Phosphorus Speciation and Loads in Stormwater and CSOs of the MMSD Service Area (2000 – 2008)

Final Report: February, 2011

MMSD Contract No. M03029P03

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Department of Civil Engineering and Mechanics

Phosphorus Speciation and Loads in Stormwater and CSOs of the MMSD Service Area, 2000 – 2008

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Final Report to Milwaukee Metropolitan Sewerage District
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EXECUTIVE SUMMARY

A comprehensive statistical data analysis of total phosphorus (TP), total soluble phosphorus (TSP), total suspended solids (TSS), and biochemical oxygen demand (BOD) samples collected and analytically analyzed by the Milwaukee Metropolitan Sewerage District (MMSD) during 2000-2008 has been performed by the Department of Civil Engineering and Mechanics at University of Wisconsin, Milwaukee. Data source categories include the three major rivers; the Milwaukee, Menomonee, Kinnickinnic Rivers along with stormwater, combined sewer overflow (CSO), Outer Harbor, and Water Reclamation Facility effluent.

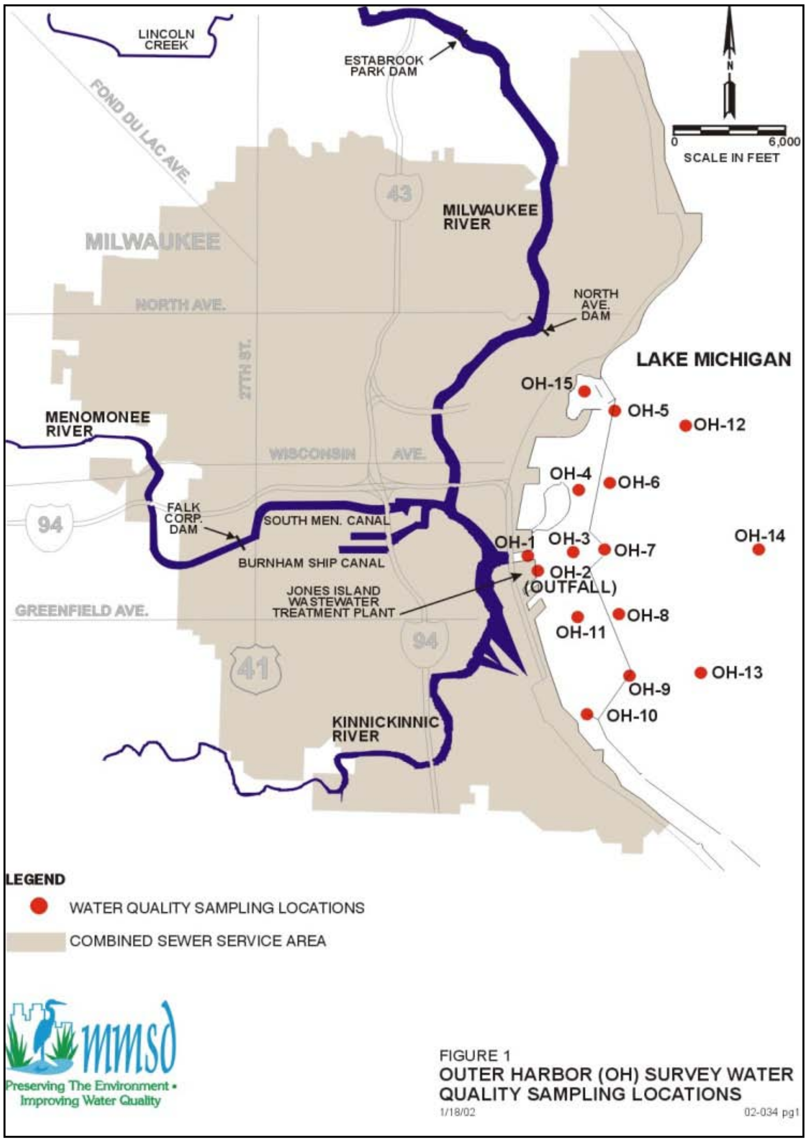

Figure ES-1. Outer Harbor Monitoring Locations.
Source: MMSD

The highest TP and TSP concentrations are found in stormwater and CSO. Stormwater after the initial surface washoff period typically carries phosphorus in the dissolved soluble form which is highly bioavailable for algal growth. CSOs are generally, by volume, estimated to be greater than 90% stormwater (MMSD, personal communication). However the first flush of stormwater is captured and treated in the CSO area.

Statistical analysis (t-tests and Mann-Kendall tests) of phosphorus data showed that TP decreased slightly over the study period of 2000-2008 for site OH-01 representing the confluence of the three rivers into the Outer Harbor (Figure: ES-1) while TP remained the same or slightly increased over the same study period for site OH-02 near the Jones Island Water Reclamation Facility (WRF) outfall. Concentrations of TP at OH-02 (0.095 ± 0.005 mg/L) are higher than at OH-01

(0.073 ± 0.006 mg/L) for the time period 2000 - 2008. Years with high rainfall and river discharge during May through June (i.e., 2000, 2007, 2008, and especially 2004) produce high daily as well as high annual average TP loads. This appears to be caused by re-suspension and erosion of sediments containing TP in the river beds.

The average loading calculations (TP kg/year) for the time period 2004-2008 indicate that Jones Island WRF contributes 39,500 kg/yr (87,082 lbs/yr), or less than 34% of the total load to the Harbor which also includes the rivers, CSOs, SSOs and stormwater. Estimates of TP load to Lake Michigan from rivers is 76,500 kg/yr (65.7%) (168,653 lbs/yr). This estimate of TP loading for the rivers is 24 – 50% lower than what USGS estimates for the rivers. The reason for this difference may be that USGS uses daily measurements of TP load and flow whereas data collected by MMSD has typically 10 – 15 days between TP measurements.

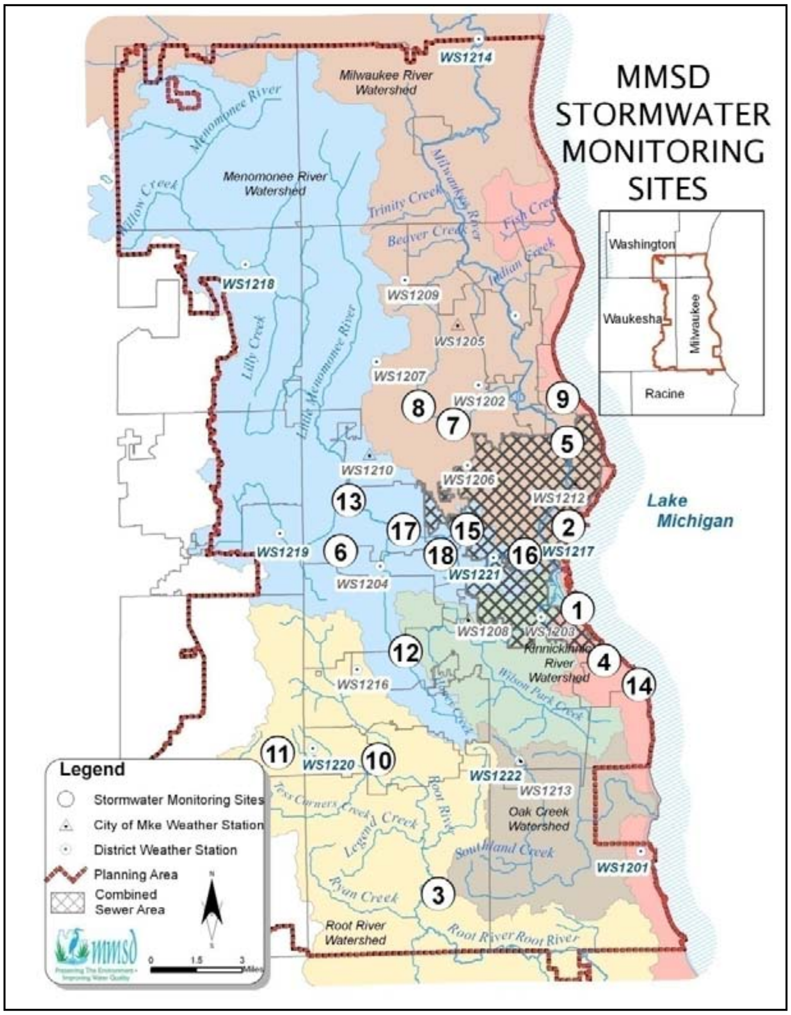

Figure ES-2. Stormwater sites SWMI01-SWMI18 (Stormwater monitoring sites represented by numbers).
Source: MMSD

Stormwater sites show inverse correlation between TP and runoff flow. This reflects dilution of remaining TP in the drainage areas at larger runoff flows with soluble phosphorus being the larger percentage of the phosphorus species present. Most TSP/TP (%) ratios for stormwater sites are between 10 and 100% with second flush runoff producing the highest ratio values as expected because second flush is mostly dissolved or soluble P. The stormwater load directly to Lake Michigan (as measured by stormwater outfalls SWMI01, SWMI02, SWMI04, SWWB09, and SWSF14) (Figure ES-2) is 141 kg/yr (310 lbs/yr or 0.12%). The annual TP load from CSOs is estimated to be 4,200 kg/yr (9,259 lbs/yr), of which 308 kg/yr (679 lbs/yr or 0.26%) flows directly from outfalls to Lake Michigan. Other industrial non-contact cooling water discharges, SSOs and stormwater discharges are included in the overall river loads (Table: ES-1).

Table ES-1. TP load from rivers, stormwater, CSOs, and WRF.

	USGS Estimated[a] (kg/yr)	This Research Estimated (kg/yr)	This Research Estimated (lb/yr)	Percentage (%)
Milwaukee River	89,100	67,300	148,370	57.79
Jones Island		39,500	87,082	33.92
Menomonee River	10,700	7,100	15,653	6.10
Combined Sewer Overflows (CSOs)		4,200[b]	9,259	b
Kinnickinnic River	4,800	2,100	4,630	1.80
Stormwater (Sites 1-18)		602[b,c]	1,327	b
Stormwater New Sites		331[b,c]	730	b
CSO loads to Lake Michigan, LMN, LMS		308	679	0.26
Stormwater loads from sites 1-18 to Lake Michigan, sites 1, 2, 4, 9, 14		141[c]	311	0.12

[a]Data acquired from USGS website: http://wi.water.usgs.gov/
[b]Included in river loads and loads to Lake Michigan.
[c]Stormwater TP load is underestimated.

Stepwise regression results show that TSP is the most important factor when predicting TP in the stormwater and the river watershed loads. TSP may come from many sources, but application of commercially available fertilizers is one important anthropogenic source. Regarding total suspended solids, TSS at stations OH – 01 (River mouth), RI – 04 (Milwaukee River), RI – 09 (Menomonee River), and RI – 13 (Kinnickinnic River) has a correlation comparable to that of TSP when predicting TP concentrations. With respect to correlation between the contributions of BOD related organic compounds to TP, the relationship is significant but less than what was seen for TSS. However, for station OH – 02 (the discharge location for Jones Island WRF effluent) both TSS and TSP are less correlated to TP. Therefore, at OH – 02, TSS and TSP of the mix of wastewater effluent, harbor water and river discharge is not specifically TP related, and prediction of TP concentrations is difficult and must be based on factors other than TSP and TSS concentrations for this location.

The main conclusions of this study were:

1. The highest TP and TSP concentrations are found in stormwater and CSO, between 0.6 and 1.5 mg/L. Stormwater, after the initial surface washoff period, typically carries phosphorus in the dissolved soluble form which is highly bioavailable for algal growth.

CSOs are generally, by volume, estimated to be greater than 90% stormwater; however the first flush of stormwater is captured and treated in the CSO area. The second flush, measured 2 hours after the first flush, generally has higher percentage soluble phosphorus; therefore the second flush of stormwater would be expected to be more bioavailable for algal growth.

2. TP is strongly correlated with river flows during periods of high flow while there is an inverse correlation between TP and stormwater flows. Years with large discharges during May-June show large TP concentrations, especially during 2004 but also 2000, 2007 and 2008. In the rivers, average TP concentrations are between 0.1 and 0.15 mg/L which are at or above the new TP water quality standard of 0.10 mg/L. The average TP concentrations in the Outer Harbor are between 0.02 and 0.05 mg/L which are well below the new TP water quality standard of 0.10 mg/Liter.

3. Statistical analysis (t-tests and Mann-Kendall tests) of phosphorus data showed that TP decreased slightly over the study period of 2000-2008 for site OH-01 representing the confluence of the three rivers into the Outer Harbor while TP remained the same or slightly increased over the same study period for site OH-02 near the Jones Island Water Reclamation Facility (WRF) outfall. The average concentration of TP found at OH-02 represents the mixture of river water, lake water and Jones Island effluent. The average TP concentrations at OH-02 (0.095 ± 0.005 mg/L) are higher than at OH-01 (0.073 ± 0.006 mg/L) for the time period 2000 - 2008. Years with high rainfall and river discharge during May through June (i.e., 2000, 2007, 2008, and especially 2004) produce high daily and high annual average TP loads. This appears to be caused by re-suspension and erosion of sediments containing TP in the river beds.

4. The average loading calculations (TP kg/year or lbs/yr)) for the time period 2004-2008 indicate that Jones Island WRF contributes 39,500 kg/yr (87,082 lbs/yr) or less than 34% of the total load to the Harbor which also includes the rivers, CSOs, SSOs and stormwater. Estimates of TP load to Lake Michigan from rivers is 76,500 kg/yr (65.7 %) (168,653 lbs/yr). This estimate of TP loading for the rivers is 24 – 50% lower than what USGS estimates for the rivers. The reason for this difference may be that USGS uses daily measurements of TP load and flow whereas data collected by MMSD has typically 10 – 15 days between TP measurements resulting in an underestimation of river loadings.

ACKNOWLEDGMENTS

We are pleased to acknowledge the work done by MMSD staff, especially Mary Singer and Eric Waldmer, in providing us with maps, water quality and flow data in a timely manner and to the field crew the collected the data. Many thanks also to Breanne McDonald and Christopher Magruder of MMSD for color photos and for reviewing, commenting and editing this report. Chris helped us focus on the important issues and outlining the community and regulatory context for the work.

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INTRODUCTION

There is a renewed interest in phosphorus (P) levels found in the nearshore areas among the Great Lakes communities including Milwaukee due to unsightly mats of *Cladophora* algae developing along many of the swimming beaches. These algae are stimulated and sustained by the high levels of nutrients, including phosphorus. However, many factors may be at play especially the high numbers of the invasive Dreissenid Mussels that include *Dreissena polymorpha* (zebra mussels), and more recently *Dreissena bugensis* (quagga mussels) that have become dominant benthic species in the Great Lakes (French III, 2009). Quagga mussels are filter feeders that take up particulate phosphorus in the form of phytoplankton biomass and expel fecal pellets rich in soluble phosphorus that drop to the lake bottom as well as fecal material that's partially recycled into the water column. The fecal material that is recycled to the water column contains phosphorus in dissolved and colloidal form that is more bioavailable for algae growth than phosphorus on the ingested material and therefore is able to enhance or sustain the growth of *Cladophora.*

Even with this more efficient use of phosphorus by algae, the overall growth is still dependent on phosphorus supply from the three major rivers in the Milwaukee area; the Milwaukee, Menomonee, and Kinnickinnic Rivers as well as from stormwater runoff, combined sewer overflows, wastewater effluent, and industrial inputs from noncontact cooling water. In order to reduce phosphorus loadings, new water quality standards for total phosphorus (TP) have recently been established by Wisconsin Department of Natural Resources (WDNR). Limits have been established at 0.1 mg/L for select rivers/creeks/harbors, 0.075 mg/L for all other streams and 0.007 mg/L for open waters of Lake Michigan in the *Wisconsin Administrative Code*-Chapter NR 102 (November, 2010). Also, phosphates that were in dishwasher detergents at 8.0% by weight were banned in October 2009 by the Wisconsin State Assembly; this ban was enacted into law July 1, 2010 (Christopher Magruder, personal communication). The WDNR also established new discharge rules to calculate limits of TP in wastewater effluents. The new rule found in *Wisconsin Administrative Code* Chapter NR 217 "Effluent Standards and Limitations for Phosphorus" (November, 2010) establishes a process for implementing the numeric TP criteria through effluent limits for point source discharge permits. Another source of phosphorus is the addition of ortho- phosphates to the drinking water by the City of Milwaukee (i.e. Linnwood, Howard Avenue) and other drinking water utilities in order to reduce lead levels in the plumbing of the public water supply. Industries using treated drinking water and discharging this water as non-contact cooling water to the rivers therefore contribute to the overall phosphorus load of the Milwaukee Outer Harbor and Lake Michigan.

The Minnesota Pollution Control Agency (MPCA) finds that 25% of total phosphorus (TP) comes from wastewater treatment plants and 75% from nonpoint sources in Minnesota.

MPCA also estimates that out of the TP from wastewater effluent, 80% is in the soluble form and therefore bioavailable for biological growth (algae and aquatic macrophytes) (MPCA, 2004). Ellison and Brett (2006) found that 20% of urban stormwater phosphorus was also bioavailable. Water resource managers and engineers at MMSD as well as researchers at the UWM School of Freshwater Sciences have suggested that this percentage is actually much higher in stormwater and that most phosphorus from rivers and stormwater runoff may become bioavailable. Bioavailability is linked to the fraction of TP that is soluble and reactive. A letter from Kent (2008) also emphasizes the need to address nonpoint phosphorus pollution rather than solely focusing on TP from water reclamation facilities that are highly regulated. However, in response to comments submitted by Kent (2008) on behalf of the Municipal Environmental Group on August 29, 2008, Midwest Environmental Advocates (Saul et al. 2008) recognize different phosphorus sources, but feel that wastewater treatment plants should first reduce their TP load.

Although combined sewer overflows (CSOs) have become much less frequent since the Milwaukee inline storage (Deep Tunnel) system came online in 1994, CSO TP contributions to the river system remain a source to be considered. It should be noted however that CSOs are, by volume, approximately 90% stormwater and therefore a significant portion of the overall TP load found in CSOs is from stormwater origin.

This study addresses phosphorus speciation, concentrations and loads in the outer harbor and outside the breakwaters needed for a phosphorus reduction effort. It will form the basis for recommendations for phosphorus monitoring and mitigation in order to eliminate or strongly reduce *Cladophora* growth in the Lake Michigan nearshore areas. Concentrations of total and soluble phosphorus in the three major rivers, outer harbor, stormwater, CSOs, and wastewater effluent will be plotted based on data collected by MMSD between 2000 and 2008. Loadings from each of these source areas will also be estimated. Stepwise regression will be applied to examine the most important factors contributing to the TP load in the MMSD service area, and trends in phosphorus concentrations and loads will be examined along with possible explanations for the results.

LITERATURE REVIEW

Cladophora

Cladophora glomerata is widely distributed throughout freshwater and estuarine ecosystems of the world, including North America, Europe, the Atlantic Islands, the Caribbean Islands, Asia, Africa, Australia and New Zealand, and the Pacific Islands (Higgins et al., 2008). Marks and Cummings (1996) have demonstrated that one cosmopolitan species of *Cladophora* dominates North American freshwaters, including the Great Lakes. According to Whitton (1970), *Cladophora* requires a hard surface for attachment, a relatively high light environment, mild temperature (between 10-25 ˚C), ambient pH between 7 and 10, and some degree of water motion.

Cladophora blooms were a common feature of the lower North American Great Lakes (Erie, Michigan, Ontario) from the 1950s through the early 1980s (Higgins et al., 2008). Numerous studies were conducted during the 1970s and early 1980s to better understand the ecology of *Cladophora glomerata* and provide the information necessary for successful management. These studies provided a scientific consensus that elevated concentrations of soluble phosphate associated with cultural eutrophication were ultimately responsible for the bloom occurrences (Higgins et al., 2008). A multi-billion dollar phosphorus abatement program was implemented to eradicate the *Cladophora* in the lower Great Lakes (Mortimer, 2004). Restrictions on point sources, especially wastewater treatment plants, of TP loading to the Great Lakes basin from the 1970s to the mid-1990s brought significant reduction in TP concentration in the lower Great Lakes and corresponding reductions in *Cladophora* growth.

Effect of Dreissenids

Widespread *Cladophora* blooms returned in the lower Great Lakes in the mid-1990s. However, the return of the *Cladophora* blooms was not associated with increases in P loading. Indeed, there was no detectable trend of increasing ambient TP concentrations in either the nearshore or offshore waters of the Great Lakes from the 1990s to 2006 (Higgins et al., 2008). Nuisance blooms of *Cladophora* were coincident with the establishment of dense communities of invasive zebra and quagga mussels. Several major ecological consequences of the dreissenid invasion are well recognized, including the collapse of native unionid mussel populations through fouling, a decrease in phytoplankton biomass and changes in nearshore optical properties (increased light penetration) through intensive filtration, and physical restructuring of the benthic environment (Vanderploeg et al., 2002).

Dreissenid mussels may be increasing the prevalence of *Cladophora glomerata* in the lower Great Lakes through a number of physical-chemical processes/mechanisms. Due to their high filter feeding capacity and possibly their demand for calcium (Ca^{2+}) reducing the frequency of calcium carbonate precipitation (whitening) events, establishment of large dreissenid mussel populations has been associated with increases in water clarity, enhancing the growth of *Cladophora glomerata* at previously light-limited depths. Dreissenids may also be facilitating the areal expansion of *Cladophora glomerata* in the Great Lakes through an increase in the availability of hard substrate for algal attachment and finally by filtering suspended particulate matter and voiding or excreting feces, pseudofeces and dissolved nutrients (including P). Dreissenid mussels may be redirecting nutrients from the pelagia to the benthos zone, potentially leading to eutrophication of the nearshore benthic environment (Ozersky et al., 2009). Fishman et al. (2009) adopted a multi-class phytoplankton model to show that changes in the phytoplankton community can be linked to three zebra/quagga mussel-mediated effects: (1) removal of particles resulting in clear water, (2) increased recycle of available phosphorus throughout the summer, and (3) selective rejection of certain Microcystis (blue-green) algae strains.

Laboratory studies have shown that soluble phosphorus released by dreissenid mussel is more important than that released from zooplankton, macrophytes, sediment or external sources (Arnott and Vanni, 1996). Conroy et al. (2005) estimated that phosphorus turn-over rates in Lake Erie increased by 25-30% following the invasion of dreissenid mussels. Through an *in situ* study along an 8 km stretch of Halton shoreline between the depth of 0-12 m in Lake Huron, Ozersky et al. (2009) found that the soluble reactive phosphorus (SRP) excretion rates by dreissenid mussels is more than three times the uptake rates by *Cladophora glomerata*. The dreissenid mussels could be recycling, and thus supplying as much as 32,300 kg of bioavailable phosphorus to the study area annually. This is well in excess of all other sources. Fishman et al. (2009) estimated that, in 1992 and 1994, zebra mussel recycling was on average 24% of the recycled daily total available phosphorus in Lake Huron. Available phosphorus tributary loads would have to be reduced by 75% to overcome the increased available phosphorus provided by zebra mussel recycle and prevent summer *Cladophora glomerata* blooms in 1994. Ozersky et al. (2009) concluded that if much of the phosphorus recycled by dreissenids is brought to the nearshore by currents from the open lake in the form of phytoplankton and not from local watershed sources, then local reductions in nutrient input may not be sufficient to control growth of nuisance benthic algae. Lake-wide reductions in TP concentrations would be required. However, lake-wide decreases in TP levels and primary productivity may not be feasible or even desirable due to the negative effect they might have on pelagic food webs and fisheries.

Previous Work

MMSD has partnered with Dr. H. Bootsma et al. (2008) (University of Wisconsin Milwaukee, Great Lakes WATER Institute) to execute a research program on the physical/chemical conditions for *Cladophora* abundance in the Milwaukee Region of Lake Michigan. The results show that inputs of dissolved phosphorus concentrations from the Milwaukee Harbor (rivers & WRF) are not sufficient to support the observed biomass of *Cladophora* in the nearshore zone over the course of a growing season. This suggests that there is an offshore benthic source of phosphorus. Quagga mussels are the likely source of this phosphorus. From a management perspective, an important question to answer is whether the phosphorus from the lake's internal pool in the form of plankton is derived from quagga mussels, or from suspended particulate materials delivered to the lake from rivers. Their studies show that the recent resurgence of *Cladophora* in the Milwaukee area of Lake Michigan (Figure 1.) appears to be a result of the combined effect of increased light availability, increased summer nearshore temperatures, and increased phosphorus availability. However, because it is not possible to control light or water temperature, any management strategy to control *Cladophora* growth must focus on managing sources of phosphorus. The two most likely sources of phosphorus that fuel *Cladophora* growth are direct source inputs to the Lake (rivers, stormwater, cooling water discharge, SSOs, CSOs and wastewater effluent) and bioavailable phosphorus excreted by dreissenid mussels. The relative importance of these two sources of phosphorus must be quantified in order to develop effective management strategies.

Figure 1. *Cladophora* bloom along Milwaukee shoreline.
Source: MMSD

Point Source vs. Nonpoint Source

Point source and nonpoint source are both important in phosphorus load. Due to human activity, the proportion of phosphorus load from nonpoint source has increased. However, because of the wide dispersion and variability in time, it is difficult to control the nonpoint pollution. To decrease the total load to the environment, typically a more feasible strategy in the past has been to control the load from point sources by imposing low effluent discharge limits. WDNR banned synthetic phosphorus in commercial lawn fertilizers in 2008. As mentioned before, due to the *Cladophora* blooms in the lower Great Lakes during 1950s to 1980s, a phosphorus abatement program was implemented in laundry detergents which significantly decreased the release of TP load from point sources like wastewater treatment plants (WWTPs) and reduced the TP concentration in the watershed of the lower Great Lakes basin.

A more stringent water quality standard for TP has been adopted by the WDNR (0.1 mg/L for the rivers and harbor and 0.007 mg/L for Lake Michigan). Its goal is to dramatically reduce the total loads of TP into the environment from both point sources and nonpoint sources. However, regarding the question of who will take the main responsibility to satisfy the new standard, the various stakeholders have some disagreements. Two different opinions were expressed on the implementation of the phosphorus rule. Clean Wisconsin and Midwest Environmental Advocates insisted that the Municipal Environmental Group (MEG) Wastewater Division should take further steps to reduce the phosphorus loads from their member wastewater treatment plants (Saul et al., 2008). However, the MEG Wastewater Division claimed that the municipal wastewater treatment plants have been subject to strict effluent limits on phosphorus under NR 217 for many years and to comply with the new suggested standards would result in unreasonable costs with minimal water quality gains (Kent, 2008).

A key point is to determine the phosphorus load from point and nonpoint sources. From the study of MPCA (2004), point source and nonpoint source contributions of phosphorus to Minnesota waters statewide were 25% and 75%, respectively, in an average year (MPCA, 2004). For the state of Wisconsin, as NR 217 implementation took effect, the current data shows that point source contributions in Rock River decreased from approximately 40% in 1998 to 20% in 2008 (Kent, 2008). Wastewater treatment facilities, those similar to Jones Island Water Reclamation Facility (WRF), are highly effective at removing phosphorus from the influent during the treatment process (Figure 2, 85 - 95% removed).

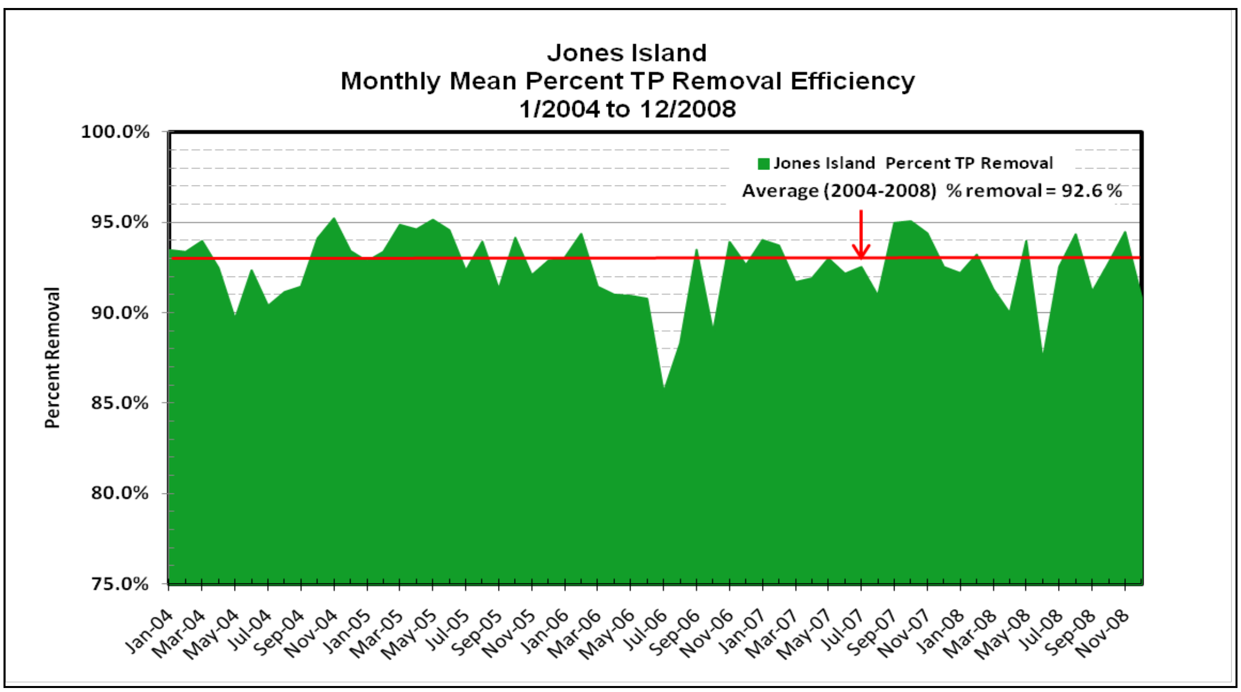


Figure 2. Jones Island Monthly Mean Percent TP Removal Efficiency (2004-2008). ***Source MMSD***

Phosphorus Bioavailablity

Point source contributions of P from municipal wastewater treatment plants in Minnesota were found to be largely in a soluble form that is directly available for biotic uptake (MCPA, 2004). The proportion of bioavailable phosphorus from wastewater point sources is generally thought to be higher than the proportion in nonpoint sources (MCPA, 2004). The studies conducted by MPCA (2004) show that phosphorus in Minnesota municipal wastewater effluents and commercial and industrial wastewater effluents was more than 80% bioavailable. Ellison and Brett (2006) found that 17 to 26% of rural stream water phosphorus and 20% of urban stormwater total phosphorus was bioavailable. However, mass loadings of soluble P from large frequent runoff/flooding events are generally much higher than from annual WWTP's inputs. Personal communications with Christopher Magruder (MMSD) and Val Klump (GLWI) indicate that most phosphorus even in nonpoint sources ultimately becomes bioavailable given enough time.

Point source contribution of soluble reactive phosphorus (SRP) has its greatest impact during low river discharge. Soluble reactive phosphorus (SRP) is usually the majority of TSP with the difference representing organically bound soluble and unreactive phosphorus (Bradford and Peters, 1987). For large watersheds, nonpoint sources of phosphorus comprise a greater percentage of the load at higher river discharge. Bowes et al. (2009) illustrated that high TP concentrations are closely associated with storm events, which indicated that diffuse source phosphorus is being washed into the river from the catchment through soil erosion, leaf material, and in-wash of manures and fertilizers. Furthermore, the resultant increase in river discharge will also mobilize phosphorus that had been stored within the river channel in deposited sediments.

Estimate of Phosphorus Loads

Estimated annual TP and TSP loads are highly dependent on the sampling interval, Bowes et al. (2009) showed that monthly sampling intervals were insufficient to observe peaks in phosphorus concentration in response to storm events, thus resulting in significant errors of up to 35% and 28% in TP and soluble reactive phosphorus (SRP) annual load, respectively.

As shown later in this study, this error results in underestimation of the phosphorus load from the rivers. Weekly sampling reduced the corresponding maximum percentage errors in annual load estimate to 15.4% and 6.5% for TP and TSP, respectively. However, to investigate within-river phosphorus dynamics, daily sampling would be a minimum requirement.

DATA ANALYSIS

Stormwater

Contaminated stormwater runoff is among the most serious threats to water quality in the Greater Milwaukee watersheds. In the SSO area, stormwater runoff collects the pollutants from impervious surfaces and brings them directly to creeks, streams, rivers and Lake Michigan. The contaminated stormwater runoff is difficult to manage because these pollutants are spread widely over the watersheds (Figure 3). Soonthornnonda et al. (2007) have shown that the pollutant levels are variable according to different land uses. Stormwater runoff from residential areas tends to have higher average concentrations of phosphorus, BOD, and bacteria than other land use average concentrations.

Figure 3. Stormwater pollutants in the Menomonee River.
Source: MMSD

Since 2000, the MMSD has conducted a voluntary stormwater monitoring program for research purposes that includes sampling and analysis of stormwater runoff. Originally, samples were collected at 18 storm sewer locations. Now that has been increased to 46 sites (Tables 1, 2). The 18 original sampling sites are shown in Figure 5. Some newly added sites are shown in Figures 5 and 6. Maps of the rivers, Outer Harbor, and CSOs monitoring sites are shown in Appendix A.

The stormwater sampling method follows the recommendations for stormwater discharge permits by the Wisconsin Department of Natural Resources (Soonthornnonda et al., 2007). The first sample, or “first flush,” was taken at a specified time triggered by a certain water level in the storm sewer; a second sample, or “second flush,” was taken 2 hours later. The trigger point level varied from site to site based on 0.2 feet above baseline flow. Date and time are recorded for each sample. Sample constituents analytical methods for 33 pollutants are explained by Soonthornnonda et al. (2007). TP, TSP, TSS, and BOD from stormwater samples were statistically analyzed in this report. Runoff flows were measured by MMSD sampling crews using area velocity meters (Soonthornnonda et al., 2007). The event runoff volume was derived by integrating runoff hydrographs through each storm event's duration. This is demonstrated using actual storm event data contained within this report.

Table 1. Stormwater monitoring sites. *Source: MMSD*

ID	LOCATION	COMMUNITY	Watershed
SWMI01	LINCOLN MEMORIAL DR. AND CARFERRY DR. (Stormwater discharge to Lake Michigan) **INACTIVE SINCE 2005**	Milwaukee	Lake Michigan
SWMI02	1700 N. LINCOLN MEMORIAL DR. @ LAFAYETTE HILL RD. (Stormwater to Lake @ McKinley Marina) **INACTIVE SINCE 2005**	Milwaukee	Lake Michigan
SWFR03	54TH AND ASHLAND (Stormwater to Franklin Park to detention pond) **INACTIVE SINCE 2007**	Franklin	Root River
SWMI04	3500 S. LAKE DR. @ BAY VIEW PARK (Stormwater to Lake across from St. Francis Seminary)	Milwaukee	Lake Michigan
SWMI05	1200 E. SINGER CIR. (Stormwater to Milw. River @ Kern Park) **INACTIVE SINCE 2003**	Milwaukee	Milwaukee
SWMI06	MILW CNTY. ZOO (Stormwater to Underwood Creek across from Moose End.) **INACTIVE SINCE 2007**	Milwaukee	Menomonee
SWMI07**	4345 N. 47TH ST. (Stormwater to Lincoln Creek)	Milwaukee	Milwaukee
SWMI08	HAMPTON AND LINCOLN CR. PARKWAY (Stormwater to Lincoln Creek under bridge) **INACTIVE SINCE 2002**	Milwaukee	Milwaukee
SWWB09	4939 N. NEWHALL (Stormwater to Lake @ Big Bay Park)	Whitefish Bay	Lake Michigan
SWGF10	BOERNER BOTANICAL GARDENS FORMERLY 10007 W. MEADOW DR. (Stormwater to Root River) **INACTIVE SINCE 2005**	Greenfield	Root River
SWNB11	13380 EAGLE TRACE AND TIMBER RIDGE (Stormwater to wetland residential site) **INACTIVE SINCE 2007**	New Berlin	Root River
SWMI12	3275 S. 72ND ST. (Stormwater to Honey Creek) **INACTIVE SINCE 2006**	Milwaukee	Menomonee
SWWA13**	RIDGE BLVD. AND HARDING BLVD. (Stormwater to Menomonee River Parkway)	Wauwatosa	Menomonee
SWSF14	LAKE DR. AND TESCH AVE. (Stormwater to Lake Michigan) **INACTIVE SINCE 2003**	St. Francis	Lake Michigan
SWMI15**	42ND AND MT. VERNON (I-94 x-way Stormwater to Menomonee River) **INACTIVE SINCE 2007**	Milwaukee	Menomonee
SWMI16	MARQUETTE INTERCHANGE **INACTIVE SINCE 2005**	Milwaukee	Menomonee
SWWA17	71ST AND CHESTNUT ST. (Stormwater to Menomonee River) **INACTIVE SINCE 2006**	Wauwatosa	Menomonee
SWMI18**	MILLER PARK- PADRES PARKING LOT (Stormwater to Menomonee River)	Milwaukee	Menomonee

Table 2. Added stormwater monitoring sites. *Source MMSD*

ID	LOCATION	COMMUNITY	Watershed
SWMI19	LINCOLN MEMORIAL DR. AND PICNIC POINT (Stormwater to Lake Michigan) **INACTIVE SINCE 2006**	Milwaukee	Lake Michigan
SWWA20	DANA CT. AND 83RD ST. EXT'D (Stormwater to Honey Creek) **INACTIVE SINCE 2007**	Wauwatosa	Menomonee
SWMI21	MILLER PARK -WEST OF SAUSAGE HAUS (Stormwater to Menomonee River)	Milwaukee	Menomonee
SWMI22	MILLER PARK-SW CORNER ON FREDERICK MILLER WAY (Stormwater to Menomonee River)	Milwaukee	Menomonee
SWMI23	MILLER PARK- NORTH OF PHILLIES PARKING LOT (Stormwater to Menomonee River)	Milwaukee	Menomonee
SMN01A	10435 W. Concordia Ave.	Wauwatosa	Menomonee
SMN03A	Center St. & 97th St.	Wauwatosa	Menomonee
SMN04A	96th St. & Center St.	Wauwatosa	Menomonee
SUC02A	North Ave. & Mt. Kisco Dr.	Brookfield	Menomonee
SMN02A	69th Ext'd & Hart Park Lane Ext'd.	Wauwatosa	Menomonee
SOC02A	S. Shepard Ave. ext'd & Hwy. 100	Oak Creek	Oak Creek
SOC01A	2345 E. Montana Ave.	Oak Creek	Oak Creek
SKK01A	35th & Manitoba St.	Milwaukee	Kinnickinnic
S4301A	4000 W. Lincoln Ave.	Milwaukee	Kinnickinnic
SLP01A	61st & Harrison Ave.	West Allis	Kinnickinnic
SLC020	Outfall at Mill Rd. and 51st (West)	Milwaukee	Milwaukee
SLC02A	49th & Mill Rd. (East)	Milwaukee	Milwaukee
SLC01A	Mill Rd. and 51st (West)	Milwaukee	Milwaukee
S4302A	44th and W. Burnham St.	West Milwaukee	Kinnickinnic
SMN13A	94th St., South of Ridge Blvd.	Wauwatosa	Menomonee
SMN13B	Ridge Blvd., East of 94th St.	Wauwatosa	Menomonee
SMN13C	N. 90th and Clarke St.	Wauwatosa	Menomonee
SUC01A	Fairview Ext'd and Curtis Rd.	Milwaukee	Milwaukee
SLM01A	Klode Park Beach (SW)	Whitefish Bay	Lake Michigan
SLM01B	Klode Park Beach (W)	Whitefish Bay	Lake Michigan
SLM01C	Klode Park Beach (NW)	Whitefish Bay	Lake Michigan
SLM020	Klode Park Beach (N)	Whitefish Bay	Lake Michigan
SLM03A	Lake Michigan and Ravine Rd.	Milwaukee	Lake Michigan

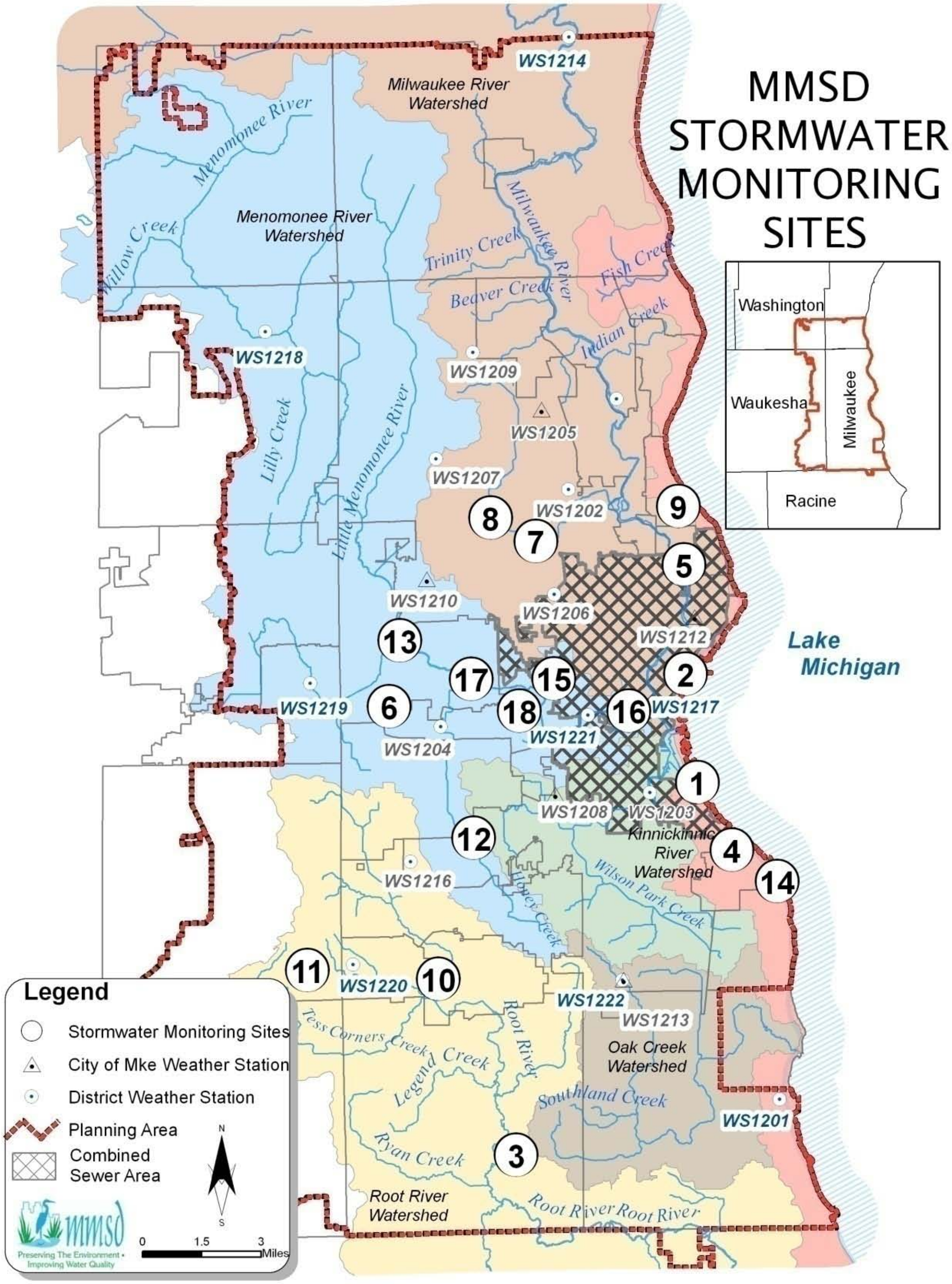


Figure 4. Map of stormwater monitoring sites SWMI01-SWMI18.
(Stormwater monitoring sites represented by numbered dots).
Source: MMSD

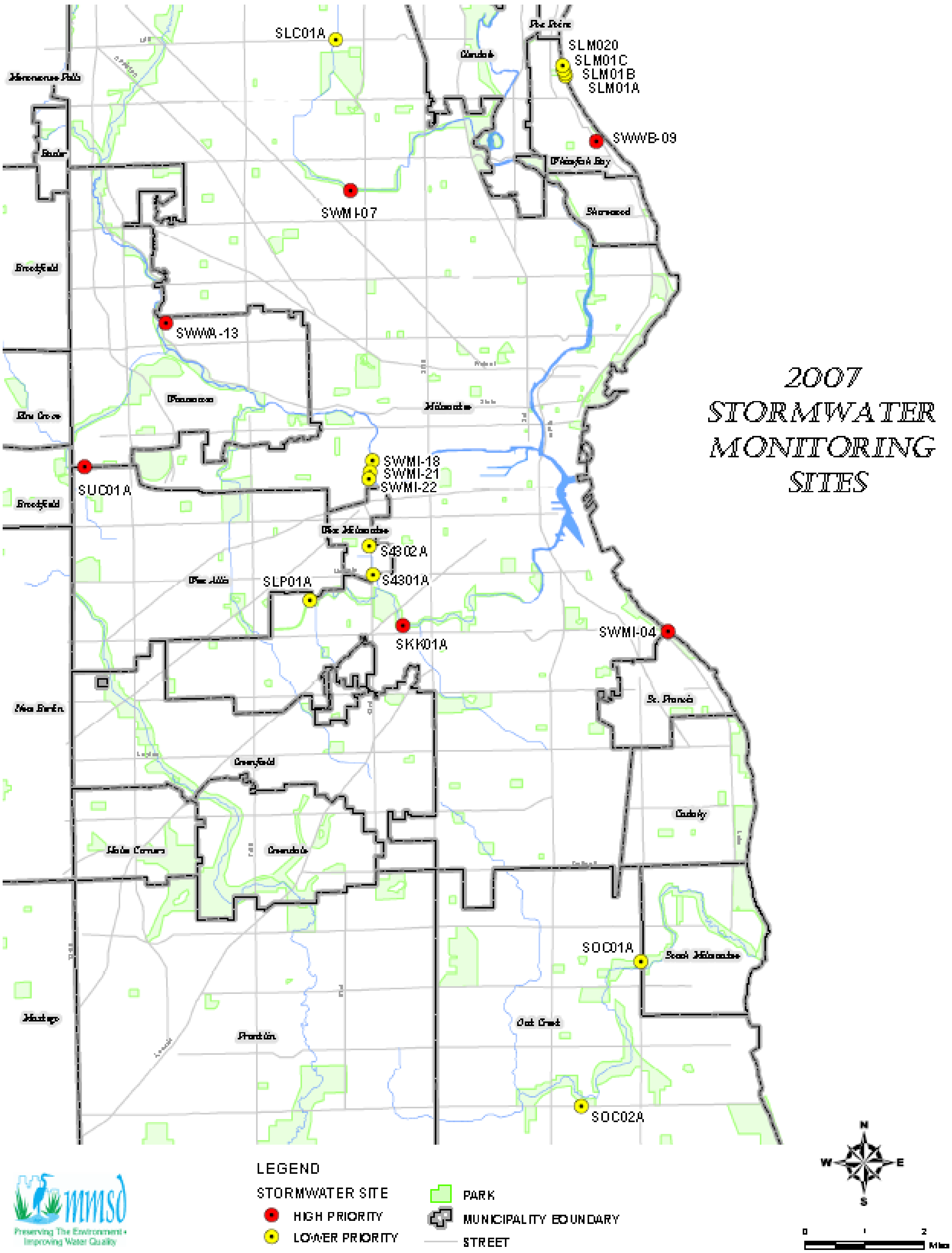


Figure 5. 2007 stormwater monitoring sites.
Source: MMSD

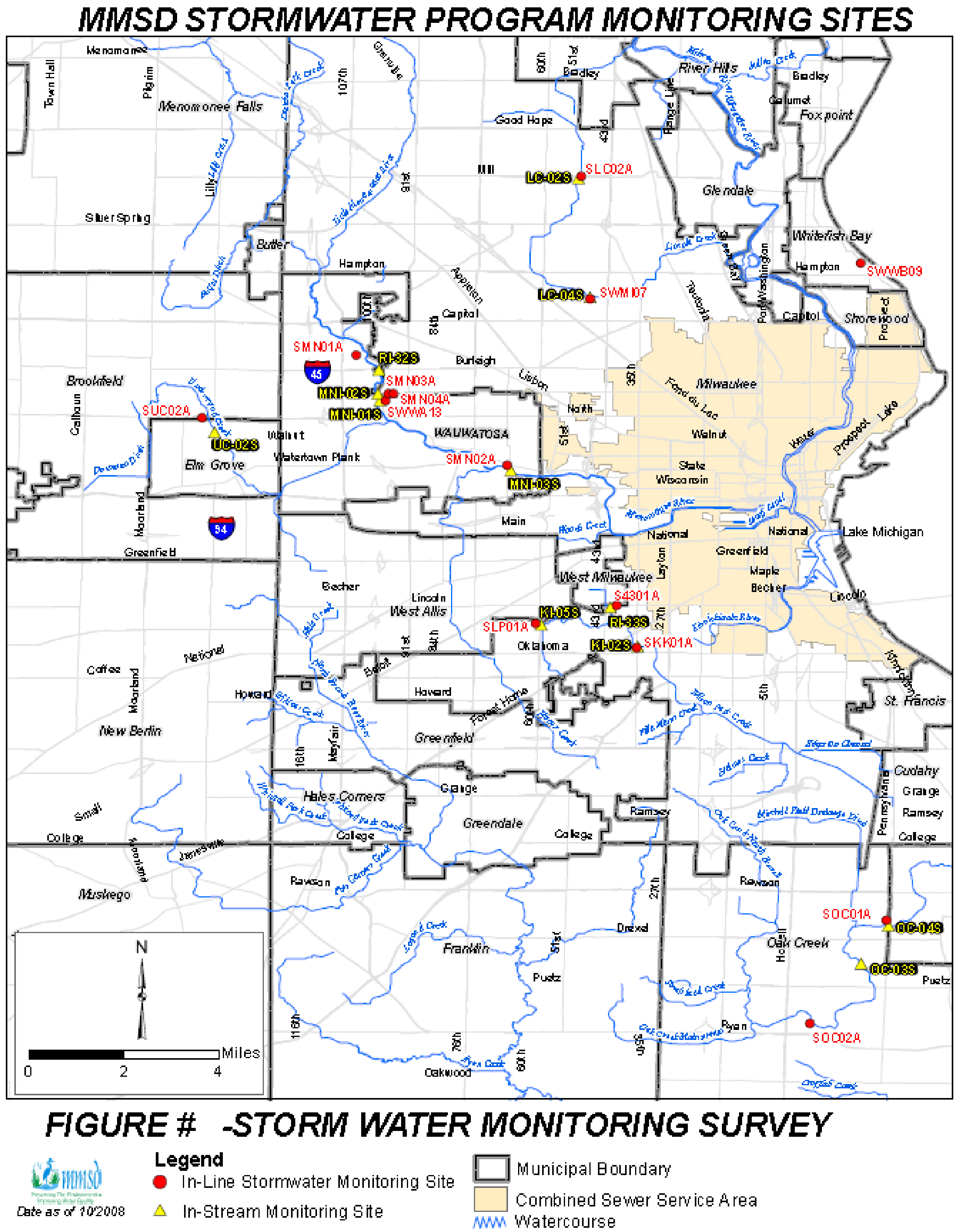


Figure 6. Map of some newly added stormwater monitoring sites.
Source: MMSD

Phosphorus Concentration in Stormwater

Most of the total phosphorus (TP) concentrations measured in stormwater during 2000-2008 were lower than 1 mg/L, conforming to the 2010 Wisconsin Pollutant Discharge Elimination System (WPDES) (WDNR, 2003) limit for effluent discharge but higher than the new water quality standard of 0.1 mg/L for rivers. The total soluble phosphorus (TSP) concentration in stormwater exceeds the recommended EPA Gold Book (US EPA, 1986) criteria limit of 0.05 mg/L. TP and TSP concentrations seem to be fairly randomly distributed for most stormwater monitoring sites, except that there are high values of TP in 2004 for some stations, e.g. SWMI04, SWMI06, and SWMI15(Figure 5). TP concentrations of all measurements for 18 plus 8 out of 28 new sites are plotted in Figures 7-14 (Closed circle represents: 1st flush; open circle represents: 2nd flush).

Pollutant concentrations including TP are generally much higher in first flush (first hour of storm event) than in second flush (two hours after the first flush) of runoff; it is reasonable that the pollutants, especially those associated with particles, will be washed off rapidly from the land surface by the storm runoff in the first hour of an event. There are large variances in the TSP/TP ratio values found in stormwater. When the ratio of TSP to TP (TSP/TP) values is higher than 100%, the reason may be related to the analytical methods, interferences, or measurement uncertainty. The percentage of TSP/TP was consistently higher in the second flush than in the first flush (Appendix B). The reason for this is that phosphorus in second flush is mostly soluble and therefore more bioavailable for algae growth. This finding is consistent with TSS data for stormwater (plotted in Appendix C) that show much higher TSS and TP concentrations associated with the solids in first as opposed to second flush of stormwater.

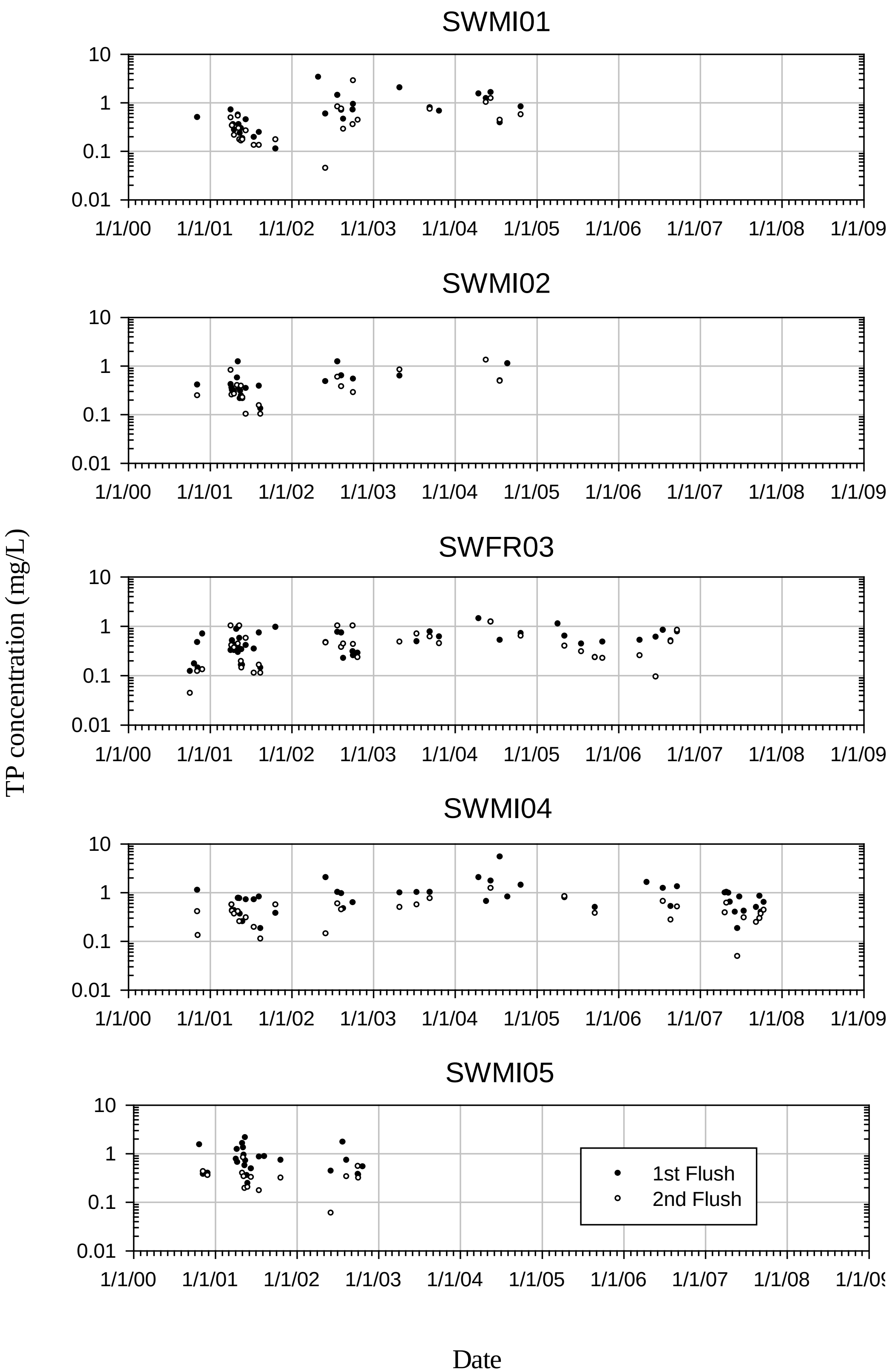


Figure 7. TP concentrations for stormwater monitoring sites SWMI01-SWMI05.

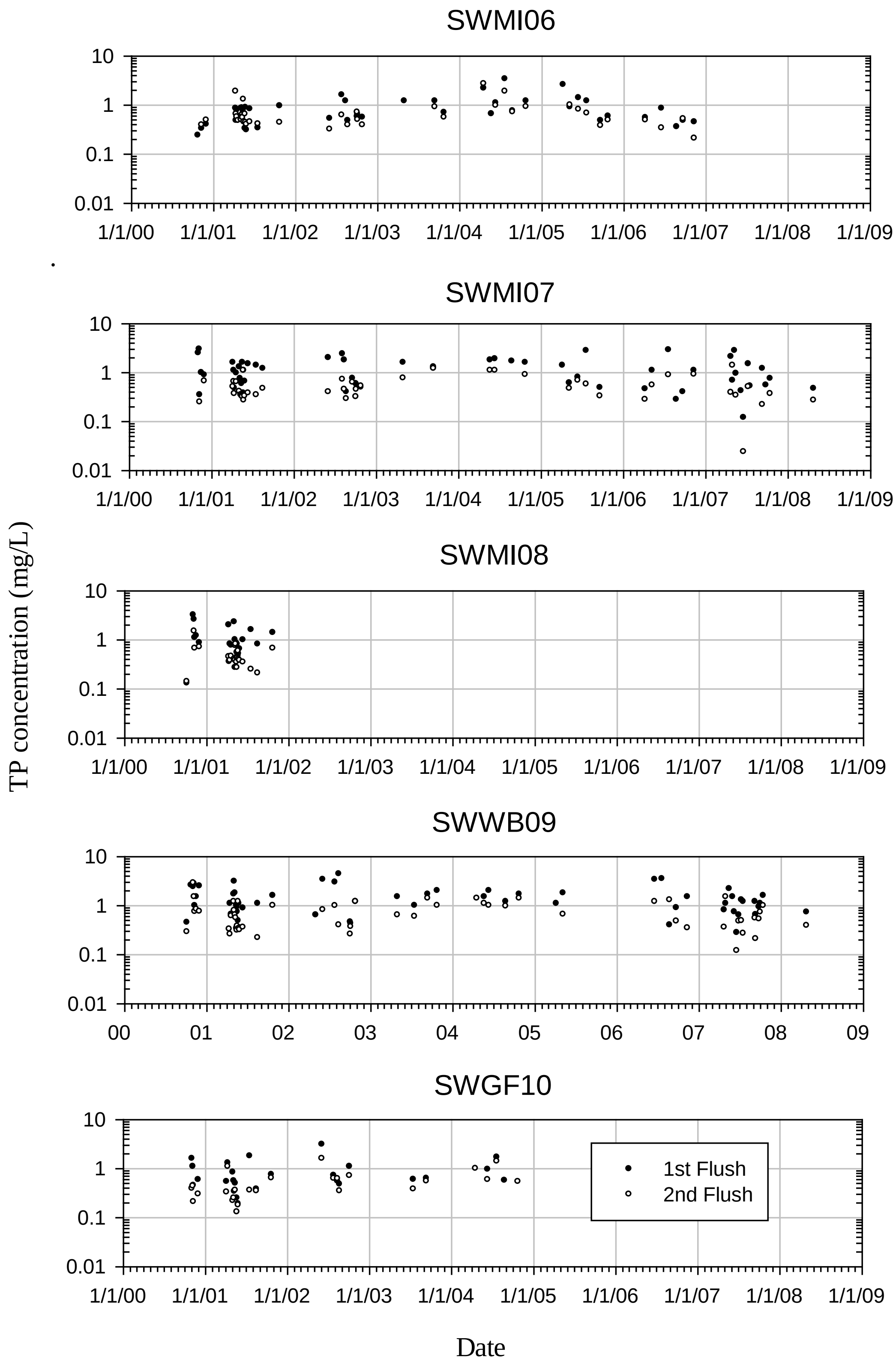


Figure 8. TP concentrations for stormwater monitoring sites SWMI06-SWGF10. Outlier (not shown): SWMI07, 10/22/2001, TP = 32 mg/L.

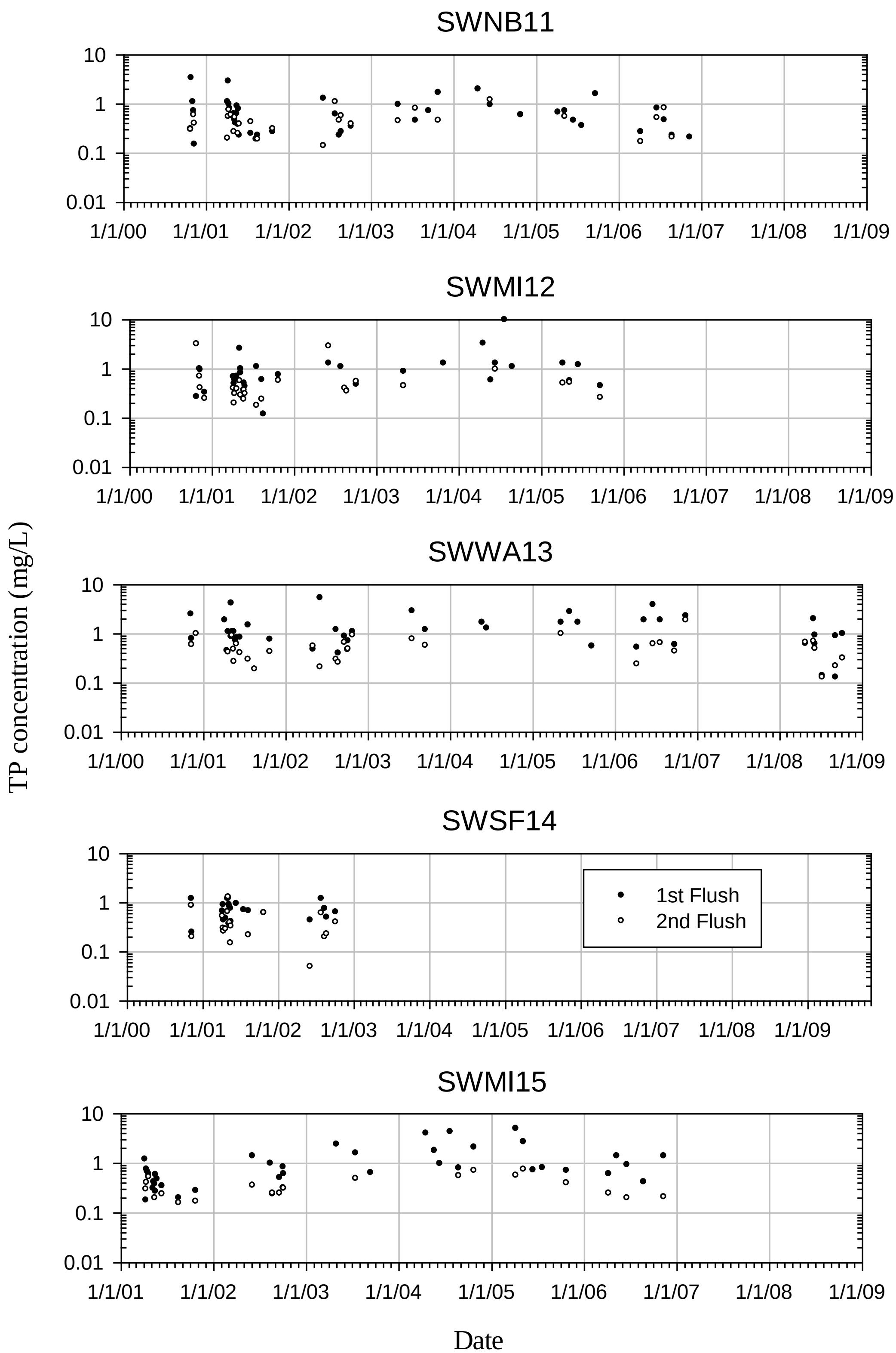


Figure 9. TP concentrations for stormwater monitoring sites SWNB11-SWMI15. Outliers (not shown): SWNB11, 7/21/2004, TP = 11 mg/L, and SWMI12, 8/12/2002, TP = 110 mg/L.

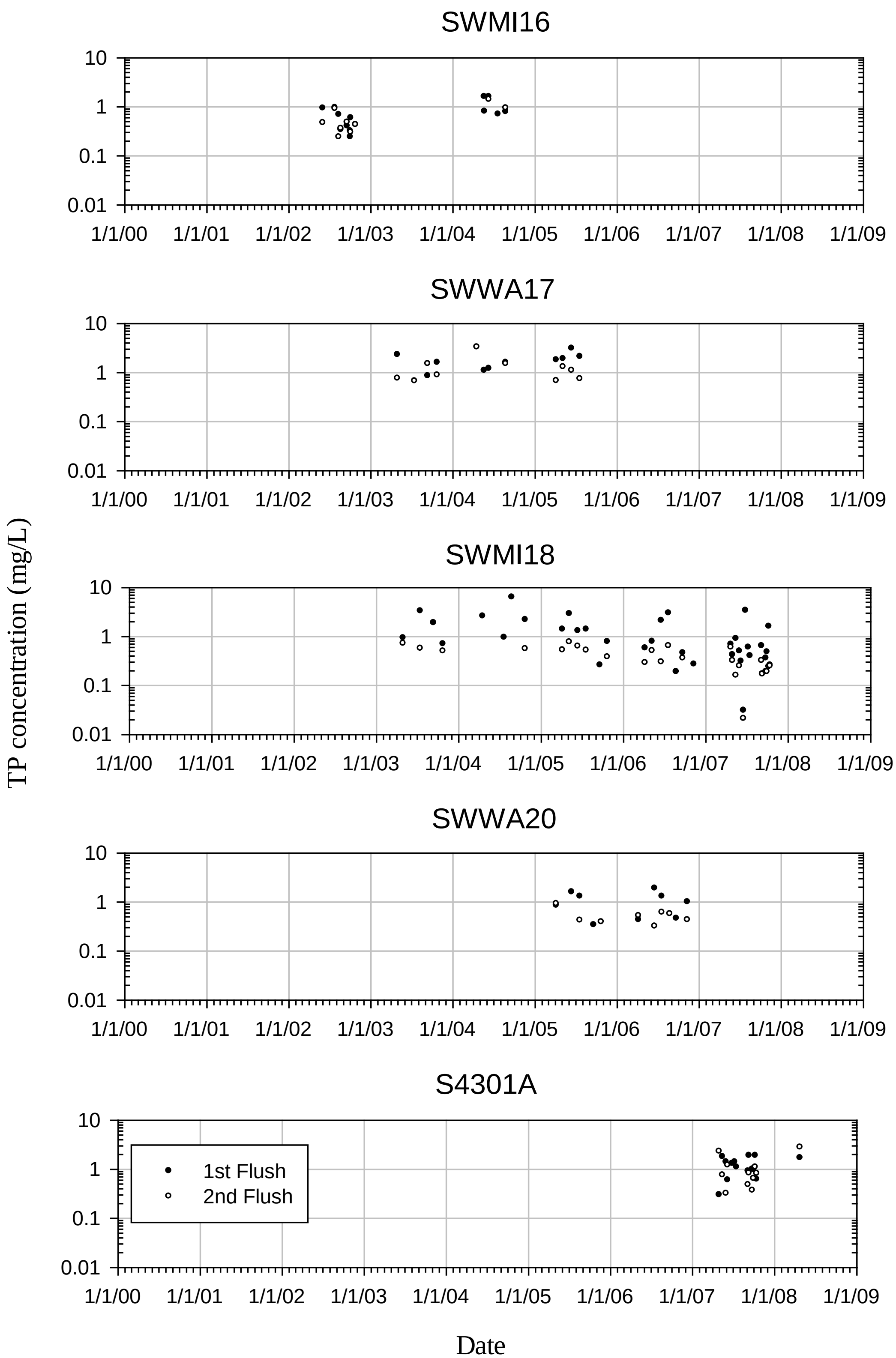


Figure 10. TP concentrations for stormwater monitoring sites SWMI16-S4301A.

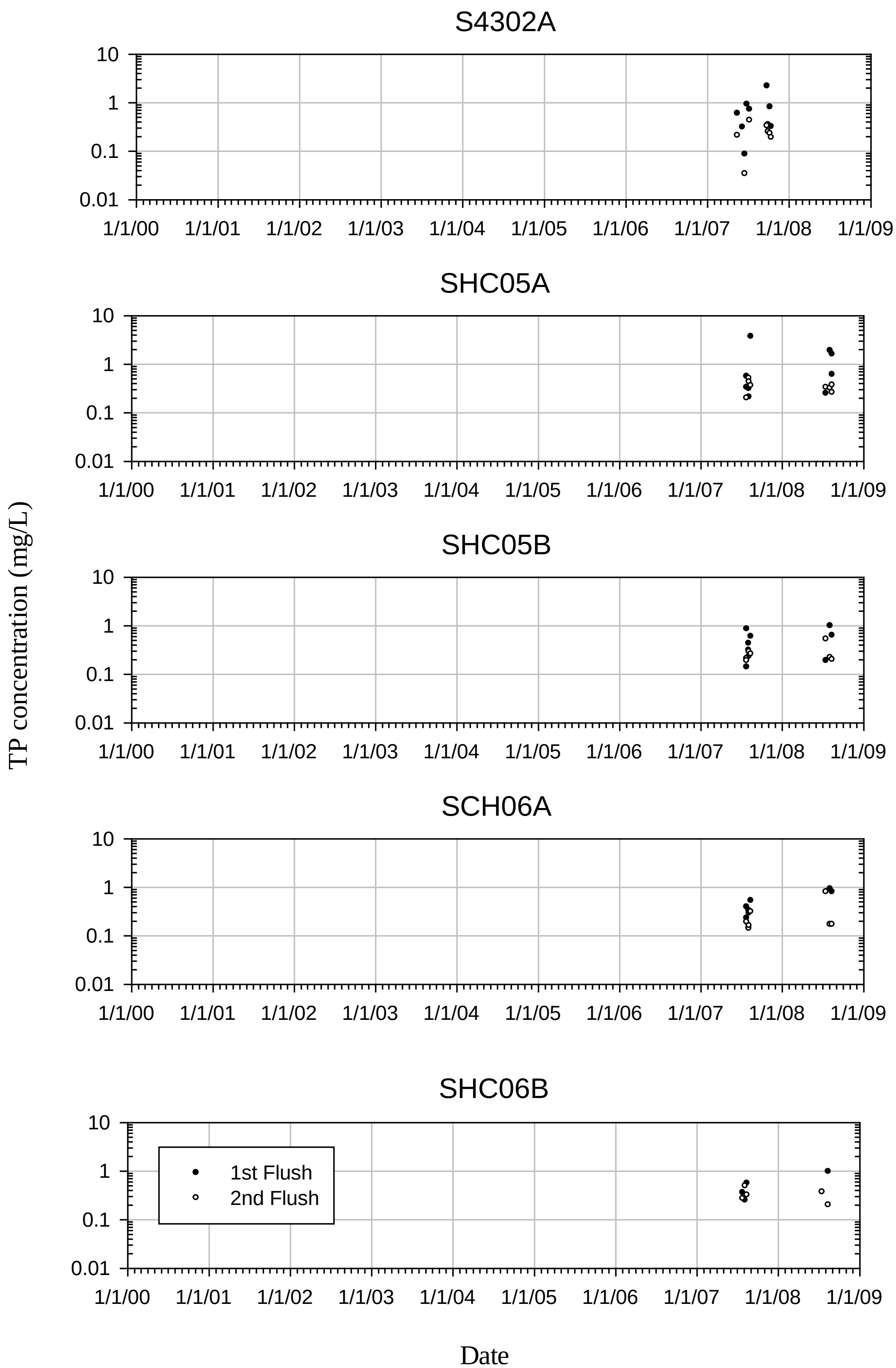


Figure 11. TP concentrations for stormwater monitoring sites S4302A-SHC06B.

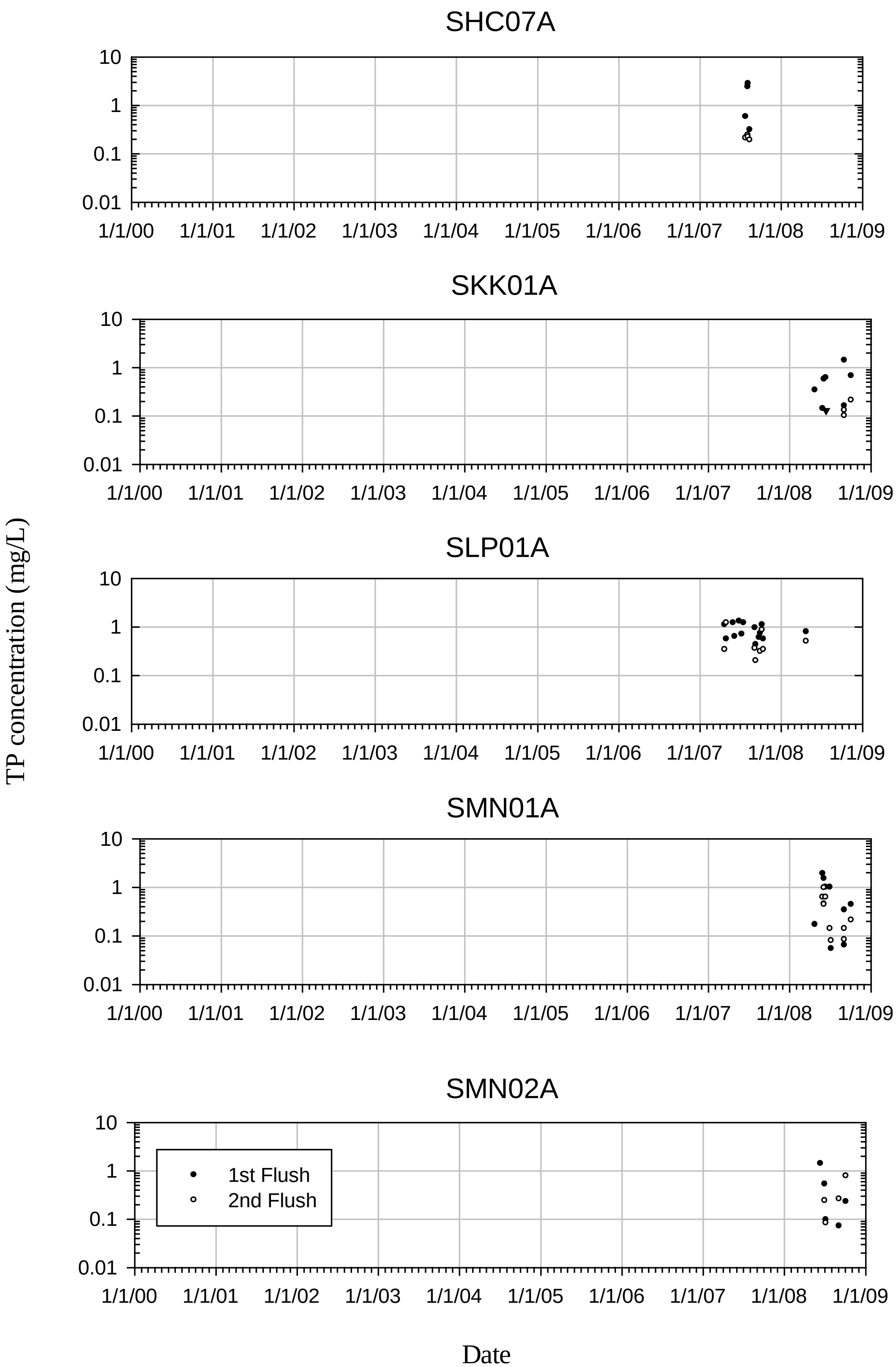


Figure 12. TP concentrations for stormwater monitoring sites SHC07A-SMN02A.

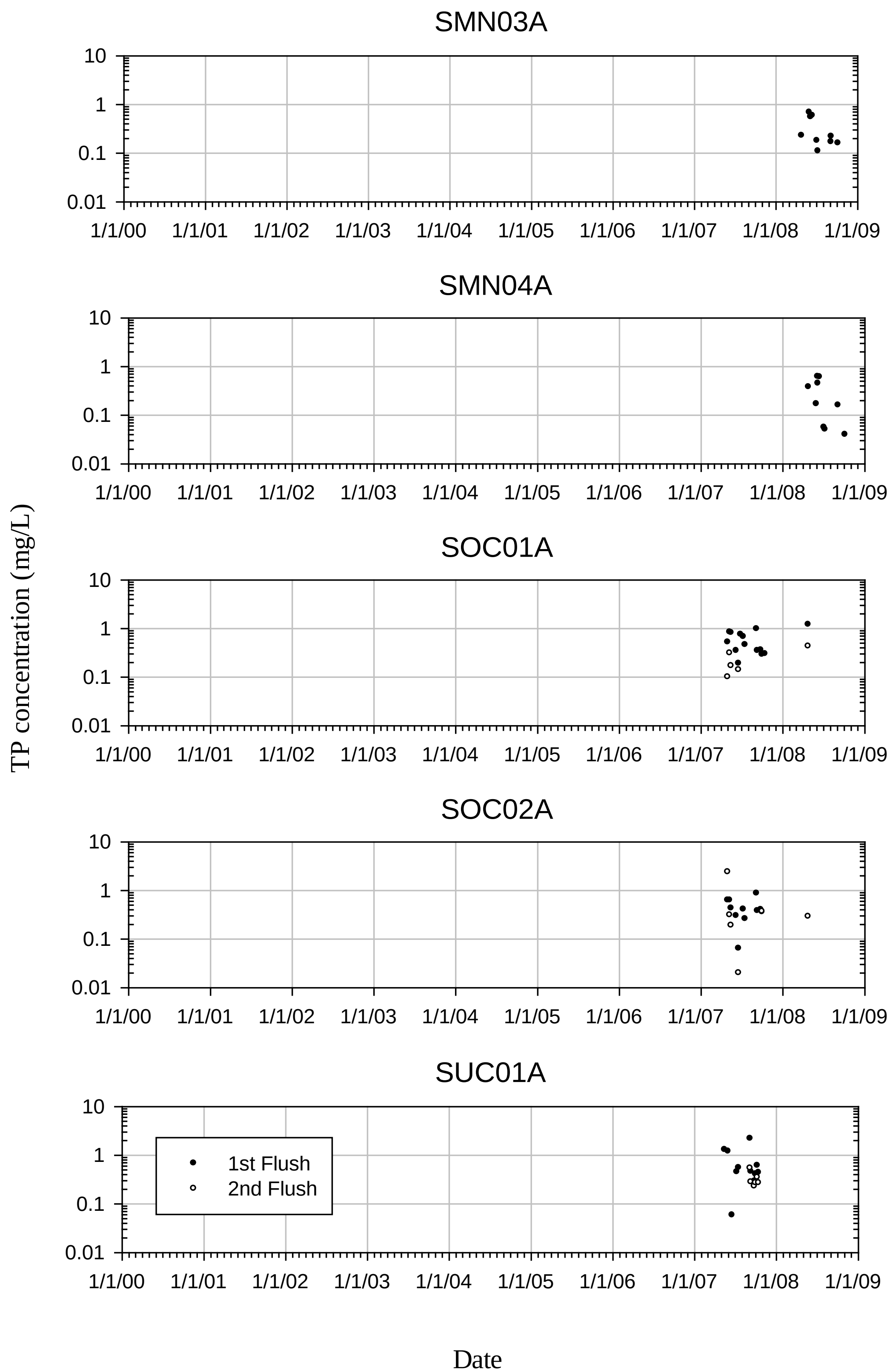


Figure 13. TP concentrations for stormwater monitoring sites SMN03A-SUC01A.

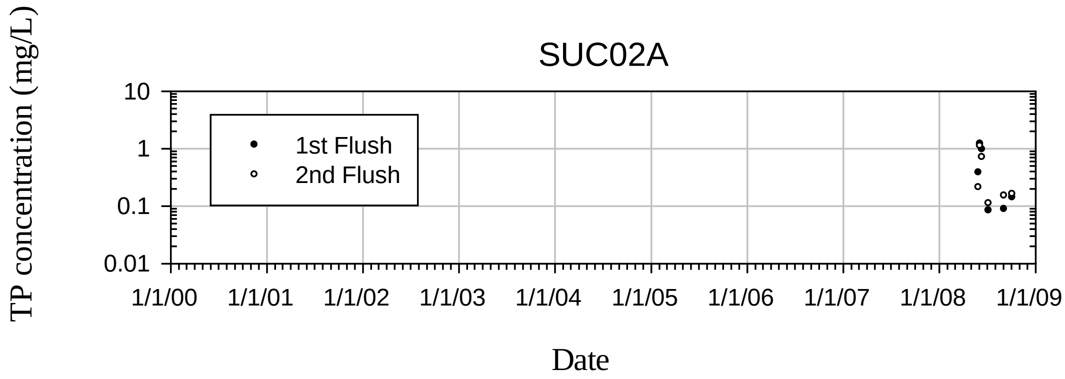


Figure 14. TP concentrations for stormwater monitoring site SUC02A.

Phosphorus Loads in Stormwater

Estimation of phosphorus load is based on measurements of TP concentrations in stormwater and measurements of the runoff volume (Figures 15-17). TP concentration in first flush was designated as C1 and second flush as C2, the measured discharge as Q1 and Q2, and the TP load for the stormwater runoff event was calculated as (McCuen, 2004):

$$TP\ Load = \Delta t \times (Q1 \times C1 + Q2 \times C2) \quad (1)$$

Where Δt is the time interval between first flush and second flush.

As the second flush was sampled 2 hours after the first flush, Δt is 2 hours for all MMSD stormwater monitoring sites. A specified level of stormwater in the stormwater sewer triggers the sample to be captured; time is recorded with the captured sample. However, due to the fact that the runoff discharge was recorded at specific time intervals (rounded hours), the Q1 and Q2 values were interpolated at the time point when the sample was taken.

An example of calculation of TP load per event, for stormwater monitoring site SWMI04 is shown in Figure 15. The stormwater runoff event took place from the evening of 11/6/2000 to the early morning of 11/7/2000. The first sample was taken at 22:30 of 11/6/2000, and the second sample at 00:30 of 11/7/2000. The TP concentrations were 1.1 mg/L and 0.4 mg/L for the first flush and second flush, respectively. The corresponding stormwater runoff from 21:00, 11/6/2000 to 02:00, 11/7/2000 were 0.445, 19.1, 21.0, 8.12, 3.55, 1.73 million gallons per day (mgd). The runoff value is converted to m^3/d, and then interpolated to the time when the samples were taken. The integrated discharges were 7.58×10^4 m^3/d and 2.21×10^4 m^3/d, respectively. The above equation was then used to calculate the TP load for this stormwater runoff event for site SWMI04 at South Lake Drive at Bayview Park (Figure 15).

The outfall for SWMI04 carries both CSO and stormwater. In some cases there are two or more peaks for the runoff events, as shown in Figure 16 for SWMI07 at North 47th Street and Congress Street and Figure 17 for SWWA13 at Ridge Blvd and Harding Blvd, but there are no concentration measurements for the later peak. Therefore, the later peak is not considered in the calculation to avoid underestimating errors.

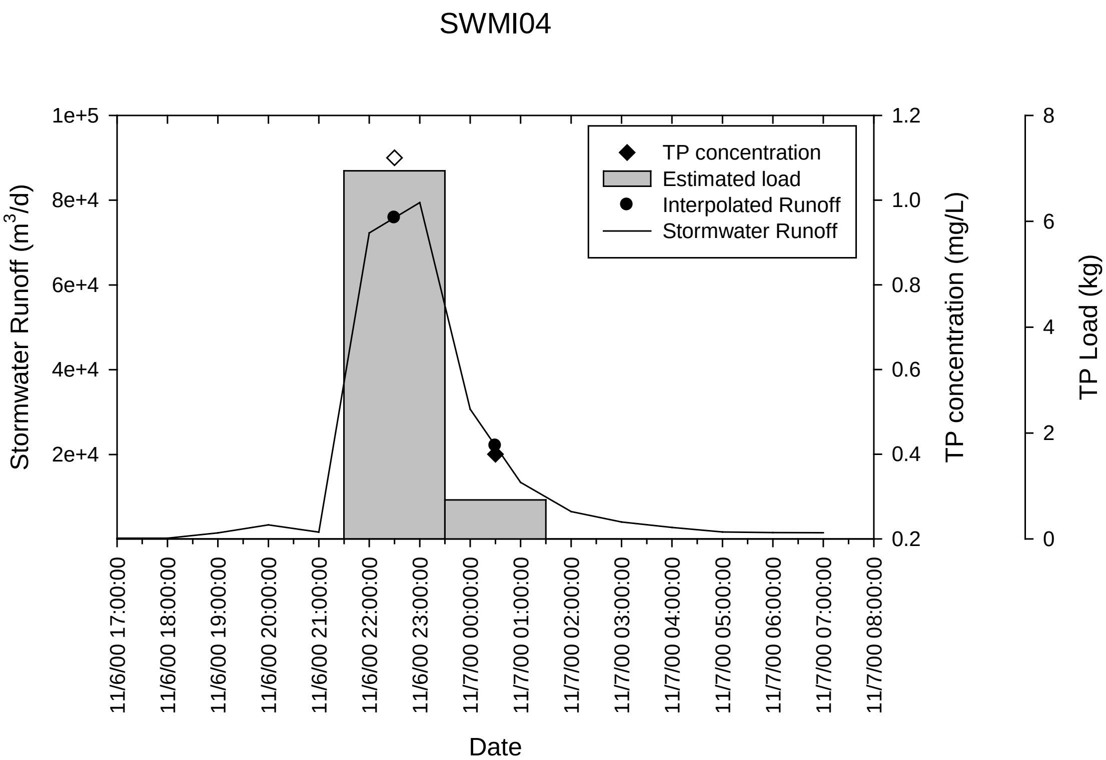


Figure 15. Illustration of TP load calculation for one runoff event at site SWMI04 (South Lake Drive at Bayview Park).

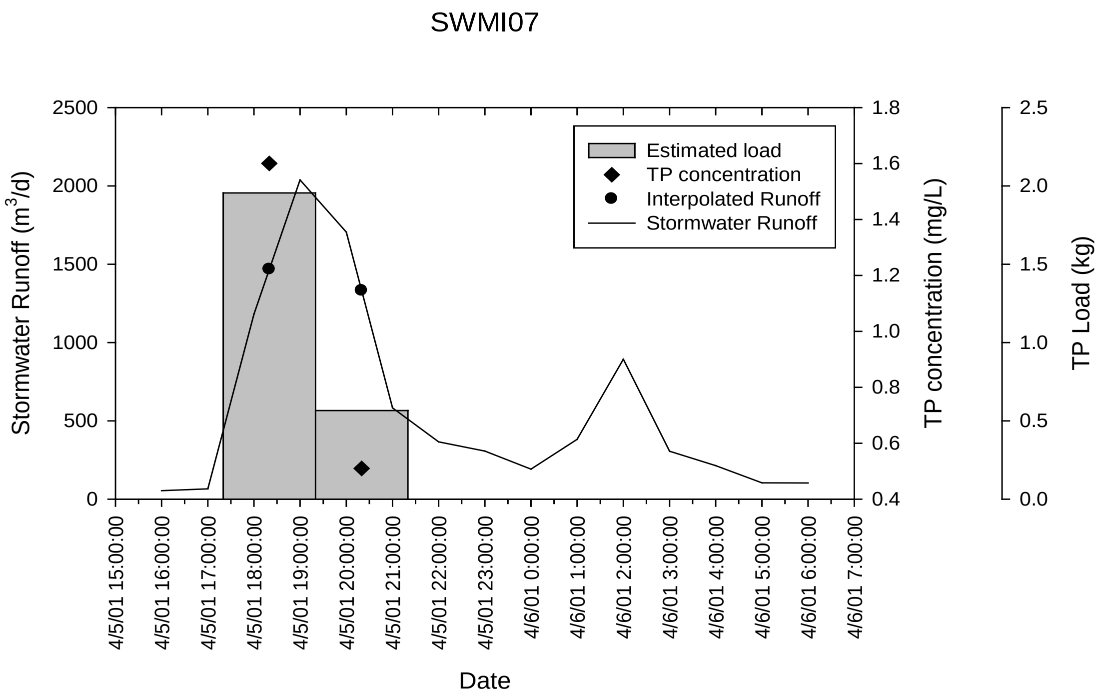


Figure 16. Illustration of TP load calculation for one runoff event at site SWMI07 (North 47th Street and Congress Street).

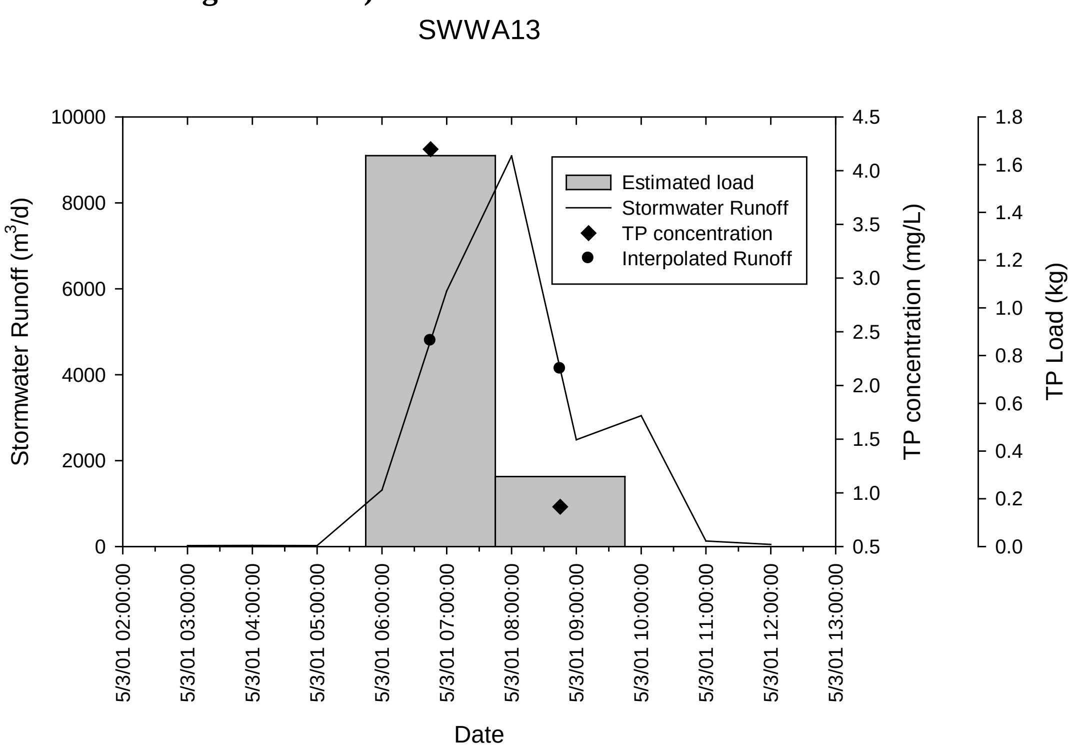


Figure 17. Illustration of TP load calculation for one runoff event at site SWWA13 (Ridge Blvd and Harding Blvd).

Because the TP concentration in stormwater varies, as does the stormwater runoff volume, each TP measurement needs to be related to the runoff event to get an accurate TP load for the event, to avoid estimation error. The most difficult problem in estimating the TP load for the stormwater runoff is that the measurements for stormwater runoff are incomplete for both the TP concentration and runoff volume. There were no TP concentration measurements for many stormwater runoff events. Also, for some measurements, there were no stormwater runoff records. All of the events are considered where there are measurements of both TP concentrations and flow for each monitoring site. The estimated results for TP load per event for each stormwater monitoring site are plotted in Figures 18 – 23.

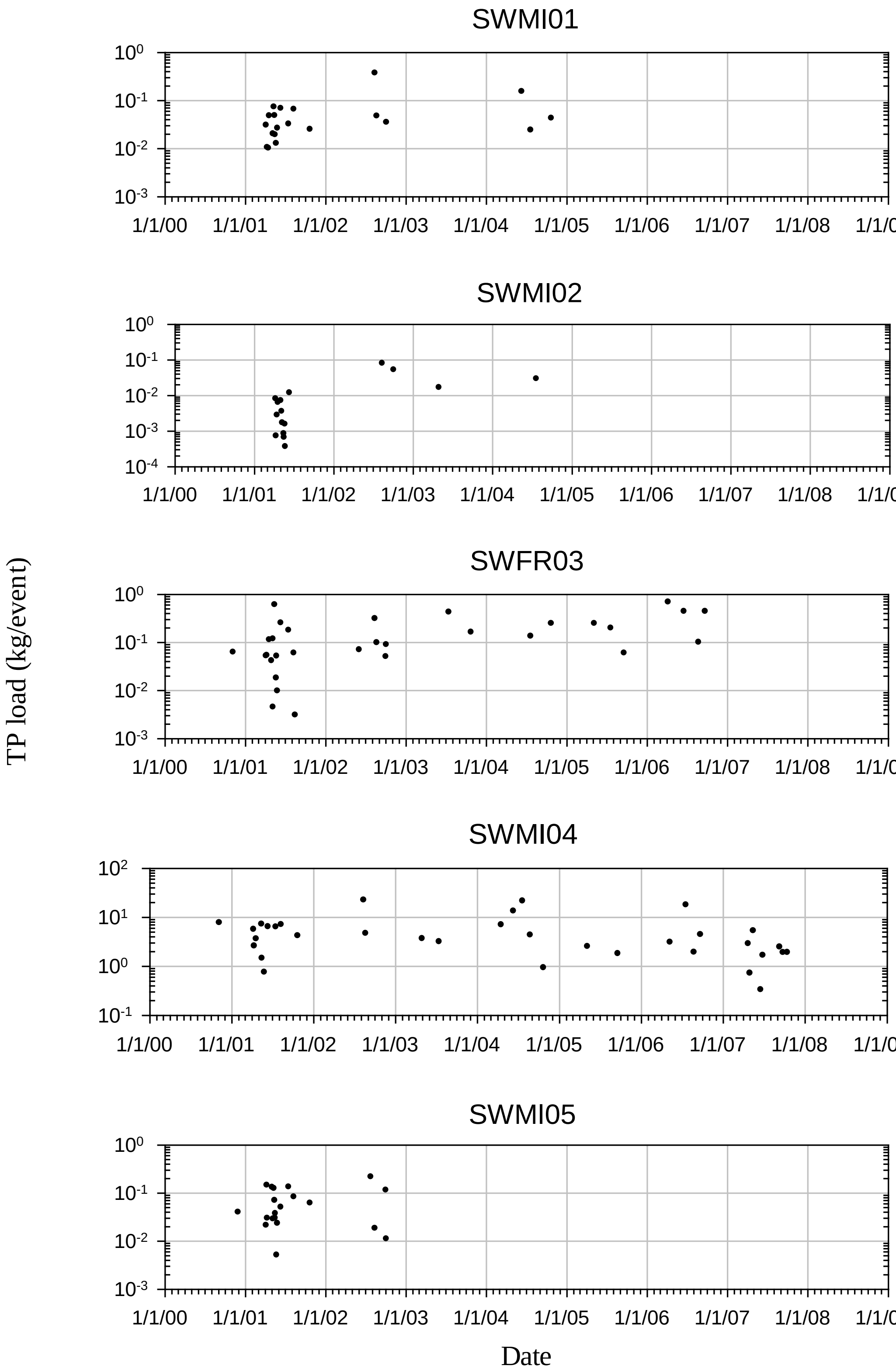


Figure 18. TP load per event for stormwater monitoring sites SWMI01-SWMI05.

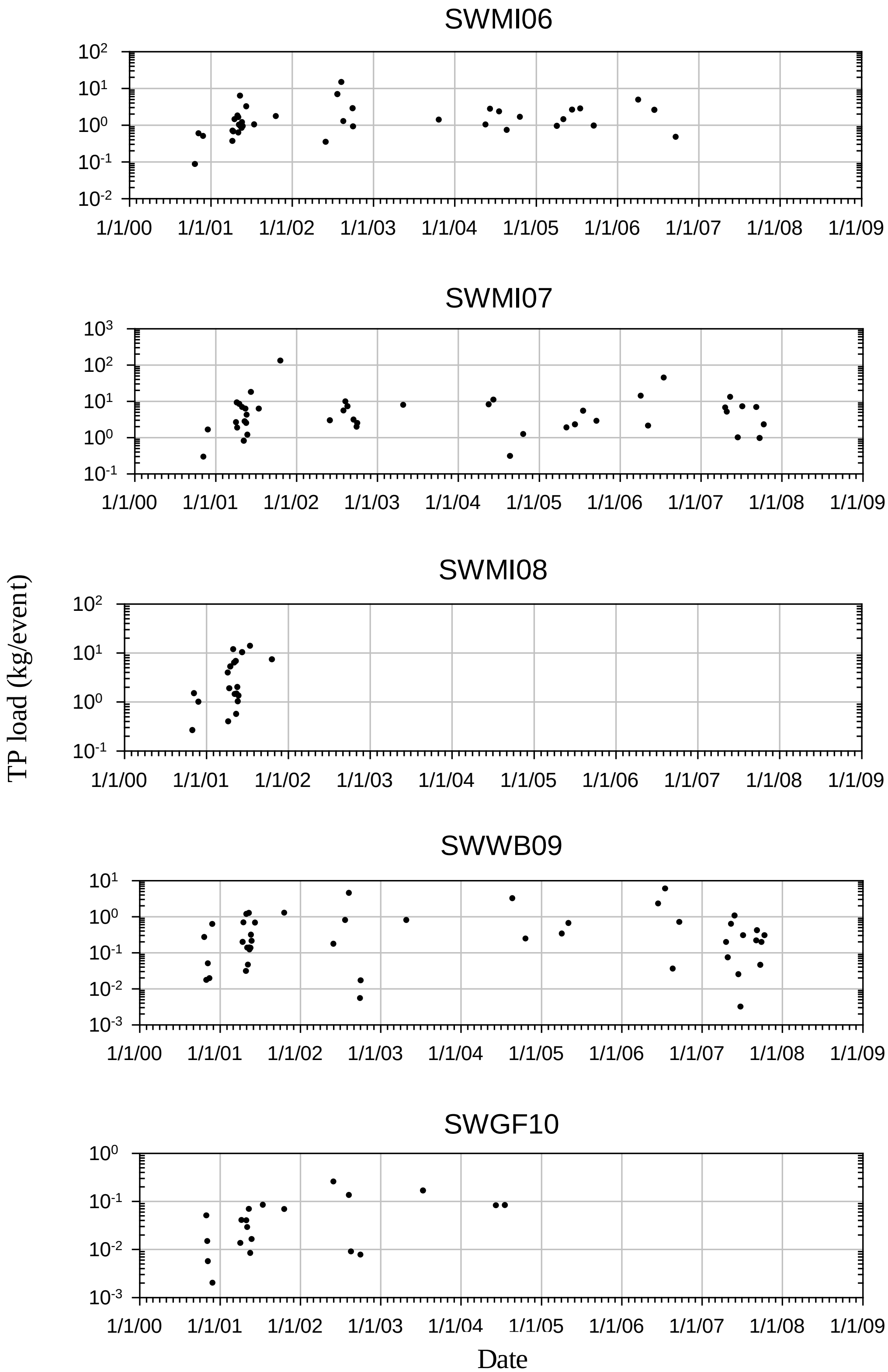


Figure 19. TP load per event for stormwater monitoring sites SWMI06-SWGF10.

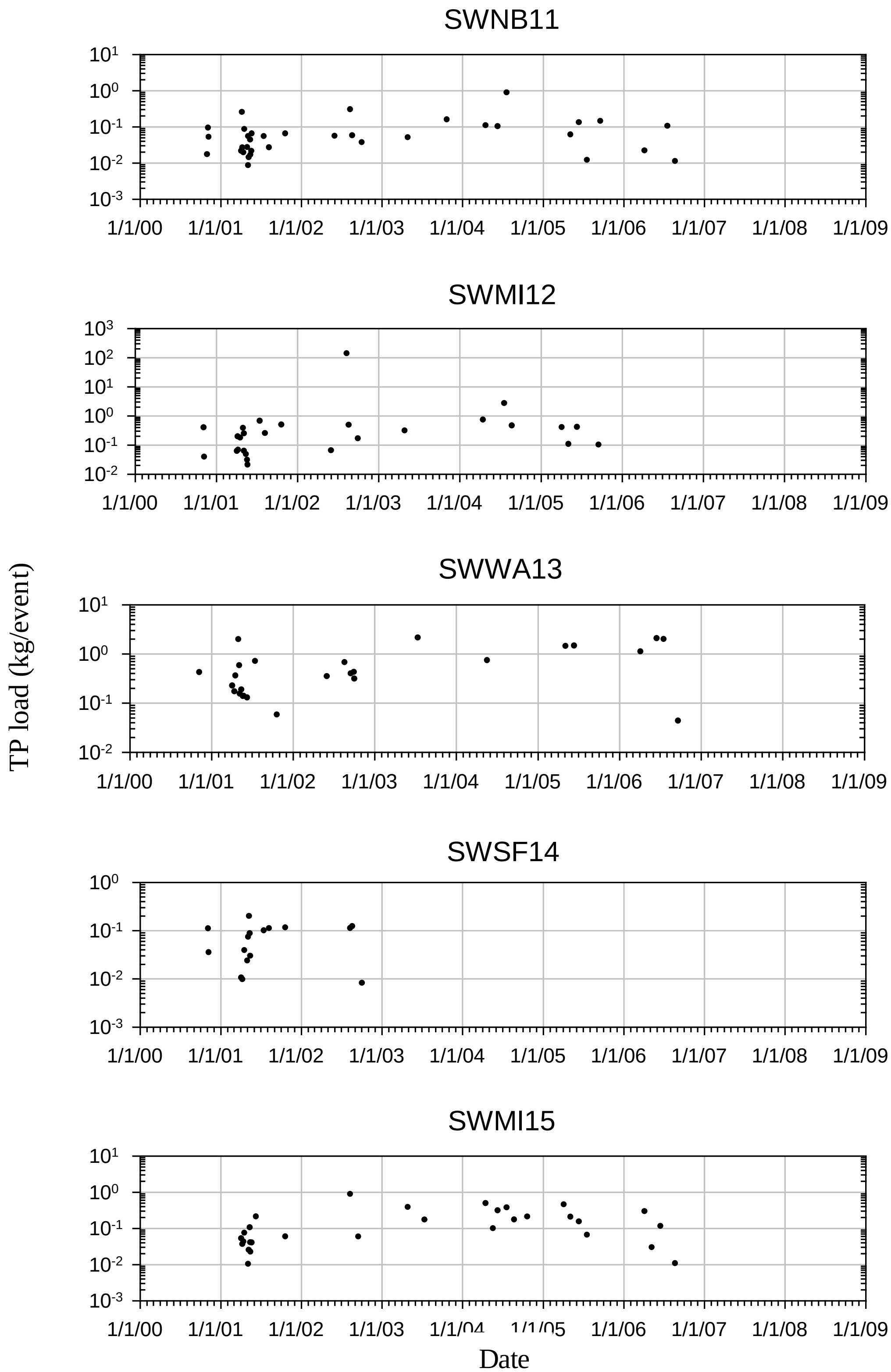


Figure 20. TP load per event for stormwater monitoring sites SWNB11-SWMI15.

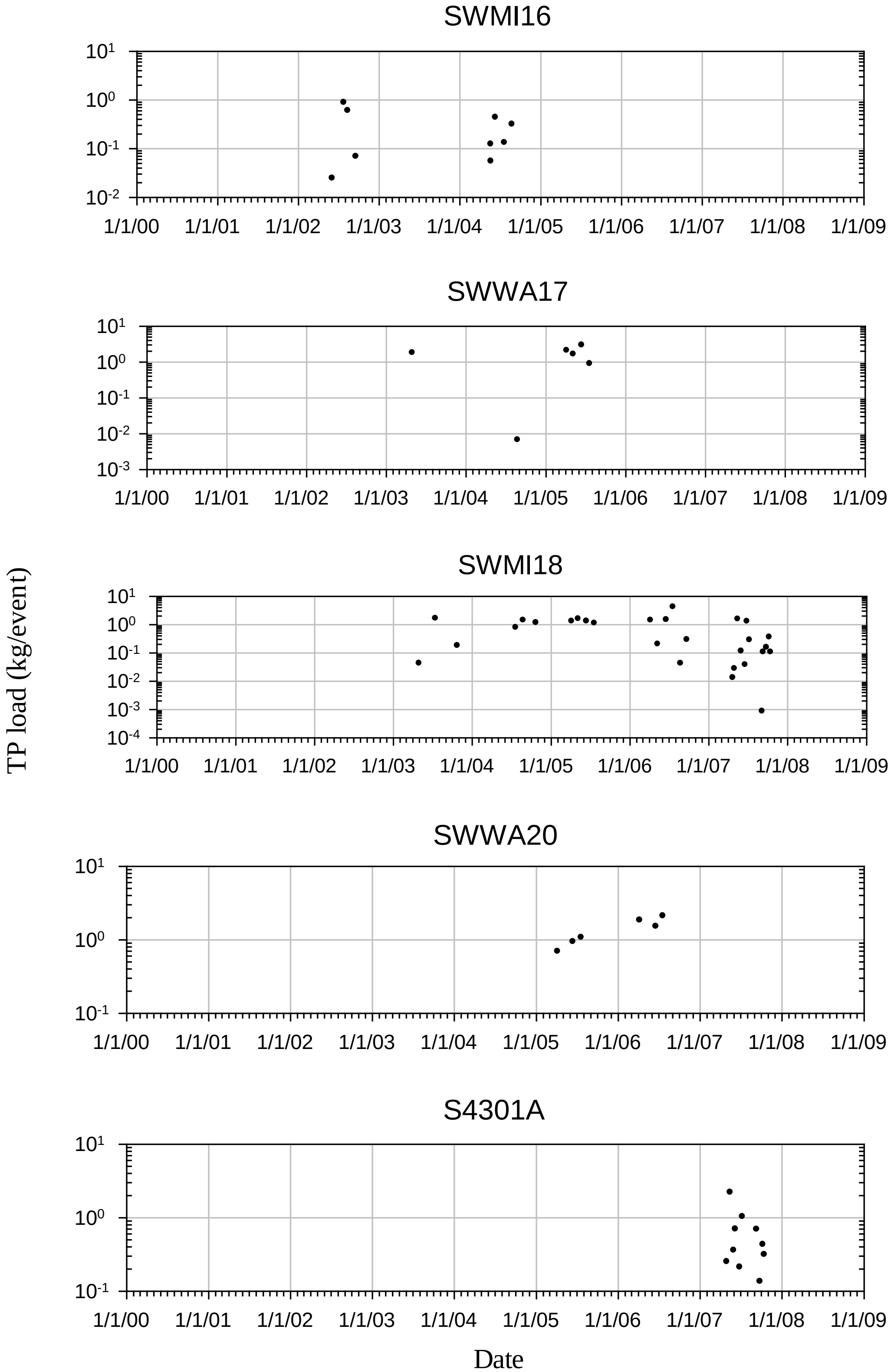


Figure 21. TP load per event for stormwater monitoring sites SWMI16-S4301A.

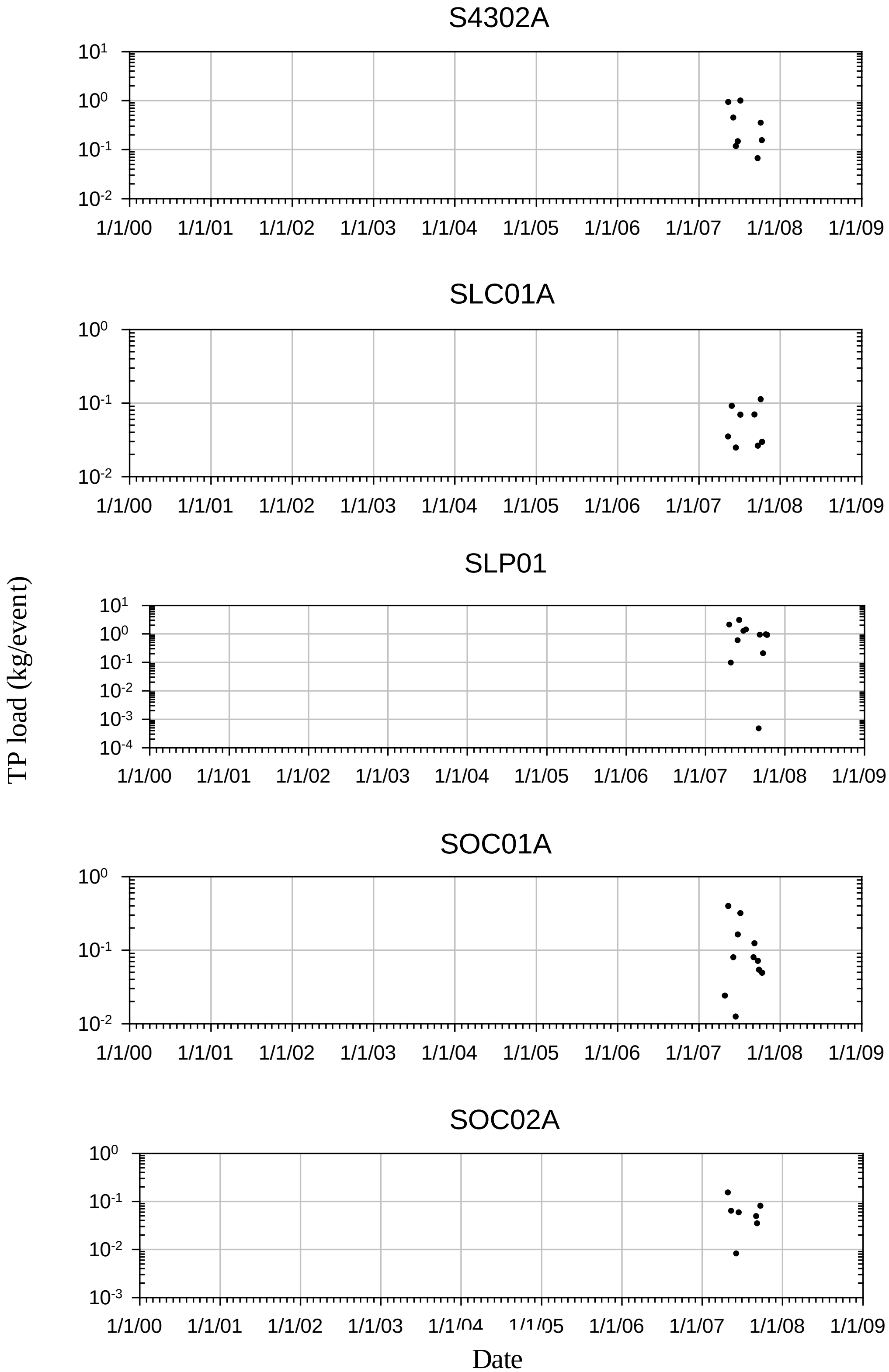


Figure 22. TP load per event for stormwater monitoring sites S4302A-SOC02A.

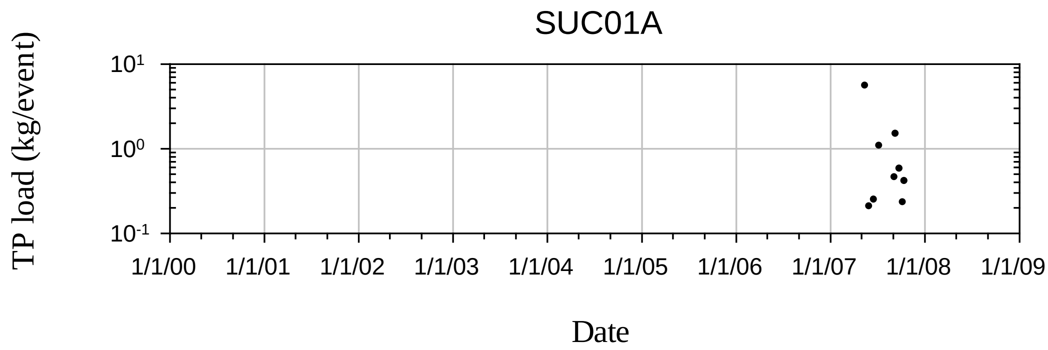


Figure 23. TP load per event for stormwater monitoring site SUC01A.

The average TP load per event has been estimated for each site, and by using the average load per event for this site times the annual number of significant stormwater runoff events we obtained the annual load for this site. However, for some stormwater monitoring sites there were no simultaneous data for measurements of phosphorus and flow matched events. Therefore, there are no load estimates available for these sites. All sites with effective runoff events and the estimated average TP load are listed in Table 3. Effective runoff events are defined here as events with actual load estimates.

The time period from June 1, 2004 to May 31, 2005 was used to estimate the annual stormwater runoff events. The time period was chosen to maintain consistency with the estimated river TP load by United States Geological Survey (USGS). Daily estimated TP load in the three main rivers in the MMSD service area was obtained from the USGS website (http://wi.water.usgs.gov/) for the time period from June 1, 2004 to September 30, 2005. Both daily flow and daily TP load are listed in the USGS web page.

The number of annual runoff events was estimated as follows: the runoff data was plotted against time, then the distinct peaks from the plots, whose maximum discharge rates were larger than 0.2 mgd (to rule out some base flow), are counted. The number of peaks was taken as the number of annual runoff events.

Table 3. Estimated TP load for stormwater monitoring sites.

Stormwater Monitoring Sites	Total effective events from 2000 - 2008	Average Load (kg/event)	Estimated No. of Annual Runoff events (from 2004/6/1-2005/5/31)	Load (kg/yr)
SWMI01	20	0.058	24	1.387
SWMI02	16	0.014	20[a]	0.277
SWFR03	31	0.173	26	4.499
SWMI04	34	5.345	24	128.275
SWMI05	20	0.068	20[a]	1.367
SWMI06	39	1.948	18	35.067
SWMI07	44	8.305	20	166.100
SWMI08	19	4.009	20[a]	80.173
SWWB09	45	0.653	15	9.792
SWGF10	20	0.057	18	1.031
SWNB11	35	0.089	20	1.770
SWMI12	27	5.251	19	99.763
SWWA13	26	0.690	20	13.809
SWSF14	16	0.072	20[a]	1.448
SWMI15	30	0.168	21	3.524
SWMI16	9	0.293	19	5.565
SWWA17	6	1.558	21	32.708
SWMI18	28	0.787	19	14.949
SWWA20	6	1.359	20[a]	27.189
S4301A	10	0.631	20[a]	12.628
S4302A	8	0.389	20[a]	7.777
SLC01A	8	0.056	20[a]	1.120
SLP01A	11	0.983	20[a]	19.661
SOC01A	11	0.122	20[a]	2.433
SOC02A	7	0.062	20[a]	1.233
SUC01A	9	1.129	20[a]	22.588

[a] No data available for this site, thus we used average annual runoff events number.

The estimated number of runoff events in Table 3 is given because there were no runoff records for some of the original sites and for all new sites in the given time. For the new sites, the reason is that these sites were not active for the time period. With the estimated annual runoff events, the average number of events is about 20; this number was used as the annual number of stormwater runoff events for those sites. The number seems reasonable since the number of precipitation events cannot vary too much within the MMSD planning area due to its relatively small size. The annual TP load for each stormwater monitoring site was calculated as the average load per event multiplied by the annual number of events for the sites (Table 3).

The load for different stormwater monitoring sites varies from 0.3 kg/yr or 0.66 lb/yr (SWMI02) to 166 kg/yr or 366 lb/yr (SWMI07). TP concentrations show only minor variations, so the difference of the load is mainly due to different runoff volumes. Analyzed in this study are stormwater samples from stations 1-18 listed in Table 1 and 28 new stormwater stations listed in Table 2. The load from the 18 original stormwater sites was calculated as the sum of the corresponding annual loads listed in Table 3 (602 kg/yr). For the new sites, only 8 out of 28 sites had data. The average for the eight stations (11.8 kg/ yr) is multiplied by the total number of sites, 28, to get 331 kg/yr (782 lbs/yr) as a TP load. Most stormwater stations for this study discharge directly to the rivers. However stormwater stations discharging directly to Lake Michigan (SWMI01, SWMI02, SWMI04, SWWB09, and SWSF14) are analyzed separately in this study. Out of the 28 new stations, six discharge directly to Lake Michigan (SWMI19, SLM01A, SLM01B, SLM01C, SLM020, SLM03A), but because the load estimates are less certain they are not included in stormwater discharges to Lake Michigan.

Rivers

MMSD has maintained an extensive water quality monitoring program since 1975. A large comprehensive database of physical, chemical, and biological measurements has been accumulated through this program. More water quality sample parameters as well as more sampling sites have been added each year; the sampling sites for the three larger rivers has increased to 37 locations. The maps of the three main (Milwaukee, Menomonee and Kinnickinnic) rivers with sampling sites are given in Appendix A (Figure A-1).

Phosphorus Concentration in Rivers

There was no significant difference in phosphorus concentrations in the three main rivers. The average TP concentration is 0.12 mg/L in the three main rivers, which is lower than the WPDES (WDNR, 2003) limit of 1 mg/L, but is slightly higher than the new water quality standard 0.1 mg/L. The average TSP concentration is 0.056 mg/L which is also slightly higher than the EPA (EPA Gold Book, 1986) limit of 0.05 mg/L. The TP concentrations correlate with the flow volume in the rivers. The higher TP concentration occurred in the months of May-June of the years 2000, 2004, 2007, and 2008, corresponding to high flow rate in rivers. These time periods also correspond to reported high rainfall amounts and resulting runoff. All TP concentration measurements in the three main rivers and the flow rate of the rivers are plotted against time and shown in Appendix D.

Phosphorus Loads in Rivers

TP load for the rivers is determined by the measured TP concentration in the rivers multiplied by the measured river discharge acquired from USGS gage. The monitoring site RI-04 (Milwaukee River @ Port Washington Road), RI-09 (Menomonee River @ 70th Street and State Street), and RI-13 (Kinnickinnic River @ 11th Street), are close to the USGS monitoring sites 04087000 (Milwaukee River @ Milwaukee), 04087120 (Menomonee River @ Wauwatosa), 04087159 (Kinnickinnic River @ 11th Street), respectively. Daily TP loads (lb/day) for Milwaukee River, Menomonee River and Kinnickinnic River from June 2004 to September 2005 were acquired at the USGS website (http://wi.water.usgs.gov/), and the data was converted into kg/day.

The river discharge data were recorded as daily discharge. However, the TP concentration measurements were randomly taken and so the time interval could be five days, one week, ten days, half a month, etc. To calculate the daily TP load for days without measurements, TP concentrations were interpolated between concentrations obtained at sampling dates. To estimate the daily TP load and make it comparable to USGS daily loads, the time period from June 1, 2004 to May 31, 2005 was chosen. The estimated total annual TP loads for Milwaukee, Menomonee, and Kinnickinnic Rivers for this study are shown in Table 4 for the June 1st , 2004 to May 31rd 2005 time period. The annual TP loads for the Milwaukee, Menomonee, and Kinnickinnic Rivers estimated by USGS for the same time period are shown as a comparison. The annual loads given by USGS for the rivers are between 24% and 56% higher than those of this study. The reason for this difference may be that USGS uses daily TP loads whereas MMSD has various time periods, typically 10-15 days, between TP measurements and therefore the calculated river loads for this study may be underestimated. An example of how the TP load in the Milwaukee River was calculated for this study is shown in Table 5.

Table 4. Calculated Total Annual TP loads for Milwaukee, Menomonee, and Kinnickinnic Rivers.

River	This Study Total annual TP loads kg/yr (lbs/yr)	USGS Total Annual TP loads kg/yr (lbs/yr)
Milwaukee	63,700 (140,400)	89,100 (196,400)
Menomonee	7,100 (15,650)	10,700 (23,590)
Kinnickinnic	2,100 (4,630)	4,800 (10,580)

Table 5. Example of the TP loads computation in Milwaukee River.

Date	Discharge Q[a] (m^3/d)	TP concentration (mg/L)[b]	interpolated TP concentration (mg/L)	Estimated daily TP load (kg/d)	P load estimated by USGS (kg/d)[a]
6/7/2004	3.99E+06	0.13	0.13	518.43	539.77
6/8/2004	3.25E+06		0.132	430.67	431.82
6/9/2004	3.13E+06		0.135	421.85	363.78
6/10/2004	3.52E+06		0.137	482.87	467.20
6/11/2004	7.93E+06		0.139	1105.10	893.58
6/12/2004	1.18E+07		0.142	1668.29	2630.84
6/13/2004	1.35E+07		0.144	1946.32	2961.96
6/14/2004	1.51E+07		0.146	2207.44	2798.67
6/15/2004	1.44E+07		0.149	2148.23	2540.12
6/16/2004	1.24E+07		0.151	1875.21	2032.09
6/17/2004	1.04E+07		0.154	1596.39	2000.34
6/18/2004	8.83E+06		0.156	1376.77	1846.12
6/19/2004	7.39E+06		0.158	1169.14	1515.00
6/20/2004	6.14E+06		0.161	986.16	1174.80
6/21/2004	4.92E+06		0.163	801.28	898.11
6/22/2004	3.94E+06		0.165	651.09	712.14
6/23/2004	3.30E+06		0.168	553.72	571.53
6/24/2004	3.18E+06	0.17	0.17	540.69	548.85
6/25/2004	3.03E+06		0.173	525.07	494.42
6/26/2004	2.81E+06		0.176	495.62	452.69
6/27/2004	2.62E+06		0.179	469.20	410.95
6/28/2004	2.50E+06		0.182	454.95	384.19
6/29/2004	2.32E+06		0.185	429.97	348.81
6/30/2004	2.11E+06		0.188	397.45	310.26
7/1/2004	1.90E+06		0.192	363.64	273.52
7/2/2004	1.78E+06		0.195	347.11	235.87
7/3/2004	1.84E+06		0.198	364.69	254.92
7/4/2004	2.89E+06		0.201	579.61	566.99
7/5/2004	2.94E+06		0.204	598.47	526.17
7/6/2004	2.69E+06		0.207	556.88	530.70
7/7/2004	2.50E+06	0.21	0.21	524.06	476.27

[a] Data acquired from USGS website: http://wi.water.usgs.gov/, USGS TP loads were given in lb/d, here converted to kg/d.
[b] Measurements taken by MMSD.

Outer Harbor

TP concentrations in the Outer Harbor are influenced by discharge from the three main rivers as well as the discharge of effluent from the Jones Island Water Reclamation Facility (Figure 24). A map of the Outer Harbor water quality monitoring sites is shown in Appendix A (Figure A-2).

Figure 24. Jones Island Water Reclamation Facility Outfall – OH-02.
Source: MMSD

The average TP concentration in the Outer Harbor is 0.034 mg/L, which is lower than 0.1 mg/L proposed for rivers and the Outer Harbor. The Milwaukee Outer Harbor is dominated by river water from the Milwaukee, Menomonee and the Kinnickinnic rivers during runoff events and thus acts as an extension of the river system during high flows.

The total phosphorus (TP) concentration measurements for all 15 Outer Harbor monitoring sites for the MMSD are plotted in Figures 25-27. Similar to TP concentration in the rivers, there were some high values shown in the year 2000, 2004, 2007, and 2008. This was especially true for 2004 where nearly all Outer Harbor monitoring sites were greatly influenced by the river discharge entering at site OH-01 (mouth of the Milwaukee River). In May 2004 there were 19 days of nearly consecutive rainfall. The high TP concentration in the Outer Harbor during these times is considered to be primarily related to the high TP load from river sediment re-suspension, surface stormwater runoff, sewer overflows and wastewater treament.

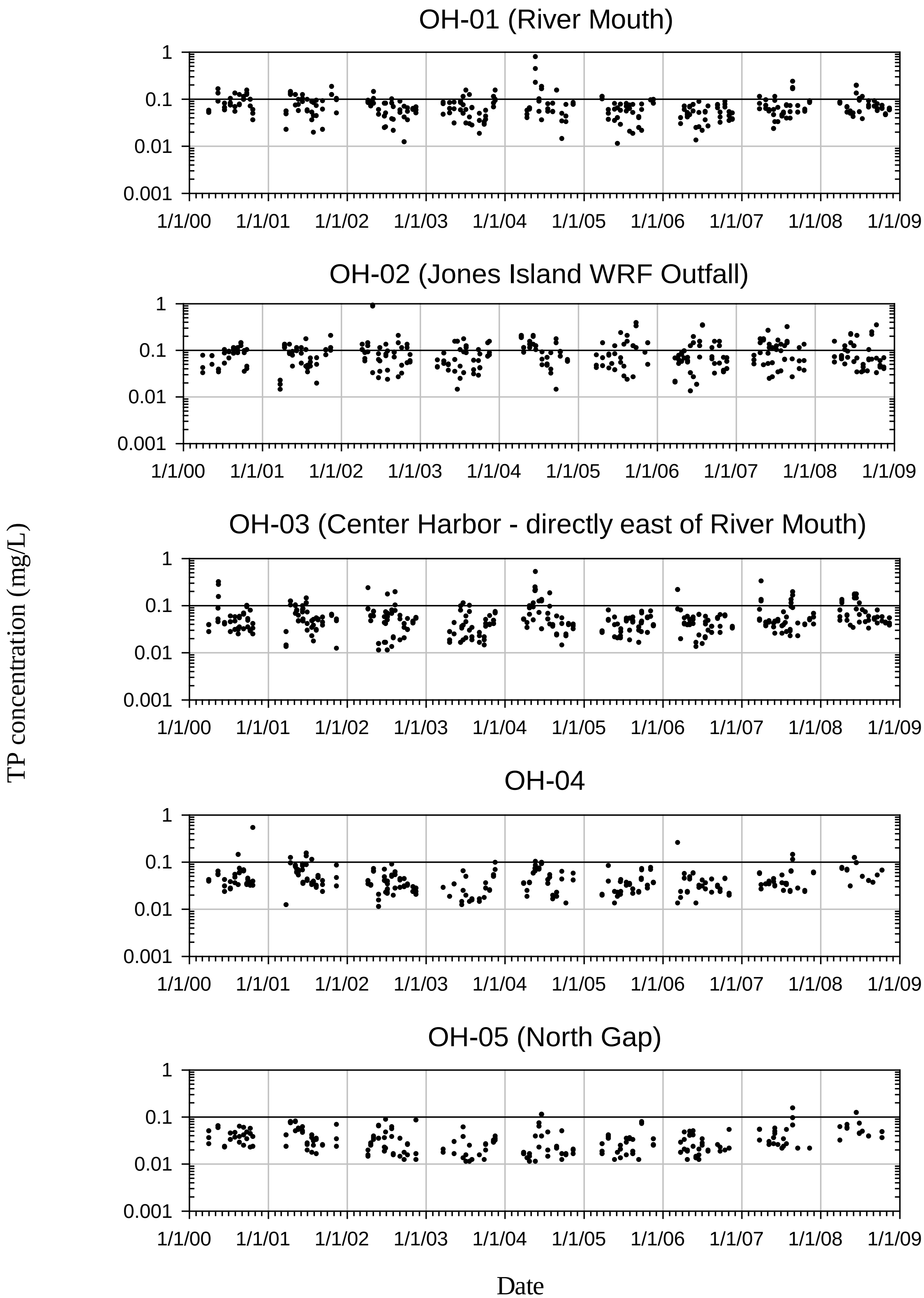


Figure 25. TP levels in Outer Harbor monitoring sites OH01-OH05. The recommended limit of 0.1 mg/L for inside the water gap is indicated.

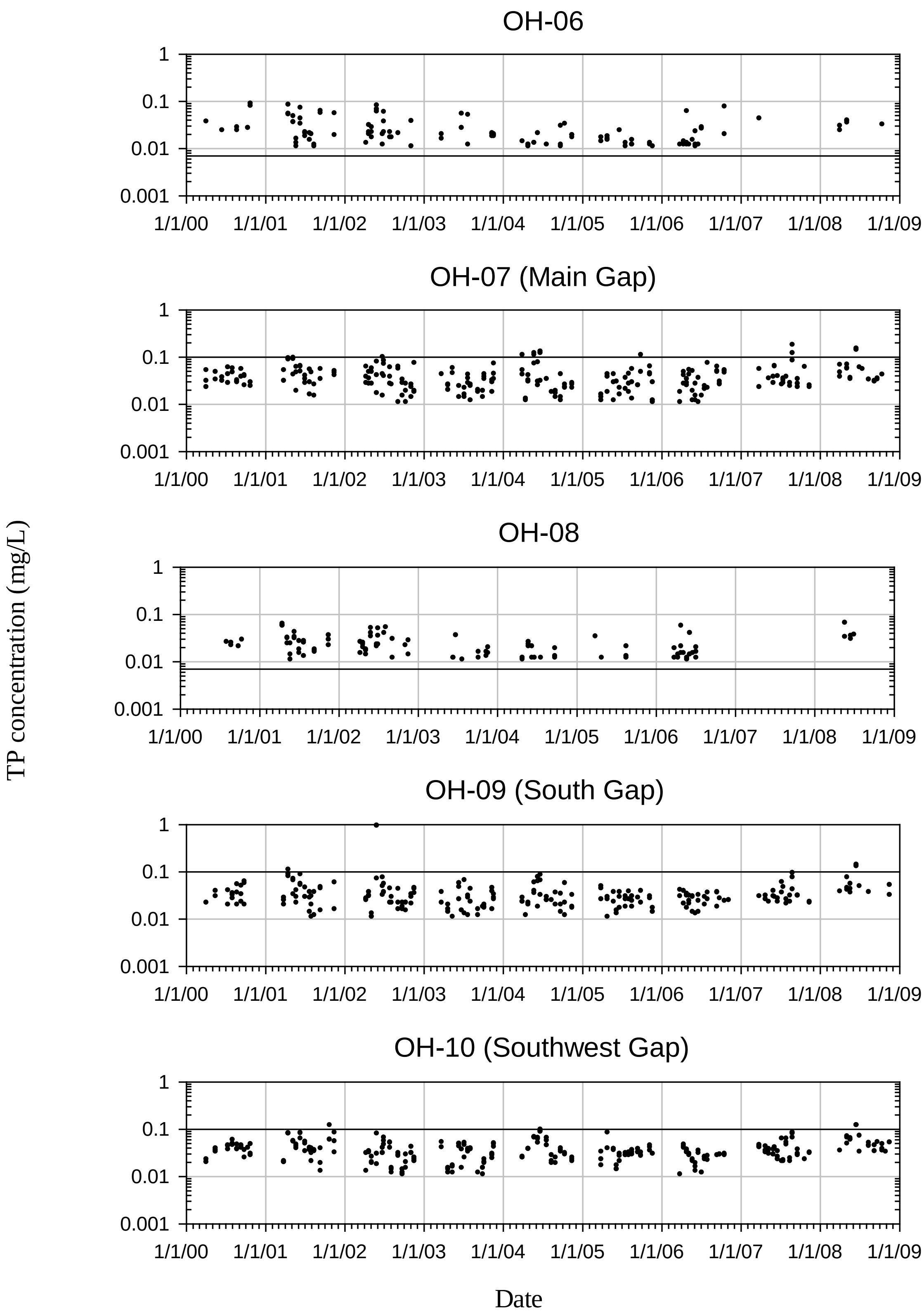


Figure 26. TP levels in Outer Harbor monitoring sites OH06-OH10. The recommended limits of 0.007 mg/L for sites outside and 0.1 mg/L for inside the water gap are indicated.

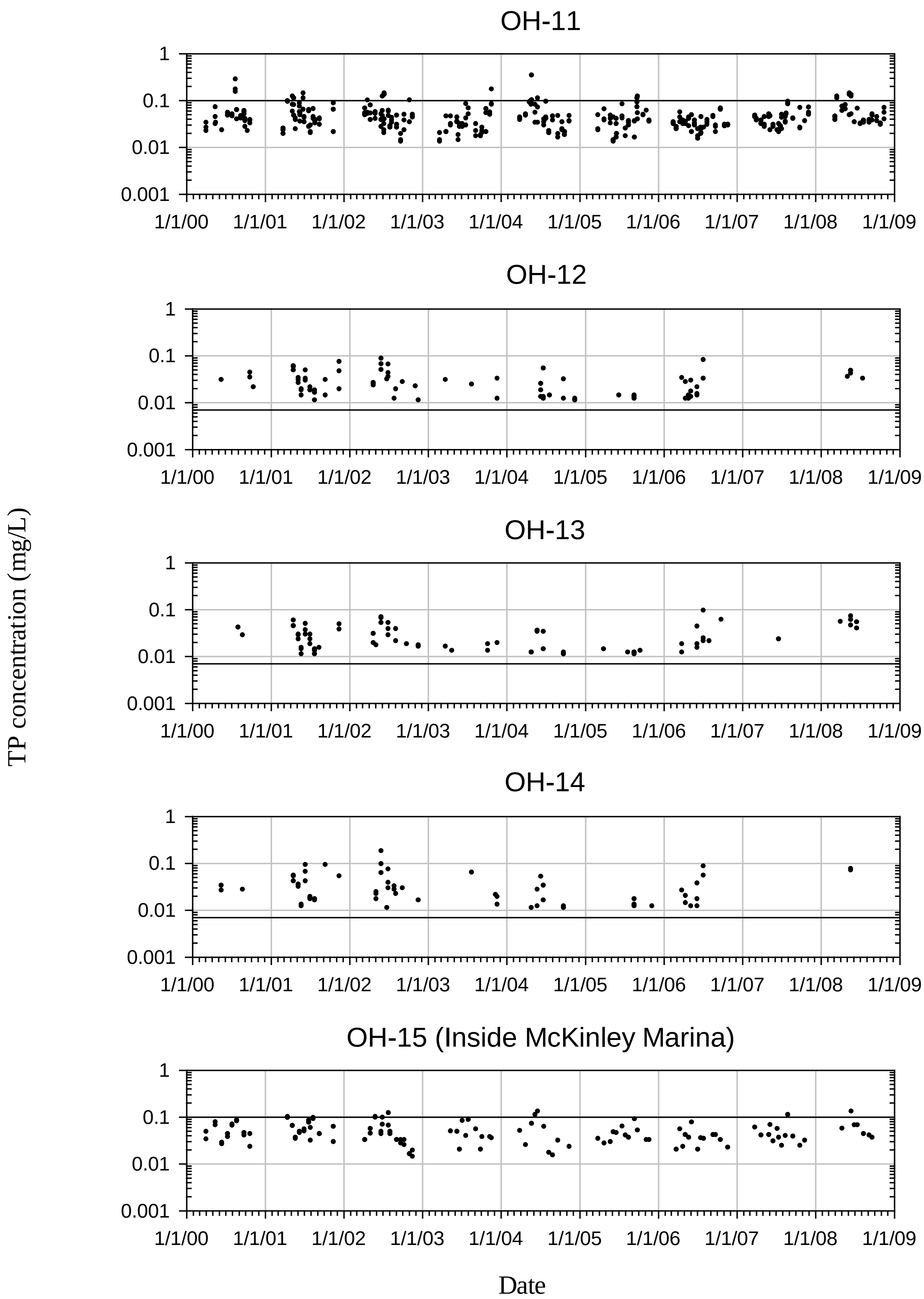


Figure 27. TP levels in Outer Harbor monitoring sites OH11-OH15. The recommended limits of 0.007 mg/L for sites outside and 0.1 mg/L for inside the water gap are indicated.

Combined Sewer Overflow

Phosphorus Concentration in Combined Sewer Overflow

Although Combined Sewer Overflows (CSO) are also a source of phosphorus to the watersheds, the low frequency of overflows (2 – 3x/year) limits the impact since the Deep Tunnel system became operational (Figure 28). Compared to rivers and stormwater samples, there were few measurements for CSOs due to this low frequency of occurrence. The average TP concentrations in CSOs are close to those of stormwater, but higher than the TP concentrations in the rivers. There is no obvious trend for TP concentrations in CSOs during 2000 – 2008. The TP concentrations for CSOs are shown in Appendix E. CSO events occur during heavy rainfall as in 2000, 2004, 2007, and 2008. There were no CSO events during 2003.

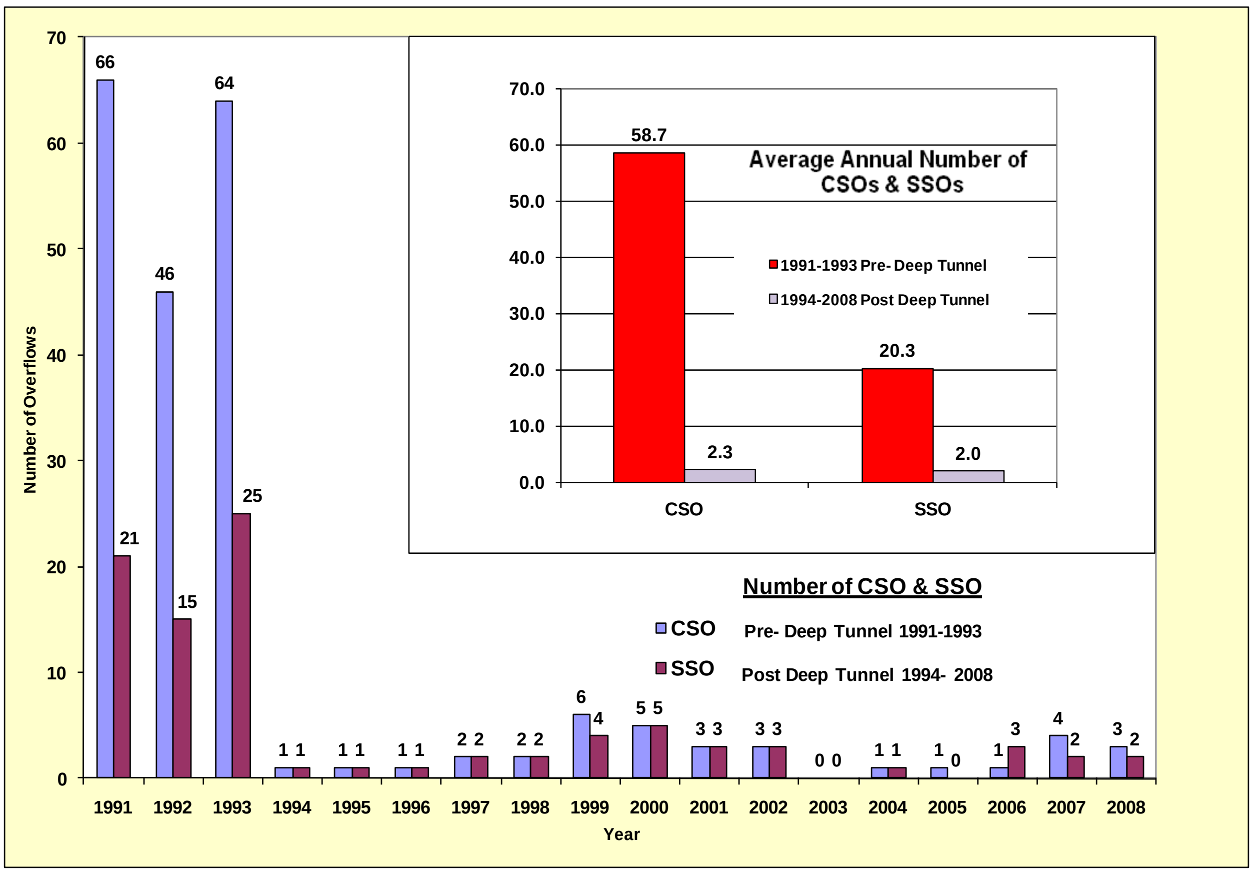


Figure 28. Number of CSOs and SSOs and Average Annual Number of CSOs and SSOs (1991-2008). ***Source: MMSD***

Phosphorus Loads in Combined Sewer Overflow

The available CSO flow data from MMSD are in the form of total volumes discharged per year for each of the overflow drop shafts. Estimation of CSO load per event like that done for stormwater is not feasible due to the lack of flow measurement or monitoring data. However using the annual CSO flow volume data along with average TP concentration calculated from the CSO monitoring data, an estimate of the TP load from CSOs has been performed. It should be noted that CSOs are typically by volume 90% stormwater; therefore a significant portion of the overall TP load found in CSOs is from stormwater. Results are shown in Table 6.

Table 6. TP load from Combined Sewer Overflow sites.

NCS ID	Total CSO Volume (2000 - 2008) (× 10^3 m^3)	Average TP Concentration (mg/L)	Total TP Load (2000 - 2008) (kg)	Load Per Year (kg/yr)
CT02	682.51	0.71	482.25	53.58
CT3/4	5263.62	0.69	3612.75	401.42
CT5/6	10219.10	1.90	19378.11	2153.12
CT07	622.32	0.74	459.90	51.10
CT08	108.64	1.13	122.91	13.66
KK1	2053.95	0.65	1342.39	149.15
KK2	771.85	0.95	732.58	81.40
KK3	646.55	0.97	624.66	69.41
KK4	735.51	1.20	880.06	97.78
LMN	2905.30	0.65	1888.24	209.80
LMS	711.66	1.24	881.07	97.90
NS04	1810.18	0.57	1023.93	113.77
NS05	171.86	1.02	174.56	19.40
NS06	2235.66	0.53	1184.77	131.64
NS07	3060.17	0.83	2548.41	283.16
NS08	1062.94	0.69	736.62	81.85
NS09	1129.33	0.71	796.09	88.45
NS10	695.00	0.52	363.10	40.34
NS11	652.23	0.62	406.95	45.22
NS12	86.31	0.49	42.29	4.70
			Sum =	4186.85

Jones Island Water Reclamation Facility

MMSD measures mean daily flow and mean monthly TP effluent concentrations for each month from January 2004 to December 2008 for Jones Island and South Shore Water Reclamation Facilities (Figure 29).

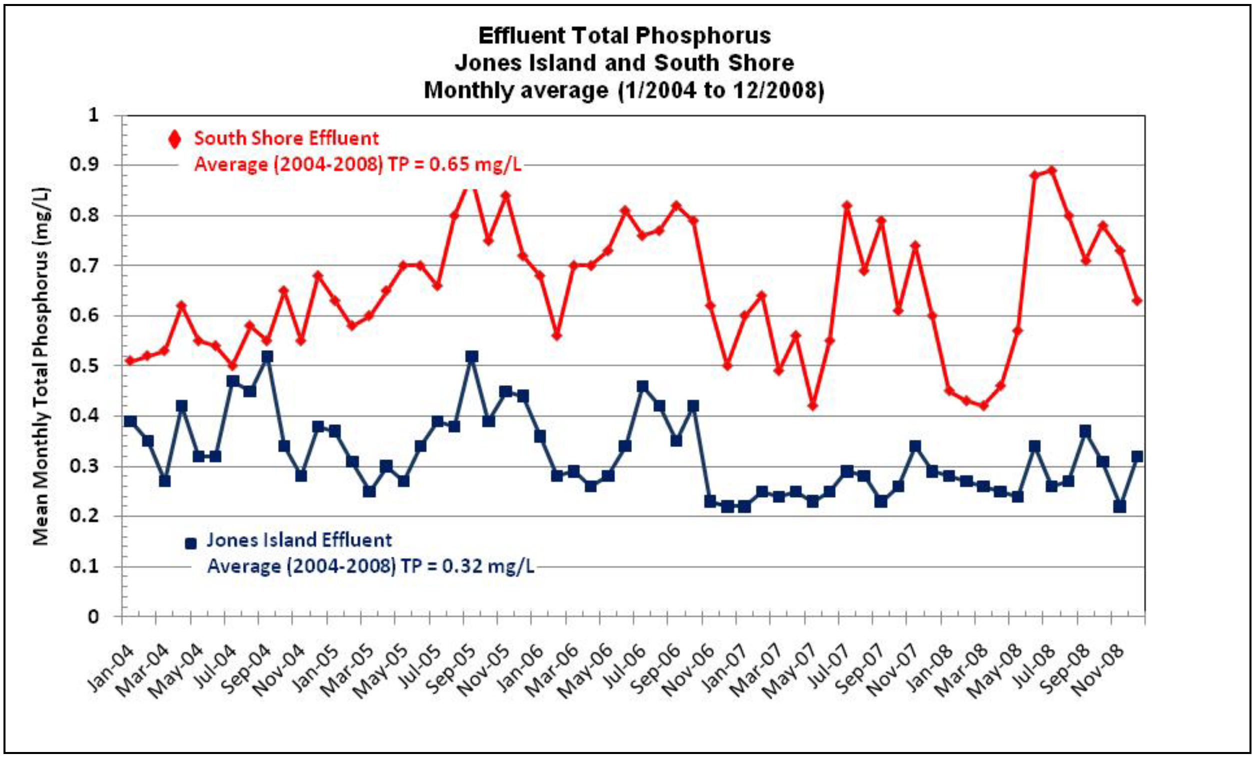


Figure 29. Monthly Average Total Phosphorus for Jones Island and South Shore WRF Effluent 2004-2008. ***Source: MMSD***

From these data, estimates of the annual TP load from the water reclamation facilities were calculated by multiplying the average monthly TP concentration (applied as an average daily TP concentration) with the daily flow rate. Table 7 shows the calculation of TP load from Jones Island Water Reclamation Facility for the year 2004.

Table 7. TP load from Jones Island Water Reclamation Facility Effluent for the year 2004.

Month	Average Daily Flow, MGD	Average Daily TP, mg/L	Average Daily TP Load (kg/d)	Monthly TP Load (kg/month)	Monthly TP Load (lbs/month)
1	69	0.39	101.87	3,060	6,732
2	74	0.35	98.04	2,840	6,248
3	105	0.27	107.32	3,330	7,326
4	90	0.42	143.09	4,290	9,438
5	154	0.32	186.55	5,780	12,761
6	109	0.32	132.04	3,960	8,712

Table 7. (cont.)TP load from Jones Island Water Reclamation Facility Effluent for the year 2004.

Month	Average Daily Flow, MGD	Average Daily TP, mg/L	Average Daily TP Load (kg/d)	Monthly TP Load (kg/month)	Monthly TP Load (lbs/month)
7	106	0.47	188.59	5,500	12,870
8	96	0.45	163.53	5,070	11,154
9	78	0.52	153.54	4,610	10,142
10	73	0.34	93.95	2,910	6,402
11	85	0.28	90.09	2,700	5,940
12	77	0.38	110.76	3,430	7,546
			Yearly Total =	47,830	105,276

Stepwise Regression Analysis of TP, TSP, TSS, and BOD

In order to take appropriate action to lower the phosphorus concentration in Milwaukee area watersheds, it is important to determine the major sources of TP. The TP loads from stormwater, rivers, CSOs, and Jones Island Water Reclamation Facility have been calculated. These estimates give us an overall picture of the TP load from all possible sources. To acquire a full understanding of the magnitude of the different sources to the TP load in the watershed, it is important to analyze the correlations between the TP concentration and water quality parameters such as TSS, TSP, and BOD.

There is more than one independent variable when we apply correlation analysis. Thus, multiple linear regressions are needed. A multiple regression equation can be expressed as (Berger, 2010),

$$Y = \alpha + B_1 x_1 + B_2 x_2 + B_3 x_3 \tag{2}$$

where α is the intercept of the linear regression and B_i are the coefficients of the independent variables. The coefficients α and B_i are determined from standardized regression coefficient β_i (Berger, 2010),

$$\beta_i = \frac{r_{Yx_i} - r_{Yx_j} r_{x_i x_j}}{1 - (r_{x_i x_j})^2} \tag{3}$$

$$B_i = \beta_i \frac{SD_Y}{SD_{x_i}} \tag{4}$$

$$\alpha = \bar{Y} - \sum_i B_i \bar{x}_i \tag{5}$$

where r is correlation between two variables and SD is the standard deviation of the variable.

In order to find the water quality parameters with the highest correlation with TP, stepwise regression should be used. All the parameters of interest are entered in sequence of importance when applying multiple regressions, and their contribution and significance are assessed. If the new added parameter contributes significantly ($p<0.01$) to the model, it is retained. Then all the other parameters are retested to determine if they are still contributing to the model. If they are found not to be contributing to the model, a given parameter will be excluded. In conclusion, stepwise regression will end up with the smallest possible set of predictor objectives included in the regression model (Brace et al. 2010). All the regression analyses in this research were carried out using statistical package for the social sciences (SPSS) 17.0 (2008).

When estimating the TP load, the most interesting sites are Outer Harbor 01 (OH – 01), which is at the confluence of the three rivers into Lake Michigan, and Outer Harbor 02 (OH – 02), which is near the Jones Island Water Reclamation Facility (WRF) Outfall. These two sites represent river input (OH-01, nonpoint sources), and municipal wastewater treatment facility input and river input (OH-02, point and nonpoint sources).

Three river monitoring sites RI – 04 (Milwaukee River @ Port Washington Road), RI – 09 (Menomonee River @ 70th Street and State Street), and RI – 13 (Kinnickinnic River @ 11th Street) inside the combined sewer area were chosen to calculate the TP load in the three main rivers and make a comparison with USGS data. The stepwise multiple regression analysis is also conducted for the three river monitoring sites to determine what the main sources of TP are in the three rivers. We believe there is a strong suggestion of source for a high correlation, but there should be other evidence as well to have good source evidence. In the present case there is a significant correlation between TP vs TSP, TSS, and sometimes BOD in many parts of the water system which suggests that the regressions determine source materials.

When applying regression analysis, the regression of TP is made first based on TSS, TSP, and BOD individually, to examine the single correlations between TP and these independent variables. Then TP regressions with two of these independent variables are carried out to determine how the regressions are improved. Finally TP regressions are done with three independent variables. When there are two and more independent variables, stepwise regression is performed. The available data for OH – 01 and OH – 02 are TSS and TSP. The available data for the three river monitoring sites are TSS, TSP, BOD_5, and BOD_{20}. The coefficients (α, B), and standardized regression coefficients β, R^2 and p value of the regressions are listed in Appendix F. Selected plots of TP vs TSS, and TP vs TP calculated by multiple regressions are show in Figures 30 – 36.

Example output of the regressions with two independent variables is shown for OH-01 and OH-02 in Figures 30, 34 and Tables F1, F5. For OH – 01, the R^2 value of correlation between TP and TSS is 0.360 (panel 1, Figure 30), while for TP and TSP, the R^2 value is 0.418 (panel 1, Figure 34). A multiple regression which takes TSS and TSP as independent variables gives a better correlation (R^2 = 0.646, panel 3, Figure 30). However, for OH – 02, the R^2 value between TP and TSP is only 0.249 (panel 2, Figure 34). TP has also a poor correlation with TSS

(R^2 = 0.012, p = 0.244, see panel 2 in Figure 30 and Table F-1), so no significant multiple regression can be made for OH - 02.

For the three river stations RI-04, RI-09, and RI-13 we looked at TP vs TSS, TSP, and BOD. In general, the best correlations are between TP and either TSP or TSS. There is less but still significant correlation with BOD. For the Milwaukee River (RI – 04), TP is almost equally correlated with TSP (R^2 = 0.469) and TSS (R^2 = 0.457) (Figures 31, 35). For the Menomonee River (RI – 09), TP is highly correlated with TSS (R^2 = 0.568) and TSP (R^2 = 0.437) (Figure 32). Note that the R^2 value between TP and TSS is higher than between TP and TSP for the single variate cases (Table F-3). For the Kinnickinnic River, the correlation between TP and TSP has an R^2 value (0.488) which is more than double that of the R^2 value between TP and TSS (0.239), thus indicating that the stormwater here is related to urban rather than agricultural runoff (Table F-4). As shown in panel 2 of Figures 31 – 33 for all three river stations, a multiple regression with TSP and TSS as independent variables gives a very good prediction of TP. The regression is improved when BOD as a third independent variable is included even though the R^2 value improvement is small (panel 3, Figures 31 - 33).

The TSP is part of TP, so it is not surprising that TSP is highly correlated to TP in all stations, except perhaps for station OH-02 where the R^2 = 0.249 (Figure 34). This indicates that in the outfall area of Jones Island WRF TP is not well correlated with TSS which is confirmed by Figure 30. A high correlation between TP and TSP shows that they have a common origin, as in particular form, and that kinetics plays a minor role in distributing P between the particulate and aqueous phases.

Soluble phosphorus TSP is readily used for growth by *Cladophora*, and it may be of interest to take TSP as a dependent variable vs TP, TSS, and BOD. But the correlation between TSP and TSS or BOD individually is not significant for some stations such as RI-13 (Kinnickinnic River, Table F-8) while it is always significant with TP as dependent variable. Another point is that when TSP is used as dependent variable, several of the standardized regression coefficients β are negative which does not occur with TP as dependent variable (Tables, F-2, F-6). Also, the correlation of TP vs variables such as TSP, TSS, and BOD is generally higher than for TSP vs TP, TSS, BOD (Figure 36).

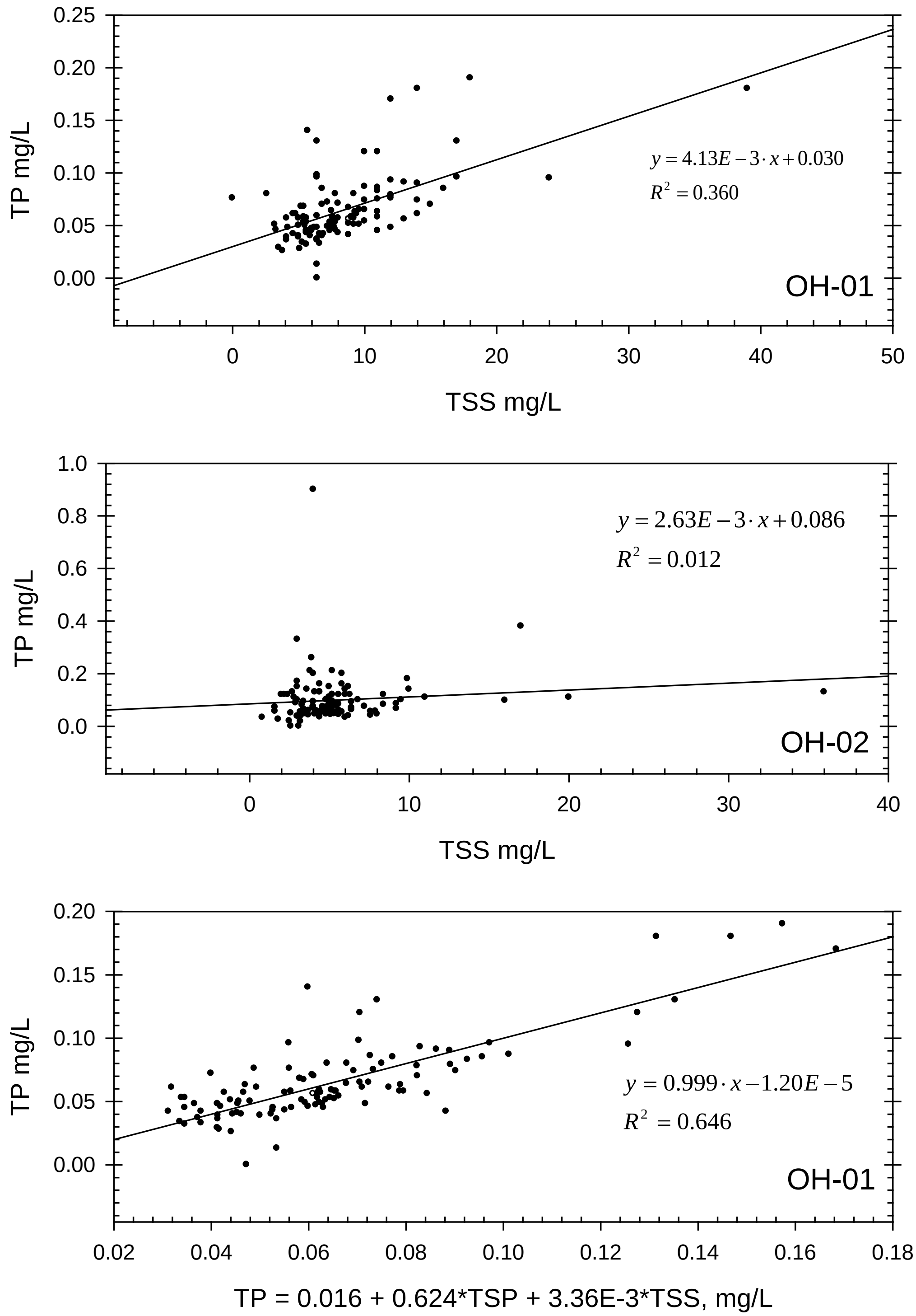


Figure 30. TP vs TSS OH – 01 (River Mouth) and OH-02 (Jones Island WRF Outfall), and TP vs TSP + TSS regression plots for OH-01.

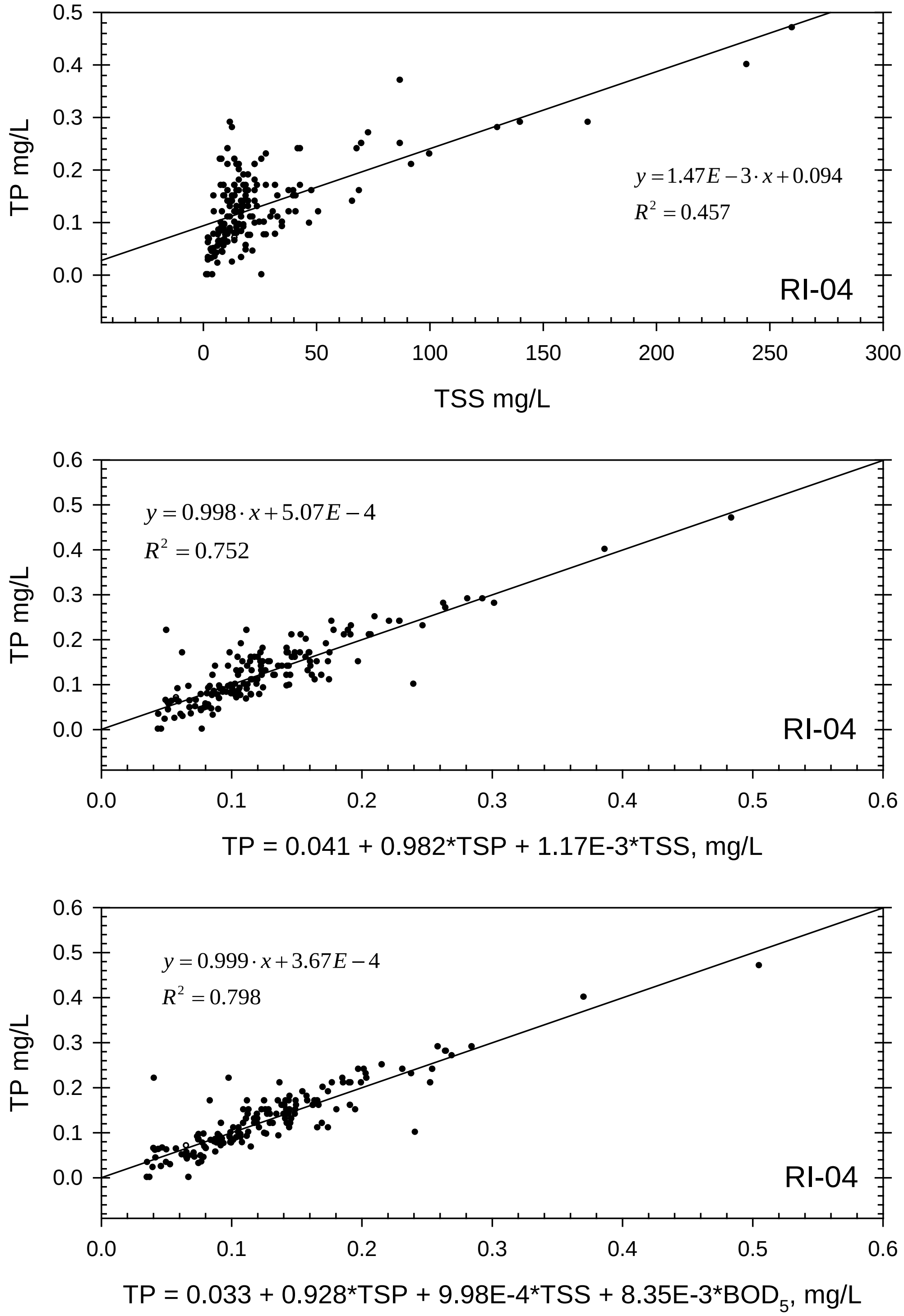


Figure 31. TP vs TSS, TSP + TSS, and TSP + TSS + BOD_5 regressions for RI-04 (Milwaukee River monitoring site corresponding to USGS monitoring site 04087000).

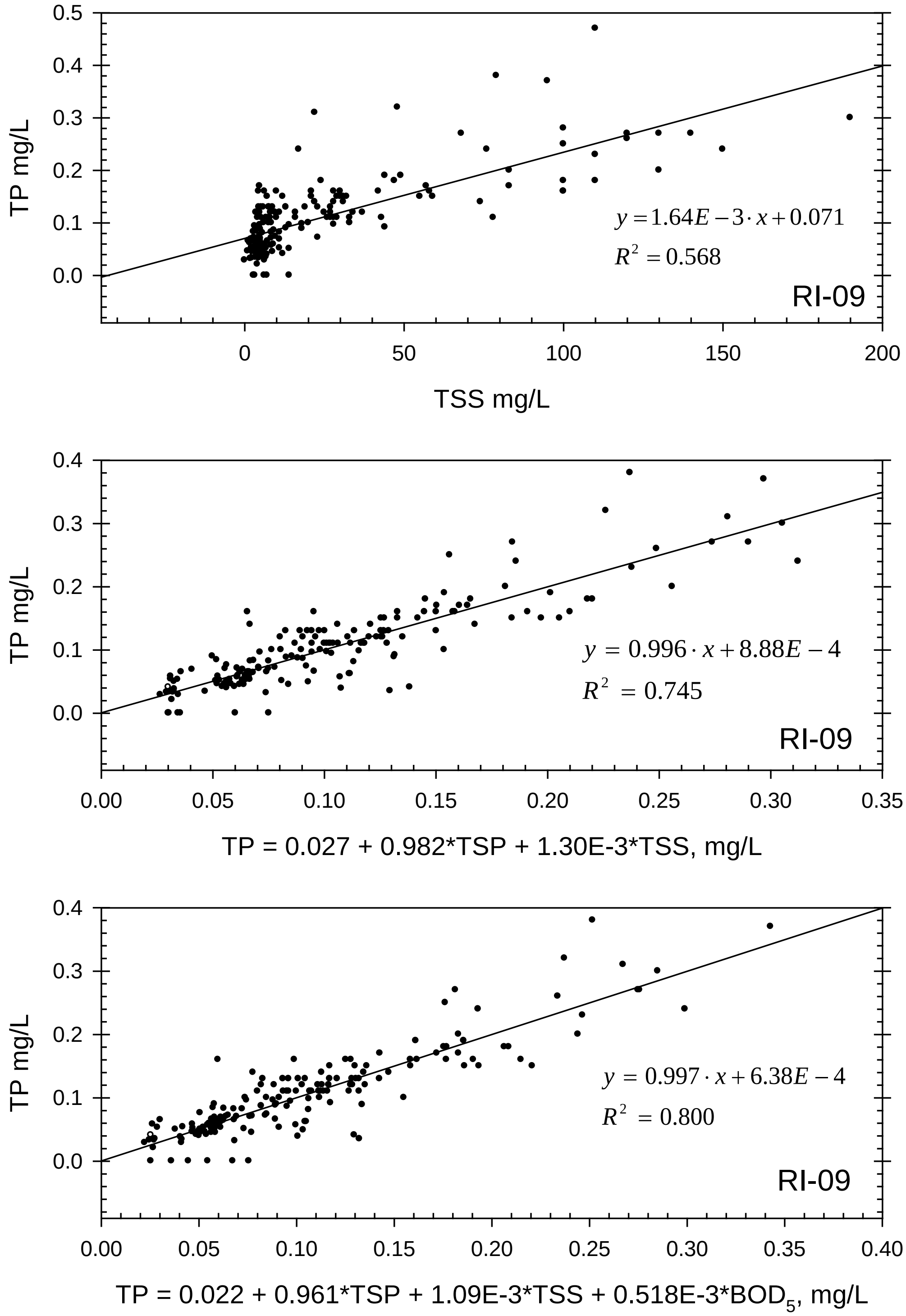


Figure 32. TP vs TSS, TSP + TSS, and TSP + TSS + BOD$_5$ regressions for RI-09 (Menomonee River monitoring site corresponding to USGS monitoring site 04087120).

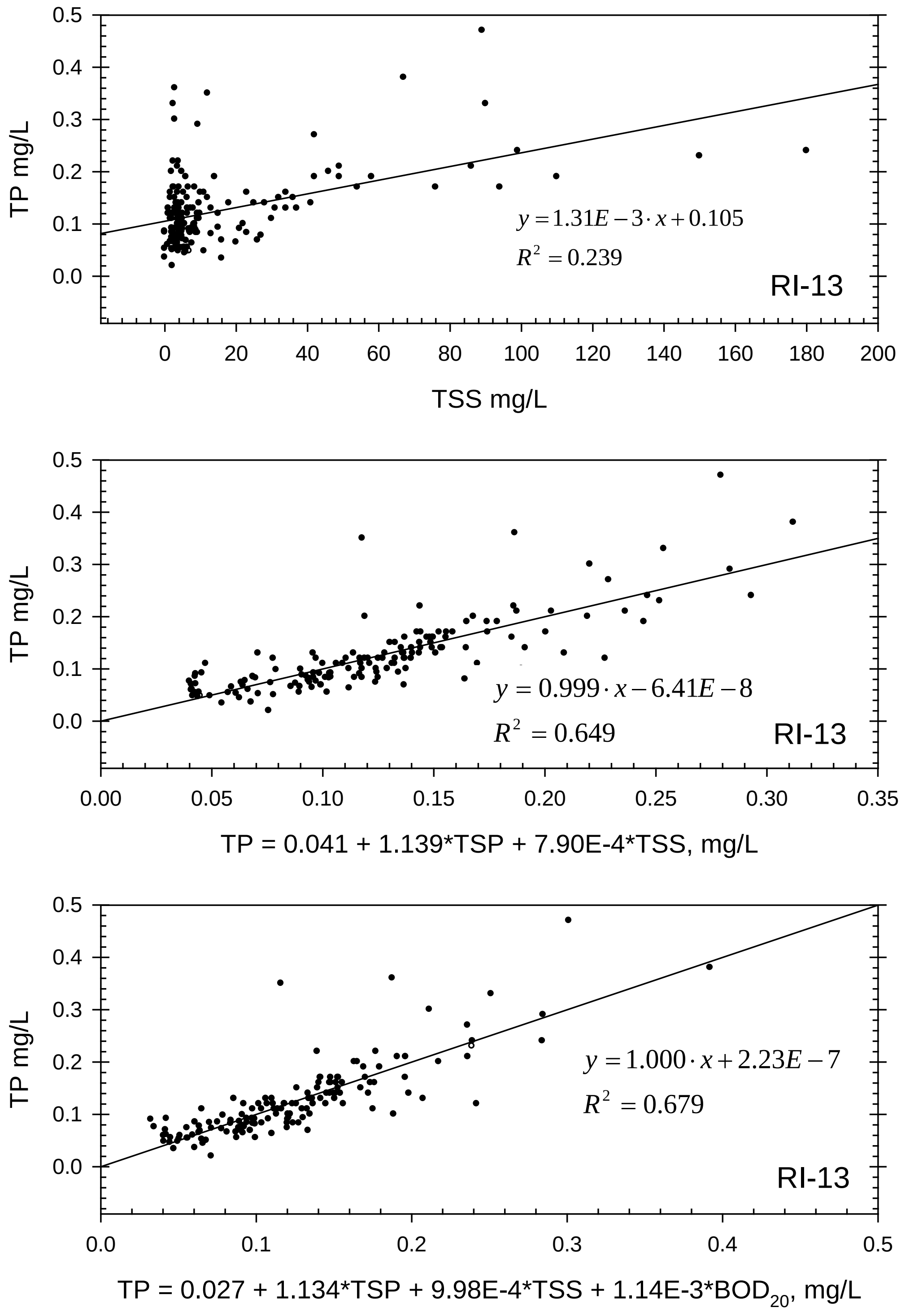
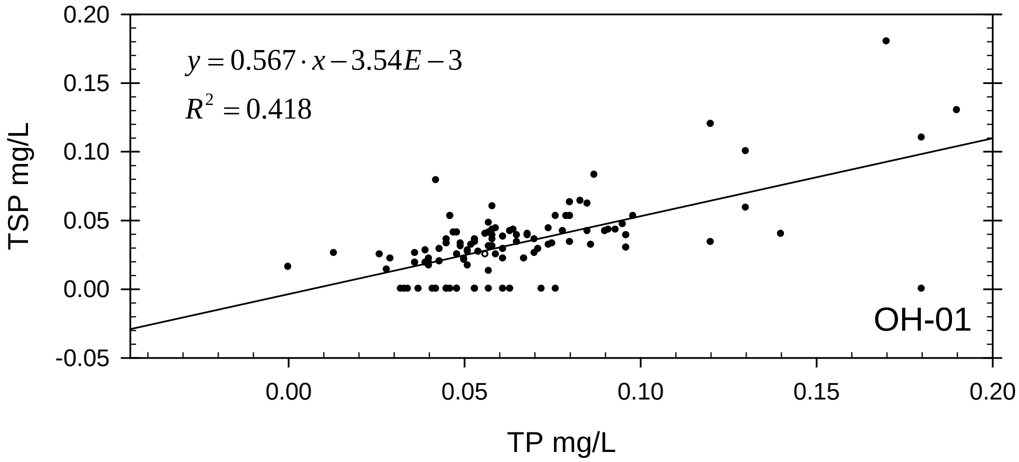


Figure 33. TP vs TSS, TSP + TSS, and TSP + TSS + BOD_{20} regressions for RI – 13 (Kinnickinnic River monitoring site corresponding to USGS monitoring site 04087159).



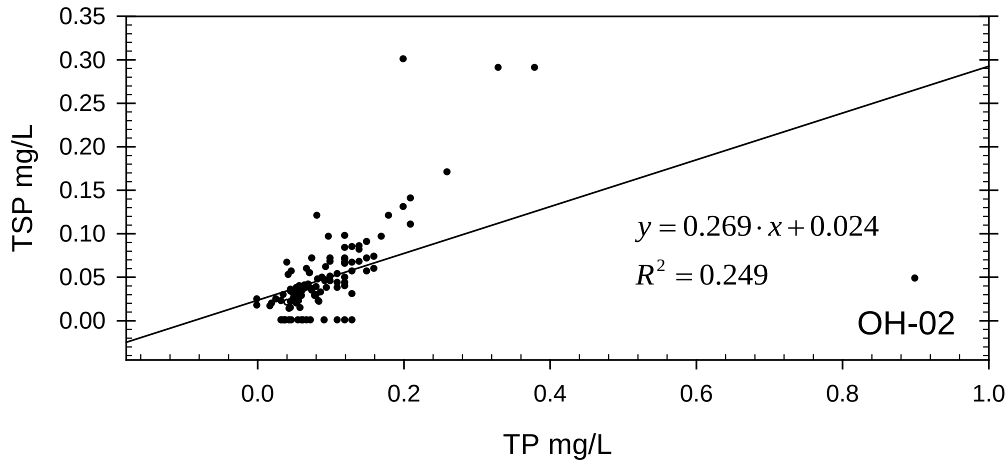


Figure 34. TSP vs TP for OH-01 (River Mouth) and OH-02 (Jones Island WRF Outfall).

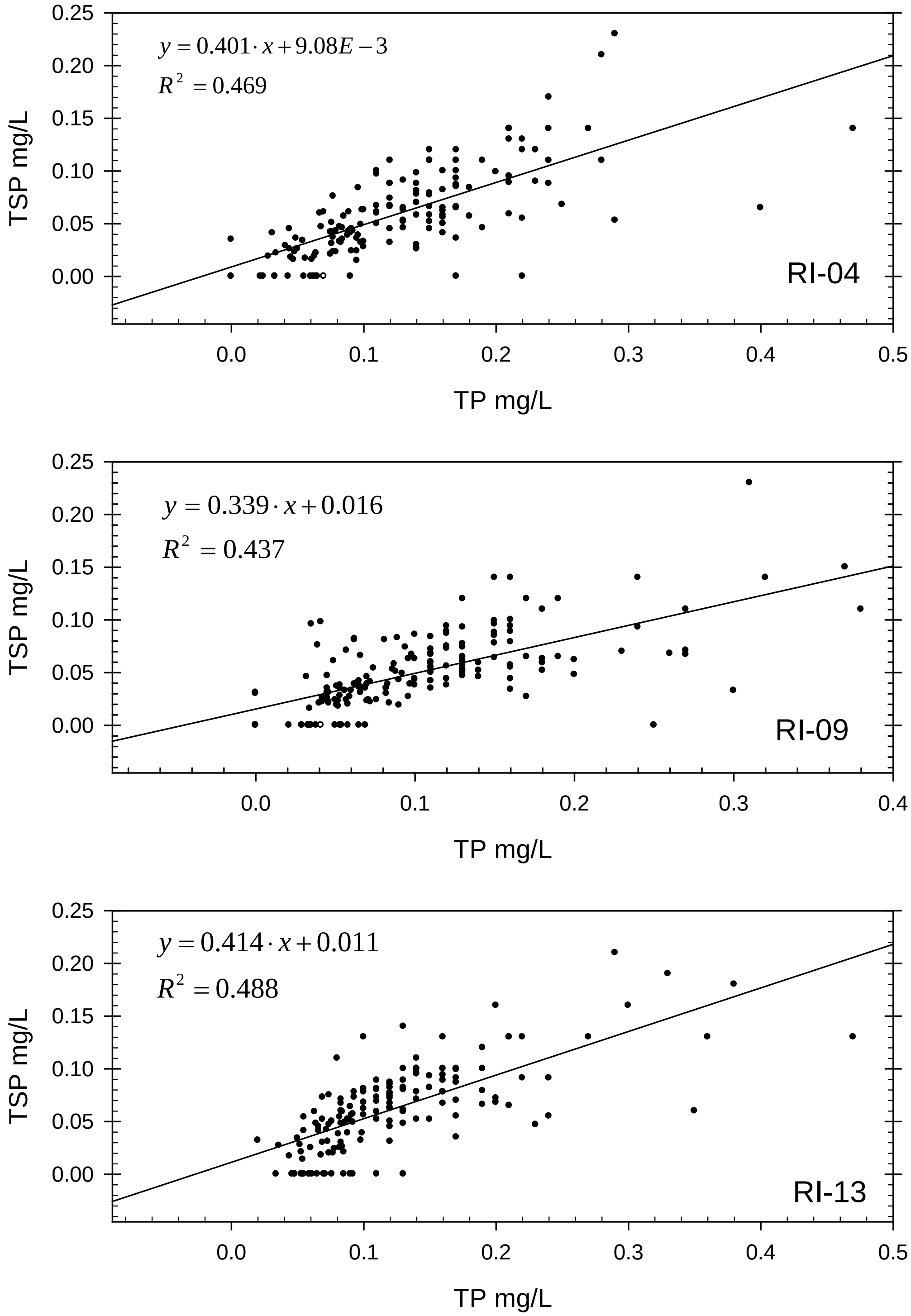
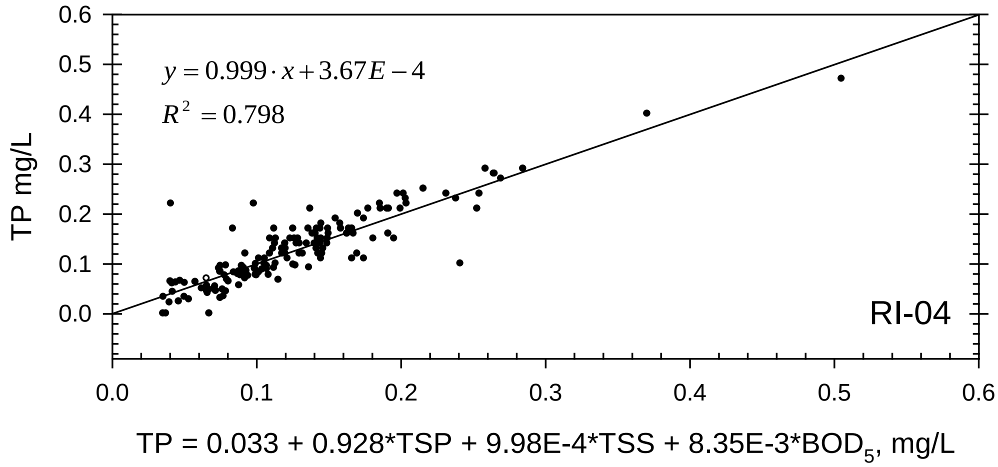


Figure 35. TSP vs TP for RI-04, RI-09, and RI-13.



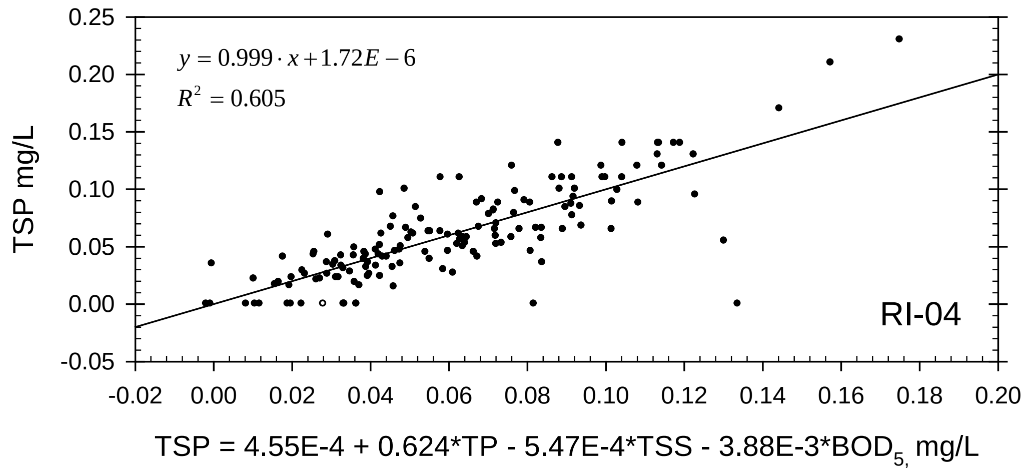


Figure 36. A comparison of TP vs TSP + TSS + BOD_5 regression with TSP vs TP + TSS + BOD_5 regression.

Correlation of TP with Flow for Stormwater Sites and Outer Harbor Stations

The seasonal variation is important information to look at when considering TP load in the regional watersheds (Milwaukee, Menomonee, Kinnickinnic). Bowes et al (2008) found that for rivers, high TP concentration accompanies high river flows. There were high TP concentrations in 2004 for some stormwater sites (e.g. SWMI06 and SWMI15) and for some Outer Harbor sites (OH – 01 and OH – 03), and we know that there were high river flows in the year 2004 due to rainfall. Figure 37 shows the TP concentration versus river flows for OH – 01(river mouth) and OH – 03 (mid-harbor). The river flows are the summation of the three rivers at stations (RI-04 – Milwaukee River at Port Washing Road; RI-09 - Menomonee River at 70th Street; and RI-13 – Kinnickinnic River at 27th Street) (Tables G-1 to G-8).

Figure 37 shows that there is a very high correlation between TP and the river flows, especially for OH – 01 (R^2 = 0.974) (river mouth). For OH – 03, the R^2 value is 0.631, indicating a significant but smaller correlation due to mixing with the Outer Harbor water. The results are in accordance with Bowes' study. However, the plots of TP concentration vs stormwater runoff show strong negative correlation between TP concentration and stormwater runoff (Figure 38), especially for the second flush (panel 2, Figure 38). For rivers with very large flows, erosion brings the TP settled on the river channel to Lake Michigan. However, for stormwater sites, it is more likely a matter of dilution during high flows. Low flows will carry most TP from the drainage area, while higher flows serve to dilute remaining TP yielding a lower TP concentration (panel 2, Figure 38). The dates along with TP and runoff flows corresponding to Figure 38 for the stormwater stations SWMI06 and SWMI15 are shown in Tables G-9, G-10.

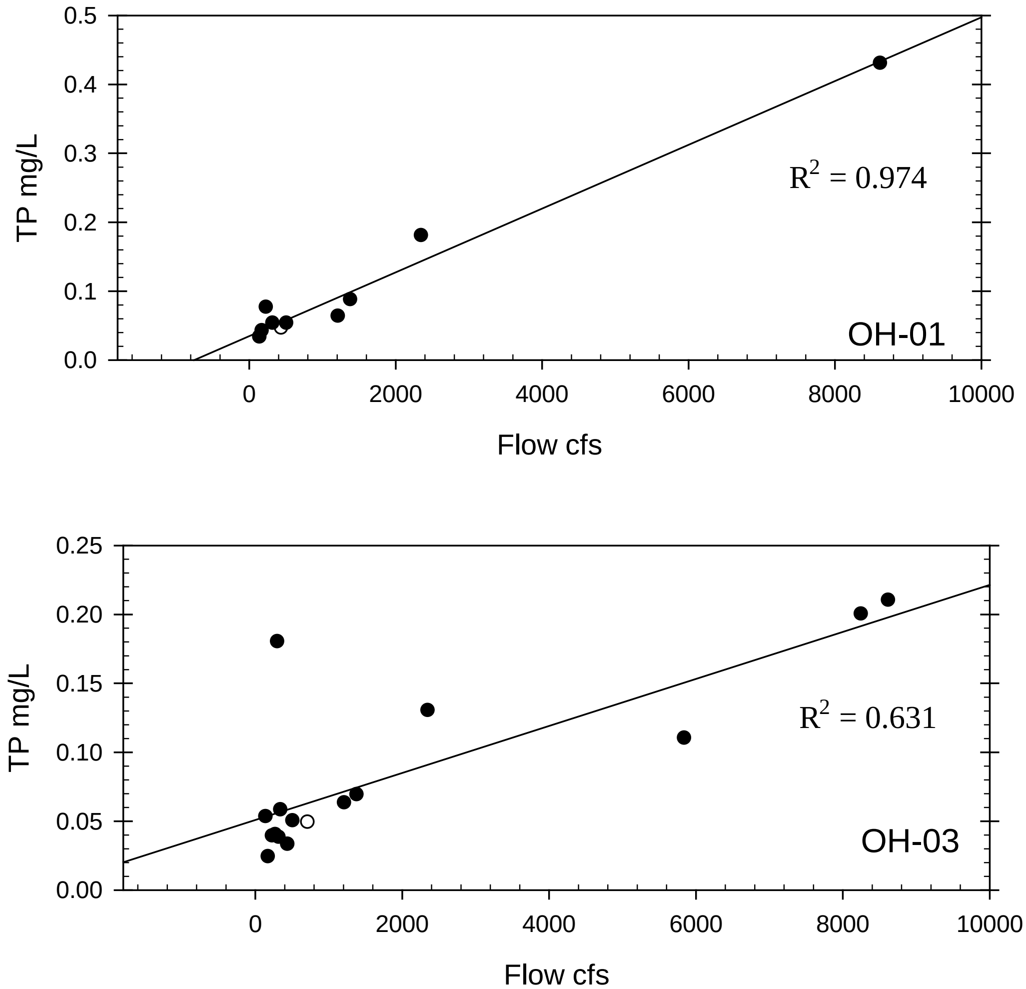


Figure 37. Correlation of TP vs river flow for Outer Harbor sites OH-01, and OH-03.

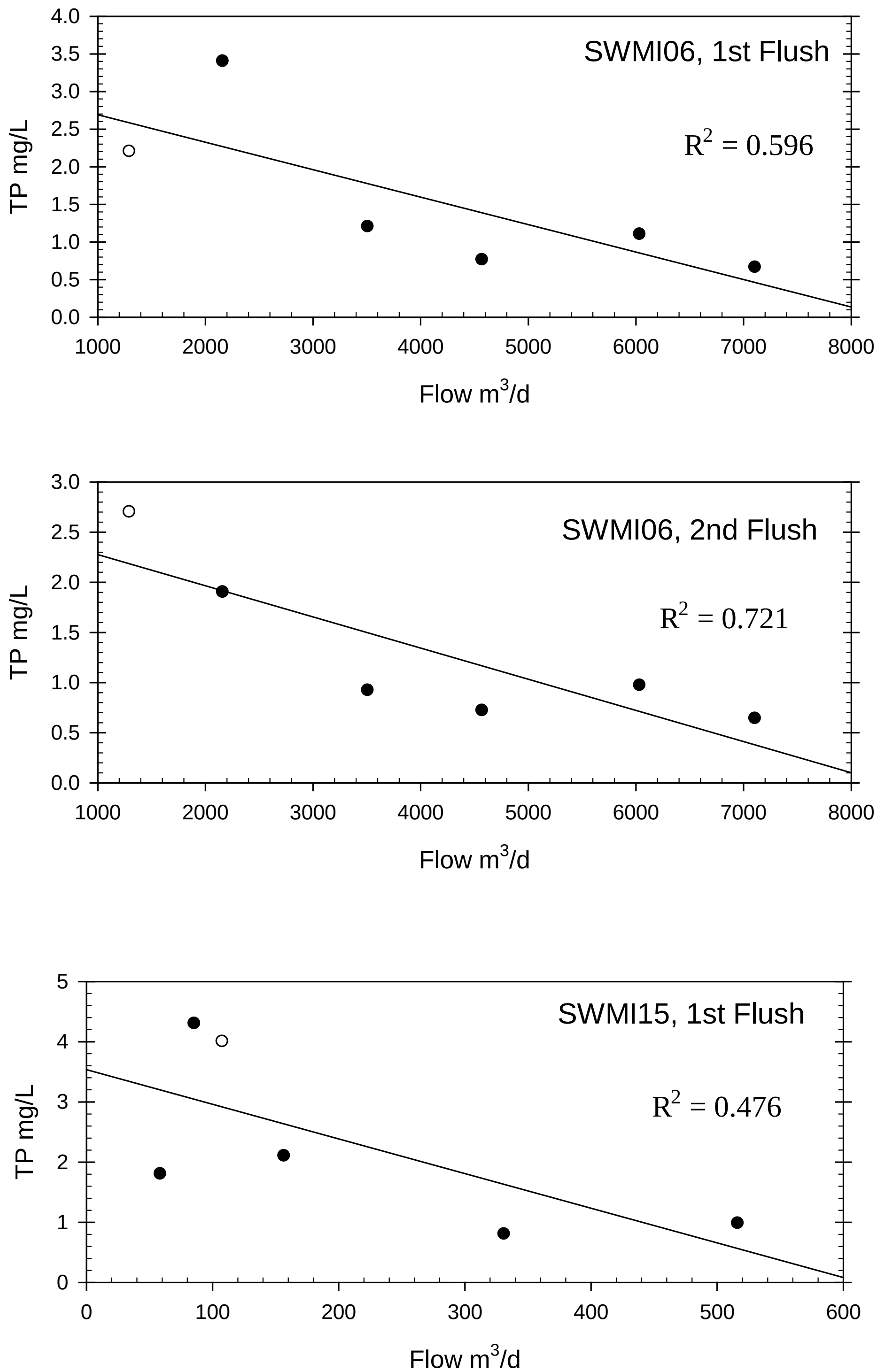


Figure 38. Correlation of TP vs stormwater runoff for SWMI06 and SWMI15.

Summary Concentration Plots and Load Tables

Average TP, TSP, and TSS concentrations for 46 stormwater monitoring sites (Table 1 and 2), 26 rivers monitoring sites (sites 1-7, 9, 11-14, 16-22, 31-37), 15 Outer Harbor monitoring sites (sites 1-15), and 20 CSO monitoring sites (IssCT02-08, IssKK01-04, IssLMN, IssLMS, IssNS04-12) are plotted in Figure 39. Highest concentrations of TP and TSP are from stormwater and CSO, and lowest for the Outer Harbor. Trend plots of TP concentrations for the Outer Harbor sites OH-01 and OH-02 are shown in Figure 39. The average TP concentration at OH-02 (0.095 ± 0.005) is higher than at OH-01 (0.073 ± 0.006). As for the trend plots, the peaks in year 2004 can be seen clearly.

The TP load from stormwater, CSO, rivers, and the water reclamation facility (WRF) is shown in Table 8. Rivers are dominant in the total TP load in the watershed and Harbor. The Jones Island WRF is also a measurable source. The TP loads from 46 stormwater monitoring sites are small compared to the river loads. However, stormwater loads discharged to the rivers are included in the river load. For the rivers there are base loads of TP from groundwater and other sources in addition to input of TP and TSP from stormwater. Phosphorus discharged by stormwater into Lake Michigan is included in the present overview to the extent that good data are available.

The TP concentration plots of Figure 37 for sites OH-01 (rivers) and OH-02 (Jones Island WRF) suggest that there is a trend of weak decreasing P concentration with time for the rivers and a weak increasing TP concentration with time trend or no trend for Jones Island effluent plus river discharge. This is confirmed by t-tests showing $t = -1.472$, $P > 90\%$ for OH-01 and $t = 0.517$, $P > 60\ \%$ for OH-02. Further confirmation comes from Mann-Kendall tests on the same sites indicating $P = 23.8\%$ for no trend at OH-01 and $P = 54\%$ for no trend at OH-02.

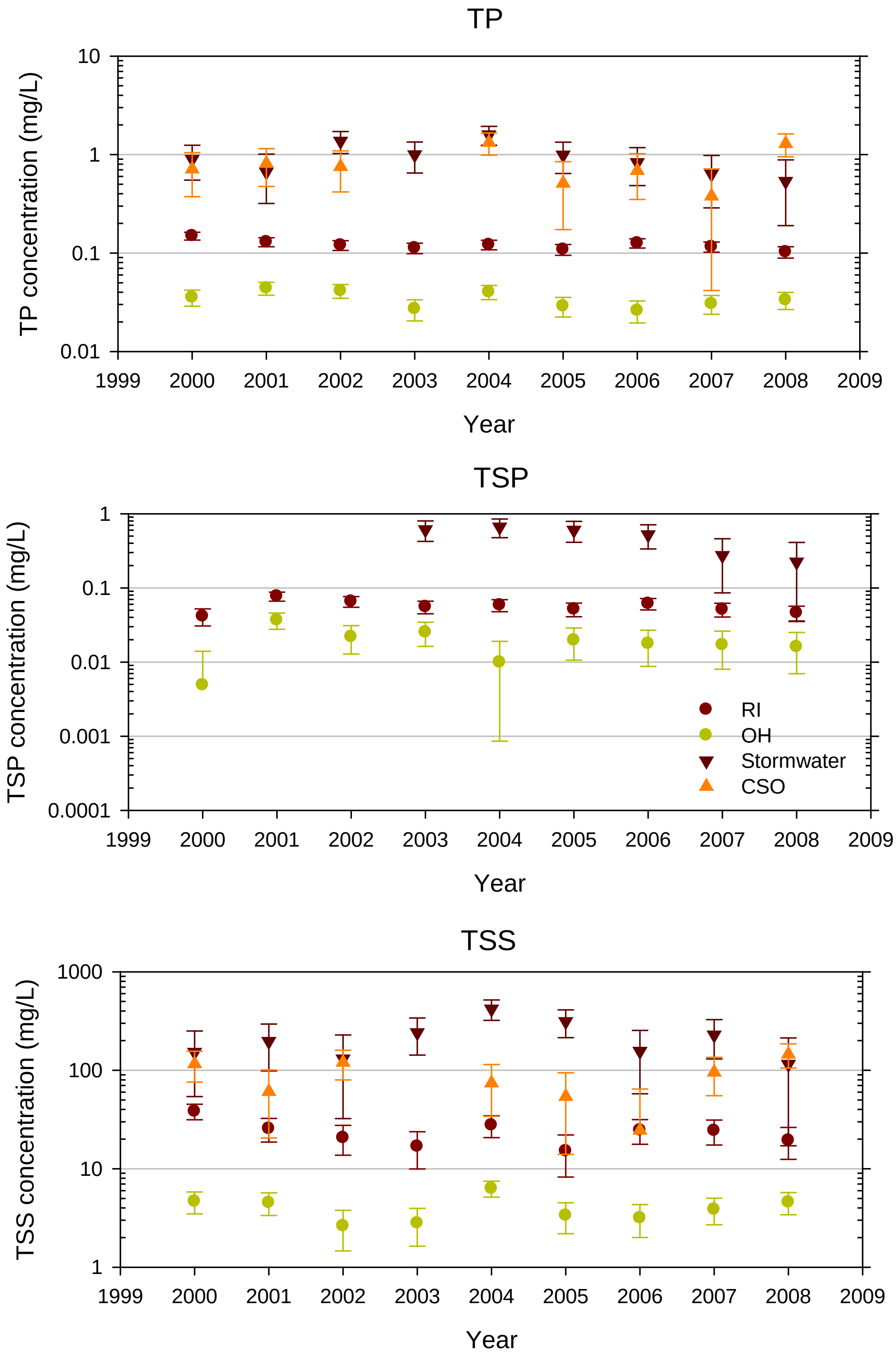


Figure 39. Average concentration of TP, TSP, TSS for stormwater, rivers (RI), Outer Harbor (OH), and combined sewer overflow (CSO).

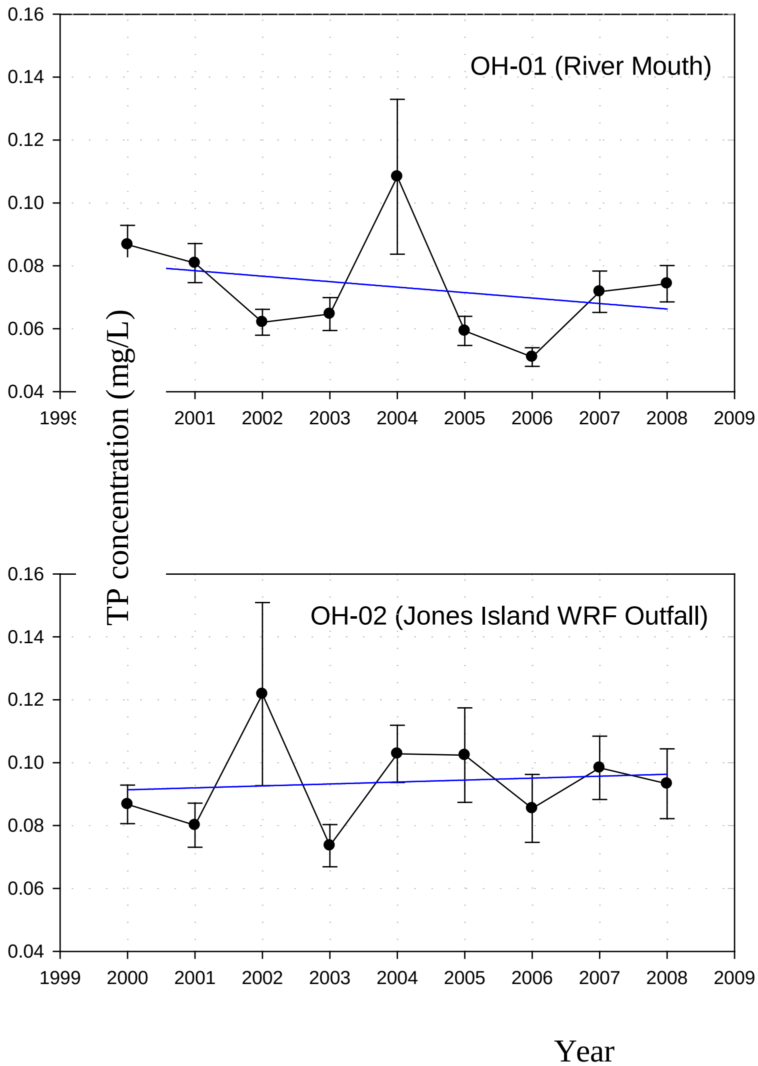


Figure 40. Yearly averages of TP concentrations with trend lines for Outer Harbor OH-01 and OH-02.

Load estimates for Jones Island, the Milwaukee, Menomonee, and Kinnickinnic Rivers, CSOs, and for the stormwater sites are summarized in Table 8. Industrial non-contact cooling water discharges and SSO's are included in the river loads. As can be seen from Table 9, these estimates are reasonably comparable to those made by SEWRPC.

Table 8. TP load from rivers, stormwater, CSOs, and WRF.

	USGS Estimated[a] (kg/yr)	This Research Estimated (kg/yr)	This Research Estimated (lb/yr)	This Research Percentage (%)
Milwaukee River	89,100	67,300	148,370	57.79
Jones Island		39,500	87,082	33.92
Menomonee River	10,700	7,100	15,653	6.10
Combined Sewer Overflows (CSOs)		4,200[b]	9,259	b
Kinnickinnic River	4,800	2,100	4,630	1.80
Stormwater (Sites 1-18)		602[b,c]	1,327	b
Stormwater New Sites		331[b,c]	730	b
CSO loads to Lake Michigan, LMN, LMS		308	679	0.26
Stormwater loads from sites 1-18 to Lake Michigan, sites 1, 2, 4, 9, 14		141[c]	311	0.12

[a]Data acquired from USGS website: http://wi.water.usgs.gov/
[b]Included in river loads and loads to Lake Michigan.
[c]Stormwater TP load is underestimated.

Table 9. Milwaukee Harbor total phosphorus loading (year 2000) from the Milwaukee, Menomonee, & Kinnickinnic Rivers (SEWPRC, 2010).

Category	Load, kg/yr	Load, lbs/yr	Percentage %
Industrial	51,179	112,830	26.50
Jones Island Water Reclamation Facility	38,556	85,002	20.00
Nonpoint Rural	38,646	85,200	20.00
Nonpoint Urban	38,188	84,190	19.80
Other Wastewater Treatment Plants	23,469	51,740	12.20
Combined Sewer Overflows (CSO)	1,887	4,160	1.00
Sanitary Sewer Overflows (SSOs)	1,021	2,250	0.50

CONCLUSIONS

The following conclusions are drawn based on the present study for 2000-2008:

1) A comprehensive overview of individual and average TP and TSP concentrations in the three major rivers (the Milwaukee, Menomonee, and Kinnickinnic Rivers), the Outer Harbor, stormwater, and combined sewer overflow has been presented. Average concentrations of TSS concentrations in these source areas are also plotted. Average TP concentrations in stormwater and CSO are between 0.6 and 1.5 mg/L. In the rivers, average TP concentrations are between 0.1 and 0.15 mg/L which are at or above the new TP water quality standard of 0.10 mg/L. Average TP concentrations in the Outer Harbor are between 0.02 and 0.05 mg/L, which is well below the new TP water quality standard of 0.10 mg/L. TSP values follow largely TP based on the TSP/TP ratios in stormwater and the correlations between TP and TSP in the rivers and at OH-01.

2) Most percentages of TP in the soluble phase are between 10 and 100% (TSP/TP * 100) for the stormwater sites. This ratio does exceed 100% in some cases reflecting measurement uncertainty. As expected, the second flush, measured 1.7 to 2 hours after the first flush, has generally a higher soluble phosphorus percentage. Therefore the second flush of stormwater would be expected to be more bioavailable for algal growth.

3) TP trends were estimated by t-tests and Mann-Kendall tests from average values measured at OH-01 at the confluence of rivers into the Outer Harbor and OH-02 at the outfall for effluent from the Jones Island Water Reclamation Facility (WRF). The average TP concentration at OH-02 (0.095 ± 0.005 mg/L) is higher than at OH-01 (0.073 ± 0.006 mg/L). TP remained the same or slightly increased over the study period of 2000 - 2008 for site OH-02 near the Jones Island WRF outfall. Also, TP slightly decreased over the study period of 2000-2008 for site OH-01 representing the confluence of the three rivers into the Outer Harbor.

4) TP is strongly correlated with river flows during periods of high flow while there is an inverse correlation between TP and stormwater flows. Years with large discharges during May-June show large TP concentrations, especially during 2004 but also 2000, 2007 and 2008. The negative trend of TP in rivers and runoff with time is consistent with a negative trend of TSS.

5) Average stormwater TP values in rivers and stormwater show a negative trend (i.e., have been declining since 2003). The reasons for the overall negative trend may be due to be phosphorus regulation including the synthetic phosphorus fertilizer ban and potentially local climate variations (e.g. rainfall frequency and amount).

6) Variations in total suspended solids (TSS) appear to mirror TP variations. TSS values are highest for stormwater and CSO (30 – 400 mg/L), lower for river sites (17- 40 mg/L), and lowest for the Outer Harbor (3 – 7 mg/L). There has been emphasis on construction site and stormwater BMPs installed for TSS control that could also have affected the amount of TP.

7) Loads of TP are estimated for Jones Island WRF effluent at 39,500 kg/yr, for the Milwaukee River at 67,300 kg/yr, for the Menomonee River at 7,100 kg/yr, and for the Kinnickinnic River at 2,100 kg/yr. The river estimates are 24-50% lower than USGS estimates probably due to the fact that the USGS estimates are based on daily TP loads whereas MMSD's estimate is based on TP measurements carried out at 10 - 15 days intervals. Estimates of the old stormwater sites 1-18 are 602 kg/yr, with 141 kg/yr discharged to Lake Michigan. In addition, 331 kg/yr of TP is discharged from 28 new stormwater sites out of which 6 stations empty into Lake Michigan. TP loads from CSOs amounts to 4,200 kg/yr out of which 308 kg/yr is discharged to Lake Michigan.

8) TP is highly correlated with TSP and TSS, while the correlation with BOD (organic phosphorus) is significant but less important. Thus nonpoint sources make important contributions to TP through TSP in fertilizer and TSS in stormwater runoff. Due to the significant correlations of TSP vs TP for river stations RI-04, RI-09, and RI-13 and Outer Harbor station OH-01, TSP follows largely the TP description. However, the correlations of TSP with TP and also TP vs TSS are much lower for station OH-02 for which R^2 = 0.249 and 0.012, respectively, meaning TP prediction in this area must depend on factors other than TSP and TSS.

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APPENDICES

Appendix A. Maps of River, Outer Harbor, and CSOs Monitoring Sites

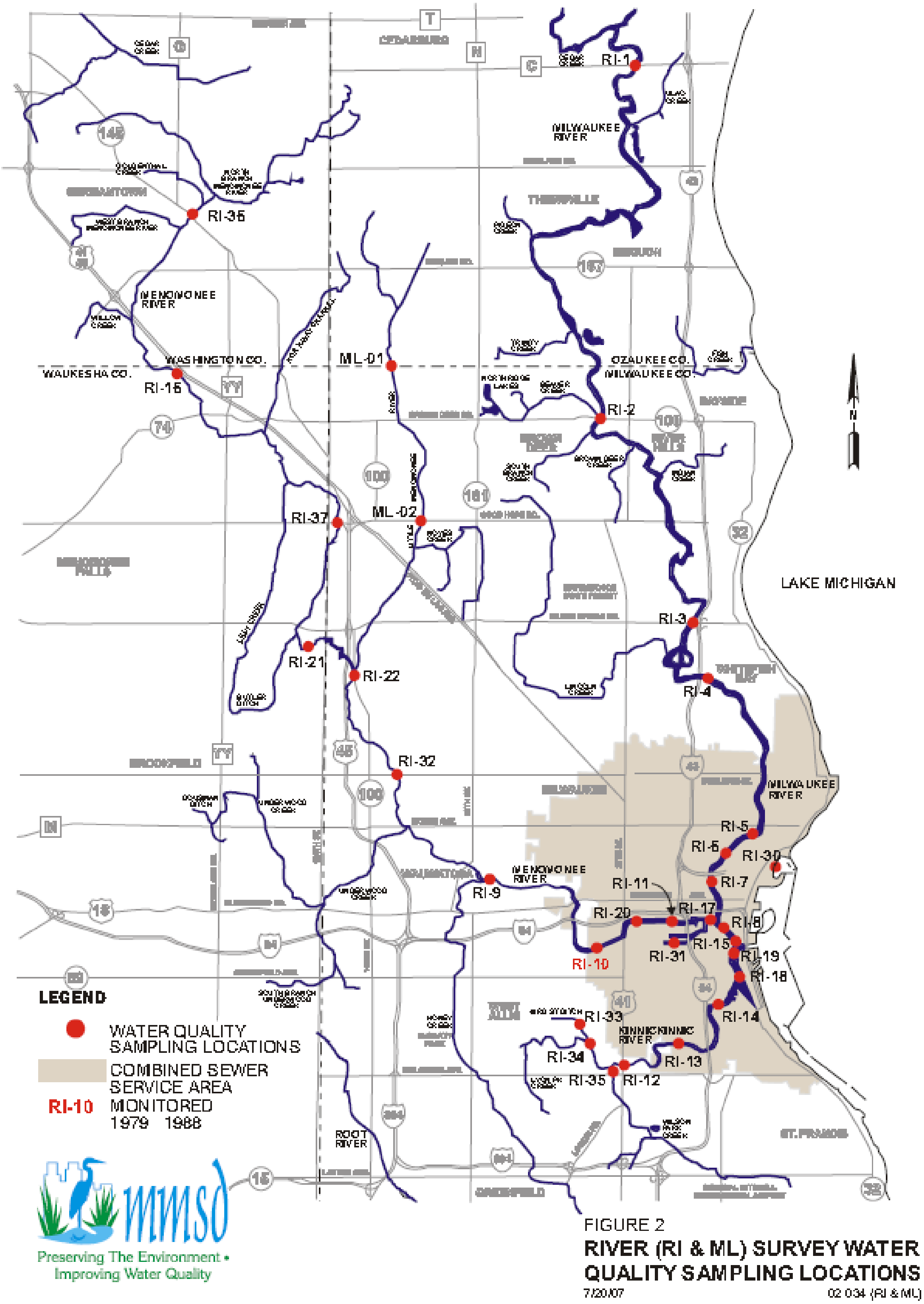

Figure A-1. Map of Rivers water quality sampling sites.

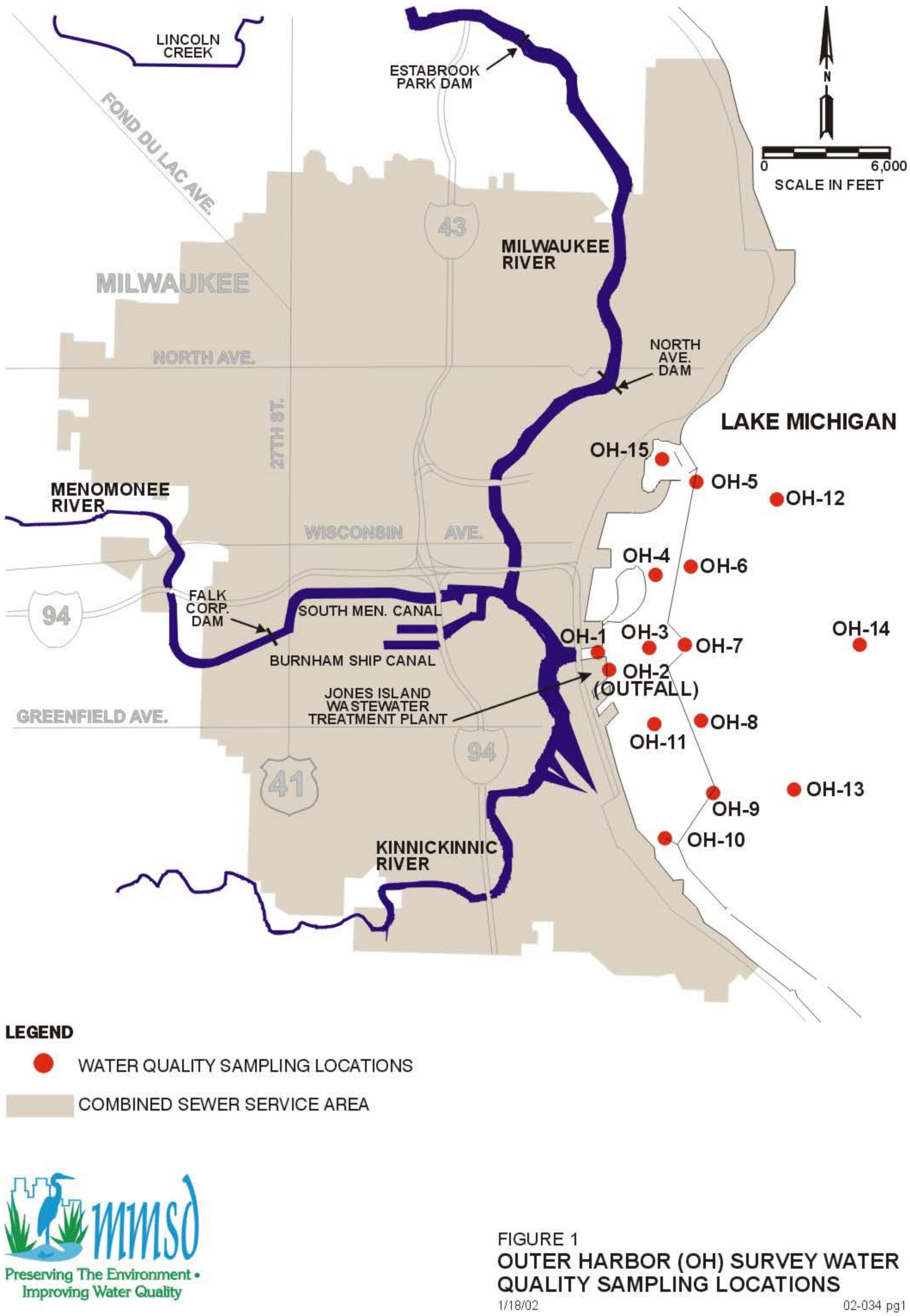

Figure A-2. Map of Outer Harbor water quality sampling sites.

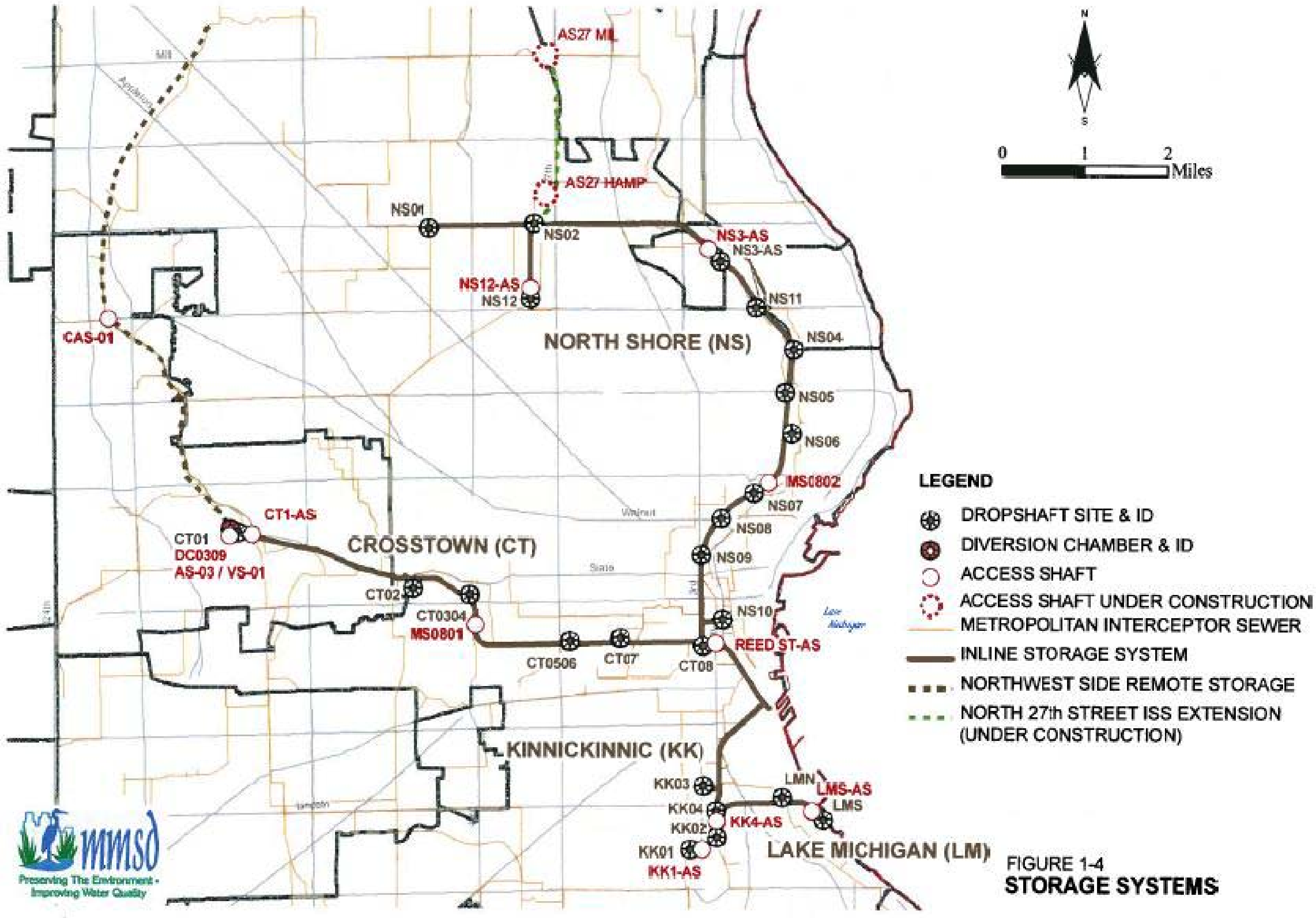

Figure A-3. Map of CSO sites.

Appendix B. TSP/TP in Stormwater

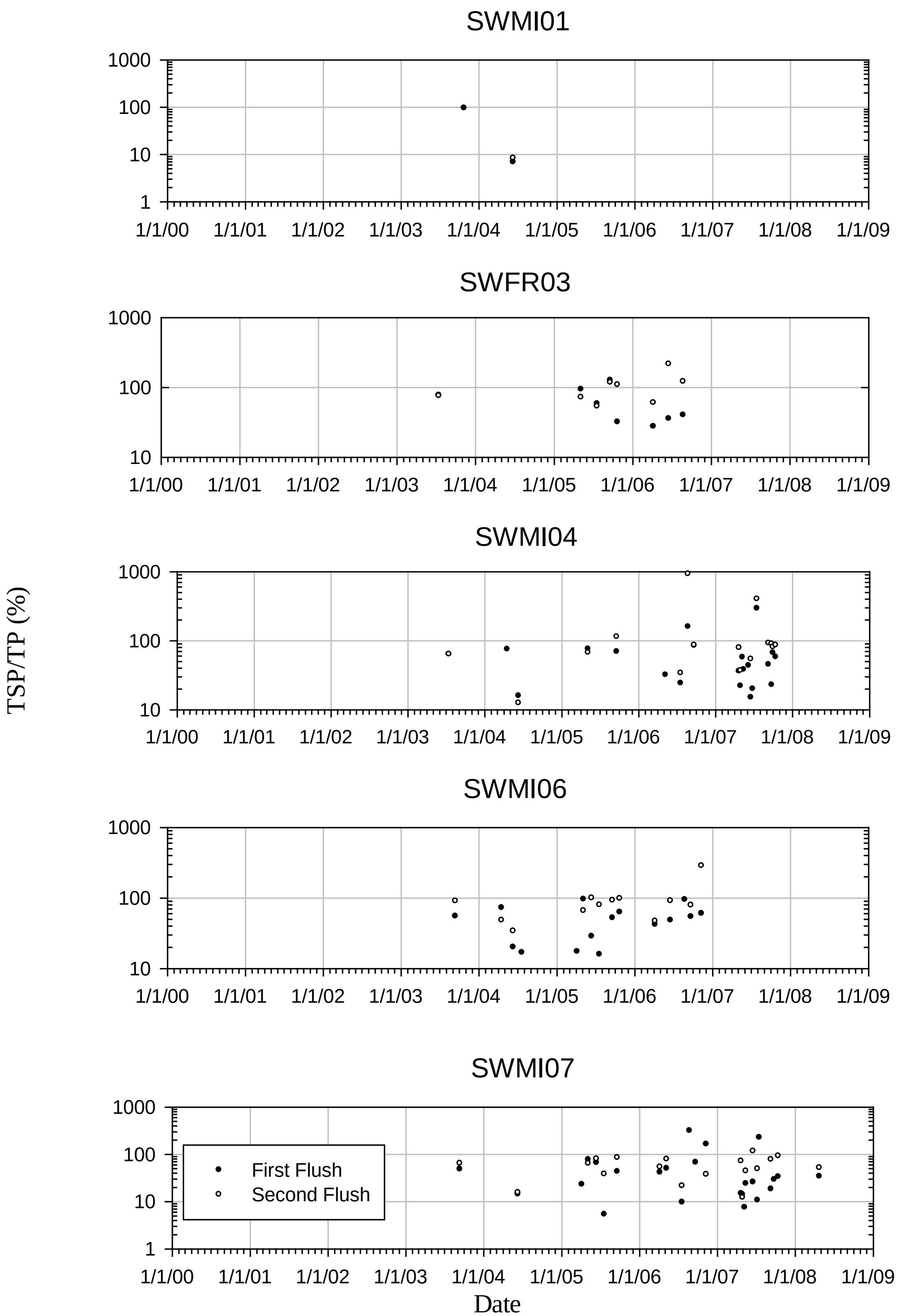

Figure B-1.TSP/TP (%) in stormwater sites SWMI01-SWMI07. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

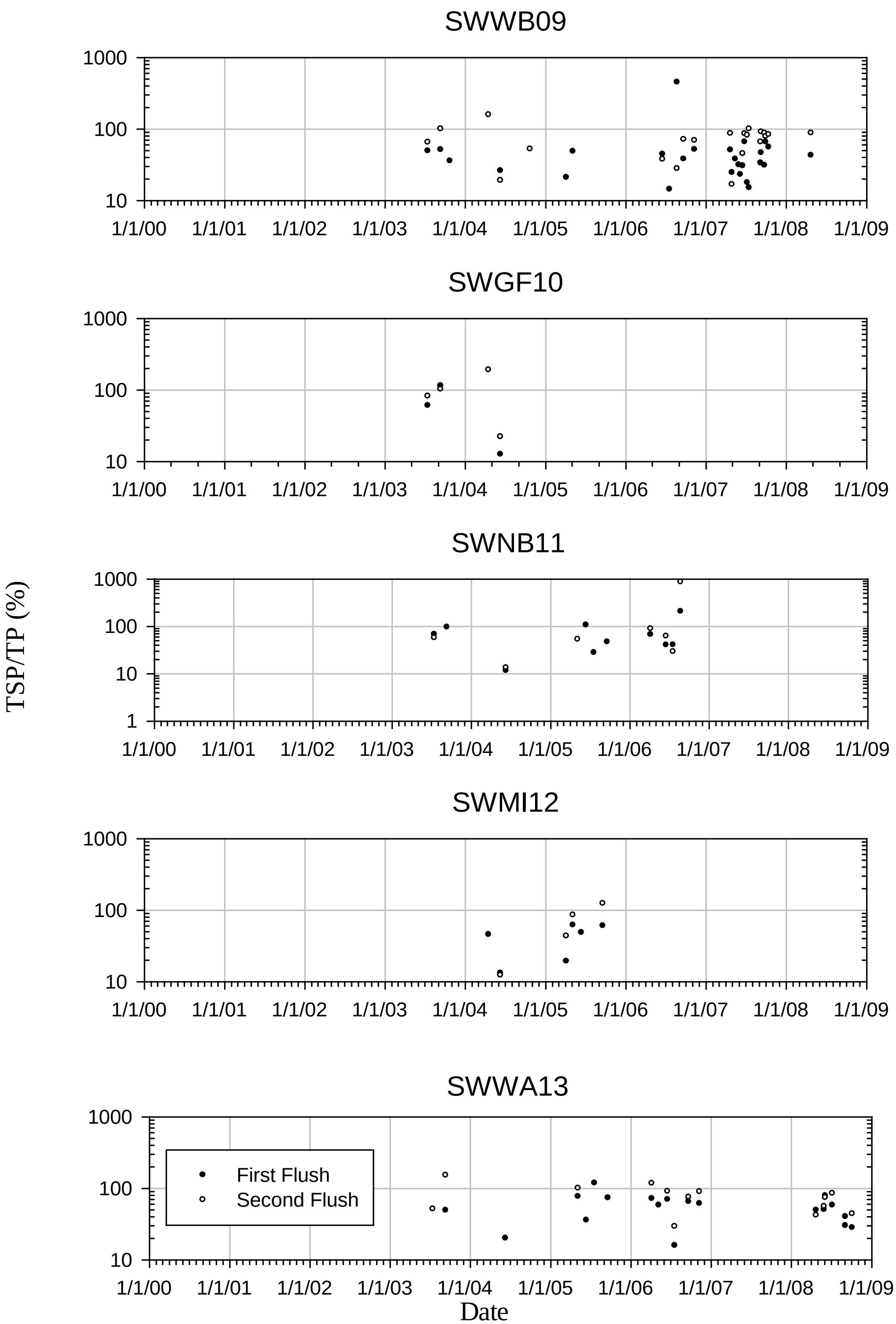

Figure B-2.TSP/TP (%) in stormwater sites SWWB09-SWWA13. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

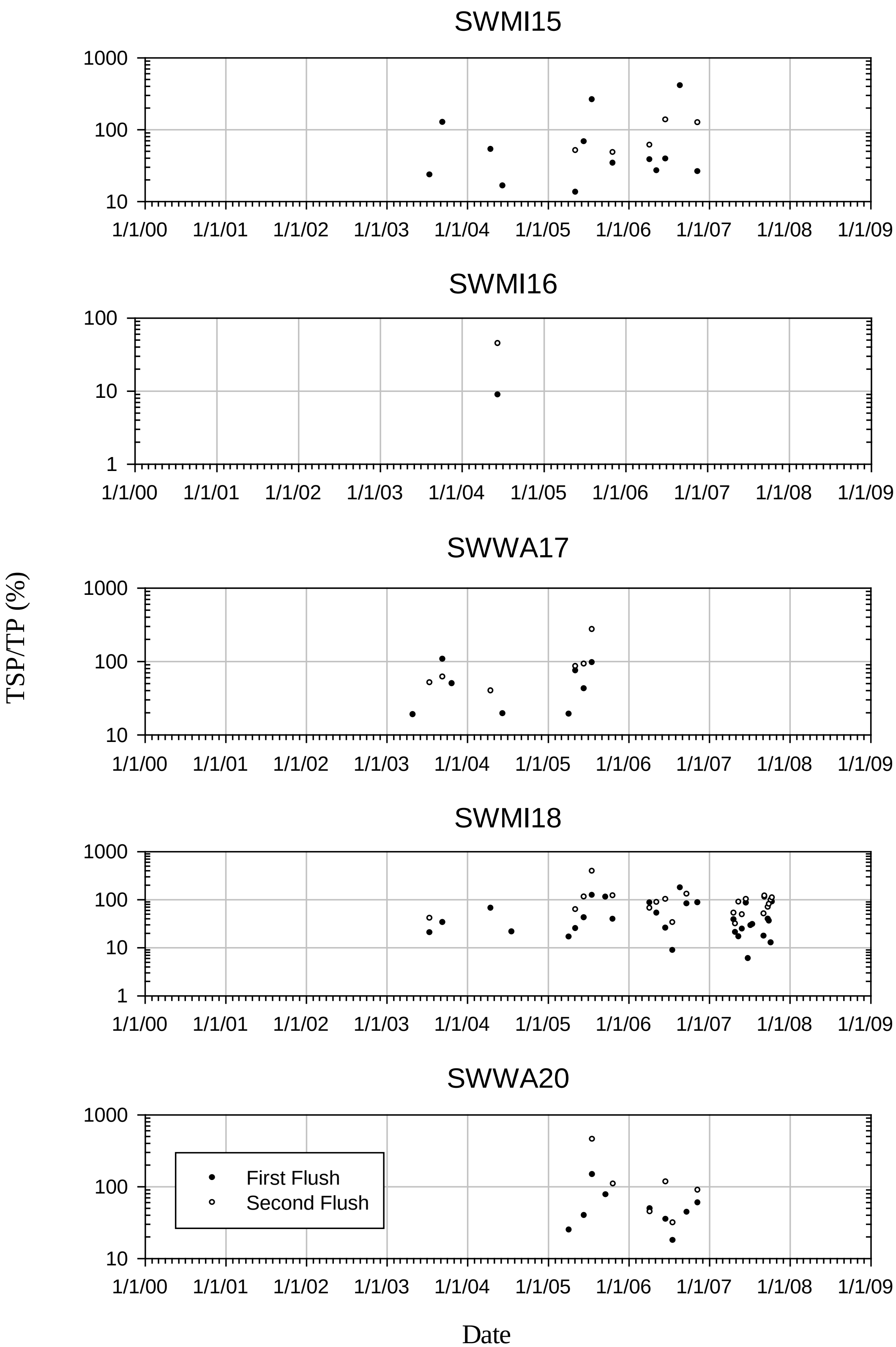

Figure B-3.TSP/TP (%) in stormwater sites SWMI15-SWWA20. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

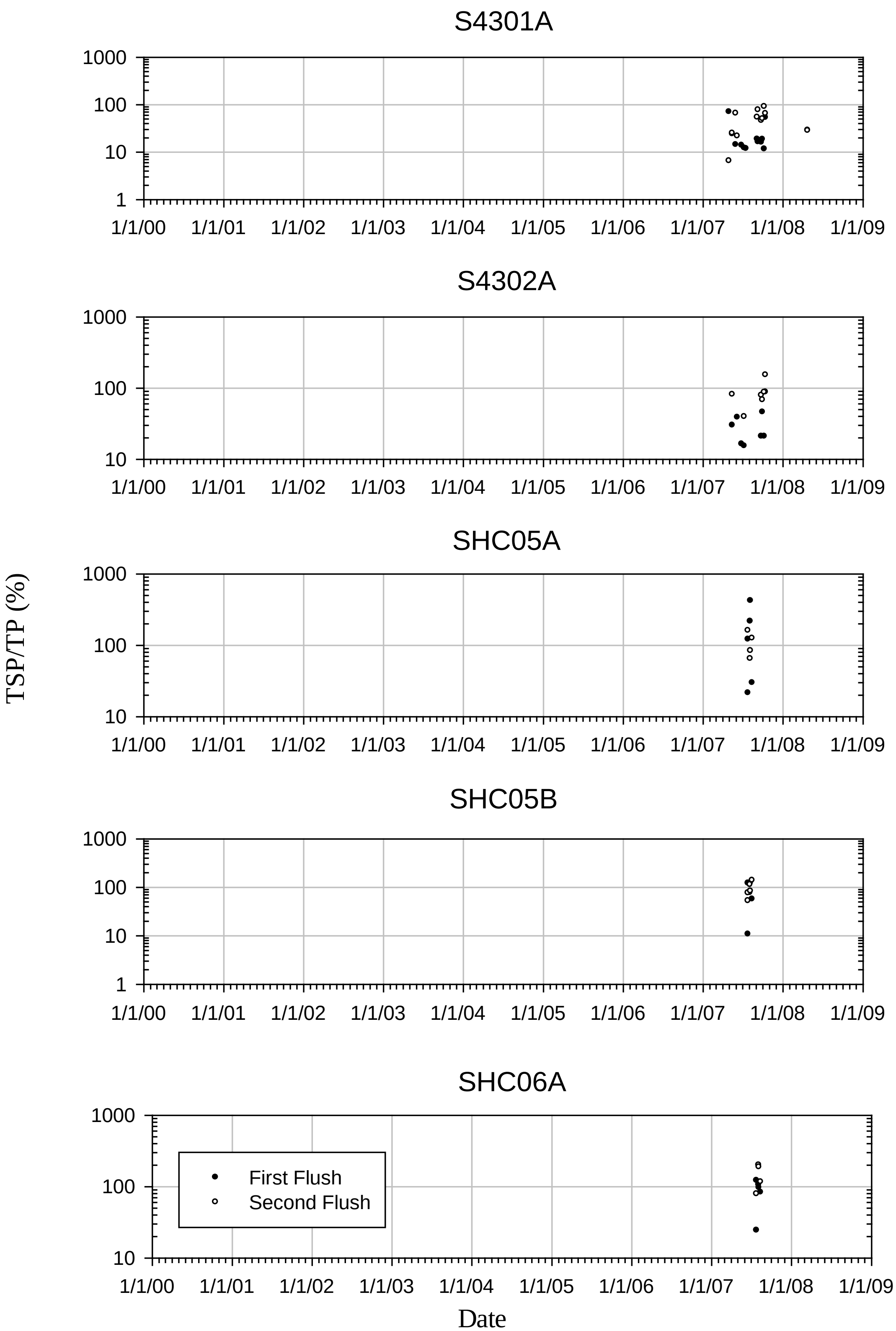

Figure B-4.TSP/TP (%) in stormwater sites S4301A-SHC06A. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

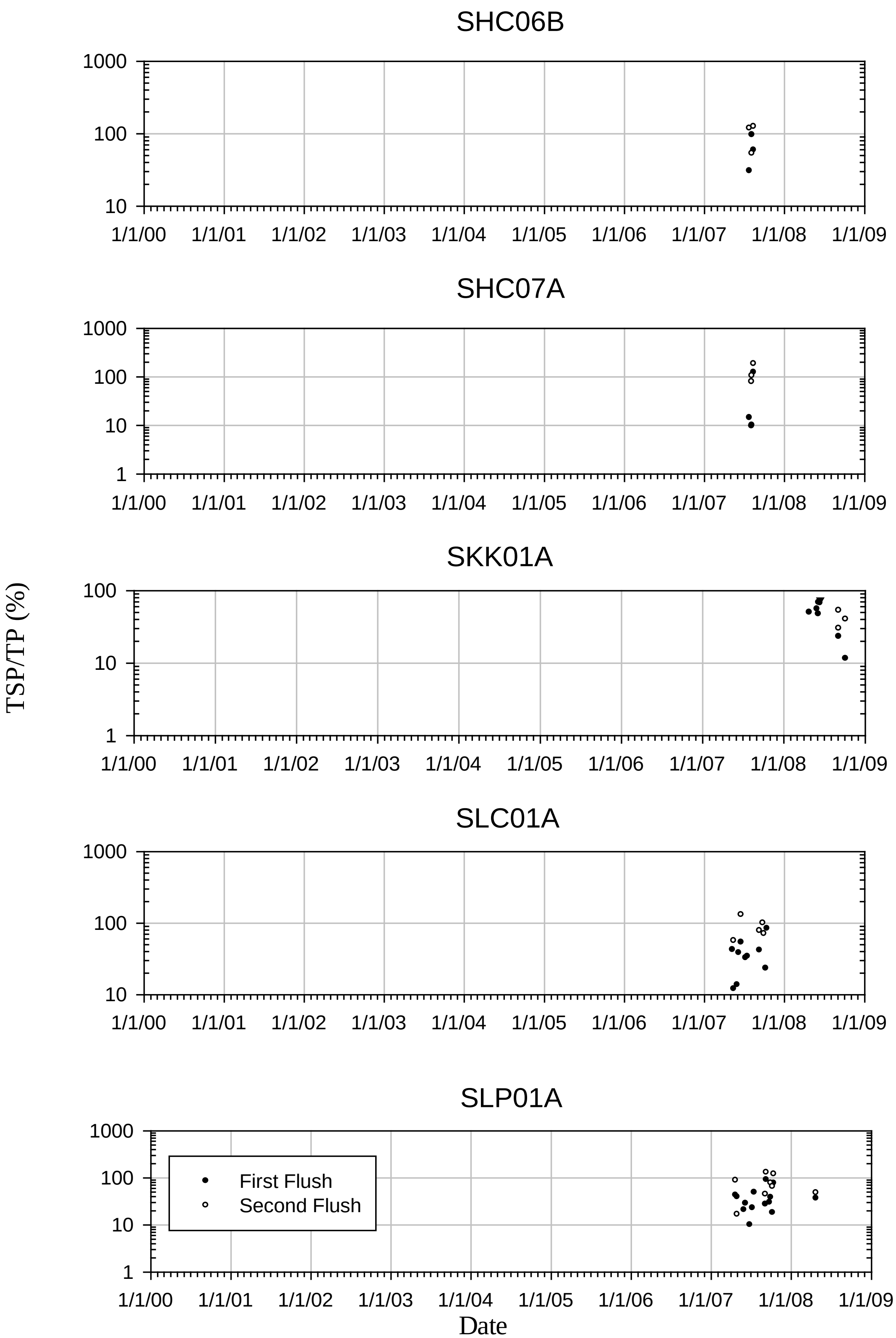

Figure B-5.TSP/TP (%) in stormwater sites SHC06B-SLP01A. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

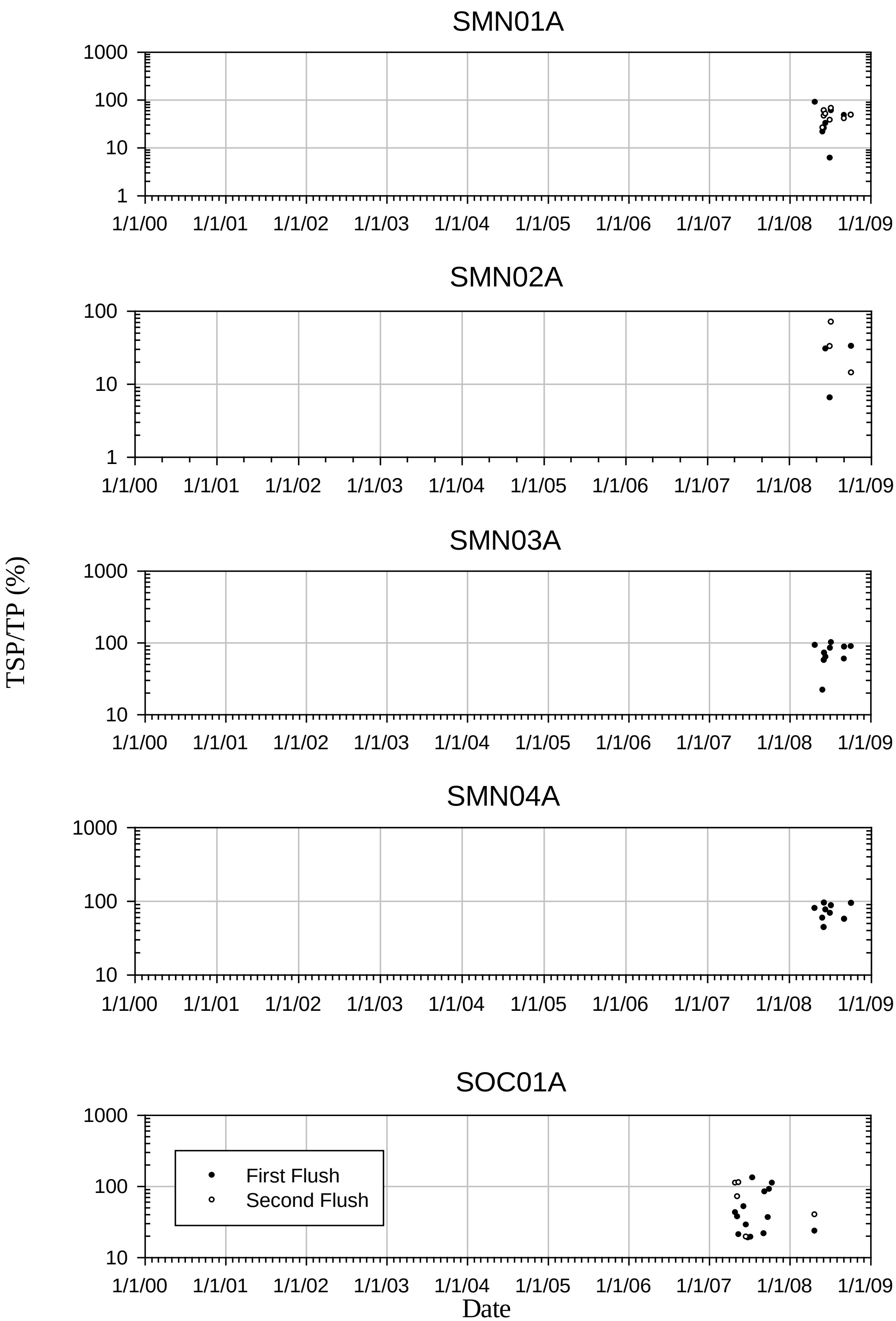

Figure B-6.TSP/TP (%) in stormwater sites SMN01A-SOC01A. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

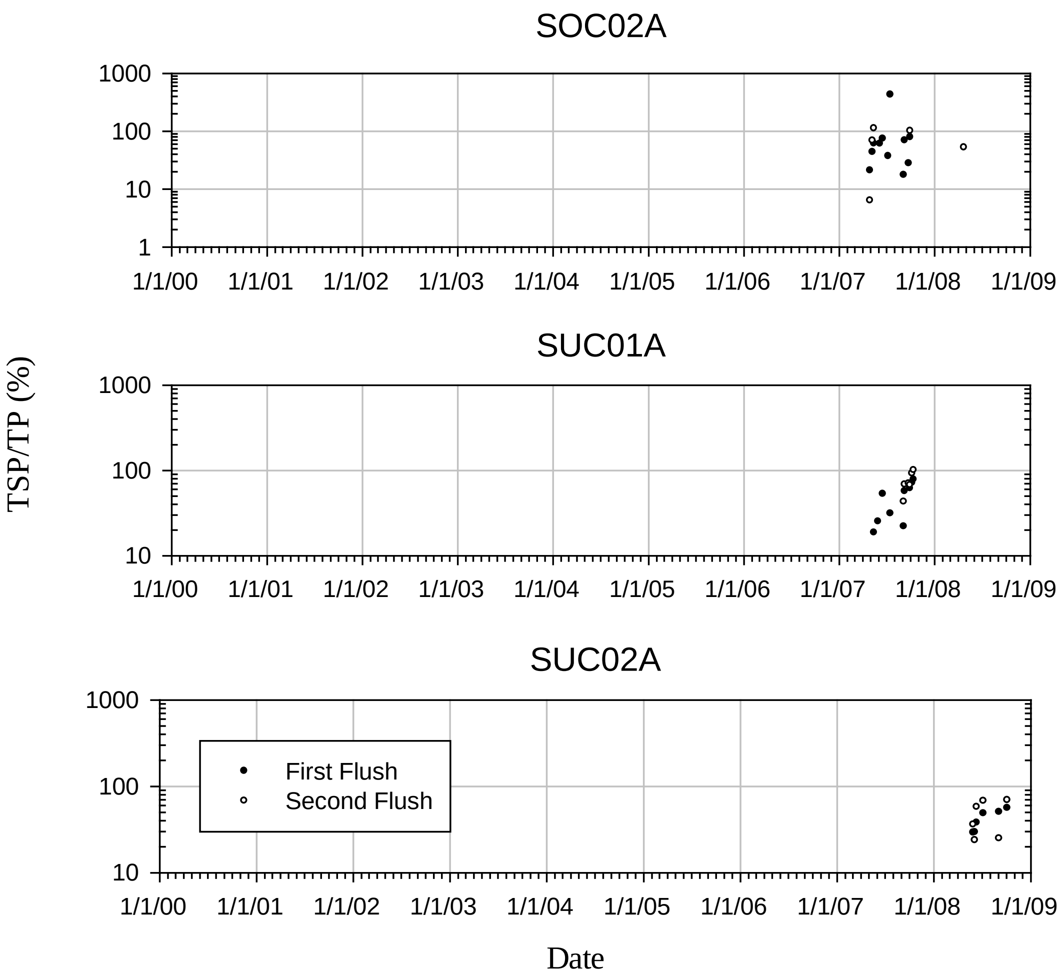

Figure B-7.TSP/TP (%) in stormwater sites SOC02A-SUC02A. Values of TSP/TP*100 above 100% reflect measurement uncertainty.

Appendix C. TSS Concentration in Stormwater

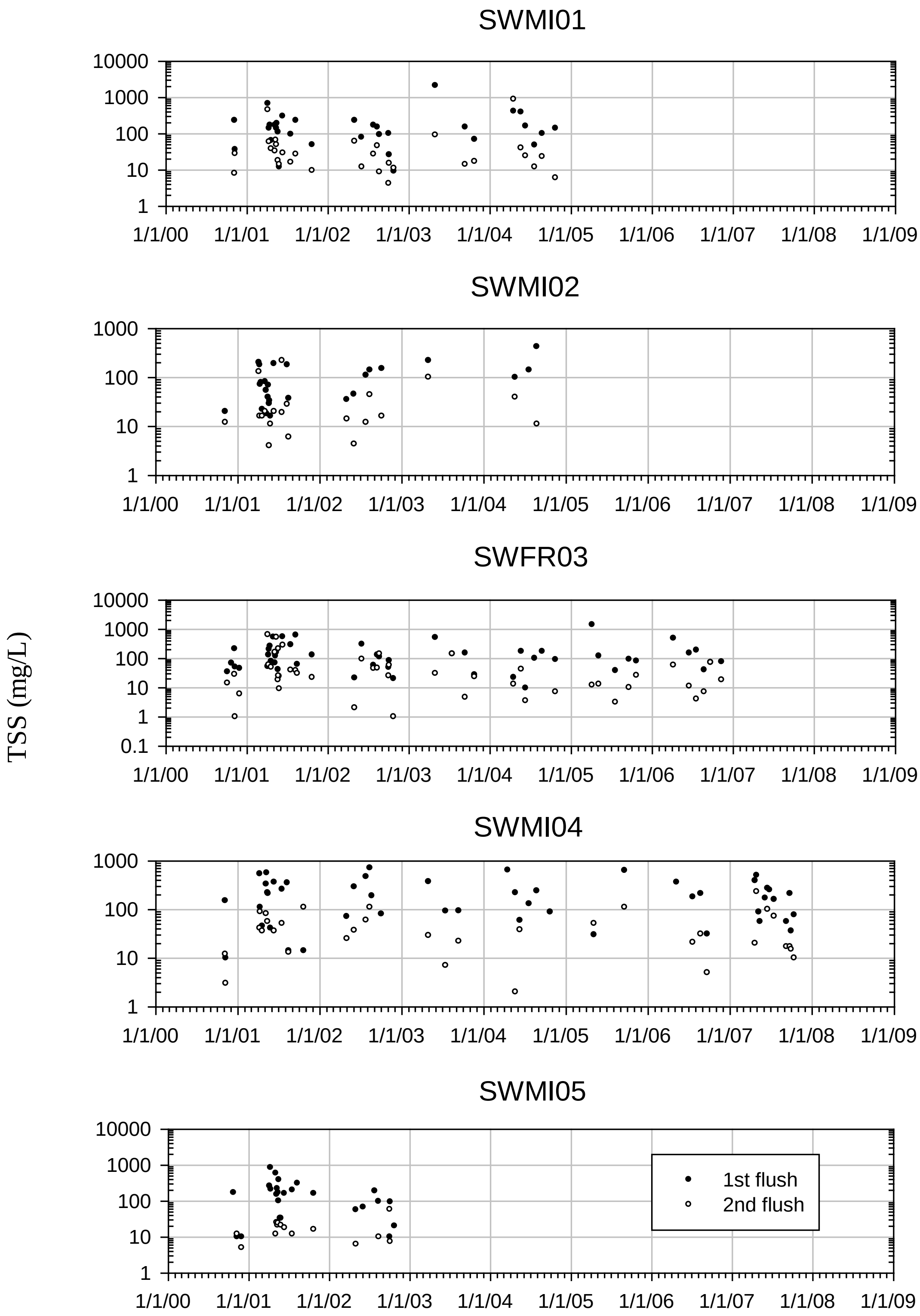

Figure C-1. TSS concentration for stormwater monitoring sites SWMI01-SWMI05.

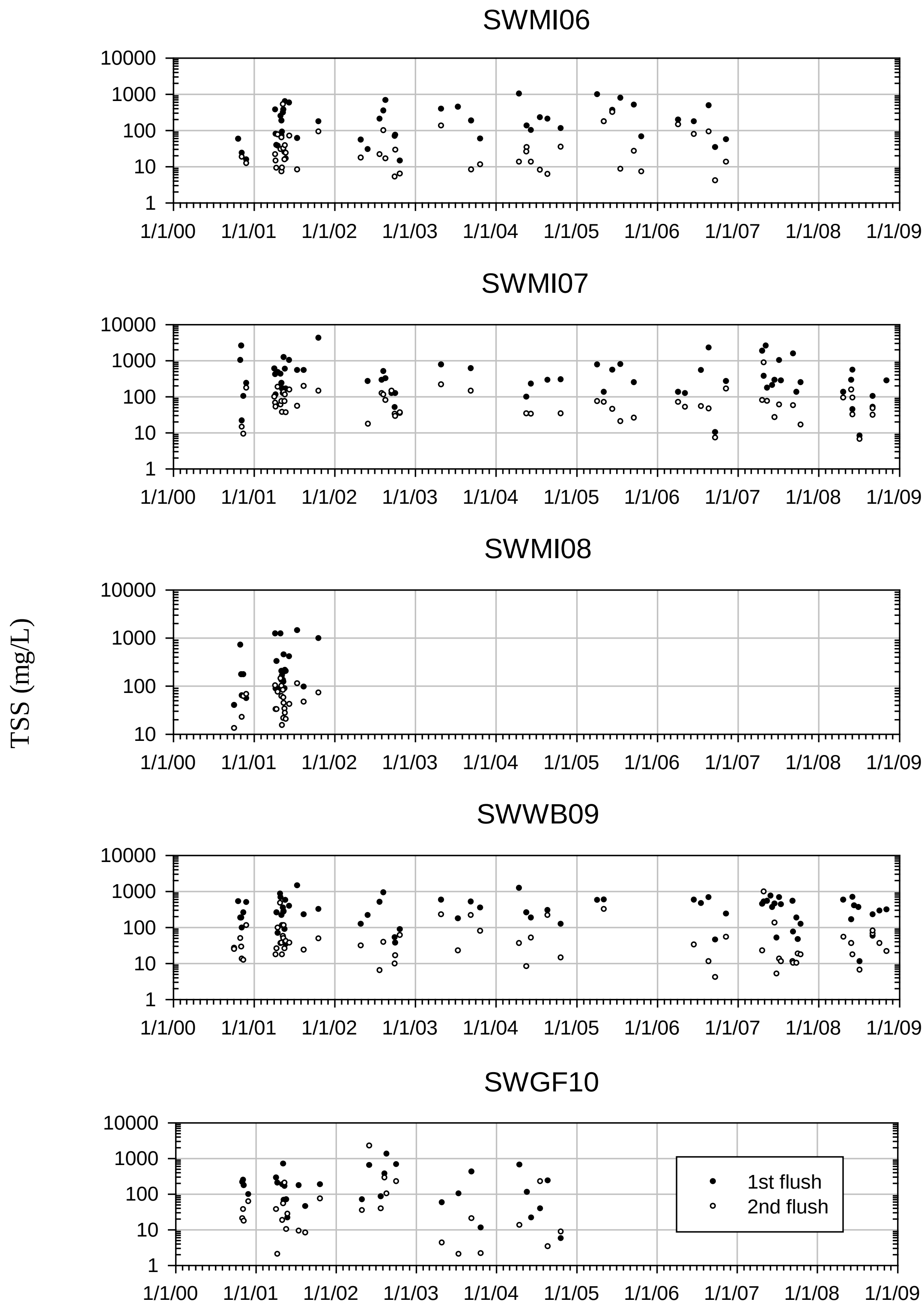

Figure C-2. TSS concentration for stormwater monitoring sites SWMI06-SWGF10.

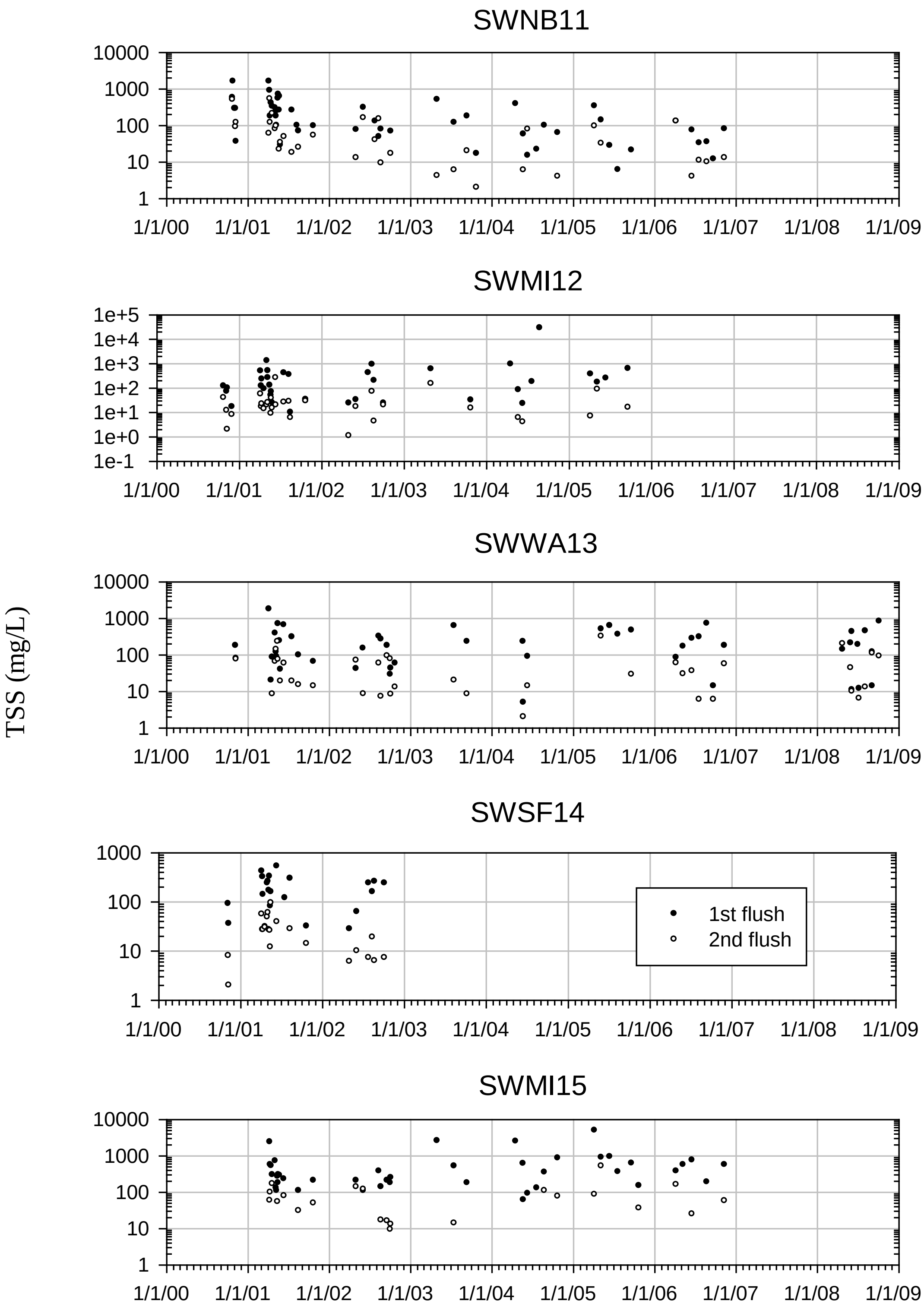

Figure C-3. TSS concentration for stormwater monitoring sites SWNB11-SWMI15.

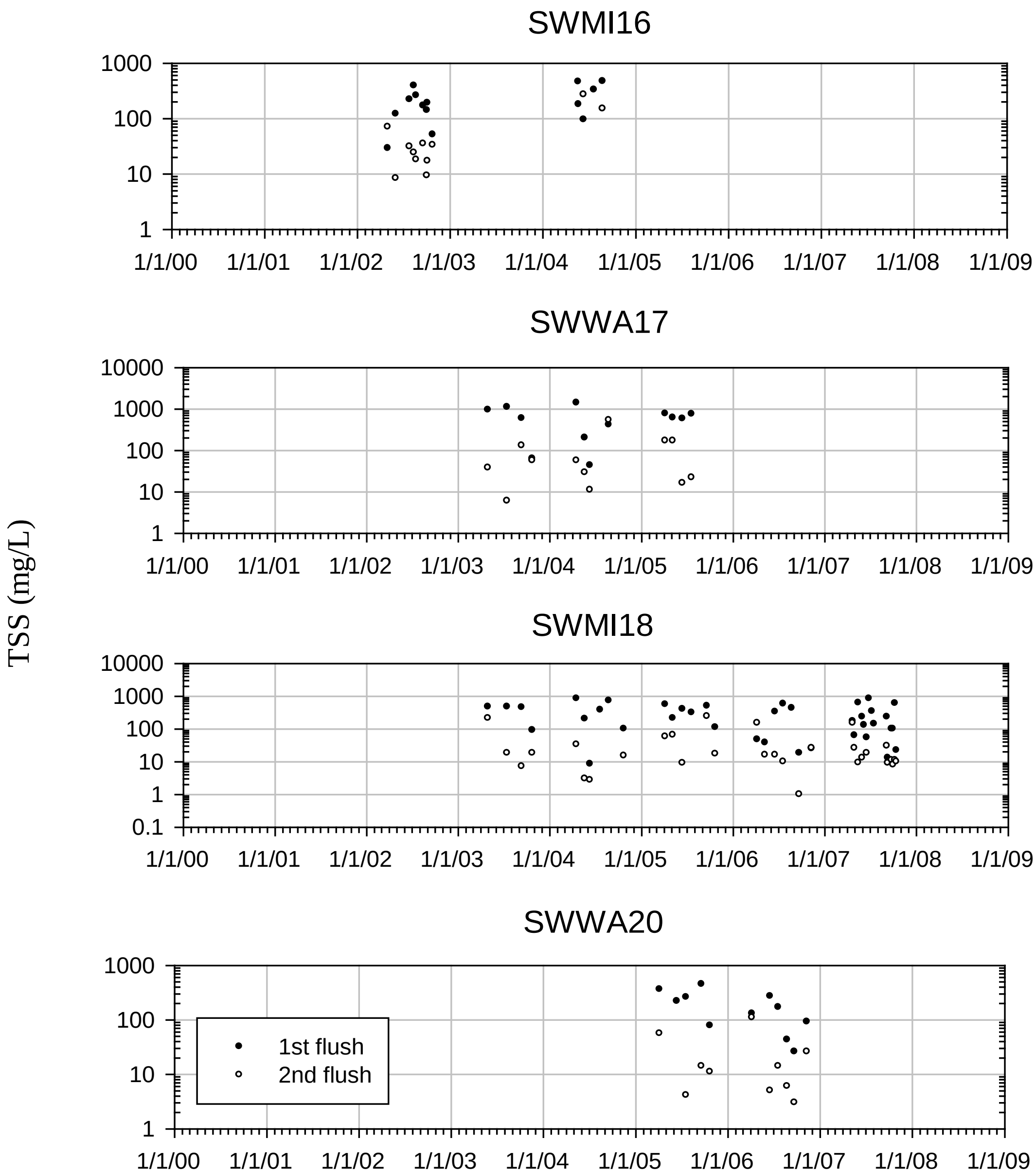

Figure C-4. TSS concentration for stormwater monitoring sites SWMI16-SWWA20.

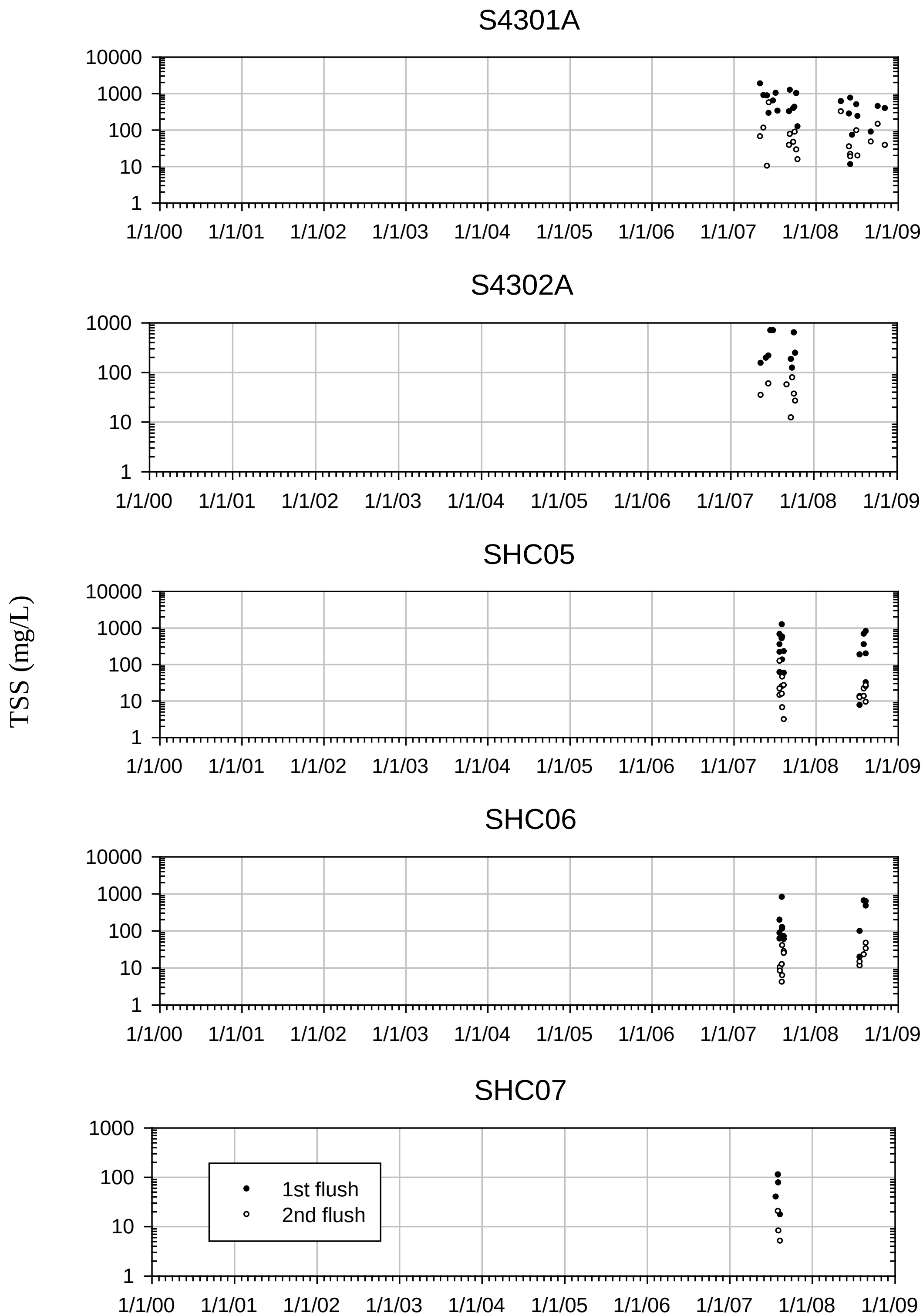

Figure C-5. TSS concentration for stormwater monitoring sites S4301A-SHC07.

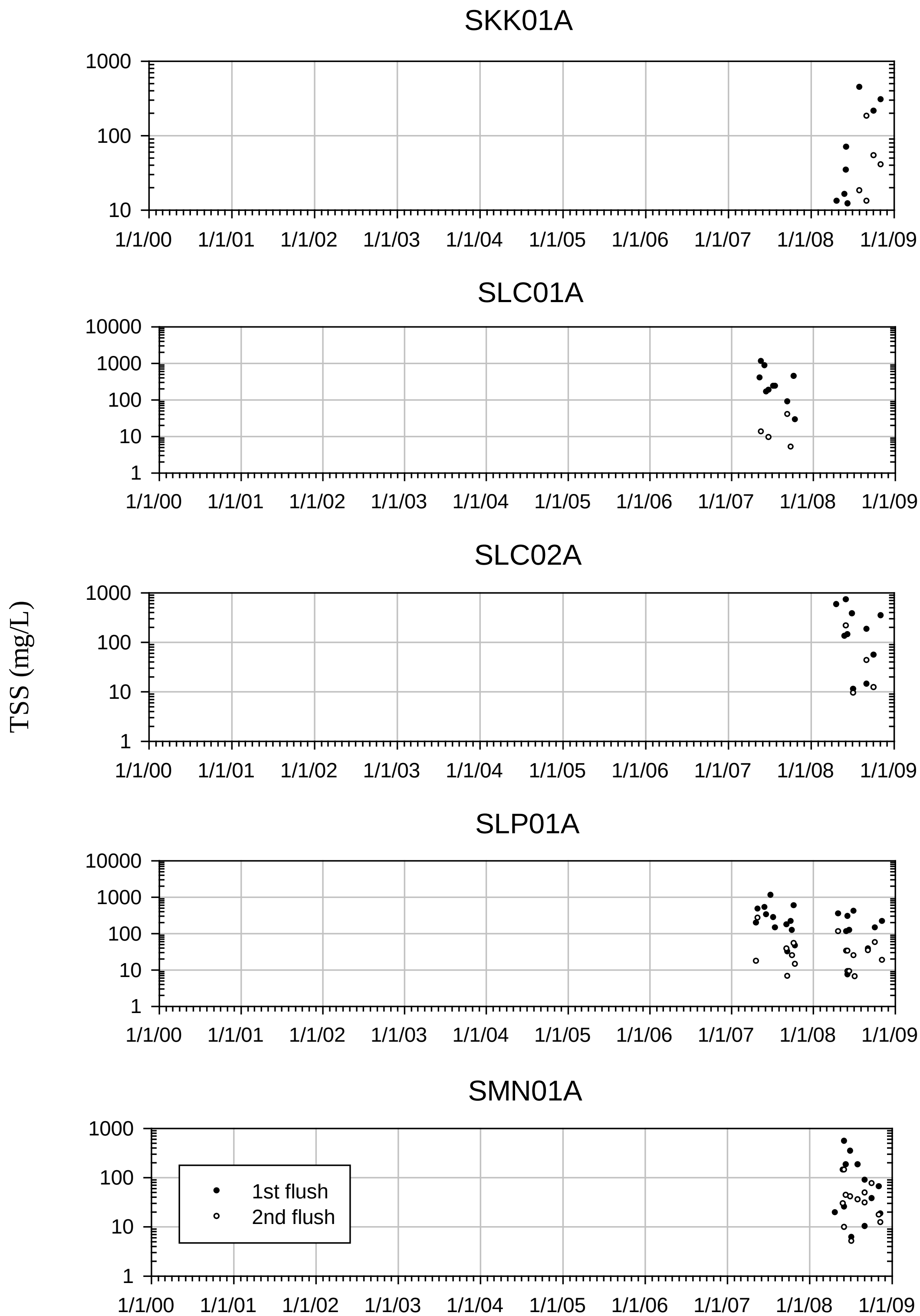

Figure C-6. TSS concentration for stormwater monitoring sites SKK01A-SMN01A.

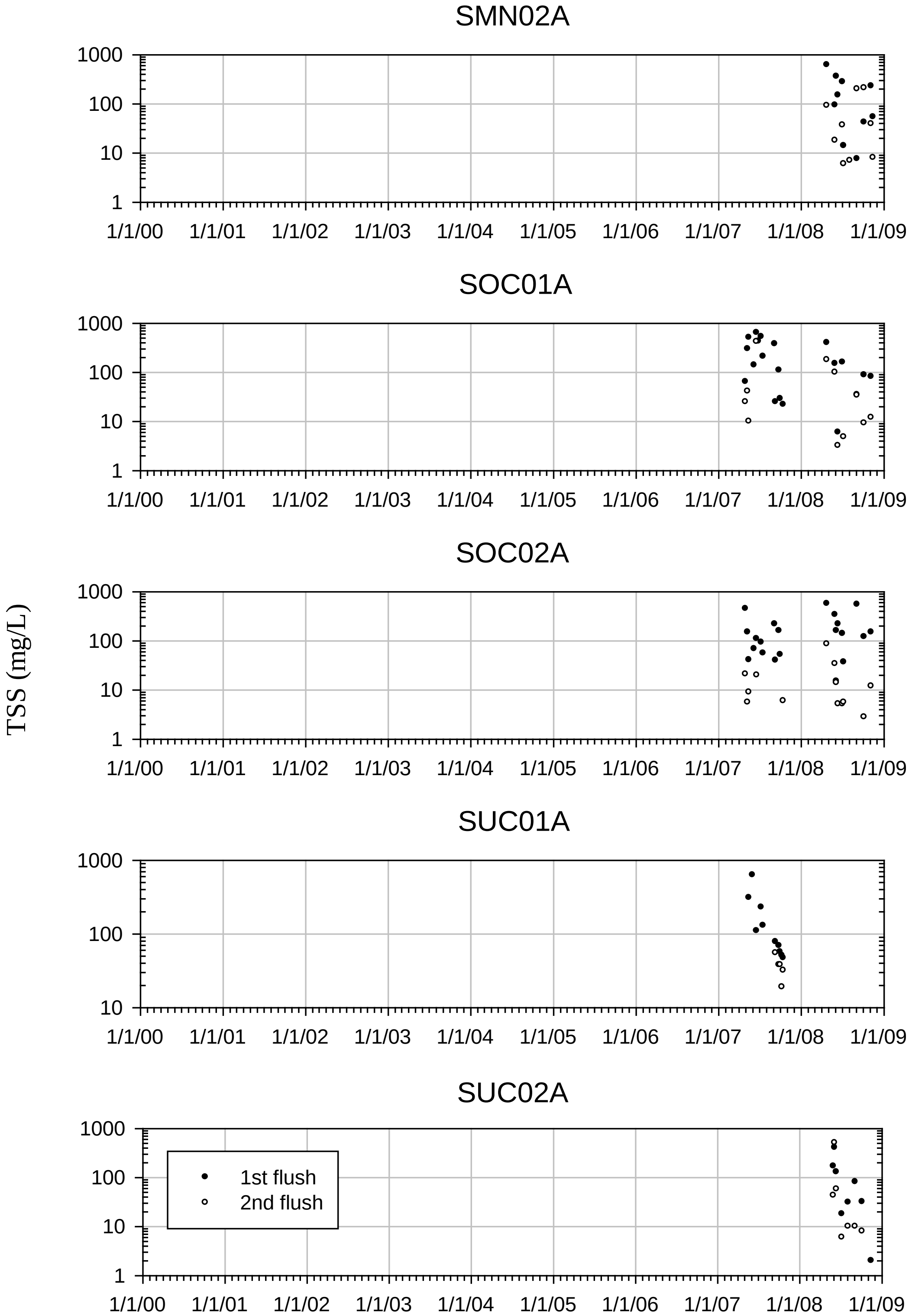

Figure C-7. TSS concentration for stormwater monitoring sites SMN02A-SUC02A.

Appendix D. TP Concentration in Rivers

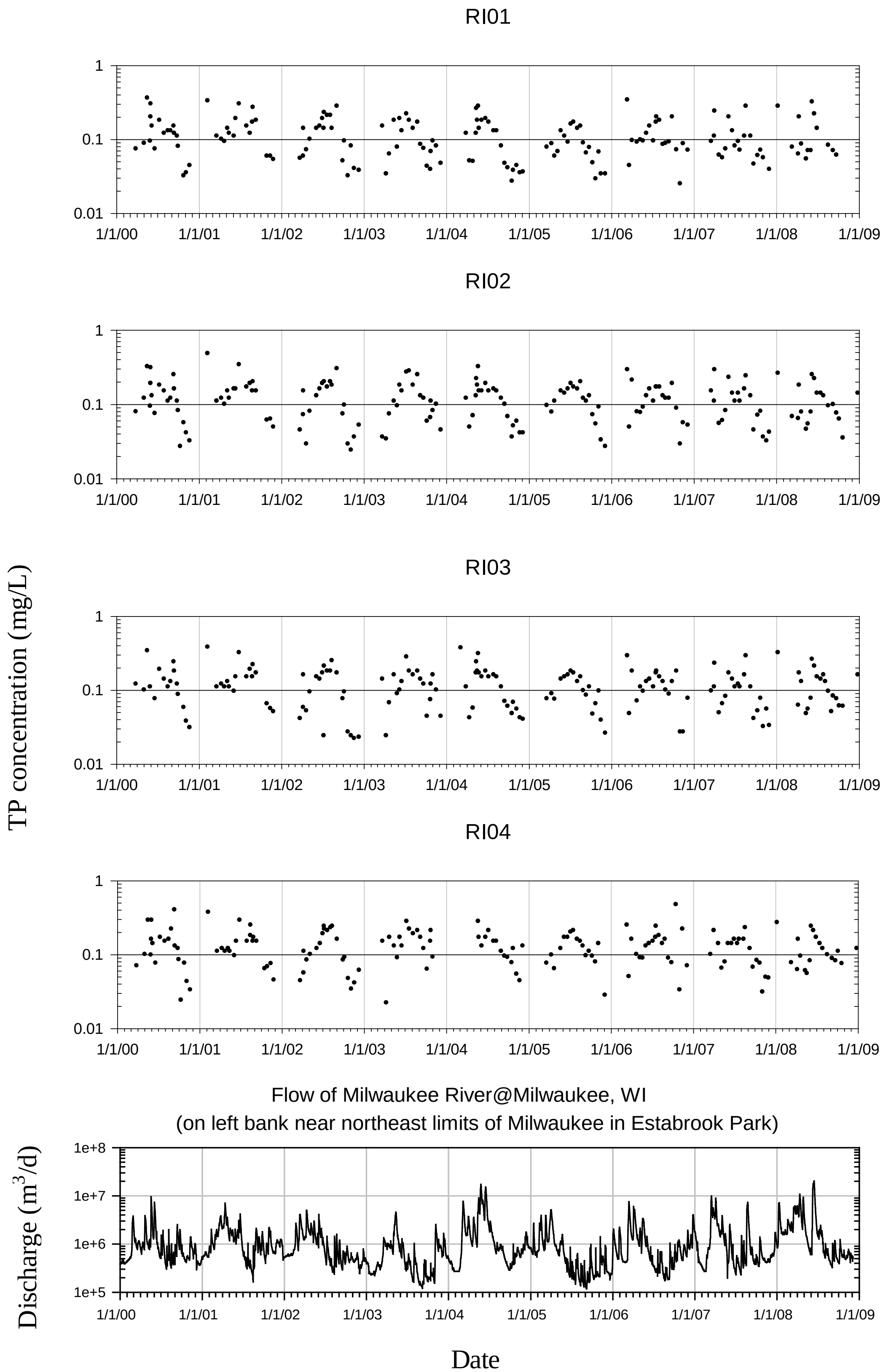

Figure D-1. TP level in Milwaukee River (outside CSO area).

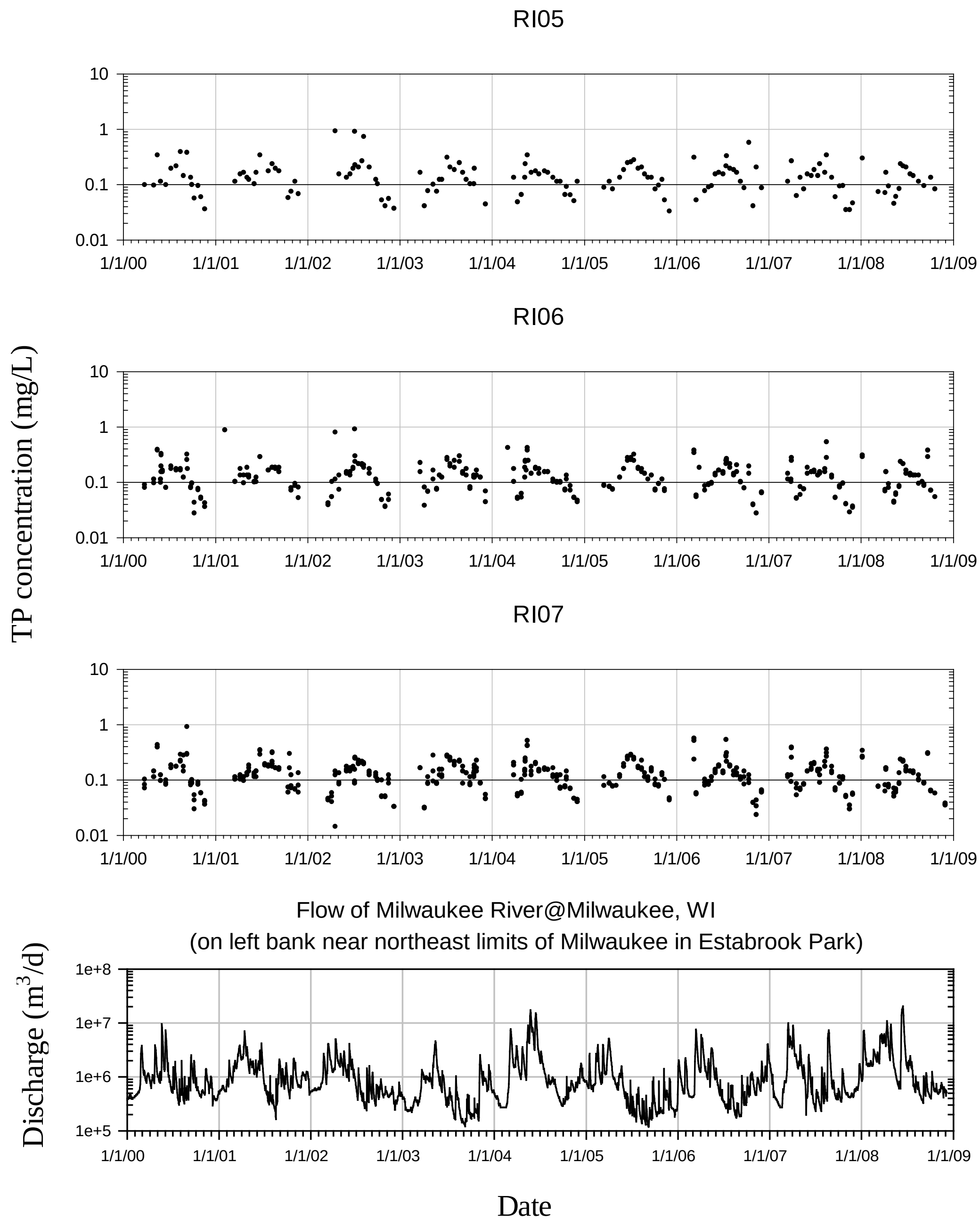

Figure D-2. TP level in Milwaukee River (inside CSO area).

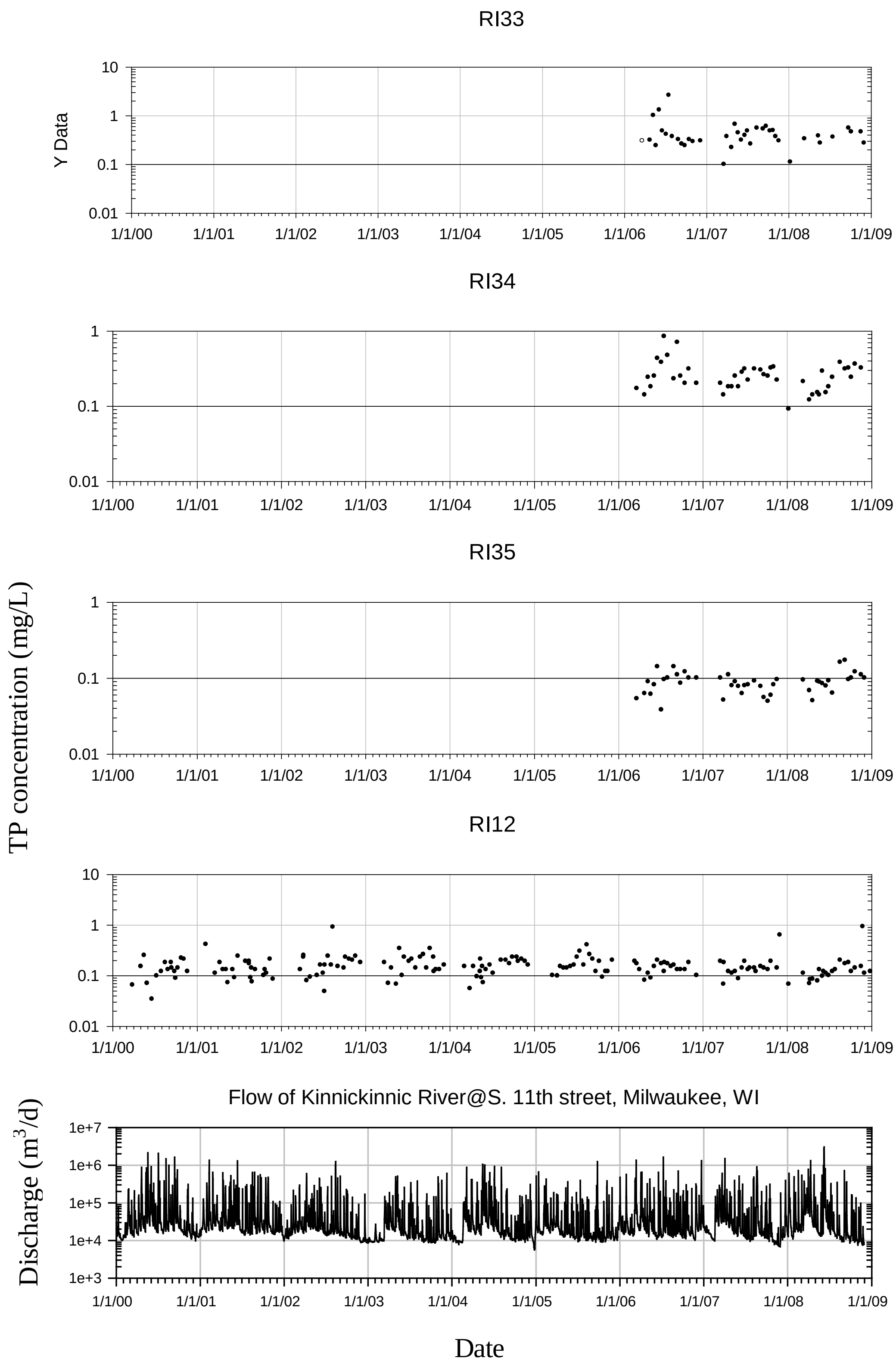

Figure D-3. TP level in Kinnickinnic River (outside CSO area).

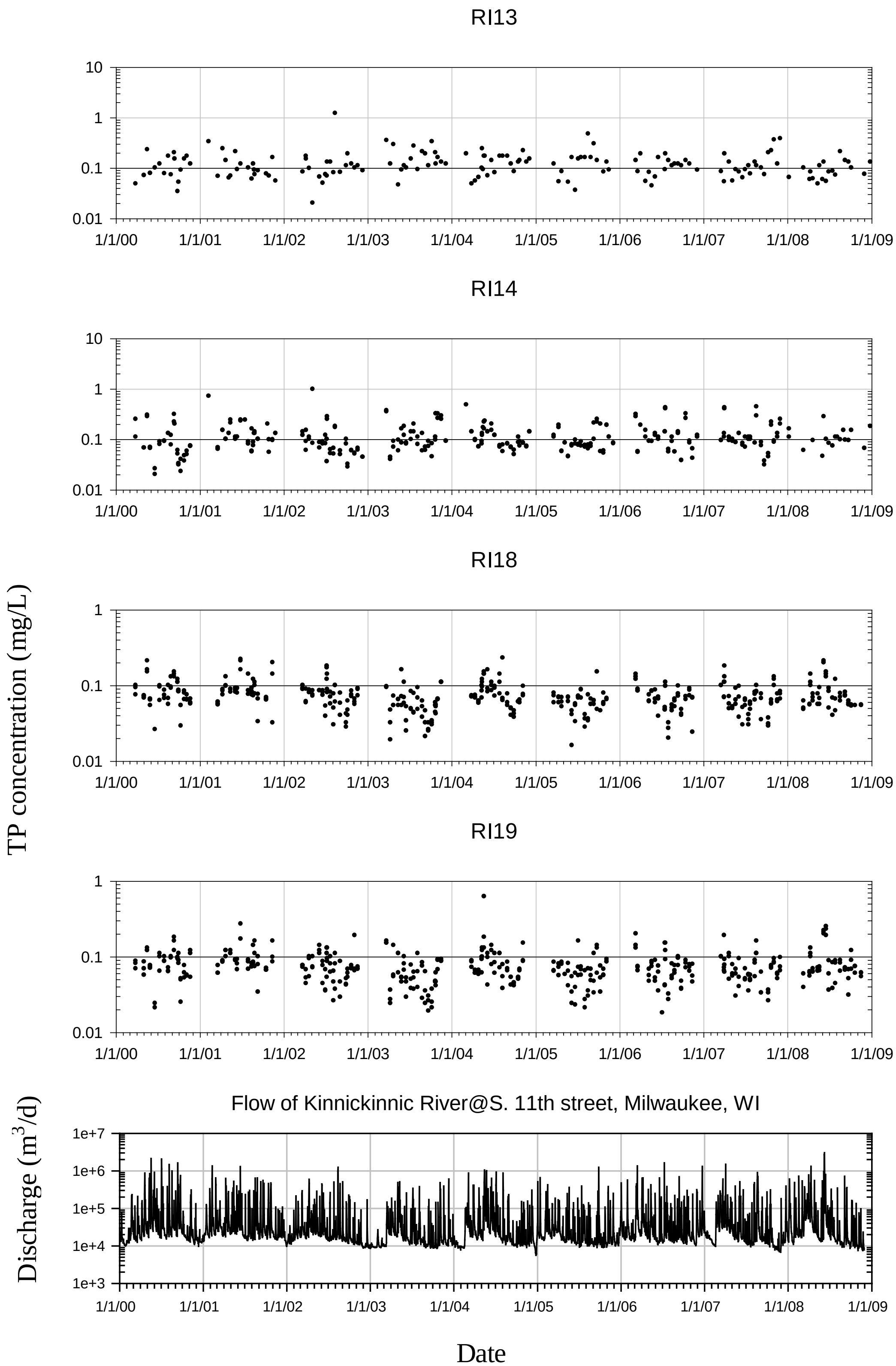

Figure D-4. TP level in Kinnickinnic River (inside CSO area).

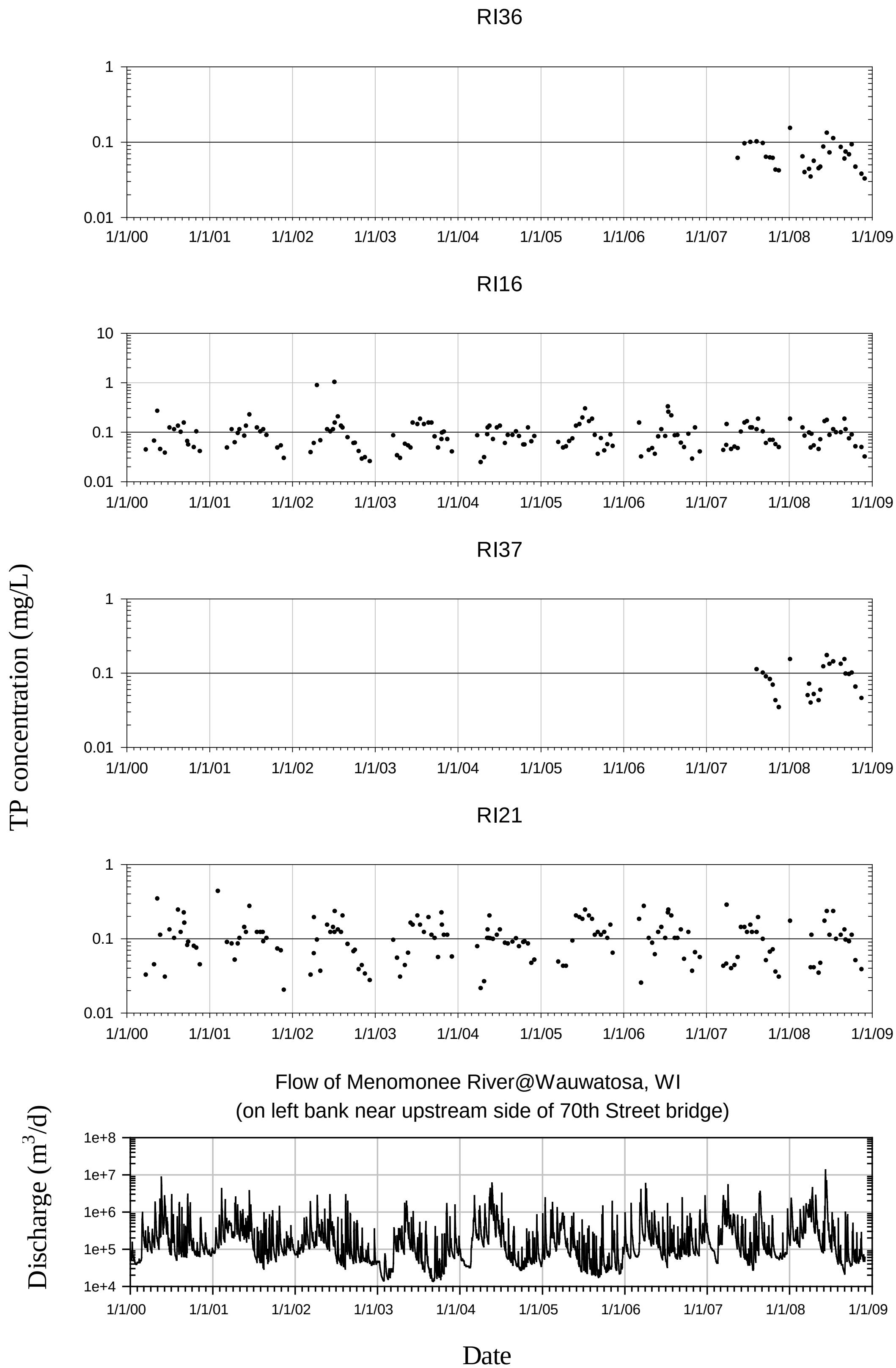

Figure D-5. TP level in Menomonee River (outside CSO area).

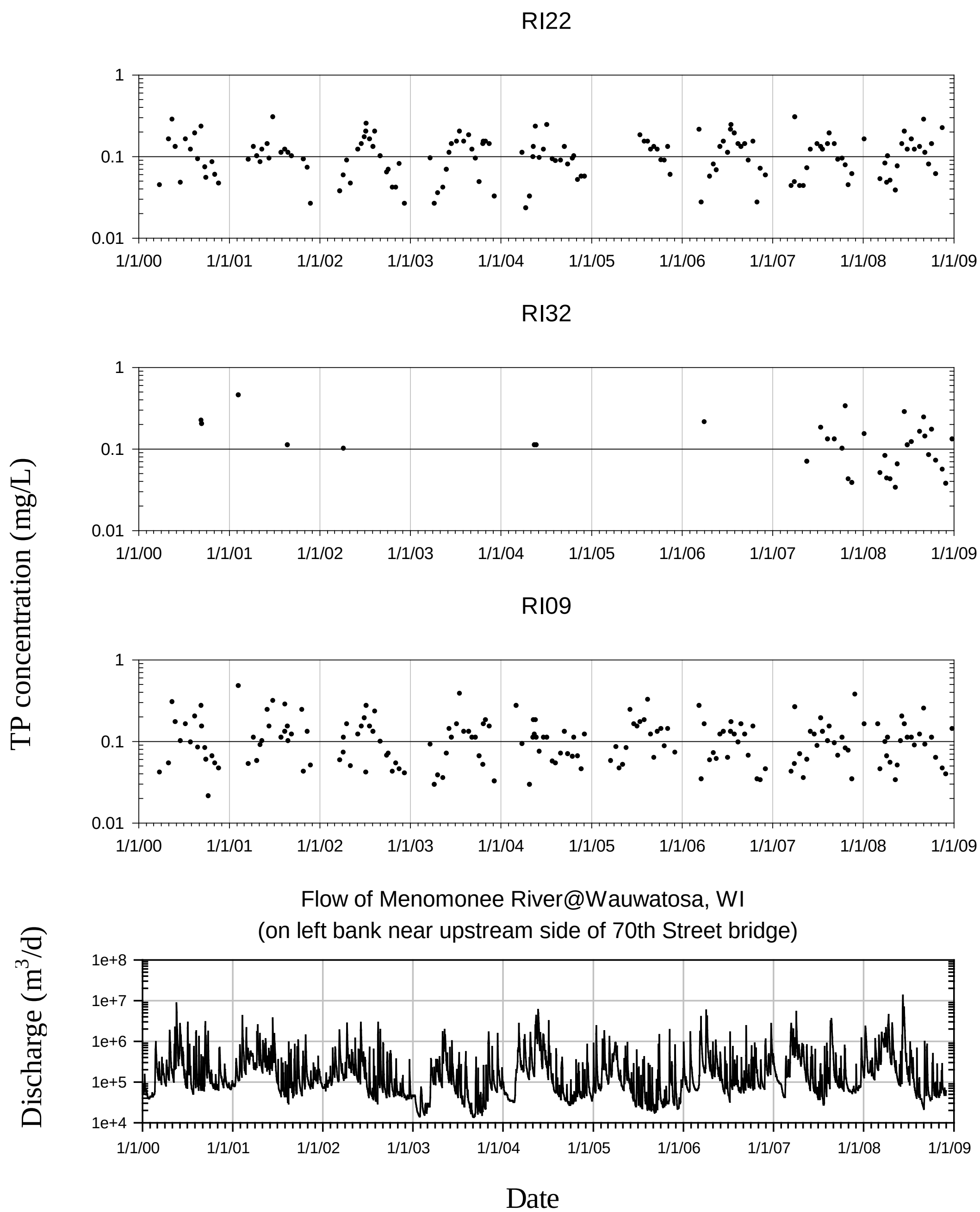

Figure D-6. TP level in Menomonee River (outside CSO area).

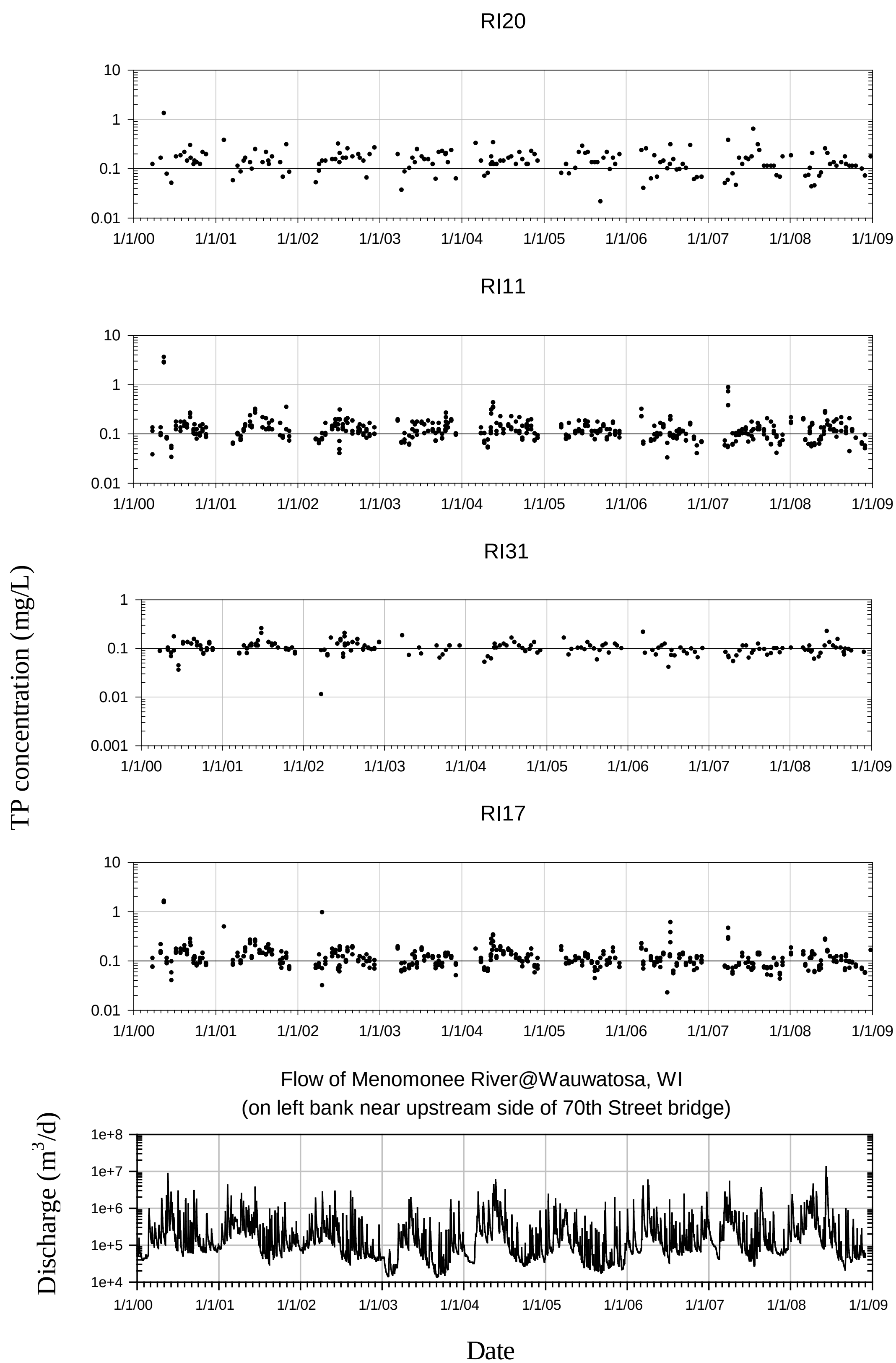

Figure D-7. TP level in Menomonee River (inside CSO area).

Appendix E. TP Concentration in CSOs

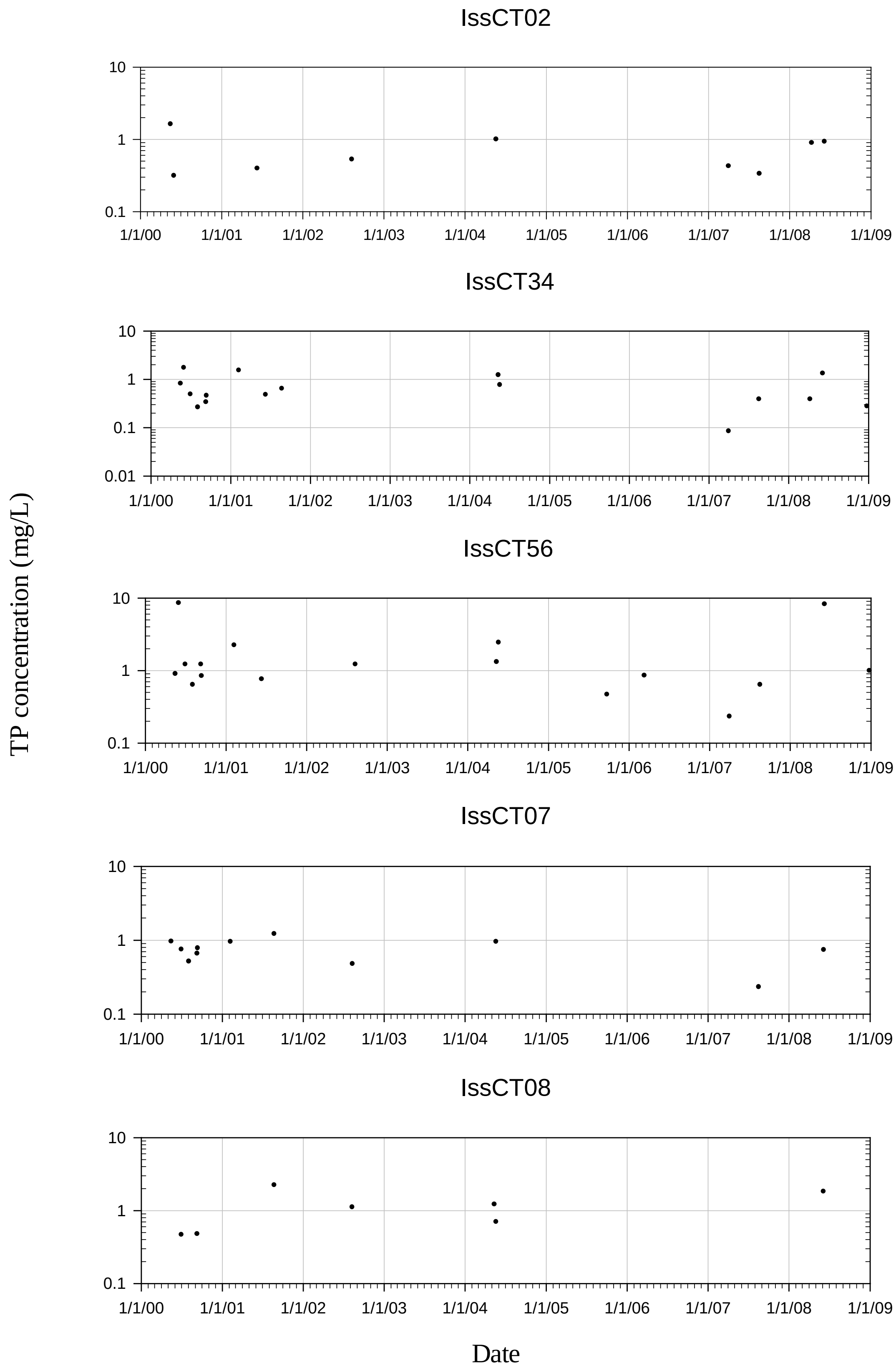

Figure E-1. TP level in CSO sites IssCT02-IssCT08.

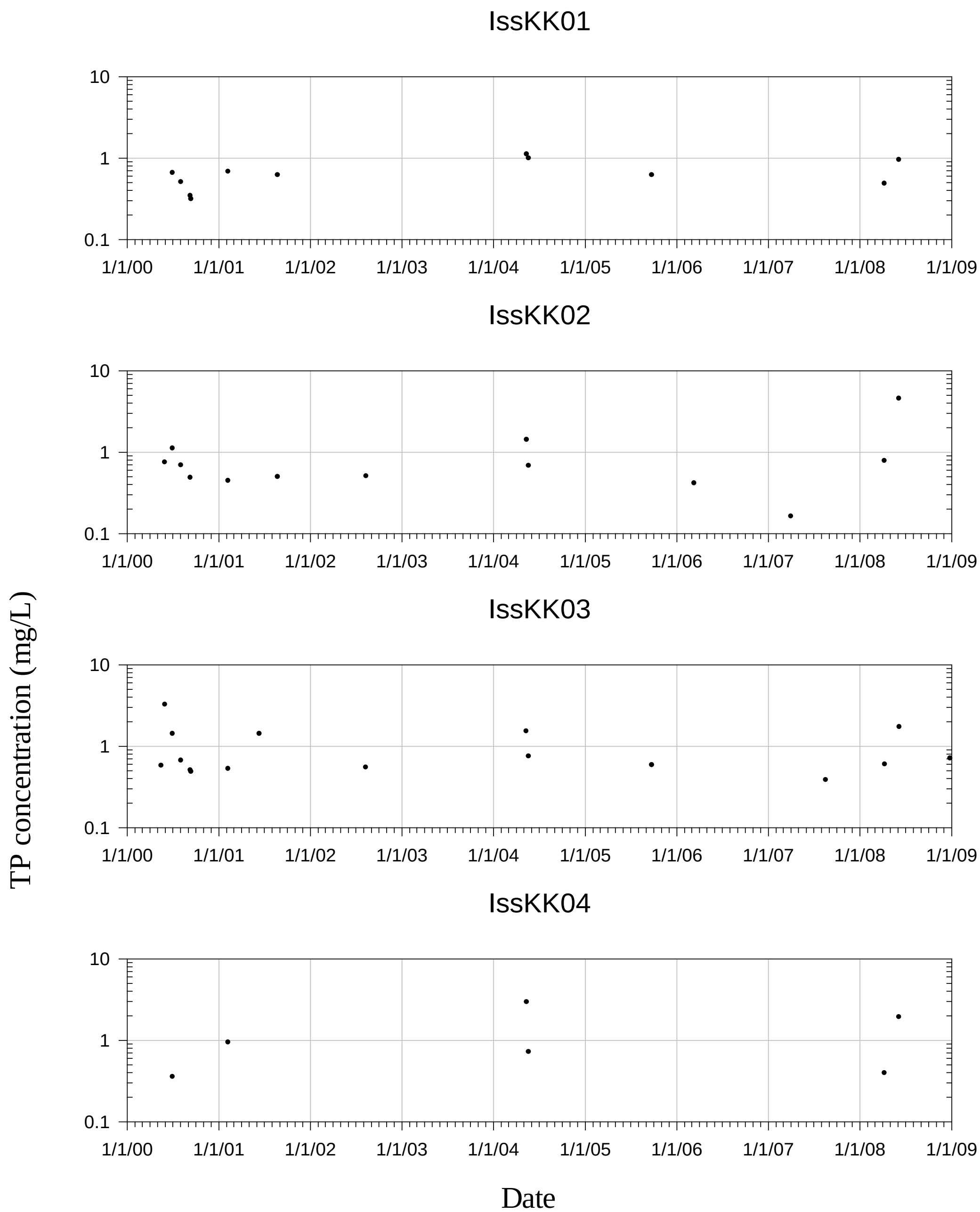

Figure E-2. TP level in CSO sites IssKK01-IssKK04.

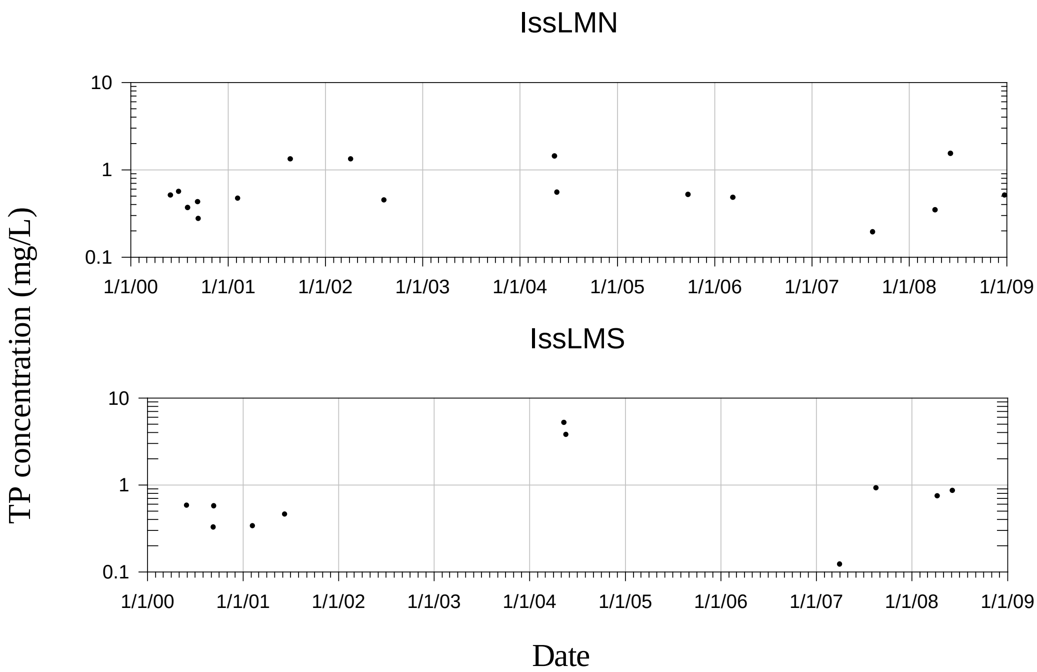

Figure E-3. TP level in CSO sites IssLMN-IssLMS.

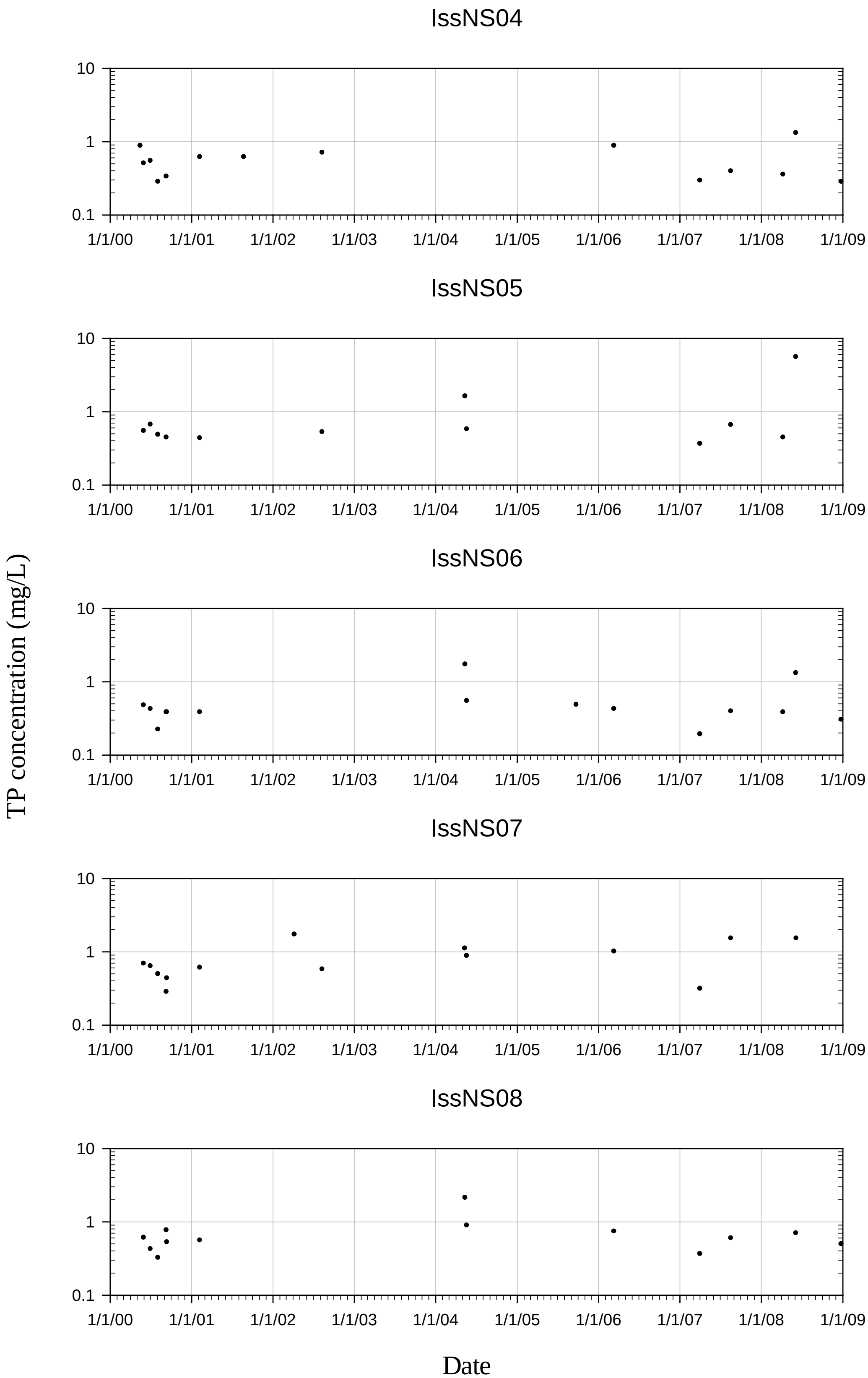

Figure E-4. TP level in CSO sites IssNS04-IssNS08.

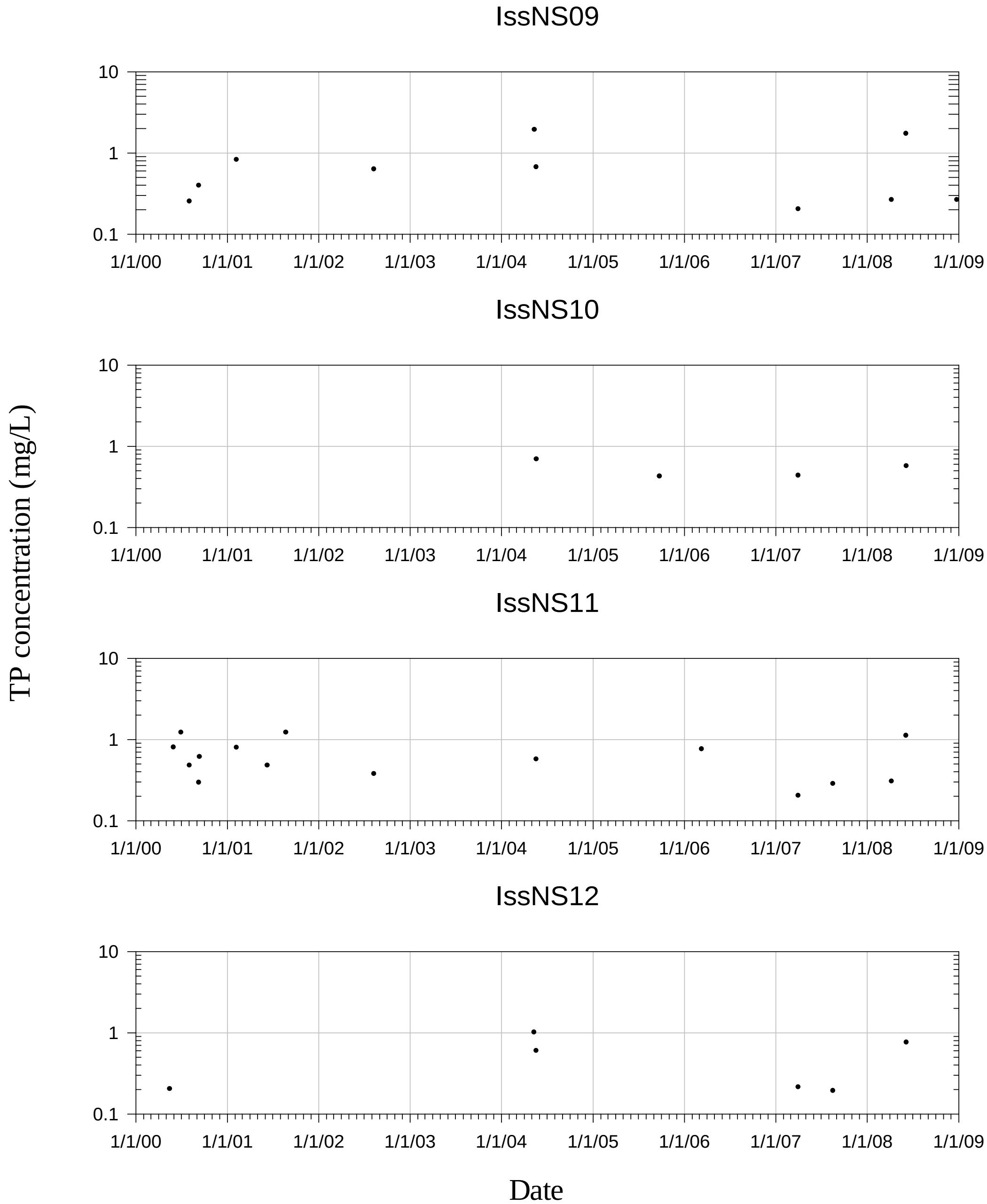

Figure E-5. TP level in CSO sites IssNS09-IssNS12.

Appendix F. Stepwise Regression Results for Selected Outer Harbor and River Sites

Table F-1. Stepwise Regression results with TP as dependent variable for OH – 01 (River Mouth) and OH – 02 (Jones Island WRF Outfall).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
OH-01	TP	TSS	0.030	4.13E-03	0.600	0.360	0.353	0[a]
		TSP	0.041	0.738	0.647	0.418	0.413	0
		STEPWISE				0.647	0.640	
		Constant	0.016					0
		TSP		0.624	0.547			0
		TSS		3.36E-03	0.488			0

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
OH-02	TP	TSS	0.084	2.64E-03	0.111	0.012	0.003	0.244
		TSP	0.053	0.928	0.499	0.249	0.242	0
		STEPWISE				0.249	0.242	
		Constant	0.053					
		TSP		0.928	0.499			0
		TSS (Excluded)			0.076			0.369

[a] $P < 0.001$

Table F-2. Stepwise regression results with TP as dependent variable for RI – 04 (Milwaukee River monitoring site corresponding to USGS monitoring site 04087000).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
RI-04	TP	TSS	0.094	1.47E-03	0.676	0.457	0.454	0[a]
		BOD5	0.096	0.018	0.488	0.238	0.234	0
		BOD20	0.063	7.20E-03	0.449	0.202	0.196	0
		TSP	0.057	1.169	0.685	0.469	0.465	0
		STEPWISE				0.519	0.513	
		Constant	0.081					0
		TSS		1.24E-03	0.574			0
		BOD5		0.010	0.268			0
		STEPWISE				0.753	0.75	
		Constant	0.041					0
		TSP		0.982	0.575			0
		TSS		1.17E-03	0.544			0
		STEPWISE				0.618	0.613	
		Constant	0.040					0
		TSP		1.030	0.603			0
		BOD5		0.140	0.396			0
		STEPWISE				0.799	0.795	
		Constant	0.033					0
		TSP		0.928	0.543			0
		TSS		9.98E-04	0.463			0
		BOD5		8.35E-03	0.234			0

[a] $P < 0.001$

Table F-3. Stepwise regression results with TP as dependent variable for RI – 09 (Menomonee River monitoring site corresponding to USGS monitoring site 04087120).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
RI-09	TP	TSS	0.071	1.64E-03	0.753	0.568	0.565	0[a]
		TSP	0.040	1.288	0.661	0.437	0.433	0
		BOD20	0.047	7.04E-03	0.537	0.288	0.283	0
		BOD5	0.077	0.017	0.561	0.314	0.311	0
		STEPWISE				0.598	0.594	
		Constant	0.064					0
		TSS		1.39E-03	0.639			0
		BOD5		6.43E-03	0.209			0
		STEPWISE				0.781	0.778	
		Constant	0.027					0
		TSS		1.30E-03	0.608			0
		TSP		0.982	0.504			0
		STEPWISE				0.626	0.621	
		Constant	0.025					0
		TSP		1.120	0.575			0
		BOD5		0.013	0.443			0
		STEPWISE				0.805	0.801	
		Constant	0.022					0
		TSS		1.09E-03	0.512			0
		TSP		0.961	0.493			0
		BOD5		5.18E-03	0.184			0

[a] $P < 0.001$

Table F-4. Stepwise regression results with TP as dependent variable for RI – 13 (Kinnickinnic River monitoring site corresponding to USGS monitoring site 04087159).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
RI-13	TP	TSS	0.105	1.31E-03	0.489	0.239	0.234	0[a]
		TSP	0.050	1.18	0.699	0.488	0.485	0
		BOD5	0.110	4.59E-03	0.257	0.066	0.060	0.001
		BOD20	0.103	2.13E-03	0.300	0.090	0.084	0
		STEPWISE				0.241	0.230	
		Constant	0.095					0
		TSS		1.11E-03	0.403			0
		BOD20		1.37E-03	0.193			0.012
		STEPWISE				0.649	0.645	
		Constant	0.037					0
		TSS		1.08E-03	0.402			0
		TSP		1.124	0.665			0
		STEPWISE				0.558	0.552	
		Constant	0.033					0
		TSP		1.17	0.686			0
		BOD20		1.81E-03	0.255			0
		STEPWISE				0.679	0.672	
		Constant	0.027					0
		TSP		1.134	0.664			0
		TSS		9.98E-04	0.362			0
		BOD20		1.14E-03	0.161			0.001

[a] $P < 0.001$

Table F-5. Stepwise regression results with TSP as dependent variable for OH-01 and OH-02.

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
OH-01	TSP	TSS	0.023	1.23E-03	0.204	0.042	0.032	0.0344
		TP	-3.54E-03	0.567	0.647	0.418	0.413	0[a]
		STEPWISE				0.647	0.64	
		Constant	1.37E-03					0
		TP		0.718	0.819			0
		TSS		-1.73E-03	-0.287			0.002

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
OH-02	TSP	TSS	0.0456	9.01E-04	0.0705	4.97E-03	-4.33E-03	0.466
		TP	0.0237	0.269	0.499	0.249	0.242	0
		STEPWISE				0.249	0.242	
		Constant	0.0237					
		TP		0.269	0.499			0
		TSS (Excluded)			0.0155			0.855

[a] $P < 0.001$

Table F-6. Stepwise regression results with TSP as dependent variable for RI – 04 (Milwaukee River monitoring site corresponding to USGS monitoring site 04087000).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
RI-04	TSP	TSS	0.0542	2.57E-04	0.203	0.0413	0.0351	0.0105
		BOD5	0.0522	4.40E-03	0.211	0.0443	0.0382	8.12E-03
		BOD20	0.0411	2.09E-03	0.219	0.0479	0.0414	7.52E-03
		TP	0.0091	0.401	0.685	0.469	0.465	0[a]
		STEPWISE				0.0443	0.0382	
		Constant	0.0522					0
		BOD5		4.40E-03	0.211			8.12E-03
		TSS (Excluded)			0.145			0.0881
		STEPWISE				0.580	0.575	
		Constant	1.26E-04					0.979
		TP		0.573	0.978			0
		TSS		-5.61E-04	-0.445			0
		STEPWISE				0.499	0.492	
		Constant	9.23E-03					0.0637
		TP		0.463	0.791			0
		BOD5		-4.28E-03	-0.205			2.64E-03
		STEPWISE				0.605	0.597	
		Constant	4.55E-04					0.922
		TP		0.624	1.067			0
		TSS		-5.47E-04	-0.434			0
		BOD5		-3.88E-03	-0.186			2.24E-03

[a] $P < 0.001$

Table F-7. Stepwise regression results with TSP as dependent variable for RI – 09 (Menomonee River monitoring site corresponding to USGS monitoring site 04087120).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
RI-09	TSP	TSS	0.0453	2.81E-04	0.256	0.0657	0.0602	7.00E-04
		TP	0.0156	0.339	0.661	0.437	0.433	0[a]
		BOD5	0.0462	2.83E-03	0.196	0.0383	0.0327	0.010
		BOD20	0.0359	1.90E-03	0.278	0.0770	0.0713	3.00E-04
		STEPWISE				0.0753	0.0696	
		Constant	0.0362					0
		BOD20		1.88E-03	0.274			4.00E-04
		TSS (Excluded)			0.161			0.0538
		STEPWISE				0.551	0.546	
		Constant	7.72E-03					0.0327
		TSS		-5.53E-04	-0.505			0
		TP		0.530	1.031			0
		STEPWISE				0.434	0.43	
		Constant	0.0152					0
		TP		0.343	0.658			0
		BOD20 (Excluded)			-0.108			0.126
		STEPWISE				0.548	0.543	
		Constant	7.12E-03					0.0626
		TSS		-5.54E-04	-0.500			0
		TP		0.553	1.023			0
		BOD20 (Excluded)			-0.0881			0.163

[a] P < 0.001

Table F-8. Stepwise regression results with TSP as dependent variable for RI – 13 (Kinnickinnic River monitoring site corresponding to USGS monitoring site 04087159).

Station	Dependent Variable	Independent Variable	Coefficients			R Square	Adjusted R Square	P Value
			alpha	B	Beta			
RI-13	TSP	TSS	0.0609	1.32E-04	0.0831	6.91E-03	4.00E-04	0.305
		TP	0.0114	0.414	0.699	0.488	0.485	0[a]
		BOD5	0.0647	-3.42E-04	-0.0337	1.09E-03	-5.53E-03	0.685
		BOD20	0.0603	2.73E-04	0.0655	0.0043	-2.62E-03	0.432
		STEPWISE				0.559	0.553	
		Constant	8.47E-03					0.0681
		TSS		0.495	0.836			0
		TP		-4.74E-04	-0.299			0
		STEPWISE				0.516	0.510	
		Constant	0.0149					3.84E-03
		TP		0.439	0.750			0
		BOD20		-6.64E-04	-0.160			9.83E-03
		STEPWISE				0.580	0.571	
		Constant	0.0113					0.0210
		TP		0.509	0.868			0
		TSS		-4.65E-04	-0.287			0
		BOD20		-4.97E-04	-0.119			0.0409

[a] $P < 0.001$

Appendix G. River Flow and TP Measurements for Two Outer Harbor Sites and Two Stormwater Stations

Table G-1. Rivers flows and TP measurements for OH-01 (River Mouth) from 1/1/2004 to 4/2/2004.

Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)
1/1/2004	239.6		2/1/2004	128		3/3/2004	1439	
1/2/2004	244		2/2/2004	127.9		3/4/2004	2000	
1/3/2004	236.4		2/3/2004	127.9		3/5/2004	4448	
1/4/2004	215.6		2/4/2004	127.9		3/6/2004	3802	
1/5/2004	211		2/5/2004	127.8		3/7/2004	3304	
1/6/2004	208		2/6/2004	127.8		3/8/2004	2858	
1/7/2004	194.8		2/7/2004	127.8		3/9/2004	2401	
1/8/2004	195		2/8/2004	127.8		3/10/2004	2047	
1/9/2004	194.4		2/9/2004	127.8		3/11/2004	1762	
1/10/2004	184.6		2/10/2004	127.7		3/12/2004	1452.1	
1/11/2004	185.7		2/11/2004	126.7		3/13/2004	1154.3	
1/12/2004	197.5		2/12/2004	126.6		3/14/2004	1102	
1/13/2004	206.5		2/13/2004	126.6		3/15/2004	966.1	
1/14/2004	196		2/14/2004	126.6		3/16/2004	848.5	
1/15/2004	184.5		2/15/2004	126.6		3/17/2004	795	
1/16/2004	184.8		2/16/2004	126.8		3/18/2004	774	
1/17/2004	175		2/17/2004	128.2		3/19/2004	723	
1/18/2004	153		2/18/2004	142		3/20/2004	720.1	
1/19/2004	142.6		2/19/2004	149		3/21/2004	771.3	
1/20/2004	150.8		2/20/2004	210		3/22/2004	764.1	
1/21/2004	150		2/21/2004	212		3/23/2004	729.1	
1/22/2004	149		2/22/2004	203		3/24/2004	719	
1/23/2004	149		2/23/2004	293		3/25/2004	710.2	
1/24/2004	139		2/24/2004	300		3/26/2004	1527	
1/25/2004	139		2/25/2004	298		3/27/2004	1133	
1/26/2004	129		2/26/2004	327		3/28/2004	1716	
1/27/2004	128.7		2/27/2004	365		3/29/2004	2150	
1/28/2004	127.7		2/28/2004	415		3/30/2004	1933	
1/29/2004	127.6		2/29/2004	621		3/31/2004	1650	
1/30/2004	127.4		3/1/2004	929		4/1/2004	1441	
1/31/2004	127.2		3/2/2004	1191		4/2/2004	1252	

Table G-2. Rivers flows and TP measurements for OH-01 (River Mouth) from 4/3/2004 to 7/7/2004.

Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)
4/3/2004	1088.3		5/5/2004	472.4		6/6/2004	2134.2	
4/4/2004	949.2		5/6/2004	460		6/7/2004	1737.3	
4/5/2004	833		5/7/2004	417.7		6/8/2004	1425.7	
4/6/2004	759		5/8/2004	581		6/9/2004	1389	0.087
4/7/2004	705.2		5/9/2004	1120		6/10/2004	1888	
4/8/2004	652.5		5/10/2004	2388		6/11/2004	3951	
4/9/2004	604.8		5/11/2004	2827		6/12/2004	5415	
4/10/2004	562.6		5/12/2004	2562		6/13/2004	5994	
4/11/2004	531.2		5/13/2004	4051		6/14/2004	6989	
4/12/2004	503		5/14/2004	5851		6/15/2004	6252	
4/13/2004	479.3		5/15/2004	4492		6/16/2004	5364	
4/14/2004	461.3		5/16/2004	3350		6/17/2004	4639	
4/15/2004	444.6	0.046	5/17/2004	2567		6/18/2004	3873	
4/16/2004	432		5/18/2004	2612		6/19/2004	3226	
4/17/2004	660		5/19/2004	2103		6/20/2004	2671	
4/18/2004	566		5/20/2004	2575		6/21/2004	2358	0.18
4/19/2004	635		5/21/2004	4452		6/22/2004	1805	
4/20/2004	1226		5/22/2004	8256		6/23/2004	1491	
4/21/2004	2064		5/23/2004	8519		6/24/2004	1513	
4/22/2004	1853		5/24/2004	8627	0.43	6/25/2004	1376	
4/23/2004	1580.9		5/25/2004	7423		6/26/2004	1257	
4/24/2004	1306		5/26/2004	5989		6/27/2004	1172	
4/25/2004	1392		5/27/2004	4939		6/28/2004	1180	
4/26/2004	1219	0.063	5/28/2004	4025		6/29/2004	1033.9	
4/27/2004	1068.5		5/29/2004	3289		6/30/2004	933	
4/28/2004	911.5		5/30/2004	3466		7/1/2004	836.7	
4/29/2004	802.1		5/31/2004	3899		7/2/2004	783.3	
4/30/2004	716.3		6/1/2004	3930		7/3/2004	1135	
5/1/2004	667		6/2/2004	3603		7/4/2004	2828	
5/2/2004	604.2		6/3/2004	3236		7/5/2004	1572	
5/3/2004	537.2		6/4/2004	2919		7/6/2004	1375	
5/4/2004	499.2		6/5/2004	2564.6		7/7/2004	1428	

Table G-3. River flows and TP measurements for OH-01 (River Mouth) from 7/8/2004 to 10/11/2004.

Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)
7/8/2004	1145		8/9/2004	379		9/10/2004	207.3	
7/9/2004	981		8/10/2004	326.9		9/11/2004	201.7	
7/10/2004	887.9		8/11/2004	322		9/12/2004	194.4	
7/11/2004	946		8/12/2004	326.6	0.053	9/13/2004	187.8	
7/12/2004	957		8/13/2004	344.3		9/14/2004	183.1	
7/13/2004	803		8/14/2004	363.8		9/15/2004	209	
7/14/2004	703		8/15/2004	360.4		9/16/2004	223	
7/15/2004	631.3		8/16/2004	343.7		9/17/2004	170	
7/16/2004	643		8/17/2004	389.6		9/18/2004	167.3	
7/17/2004	628.7		8/18/2004	394.5		9/19/2004	159.2	
7/18/2004	566.2		8/19/2004	420.3		9/20/2004	158.3	
7/19/2004	533.2		8/20/2004	426		9/21/2004	153.5	
7/20/2004	517.4	0.053	8/21/2004	411.6		9/22/2004	151.2	
7/21/2004	564		8/22/2004	390.4		9/23/2004	148.3	0.033
7/22/2004	495.9		8/23/2004	356.8		9/24/2004	140.4	
7/23/2004	456.1		8/24/2004	489		9/25/2004	136.4	
7/24/2004	416.8		8/25/2004	546		9/26/2004	134.5	
7/25/2004	413.4		8/26/2004	330.9		9/27/2004	134.4	
7/26/2004	359.2		8/27/2004	536		9/28/2004	136.3	
7/27/2004	345		8/28/2004	599		9/29/2004	132.2	
7/28/2004	328.5		8/29/2004	470		9/30/2004	132.4	
7/29/2004	307.9		8/30/2004	352		10/1/2004	159	
7/30/2004	298.2		8/31/2004	326.5		10/2/2004	223	
7/31/2004	287.4		9/1/2004	301.2		10/3/2004	152.9	
8/1/2004	320		9/2/2004	288.1		10/4/2004	156.8	
8/2/2004	355.6		9/3/2004	277.7		10/5/2004	148.8	
8/3/2004	977		9/4/2004	265.3		10/6/2004	144.6	
8/4/2004	744		9/5/2004	254.8		10/7/2004	146.7	
8/5/2004	427		9/6/2004	236.4		10/8/2004	170	
8/6/2004	405		9/7/2004	230.5		10/9/2004	163.4	
8/7/2004	367.6		9/8/2004	225.8		10/10/2004	189.7	
8/8/2004	341		9/9/2004	216		10/11/2004	184.7	

Table G-4. Rivers flows and TP measurements for OH-01 (River Mouth) from 10/12/2004 to 12/31/2004.

Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)	Date	Flow (cfs)	OH-01 (TP mg/L)
10/12/2004	181	0.042	11/14/2004	243.7		12/17/2004	608.7	
10/13/2004	177		11/15/2004	237.2	0.076	12/18/2004	435.3	
10/14/2004	175.2		11/16/2004	237.5		12/19/2004	425	
10/15/2004	448		11/17/2004	241.7		12/20/2004	403.8	
10/16/2004	184.9		11/18/2004	252.9		12/21/2004	372.6	
10/17/2004	173.3		11/19/2004	431		12/22/2004	371.3	
10/18/2004	173.1		11/20/2004	384		12/23/2004	369.7	
10/19/2004	181.7		11/21/2004	359.8		12/24/2004	378.5	
10/20/2004	180.8		11/22/2004	349.1		12/25/2004	357.3	
10/21/2004	184.4		11/23/2004	335.8		12/26/2004	346.4	
10/22/2004	183.3		11/24/2004	313.5		12/27/2004	346.5	
10/23/2004	463		11/25/2004	292.4		12/28/2004	351	
10/24/2004	281.2		11/26/2004	281.1		12/29/2004	353	
10/25/2004	254.5		11/27/2004	419		12/30/2004	356.6	
10/26/2004	260		11/28/2004	396.8		12/31/2004	381	
10/27/2004	264.7		11/29/2004	437.4				
10/28/2004	247.2		11/30/2004	431.7				
10/29/2004	257.1		12/1/2004	442				
10/30/2004	347		12/2/2004	413.8				
10/31/2004	261.6		12/3/2004	381.6				
11/1/2004	461		12/4/2004	343.8				
11/2/2004	497		12/5/2004	333.9				
11/3/2004	340.6		12/6/2004	529				
11/4/2004	449		12/7/2004	1030				
11/5/2004	344.9		12/8/2004	656				
11/6/2004	334.3		12/9/2004	646.7				
11/7/2004	325.5		12/10/2004	814				
11/8/2004	312.6		12/11/2004	833				
11/9/2004	301.6		12/12/2004	768				
11/10/2004	284.4		12/13/2004	712				
11/11/2004	296		12/14/2004	593.5				
11/12/2004	261.9		12/15/2004	430.1				
11/13/2004	254.4		12/16/2004	514.8				

Table G-5. Rivers flows and TP measurements for OH-03 (Center Harbor – Directly East of River Mouth) from 1/1/2004 to 4/2/2004.

Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)
1/1/2004	239.6		2/1/2004	128		3/3/2004	1439	
1/2/2004	244		2/2/2004	127.9		3/4/2004	2000	
1/3/2004	236.4		2/3/2004	127.9		3/5/2004	4448	
1/4/2004	215.6		2/4/2004	127.9		3/6/2004	3802	
1/5/2004	211		2/5/2004	127.8		3/7/2004	3304	
1/6/2004	208		2/6/2004	127.8		3/8/2004	2858	
1/7/2004	194.8		2/7/2004	127.8		3/9/2004	2401	
1/8/2004	195		2/8/2004	127.8		3/10/2004	2047	
1/9/2004	194.4		2/9/2004	127.8		3/11/2004	1762	
1/10/2004	184.6		2/10/2004	127.7		3/12/2004	1452.1	
1/11/2004	185.7		2/11/2004	126.7		3/13/2004	1154.3	
1/12/2004	197.5		2/12/2004	126.6		3/14/2004	1102	
1/13/2004	206.5		2/13/2004	126.6		3/15/2004	966.1	
1/14/2004	196		2/14/2004	126.6		3/16/2004	848.5	
1/15/2004	184.5		2/15/2004	126.6		3/17/2004	795	
1/16/2004	184.8		2/16/2004	126.8		3/18/2004	774	
1/17/2004	175		2/17/2004	128.2		3/19/2004	723	
1/18/2004	153		2/18/2004	142		3/20/2004	720.1	0.049
1/19/2004	142.6		2/19/2004	149		3/21/2004	771.3	
1/20/2004	150.8		2/20/2004	210		3/22/2004	764.1	
1/21/2004	150		2/21/2004	212		3/23/2004	729.1	
1/22/2004	149		2/22/2004	203		3/24/2004	719	
1/23/2004	149		2/23/2004	293		3/25/2004	710.2	
1/24/2004	139		2/24/2004	300		3/26/2004	1527	
1/25/2004	139		2/25/2004	298		3/27/2004	1133	
1/26/2004	129		2/26/2004	327		3/28/2004	1716	
1/27/2004	128.7		2/27/2004	365		3/29/2004	2150	
1/28/2004	127.7		2/28/2004	415		3/30/2004	1933	
1/29/2004	127.6		2/29/2004	621		3/31/2004	1650	
1/30/2004	127.4		3/1/2004	929		4/1/2004	1441	
1/31/2004	127.2		3/2/2004	1191		4/2/2004	1252	

Table G-6. Rivers flows and TP measurements for OH-03 (Center Harbor – Directly East of River Mouth) from 4/3/2004 to 7/7/2004.

Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)
4/3/2004	1088.3		5/5/2004	472.4		6/6/2004	2134.2	
4/4/2004	949.2		5/6/2004	460		6/7/2004	1737.3	
4/5/2004	833		5/7/2004	417.7		6/8/2004	1425.7	
4/6/2004	759		5/8/2004	581		6/9/2004	1389	0.069
4/7/2004	705.2		5/9/2004	1120		6/10/2004	1888	
4/8/2004	652.5		5/10/2004	2388		6/11/2004	3951	
4/9/2004	604.8		5/11/2004	2827		6/12/2004	5415	
4/10/2004	562.6		5/12/2004	2562		6/13/2004	5994	
4/11/2004	531.2		5/13/2004	4051		6/14/2004	6989	
4/12/2004	503		5/14/2004	5851	0.11	6/15/2004	6252	
4/13/2004	479.3		5/15/2004	4492		6/16/2004	5364	
4/14/2004	461.3		5/16/2004	3350		6/17/2004	4639	
4/15/2004	444.6	0.033	5/17/2004	2567		6/18/2004	3873	
4/16/2004	432		5/18/2004	2612		6/19/2004	3226	
4/17/2004	660		5/19/2004	2103		6/20/2004	2671	
4/18/2004	566		5/20/2004	2575		6/21/2004	2358	0.13
4/19/2004	635		5/21/2004	4452		6/22/2004	1805	
4/20/2004	1226		5/22/2004	8256	0.2	6/23/2004	1491	
4/21/2004	2064		5/23/2004	8519		6/24/2004	1513	
4/22/2004	1853		5/24/2004	8627	0.21	6/25/2004	1376	
4/23/2004	1580.9		5/25/2004	7423		6/26/2004	1257	
4/24/2004	1306		5/26/2004	5989		6/27/2004	1172	
4/25/2004	1392		5/27/2004	4939		6/28/2004	1180	
4/26/2004	1219	0.063	5/28/2004	4025		6/29/2004	1033.9	
4/27/2004	1068.5		5/29/2004	3289		6/30/2004	933	
4/28/2004	911.5		5/30/2004	3466		7/1/2004	836.7	
4/29/2004	802.1		5/31/2004	3899		7/2/2004	783.3	
4/30/2004	716.3		6/1/2004	3930		7/3/2004	1135	
5/1/2004	667		6/2/2004	3603		7/4/2004	2828	
5/2/2004	604.2		6/3/2004	3236		7/5/2004	1572	
5/3/2004	537.2		6/4/2004	2919		7/6/2004	1375	
5/4/2004	499.2		6/5/2004	2564.6		7/7/2004	1428	

Table G-7. River flows and TP measurements for OH-03 (Center Harbor – Directly East of River Mouth) from 7/8/2004 to 10/11/2004.

Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)
7/8/2004	1145		8/9/2004	379		9/10/2004	207.3	
7/9/2004	981		8/10/2004	326.9		9/11/2004	201.7	
7/10/2004	887.9		8/11/2004	322		9/12/2004	194.4	
7/11/2004	946		8/12/2004	326.6	0.038	9/13/2004	187.8	
7/12/2004	957		8/13/2004	344.3		9/14/2004	183.1	
7/13/2004	803		8/14/2004	363.8		9/15/2004	209	
7/14/2004	703		8/15/2004	360.4		9/16/2004	223	
7/15/2004	631.3		8/16/2004	343.7		9/17/2004	170	
7/16/2004	643		8/17/2004	389.6		9/18/2004	167.3	
7/17/2004	628.7		8/18/2004	394.5		9/19/2004	159.2	
7/18/2004	566.2		8/19/2004	420.3		9/20/2004	158.3	
7/19/2004	533.2		8/20/2004	426		9/21/2004	153.5	
7/20/2004	517.4	0.05	8/21/2004	411.6		9/22/2004	151.2	
7/21/2004	564		8/22/2004	390.4		9/23/2004	148.3	0.053
7/22/2004	495.9		8/23/2004	356.8		9/24/2004	140.4	
7/23/2004	456.1		8/24/2004	489		9/25/2004	136.4	
7/24/2004	416.8		8/25/2004	546		9/26/2004	134.5	
7/25/2004	413.4		8/26/2004	330.9		9/27/2004	134.4	
7/26/2004	359.2		8/27/2004	536		9/28/2004	136.3	
7/27/2004	345		8/28/2004	599		9/29/2004	132.2	
7/28/2004	328.5		8/29/2004	470		9/30/2004	132.4	
7/29/2004	307.9	0.18	8/30/2004	352	0.058	10/1/2004	159	
7/30/2004	298.2		8/31/2004	326.5		10/2/2004	223	
7/31/2004	287.4		9/1/2004	301.2		10/3/2004	152.9	
8/1/2004	320		9/2/2004	288.1		10/4/2004	156.8	
8/2/2004	355.6		9/3/2004	277.7		10/5/2004	148.8	
8/3/2004	977		9/4/2004	265.3		10/6/2004	144.6	
8/4/2004	744		9/5/2004	254.8		10/7/2004	146.7	
8/5/2004	427		9/6/2004	236.4		10/8/2004	170	
8/6/2004	405		9/7/2004	230.5		10/9/2004	163.4	
8/7/2004	367.6		9/8/2004	225.8		10/10/2004	189.7	
8/8/2004	341		9/9/2004	216		10/11/2004	184.7	

Table G-8. River flows and TP measurements for OH-03 (Center Harbor – Directly East of River Mouth) from 10/12/2004 to 12/31/2004.

Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)	Date	Flow (cfs)	OH-03 (TP mg/L)
10/12/2004	181	0.024	11/14/2004	243.7		12/17/2004	608.7	
10/13/2004	177		11/15/2004	237.2	0.039	12/18/2004	435.3	
10/14/2004	175.2		11/16/2004	237.5		12/19/2004	425	
10/15/2004	448		11/17/2004	241.7		12/20/2004	403.8	
10/16/2004	184.9		11/18/2004	252.9		12/21/2004	372.6	
10/17/2004	173.3		11/19/2004	431		12/22/2004	371.3	
10/18/2004	173.1		11/20/2004	384		12/23/2004	369.7	
10/19/2004	181.7		11/21/2004	359.8		12/24/2004	378.5	
10/20/2004	180.8		11/22/2004	349.1		12/25/2004	357.3	
10/21/2004	184.4		11/23/2004	335.8		12/26/2004	346.4	
10/22/2004	183.3		11/24/2004	313.5		12/27/2004	346.5	
10/23/2004	463		11/25/2004	292.4		12/28/2004	351	
10/24/2004	281.2	0.04	11/26/2004	281.1		12/29/2004	353	
10/25/2004	254.5		11/27/2004	419		12/30/2004	356.6	
10/26/2004	260		11/28/2004	396.8		12/31/2004	381	
10/27/2004	264.7		11/29/2004	437.4				
10/28/2004	247.2		11/30/2004	431.7				
10/29/2004	257.1		12/1/2004	442				
10/30/2004	347		12/2/2004	413.8				
10/31/2004	261.6		12/3/2004	381.6				
11/1/2004	461		12/4/2004	343.8				
11/2/2004	497		12/5/2004	333.9				
11/3/2004	340.6		12/6/2004	529				
11/4/2004	449		12/7/2004	1030				
11/5/2004	344.9		12/8/2004	656				
11/6/2004	334.3		12/9/2004	646.7				
11/7/2004	325.5		12/10/2004	814				
11/8/2004	312.6		12/11/2004	833				
11/9/2004	301.6		12/12/2004	768				
11/10/2004	284.4		12/13/2004	712				
11/11/2004	296		12/14/2004	593.5				
11/12/2004	261.9		12/15/2004	430.1				
11/13/2004	254.4		12/16/2004	514.8				

Table G-9. Stormwater runoff and TP measurements for SWMI06.

Date	Flow m^3/d	TP 1st Flush, mg/L	TP 2nd Flush, mg/L
4/17/2004	1295.60	2.2	2.7
5/21/2004	7109.46	0.66	0.64
6/10/2004	6038.50	1.1	0.97
7/21/2004	2164.71	3.4	1.9
8/24/2004	4573.29	0.76	0.72
10/23/2004	3510.91	1.2	0.92

Table G-10. Stormwater runoff and TP measurements for SWMI15.

Date	flow m^3/d	TP 1st Flush, mg/L
4/17/2004	107.90	4.0
5/21/2004	58.91	1.8
6/10/2004	516.56	1.0
7/21/2004	85.71	4.3
8/24/2004	331.35	0.8
10/23/2004	156.89	2.1