow conditions. The water level depth in the center of the sewers/outfalls was measured with a meter stick or with a water-level measuring tape.

Time Series

Samples were taken approximately every 20 to 30 minutes for three to four hours at each site during an event to create a time series at each site. Discharge measurements were collected and samples were analyzed for total phosphorus, total suspended solids, and total coliform bacteria. The sites were sampled during events on 28 October 2012 (Scottsville Road), 11 February 2013 (Court Street), 10 April 2013 (Maplehurst Drive and Chapel Hill Drive), 28 May 2013 (Merrill Street and St. Paul Street), 29 May 2013 (Elmwood Avenue), 1 June 2013 (Kendrick Road), and 6 June 2013 (Beaconview Court). Event mean concentration was calculated from the concentrations and discharge values collected during the time series at each site for total phosphorus, total suspended solids, and total coliform bacteria by equation A.

Equation A: $EMC = \frac{\sum_{i=0}^{n}(Ci * Qi)}{\sum_{i=0}^{n} Qi}$

Ci = concentration (mg/L or µg/L) at time i

Qi = discharge (m^3/s) at time i

Genesee River and the New York State Barge Canal

Water quality samples were collected weekly from the Genesee River at three sites: Ballantyne Road, University of Rochester (U of R), and Ford Street (Table 1). Ballantyne Road is approximately 5 km upstream of the intersection of the Genesee River and the New York State Barge Canal, while U of R and Ford Street are located approximately 2 km and 4 km downstream from the canal, respectively (Fig. 2). Sampling at Ballantyne Road and U of R began 17 January 2012; sampling at Ford Street began 22 April 2012. Weekly samples, taken by Monroe County Environmental Services, were also taken at three sites (Ballantyne Road, U of R, and Charlotte, which was near the mouth of the Genesee River) along the Genesee River for 12 weeks from 24 August 2010 to 9 November 2010. Once the canal was closed on 15 November 2010, seven additional weekly samples were taken from 16 November 2010 to 28 December 2010.

The New York State Barge Canal, or Erie Canal, was opened on 28 April 2012 for the navigation season. Weekly water samples of the canal were collected at two sites beginning 1 May 2012 until 15 November 2013 when the canal was closed. Canal West is located less than 0.5 km upstream (west) of the intersection of the canal and the Genesee River, and Canal East is located approximately 1 km downstream of the Genesee River (Table 1) (Fig. 2).

River and canal samples were collected by lowering a bucket from a bridge that crossed over the waterway. Velocity measurements at the canal were taken every 2.0 m at a depth of 0.4 m (due to the length of the cable) with a sonar Doppler digital current meter (OTT ADC 10M model). All water samples were kept on ice in the field. Samples were also collected during hydrometeorologic events, which were defined as snowmelt or rainstorms greater than 0.64 cm (0.25 inches).

In addition to the weekly monitoring of the Genesee River and New York State Barge Canal, a Hydrolab (Hach Company, Model DS5) was used to measure conductivity and temperature at 0.5-m intervals at four sites along the Genesee River and the New York State Barge Canal on eight dates: 12 June 2012, 26 June 2012, 10 July 2012, 18 July 2012, 30 July 2012, 7 August 2012, 3 September 2012, and 15 October 2012. Of the four sites, two were Genesee River sites, upstream and downstream of the canal (River South and River North), and two were along the New York State Barge Canal, upstream and downstream of the Genesee River (Canal West and Canal East) (Fig. 4). The Hydrolab was calibrated in the lab against known standards for accuracy for temperature, conductivity, pH, dissolved oxygen, and for depth in the field throughout the sampling period.

Discharge

The USGS station at Ballantyne Road measured gauge height, not flow. For high flows a rating curve existed to calculate flow from gauge height, but the curve did not exist for low flows. Discharge at low flows at Ballantyne Road was estimated by Equation B. This equation assumes similar geology, land cover, and climate between the two sites, as well as a net balance of input and output from the New York State Barge Canal. Since the two sites (Ballantyne Road and Ford Street) are separated by a few miles, geology, land cover, and climate of their entire watersheds are indeed the same except for the few miles that separate them. Also the net balance of input and output from the New York State Barge Canal is a reasonable assumption (Makarewicz *et al*., 2013).

Equation B:

$$\frac{Mean\ Disc(Ford)}{Basin\ Area(Ford)} = \frac{Mean\ Disc(Bal)}{Basin\ Area(Bal)}$$

Mean Disc(Ford) = Mean annual daily discharge at Ford Street
Mean Disc(Bal) = Mean annual daily discharge at Ballantyne Road
Basin Area(Ford) = Area of Ford drainage basin, i.e., Genesee River
Basin Area(Bal) = Area of Ballantyne drainage basin

Gauge height was obtained from the United States Geological Survey (USGS # 04230650) station (http://waterdata.usgs.gov/ny/nwis/rt) , located on the right bank, 122 m upstream of Ballantyne Bridge in Chili, NY (Table 1). Discharge from the Ford Street site was collected from the USGS station (# 04231600) ((http://waterdata.usgs.gov/ny/nwis/rt), located on the left bank adjacent to the floodwall, approximately 80 m upstream of the Ford Street Bridge in Rochester, NY (Table 1).

Rating curves were developed by measuring depth at the deepest point of the storm sewer or outfall and by measuring velocity with a Gurley meter (Model D625) or sonar Doppler digital current meter (OTT ADC 10M model) at 0.6 of the depth at horizontal increments (0.25 m) allowed by size of the pipe and depth of the water column. During low flow conditions, velocity was measured once, at the center of the pipe. Measurements were taken during high flow 'event' conditions and low flow 'nonevent' conditions to obtain a wide range of values. Dimensional measurements of the pipes/culverts were taken and drawn proportionally to the site, and cross-sectional area was determined with a planimeter. Cross-sectional area (m^3) of the water in the pipe was multiplied by average velocity (m/s) to calculate discharge (m^3/s). A regression line was fit to each rating curve using Microsoft Excel.

Rating curves were developed for separate storm sewer sites at Scottsville Road, Kendrick Road, Elmwood Avenue, Court Street, Maplehurst Road, Merrill Street, Chapel Hill Drive, and Beaconview Court. A rating curve was not developed for the site at St. Paul Street. Due to accessibility problems, discharge at that site was calculated by measuring the amount of water flowing from the outfall over a period of time into a container.

Cross-sectional area was also calculated for the two sites (Canal East and Canal West) along the New York State Barge Canal (Fig. 2). A tape measure was used to determine precise dimensional measurements at a bridge over the canal. Those measurements were drawn on gridded paper, and a planimeter was used to determine the cross-sectional area at various depths. Water depth measurements were taken with a measuring tape from a fixed point on the bridge every time the canal was sampled. Velocity measurements were taken with a sonar Doppler digital current meter at 2.0-m intervals. The average velocity (m/s) measurements were multiplied by the cross-sectional area for the depth measured at that time (m^2) to determine discharge (m^3/s). For each site, loading (mass/unit time) was calculated by multiplying the concentration (mg/L or µg/L) by the discharge (m^3/s) for total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate, total suspended solids, dissolved sodium, and total coliform bacteria.

Water Quality Analysis

All samples were kept on ice in the field and refrigerated upon arrival at the lab. Samples were analyzed for nitrate+nitrite (NO_3+NO_2), soluble reactive phosphorus (SRP), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and dissolved sodium according to American Public Health Association (APHA) methods (Table 2). Samples for NO_3+NO_2 and SRP were filtered on site with a 0.45-µ, Magna nylon filter, refrigerated at 4°C, and analyzed within 24 hours of sample collection (APHA, 1998).

Quality Control

All samples collected were analyzed at the State University of New York at Brockport Water Chemistry Laboratory, which is certified through the Environmental Protection Agency's National Environmental Laboratory Accreditation Conference (NELAC). The water chemistry laboratory is ELAP-accredited (Environmental Laboratory Accreditation Program) (EPA#NY01449). Replicate samples, laboratory controls, method blanks, and matrix spikes were performed once every 20 samples.

Statistics

The Shapiro-Wilk test is a well-established and powerful test to determine normality and was used to analyze data from this study (Royston, 1992). If data were normally distributed, a parametric statistical test was used. If data did not have a normal distribution, a nonparametric test was used to determine statistical significance. Mann-Whitney U-tests were used to compare nonparametric data for two independent samples; Wilcoxon signed-rank tests were used for paired samples with nonparametric distributions. Analyses of variance (ANOVAs) were used regardless of normality to determine significance between multiple groups because the validity of the analysis is only slightly affected by considerable deviations from normality (Zar, 1996).

Multivariate statistical methods are also useful tools for examining, modeling, and interpreting large data sets. Cluster analysis is a multivariate method that is a useful classification technique. It identifies the natural groups of the observations based on the measured variables (Simeonov *et al.,* 2003). A cluster analysis was run on the nine separate storm sewers for average annual, average event, and average nonevent concentrations of TP, nitrate, TSS, SRP, TN, and total coliform. The variables were standardized to z-scores in order to give equal weight to each variable.

PCSWMM (Storm Water Management Model) Use

Computational Hydraulics International (CHI) has an updated version of the Environmental Protection Agency Storm Water Management Model (SWMM), and the CHI model (PCSWMM) was used to build a model of the separate storm sewer network of the City of Rochester and the surrounding areas. Dynamic wave routing produces the most theoretically accurate results of all the routing options and was selected for the routing method for this model (James *et al.,* 2010). Since the area rarely experiences infiltration-excess runoff, the curve number method was used for the infiltration model since it is best for saturation-excess events (personal communication: J. Zollweg, The College at Brockport, State University of New York). The event mean concentration (EMC) wash-off function in the PCSWMM land-use editor was used to model water quality for TP and TSS. This option was chosen due to the lack of pollutant build-up data, which is not needed for the EMC function (James *et al.*, 2010).

Inputs

Digital layers used in the model included a DEM (digital elevation model) from the National Elevation Dataset (National Elevation Data Set, United States Geological Survey, http://ned.usgs.gov/) and the City of Rochester storm sewer network (Andy Sansone, Monroe County Environmental Services). The storm sewer network for the Town of Irondequoit was digitized from a georeferenced paper copy of the sewer network (Irondequoit Department of Public Works). Pipe sizes and flow directions were set in PCSWMM.

Average daily climate data (air temperature, evaporation, and wind speed) were downloaded from the National Climatic Data Center (NCDC) (www.ncdc.noaa.gov/oa/ncdc.html), converted into metric units, and entered into the model using climatology editor (James *et al.*, 2010). Evapotranspiration was calculated by PCSWMM using the climate data entered into the model (James *et al.*, 2010). Instantaneous precipitation NEXRAD (Next-Generation Radar) radar data, downloaded from NOAA’s (National Oceanic and Atmospheric Administration)

National Weather Service, was used for the rainfall data in the model. The radar rainfall was ground-truthed (bias removal) to the rain gage at the Greater Rochester International Airport. Data was downloaded, imported into a RAP (Radar Acquisition and Processing) project where a rainfall time series was created for each individual subcatchment (CHIwater, 2013b).

Nonevent flows (m^3/s) from observed average discharge values measured during weekly dry weather sampling were imported into the model, using the inflows editor tool, for each sampled junction. The majority of sampled sites did not have baseflow during dry weather periods, so dry baseline flows were not entered into non-sampled sites. Baseline TP and TSS concentrations averaged from weekly nonevent samples at each site were added as the concentration of nonevent flow via the inflows editor, as a part of model calibration and to eventually calculate loads. Baseline concentrations of TP and TSS were averaged due to low variability within sites (Table 3). Total phosphorus and TSS event mean concentrations were determined for each sampled storm sewer site through time series samples and were entered into the model as the coefficient for the EMC wash-off function via the land-use editor tool (James *et al.*, 2013). The EMCs at each individual site were used to calibrate the model and to determine total loadings from the storm sewer network during hydrometeorologic events.

Subcatchment Characteristics

Subcatchments were delineated using the DEM in ArcGIS. A flow-direction raster was generated from the DEM in ArcGIS using the hydrology toolbox and then was used with the basins tool to convert the DEM into smaller subcatchments. The raster was converted to polygons in ArcGIS and imported to PCSWMM. Each subcatchment was set to have one node/outlet using the Voronoi decomposition tool in PCSWMM (James *et al.*, 2010). The National Land Cover Dataset (NCLD) was used to determine average percent imperviousness for each subcatchment using ArcGIS (Fry *et al.*, 2011). Using the conversion toolbox in ArcGIS, the raster data was converted to points, and the spatial analyst toolbox was used to extract by points. These points were then spatially joined in ArcGIS to the subcatchment shapefile imported from PCSWMM. Zonal statistics were used to determine the average percent imperviousness in each subcatchment, which were then imported into the subcatchment attribute table in PCSWMM.

Soil data was downloaded (SSURGO, United States Department of Agriculture: Natural Resources Conservation Service, http://soildatamart.nrcs.usda.gov), and soil composition of each subcatchment was handled in a similar method as the method to determine average percent imperviousness. The raster data set was converted to points, values were extracted to the points, and the points were spatially joined to the subcatchments. Zonal statistics were used in ArcGIS to find the majority soil in each subcatchment. Curve number values for the majority soil type were determined from literature (James *et al.*, 2010).

Calibration/Validation

The model for each of the nine sampled storm sewer sites was calibrated with observed data. Parameters adjusted to model water balance included manning's N at pervious and impervious areas and depression storage for both pervious and impervious areas. Values changed all stayed within normal ranges suggested by James *et al.* (2010). At each site, six to eight observed discharge and concentration measurements taken over the course of single events were used to calculate TP and TSS loadings and compared to simulated flow and load with the Nash – Sutcliffe efficiency index (NSE) and the coefficient of determination (R^2). Nash – Sutcliffe efficiency index and R^2 values close to zero indicate a poor or unacceptable model while values close to 1.0 represent more accurate predictions (Santhi *et al.,* 2001). Nash – Sutcliffe efficiency values greater than 0.5 and R^2 values greater than 0.6 indicate a satisfactory or acceptable model (Ramanarayanan *et al.,* 1997).

After the calibration was completed, the model of each separated sewershed was validated against multiple discharge and loading measurements taken during other hydrometeorologic events in the 2012 sampling year (1 January 2012 to 31 December 2012). Observed flow, and calculated TP and TSS loads from taken from six to 15 dates, depending on site, were compared against the model-predicted flows and loadings at the same time as sample collection. Coefficients of determinations were used to assess model accuracy.

Low Impact Developments (LIDs)

Low impact developments (LIDs) were used in PCSWMM to determine the percent reduction of maximum flow (m^3/s), average flow (m^3/s), total flow (m^3), TP load (kg), and TSS load. Outfalls from five sewersheds of various drainage sizes, land uses, average nutrient concentrations, and from various groupings determined by the cluster analysis were selected for LID analysis. Management scenarios included porous pavement, bio-retention cells, infiltration trenches, vegetative swales, and rain barrels. The area impervious land in each subcatchment was calculated from subcatchment area and percent imperviousness, and the LIDs were applied to various percentages of that imperviousness area. Once the LIDs were applied to the model, the percent imperviousness values were changed in the subcatchments table to account for the reduction of impervious area due to implementation of the management practices (James *et al.,* 2010).

Default values for the characteristics of LIDs in the LID-control editor were changed to average values found in literature (James *et al.,* 2010). Porous pavement was applied in 25-m^2 units to 25, 50 and 75% of impervious areas in each subcatchment. Bio-retention cells, infiltration trenches, and vegetative swales were set in 25-m^2 units to account for 10 and 20% of the impervious area of each subcatchment. Rain barrels with a 1- m^2 diameter were applied to each subcatchment draining to the outfalls of interest to cover 0.5% of the subcatchment area treating 10 and 20% of impervious area.

The time period of 23 October 2012 through 30 October 2012 was used to analyze for effectiveness of the LIDs. The week was chosen due to the high amount of rain that fell within that week. A base-model simulation was run for the one-week period to determine outfall discharge and loadings with no management practices. Simulations were then run for each individual low impact development, and outfall discharge and loadings were compared to the results from the base model.

Results

The Genesee River and New York State Barge Canal

During the navigation season (28 April to 15 November 2012) the New York State Barge Canal flows east and intersects the Genesee River. The NYS Barge Canal continues flowing east of the Genesee River after the intersection, and the Genesee River continues north after the canal/river intersection. Outside of the navigation season (1 January to 28 April 2012 and 15 November to 31 December 2012) the New York State Barge Canal is drained and gates upstream (approximately 650 m) and downstream (approximately 730 m) of the Genesee River are closed, allowing the river to flow through the intersection uninterrupted.

There were three sites that were sampled along the Genesee River at Ballantyne Road, University of Rochester (U of R), and Ford Street (Fig. 2). Statistical analyses of water chemistry data determined the influence of the canal on concentration at each site. During the time the canal was closed, there were no significant differences in mean concentrations of TP, SRP, TN, TSS, and total coliform bacteria between the Genesee River sites upstream (Ballantyne Road) and the sites downstream of the New York State Barge Canal (U of R and Ford Street) (Table 4). Significant differences in dissolved sodium concentrations were found among the three sites along the Genesee River (Table 4). The upstream Ballantyne Road site and downstream Ford Street site had significantly lower dissolved sodium concentrations (26.7 mg Na/L and 32.1 mg Na/L, respectively) than the U of R site (50.3 mg Na/L), which was in between the other two sites (Table 4).

After the New York State Barge Canal was opened on 28 April 2012 for the navigation season, there were no significant differences (Table 4) in mean concentrations of TP, SRP, TN, nitrate, dissolved sodium, and total coliform bacteria among sites located at Ballantyne Road, U of R, and Ford Street (Fig. 5). The mean concentrations of SRP, TN, nitrate, dissolved sodium, and TSS among all three (Ballantyne Road, U of R, and Ford Street) sites during the navigation season were significantly lower than the mean concentrations from the three sites along Genesee River during the non-navigation season; however, average total coliform bacteria concentrations in the Genesee River were statistically greater in the navigation season when compared to the non-navigation season (Fig. 5).

From 28 April to 15 November 2012 when the New York State Barge Canal was open, dissolved sodium, TSS, and total coliforms concentrations in the canal were significantly higher at the site downstream (Canal East) than at the upstream site (Canal West) of the intersection with the Genesee River (Table 5). Although not necessarily significant statistically, average concentrations of TP, SRP, TN, and nitrate were greater at Canal West than at Canal East; TSS, dissolved sodium, and total coliform bacteria were greater at Canal East than at Canal West (Table 5).

Total phosphorus, SRP, TN, nitrate, dissolved sodium, and TSS loads were statistically different at Canal West than at Canal East (Table 5). From the upstream (Canal West) site to the downstream (Canal East) site there were decreases in TP (60%), SRP (76%), TN (66%), nitrate (66%), dissolved sodium (30%), and TSS

(40%) loads, and discharge (59%) (Fig. 6). There was no significant difference in total coliform load between the upstream and downstream site (Table 5).

Depth profiles of conductivity (µS/cm) and temperature (°C) were measured at four sites surrounding the intersection of the Genesee River and New York State Barge Canal (Fig. 4). Conductivity at Canal West (upstream of the intersection) and River North (downstream of the intersection) sites was lower (Canal West – 502.6 µS/cm, River North – 533.1 µS/cm) than at Canal East (downstream of the intersection) and River South (upstream of the intersection) sites (Canal East – 558.3 µS/cm, River South – 621.2µS/cm) on 6 June 2012 (Table 6). Also, at depths of 0.5 and 1.0 m, the conductivity of the canal after the intersection with the river was lower than the conductivity of the canal water prior to the intersection, and the conductivity of the river water north of the intersection was lower than the river water south of the intersection (Table 6). Similarly, conductivity on 18 July 2012 at the shallower surface waters (0.0-m and 0.5-m depth) was greater at the Genesee River, upstream of the intersection (River South) (0.0-m depth – 781.3 µS/cm, 0.5-m depth – 781.9 µS/cm), and at the site along the New York State Barge Canal downstream of the intersection, Canal East (0.0-m depth – 495.9 µS/cm, 0.5-m depth – 507.3 µS/cm), when compared to the River North site (0.0-m depth – 489.5 µS/cm, 0.5-m depth – 497.3 µS/cm) and Canal West (0.0-m depth – 409.8 µS/cm, 0.5-m depth – 410.0 µS/cm) (Table 7).

Separate Storm Sewers

A cluster analysis (IBMSPSS software) was performed on the nine separate storm sewers for average event and average nonevent concentrations of TP, SRP, TN, nitrate, dissolved sodium, TSS, and total coliform bacteria. The cluster analysis indicated natural groupings among the sites, and from the dendogram five clusters were defined from the analysis (Fig. 7).

Cluster 1 represented the event and nonevent conditions at the site located on Maplehurst Road (Fig. 7). The Maplehurst Road sewershed drains a primarily suburban residential neighborhood east of the Genesee River (Fig. 2). There are known cross-connections between the separate storm sewer network and the sanitary sewer network (Personal communication: A. Sansone, Monroe County Environmental Services). The event and nonevent conditions at Maplehurst Road had the highest nutrient levels (TP, SRP, TN, and nitrate) compared to all other sites (Table 8). For example, nonevent nitrate concentration (4.0 mg N/L) at the Maplehurst Road site was statistically higher than the nonevent nitrate concentration at all other sampled storm sewer sites (Table 8).

Cluster 2 was formed from the nonevent conditions at the sites on Chapel Hill Drive, Merrill Street, and St. Paul Street and event conditions at the St. Paul Street site (Fig. 7). The site at Chapel Hill Drive is located on the east side of the Genesee River in the Town of Irondequoit and drains a sewershed with primarily residential land use (Fig. 2). The site at Merrill Street is west of the Genesee River and drains a large sewershed, approximately 10 km^2, of mixed land use including residential, commercial, and industrial areas (Fig. 2), while the St. Paul Street site drains a sewershed located east of the Genesee River of approximately 2.5 km^2 and of primarily residential and commercial land uses (Fig. 2). The cluster containing event conditions at St. Paul Street and nonevent conditions at St. Paul Street, Chapel Hill Drive, and Merrill Street differed from the other sites by the generally low TSS concentrations (Table 9). Average TSS concentration at all of the clusters with the exception of cluster 2 was 36.7 mg/L, and cluster 2 had an average TSS concentration of 10.4 mg/L. While not significantly lower from all other sites, the lowest event TSS concentration of all sites was at St. Paul Street (6.0 mg/L) (Table 8).

The event conditions at the site on Elmwood Avenue and the nonevent conditions at Elmwood Avenue and Kendrick Road formed cluster 3 in the cluster analysis (Fig. 7). The sites at Kendrick Road and Elmwood Avenue drain the same sewershed located at the northeast corner of the intersection of the Genesee River and New York State Barge Canal (Fig. 2), which is an area of mixed land use including a section of the University of Rochester, residential areas, and commercial areas (personal communication: A. Sansone, Monroe County Environmental Services). The nonevent conditions at Kendrick Road and Elmwood Avenue and the event conditions at Elmwood Avenue differed from other sites and conditions by the high dissolved sodium concentrations (Table 9). For example, the nonevent dissolved sodium concentration at Elmwood Avenue was 822.1 mg Na/L and 724.6 mg Na/L at Kendrick Road, which were statistically greater than nonevent concentrations at every other sampled storm sewer site (Table 8).

Cluster 4 was formed by nonevent conditions at the sites on Court Street and Beaconview Court and by event conditions at six of the nine sampled storm sewer sites: Beaconview Court, Chapel Hill Drive, Merrill Street, Kendrick Road, Court Street, and Scottsville Road (Fig. 7). Wide ranges of TP, SRP, TN, nitrate, dissolved sodium, and TSS were found in all sites in the cluster, but there were no extreme high or low values when compared to other clusters (Table 9). Total coliform bacteria concentrations in this cluster were high compared to other clusters; cluster 4 had an average total coliform bacteria concentration of 5.8E4 CFU/100 mL, and the average total coliform bacteria of all other clusters was 3.0E4 CFU/100 mL (Table 9).

Cluster 5 defined by the dendogram contained only the nonevent conditions at the Scottsville Road site (Fig. 7). While not statistically different from all other sites, the site had a high average nonevent TN (5.3 mg N/L) concentration but the lowest concentrations in TP (34.5 µg P/L) and SRP (4.5 µg P/L) when compared to other nonevent sites (Table 9).

Event versus Nonevent

During nonevent conditions, concentrations of total nitrogen (except St. Paul Street), nitrate (except Court Street and St. Paul Street), and dissolved sodium (except Beaconview Court) were generally higher and often significantly higher than event concentrations (Table 10). Concentrations of total coliform bacteria were higher during event conditions than during nonevent conditions for all storm sewer sites and statistically higher for all sites except Court Street and Beaconview Court (Table 10).

Concentrations of TP, SRP, and TSS did not have overwhelming trends between event and nonevent conditions (Table 10).

Seasonal Trends

While some water quality constituents had strong seasonal trends across the storm sewer sites, others had statistical differences at one or two sites, and some had no seasonal trends. There was a strong trend in monthly dissolved sodium concentrations among the storm sewer sites (Fig. 8). Dissolved sodium was greater in the winter months of January, February, and March and lowest during the summer and fall months at all of the sampled storm sewer sites, and significant differences were found at sites located on Kendrick Road (ANOVA, p=0.000), Elmwood Avenue (ANOVA, p=0.000), Scottsville Road (ANOVA, p=0.000), Court Street (ANOVA, p=0.009), Maplehurst Road (ANOVA, p=0.003), and Merrill Street (ANOVA, p=0.000) (Fig. 8).

Total coliform bacteria concentrations had a strong seasonal trend with the greatest concentrations found in the spring and summer months and lower concentrations during the winter months (Fig. 9). Sites at Kendrick Road (ANOVA, p=0.028), Elmwood Avenue (ANOVA, p=0.000), Scottsville Road (ANOVA, p=0.022), and Merrill Street (ANOVA, p=0.015) had statistical differences in their average monthly total coliform concentration (Fig. 9).

There were statistical differences in average monthly TN concentrations at Elmwood Avenue (ANOVA, p=0.002), Scottsville Road (ANOVA, p=0.000), Court Street (ANOVA, p=0.001), and Merrill Street (ANOVA, p=0.004) (Fig.10). While there were statistical differences in these sites, there were no general trends seen across the majority of the sites (Fig. 10). Monthly nitrate concentrations statistically differed at sites on Elmwood Avenue (ANOVA, $p=0.006$) and Merrill Street (ANOVA, $p=0.001$). Both sites exhibited a sinusoidal relationship in average monthly nitrate concentration from January to December. A similar trend was seen at the site on St. Paul Street where there were higher nitrate concentrations during the winter months and lower concentrations in August, September, and November (Fig. 11).

Total suspended solids had statistical differences in monthly concentrations at only two sites (Fig. 12). The site at Scottsville Road (ANOVA, $p=0.000$) had statistically higher TSS concentrations in September when compared to every other month, and at Court Street (ANOVA, $p=0.001$) November TSS had the greatest concentration. There were no seasonal trends seen at the storm sewer sites for monthly concentrations of TP (Fig. 13) and SRP (Fig. 14).

Rating Curves

Rating curves were developed for storm sewer sites at Scottsville Road, Kendrick Road, Elmwood Avenue, Court Street, Maplehurst Road, Merrill Street, Chapel Hill Drive, and Beaconview Court (Fig. 15). The rating curve at Elmwood Avenue is different from other curves as height was measured from the top of the pipe/outfall and depth calculated by subtraction from the total height of the pipe (Fig. 15). The relationship between discharge and water depth was strong at all the sites with R^2 values ranging from 0.72 to 0.98 (Fig. 15).

Time Series

Each storm sewer site was sampled periodically over the course of a precipitation event for water quality and water quantity. Event mean concentration (EMC) was calculated for total TP and TSS. Event mean concentrations of TP ranged from 23.9 µg P/L at St. Paul Street to 1,078.2 µg P/L at Kendrick Road (Table 11), and TSS concentrations ranged from 4.4 mg/L at the site on St. Paul Street to 330.7 mg/L at the Kendrick Road site (Table 11). Average discharge during the time series was highly variable with the lowest average discharge at the site on Beaconview Court (1.57E-4 m^3/s) and the greatest average discharge at the outfall on Merrill Street (1.15 m^3/s) (Table 11).

Total phosphorus was compared to discharge during the time series at each site (Fig. 16). There were strong relationships between TP load and discharge at all the sites with R^2 values between 0.94 and 0.99 (Fig. 17). Total suspended solids also had a strong relationship with discharge for the time series done at each site with a minimum $R^2=0.62$ and maximum $R^2=0.98$.

PCSWMM Results

Calibration and Validation

Discharge measurements and calculated TP and TSS loads from single hydrometeorologic events were used to calibrate the model, ROCSWMM, at each of the nine storm sewer sites. Flow calibrations were in the acceptable range for R^2 (range=0.69 to 0.99) and for the NSE (range= 0.67 and 0.99, Table 12) (Ramanarayanan *et al.*, 1997) (Table 12). Total phosphorus loads calibration values ranged from 0.65 to 0.98 for R^2 and 0.60 and 0.96 for NSE, and TSS loads calibration values ranged from 0.60 to 0.98 for R^2 and from 0.55 to 0.97 for the NSE (Table 12). ROCSWMM models of the nine sewersheds were validated during periods of elevated flow in 2012. Coefficients of determinations (R^2) ranged between 0.80 and 1.00 for flow, between 0.73 and 0.99 for TP, and between 0.67 and 0.99 for TSS loads (Table 13).

Discharge and Loadings

The total predicted flow, TP loads, and TSS loads for the 2012 year from the storm network that drains stormwater from the City of Rochester and surrounding areas to the Genesee River were approximately 19,200,000 m^3, 2,300 kg P, and 626,000 kg, respectively (Table 14). The total loads and flows are the sum of water and pollutants from the outfalls that drain the seven main sewersheds and from a few additional small drainage areas comprising the storm network that drains stormwater from the City of Rochester and surrounding areas to the Genesee River (Fig. 3).

The Merrill sewershed (Fig. 3), the largest sewershed (1,952 ha), discharged over 11,000,000 m^3 of stormwater to the Genesee River in 2012 and accounted for 59% of the volume discharged by the entire “separated” storm sewer system (Table 15). Within the Merrill sewershed, there are 12 outfalls that drain to the Genesee River (Appendix B). Outfall 18 (OF18) is one of the outfalls in the Merrill Sewershed (Fig. 3). Outfall 18 (OF18) alone accounts for 52% of the total flow from the “separated” storm sewer system (Appendix B). The Irondequoit sewershed is the second largest sewershed (684 ha) and had the second greatest volume of water

(2,659,179 m^3) discharged of all the sewersheds (Table 15). There were five drainage areas that were not listed as sewersheds due to their small size totaling only 29 ha. These drainage areas provided only one percent (210,000 m^3) of water to the Genesee River in 2012 (Table 15).

Average areal flow for all the sewersheds within the storm sewer network was 7,506 m^3/ha. The range of areal flows was 3,883 m^3/ha in the Irondequoit sewershed to 11,826 m^3/ha at the Merrill sewershed (Appendix B). A strong correlation existed between average percent imperviousness of a sewershed and the areal flow of that sewershed ($R^2=0.94$) if the Merrill sewershed is not included (Fig. 18). Addition of the Merrill sewershed reduces $R^2=0.94$ to $R^2=0.25$. Outfall 18 (OF18) within the Merrill sewershed had a high baseflow, which increased total discharge volume without increasing average percent imperviousness and causing the deviation from the relationship between areal flow and imperviousness seen in the other sewersheds.

Similar to stormwater flow, the Merrill sewershed, drained by 12 outfalls, contributed 42% of the TP load (966 kg) entering the Genesee River from the "separated" storm sewer network (Table 16). A single outfall in the Merrill sewershed (Outfall 18 - OF18) contributed 52% of the total flow and also accounted for 27% of the TP load (793 kg) to the Genesee River (Appendix C). The Irondequoit sewershed contributed 21% (480 kg P) of the overall TP load from the storm sewer system (Table 16) while approximately 15% of the TP load to the Genesee River was contributed from the KenElm sewershed even though that sewershed only contributed only 4% of the total volume (684,151 m^3) (Tables 15 and 16). The St. Paul sewershed added 36 kg P to the total load, only 2% of the total (Table 16).

Trends in areal loads of phosphorus (g/ha) differed from areal discharge (m^3/ha) (Appendix C). The KenElm sewershed (Fig. 3) had the greatest areal load with over 1,800 g P/ha and the St. Paul sewershed (Fig. 3) had the lowest areal loads, only 145 g/ha (Appendix C). The average areal TP load from all the sewersheds was 988 g P/ha.

Over half of the entire TSS load was accounted for by the Merrill (29% of total) and KenElm (24% of total) sewersheds (Table 17). The St. Paul sewershed had the lowest TSS load of all the sewersheds with only 6,611 kg contributed to the total of 625,694 kg (Table 17). The KenElm sewershed also had the highest areal TSS load with approximately 800,000 g/ha (Appendix D). The next highest areal load was at the Court sewershed with 572,000 g/ha, and average areal loads from separate storm sewer network was 326,000 g/ha (Appendix D).

Effectiveness of Low Impact Developments (LIDs)

Five LID practices were simulated to determine the effectiveness of decreasing flow, TP, and TSS loads to the Genesee River from the “separated” storm sewer network. During a period of approximately 50 mm of precipitation, simulations without any LIDs determined reference values for total flow (m^3), TP load (kg), and TSS load (kg) for the week of 23 October 2012 through 30 October 2012. The LIDs (porous pavement, bio-retention cells, infiltration trenches, vegetative swales, and rain barrels) were applied and simulated in the drainage areas of five outfalls:

Scottsville, Elmwood, Court, Merrill, and Beaconview (Fig. 2). The sites were chosen because they were of varying size, land use and pollutant loads and represented sites in three of the five clusters from the cluster analysis performed on concentrations storm water pollutants (Fig. 7).

As the impervious area treated by porous pavement increased, reductions in total flow from the sewersheds of six to 44 percent were observed (Table 18). Percent reductions in TP and TSS loads were also observed with an increase in porous pavement (increase in pervious area). For example, TP reductions ranged from eight to 45 percent and TSS reductions from ten to 47 percent (Table 18). When equal amounts of impervious area were converted to porous pavement, reductions in flow were greatest at the Court site (Table 18). Total phosphorus reductions due to porous pavement were greatest at Scottsville, Court, and Elmwood sites with reductions in the 37 to 45 percent range while sites at Merrill and Beaconview TP load reductions between 25 and 30 percent were observed (Table 18). Total suspended solid reductions were also high at Court and Elmwood sites (44 and 47 percent reductions, respectively) while Scottsville, Merrill, and Beaconview had reductions in TSS load in the 30 percent range (Table 18).

Bio-retention cells and infiltration trenches had similar percent reductions at each site for total flow and TP and TSS load. Treating ten percent of the impervious area to bio-retention cells and infiltration trenches resulted in reductions from two to seven percent, four to seven percent, and three to seven percent for flow and TP and TSS loading (Table 18). The Court Street site had the greatest percent reductions in flow and TP and TSS loads from bio-retention cells and infiltration trenches, with seven percent reductions when ten percent of impervious area was converted to LIDs (Table 18). Treating 20% of impervious area to bio-retention cells and infiltration trenches further decreased stormwater flows and TP and TSS loads. Flows and TP loads were reduced up to 12% and TSS loads were reduced by up to 13% (Table 18). The site at Court had the greatest percent reductions in flow and TP load, while the Elmwood site had the greatest TSS load reduction (13%) due to bio-retention cells and infiltration trenches.

Vegetative swales consistently produced the smallest reductions in flow and TP and TSS loads of all simulated LIDs. Increasing the percent impervious area treated by vegetative swales from ten to 20 percent did not always increase percent reductions in flow and loads. Converting ten percent of impervious area to vegetative swales only produced flow, TP load, and TSS load reductions ranging from zero to two percent (Table 18). With an increase to 20% impervious area treated by swales, flow and TSS load reductions increased to reductions from zero to four percent, and TP reductions ranged from zero to three percent (Table 18). The site at Elmwood had no reductions in flow volume and TP and TSS load when vegetative swales were simulated (Table 18).

Rain barrels were used to capture runoff from impervious areas such as roofs. Simulations were run where runoff from ten and 20 percent of the impervious area of a sewershed was captured by rain barrels. Increasing the impervious runoff treated decreases flow volume and TP and TSS loads at all the sites. Rain barrels had a larger effect on flow and load reductions than bio-retention cells, infiltration trenches, and vegetative swales (Table 18). Capturing runoff from ten percent of the impervious surface area in a sewershed resulted in reductions by three to eight percent, four to eight percent, and five to eight percent, for flow and TP and TSS loads (Table 18). As expected, flow from a sewershed decreased three to 14 percent when runoff from 20 percent of impervious surface area was captured by rain barrels (Table 18). Of all the simulations with rain barrels as an LID, the site at Merrill was least impacted by the LID. When runoff from 20 percent of impervious surface area was captured, flow decreased by only three percent compared to the site with no LID, while the site at Court Street had 14 percent reduction in stormwater flow with rain barrel application to treat 20% of impervious surface area (Table 18).

Kodak King's Landing Wastewater Treatment Plant

Kodak King's Landing Wastewater Treatment Plant discharges into the lower Genesee River 8 km upstream of the mouth of where the Genesee River discharges into Lake Ontario (Fig. 2). Average daily discharge from January 2012 to December 2012 was approximately 42,800 m^3 (11.3 million gallons) (personal communication: M. Bishopp, Eastman Kodak Company). The average daily load of TSS ranged from 224 kg/d to 499 kg/d with an annual TSS load of 4,240 kg entering the Genesee River (Table 19). Total Kjeldahl nitrogen (TKN) had average daily loads ranging from 113 kg TKN/d to 213 kg TKN/d with an annual load of 1,825 kg TKN (Table 19) while nitrate (NO_3) and nitrite (NO_2) had average daily loads ranging from 183 kg NO_3/d to 1,586 kg NO_3/d and 7 kg NO_2/d to 99 kg NO_2/d and annual loads of 8480 kg NO_3 and

451 kg NO_2 (Table 19). Total phosphorus average daily loads were between 8 and 26 kg P/d with an annual load of 200 kg P entering the Genesee River (Table 19).

Combined Sewer Overflows (CSOs)

From 1 January 2012 to 31 December 2012, there were four events that resulted in overflows from the combined sewer network with an estimated total discharge of 876,323 m^3 (231.5 million gallons), with 810,457 m^3 (214.1 million gallons) of it overflowing into the Genesee River (Table 20). Total phosphorus concentrations taken from grab samples of the CSO during the event on 5 August 2012 ranged from 0.437 mg/L to 2.2 mg/L, and grab samples from the event on 4 September 2012 ranged from 0.727 mg/L to 4.18 mg/L (Table 20). Total suspended solid concentrations ranged from 180 mg/L to 580 mg/L and 156 mg/L to 810 mg/L at CSOs that occurred on 5 August 2012 and 4 September 2012, respectively (Table 20). *Escherichia coli* levels in the CSOs were extremely high, up to 241,960 MPN/100 mL during the 5 August 2012 event and 483,920 MPN/100 mL during the event on 4 September 2012 (Table 20). There were high loads of TP and TSS from overflow events that occurred on 5 August and 4 September 2012 (Table 20). During the 5 August 2012 overflow, 147 kg of phosphorus and 50,914 kg of TSS were discharged into the Genesee River, and during the 4 September 2012 overflow, 1,387 kg phosphorus and 304,958 kg of TSS entered the Genesee River and Irondequoit Bay (Table 20).

Discussion

An assessment of the lower Genesee River (from Ballantyne Road to the mouth of the Genesee River) was initiated to determine impacts from the New York State Barge Canal, “separated” storm sewers, and major point sources such as combined storm sewers and the Kodak King’s Landing Wastewater Treatment Plant (WWTP) on the water quality of the Genesee River. An integrated approach combining water sampling, data collection, and modeling (PCSWMM – Storm Water Management Model) was employed. Weekly samples and discharge measurements were collected at nine separate storm sewers, at three points along the Genesee River (one below and two above the intersection of the Genesee River and New York State Barge Canal), and at two sites along the New York State Barge Canal (above and below the intersection of the Genesee River and New York State Barge Canal) for the period of one year (17 January 2012 – 15 January 2013).

Genesee River and New York State Barge Canal Interaction

The interaction between the Genesee River and the New York State Barge Canal at their intersection is complex; however, through routine monitoring of both the river and the canal it is apparent that they have an effect on each other. Previous work has suggested that water from the canal west of the canal/river intersection discharges into and joins the Genesee River as it flows north to Lake Ontario while a small amount of water from the Genesee River south of the intersection enters the eastern continuation of the canal (Fig. 4) (Hayhurst *et al.,* 2010). My data provides qualitative and quantitative support for this hypothesis.

An aerial photograph (Fig. 19) taken on 8 October 2003 of the intersection of the Genesee River and New York State Barge Canal provides visual evidence of an exchange of water between the two waterways. In the photograph, the turbid surface water from the Genesee River flows east into the New York State Barge Canal, and the clearer surface water from the canal west of the intersection flows north and continues into the Genesee River.

Temperature and conductivity data also support the hypothesis that the water from the Genesee River is entering the “Canal East” portion of the New York State Barge Canal, and water from “Canal West” is flowing downstream into the Genesee River (Fig. 4). The lower conductivity, warmer water of the canal site upstream of the intersection flows into the Genesee River north of the intersection, decreasing the conductivity at the surface waters of the river (Tables 6 and 7). Conductivity in the Genesee River decreased by 90 µS/cm on 6 June 2012 and by 290 µS/cm on 18 July 2012 between the sites upstream of its intersection with the canal and downstream of the intersection, while conductivity of the surface water of the New York State Barge Canal increased by 55.7 µS/cm on 6 June 2012 and by 86.1 µS/cm on 18 July 2012 between the sites upstream and downstream of the intersection with the river (Tables 6 and 7). The lower conductivity water of the New York State Barge Canal flows north into the Genesee River decreasing the conductivity of the surface waters while the higher conductivity water of the Genesee River south of the intersection flows east into the canal increasing the conductivity of the surface water.

While no significant differences were found in TSS or TP concentrations between the three sites along the Genesee River during the 2012 navigation season, TSS from the 2010 navigation season were routinely higher at the Ballantyne Road (upstream) Genesee River site when compared to the mouth of the Genesee River at Charlotte, with one exception on 5 October 2010 (Fig. 20). Similar to TSS during the navigation season, TP concentrations were generally greater at the upstream site at Ballantyne Road when compared to the site at Charlotte. When the canal was isolated from the Genesee River by seasonal dams during the non-navigation season, there was no significant difference in TP concentrations at the Genesee River upstream (Ballantyne Road) site and at the Genesee River downstream sites (U of R and Charlotte) (Fig. 21) (R^2=0.91). The TP and TSS differences between the Genesee River sites during and not during the navigation season indicates that TP and TSS are being transported somewhere other than downstream site in the river during the navigation period. At the New York State Barge Canal, TSS concentrations were statistically higher in the downstream (Canal East) site than at the upstream (Canal West) site (Table 5). The difference in TP and TSS concentrations (TP: average difference=112 µg/L, range=-82 µg/L to 781 µg/L, TSS: average difference=92.5 mg/L, range=-53.7 mg/L to 576 mg/L) between the upstream (Ballantyne Road) and at the downstream (Charlotte) Genesee River sites during the navigation season and not during the navigation season, combined with statistically higher TSS concentrations at the canal site downstream (Canal East) of the intersection when compared to the upstream (Canal West) site (Table 5), support the hypothesis that water from the Genesee River is flowing east into New York State Barge Canal at the intersection of the two waterways.

The higher nutrient and sediment (TSS) load of Canal East than Canal West can be attributed to the differences in discharge between the two sites (Table 5). The average discharge of the canal at the site upstream (Canal West) of the intersection of the NYS Barge Canal and Genesee River was statistically greater than and almost double the average discharge of the canal downstream (Canal East) of the intersection (Table 5). This difference in discharge greatly affected the loadings at each site. While there were significant differences in dissolved sodium, TSS, and total coliform bacteria concentrations between the upstream and downstream site, the loadings of TP, SRP, TN, nitrate, dissolved sodium, TSS, and total coliform bacteria were all significantly greater at the site upstream (Canal West) of the intersection compared to the site downstream (Canal East) (Table 5). The intersection is an area of mixing where the flow of the canal is disrupted, which may explain the lower velocities and subsequent lower loadings at the downstream site (Canal East).

Total phosphorus and TSS loads in the Genesee River support the hypothesis of the exchange of water between the Genesee River and New York State Barge Canal. In the spring and summer, when the canal is open to navigation as the seasonal dams are removed, TP and TSS loads were much greater at the upstream (Ballantyne) Genesee River site (TP=285,725 kg P, TSS=239,817,880 kg) than the downstream Genesee River site (Charlotte) (TP=257,633 kg P, TSS=208,704,724 kg) (Makarewicz *et al.*, 2013) (Table 21). During the navigation season (spring and summer), the TSS load was 17,798,154 kg greater at the upstream (Ballantyne) site than the downstream (Charlotte) site but only 1,989,643 kg greater at the upstream (Ballantyne) site than the downstream (Charlotte) site in the fall and winter, when the canal was isolated from the river (Makarewicz *et al*., 2013) (Table 21). Total phosphorus loads were higher at the downstream (Charlotte) Genesee River site (199,938 kg P) compared to the upstream (Ballantyne) site (167,220 kg) outside of the navigation season (Makarewicz *et al*., 2013) (Table 21).

Grab samples, conductivity measurements, TP and TSS concentrations, pollutant load data, and aerial photography each provide evidence for the idea that there is a transfer of water between the Genesee River and New York State Barge Canal. While these data suggest the transfer of water between the two bodies they do not answer how much water from the Genesee River is diverted into the canal and vice versa. The difference in P and TSS load in the navigation compared to non-navigation period when the canal is isolated from the Genesee River suggests there may be major exchanges between the two bodies of water.

"Separated" Storm Sewers

Average event concentrations of TP and TSS from the monitored separate storm sewers were similar to literature values. Total phosphorus concentrations from monitored Rochester storm sewer sites ranged from 70.0 µg P/L to 264.6 µg P/L (Table 10), which were below the mean and median values of TP concentrations of 600 µg P/L and 400 µg P/L, respectively, but within the range of 30 µg P/L and 3,000 µg P/L observed in urban watersheds (Lee *et al*., 2010). Total suspended solid concentrations in monitored sites ranged from 6.7 mg/L to 53.5 mg/L (Table 10), which were below the mean event TSS concentrations (83.5 mg/L) found in an urban environment by Lee *et al.* (2010) but near the mean of 20 mg/L from the same study (Lee *et al.*, 2010).

Event mean concentrations calculated from individual storm events at each site had values consistent with literature values. The Environmental Protection Agency's (EPA) Nationwide Urban Runoff Program (NURP) reported TP EMCs ranging from approximately 100 µg P/L to 875 µg P/L for residential, commercial, and industrial land uses (USEPA, 1983) with median values for residential land use, mixed land use, and commercial land use of 383 µg P/L, 263 µg P/L, and 201 µg P/L, respectively (USEPA, 1983). All of the EMCs from monitored sites were within this range and near the median values with the exception of the sites at Kendrick Road, which had a TP EMC greater than the literature range, and St. Paul Street, which had TP EMC less than the range found in the EPA NURP study (Table 11). Average TP values at the Kendrick outfall were similar to those at the other storm sewer outfalls. The St. Paul outfall drains a very small area and had consistently lower TP concentrations (Table 8), but the high TP EMC at the Kendrick Road site is due to one extreme high value taken during the time series (Fig.16). Total suspended solid EMCs for the monitored separate storm sewer sites followed the same trend as TP EMCs. All monitored sites with the exception of the site at Kendrick Road, which was higher than the literature range, and St. Paul Street site, which was lower than the literature range, had EMCs that fell within the range found by the EPA NURP (approximately 15 mg/L to 300 mg/L) for residential, commercial, and industrial land uses (USEPA, 1983).

The cluster analysis performed in this study grouped the nine sampled storm sewers into five clusters. Sites at Maplehurst Road and nonevent samples from Scottsville Road each were in a cluster alone (Fig. 7). These sites have very specific characteristics that are not shared by any other storm sewer site sampled in this study. The site at Maplehurst Road has known cross-connections with the sanitary sewer network (personal communication: A. Sansone, Monroe County Environmental Services), which is the likely the cause of the statistically higher concentrations of nutrients (TP, SRP, TN, and nitrate) compared to other sites (Table 8). The sewershed at Scottsville Road drains an area that surrounds the Greater Rochester International Airport, a land-use not found at the other sampled storm sewer sites, and thus is chemically differentiated from the other sites by the cluster analysis. The largest cluster included eight sites, six of which were sites monitored during events (Fig. 7). The sites in that large cluster had land-uses ranging from suburban residential, to urban residential, to commercial, but most were a combination of at least two land-uses. The Elmwood and Kendrick sites also grouped together, which was expected since these two sites drain the same sewershed and both are surrounded by residential land-use and the University of Rochester (Fig. 2). The cluster analysis allows us to group sites that drain similar land-use and under similar conditions together. The sites that were alone in a cluster were sites that had considerable differences in drainage area or cross-connections in the case of the Maplehurst Road site (Fig. 7).

PCSWMM

The total rainfall in 2012 was 77.6 cm, which was less than the average total rainfall from 2002 to 2011 of 90.8 cm (National Climatic Data Center NCDC, www.ncdc.noaa.gov). The flow and loading results produced from these simulations were only applicable to the 2012 year, but the model could be used to predict future loads and flows from annual precipitation data.

There were 45 storm sewer outfalls that drained the “separated” storm sewer network to the Genesee River in the ROCSWMM model. Subcatchment and sewer network characteristics can vary significantly among sewersheds. Developing a model utilizing site-specific inputs, as done with the nine ROCSWMM sewer models, provided a higher degree of confidence in model simulations (Tsihrintzis and Hamid, 1998). For the 36 storm sewer outfalls, where site-specific input values were not available, models calibrated at similar sites can be used for area-specific parameters (Tsihrintzis and Hamid, 1998). Here I used cluster analysis to identify via water quality data sewersheds that behaved similarly and use the area-specific parameters from simulated areas in a cluster to simulate the entire City of Rochester storm sewer network in ROCSWMM. For example, storm sewer outfalls at Kendrick Road and Elmwood Avenue, and outfalls on Beaconview Court and Chapel Hill Drive were statistically clustered together (Fig. 7). Each of these pairs of sample sites drained the same sewersheds and areas of similar land use but to different outfalls within that sewershed. The fact that each of the pairs clustered together suggested using the same approach for other sewersheds provided confidence that parameters from the nine sampled storm sewer sites could be extrapolated to the storm sewer sites that were not sampled and used to build a model that would accurately represent the entire storm sewer network.

The calibration and validation of the ROCSWMM at the nine sampled storm sewer sites met the acceptable standards (e.g., Ramanarayanan *et al.* , 1997),. The Maplehurst Road simulation had the worst fit to the observed loads (Fig. 2). The Maplehurst Road sewershed has cross-connections with the sanitary sewer network (personal communication: A. Sansone, Monroe County Environmental Services), which makes it difficult to model compared to storm sewer sites that have only stormwater inputs. However, R^2 validation values were close to 1.0 R^2=0.84=flow, 0.73=TP, 0.75=TSS) indicating that the ROCSWMM accurately represents the storm sewer network at Maplehurst Road. The site at Kendrick Road had the strongest calibration and validation values with R^2 values ranging from 0.98 to 1.00 (Tables 12 and 13).

The ROCSWMM models were used to estimate annual (1 January 2012 to 31 December 2012) TP loads from the “separated” storm sewers. Annual predicted storm sewer flows and loads were small compared to the overall flow and load from the Genesee River. For example, the total annual flow from storm sewers is comparable to slightly more than two days of flow from the Genesee River (Table 22). Similarly, discharge from storm sewers is low relative to major tributaries

(Table 22). The discharge of Conesus Creek, a small creek (drainage area=239.8 km^2), is four times higher than from "separated" storm sewers (Table 22).

Similarly, TP and TSS loads from the "separated" storm sewers to the Genesee River were low compared to the TP and TSS loads found in the Genesee River and its tributaries. For example, the annual TP and TSS loads from the Rochester storm sewer network were 2,277 kg P and 625,694 kg, respectively, while loads in the Genesee River were 457,572 kg P and 383,182,294 kg for suspended solids (Makarewicz *et al.,* 2013) (Table 22). The TP load from the "separated" storm sewer network represents only 0.5 percent of the annual TP load from the Genesee River, and the TSS load from the storm sewer network is only 0.2 percent of the total load from the Genesee River.

Model Limitations

Rainfall

Rainfall is the driving force behind the Storm Water Management Model (SWMM), and the temporal and spatial variability of rainfall can have a large effect on accuracy of model calibration. Theissen polygons are one of the most common approaches for modeling the spatial distribution of rainfall. The approach defines the area closer to a rain gage than any alternative gage as best represented by the point measured by that rain gage. However, Theissen polygons have a large variability (-47 to 133 relative percent error) in rainfall intensity predictions (Ball and Luk, 1998).

I chose not to use the Theissen polygons to calculate precipitation as the results from of predicted versus flows from sewersheds were not good. For example, at the Chapel Hill sewershed the poor correlation between observed and predicted flow ($R^2 = 0.02$) (Fig. 22) produced a predicted flow of 0.16 m^3/s while observed flow on 26 July 2012 was 0.005 m^3/s. Similarly, on 5 August 2012 the predicted flow was 0.003 m^3/s while observed flow was 0.027 m^3/s. The problem was rainfall measurements were only at one location (Greater Rochester International Airport) that did not represent the entire sewershed.

I changed my approach and used NEXRAD radar instantaneous precipitation data for each subcatchment instead of a single rain gage for the entire study site. Correlation coefficients improved from R^2=0.02 to R^2= 0.75 at the Chapel Hill site and from R^2=0.52 to R^2=0.80 at the Elmwood site (Fig 22). The inconsistencies between observed and predicted flows, when a singular rain gage is used, are a result of spatial differences in rainfall between the sites and the single rain gage at the Greater Rochester International Airport. The site at Chapel Hill is approximately 11 km from the rain gage and the site at Elmwood is only 2.8 km from the gage. Without rain gages at each calibration site, the spatial variability of precipitation events, even at a short distance of less than three km, cannot be accounted for with enough detail to produce accurate calibrations at minute time steps.

Flow Errors

During calibration it was often found that there were inexplicable flow oscillations at some sites during dry weather periods and periods of very little rainfall. Due to numerical methods used for dynamic wave routing, which was used in ROCSWMM, there can be numerical instabilities in the solution method which is not identified by SWMM. It is up to the user to identify these errors and reduce numerical instabilities by reducing routing time steps, selecting to ignore inertial terms of the momentum equation, and/or selecting the option to lengthen short conduits (CHIwater, 2013a).

Kodak King's Landing Wastewater Treatment Plant

Known to be a source of pollution to the Genesee River, Kodak's King's Landing Wastewater Treatment Plant (WWTP) is located on the western side of the Genesee River approximately 6.5 km upstream from the mouth of the river at Lake Ontario. The King's Landing WWTP releases an average of 42,650 m^3/d of water to the Genesee River during the 2012 year. Highly toxic sediments are associated with WWTP discharge at King's Landing (NYSDEC, 2003). Average TSS concentrations from the WWTP (8.3 mg/L) were low in comparison to the TSS concentrations of the Genesee River (73.2 mg/L) (Makarewicz *et al*., 2013). Nevertheless, King's Landing contributed 129,029 kg of suspended solids in 2012, which is significant as it is released just above the area of marinas, the mouth of the Genesee River, and the nearby beaches at Charlotte, but small compared to the total TSS load of the Genesee River (380,000,000 kg; Table 22). While the discharge and TSS load from the King's Landing WWTP were relatively low compared to the flow and TSS concentration and load of the Genesee River, the concentrations of phosphorus were substantially greater in effluent discharge from the WWTP. Average TP concentration from discharge at Kodak King's Landing was 400 µg P/L, while average concentrations in the Genesee River were 96.7 µg P/L (Makarewicz *et al*., 2013). The annual load of

TP in the Genesee River at Charlotte from 1 August 2010 to 31 July 2011 was 457,572 kg (Makarewicz *et al.,* 2013) compared to the 6,106 kg P/yr load from the King's Landing WWTP. Although this represents roughly 1.3% of the TP load of the Genesee River, it is a large amount from a single point and its impact is likely high on the nearshore of Lake Ontario as the Genesee River plumes moves to the east and west depending on wind direction directly on the Charlotte and Durand Eastman beaches (Makarewicz *et al*., 2012).

Combined Sewer Overflows

Combined sewer overflows (CSOs), a known point source, have the potential to contaminate the lower Genesee River (NYSDEC, 2003). There were no dry weather overflows at combined sewer overflow relief points during 2012, but there were four precipitation events that lead to overflows discharging into the Genesee River (personal communication: A. Sansone, Monroe County Environmental Services). The combined sewer overflow at Control Structure 45 on 4 September 2012 resulted in an estimated discharge of over 400,000 m^3 of water, which was almost 5% of the daily discharge at the Charlotte site (9,387,805 m^3/d) (Makarewicz *et al.,* 2013). Concentrations of TP (727 µg P/L to 4,180 µg P/L), TSS (156 mg/L to 810 mg/L), and *E. coli* (282,720 MPN/100 mL to 483,920 MPN/100 mL) were very high compared to average TP (96.7 µg P/L), TSS (73.2 mg/L) and total coliform (5,153CFU/100 mL) observed in the Genesee River from 3 August 2010 to 23 August 2011 (Makarewicz *et al.,* 2013). While these discharges are rare, they do introduce an extremely large amount of pollutants to the Genesee River in close proximity to the mouth of the Genesee River and thus almost directly into the nearshore of Lake Ontario. An estimated total load of 1,534 kg of phosphorus and 355,872 kg of suspended solids entered the Genesee River from combined sewer overflows in 2012 (Tables 20 and 22). The load from just the two combined sewer overflows on 5 August 2012 and 4 September 2012 is more than 50 percent of the total load from the annual load from of the “separated” storm sewer network (Table 22).

Low Impact Development (LID) Reductions

Low impact development (LID) techniques are relatively new and pioneered in the early 1990s. In recent years research on individual techniques has increased (USEPA, 2000; Dietz, 2007). Low impact developments reduce the amount of Effective Impervious Area (EIA) in a watershed, or areas of imperviousness that are directly connected to the storm drain system, which contributes to increased watershed volume and runoff rate (USEPA, 2000). Basic principles of LIDs include conservation of natural features, minimization of impervious surfaces, hydraulic disconnects, disbursement of runoff, and phytoremediation (USEPA, 2000). Commonly studied LID practices include but are not limited to bio-retention areas, grass (vegetative) swales, permeable pavements, and vegetative roof tops (USEPA, 2000). According to design principles of LID the best subcatchments on which to implement LIDs have an impermeability greater than 80 percent (Liao *et al.,* 2013). No sewershed in my study had an 80% imperviousness area. The size of areas covered by LID practices has varied greatly in previous studies (9.3 to 15.2% of each subcatchment (Liao *et al.,* 2013); 5 to 7 of the drainage basin (USEPA, 2000); 10 to

20% of the impervious area (Dussaillant *et al.,* 2004)) in which effective reduction were realized. In my simulation, the Court Street sewershed (Fig. 3) was the closest with an average imperviousness of only 55.6 percent. Even so, the LIDs were applied to different sewersheds to determine what theoretical potential reductions were possible.

Depending on the sewershed, various LIDs had different effectiveness at reducing total flow and loads to the outfalls (Table 18). Vegetative swales did routinely produce the lowest percent reductions of all five of the LIDs. This result was echoed by the model produced by Liao *et al.* (2013) with vegetative, or green, swales having the smallest effect on peak flow and total volume reductions. While not observed in the ROCSWMM model, a common theme in implemented LIDs was that grass (vegetative) swales and bio-retention areas often resulted in an export of phosphorus due to the media used in the LID or from the fertilization of the media (Dietz, 2007).

Low impact developments are often combined within subcatchments to have an even greater effect on reducing stormwater runoff and pollutant loads. However, with the modeling approach used here for placing LIDs in the ROCSWMM model, LIDs cannot act in series and cannot have the outflow from one LID control become the inflow for another LID (James *et al.,* 2010). In practical applications, the outflow from rain barrels is often diverted as the inflow to a second LID, such as a bio-retention cell (Zheng *et al.,* 2006). Vegetative swales were found to reduce average runoff amounts by 30 percent in a study site in Tampa, Florida, but when swales were combined with pervious pavement, runoff was reduced by an additional 10 to 15 percent (Rushton, 2001).

Effectiveness of LIDs can also vary based on site characteristics. Rain barrels, which allow for temporary storage until stormwater can be repurposed for irrigation, produced some of the highest percent reductions in stormwater runoff and pollutant load (up to 14% reductions) in the ROCSWMM model (Table 18). Similar model-predicted results with rain barrels were reported by Liao *et al.* (2013), with rain barrels not only having the greatest impact on stormwater-runoff reduction but also being the most cost-effective approach (Liao *et al.,* 2013). While rain barrels are a cost-effective approach to reducing stormwater runoff at some sites, rain barrels may not be a cost-effective choice for sites that have large areas where bio-retention cells may be installed (Zheng *et al.,* 2006). Due to the variability of subcatchment characteristics, LID implementation is often done with site-specific goals in mind, on small individual drainage areas, or with a focus on one particular type of LID by the use of micro-scale controls distributed throughout the site (USEPA, 2000).

Reductions in stormwater flow through LID implementation are the cause of reductions in pollutant loads; that is, pollutants are kept on the watershed since flows removing them are reduced. Sites that had no or very low baseline flows included Court and Beaconview which saw equal reductions in flow, TP loads, and TSS loads within LIDs. Scottsville, Elmwood, and Merrill sites had larger baseline flows and concentrations of pollutants input into the model for calibration and validation, and pollutant reductions were similar to or higher than flow reductions (Table 18).

Clearly, the LIDs implemented to portions of sewersheds resulted in reductions at outfalls as the reduced flow and loads of stormwater occurred. However, the reductions in terms of total flow and loads would be trivial when compared to the total load of the Genesee River. For example, treating 25 percent of the impervious land to porous pavement in the subcatchments of the Merrill sewershed would reduce total flow by five percent, TP load by eight percent, and TSS load by 12 percent at the outfall (OF18) (Table 18). Based on annual flows and loads from OF18, these percent reductions translate to a 498,159 m^3 reduction in annual stormwater volume, 63.5 kg reduction in annual TP load, and a 15,373 kg reduction in suspended sediment to the Genesee River annually. Although this represents less than one percent of the total flow and P load of the Genesee River, the cumulative effect of many of these sites combined with other anthropogenically derived non-point (Makarewicz *et al*., 2013) and point sources (Makarewicz et al. 2013) to the Genesee River represent as much as 53% of the P load of the Genesee River.

Summary

1. Lake Ontario suffers from many beneficial use impairments including beach closings, nuisance algae blooms, and aesthetic issues. The Genesee River is a large tributary to Lake Ontario and flows into the lake at the Rochester Embayment, which is listed as an Area of Concern (AOC) by the United States Environmental Protection Agency (USEPA). The lower Genesee River flows through the urbanized City of Rochester before reaching Lake Ontario. Urbanization can have massive effects on water quality with increases seen in nutrients, suspended solids, biochemical oxygen demand, pathogenic organisms, and trace metal loads by an order of magnitude over natural catchment conditions.

2. The lower Genesee River suffers from beneficial use impairments from the New York State Barge Canal to the mouth at Lake Ontario. As the Genesee River flows through the City of Rochester it receives inputs from the New York State Barge Canal, storm sewers, combined sewer overflows, and a wastewater treatment plant.
3. Weekly samples were collected at three sites along the Genesee River, two sites along the New York State Barge Canal, and seven storm sewer sites for the period of 17 January 2012 to 15 January 2013. Two additional storm sewer sites were sampled weekly from 19 June 2012 to 15 January 2013. Samples were analyzed in the SUNY Brockport water quality laboratory for nitrate+nitrite, total nitrogen, soluble reactive phosphorus, total phosphorus, total suspended solids, total coliform bacteria, and dissolved sodium. Discharge measurements were also taken at storm sewer and canal sites. Samples were also collected during precipitation events, and at each storm sewer site samples were collected at regular intervals over the course of one precipitation event.
4. Average total phosphorus concentrations in stormwater ranged from 70.0 µg P/L to 264.6 µg P/L and average total suspended solids concentrations ranged from 6.7 mg/L to 53.5 mg/L. Results were consistent with literature values of average TSS concentrations of 20 mg/L and the range of 30 to 3,000 µg P/L for total phosphorus concentrations in urban watersheds (Lee *et al.*, 2010).
5. During the navigation season (28 April to 15 November 2012) the New York State Barge Canal flows east and intersects with the Genesee River in Rochester, New York. The canal continues flowing east after the intersection and the river continues to flow north after the intersection. Outside of the navigation season, gates in the canal on both sides of the Genesee River are closed and the river flows through the intersection uninterrupted.
6. There were no significant differences in nutrient and sediment concentrations in the Genesee River sites above and below the intersection with the canal during both the navigation and non-navigation season. However, there were significantly higher total suspended concentrations (TSS) in the New York State Barge Canal downstream of the intersection (22.0 ± 1.9 mg/L) compared to the site upstream (15.0 ± 1.5 mg/L).
7. On 6 June 2012 the conductivity of the surface water of the Genesee River decreased from 621.2 µS/cm before the intersection with the New York State Barge Canal to 533.1 µS/cm while the conductivity of the surface water of the canal increased from 502.6 µS/cm to 558.3 µS/cm after its intersection with the river.

8. Kodak King's Landing Wastewater Treatment Plant discharged 6,106 kg total phosphorus and 129,029 kg total suspended solids to the Genesee River in 2012.
9. In 2012, four precipitation events resulted in combined sewer overflows that discharged untreated sanitary waste and stormwater to the Genesee River and Irondequoit Bay. Average total phosphorus concentrations ranged from 0.437 mg/L to 2.2 mg/L and total suspended solid concentrations from 156 mg/L to 810 mg/L and *E. coli* concentrations as high as 483,920 MPN/100 mL. Estimated loads of total phosphorus and total suspended solids from the overflows were 1,534 kg and 355,872 kg, respectively.
10. PCSWMM (Storm Water Management Model) was used to create a model of the City of Rochester and Town of Irondequoit storm sewer networks. The model was calibrated at the nine storm sewer sites from time series data for flow, total phosphorus, and total suspended solid loads. Coefficients of determination (R^2) and Nash – Sutcliffe Efficiency Indexes (NSE) were used to calibrate the model. All R^2 values between 0.62 and 0.99 NSE values ranged from 0.56 to 0.99, which were all acceptable according to Ramanarayanan *et al.,* (1997).
11. Model validation was done by comparing observed flow, TP, and TSS loads from elevated flow sampling dates to model predicted values. R^2 values ranged from 0.74 to 1.00 for flow, 0.73 to 0.99 for TP load, and 0.67 to 0.99 for TSS load.
12. Total model annual predicted flows, total phosphorus loads, and total suspended solid loads entering the Genesee River from separate storm sewers were 19,197,116 m^3, 2,277 kg, and 625,694 kg, respectively.
13. Total flows and loads from stormwater represent a very small portion of the total flow and phosphorus and suspended solids loads in the Genesee River with TP and TSS loads in the Genesee River 457,572 kg and 383,182,294 kg, respectively (Makarewicz *et al.,* 2013).
14. Using PCSWMM, the effectiveness of five low impact developments (LIDs) (porous pavement, bio-retention cells, infiltration trenches, vegetative swales, and rain barrels) was tested on percent reductions of model predicted stormwater flow, total phosphorus load, and total suspended solid load at five different sites.
15. Percent reductions in flows and loads varied across sites, but rain barrels consistently had the greatest percent reductions when compared to other LIDs with eight percent reduction in flow and TP and TSS loads when ten percent of impervious area was treated.

16. Vegetative swales only reduced stormwater flows by zero to two percent when ten percent of impervious area at the sites was converted to swales.
17. Further research needs to be done with greater detail and with site-specific goals for LID placement to reduce impacts from both the “separated” storm sewer and combined sewer networks.

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Table 1. Sampling sites in the City of Rochester. University of Rochester is abbreviated as U of R. Discharge data were obtained from the USGS stations at Ballantyne Road and Ford Street.

Sampling Sites	Type	Latitude	Longitude
Ballantyne Road	River	43° 5’ 34” N	77° 40’ 49” W
U of R	River	43° 7’ 53” N	77° 38’ 1” W
Ford Street	River	43° 8’ 31” N	77° 36’ 54” W
Ballantyne Road - USGS Station	River	43° 5’ 32” N	77° 40’ 50” W
Ford Street - USGS Station	River	43° 8’ 30.2” N	77° 36’ 58.7” W
Canal West	Canal	43° 7’ 23” N	77° 38’ 43” W
Canal East	Canal	43° 6’ 59” N	77° 37’ 56” W
Scottsville Road	Storm Sewer	43°6'52" N	77°39'27" W
Elmwood Avenue	Storm Sewer	43°7'23" N	77°38'1" W
Kendrick Road	Storm Sewer	43°11'29" N	77°37'12" W
Court Street	Storm Sewer	43°9'11" N	77°36'33" W
St. Paul Street	Storm Sewer	43°11'29" N	77°37'12" W
Maplehurst Road	Storm Sewer	43°12'16" N	77°37'21" W
Merrill Street	Storm Sewer	43°12'16" N	77°37'40" W
Chapel Hill Drive	Storm Sewer	43°13'11" N	77°36'42" W
Beaconview Court	Storm Sewer	43°14'40" N	77°36'38" W

Table 2. Analytes measured and methods for chemical analysis. NO_3+NO_2=nitrate + nitrite; SRP= soluble reactive phosphorus; TN=total nitrogen; TP=total phosphorus (APHA, 1998).

Analyte	Method	Method Detection Limits
NO_3+NO_2	APHA 4500-NO3-F	0.005 mg NO_3-N/L
SRP	APHA 1998 4500-P	0.48 µg P/L
TN	APHA 4500-N	0.15 µg N/L
TP	APHA 4500-P-F	0.38 µg P/L
Sodium	APHA 3500-Na	0.78 mg Na/L
TSS	APHA 2540-D	0.2 mg/L

Table 3. Average dry weather concentrations ± standard error of total phosphorus (TP) and total suspended solids (TSS) at five sampled storm sewer sites (Fig. 2). Concentrations were input into PCSWMM as baseline concentrations for dry weather flow.

Site	**TP (µg P/L)**	**TSS (mg/L)**
Scottsville	34.5 ± 2.6	13.6 ± 1.9
Elmwood	39.3 ± 2.2	6.1 ± 0.5
Chapel Hill	40.7 ± 4.2	14.1 ± 2.9
Maplehurst	250 ± 11.5	8.6 ± 1.0
Merrill	65.8 ± 4.1	6.0 ± 0.6

Table 4. Concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate, dissolved sodium (Na), total suspended solids (TSS), and total coliform bacteria at sites along the Genesee River while the New York State Barge Canal was closed [non-navigation season (1 January – 28 April and 15 November – 31 December 2012)] and opened [navigation season (28 April – 15 November 2012)]. Ballantyne Road is upstream of the intersection of the Genesee River and New York State Barge Canal, and U of R (University of Rochester) and Ford Street are downstream of the intersection. Comparisons were done with a one-way ANOVA. Means ± standard error are shown.

		TP (µg P/L)	**SRP (µg P/L)**	**TN (mg N/L)**	**Nitrate (mg N/L)**	**Na (mg Na/L)**	**TSS (mg/L)**	**TC (CFU/100mL)**
Non-Navigation Season (Canal Closed)	Ballantyne Road (n=26)	58.2 ± 8.0	11.3 ± 0.8	1.58 ± 0.09	1.29 ± 0.07	26.7 ± 1.6	43.2 ± 8.9	3,027 ± 609
	U of R (n=26)	57.2 ± 8.6	10.7 ± 1.0	1.56 ± 0.09	1.20 ± 0.06	50.3 ± 6.1	41.9 ± 9.6	3,646 ± 742
	Ford Street (n=11)	52.3 ± 10.7	11.3 ± 1.0	1.4 ± 0.1	1.1 ± 0.04	32.1 ± 5.4	27.6 ± 9.4	6,527 ± 2009
	p-value	0.923	0.887	0.654	0.433	0.001**	0.603	0.069
Navigation Season (Canal Open)	Ballantyne Road (n=34)	48.2 ± 4.8	8.0 ± 1.3	1.08 ± 0.05	0.65 ± 0.05	31.3 ± 2.4	23.2 ± 4.7	10,932 ± 3719
	U of R (n=34)	51.2 ± 4.2	6.2 ± 0.9	1.14 ± 0.10	0.58 ± 0.04	30.0 ± 1.9	20.3 ± 4.1	10,305 ± 2232
	Ford Street (n=34)	51.8 ± 4.3	8.0 ± 1.8	1.08 ± 0.07	0.58 ± 0.07	28.5 ± 1.5	22.4 ± 4.3	1,154 ± 3617
	p-value	0.832	0.617	0.820	0.311	0.586	0.889	0.712

*Represents significance at α = 0.05 ** Represents significance at α = 0.01 ***Represents significance at α = 0.001

Table 5. Average concentrations and loads ± standard error for total phosphorus (TP), nitrate (NO_3), total suspended solids (TSS), dissolved sodium (Na), soluble reactive phosphorus (SRP), total nitrogen (TN), and total coliform at two sites along the New York State Barge Canal from 28 April 2012 to 15 November 2012. Concentration data for TP, TSS, TN, and total coliform were transformed by a factor of log10 to normalize the data. Canal West is upstream of the intersection of the Genesee River and the New York State Barge Canal, and Canal East is downstream of the intersection. Concentration data were analyzed with a paired t-test and load data were analyzed with a Wilcoxon Signed Rank test. See Figure 2 for site locations.

	TP (µg P/L)	**SRP (µg P/L)**	**TN (mg N/L)**	**NO_3 (mg N/L)**	**Na (mg/L)**	**TSS (mg/L)**	**Total Coliform (CFU/100mL)**	
Canal West	55.9 ± 2.5	14.2 ± 1.4	1.2 ± 0.08	0.7 ± 0.06	28.5 ± 1.7	15.0 ± 1.5	6.5E+3 ± 2.0E+3	
Canal East	59.1 ± 4.2	10.2 ± 1.1	1.1 ± 0.07	0.6 ± 0.04	34.4 ± 2.3	24.9 ± 2.9	1.4E+4 ± 6.3E+3	
p-value	0.833	0.081	0.541	0.335	0.039*	0.001**	0.041*	
	TP (kg/d)	**SRP (kg/d)**	**TN (kg/d)**	**NO_3 (kg/d)**	**Na (kg/d)**	**TSS (kg/d)**	**Total Coliform (CFU/d)**	**Flow (m^3/d)**
Canal West	54.6 ± 5.7	15.8 ± 1.9	1.2E+3 ± 128	684 ± 83.7	2.3E+4 ± 2.5E+3	1.3E+4 ± 1.9E+3	5.4E+13 ± 2.0E+13	9.7E+5 ± 6.5E+4
Canal East	21.4 ± 3.6	3.8 ± 0.9	411 ± 61.9	233 ± 40.6	1.7E+4 ± 2.4E+3	7.8E+3 ± 1.7E+3	5.8E+13 ± 2.7+13	4.0E+5 ± 5.9E+4
p-value	0.000***	0.000***	0.000***	0.000***	0.001**	0.016*	0.505	0.000***

* Represents significance at α = 0.05

** Represents significance at α = 0.01

*** Represents significance at α = 0.001

Table 6. Conductivity (μS/cm) and (temperature) (°C) recorded at different depths at two sites along the Genesee River and two sites along the New York State Barge Canal (Fig. 4) on 6 June 2012. Highlighted areas represent sites in which there was the greatest interaction between the water from the Genesee River and New York State Barge Canal. Discharge (m^3/s) is shown for sites along the Genesee River, but due to broken equipment, could not be measured at the New York State Barge Canal. ND = No data.

Depth (m)	**River South**	**Canal West**	**River North**	**Canal East**
0.0	621.2 (22.91)	502.6 (24.72)	533.1 (24.82)	558.3 (24.34)
0.5	621.0 (22.98)	502.4 (24.74)	563.8 (24.29)	562.7 (24.32)
1.0	621.1 (22.95)	501.8 (24.74)	574.3 (24.21)	562.4 (24.30)
1.5	621.5 (22.94)	501.3 (24.74)	625.0 (23.64)	562.5 (24.36)
2.0	ND	501.5 (24.73)	629.9 (23.56)	561.7 (24.30)
Discharge (m^3/s)	25.30	ND	28.32	ND

Table 7. Conductivity (μS/cm) and (temperature) (°C) recorded at different depths at two sites along the Genesee River and two sites along New York State Barge Canal (Fig. 4) on 18 July 2012. Highlighted areas represent sites in which there was the greatest interaction between the water from the Genesee River and New York State Barge Canal. Discharge (m^3/s) is shown.

Depth (m)	**River South**	**Canal West**	**River North**	**Canal East**
0.0	781.3 (27.46)	409.8 (28.25)	489.5 (28.79)	495.9 (28.03)
0.5	781.9 (27.26)	410.0 (28.23)	497.3 (28.47)	507.3 (28.10)
1.0	781.4 (27.07)	410.0 (28.23)	513.6 (28.26)	503.1 (28.13)
1.5	782.0 (27.00)	409.5 (28.21)	566.4 (27.88)	512.9 (28.06)
2.0	784.1 (26.77)	409.4 (28.19)	594.1 (27.65)	519.3 (28.01)
Discharge (m^3/s)	12.72	7.11	14.24	3.30

Table 8. Average event (E) and average nonevent (N) concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate (NO_3), dissolved sodium (Na), total suspended solids (TSS), and total coliform bacteria [TC(CFU/100mL)] from nine separate storm sewers (Fig. 2). Data were analyzed with one-way ANOVAs and Tukey's post hoc tests were run to determine differences between sites. Sites that do not share a letter across a row are statistically different from each other. Means ± standard error are shown. See Figure 2 for site locations.

		Maplehurst	**Elmwood**	**Kendrick**	**St. Paul**	**Chapel Hill**	**Merrill**	**Court**	**Beaconview**	**Scottsville**
TP (µg P/L)	**E**	264.6±54.5^{A}	91.3±14.1^{B}	154.1± 20.8^{AB}	70.3± 14.9^{B}	128.8± 33.3^{AB}	116.8±29.7^{B}	145.3± 24.6^{AB}	129.6± 31.3^{AB}	70.0±9.9^{B}
	N	260.6±41.6^{A}	85.2±28.7^{A}	110.1± 19.4^{A}	219.5± 120.9^{A}	58.1±9.1^{A}	187.3±91.8^{A}	224.9±35.3^{A}	150.1±61.3^{A}	34.5±2.6^{A}
SRP (µg P/L)	**E**	120.2±19.6^{A}	40.7±6.8^{BC}	57.1±8.2^{BC}	37.0± 7.4^{BC}	86.4±29.3^{AB}	57.1±11.2^{BC}	58.0±12.1^{BC}	82.5±30.2^{AB}	15.0±3.5^{C}
	N	154.7±10.1^{A}	18.7±1.3^{B}	4.2±17.2^{AB}	48.3± 21.9^{AB}	21.0±4.4^{AB}	107.9± 76.2^{AB}	80.4±6.0^{AB}	28.3±4.5^{AB}	4.5±0.5^{B}
TN (mg N/L)	**E**	3.6±0.4^{A}	1.9±0.2^{AB}	2.1±0.3^{AB}	1.4±0.2^{B}	1.7±0.2^{AB}	1.4±0.1^{B}	2.4±0.5^{AB}	2.2±0.3^{AB}	3.3±0.7^{AB}
	N	5.6±0.2^{A}	2.3±0.1^{C}	2.6+0.4^{C}	1.2±0.3^{C}	2.5±0.2^{C}	1.8±0.2^{C}	3.1±0.2^{ABC}	3.1±0.6^{BC}	5.3±1.1^{AB}
NO_3 (mg N/L)	**E**	1.9±0.4^{A}	1.2±0.2^{AB}	1.1±0.2^{AB}	0.8±0.1^{AB}	1.1±0.2^{AB}	0.6±0.1^{B}	1.4±0.4^{AB}	1.5±0.2^{AB}	1.8±0.3^{AB}
	N	4.0±0.1^{A}	1.9±0.1^{BC}	1.2±0.1^{DE}	0.7±0.1^{E}	1.9±0.1^{BC}	0.9±0.1^{E}	2.3±0.1^{B}	1.7±0.3^{CD}	1.3±0.1^{D}
Na (mg Na/L)	**E**	60.5±19.0^{B}	497.1± 135.4^{A}	265.6± 153.0^{AB}	19.3±8.2^{B}	35.8±9.5^{B}	88.4±29.8^{AB}	132.1± 46.7^{AB}	114.8± 23.8^{AB}	188.1± 70.0^{AB}
	N	77.4±3.6^{D}	822.1±93.9 A	724.6± 147.5^{AB}	48.7± 12.8^{D}	80.9±13.1^{D}	113.6±16.9^{D}	507.9± 98.5^{BC}	112.1±38.1^{D}	268.4± 32.8^{CD}
TSS (mg/L)	**E**	43.8±18.0^{A}	32.0±10.2^{A}	53.5±15.3^{A}	6.7±1.1^{A}	16.0±5.1^{A}	22.5±5.4^{A}	35.2±10.2^{A}	18.8±3.7^{A}	33.4±8.6^{A}
	N	8.6±1.3^{C}	26.7± 14.6^{ABC}	23.9± 4.7^{ABC}	9.3±2.2^{C}	19.5±4.5^{BC}	6.0±1.3^{C}	55.0±11.6^{AB}	60.3±20.3^{A}	13.6±1.9^{C}
TC	**E**	6.2E4± 7.0E3^{A}	4.3E4± 8.4E3^{A}	7.5E4± 1.4E4^{A}	2.8E4± 7.9E3^{A}	5.9E4± 8.4E3^{A}	5.3E4± 8.1E3^{A}	6.5E4± 9.3±E3^{A}	5.7E4± 1.2E4^{A}	5.1E4± 1.2E4^{A}
	N	3.2E4± 4.1E3^{ABC}	1.4E4± 2.6E3^{BC}	4.2E4± 6.9E3^{AB}	8.1E3± 4.3E3^{C}	2.5E4± 5.4E3^{BC}	2.5E4± 2.9E3^{BC}	5.9E4± 2.2E4^{A}	4.3E4± 9.7E3^{AB}	1.3E4± 3.8E3^{BC}

Table 9. Water chemistry data for nine storm sewer sites (CH = Chapel Hill, SP = St. Paul, Elm = Elmwood, Ken = Kendrick, BV= Beaconview, Scott = Scottsville) during events (E) and nonevents (N) arranged by clusters formed from the cluster analysis (Fig. 7). Water chemistry data includes means (± standard error) of total phosphorus [TP (µg P/L)], soluble reactive phosphorus [SRP (µg P/L)], total nitrogen [TN (mg N/L)], nitrate [NO_3 (mg N/L)], dissolved sodium [Na (mg Na/L)], total suspended solids [TSS (mg/L)], and total coliform bacteria [TC (CFU/100 mL)] (Fig. 2).

		Cluster 1	**Cluster 2**			**Cluster 3**		**Cluster 4**						**Cluster 5**
		Maple	**S.P.**	**CH**	**Merrill**	**Elm**	**Ken**	**BV**	**CH**	**Merrill**	**Ken**	**Court**	**Scott**	**Scott**
TP	**E**	264.6± 54.5	70.3± 14.9	-	-	91.3± 14.1	-	129.6± 31.3	128.8 ± 33.3	116.8± 29.7	154.1± 20.8	145.3± 24.6	70.0± 9.9	-
	N	260.6± 41.6	219.5± 120.9	58.1± 9.1	187.3± 91.8	85.2± 28.7	110.1± 19.4	150.1± 61.3	-	-	-	224.9± 35.3	-	34.5± 2.6
SRP	**E**	120.2± 19.6	37.0± 7.4	-	-	40.7± 6.8	-	82.5± 30.2	86.4± 29.3	57.1± 11.2	57.1± 8.2	58.0± 12.1	15.0± 3.5	-
	N	154.7± 10.1	48.3± 21.9	21.0± 4.4	107.9± 76.2	18.7± 1.3	4.2±1 7.2	28.3± 4.5	-	-	-	80.4± 6.0	-	4.5± 0.5
TN	**E**	3.6± 0.4	1.4± 0.2	-	-	1.9± 0.2	-	2.2± 0.3	1.7± 0.2	1.4± 0.1	2.1± 0.3	2.4± 0.5	3.3± 0.7	-
	N	5.6± 0.2	1.2± 0.3	2.5± 0.2	1.8± 0.2	2.3± 0.1	2.6+ 0.4	3.1± 0.6	-	-	-	3.1± 0.2	-	5.3± 1.1
NO_3	**E**	1.9± 0.4	0.8± 0.1	-	-	1.2± 0.2	-	1.5± 0.2	1.1± 0.2	0.6± 0.1	1.1± 0.2	1.4± 0.4	1.8± 0.3	-
	N	4.0± 0.1	0.7± 0.1	1.9± 0.1	0.9± 0.1	1.9± 0.1	1.2± 0.1	1.7± 0.3	-	-	-	2.3± 0.1	-	1.3± 0.1
Na	**E**	60.5± 19.0	19.3± 8.2	-	-	497.1± 135.4	-	114.8± 23.8	35.8± 9.5	88.4± 29.8	265.6± 153.0	132.1± 46.7	188.1± 70.0	-
	N	77.4± 3.6	48.7± 12.8	80.9± 13.1	113.6± 16.9	822.1± 93.9	724.6± 147.5	112.1± 38.1	-	-	-	507.9± 98.5	-	268.4± 32.8
TSS	**E**	43.8± 18.0	6.7± 1.1	-	-	32.0± 10.2	-	18.8± 3.7	16.0± 5.1	22.5± 5.4	53.5± 15.3	35.2± 10.2	33.4± 8.6	-
	N	8.6± 1.3	9.3± 2.2	19.5± 4.5	6.0± 1.3	26.7± 14.6	23.9± 4.7	60.3± 20.3	-	-	-	55.0± 11.6	-	13.6± 1.9
TC	**E**	6.2E4± 7.0E3	2.8E4± 7.9E3	-	-	4.3E4± 8.4E3	-	5.7E4± 1.2E4	5.9E4 ± 8.4E3	5.3E4± 8.1E3	7.5E4± 1.4E4	6.5E4± 9.3±E3	5.1E4± 1.2E4	-
	N	3.2E4 ±4.1E3	8.1E3± 4.3E3	2.5E4± 5.4E3	2.5E4± 2.9E3	1.4E4± 2.6E3	4.2E4± 6.9E3	4.3E4± 9.7E3	-	-	-	5.9E4± 2.2E4		1.3E4± 3.8E3

Table 10. Comparison between event (E) and nonevent (N) average concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate (NO_3), dissolved sodium (Na), total suspended solids (TSS), and total coliform bacteria [TC(CFU/100mL)] from nine separate storm sewers in the City of Rochester (Fig. 2). Mann-Whitney tests were used to determine significant differences between event and nonevent concentrations (p = p-value). Means ± standard error are shown.

		Scottsville	**Kendrick**	**Elmwood**	**Court**	**St. Paul**	**Maplehurst**	**Merrill**	**Chapel Hill**	**Beaconview**
TP (µg P/L)	E	70.0±9.9	154.1±20.8	91.3±14.1	145.3±24.6	70.3±14.9	264.6±54.5	116.8±29.7	128.8±33.3	129.6±31.3
	N	34.5±2.6	110.1±19.4	85.2±28.7	224.9±35.3	219.5±120.9	260.6±41.6	187.3±91.8	58.1±9.1	150.1±61.3
	p	0.000***	0.010**	0.000***	0.023*	0.163	0.700	0.004**	0.013*	1.000
SRP (µg P/L)	E	15.0±3.5	57.1±8.2	40.7±6.8	58.0±12.1	37.0±7.4	120.2±19.6	57.1±11.2	86.4±29.3	82.5±30.2
	N	4.5±0.5	4.2±17.2	18.7±1.3	80.4±6.0	48.3±21.9	154.7±10.1	107.9±76.2	21.0±4.4	28.3±4.5
	p	0.000***	0.001***	0.000***	0.003**	0.084	0.014*	0.020*	0.008**	0.012*
TN (mg N/L)	E	3.3±0.7	2.1±0.3	1.9±0.2	2.4±0.5	1.4±0.2	3.6±0.4	1.4±0.1	1.7±0.2	2.2±0.3
	N	5.3±1.1	2.6+0.4	2.3±0.1	3.1±0.2	1.2±0.3	5.6±0.2	1.8±0.2	2.5±0.2	3.1±0.6
	p	0.755	0.553	0.054	0.005**	0.022*	0.000***	0.231	0.020*	0.720
NO_3 (mg N/L)	E	1.8±0.3	1.1±0.2	1.2±0.2	1.4±0.4	0.8±0.1	1.9±0.4	0.6±0.1	1.1±0.2	1.5±0.2
	N	1.3±0.1	1.2±0.1	1.9±0.1	2.3±0.1	0.7±0.1	4.0±0.1	0.9±0.1	1.9±0.1	1.7±0.3
	p	0.097	0.005**	0.005**	0.001***	0.121	0.000***	0.040*	0.769	0.000***
Na (mg Na/L)	E	188.1±70.0	265.6±153.0	497.1±135.4	132.1±46.7	19.3±8.2	60.5±19.0	88.4±29.8	35.8±9.5	114.8±23.8
	N	268.4±32.8	724.6±147.5	822.1±93.9	507.9±98.5	48.7±12.8	77.4±3.6	113.6±16.9	80.9±13.1	112.1±38.1
	p	0.043*	0.328	0.086	0.000***	0.002**	0.000***	0.130	0.015*	0.742
TSS (mg/L)	E	33.4±8.6	53.5±15.3	32.0±10.2	35.2±10.2	6.7±1.1	43.8±18.0	22.5±5.4	16.0±5.1	18.8±3.7
	N	13.6±1.9	23.9±4.7	26.7±14.6	55.0±11.6	9.3±2.2	8.6±1.3	6.0±1.3	19.5±4.5	60.3±20.3
	p	0.058	0.000***	0.029*	0.049*	0.753	0.004**	0.000***	0.918	0.022*
TC	E	5.1E4±1.2E4	7.5E4±1.4E4	4.3E4±8.4E3	6.5E4±9.3E3	2.8E4±7.9E3	6.2E4±7.0E3	5.3E4±8.1E3	5.9E4±8.4E3	5.7E4±1.2E4
	N	1.3E4±3.8E3	4.2E4±6.9E3	1.4E4±2.6E3	5.9E4±2.2E4	8.1E3±4.3E3	3.2E4±4.1E3	2.5E4±2.9E3	2.5E4±5.4E3	4.3E4±9.7E3
	p	0.000***	0.001***	0.001***	0.062	0.001***	0.001***	0.004**	0.009**	0.249

* Represents significance at α=0.05 ** Represents significance at α=0.01 *** Represents significance at α=0.001

Table 11. Average discharge and event mean concentrations (EMCs) of total phosphorus (TP) and total suspended solids (TSS) during precipitation events at nine separate storm sewer sites in the City of Rochester (Fig. 2).

Site	Date	TP (µg P/L)	TSS (mg/L)	Discharge (m^3/s)
Scottsville	10/28/12	134	12	5.86E-02
Kendrick	6/1/13	1,078	331	1.76E-01
Elmwood	5/29/13	177	186	6.84E-02
Court	2/11/13	172	92	8.85E-02
St. Paul	5/29/13	24	4	3.35E-04
Maplehurst	4/10/13	307	90	6.76E-02
Merrill	5/29/13	136	40	1.15
Beaconview	6/6/13	230	40	1.57E-04
Chapel Hill	4/10/13	375	87	2.66E-02

Table 12. Coefficients of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) values for observed versus predicted flows, total phosphorus (TP) loads, and total suspended solid (TSS) loads for calibration at the sampled storm sewer sites. µg/s = µg per second. See Figure 2 for site locations. The acceptable range for R^2 and NSE values are from Ramanarayanan *et al.*, 1997.

	Flow (m^3/s)		TP (µg/s)		TSS (mg/s)	
Site	R^2	*NSE*	R^2	*NSE*	R^2	*NSE*
Scottsville	0.90	0.74	0.89	0.83	0.84	0.70
Elmwood	0.90	0.77	0.70	0.60	0.60	0.55
Kendrick	0.99	0.99	0.98	0.96	0.98	0.97
Court	0.88	0.67	0.81	0.80	0.83	0.82
St. Paul	0.94	0.86	0.88	0.81	0.80	0.69
Merrill	0.78	0.71	0.67	0.66	0.74	0.72
Maplehurst	0.69	0.69	0.65	0.63	0.62	0.56
Chapel Hill	0.92	0.94	0.66	0.94	0.69	0.87
Beaconview	0.96	0.85	0.98	0.92	0.94	0.93
Acceptable Range	**>0.60**	**>0.50**	**>0.60**	**>0.50**	**>0.60**	**>0.50**

Table 13. Coefficients of determination (R^2) for model validation at seven storm sewer sites for flow, total phosphorus (TP) load, and total suspended sediment (TSS) load. See Figure 2 for site locations. The acceptable range for R^2 and NSE values are from Ramanarayanan *et al.*, 1997.

Model Validation			
Site	**Flow**	**TP**	**TSS**
Scottsville	0.79	0.88	0.77
Elmwood	0.80	0.76	0.71
Kendrick	1.00	0.99	0.99
Court	0.81	0.76	0.76
Maplehurst	0.84	0.73	0.75
Chapel Hill	0.74	0.79	0.67
Beaconview	0.97	0.87	0.83
St. Paul	0.77	0.88	0.82
Merrill	0.88	0.73	0.74
Acceptable Range	**>0.60**	**>0.60**	**>0.60**

Table 14. Total PCSWMM predicted monthly and annual flow, total phosphorus (TP) loads, and total suspended solid (TSS) loads to the Genesee River from separate storm sewers in 2012.

	Flow (m^3)	**TP (kg)**	**TSS (kg)**
January	2,275,641	305	90,329
February	1,127,216	112	26,205
March	1,099,312	99	21,379
April	1,120,596	105	23,550
May	984,106	82	16,009
June	930,519	72	12,977
July	1,647,883	199	57,966
August	1,461,488	190	46,129
September	2,017,485	249	74,298
October	1,954,913	248	72,150
November	1,165,455	109	24,624
December	3,412,502	507	160,079
Annual	**19,197,116**	**2,277**	**625,694**

Table 15. Monthly stormwater volume (m^3/month) and annual stormwater volume (m^3) of water discharged into the Genesee River from individual sewersheds and from the entire storm sewer network in 2012. See Figure 3 for site locations.

	Sewershed								
	Scottsville	KenElm	Court	NE Court	St. Paul	Merrill	Irondequoit	Small Areas	Total (m^3)
January	190,210	92,705	77,311	126,154	227,512	1,173,842	358,125	29,782	2,275,641
February	75,601	33,751	18,611	27,982	50,397	748,050	165,198	7,626	1,127,216
March	55,702	25,682	14,189	23,929	41,041	772,786	160,294	5,689	1,099,312
April	63,777	27,399	16,080	27,367	51,788	762,826	164,933	6,426	1,120,596
May	51,587	26,720	8,991	11,599	23,947	722,051	135,621	3,590	984,106
June	45,398	16,447	10,207	23,622	17,787	689,853	122,917	4,288	930,519
July	144,972	73,439	64,688	90,246	124,424	932,076	195,005	23,033	1,647,883
August	92,102	43,576	44,200	71,322	122,134	963,619	108,103	16,432	1,461,488
September	125,206	70,464	61,100	125,888	218,454	1,113,144	276,444	26,785	2,017,485
October	148,938	77,763	63,612	105,187	179,558	1,074,109	281,295	24,451	1,954,913
November	62,632	27,465	14,494	32,006	61,896	791,145	169,635	6,182	1,165,455
December	349,297	168,740	142,938	237,612	421,628	1,514,919	521,609	55,759	3,412,502
Annual (m^3)	**1,405,422**	**684,151**	**536,421**	**902,914**	**1,540,566**	**11,258,420**	**2,659,179**	**210,043**	**19,197,116**

Table 16. Monthly total annual loads (kg) of total phosphorus discharged into the Genesee River from individual sewersheds and from the entire separate storm sewer network in 2012. See Figure 3 for site locations.

	Sewershed								
	Scottsville	KenElm	Court	NE Court	St. Paul	Merrill	Irondequoit	Small Areas	Total (kg P)
January	22	52	12	20	5	111	72	10	304
February	7	15	3	4	1	57	22	3	112
March	4	9	3	4	1	57	20	2	100
April	5	11	3	4	1	58	21	2	105
May	4	9	1	2	1	51	14	1	83
June	3	3	2	4	0	48	11	1	72
July	16	38	10	15	3	79	30	8	199
August	9	19	7	12	3	84	51	5	190
September	14	36	10	20	5	105	51	8	249
October	16	43	10	17	4	97	53	8	248
November	5	10	2	5	1	61	22	2	108
December	43	103	23	38	10	157	114	19	507
Annual (kg P)	**148**	**348**	**86**	**145**	**35**	**965**	**481**	**69**	**2,277**

Table 17. Monthly and annual loads (kg) of total suspended solids discharged into the Genesee River from individual sewersheds and from the entire separate storm sewer network in 2012 (Fig. 3).

	Sewershed								
	Scottsville	KenElm	Court	NE Court	St. Paul	Merrill	Irondequoit	Small Areas	Total (kg)
January	2,370	22,633	6,246	10,190	973	23,895	19,343	4,679	90,329
February	959	6,236	1,474	2,220	207	8,450	5,469	1,189	26,205
March	724	3,832	1,142	1,924	173	8,072	4,690	821	21,379
April	821	4,459	1,305	2,222	224	8,425	5,134	959	23,550
May	670	4,080	729	934	99	6,082	2,932	483	16,009
June	598	1,376	832	1,922	75	5,540	2,146	488	12,977
July	1,824	17,313	5,261	7,371	535	14,471	7,539	3,652	57,966
August	1,171	8,822	3,596	5,820	527	15,735	7,926	2,532	46,129
September	1,582	16,410	4,991	10,288	944	22,406	13,800	3,877	74,298
October	1,873	18,494	5,173	8,548	771	19,318	14,242	3,730	72,150
November	797	4,293	1,137	2,533	257	9,364	5,437	805	24,624
December	4,346	44,271	11,642	19,349	1,825	37,546	31,998	9,102	160,079
Annual (kg)	**17,737**	**152,220**	**43,529**	**73,320**	**6,611**	**179,303**	**120,656**	**32,317**	**625,694**

Table 18. Percent reductions of total flow (m^3), total phosphorus (TP) loads (kg), and total suspended solid (TSS) loads (kg) from five stormwater sewer outfalls: Scottsville (Scot), Elmwood (Elm), Merrill (Mer), Court, and Beaconview (Beac)(Fig. 2) after low impact development (LID) application to impervious areas for the period of 23 October 2012 to 30 October 2012.

		Flow						**TP**						**TSS**				
LID	% Impervious Area Treated	Scot	Elm	Court	Mer	Beac		Scot	Elm	Court	Mer	Beac		Scot	Elm	Court	Mer	Beac
Porous Pavement	25	10	6	15	5	10		14	12	15	8	10		10	15	15	8	10
	50	21	12	29	11	20		29	25	29	17	20		20	32	29	17	20
	75	33	18	44	17	30		45	37	44	25	30		31	47	44	25	30
Bio-Retention Cell	10	3	2	7	2	4		5	5	7	4	4		3	6	7	4	4
	20	8	5	12	5	8		10	10	12	8	8		7	13	12	8	8
Infiltration Trench	10	3	2	7	2	4		5	5	7	4	4		3	6	7	4	4
	20	8	5	12	5	8		10	10	12	8	8		7	13	12	8	8
Vegetative Swale	10	0	0	2	2	0		0	0	2	1	1		0	0	2	1	1
	20	1	0	3	4	1		1	0	3	3	2		1	0	3	3	2
Rain Barrel	10	5	3	8	3	7		7	6	8	4	7		5	7	8	4	7
	20	9	5	14	3	13		12	10	14	5	13		9	13	14	5	13

Table 19. Average daily discharge and average daily (kg/d) and total loads (kg) of total suspended solids (TSS), total Kjeldahl nitrogen (TKN), ammonia, total phosphorus (TP), nitrate, and nitrite from Kodak King's Landing Wastewater Treatment Plant for January 2012 to December 2012 (personal communication: Mary Lee Bishopp, Eastman Kodak Company).

Month	**Discharge (m^3/d)**	**TSS (kg/d)**	**TKN (kg/d)**	**Ammonia (kg/d)**	**TP (kg/d)**	**Nitrate (kg/d)**	**Nitrite (kg/d)**
January	39,368	224	146	72	16	185	17
February	39,368	311	177	105	16	311	18
March	37,854	295	204	150	26	1315	27
April	37,854	318	177	109	8	1289	37
May	37,854	327	122	64	23	274	77
June	45,425	363	213	145	14	495	71
July	45,425	272	113	44	9	183	7
August	49,210	367	132	36	25	268	27
September	52,996	499	172	73	16	1020	13
October	49,210	454	127	43	15	1586	28
November	41,640	313	122	68	12	848	30
December	35,583	499	118	50	21	705	99
Total (kg)		**129,029**	**55,359**	**28,982**	**6,106**	**258,292**	**13,789**

Table 20. Dates, estimated volumes, and ranges of total phosphorus (TP), total suspended solids (TSS) and *E. coli* concentrations, and loads of TP and TSS from combined sewer overflows (CSOs) discharging into the Genesee River and Irondequoit Bay. Concentration and therefore loading data were not available for overflows on 23 April 2012 and 30 October 2012 (personal communication: A. Sansone, Monroe County Environmental Services).

Date	Receiving Water	CSO	Est. Volume (m^3)	TP (mg/L)	TSS (mg/L)	*E. coli* (MPN/100mL)	TP (kg)	TSS (kg)
23-Apr-12	Genesee	CS - 45	N/A	N/A	N/A	N/A	N/A	N/A
	Genesee	CS - 243	1,893					
5-Aug-12	Genesee	CS - 45	47,696	0.437 - 2.2	180 - 580	198,630 – 241,960	147	50,914
	Genesee	CS - 243	128,325					
4-Sep-12	Genesee	CS - 45	403,525	0.727 - 4.18	156 - 810	282,720 – 483,920	1,387	304,958
	Genesee	CS - 243	218,797					
	Genesee	CS - 44	8,328					
	Irondequoit	Culver/ Goodman CS	65,866					
	Irondequoit	Densmore DS	N/A					
30-Oct-12	Genesee	CS - 243	1,893	N/A	N/A	N/A	N/A	N/A

Table 21. Total phosphorus (TP) (kg) and total suspended solid (TSS) (kg) loads at two sites along the Genesee River during the navigation season when the New York State Barge Canal was open (spring and summer) and the non-navigation season when seasonal dams are closed isolating the canal and river (fall and winter) (Makarewicz *et al.*, 2013).

	Navigation Season		**Non-navigation Season**	
	TP	TSS	TP	TSS
Ballantyne	285,725	239,817,880	167,220	176,437,212
Charlotte	257,633	208,704,724	199,938	174,477,569

Table 22. Average daily flow (m^3/d), total annual flow (m^3/yr), annual total phosphorus (TP) load (kg/yr), and annual total suspended solid (TSS) load (kg/yr) from storm sewers, Kodak King's Landing Wastewater Treatment Plant (WWTP), combined sewer overflows, the Genesee River, and two tributaries of the Genesee River (Conesus Creek and Canaseraga Creek) (Figs. 1 & 2). The annual flow and loads for storm sewers, Kodak King's Landing WWTP, and combined sewer overflows (5 August 2012 and 4 September 2012) were from 1 January 2012 to 31 December 2012, and yearly flows and loads from the Genesee River and tributaries were from 1 August 2010 to 31 July 2011. Data from the Genesee River and tributaries is from Makarewicz *et al.* (2013).

	Average Flow (m^3/d)	**Total Flow (m^3/yr)**	**TP load (kg/yr)**	**TSS load (kg/yr)**
Storm Sewers	52,595	19,197,116	2,277	625,694
Kodak King's Landing WWTP	42,649	15,566,885	6,106	129,029
Combined Sewer Overflows	2,401	876,323	1,534	355,872
Canaseraga Creek	1,296,734	473,307,910	66,556	75,377,613
Black Creek	476,451	173,904,615	13,799	2,239,083
Oatka Creek	677,757	247,381,305	15,018	5,006,876
Conesus Creek	204,199	74,532,635	6,428	1,598,849
Honeoye Creek	406,191	148,259,715	11,537	6,050,286
Genesee River	9,387,805	3,426,548,825	457,572	383,182,294

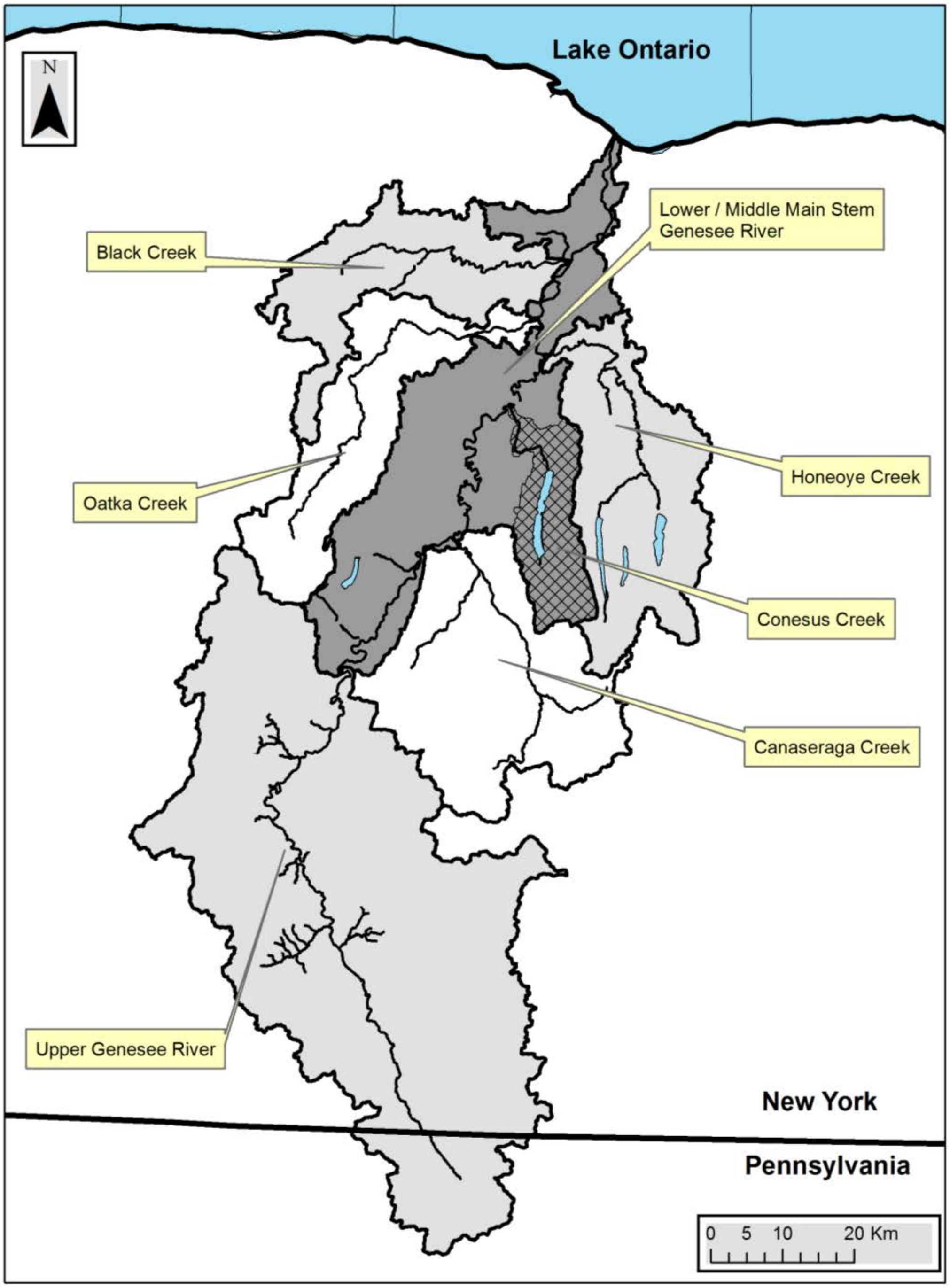


Figure 1. The Genesee River watershed with the boundary of the upper Genesee River watershed and the major streams within the watershed.

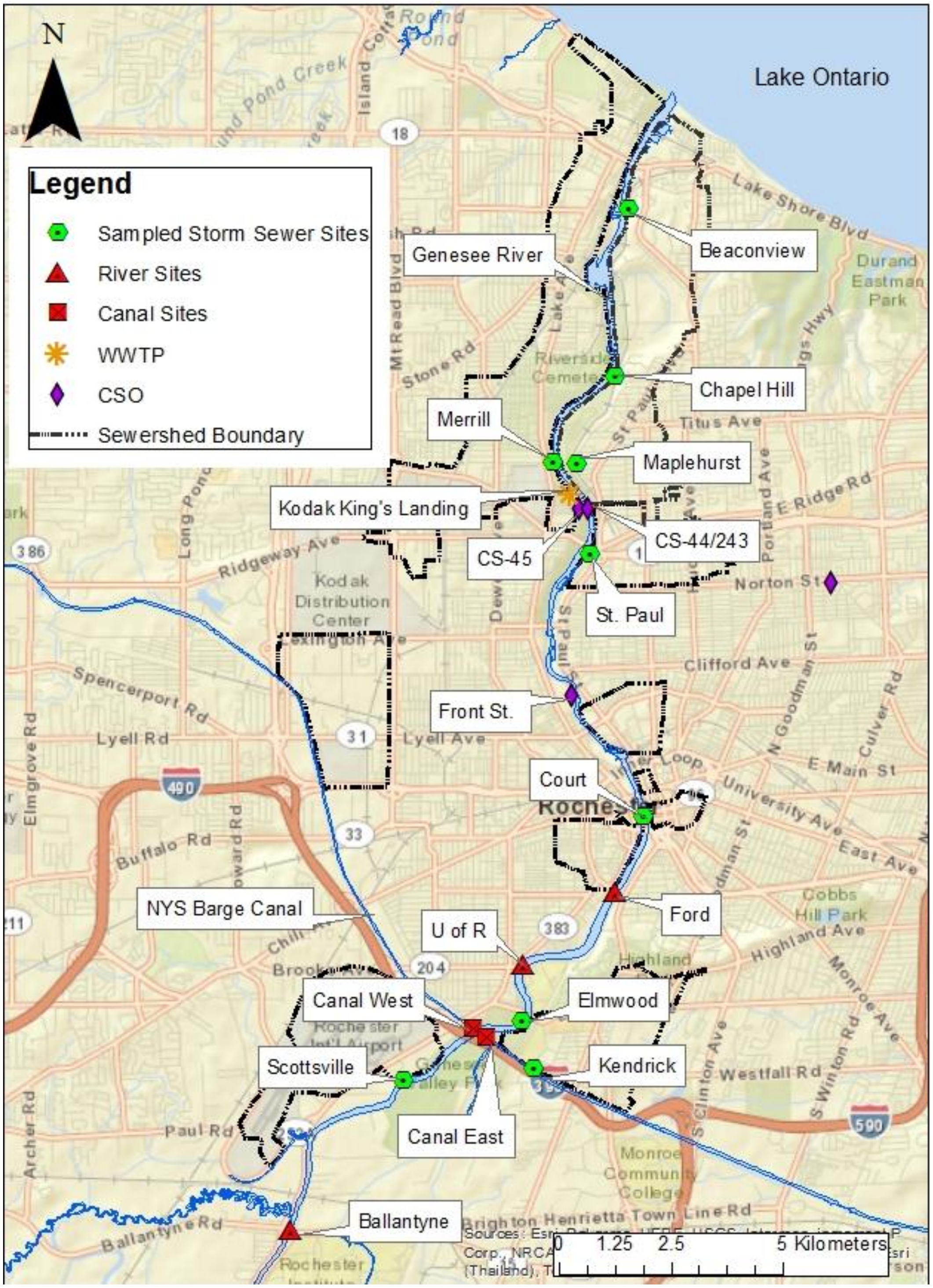


Figure 2. The study site, including storm sewer sites, sewersheds, wastewater treatment plants (WWTP), combined sewer overflows (CSO), canal sites, and river sites. U of R is a site along the Genesee River at the University of Rochester.

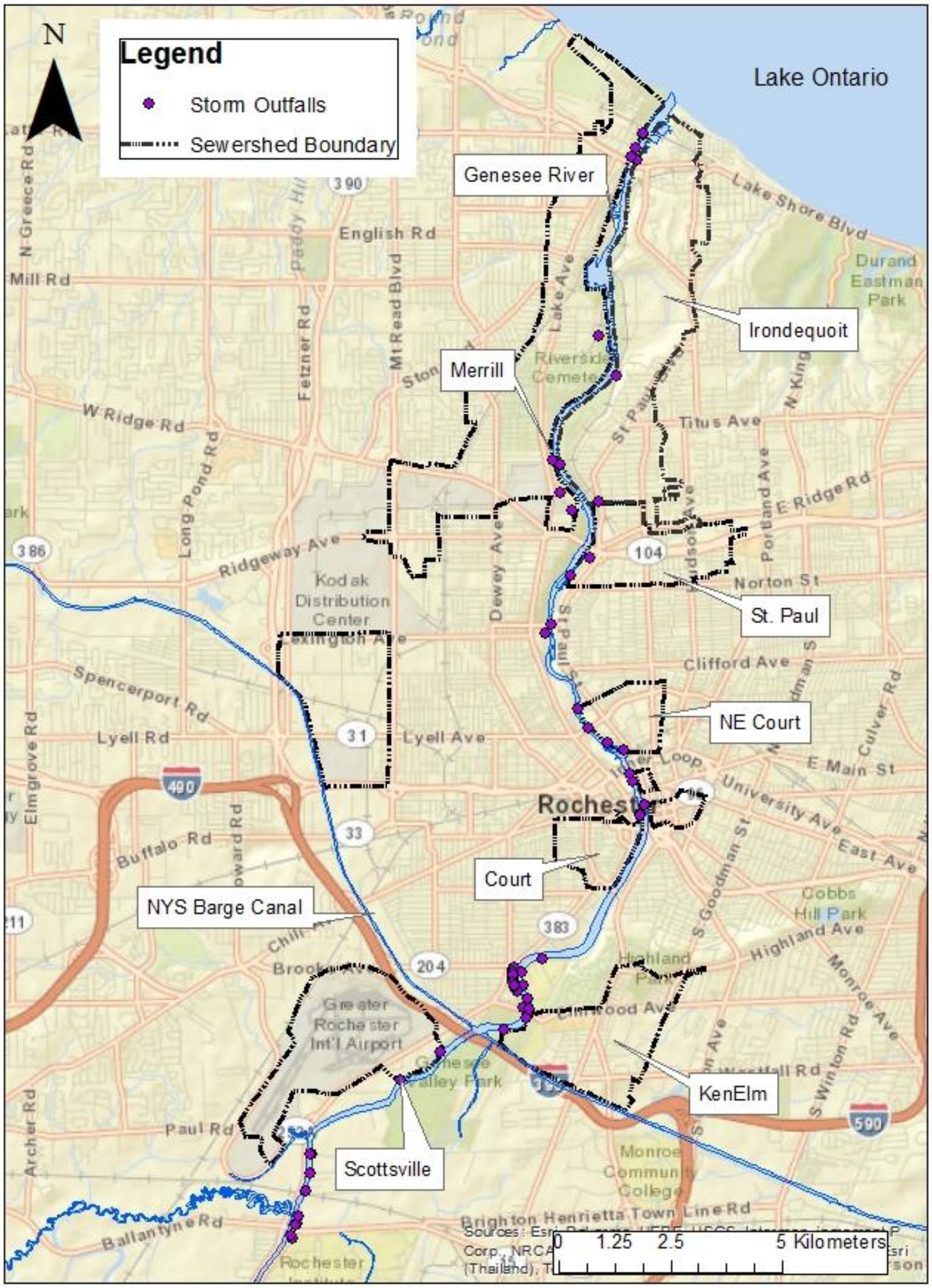


Figure 3. Sewersheds and storm sewer outfall locations on the Genesee River.

Figure 4. Conductivity and temperature sampling sites along the Genesee River and New York State Barge Canal.

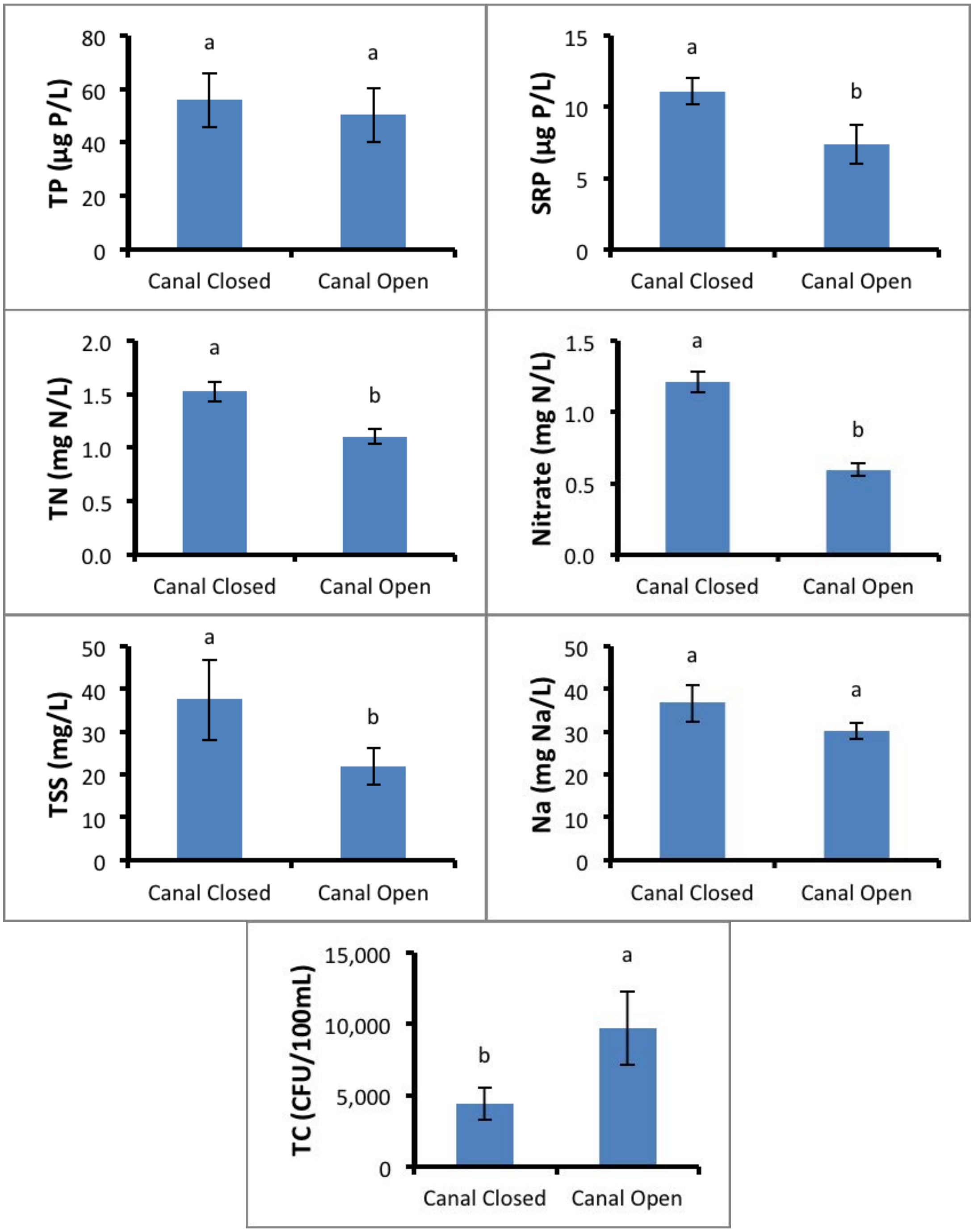


Figure 5. Average concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), nitrates, total nitrogen (TN), dissolved sodium (Na) and total coliform bacteria (TC) of samples in the Genesee River (Ballantyne Road, U of R, and Ford Street) during (Canal open) and outside of the navigation season (Canal closed). Standard error bars are shown. Letters above

standard error bars represent statistical significance; error bars that share a letter are statistically similar.

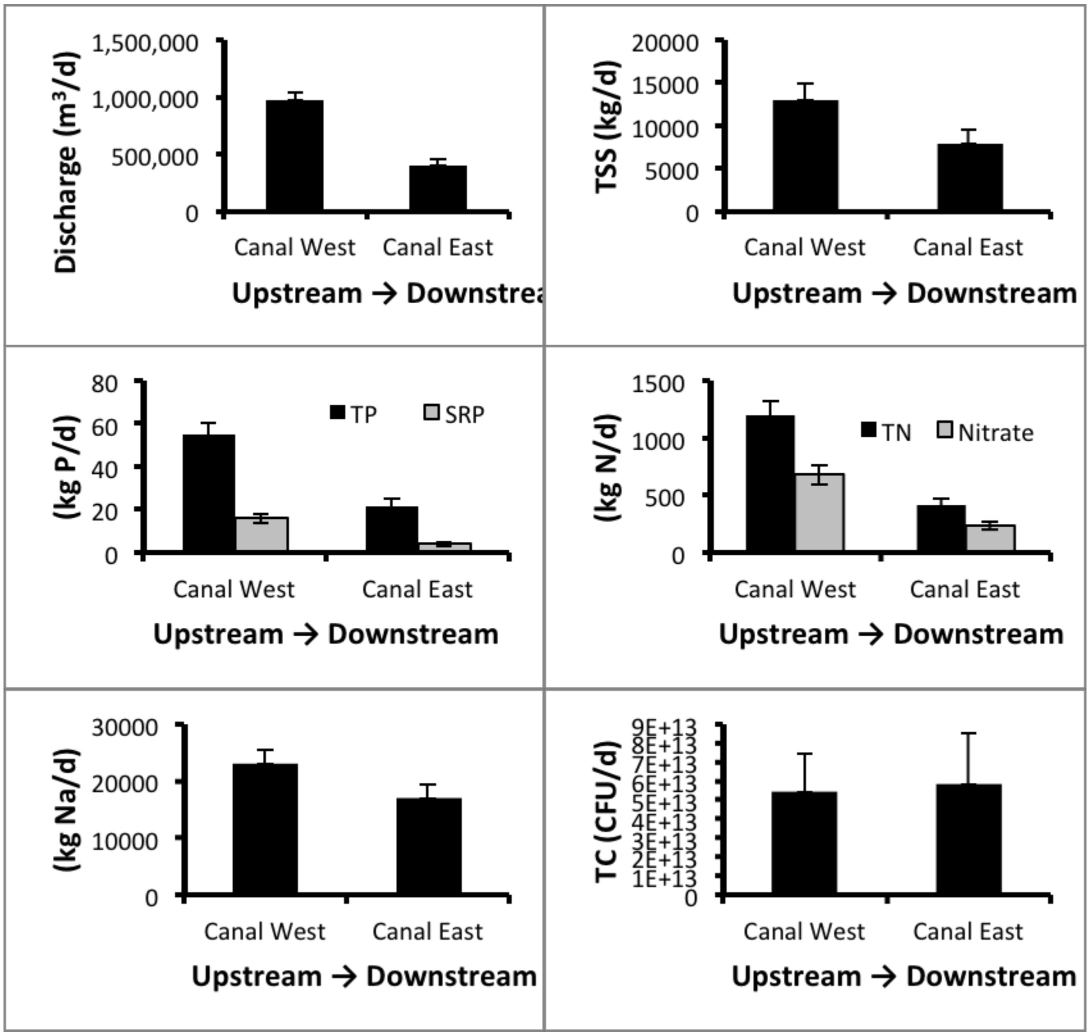


Figure 6. Average daily discharge and loadings of total suspended solids (TSS), total phosphorus (TP) and soluble reactive phosphorus (SRP), total nitrogen (TN) and nitrate, dissolved sodium, and total coliform (TC) bacteria from two sites along the New York State Barge Canal. Canal West is upstream of the intersection of the New York State Barge Canal and Genesee River and Canal East is downstream of the intersection (Fig. 2). Standard error bars are shown.

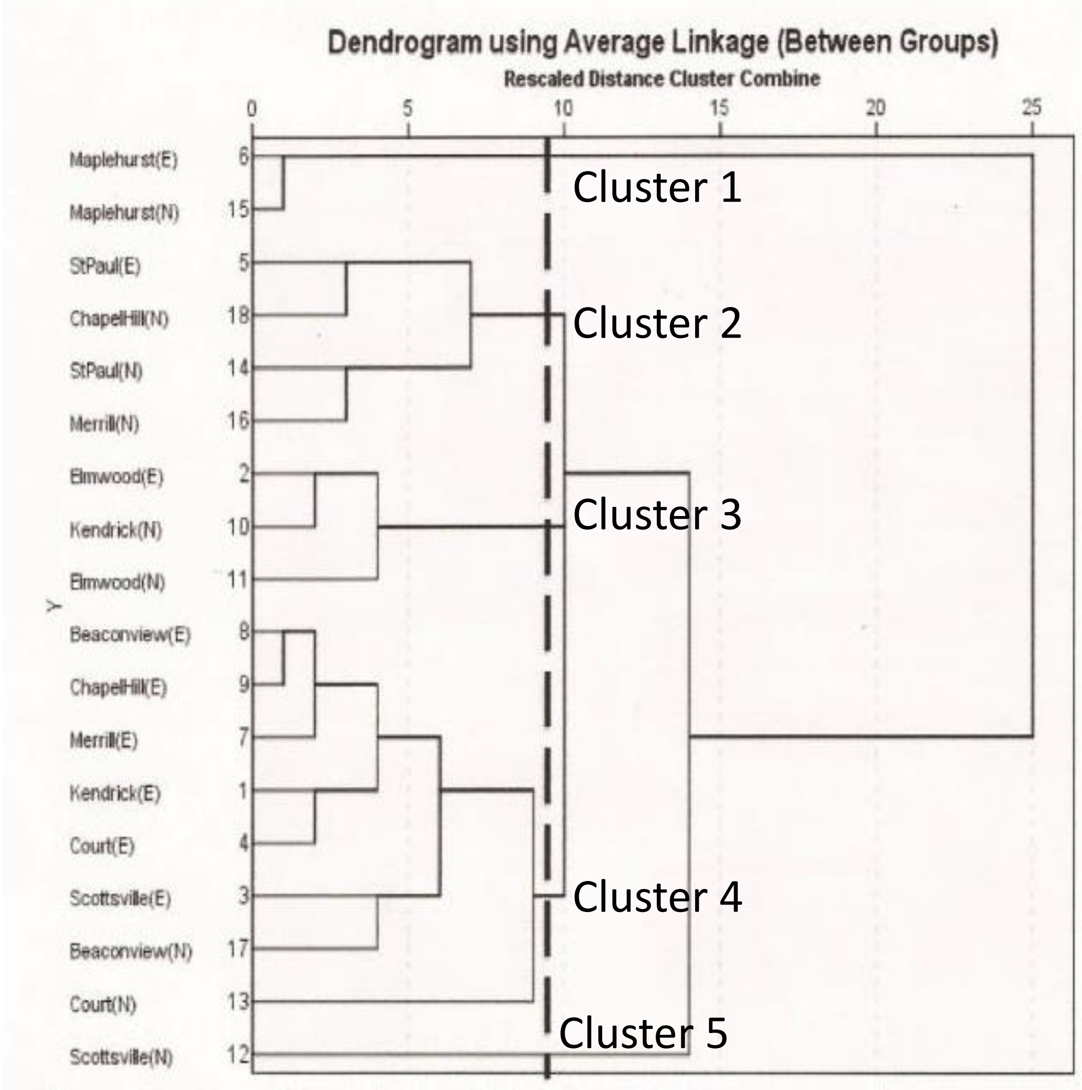


Figure 7. Dendogram from a cluster analysis performed on event average (E) and nonevent average (N) concentrations of total phosphorus, nitrates, total suspended solids, soluble reactive phosphorus, total nitrogen, and total coliform bacteria from nine different storm sewer sites in the City of Rochester.

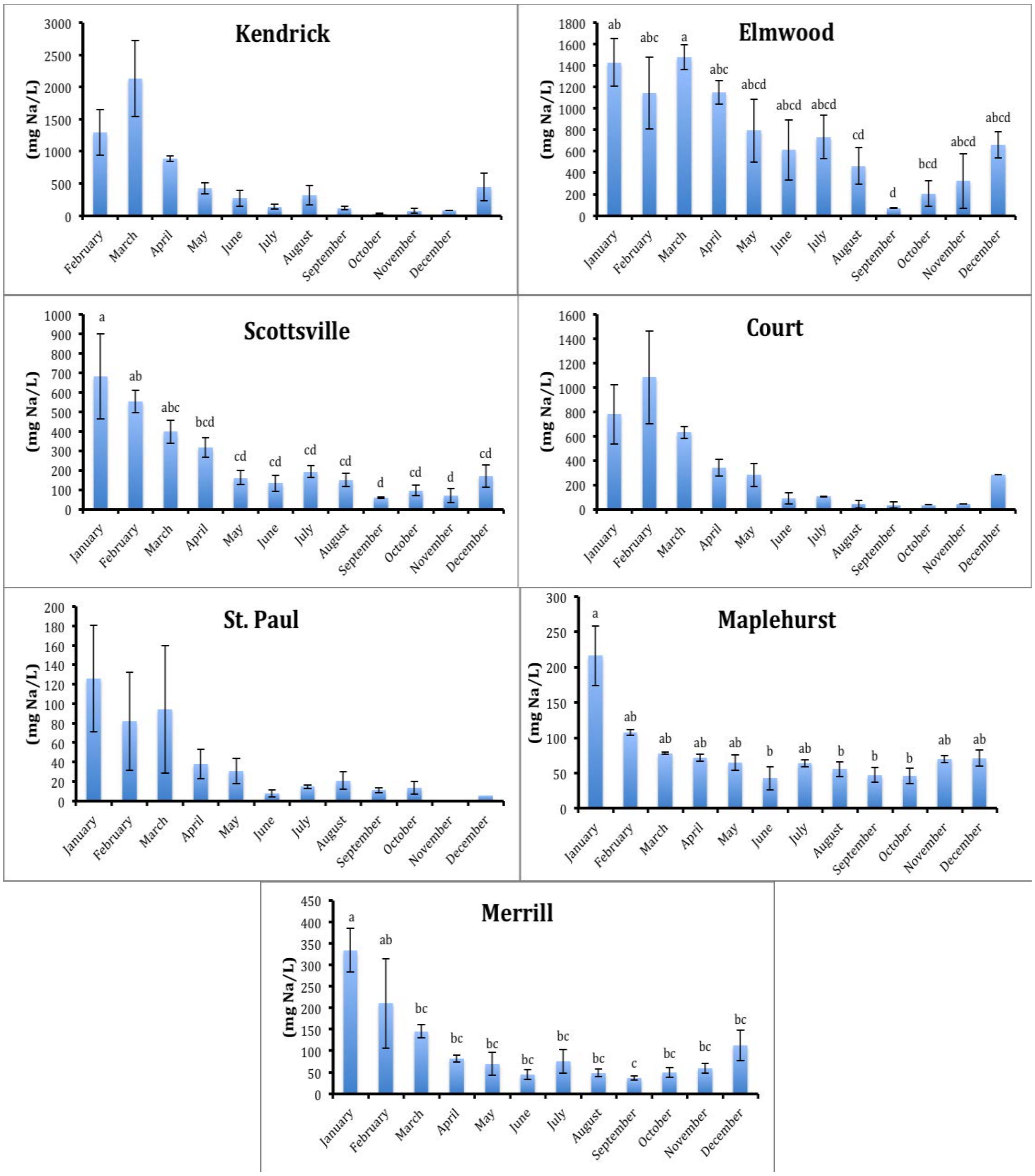


Figure 8. Average monthly dissolved sodium concentrations (± standard error) at seven different storm sewer sites (Fig. 2). Data were compared with one-way ANOVAs and Tukey's post hoc tests. Standard error bars are shown. Months that share letters above error bars are statistically similar. Post hoc tests could not be run at Kendrick Road, Court Street, and St. Paul Street due to low sample sizes in some months.

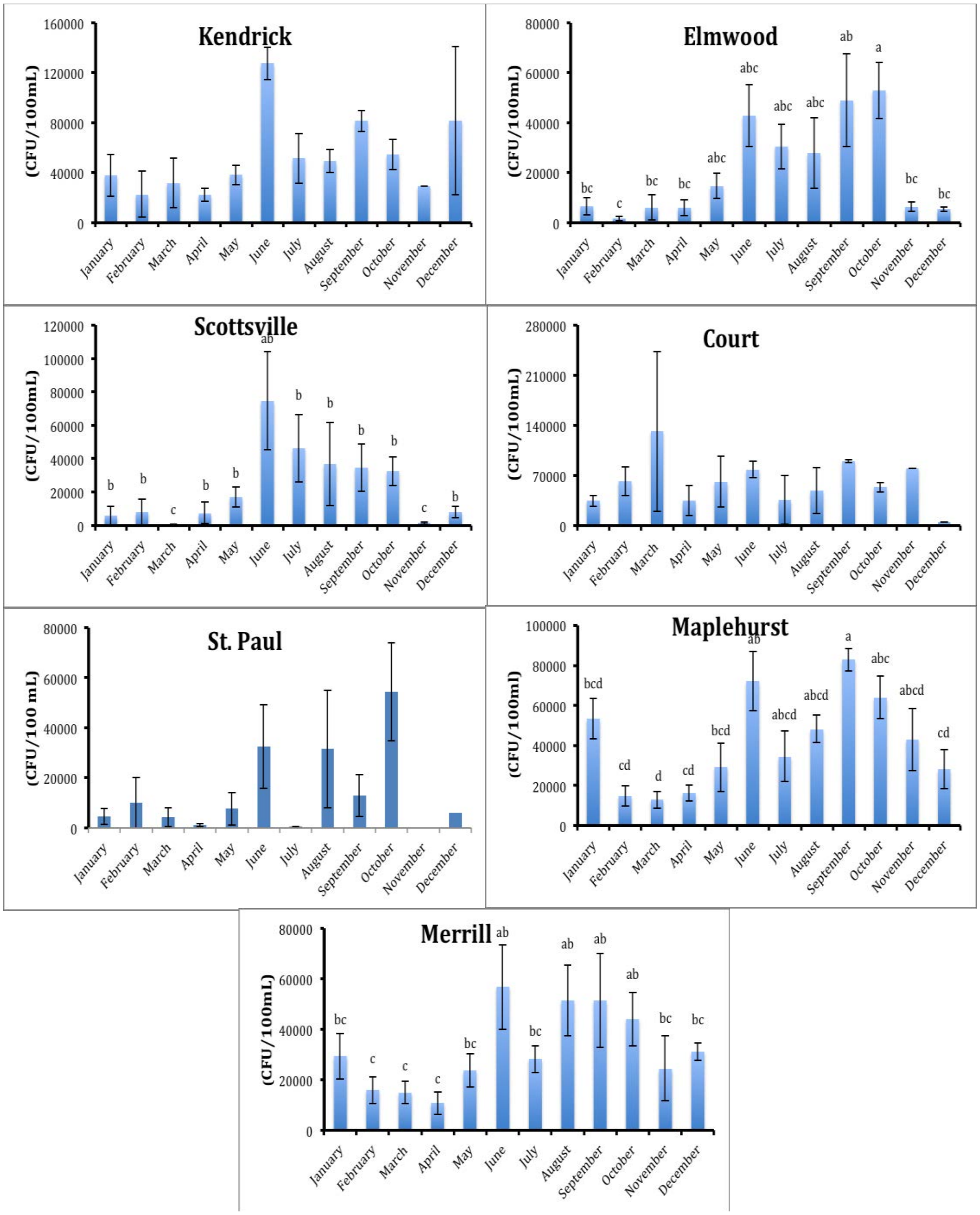


Figure 9. Average monthly total coliform concentrations (± standard error) at seven different storm sewer sites (Fig. 2). Data were compared with one-way ANOVAs (Tukey's post hoc). Months that share letters above error bars represent statistically similar months. Post hoc tests could not be run at Court Street, Kendrick Road, or St. Paul Street due to low sample sizes in some months.

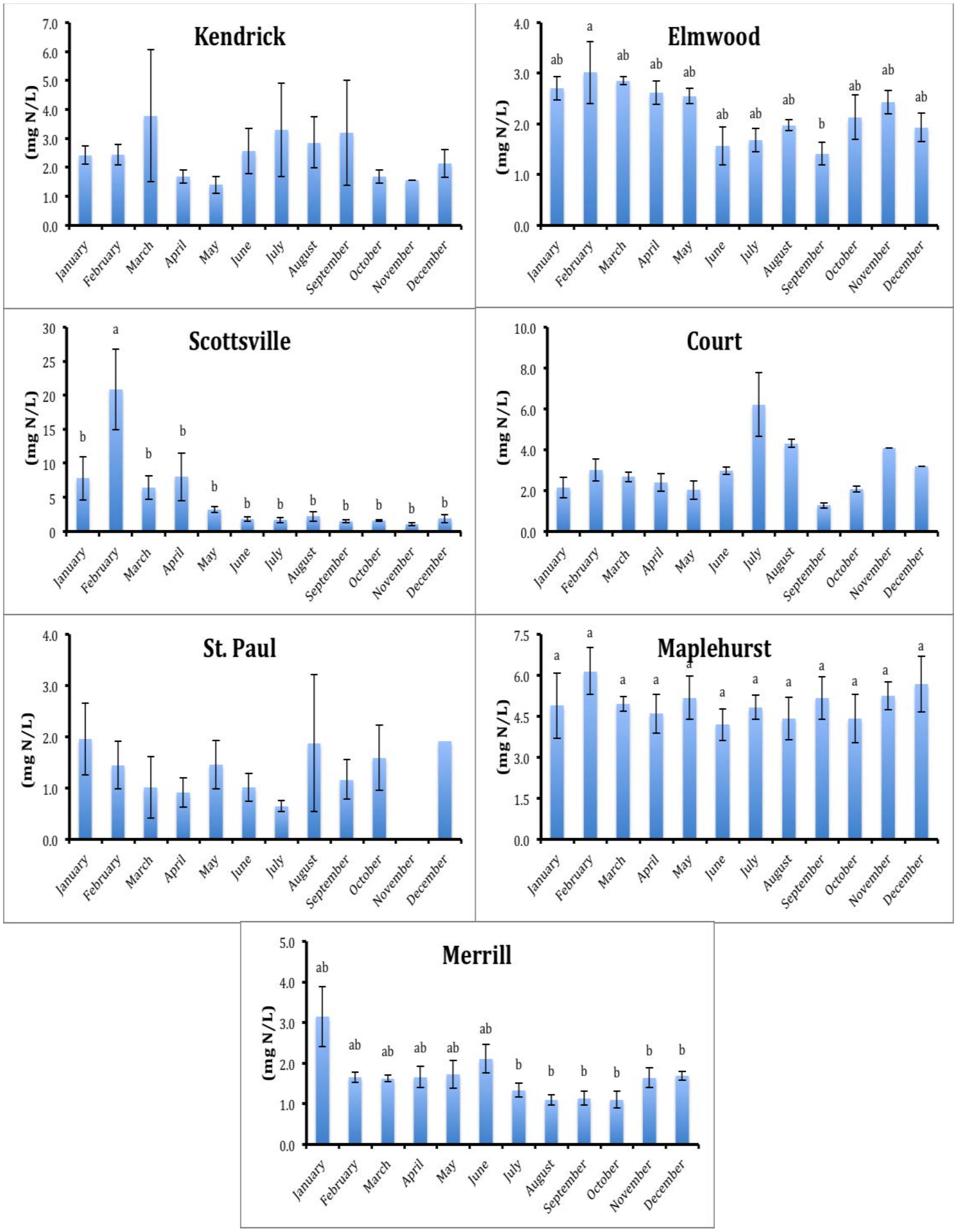


Figure 10. Average monthly total nitrogen concentrations (± standard error) at seven different storm sewer sites (Fig. 2). Data were compared with one-way ANOVAs (Tukey's post hoc). Months that share letters above error bars represent statistically similar months. Post hoc tests could not be run at Court Street, Kendrick Road, or St. Paul Street due to low sample sizes in some months.

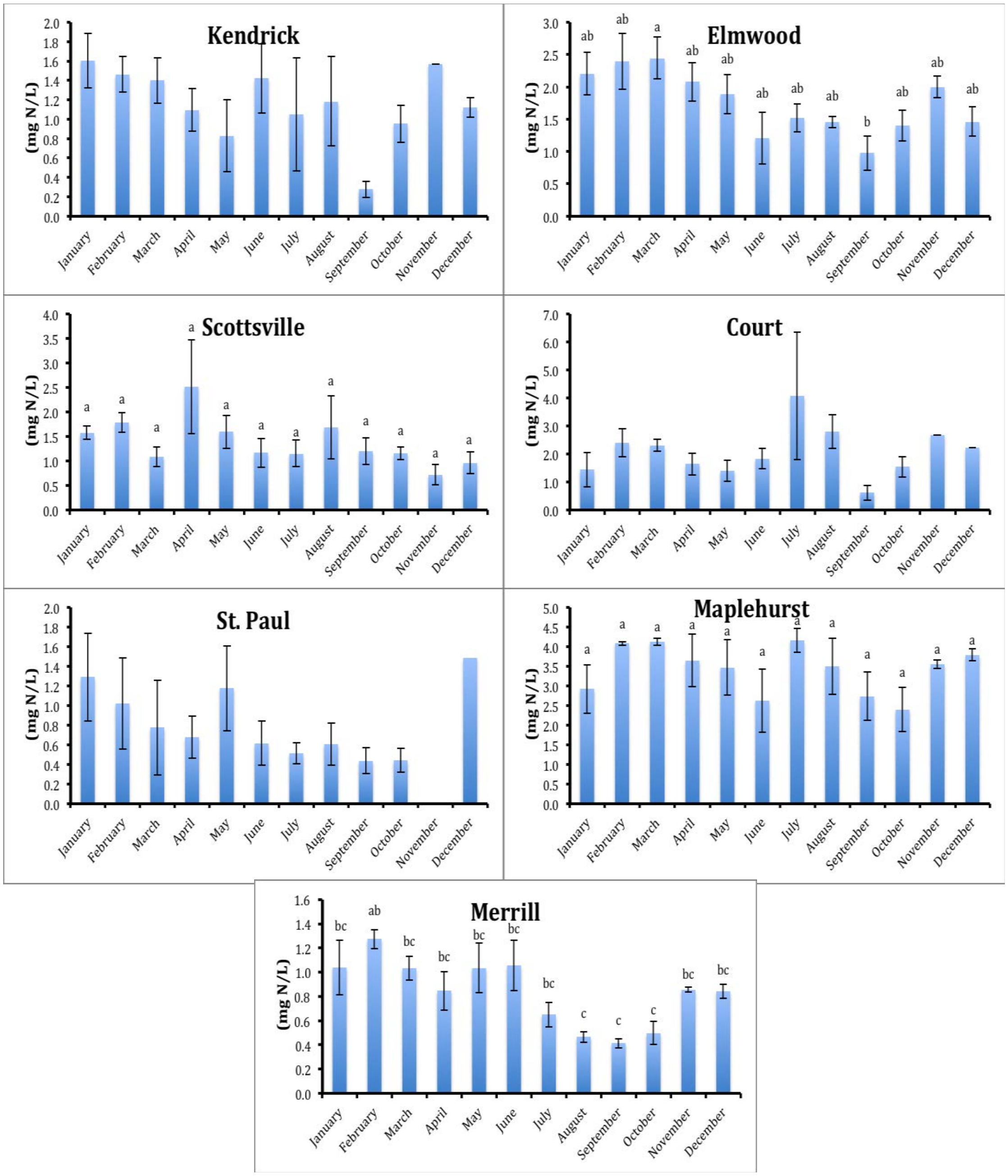


Figure 11. Average monthly nitrate concentrations (± standard error) at seven different storm sewer sites (Fig. 2). Data were compared with one-way ANOVAs and Tukey's post hoc tests. Standard error bars are shown. Months that share letters above error bars represent statistically similar months. Post hoc tests could not be run at Kendrick Road, Court Street, and St. Paul Street due to low sample sizes in some months.

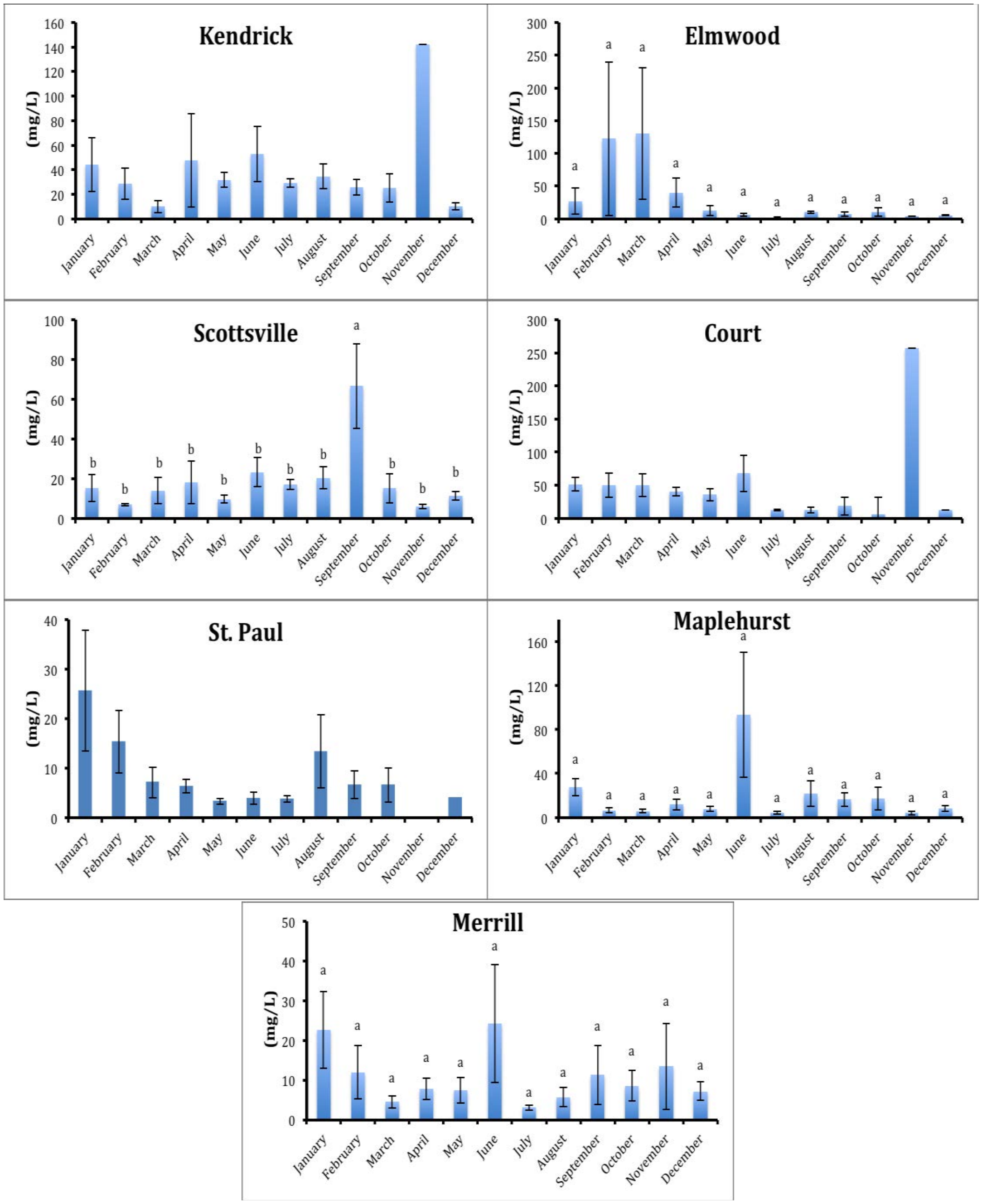


Figure 12. Average monthly total suspended solid concentrations (± standard error) at seven different storm sewer sites (Fig. 2). Data were compared with one-way ANOVAs and Tukey's post hoc tests. Months that share letters above error bars represent statistically similar months. Post hoc tests could not be run at Kendrick Road, Court Street, and St. Paul Street due to low sample sizes in some months.

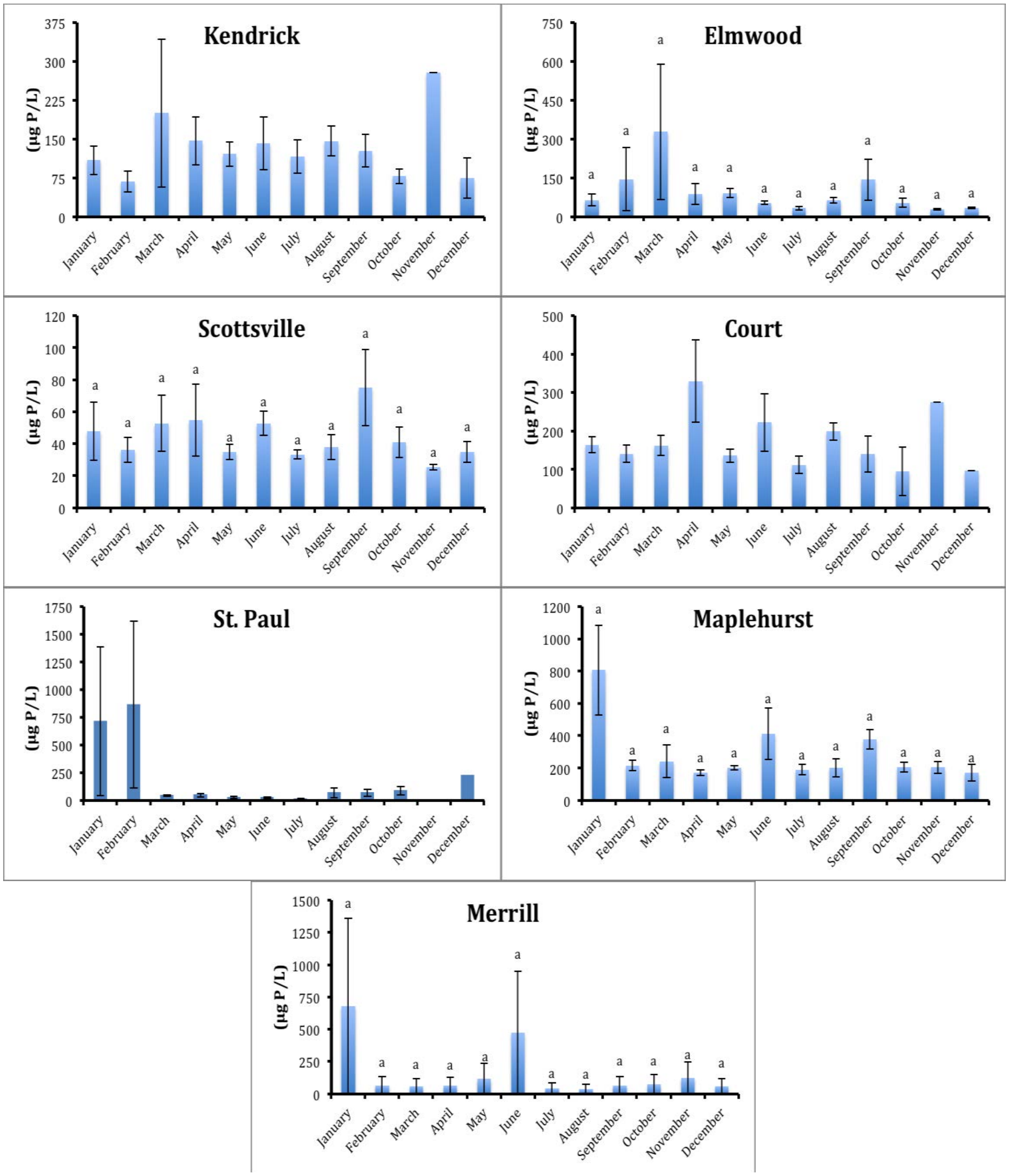


Figure 13. Average monthly total phosphorus concentrations (± standard error) at seven different storm sewers sites (Fig. 2). Data were compared with one-way ANOVAs and Tukey's post hoc tests. Months that share letters over error bars are statistically similar. Post hoc tests could not be run at Kendrick Road, Court Street, and St. Paul Street due to low sample sizes in some months.

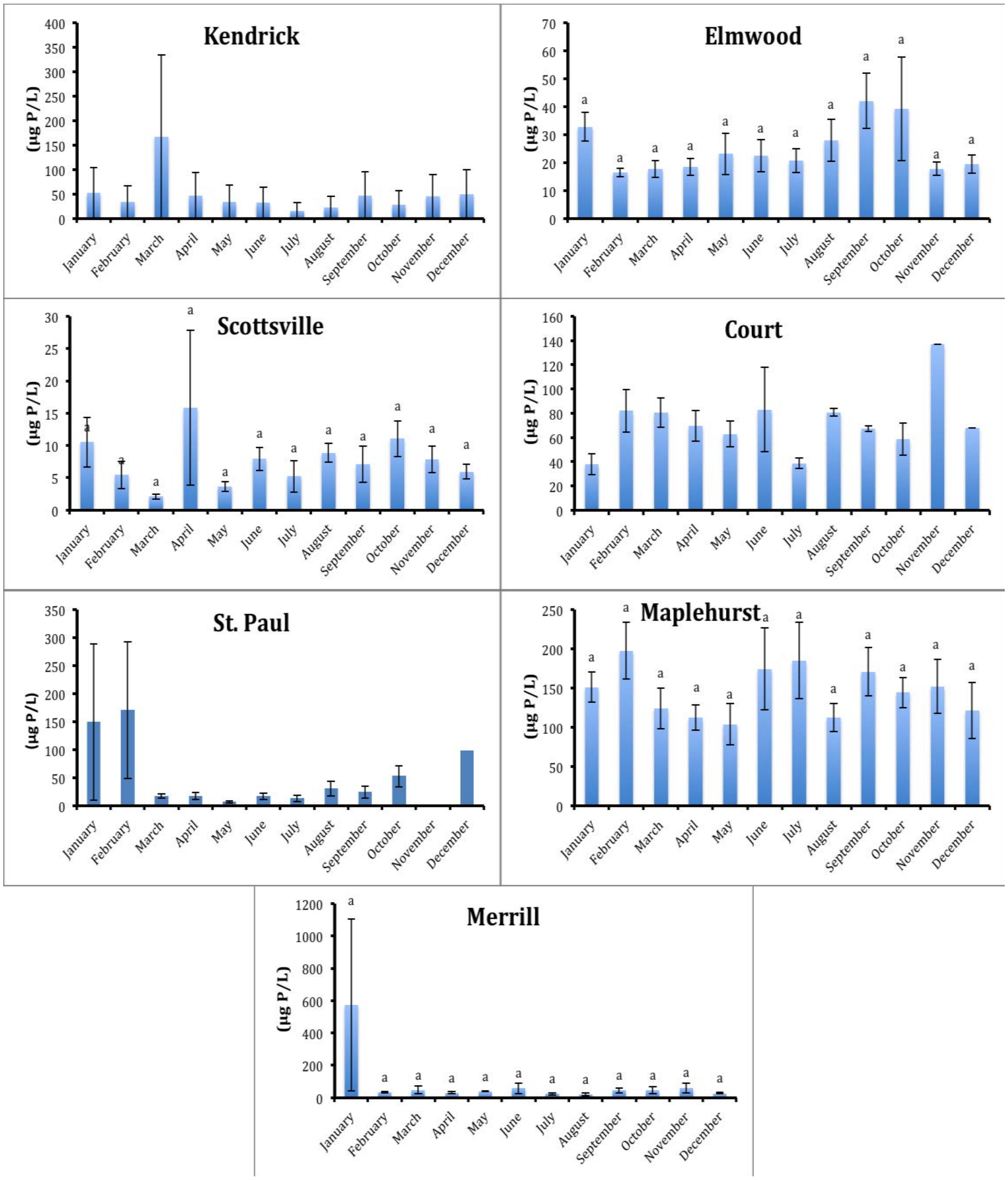


Figure 14. Average monthly soluble reactive phosphorus concentrations (± standard error) at seven different storm sewer sites (Fig. 2). Data were compared with one-way ANOVAs and Tukey's post hoc tests. Months that share letters over error bars are statistically similar. Post hoc tests could not be run at Kendrick Road, Court Street, and St. Paul Street due to low sample sizes in some months.

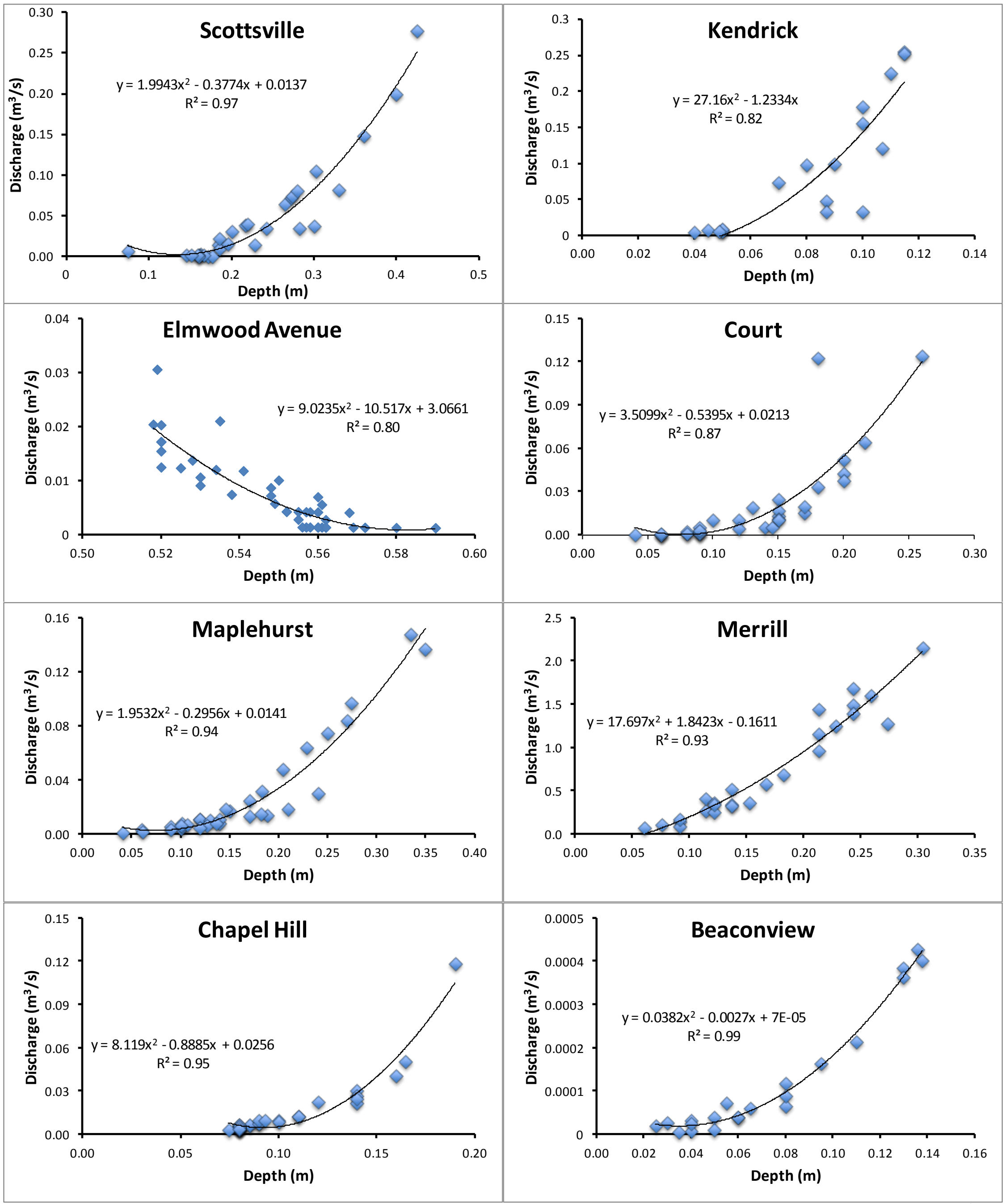


Figure 15. Rating curves with second order polynomial trendlines, equations, and R^2 for separate storm sewer sites. The depth at Elmwood Avenue was measured from top of the outfall to the water level instead of the bottom of the outfall to the water level, which resulted in a curve opposite from the others.

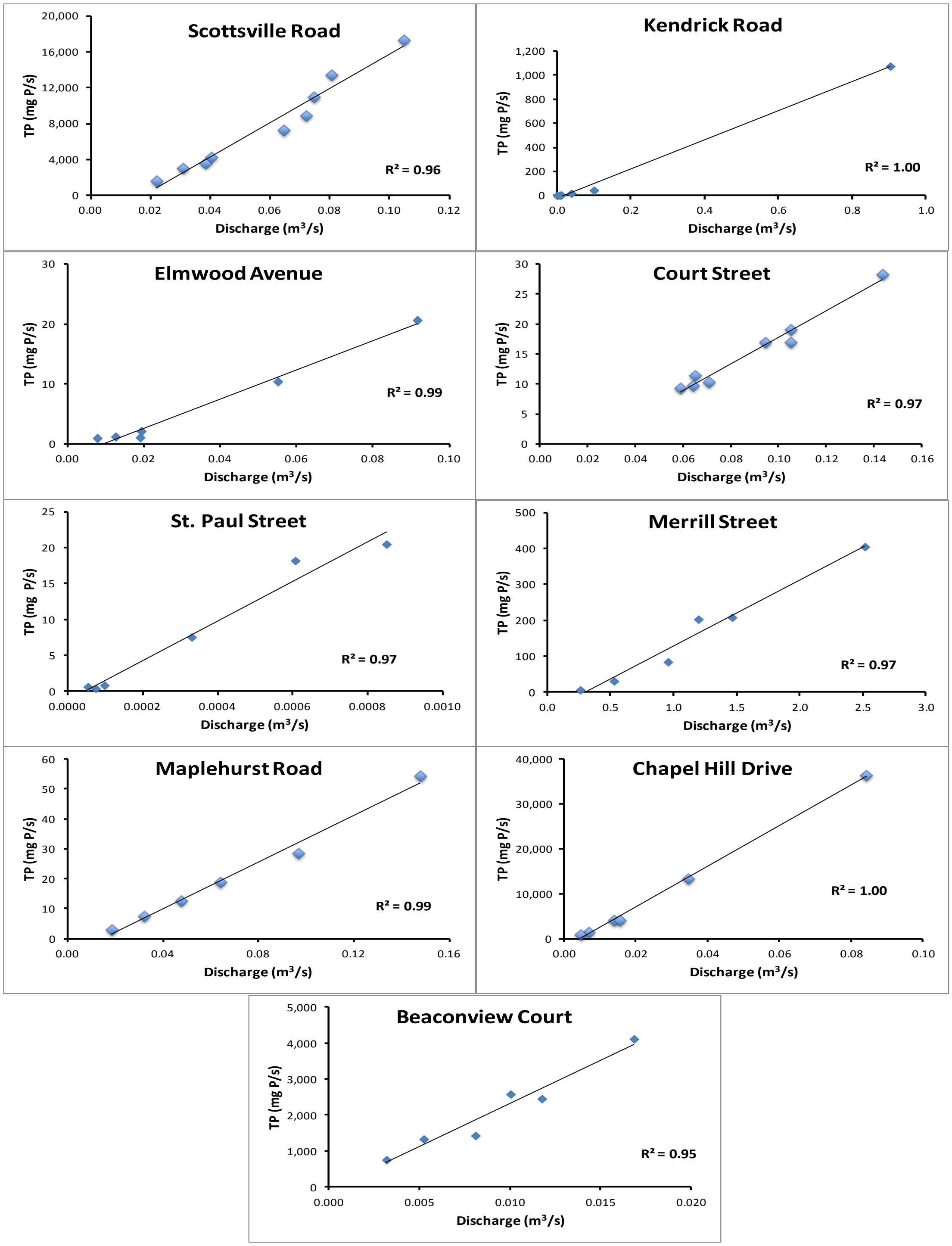


Figure 16. Total phosphorus (TP) loads versus discharge at nine storm sewer sites in the City of Rochester.

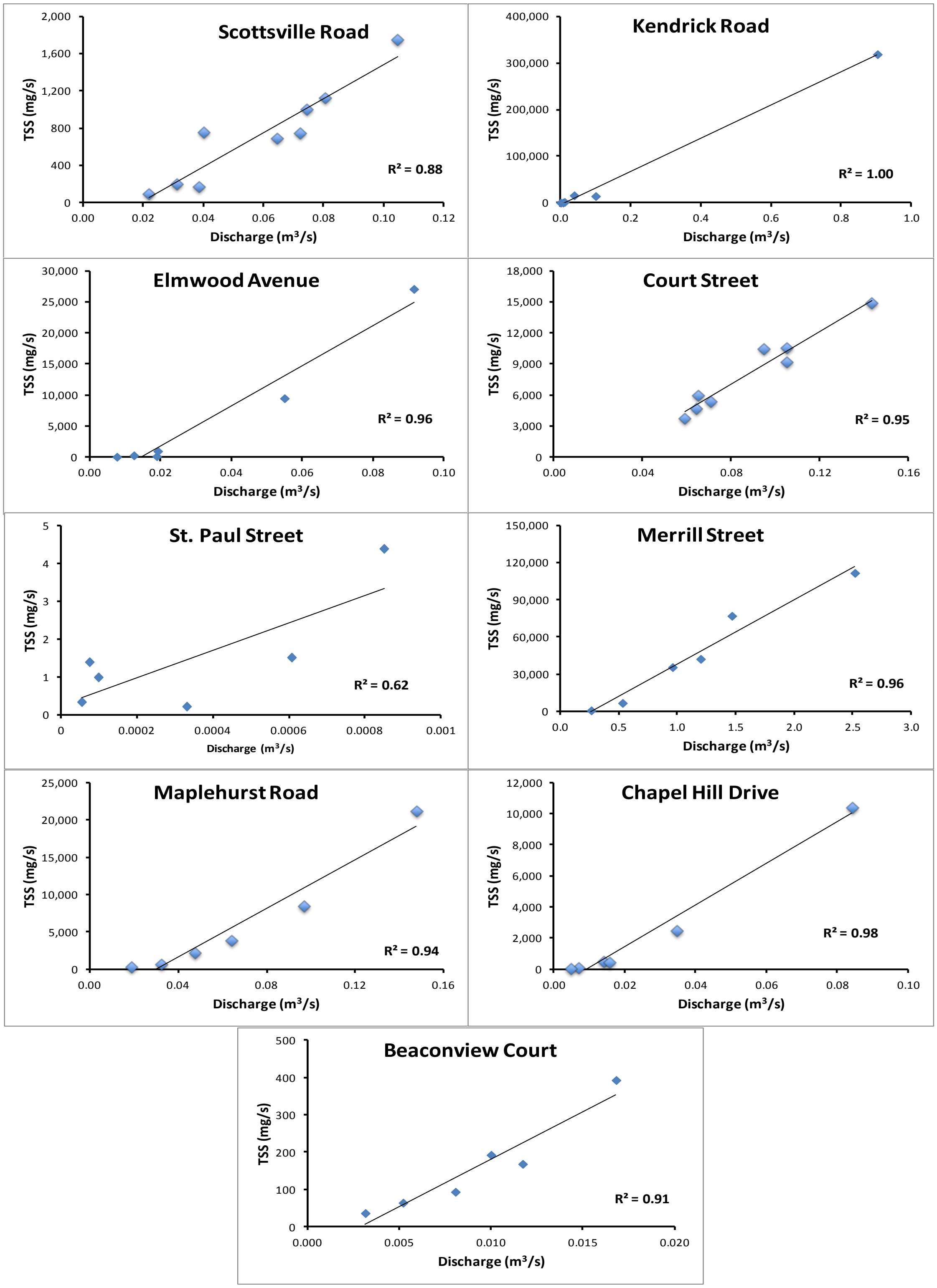


Figure 17. Total suspended solids (TSS) loads versus discharge at nine storm sewer sites in the City of Rochester.

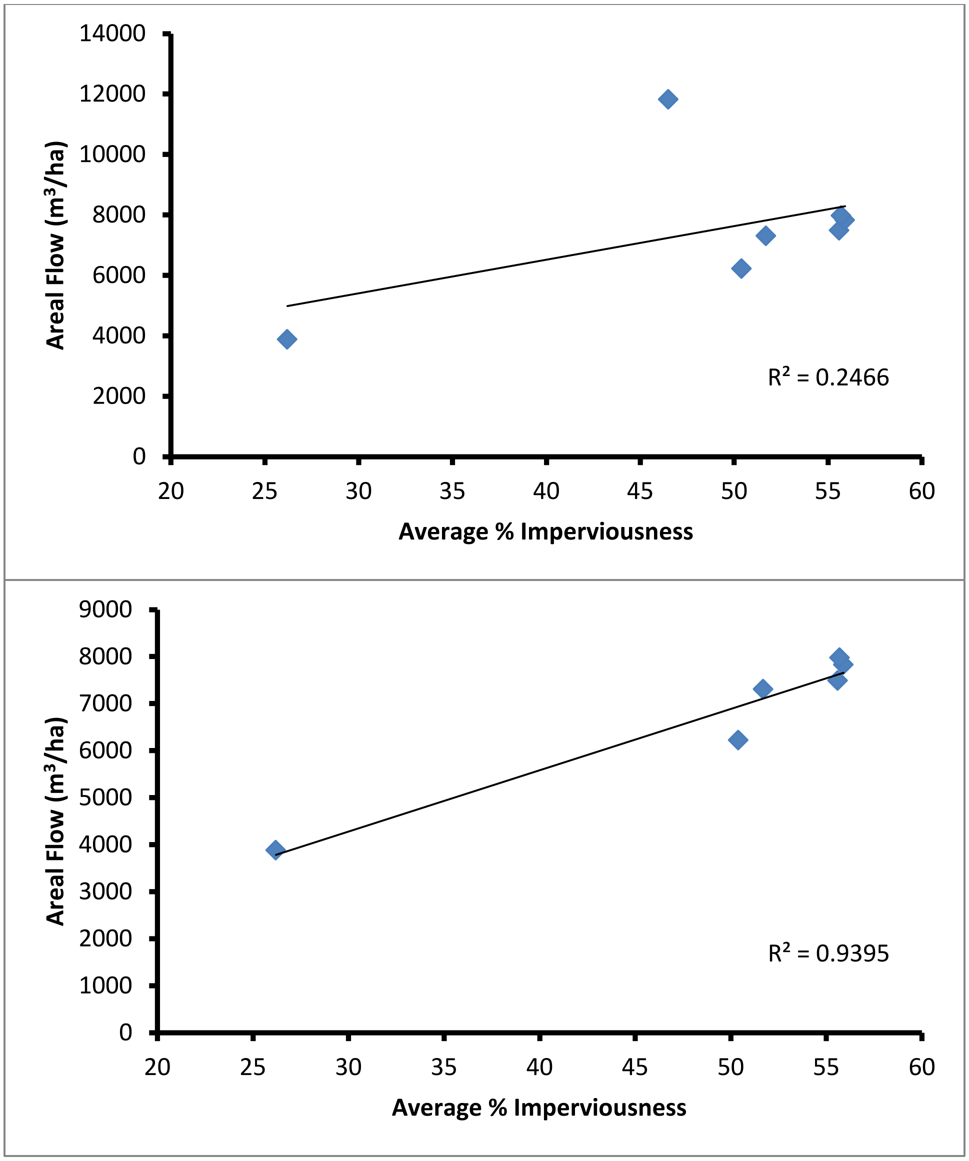


Figure 18. Relationship between sewershed average percent imperviousness and sewershed areal flow (m^3/ha) for all sewersheds in the City of Rochester (top) and for all sewersheds except the Merrill sewershed (bottom). See Figure 3 for site location.

Figure 19. Areal photograph of the intersection of the Genesee River and New York State Barge Canal taken 8 October 2003 (provided by A. Sansone, Monroe County Environmental Services).

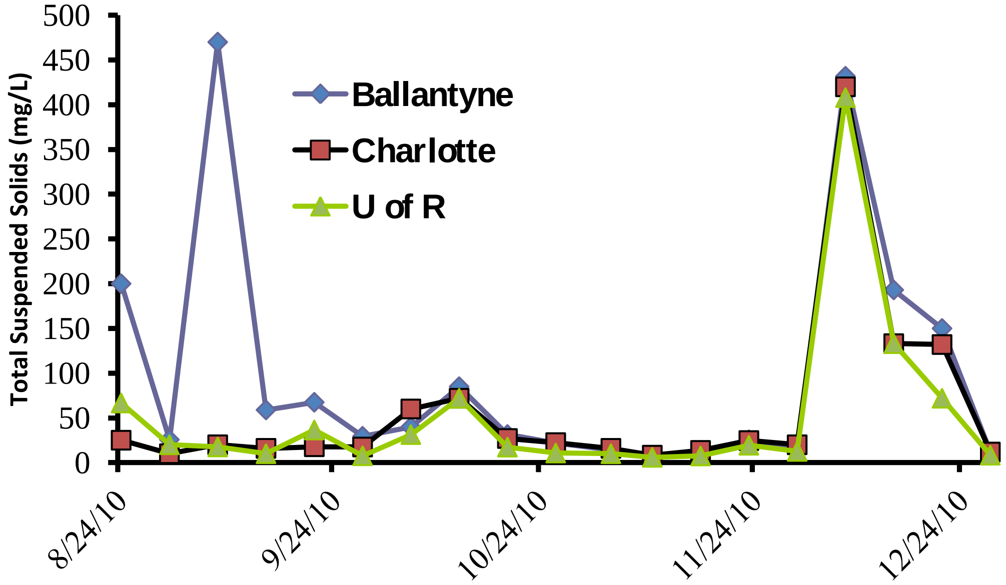


Figure 20. Total suspended solid concentrations from three sites along the Genesee River: Ballantyne, U of R, and Charlotte. Ballantyne is upstream of the Genesee River and New York State Barge Canal intersection, and U of R and Charlotte are downstream. The canal was closed on 15 November 2010 (Fig. 2).

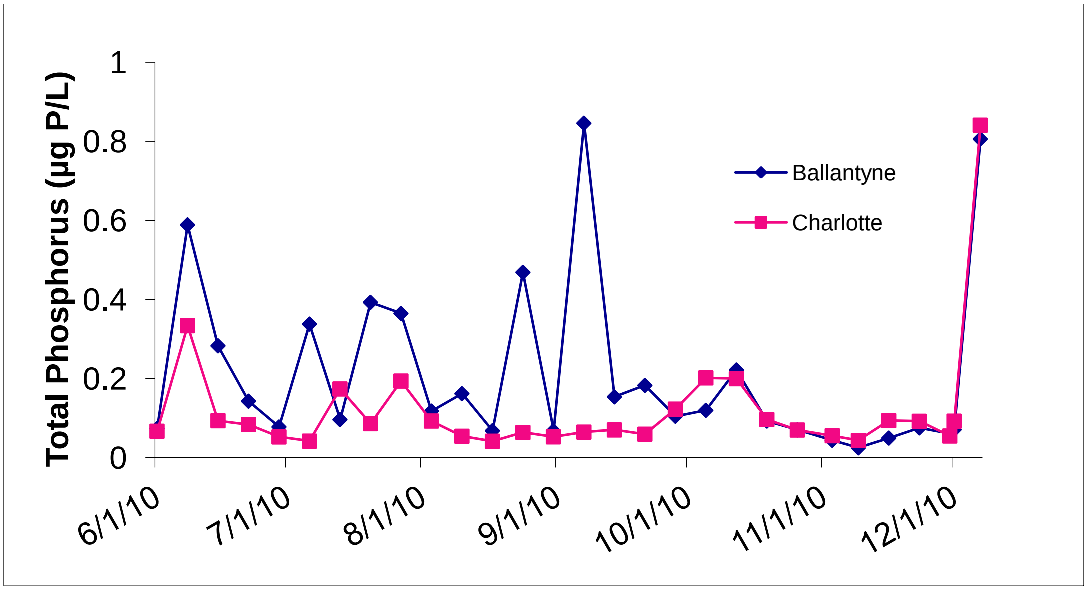


Figure 21. Total phosphorus concentrations at two sites along the Genesee River, Ballantyne, and Charlotte. Ballantyne is upstream of the Genesee River and New

York State Barge Canal intersection, and Charlotte is downstream. The canal was closed on 15 November 2010 (Fig.2).

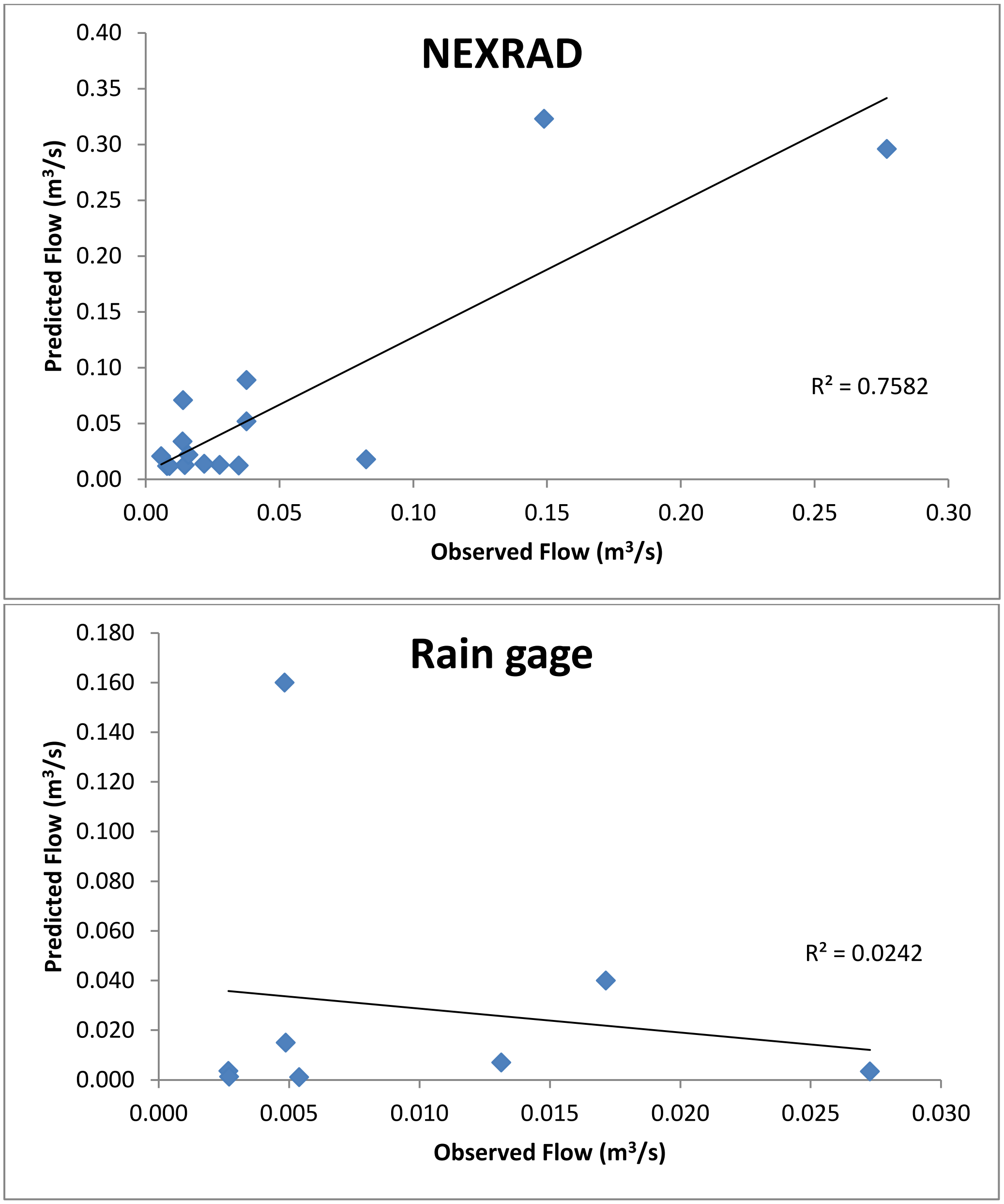
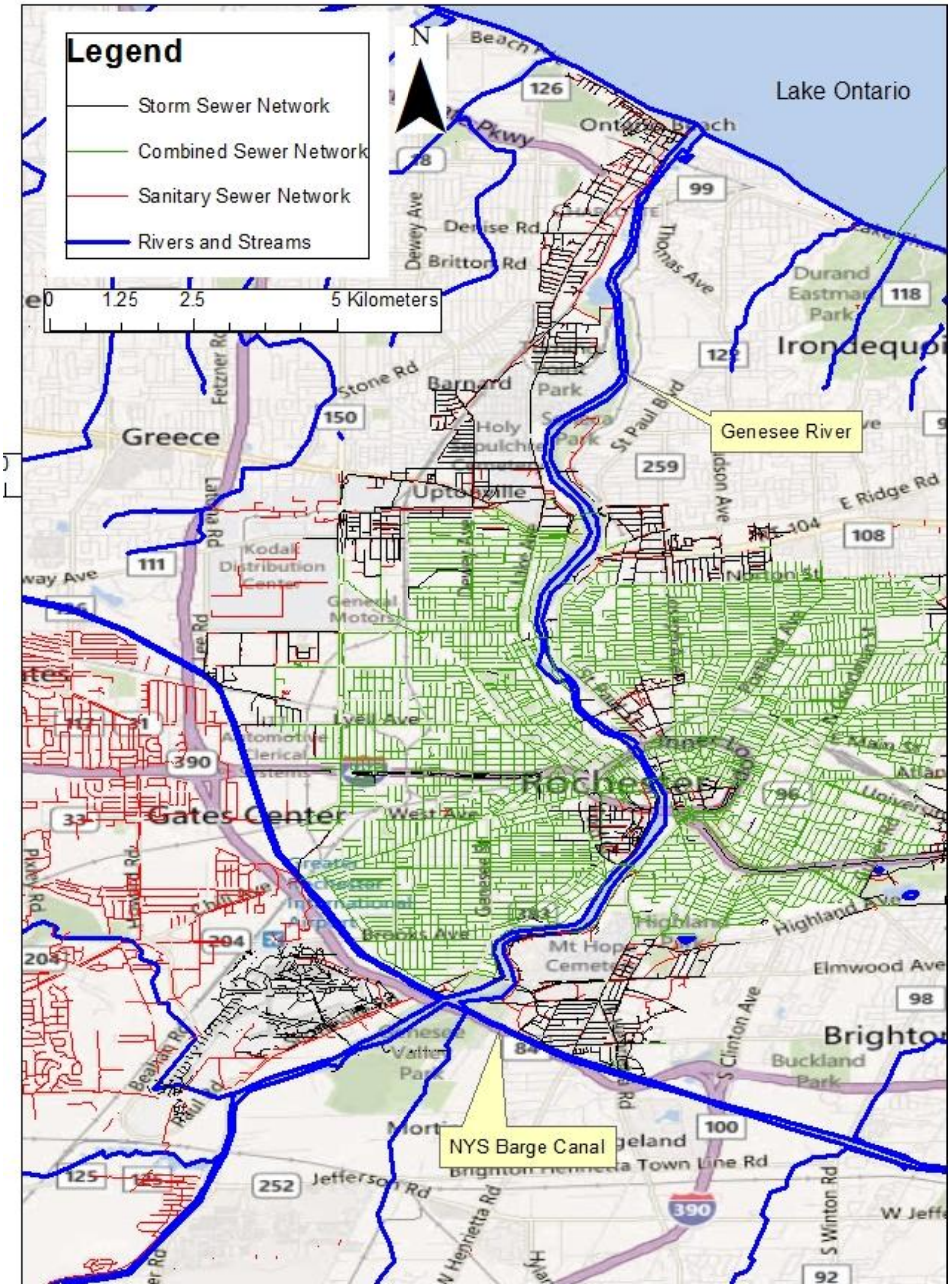


Figure 22. Model-predicted flows versus observed flows measured during periods of elevated flow for model validation at the Chapel Hill storm sewer site when NEXRAD (next generation radar) data was used for precipitation and when a singular rain gage was used for precipitation (Fig. 2). Coefficients of determination are shown.

Appendix A. The sewer networks that serve the City of Rochester. The three main sewer networks are combined (sanitary wastewater and storm water), sanitary, and storm. Water from combined and sanitary sewers is transported and treated at the Van Lare Wastewater Treatment Plant, and storm sewers discharge into the Genesee River and the New York State Barge Canal.



Appendix B. Monthly (m^3), 2012 annual (m^3), and areal flows (m^3/ha) to the Genesee River from individual stormwater outfalls that drain the Rochester sewersheds (Fig. 3). The individual outfalls that drain the sewersheds were arbitrarily assigned numbers (e.g. OF23 or 6478) by PCSWMM.

	Scottsville Sewershed			
	Individual Outfalls		Whole Sewershed	
	OF23 (m^3)	OF24 (m^3)	Total (m^3)	Areal (m^3/ha)
January	118,569	71,641	190,210	1,080
February	34,653	40,948	75,601	429
March	17,827	37,875	55,702	316
April	25,342	38,435	63,777	362
May	14,834	36,753	51,587	293
June	10,864	34,534	45,398	258
July	84,562	60,410	144,972	823
August	48,553	43,549	92,102	523
September	73,094	52,112	125,206	711
October	87,613	61,325	148,938	846
November	26,186	36,446	62,632	356
December	235,385	113,912	349,297	1,983
Annual	777,482	627,940	**1,405,422**	**7,979**

	Court Sewershed			
	Individual Outfalls		Whole Sewershed	
	OF9 (m^3)	OF10 (m^3)	Total (m^3)	Areal (m^3/ha)
January	1,969	75,342	77,311	1,080
February	499	18,112	18,611	260
March	418	13,771	14,189	198
April	452	15,628	16,080	225
May	311	8,680	8,991	126
June	317	9,890	10,207	143
July	1,853	62,835	64,688	903
August	1,242	42,958	44,200	617
September	1,790	59,310	61,100	853
October	1,704	61,908	63,612	888
November	429	14,065	14,494	202
December	3,571	139,367	142,938	1,996
Annual	14,555	521,866	**536,421**	**7,492**

Appendix B. (continued)

	St. Paul Sewershed				
	Individual Outfalls			Whole Sewershed	
	6478 (m^3)	6479 (m^3)	6551 (m^3)	Total (m^3)	Areal (m^3/ha)
January	7,623	217,881	2,008	227,512	1,292
February	1,608	48,427	362	50,397	286
March	1,297	39,445	299	41,041	233
April	1,512	49,874	402	51,788	294
May	655	23,094	198	23,947	136
June	269	17,369	149	17,787	101
July	4,215	119,206	1,003	124,424	706
August	4,874	116,217	1,043	122,134	693
September	8,422	208,128	1,904	218,454	1,240
October	5,608	172,660	1,290	179,558	1,019
November	1,709	59,740	447	61,896	351
December	13,983	404,062	3,583	421,628	2,394
Annual	51,775	1,476,103	12,688	**1,540,566**	**6,225**

	NE Court Sewershed					
	Individual Outfalls				Whole Sewershed	
	6537 (m^3)	6538 (m^3)	6546 (m^3)	6547 (m^3)	Total (m^3)	Areal (m^3/ha)
January	3,510	9,510	77,689	35,445	126,154	1,094
February	841	1,994	17,259	7,888	27,982	243
March	729	1,780	14,924	6,496	23,929	208
April	812	1,929	17,040	7,586	27,367	237
May	428	987	7,443	2,741	11,599	101
June	883	1,435	14,794	6,510	23,622	205
July	2,728	6,481	56,275	24,762	90,246	783
August	1,927	3,879	44,321	21,195	71,322	619
September	3,593	7,767	79,258	35,270	125,888	1,092
October	3,030	7,509	65,031	29,617	105,187	912
November	823	1,788	19,760	9,635	32,006	278
December	6,567	17,809	145,807	67,429	237,612	2,061
Annual	25,871	62,868	559,601	254,574	**902,914**	**7,831**

Appendix B. (continued)

	KenElm Sewershed				
	Individual Outfalls			Whole Sewershed	
Discharge	**OF2 (m^3)**	**OF4 (m^3)**	**6504 (m^3)**	**Total (m^3)**	**Areal (m^3/ha)**
January	31,039	45,298	16,368	92,705	990
February	8,767	12,495	12,489	33,751	361
March	5,424	7,462	12,796	25,682	274
April	6,234	8,627	12,538	27,399	293
May	6,624	7,434	12,662	26,720	285
June	2,092	2,410	11,945	16,447	176
July	25,952	31,748	15,739	73,439	785
August	13,537	15,753	14,286	43,576	466
September	26,076	29,448	14,940	70,464	753
October	25,316	36,472	15,975	77,763	831
November	6,557	8,436	12,472	27,465	293
December	59,688	88,643	20,409	168,740	1,803
Annual	217,306	294,226	172,619	**684,151**	**7,309**

Appendix B. (continued)

	Merrill Sewershed													
	Individual Outfalls												Whole Sewershed	
	OF11 (m^3)	**OF12 (m^3)**	**OF13 (m^3)**	**OF14 (m^3)**	**OF15 (m^3)**	**OF16 (m^3)**	**OF17 (m^3)**	**OF18 (m^3)**	**OF19 (m^3)**	**OF20 (m^3)**	**OF21 (m^3)**	**OF22 (m^3)**	**Total (m^3)**	**Areal (m^3/ha)**
January	60,042	62,593	491	15,619	18,765	13,652	2,291	974,072	1,432	7,493	12,820	4,572	1,173,842	1,233
February	13,941	14,137	132	2,594	4,603	4,296	341	701,787	309	1,741	3,161	1,008	748,050	786
March	10,245	11,568	88	1,729	3,256	2,610	330	737,179	286	1,612	2,943	940	772,786	812
April	13,347	13,819	111	2,509	4,162	3,813	317	718,982	288	1,599	2,899	980	762,826	801
May	5,184	4,340	113	1,994	3,423	2,203	479	700,895	147	895	1,857	521	722,051	758
June	4,220	2,584	50	1,024	2,157	1,725	291	675,992	61	459	983	307	689,853	725
July	23,006	19,111	468	12,958	13,232	5,969	2,473	839,427	805	4,441	8,043	2,143	932,076	979
August	34,592	30,109	369	8,782	13,845	6,825	3,795	848,232	900	4,601	8,492	3,077	963,619	1,012
September	58,336	52,019	410	9,298	21,045	14,544	4,774	924,014	1,647	7,720	14,758	4,579	1,113,144	1,169
October	44,572	48,115	350	7,244	12,755	11,075	1,062	928,267	1,058	5,736	10,337	3,538	1,074,109	1,128
November	17,880	16,632	135	2,673	4,265	3,549	289	738,757	325	1,918	3,533	1,189	791,145	831
December	104,639	108,729	736	22,044	29,777	24,680	2,548	1,175,584	2,545	13,385	22,522	7,730	1,514,919	1,591
Annual	390,004	383,756	3,453	88,468	131,285	94,941	18,990	9,963,188	9,803	51,600	92,348	30,584	**11,258,420**	**11,826**

Appendix B. (continued)

	Irondequoit Sewershed											
	Individual Outfalls										Whole Sewershed	
	OF1 (m^3)	OF2 (m^3)	OF3 (m^3)	OF5 (m^3)	OF6 (m^3)	OF7 (m^3)	OF36 (m^3)	OF42 (m^3)	OF43 (m^3)	OF44 (m^3)	Total (m^3)	Areal (m^3/ha)
January	3,547	13,704	60,454	63,162	13,064	26,992	12,656	25,458	2,274	136,814	358,125	523
February	72	1,991	20,064	26,884	3,558	11,750	1,105	6,825	364	92,585	165,198	241
March	95	1,583	16,355	26,933	2,763	9,648	1,124	5,607	297	95,889	160,294	234
April	436	2,788	15,457	27,897	3,512	8,665	2,356	6,130	409	97,283	164,933	241
May	58	1,362	10,430	23,338	2,265	5,123	485	2,630	149	89,781	135,621	198
June	470	959	6,629	19,990	1,144	3,621	603	2,280	131	87,090	122,917	179
July	762	4,968	17,348	38,783	7,095	8,909	3,520	11,503	847	101,270	195,005	285
August	1,156	5,913	19,199	40,387	6,345	7,792	5,211	10,836	991	10,273	108,103	158
September	1,687	10,157	40,965	52,662	9,756	16,351	8,030	18,441	1,636	116,759	276,444	404
October	691	6,077	39,503	53,931	8,663	22,023	4,740	20,554	1,286	123,827	281,295	411
November	209	1,845	18,491	29,206	2,639	11,052	1,493	6,376	376	97,948	169,635	248
December	4,838	22,173	88,165	94,248	22,780	44,140	19,081	43,858	3,539	178,787	521,609	762
Annual	14,021	73,520	353,060	497,421	83,584	176,066	60,404	160,498	12,299	1,228,306	**2,659,179**	**3,883**

Appendix B. (continued)

	Individual Outfalls									Small Drainage Areas
	OF1	**6457**	**6460**	**6506**	**6507**	**OF25**	**6545**	**6540**	**6541**	**Total (m^3)**
January	1,361	834	1,127	3,048	724	3,923	12,543	4,687	1,535	29,782
February	380	199	299	763	199	1,030	3,219	1,173	364	7,626
March	211	122	173	443	120	691	2,655	979	295	5,689
April	273	152	222	554	149	761	2,873	1,112	330	6,426
May	88	90	97	143	82	437	2,020	510	123	3,590
June	89	64	78	148	60	232	2,189	1,104	324	4,288
July	1,097	624	892	2,303	587	3,018	9,763	3,604	1,145	23,033
August	730	456	643	1,619	427	1,860	6,858	2,926	913	16,432
September	998	609	854	2,137	574	2,958	12,181	4,914	1,560	26,785
October	1,113	601	885	2,240	587	2,982	10,656	4,111	1,276	24,451
November	189	122	162	359	117	649	2,857	1,343	384	6,182
December	2,722	1,610	2,224	6,066	1,416	7,775	22,153	8,857	2,936	55,759
Annual	9,251	5,483	7,656	19,823	5,042	26,316	89,967	35,320	11,185	210,043

Appendix C. Monthly (kg), 2012 annual (kg P), and areal loads (g P/ha) of total phosphorus to the Genesee River from individual stormwater outfalls that drain the Rochester sewersheds (Fig. 3). The individual outfalls that drain the sewersheds were arbitrarily assigned numbers (e.g. OF23 or 6478) by PCSWMM.

	Scottsville Sewershed			
	Individual Outfalls		Whole Sewershed	
	OF23 (kg P)	OF24 (kg P)	Total (kg P)	Areal (g P/ha)
January	15.64	6.29	21.93	124.52
February	4.52	2.45	6.96	39.53
March	2.35	1.86	4.21	23.87
April	3.33	2.04	5.36	30.45
May	1.91	1.70	3.61	20.51
June	1.44	1.52	2.96	16.79
July	11.23	4.83	16.06	91.15
August	6.41	2.61	9.02	51.20
September	9.71	3.85	13.56	76.99
October	11.61	4.86	16.47	93.49
November	3.36	1.75	5.11	29.00
December	31.28	11.94	43.22	245.34
Annual	102.77	45.70	**148**	**843**

	Court Sewershed			
	Individual Outfalls		Whole Sewershed	
	OF9 (kg P)	OF10 (kg P)	Total (kg P)	Areal (g P/ha)
January	0.32	12.03	12.34	162.16
February	0.08	2.83	2.91	38.27
March	0.07	2.19	2.26	29.63
April	0.07	2.51	2.58	33.89
May	0.05	1.39	1.44	18.92
June	0.05	1.59	1.64	21.58
July	0.29	10.10	10.39	136.57
August	0.20	6.91	7.11	93.38
September	0.29	9.57	9.86	129.57
October	0.27	9.95	10.22	134.28
November	0.07	2.18	2.25	29.51
December	0.58	22.43	23.00	302.26
Annual	2.33	83.66	**86**	**1,130**

Appendix C. (continued)

	St. Paul Sewershed				
	Individual Outfalls			Whole Sewershed	
	6478 (kg P)	6479 (kg P)	6551 (kg P)	Total (kg P)	Areal (g P/ha)
January	0.18	5.06	0.05	5.28	30.00
February	0.04	1.08	0.01	1.12	6.38
March	0.03	0.90	0.01	0.94	5.34
April	0.04	1.17	0.01	1.22	6.93
May	0.02	0.52	0.01	0.54	3.07
June	0.01	0.40	0.00	0.41	2.30
July	0.10	2.78	0.02	2.91	16.50
August	0.12	2.72	0.03	2.86	16.25
September	0.20	4.88	0.05	5.13	29.11
October	0.13	4.03	0.03	4.19	23.78
November	0.04	1.35	0.01	1.40	7.94
December	0.33	9.50	0.09	9.91	56.28
Annual	1.23	34.39	0.30	**36**	**145**

	NE Court Sewershed					
	Individual Outfalls				Whole Sewershed	
	6537 (kg P)	6538 (kg P)	6546 (kg P)	6547 (kg P)	Total (kg P)	Areal (g P/ha)
January	0.56	1.52	12.40	5.66	20.13	174.60
February	0.13	0.31	2.70	1.24	4.38	38.01
March	0.12	0.28	2.37	1.03	3.80	32.97
April	0.13	0.31	2.73	1.22	4.39	38.06
May	0.07	0.16	1.18	0.44	1.85	16.01
June	0.13	0.23	2.38	1.05	3.80	32.94
July	0.44	1.05	9.08	4.00	14.56	126.29
August	0.31	0.63	7.14	3.42	11.50	99.71
September	0.58	1.25	12.79	5.70	20.32	176.27
October	0.49	1.20	10.44	4.76	16.89	146.48
November	0.13	0.28	3.09	1.51	5.00	43.39
December	1.06	2.86	23.46	10.85	38.23	331.54
Annual	4.15	10.07	89.78	40.85	**145**	**1,256**

Appendix C. (continued)

	KenElm Sewershed				
	Individual Outfalls			Whole Sewershed	
	OF2 (kg P)	OF4 (kg P)	6504 (kg P)	Total (kg P)	Areal (g P/ha)
January	6.00	45.11	1.33	52.44	275.99
February	1.67	12.22	0.68	14.57	76.66
March	1.04	7.33	0.62	8.99	47.30
April	1.21	8.58	0.63	10.42	54.84
May	1.28	7.27	0.60	9.14	48.11
June	0.41	2.35	0.52	3.27	17.21
July	5.08	32.08	1.21	38.36	201.89
August	2.64	15.73	0.92	19.30	101.56
September	5.09	29.46	1.11	35.67	187.71
October	4.92	36.73	1.19	42.85	225.51
November	1.23	8.04	0.61	9.88	51.97
December	11.63	88.93	2.14	102.70	540.50
Annual	42.19	293.82	11.55	**348**	**1,829**

Appendix C. (continued)

	Merrill Sewershed													
	Individual Outfalls												Whole Sewershed	
	OF11 (kg P)	OF12 (kg P)	OF13 (kg P)	OF14 (kg P)	OF15 (kg P)	OF16 (kg P)	OF17 (kg P)	OF18 (kg P)	OF19 (kg P)	OF20 (kg P)	OF21 (kg P)	OF22 (kg P)	Total (kg P)	Areal (g P/ha)
January	7.80	8.31	0.07	2.07	2.50	1.81	0.31	84.58	0.19	1.00	1.71	0.61	110.95	56.84
February	1.82	1.81	0.02	0.33	0.60	0.56	0.05	51.05	0.04	0.23	0.42	0.13	57.05	29.23
March	1.34	1.51	0.01	0.23	0.13	0.34	0.04	53.06	0.04	0.22	0.39	0.12	57.44	29.43
April	1.79	1.84	0.02	0.33	0.56	0.51	0.04	52.10	0.04	0.21	0.39	0.13	57.95	29.69
May	0.68	0.57	0.02	0.27	0.46	0.29	0.06	48.22	0.02	0.12	0.25	0.07	51.02	26.14
June	0.56	0.34	0.01	0.14	0.29	0.23	0.04	46.36	0.01	0.06	0.13	0.04	48.21	24.70
July	3.10	2.56	0.06	1.75	1.78	0.80	0.33	66.87	0.11	0.60	1.08	0.29	79.33	40.64
August	4.66	4.04	0.05	1.18	1.86	0.92	0.51	68.08	0.12	0.62	1.14	0.41	83.59	42.82
September	7.83	6.97	0.06	1.25	2.82	1.95	0.64	79.74	0.22	1.03	1.99	0.62	105.12	53.85
October	5.96	6.42	0.05	0.96	1.71	1.48	0.14	77.18	0.14	0.77	1.39	0.47	96.68	49.53
November	2.32	2.11	0.02	0.34	0.55	0.46	0.04	54.38	0.04	0.25	0.47	0.15	61.11	31.31
December	14.04	14.53	0.10	2.95	3.99	3.30	0.34	111.79	0.34	1.79	3.03	1.03	157.24	80.55
Annual	51.90	51.01	0.46	11.78	17.26	12.67	2.55	793.39	1.32	6.90	12.38	4.08	**966**	**1,014**

Appendix C. (continued)

	Irondequoit Sewershed											
	Individual Outfalls										Whole Sewershed	
	OF1 (kg P)	OF2 (kg P)	OF3 (kg P)	OF5 (kg P)	OF6 (kg P)	OF7 (kg P)	OF36 (kg P)	OF42 (kg P)	OF43 (kg P)	OF44 (kg P)	Total (kg P)	Areal (g P/ha)
January	0.85	3.10	14.02	19.99	3.16	7.80	3.05	6.16	0.55	12.82	71.50	104.40
February	0.01	0.43	4.53	7.68	0.84	3.27	0.25	1.63	0.09	3.47	22.21	32.42
March	0.02	0.34	3.69	7.65	0.65	2.69	0.26	1.34	0.07	3.00	19.69	28.75
April	0.10	0.63	3.67	8.04	0.85	2.55	0.57	1.49	0.10	3.41	21.42	31.27
May	0.01	0.31	2.50	0.11	0.63	0.04	1.61	6.47	0.55	1.47	13.71	20.01
June	0.01	0.22	1.59	5.39	0.28	1.04	0.15	0.56	0.03	1.62	10.88	15.89
July	0.19	1.14	4.17	11.75	1.73	2.59	0.86	2.81	0.21	4.41	29.86	43.59
August	1.16	5.91	19.20	12.31	1.55	2.23	1.28	2.65	0.24	4.80	51.33	74.95
September	0.41	2.41	9.80	16.52	2.38	4.52	1.96	4.10	0.40	8.62	51.11	74.63
October	0.16	1.39	9.48	16.95	2.11	6.42	1.15	5.01	0.31	9.75	52.73	76.99
November	0.04	0.40	4.14	8.40	0.62	3.16	0.34	1.52	0.09	3.49	22.19	32.40
December	1.18	5.08	20.62	30.71	5.57	12.73	4.65	10.00	0.87	22.21	113.61	165.88
Annual	4.14	21.36	97.40	145.50	20.38	49.03	16.12	43.72	3.51	79.06	**480**	**701**

Appendix C. (continued)

	Individual Outfalls									Small Drainage Areas
	OF1 (kg P)	**6457 (kg P)**	**6460 (kg P)**	**6506 (kg P)**	**6507 (kg P)**	**OF25 (kg P)**	**6545 (kg P)**	**6540 (kg P)**	**6541 (kg P)**	**Total (kg)**
January	0.86	0.53	0.71	1.92	0.46	2.48	2.01	0.75	0.25	9.96
February	0.24	0.12	0.19	0.47	0.12	0.64	0.51	0.18	0.06	2.53
March	0.13	0.08	0.11	0.28	0.08	0.44	0.43	0.16	0.05	1.74
April	0.17	0.10	0.14	0.35	0.10	0.48	0.46	0.18	0.05	2.03
May	0.06	0.06	0.06	0.09	0.05	0.28	0.33	0.08	0.02	1.02
June	0.06	0.04	0.05	0.09	0.04	0.15	0.35	0.18	0.05	1.01
July	0.70	0.40	0.57	1.47	0.37	1.93	1.57	0.58	0.19	7.77
August	0.46	0.29	0.41	1.03	0.27	1.18	1.11	0.47	0.15	5.37
September	0.63	0.39	0.54	1.36	0.37	1.88	1.97	0.79	0.25	8.19
October	0.71	0.38	0.56	1.42	0.37	1.89	1.72	0.66	0.21	7.91
November	0.12	0.07	0.10	0.22	0.07	0.39	0.45	0.21	0.06	1.69
December	1.73	1.02	1.41	3.85	0.90	4.94	3.63	1.43	0.47	19.39
Annual	5.86	3.47	4.86	12.56	3.20	16.67	14.52	5.68	1.80	69

Appendix D. Monthly (kg), 2012 annual (kg), and areal loads (g/ha) of total suspended solids to the Genesee River from individual stormwater outfalls that drain the Rochester sewersheds (Fig. 3). The individual outfalls that drain the sewersheds were arbitrarily assigned numbers (e.g. OF23 or 6478) by PCSWMM.

	Scottsville Sewershed			
	Individual Outfalls		**Whole Sewershed**	
	OF23 (kg)	**OF24 (kg)**	**Total (kg)**	**Areal (g/ha)**
January	1,452	919	2,370	13,455
February	419	540	959	5,443
March	218	507	724	4,113
April	309	512	821	4,662
May	177	492	670	3,801
June	133	465	598	3,394
July	1,042	782	1,824	10,357
August	595	577	1,171	6,650
September	901	681	1,582	8,983
October	1,078	796	1,873	10,636
November	312	486	797	4,527
December	2,903	1,442	4,346	24,670
Annual	9,539	8,198	**17,737**	**100,690**

	Court Sewershed			
	Individual Outfalls		**Whole Sewershed**	
	OF9 (kg)	**OF10 (kg)**	**Total (kg)**	**Areal (g/ha)**
January	160	6,087	6,246	82,082
February	40	1,435	1,474	19,374
March	34	1,108	1,142	15,007
April	37	1,268	1,305	17,148
May	25	704	729	9,580
June	26	806	832	10,933
July	149	5,112	5,261	69,127
August	101	3,496	3,596	47,260
September	146	4,845	4,991	65,586
October	139	5,034	5,173	67,974
November	34	1,103	1,137	14,941
December	291	11,351	11,642	152,989
Annual	1,181	42,348	**43,529**	**572,000**

Appendix D. (continued)

	St. Paul Sewershed				
	Individual Outfalls			St. Paul Sewershed	
	6478 (kg)	6479 (kg)	6551 (kg)	Total (kg)	Areal (g/ha)
January	33	931	9	973	5,522
February	7	198	2	207	1,174
March	6	166	1	173	983
April	7	216	2	224	1,274
May	3	96	1	99	564
June	1	73	1	75	426
July	19	512	4	535	3,039
August	21	501	5	527	2,991
September	37	899	8	944	5,360
October	24	741	6	771	4,377
November	7	248	2	257	1,462
December	61	1,748	16	1,825	10,361
Annual	226	6,330	55	**6,611**	**26,713**

	NE Court Sewershed					
	Individual Outfalls				Whole Sewershed	
	6537 (kg)	6538 (kg)	6546 (kg)	6547 (kg)	Total (kg)	Areal (g/ha)
January	284	767	6,276	2,863	10,190	88,375
February	67	158	1,369	626	2,220	19,250
March	59	142	1,201	522	1,924	16,690
April	66	156	1,384	616	2,222	19,271
May	35	79	599	221	934	8,102
June	68	117	1,206	531	1,922	16,670
July	223	530	4,595	2,023	7,371	63,929
August	158	317	3,616	1,729	5,820	50,477
September	294	634	6,476	2,884	10,288	89,225
October	246	609	5,285	2,408	8,548	74,137
November	65	141	1,565	762	2,533	21,969
December	535	1,448	11,874	5,492	19,349	167,814
Annual	2,099	5,099	45,446	20,677	**73,320**	**416,238**

Appendix D. (continued)

	KenElm Sewershed				
	Individual Outfalls			Whole Sewershed	
	OF2 (kg)	OF4 (kg)	6504 (kg)	Total (kg)	Areal (g/ha)
January	7,503	13,991	1,139	22,633	119,123
February	2,082	3,791	364	6,236	32,823
March	1,303	2,273	257	3,832	20,169
April	1,510	2,661	288	4,459	23,469
May	1,595	2,261	225	4,080	21,476
June	506	729	141	1,376	7,242
July	6,343	9,976	994	17,313	91,123
August	3,305	4,887	630	8,822	46,430
September	6,362	9,160	888	16,410	86,367
October	6,153	11,388	953	18,494	97,335
November	1,534	2,495	265	4,293	22,597
December	14,543	27,578	2,150	44,271	233,007
Annual	52,738	91,190	8,293	**152,220**	**801,160**

Appendix D. (continued)

	Outfall												Merrill Sewershed	
	OF11 (kg)	OF12 (kg)	OF13 (kg)	OF14 (kg)	OF15 (kg)	OF16 (kg)	OF17 (kg)	OF18 (kg)	OF19 (kg)	OF20 (kg)	OF21 (kg)	OF22 (kg)	Total (kg)	Areal (g/ha)
January	2,366	2,461	19	612	741	537	91	16,026	57	296	508	180	23,895	25,099
February	538	538	5	98	179	167	13	6,673	12	67	123	39	8,450	8,876
March	398	447	3	68	128	102	13	6,684	11	64	116	37	8,072	8,479
April	529	546	4	98	165	151	13	6,691	11	63	115	39	8,425	8,850
May	203	168	4	79	136	87	19	5,250	6	35	74	20	6,082	6,388
June	167	100	2	40	86	68	12	4,993	3	18	39	12	5,540	5,819
July	917	760	19	517	528	238	99	10,778	32	177	321	85	14,471	15,200
August	1,380	1,198	15	349	552	272	152	11,138	36	183	338	123	15,735	16,528
September	2,321	2,066	16	370	835	578	190	14,885	66	308	589	183	22,406	23,536
October	1,767	1,902	14	285	506	439	42	13,542	42	228	411	140	19,318	20,292
November	688	624	5	100	163	136	11	7,368	13	74	138	45	9,364	9,836
December	4,152	4,307	29	873	1,183	979	101	24,086	101	532	896	306	37,546	39,439
Annual	15,426	15,116	137	3,490	5,203	3,753	756	128,112	389	2,045	3,667	1,210	**179,303**	**188,343**

Appendix D. (continued)

	Irondequoit Sewershed											
	Individual Outfalls										Whole Sewershed	
	OF1 (kg)	OF2 (kg)	OF3 (kg)	OF5 (kg)	OF6 (kg)	OF7 (kg)	OF36 (kg)	OF42 (kg)	OF43 (kg)	OF44 (kg)	Total (kg)	Areal (g/ha)
January	241	228	3,967	5,195	895	2,375	865	1,744	156	3,677	19,343	28,242
February	3	32	1,278	1,373	239	988	72	460	25	999	5,469	7,985
March	5	25	1,040	1,290	184	811	72	378	20	865	4,690	6,848
April	30	47	1,033	1,413	241	776	162	423	28	981	5,134	7,496
May	3	23	704	918	156	444	32	180	10	462	2,932	4,281
June	3	16	448	612	79	314	41	157	9	467	2,146	3,133
July	52	84	1,177	2,587	491	783	243	797	59	1,266	7,539	11,007
August	80	100	1,308	2,767	440	678	361	750	68	1,374	7,926	11,572
September	116	178	2,794	4,156	675	1,406	555	1,278	113	2,529	13,800	20,149
October	46	102	2,672	4,234	598	1,945	325	1,419	89	2,812	14,242	20,794
November	12	29	1,179	1,529	177	958	97	429	25	1,002	5,437	7,938
December	333	374	5,967	8,591	1,577	3,943	1,318	3,027	245	6,623	31,998	46,719
Annual	924	1,238	23,567	34,665	5,752	15,421	4,143	11,042	847	23,057	**120,656**	**176,166**

Appendix D. (continued)

	Individual Outfalls									Small Drainage Areas
	OF1 (kg)	6457 (kg)	6460 (kg)	6506 (kg)	6507 (kg)	OF25 (kg)	6545 (kg)	6540 (kg)	6541 (kg)	Total (kg)
January	390	239	324	874	208	1,125	1,016	380	124	4,679
February	107	56	85	216	56	291	256	93	29	1,189
March	60	35	49	126	34	198	216	79	24	821
April	79	44	64	160	43	219	234	90	27	959
May	25	26	28	40	23	125	165	41	10	483
June	25	19	23	43	17	67	179	90	26	488
July	318	181	259	668	170	875	794	295	93	3,652
August	211	132	186	469	124	538	560	238	74	2,532
September	288	176	247	618	166	856	996	402	128	3,877
October	321	173	255	645	170	859	868	335	104	3,730
November	52	34	45	99	33	179	226	106	30	805
December	786	465	643	1,751	410	2,246	1,838	723	240	9,102
Annual	2,662.00	1,578	2,207	5,708	1,454	7,578	7,348	2,873	910	32,317