Final Report

Milwaukee Metropolitan Sewerage District (MMSD)

Stormwater Monitoring Program
2000 – 2004

Contract No. M03002P17

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Executive Summary

This report contains a statistical evaluation of stormwater flow and water quality data collected by MMSD during 2000 – 2004. Data for 2005 are included when available. The purpose of the evaluation is to characterize stormwater pollutant concentrations and loadings per sewershed, identify significant trends, and provide guidelines for best management practices (BMPs). A total of 33 constituents were considered including data for alkalinity, hardness, total solids, turbidity, E-coli, fecal coliforms (FC), nutrients, metals, and elements such as arsenic, antimony, and thallium. Regulatory guidelines i.e, NPDES, WPDES, NWQC are used as well as a comparison of stormwater data to historical combined sewer overflow data as benchmarks to determine the potential environmental impacts of stormwater. A total of 18 stations were included out of which 3 (SWMI05, SWMI08, and SWSF14) were inactive during significant time periods. The total area covered by these 18 stations is 4.26 square miles.

Stations of largest interest in relation to pollutant runoff volume are SWMI04 (S. Lake Drive, Bay view Park, Milwaukee), SWMI06 (Milwaukee Count Zoo), SWMI07 (47^{th} St, Milwaukee), and SWMI08 (Hampton and Lincoln Parkway, Milwaukee), each carrying between 17 and 25% of the total runoff volume. Pollutant concentrations relative to NPDES, EPA, and WDNR guidelines, are of greatest interest at stations SWMI07, SWMI08, SWMI12 (S. 72 St, Milwaukee), and SWMI15 (42 St & Mt Vernon, flood control area, I-94), SWMI16 (Marquette Interchange), SWMI17 (71^{st} and Chestnut St, Wauwatosa), and SWMI18 (Miller Park east parking lot). The stations' drainage areas represent various land uses. SWMI07, 08, and 12 are mainly residential, SWMI15 is both residential and highways, and stations SWMI16 and 18, are mainly highways. Station SWWA17 collects runoff from residential, commercial, and industrial areas.

Water quality parameters showing significantly higher concentrations than guideline levels were: fecal coliforms (> 400/100 mL, WPDES, WDNR, 2003, recreational), hardness (> 120 mg/L, EPA gold book, US EPA, 1986), TKN (> 1.5 mg/L, NPDES, US EPA, 2000), TSP (> 0.05 mg/L, EPA gold book, US EPA, 1986), TSS (> 30 mg/L, WPDES, WDNR, 2003), and Zn (> 0.117 mg/L, NPDES, US EPA, 2000). Hardness is exchangeable cations in the soil. Fecal coliforms are found in animal excrement and bird droppings. TKN and TSP are mainly derived from excess fertilizer applied to lawns and crops. Zinc is known to originate from automobile tires.

The length of the antecedent dry period t_d is a significant parameter determining pollutant concentrations and loadings due to the gradual accumulation of pollutants during the dry period prior to a storm. Zinc, copper, BOD, and TSP have significant correlations with t_d. Other important correlations are between copper and zinc ($r = 0.819$). Copper is known to be derived significantly from vehicle brake linings. Other correlations of interest are between TKN and BOD ($r = 0.510$), TSP and BOD ($r = 0.507$), and TSP and TKN ($r = 0.483$). High correlations between t_d and first-flush concentrations of FC and nutrients are found in residential areas

(SWMI07, 08), whereas high correlations between copper and zinc are associated with automobile traffic (SWMI15, 16, and 18).

Pollutants that have higher concentrations in stormwater than combined sewer overflow (CSO) include Ca, Mg, hardness (soil erosion), copper, zinc (automobile traffic), and TP and TSS (agricultural and urban runoff). For example, the average Zn concentration was 0.18 ± 0.02 mg/L ($n = 918$) in stormwater vs. 0.11 ± 0.0056 mg/L ($n = 176$) in CSO. It is interesting to note that FC is quite high in stormwater ($1.49 \pm 1.39 \cdot 10^5$) although it is lower, as one might expect, than in CSO ($9.34 \pm 5.43 \cdot 10^5$).

The average total loadings based on first and second flush concentrations and flow rates, along with effective length of the runoff period, were 1137 (hardness), 111 (Mg), 21.8 (TKN), 0.006 (Tl), 0.93 (TSP), 1785 (TSS), and 1.13 (Zn) lb/storm/station. The largest loads (lb/storm) are carried by SWMI04 (30% Zn, 21%TSS, 29% NH3, and 36% TSP), and stations SWMI07 (32% Zn, 40% TSS, 25%NH3, 20% TSP), and SWMI08 (16% Zn, 19% TSS, 15% NH3) where the percentages indicate contribution of each contaminant. Thus, for example, station SWMI04 has 30% of the total Zinc load for all 18 stations, 21% of the TSS load, etc.

With regards to time trends, these were determined by seasonal Kendall test based on all data. Hardness, magnesium, and calcium were found to decrease and an upward trend of 0.08 (0.05, 0.11, 90% C.L.) mg/L/yr was identified for TP. Copper and lead (0.0044 mg/L/yr) are increasing. The trend for zinc appears steady and TKN, Tl and TSS are decreasing.

Additional analysis will be carried out in the expanded stormwater contract that started late July 2005. This will include more detailed loading calculations that will determine loading vs. time on an hourly or shorter basis. Utilizing geographic information systems (GIS), and modeling tools such as XP-SWMM and SLAMM in conjunction with measured runoff will allow us to obtain a better estimate of % percolation and other parameters. The trends analysis will be expanded to look at individual stations and seasons in order to gain a better understanding of increases in pollutants that are station specific. This applies for example to zinc that is closely associated with traffic drainage areas and to phosphorus that is associated with residential areas and summer or fall season.

Once the modeling tools are implemented along with GIS, we plan to simulate a number of scenarios by changing drainage area, runoff pipes, and adding partial treatment of the initial parts of the runoff (first flush). The overall objective of the modeling is to improve the water quality while keeping costs under a specified maximum. This exercise will propose well-justified BMPs for the 18 stations with possible recommendations for scale-up to the total watershed.

1. INTRODUCTION

Since 2000, the Milwaukee Metropolitan Sewerage District (MMSD) has conducted a voluntary stormwater monitoring program that includes sampling and analysis of stormwater runoff. The samples were collected at between 15 and 18 storm sewer locations. The storm events were sampled generally from April to through October during the period 2000 through 2004. For each storm event sampled a "first flush" and "second flush" sample were collected. The samples are analyzed for 33 constituents, assuming sufficient volume. The data are then stored in *the MMSD Laboratory Information Manangement System (LIMS) SQL* database.

The scope of this work was to perform a statistical analysis of the stormwater data, to identify trends and seasonal variations, and to evaluate first flush vs. second flush sample concentrations. Pollutant loads (lb/storm/acre and lb/storm) will also be calculated when sufficient data are available. The data will be compared against in-stream water quality criteria (Appendix A), WPDES information (Appendix B), NPDES information (Appendix C), and EPA national water quality criteria (Appendix D). In addition, the data will be compared with the District's combined sewer overflow data when available, over the same time period. A sewershed analysis identifying significant sources and contaminants of concern will be included along with recommendation on how the DISTRICT stormwater monitoring program can be improved to better fill data gaps and serve the District's program needs.

1.1 BACKGROUND AND DEFINITION OF STORMWATER

Basic nature of runoff. Webster's Third New International Dictionary defines a storm as "…a violent disturbance of the atmosphere attended by wind, rain, snow, hail, sleet or thunder and lightning…".

Storm discharges are produced when the capacity of the land to retain precipitation is exceeded and runoff occurs. Runoff will be influenced by storm intensity and duration, antecedent storms, and a number of watershed and land use characteristics such as slope, soil type, and impervious area (Herricks, 1995).

One might assume that the primary natural receiving system for all runoff will be streams or river channels. In general, this is correct but the types of receiving systems that are affected by stormwater runoff can vary depending on the nature of the watershed, including buildings, landscape, detention ponds, and other features. Approximately 85% of the primary receiving waters, adjacent to urbanized areas, are rivers. Lakes will take about 5% of the total urban area receiving waters. Estuaries and oceans make up about 10% of the total urban area receiving waters.

Humanity's earliest cities were serviced by sewer systems. The first sewers were built to drain only runoff from stormwater and followed the same idea as in Roman times. In the 1840s and 1850s, following the era of industrialization, the cities of London and Paris allowed the discharge of human wastes into stormwater drains because of the increasing urban populations. This was the birth of the combined sewer or the wet-carriage waste disposal system. Existing storm sewers were converted to combined sewers, and new sewers were designed to be combined sewers. This idea was also followed in North America including in Milwaukee, Wisconsin. Subsequently, stormwater runoff flow rates and volumes were significantly increased during wet weather due to increased impervious land cover and the decreased availability of depression storage such as ponds. In 1994, the City of Milwaukee completed the deep tunnel system, which substantially reduced or eliminated combined and sanitary sewer overflows into the rivers and Lake Michigan. A study of water quality of the receiving waters after the deep tunnel indicated significant water quality improvement (Ab Razak and Christensen, 2001).

Sources of Pollutants. Stormwater discharges are varied and include visible matter, suspended solids, oxygen-demanding materials, nutrients, pathogenic microorganisms, toxicants such as heavy metals and pesticides, petroleum hydrocarbons, other hazardous contaminations, etc (U.S. EPA, "What's urban stormwater?", 2005).

Dry deposition involves the turbulent and gravitational transfer of pollutants from the air to the underlying surface, unaccompanied by atmospheric precipitation (Hicks, 1997). A study of the chemical composition of particulate matter and aerosols over Edmonton, Alberta concluded that industrial emissions and transportation are the major sources of dry deposition from the atmosphere (Klemm and Grey, 1982). A study of U.S. data indicated that the amounts and sources of toxic air pollutants can vary geographically from city to city and from neighborhood to neighborhood and are strongly influenced by types of local sources such as motor vehicles, wood stoves, combustion of oil and gas, metallurgical industries, chemical production and manufacturing, gasoline marketing, solvent use, and waste oil disposal (Hilborn and Sill, 1990).

Wet deposition is a result of cloud processes that scavenge pollutants from the air at cloud altitudes and deposit them in falling rain, snow, etc. (Hicks, 1997). Studies of pollutant mass loading in precipitation and runoff have concluded that most atmospheric contaminants are washed out during the early stages of rainfall events (Randall et al., 1982). Moreover, the washout of atmospheric pollutants by rainfall droplets is very effective and may contribute to a first-flush effect, indicating that pollutant concentrations in the earlier part of a precipitation event are higher than in the later rainfall (Novotny et al., 1985).

Street refuse accumulation is characterized by locally generated particles of various sizes on street surfaces. The general litter deposits (greater than 3-mm or 1/8-in.) in urban areas include debris, solid wastes, dead animals, animal excreta, etc. The dust and dirt (less than 3-mm or 1/8-in.) include pavement deterioration particles, soil particles, and small organisms. The rate of vegetation input, such as fallen leaves, seeds, and grass clippings increases substantially during the fall season, depending on density of vegetation. A study conducted in Etobicoke, Metropolitan Toronto, showed a significant amount of organic load from autumn leaves in an urban area (James and Boregowda, 1986). The presence of phosphorus in the runoff is commonly attributed to its leaching from vegetation in addition to plant fertilizers. The potential phosphorus content of tree leaves and seeds is found to range from 1.6 to 11 mg/g (Waller and Hart, 1986).

Vehicular traffic constitutes a major source of pollutants in urban area. It contributes to solids (including fine particles) and many chemicals such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and deicing salts (Thomson et al., 1997). Additionally, pavement conditions also have an effect on pollutant loads. Sartor et al. (1974) reported that streets paved with asphalt could have a higher pollutant loading than streets paved with concrete. A study on the characterization of highway runoff in the Netherlands has indicated that the concentration of pollutants in runoff from impervious asphalt is significantly higher than in runoff from pervious asphalt (Berbee et al., 1999).

In snow areas, deicing salts and sand are applied to road surfaces and sidewalks to provide safe driving and walking conditions during winter season. This situation creates increases of chloride content of the runoff.

Pollutant buildup such as deposition, wind erosion, and street cleaning is usually related to land uses of an urban area and to the dry periods between the rainfall events. The quantity of pollutants washed off the impervious area depends on two factors: the amount of pollutant that has accumulated during the dry period preceding a rainfall event and the characteristics of the rainfall, especially rainfall volume and intensity (Huber, 1986). The pollutant buildup on pervious areas is not considered to be significant but the erosion and dissolution mechanisms caused by runoff are considered to contribute significantly to the pollutant wash-off (Adams and Papa, 2000). The first-flush concentration is more influenced by antecedent dry period than amount of rainfall (Lee et. al., 2004). Soluble stormwater constituents (e.g. chloride, Fecal Coliform, and E-coli) show the least tendency toward a first-flush effect (1st Interim report, Soonthornnonda and Christensen, 2004).

Runoff Quality Data Analysis. Early in data analysis of urban runoff pollutants, the Great Lakes Water Quality Board identified “areas of concern” (AOCs) in the Great Lakes Basin. Most AOCs are in the proximity of large urban centers (Adams and Papa, 2000). Studies related to urban runoff have been conducted for most AOCs over the past two decades. The Ontario Ministry of the Environment conducted studies to characterize and quantify contaminants discharged from urban runoff to the metropolitan Toronto, Canada, waterfront. These studies had 16 representative catchments, which were based on drainage area, land use, type of sewershed (e.g. combined sewers carry both sanitary sewage and stormwater runoff or separated sewers carry only sanitary sewage), and complexity of the sewer system. Correlation analyses were conducted between event mean concentration (EMCs) and rainfall characteristics for Toronto.

EMC frequency analysis including Kolmogorov-Smirnov (K-S) test of all hypothesized distributions and probability density function (PDF) has also been widely used in many studies, e.g. Benjamin and Cornell (1970); U.S. EPA (1983); Driscoll (1986), Hall et al. (1990); Van Buren et al. (1997). Ab Razak and Christensen (2001) used spatial and temporal correlations to estimate confidence limits on concentrations of river contaminants. They also used t-test and Mann-Kendall test on the water quality data to evaluate trends in the pollution mitigating effects of the deep tunnel in Milwaukee from before and after the tunnel came on line.

GIS Applications for Stormwater Systems. The city of Huntington, WV, has a combined sewer system with 23 combined sewer overflow (CSO) discharge points permit under the NPDES program. One of the CSO requirements specified in the NPDES permit was to monitor each CSO event for frequency, duration, quantity, and quality of flow. ArcView, GIS was used to select a representative subset of the 23 CSO sites to be monitored. ArcView plot (Shamsi, 2005) indicated that by monitoring only 25% of the total number of CSO sites, approximately 70% of the study area was covered. This approach can be applied to the selection of storm monitoring sites for the current study. The location of the largest runoff discharge for each catchment can be found.

2. THE ROLE OF STORMWATER QUALIY AND QUANTITY IN CLEAN WATER POLICY

2.1 OVERVIEW OF STORMWATER MANAGEMENT STRATEGIES

Stormwater management planning encompasses a wide range of site-specific issues. The local issues that affect stormwater management decisions include understanding local problems and the sources of pollutants or flows that affect these problems. Local monitoring therefore plays an important role in identifying local problems and sources.

2.2 STANDARDS AND CRITERIA

Numerous state and local agencies have established regulatory programs for moderate and large-sized communities due to the EPA's NPDES (National Pollutant Discharge Elimination System) (US EPA, 2000) stormwater permit program. WPDES (Wisconsin Pollutant Discharge Elimination System) (WDNR, 2003) stormwater permit program has been established for state of Wisconsin. Stormwater permits for Wisconsin are in-place at the municipal level of government. MMSD being a state chartered, regional agency does not have a stormwater permit, but is interested in the water quality effects of stormwater. Thus, MMSD's stormwater program is not regulatory but strictly research oriented. Stormwater sampling results included in this report will be evaluated against the following standards and criteria:

1) WPDES (Wisconsin Pollutant Discharge Elimination System) (WDNR, 2003)
2) NPDES (National Pollutant Discharge Elimination System) (US EPA, 2000)
3) WDNR (Wisconsin Department of Natural Resources) in-stream water quality standards or criteria (based on Chapters NR102 & NR105) (WDNR, 1997 and 1998)
4) EPA national water quality criteria (EPA gold book and EPA red book) (US EPA, 1976 and 1986)
5) Guidance for regulatory stormwater programs with permits (Chapter NR216) (WDNR, 2002)

3. STORMWATER IN MILWAUKEE, WISCONSIN

Since 2000, the Milwaukee Metropolitan Sewerage District (MMSD) has conducted a voluntary stormwater monitoring program that includes sampling and analysis of stormwater runoff. The samples were collected from 2000-2004 at 18 of the storm sampling locations (Figs. 1, 2, 3, and 4) annually. For each storm event, samples of a “first flush” and “second flush” (2 hours later) were collected. The samples were analyzed for 33 constituents assuming sufficient volume. The stormwater drainage area descriptions of all 18 stations are shown in Table 1 and 2. Table 3 shows the predominant land use in each stormwater sampling location.

Figure 1 Overall stormwater monitoring drainage area

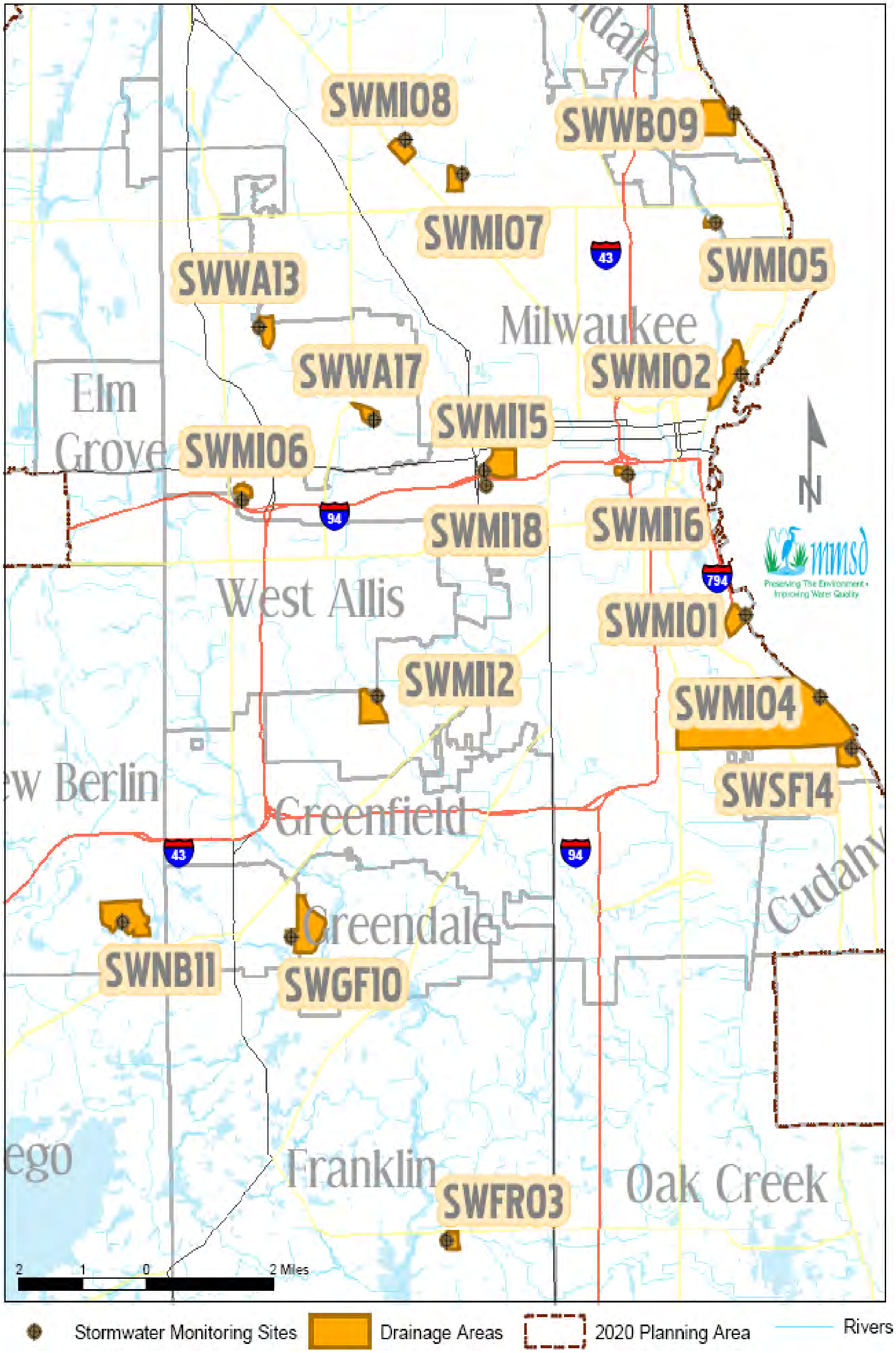


Figure 2 Northern stormwater monitoring drainage area

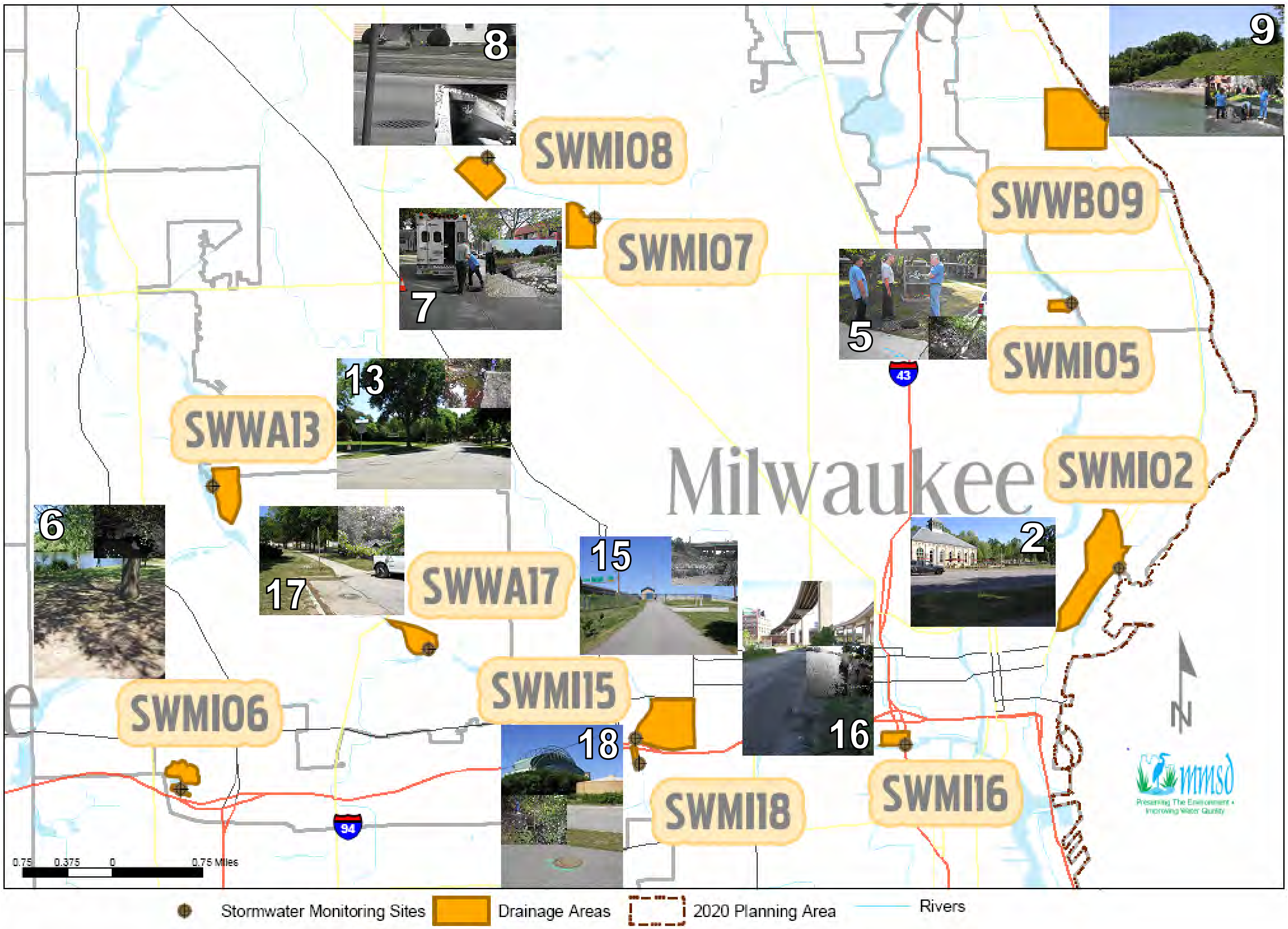


Figure 3 Central Stormwater monitoring drainage area

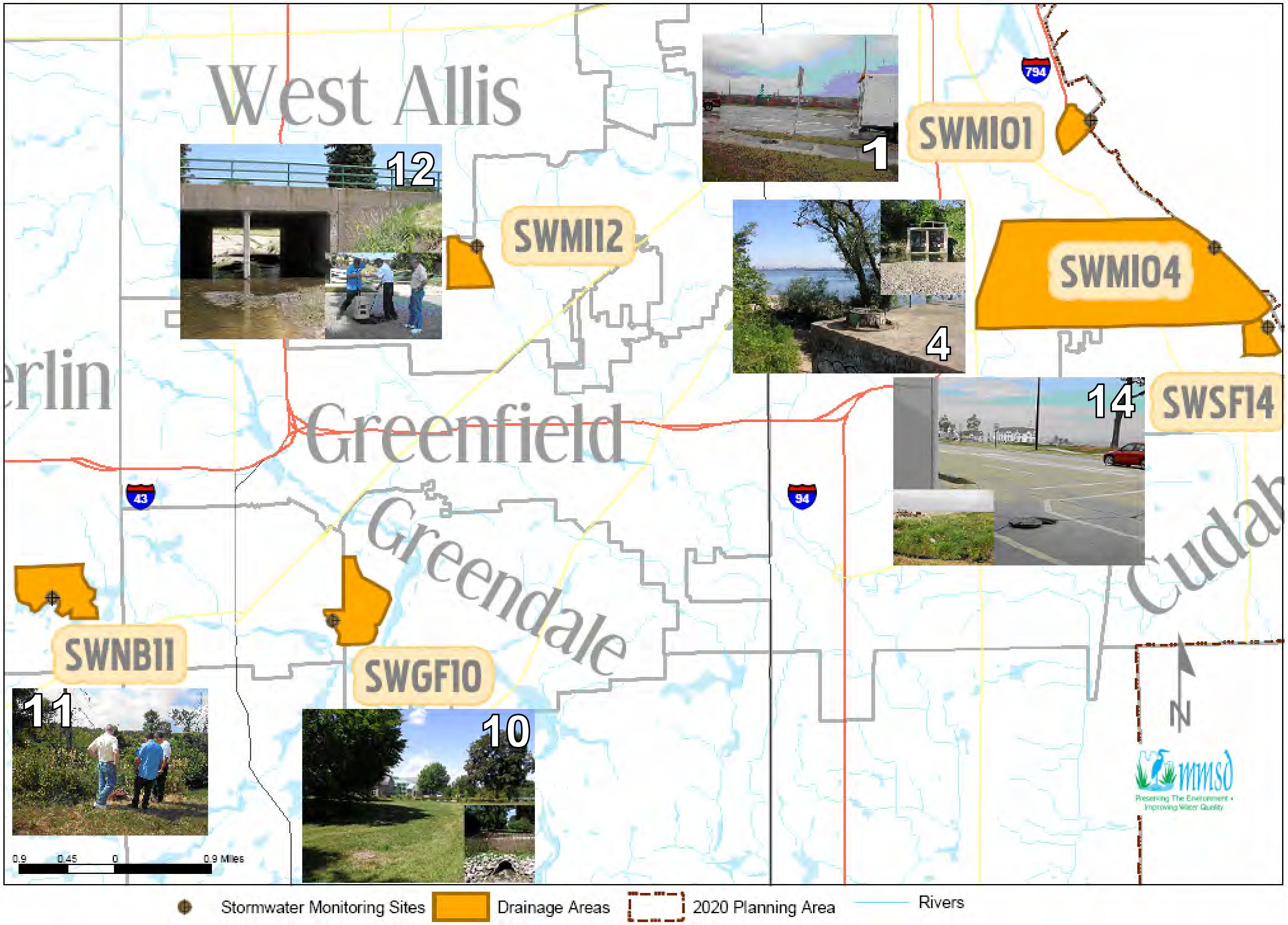


Figure 4 Southern stormwater monitoring drainage area

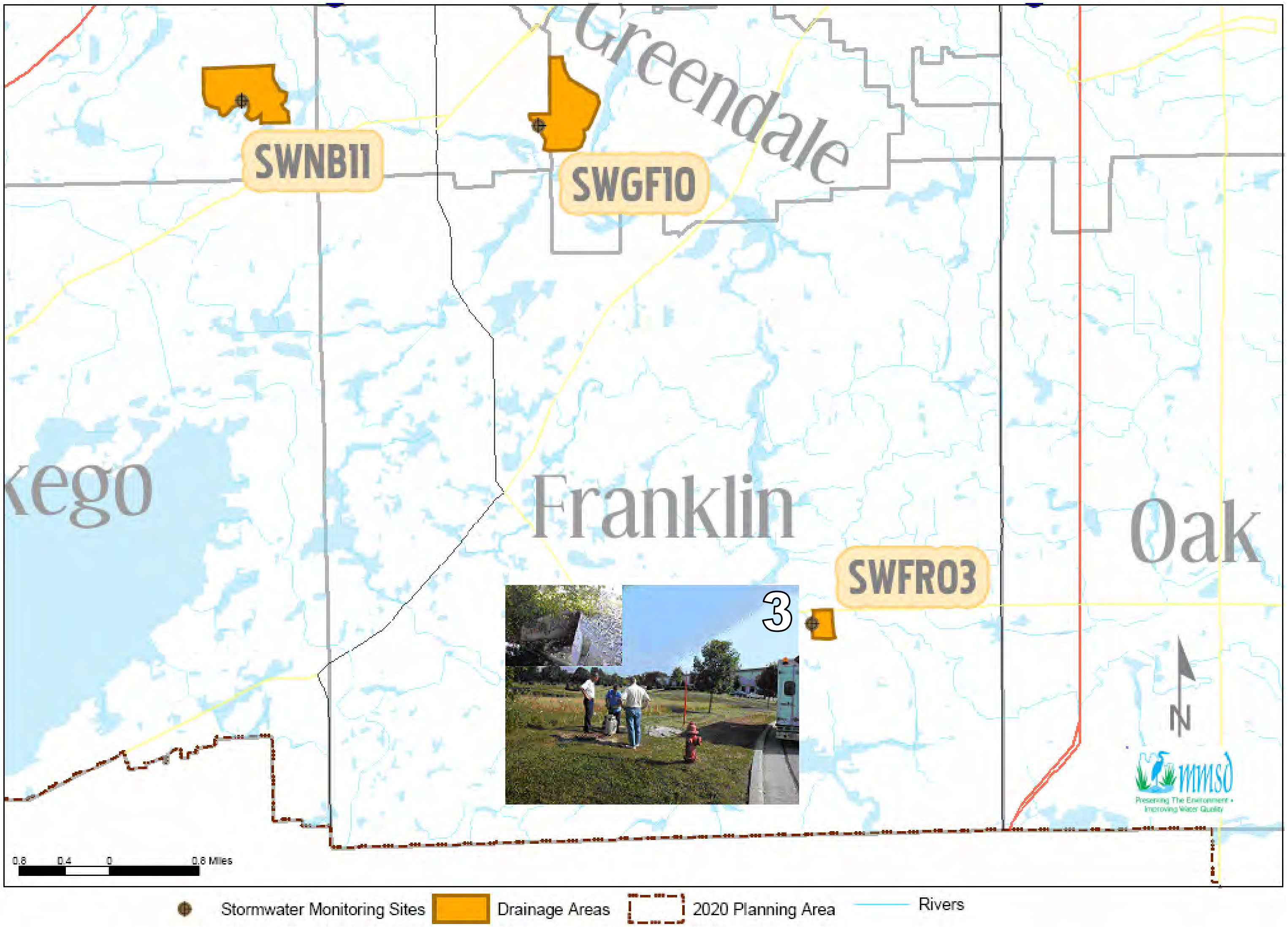


Table 1 Stormwater monitoring sites (2000-2004)

2004 MMSD STORMWATER MONITORING SITES*

MAP ID	SITE ID	LOCATION	COMMUNITY	RAIN GAUGE	Receiving Water
01	SWMI01	LINCOLN MEMORIAL DR. AND CARFERRY DR. (Stormwater discharge to Lake Michigan)	Milwaukee	WS1203	Lake Michigan
02	SWMI02	1700 N. LINCOLN MEMORIAL DR. @ LAFAYETTE HILL RD. (Stormwater to Lake @ McKinley Marina)	Milwaukee	WS1212	Lake Michigan
03	SWFR03	54TH AND ASHLAND (Stormwater to Franklin Park to detention pond)	Franklin	WS1213	Detention Pond
04	SWMI04	3500 S. LAKE DR. @ BAY VIEW PARK (Stormwater to Lake across from St. Francis Seminary)	Milwaukee	WS1203	Lake Michigan
05	SWMI05	1200 E. SINGER CIR. (Stormwater to Milw. River @ Kern Park) **INACTIVE IN 2003**	Milwaukee	WS1212	Milwaukee River
06	SWMI06	MILW CNTY. ZOO (Stormwater to Underwood Creek across from Moose Encl.)	Milwaukee	WS1219	Underwood Creek
07	SWMI07	4345 N. 47TH ST. (Stormwater to Lincoln Creek)	Milwaukee	WS1206	Lincoln Creek
08	SWMI08	HAMPTON AND LINCOLN CR. PARKWAY (Stormwater to Lincoln Creek under bridge) **INACTIVE SINCE 2002**	Milwaukee	WS1207	Lincoln Creek
09	SWWB09	4939 N. NEWHALL (Stormwater to Lake @ Big Bay Park)	Whitefish Bay	WS1202	Lake Michigan
10	SWGF10	BOERNER BOTANICAL GARDENS FORMERLY 10007 W. MEADOW DR. (Stormwater to Root River)	Greenfield	WS1220	Detention Pond
11	SWNB11	13380 EAGLE TRACE AND TIMBER RIDGE (Stormwater to wetland residential site)	New Berlin	WS1220	Detention Pond
12	SWMI12	3275 S. 72ND ST. (Stormwater to Honey Creek)	Milwaukee	WS1216	Honey Creek
13	SWWA13	RIDGE BLVD. AND HARDING BLVD. (Stormwater to Menomonee River Parkway)	Wauwatosa	WS1210	Menomonee River
14	SWSF14	LAKE DR. AND TESCH AVE. (Stormwater to Lake Michigan) **INACTIVE IN 2003**	St. Francis	WS1203	Lake Michigan
15	SWMI15	42ND AND MT. VERNON (I-94 x-way Stormwater to Menomonee River)	Milwaukee	WS1204	Menomonee River
16	SWMI16	MARQUETTE INTERCHANGE	Milwaukee	WS1221	Menomonee River
17	SWWA17	71ST AND CHESTNUT ST. (Stormwater to Menomonee River)	Wauwatosa	WS1204	Menomonee River
18	SWMI18	MILLER PARK EAST PARKING LOT AT THE SAUSAGE HOUSE (Stormwater to Menomonee River)	Milwaukee	WS1204	Menomonee River

***The Stormwater Monitoring Program started in 2000. A maximum of fifteen sites are sampled annually.**

***Station 5, 8, and 14 were inactive**

Table 2 Stormwater monitoring drainage area description

Stormwater Monitoring Sites	Location	Drainage Area (Acres)
SWMI01	Lincoln Memorial Dr & Carferry Dr, Milwaukee	58.8
SWMI02	1700 N. Lincoln Memorial Dr @ Lafayette Hill, Milwaukee	141
SWFR03	54th & Ashland, Franklin	28.9
SWMI04	3500 S. Lake Dr @ Bayview Park, Milwaukee	1502
SWMI05*	1200 E. Singer Circle, Milwaukee	8.45
SWMI06	Milwaukee County Zoo, Milwaukee	26.3
SWMI07	4345 N. 47th St, Milwaukee	45.4
SWMI08*	Hampton & Lincoln Crk Pkwy, Milwaukee	52.3
SWWB09	4939 N. Newhall, Whitefish Bay	142
SWGF10	Boerner Botanical Gardens, Hales Corners (10007 W. Meadow Dr), Greenfield	176
SWNB11	13380 Eagle Trace & Timber Ridge, New Berlin	182
SWMI12	3275 S. 72nd St, Milwaukee	95.9
SWWA13	Ridge Blvd & Harding, Wauwatosa	50.6
SWSF14*	Lake Dr and Tesch Av, St Francis	53.1
SWMI15	42nd St & Mt Vernon (I-94 & Menominee River), Milwaukee	109
SWMI16	Marquette interchange, Milwaukee	15.8
SWWA17	71st and Chestnut St, Wauwatosa	33.0
SWMI18	Miller park east parking lot at sausage house, Milwaukee	4.74
	Total	2,727

* currently inactive station

Table 3 Predominant types of land use in each stormwater sampling location

Site ID	Location	Comments	Residential	Commercial	Industrial	Traffic, highways, Parking lots	Government and Institutional	Recreational
SWMI01	Lincoln Memorial Dr & Carferry Dr, Milwaukee	Residential + Highway	X			X	X	
SWMI02	1700 N. Lincoln Memorial Dr @ Lafayette Hill, Milwaukee	Residential + Parking lot	X			X		X
SWFR03	54th & Ashland, Franklin	Industrial Park			X			
SWMI04	3500 S. Lake Dr @ Bayview Park, Milwaukee	Recreation + Residential area	X					X
SWMI05	1200 E. Singer Circle, Milwaukee	Residential + commercial (Inactive)	X					X
SWMI06	Milwaukee County Zoo, Milwaukee	Zoo						X
SWMI07	4345 N. 47th St, Milwaukee	Residential (Large area)	X					X
SWMI08	Hampton & Lincoln Crk Pkwy, Milwaukee	Residential (Inactive)	X					
SWWB09	4939 N. Newhall, Whitefish Bay	Residential	X					
SWGF10	Boerner Botanical Gardens, Hales Corners (10007 W. Meadow Dr), Greenfield	Garden + parking lot + buildings				X		X
SWNB11	13380 Eagle Trace & Timber Ridge, New Berlin	New residential	X					
SWMI12	3275 S. 72nd St, Milwaukee	Residential	X					
SWWA13	Ridge Blvd & Harding, Wauwatosa	Residential (Large area)	X					X
SWSF14	Lake Dr and Tesch Av, St Francis	Residential (Inactive)	X					
SWMI15	42nd St & Mt Vernon (I-94 & Menominee River), Milwaukee	Highway + Flood control area	X			X		
SWMI16	Marquette interchange, Milwaukee	Highway				X		
SWWA17	71st and Chestnut St, Wauwatosa	Residential+commercial+industrial	X	X	X			
SWMI18	Miller park east parking lot at sausage house, Milwaukee	Miller Park parking lot				X		

4. COMBINED SEWER OVERFLOW IN MILWAUKEE, WISCONSIN

The CSO (combined sewer overflow) samples were collected at 20 locations (Table 4) when overflow events occurred during the period 2000 through 2004.

Table 4 Combined sewer overflow sampling locations

Site Code	Description	Receiving water
IssCT02	Hawley Road	Menomonee River
IssCT07	N. 16th St. & W. Canal St.	Menomonee River
IssCT08	S. 3rd St. & W. Seeboth	Menomonee River
IssCT034	N. 44th St. & W. Well St.	Menomonee River
IssCT056	N. 25th & Menomonee River	Menomonee River
IssKK01	S. 6th St. & W. Cleveland Av.	Kinnickinnic River
IssKK02	S. 1st & Chase Av.	Kinnickinnic River
IssKK03	S. 4th St. & W. Becher St.	Kinnickinnic River
IssKK04	S. 1st St. & W. Lincoln Av.	Kinnickinnic River
IssLMN	LMN E. Bay St. & Ward St.	Lake Michigan
IssLMS	LMS Lincoln memorial Dr. & Russell Av.	Lake Michigan
IssNS04	N. Cambridge & E. Providence	Milwaukee River
IssNS05	E. Burleigh & Milwaukee River	Milwaukee River
IssNS06	Park Place & Milwaukee River	Milwaukee River
IssNS07	Commerce & Booth	Milwaukee River
IssNS08	Commerce & Walnut	Milwaukee River
IssNS09	N. 3rd & Park Freeway East	Milwaukee River
IssNS010	N. Water & St. Paul	Milwaukee River
IssNS011	N. Humboldt & Capitol	Milwaukee River
IssNS012	N. 31st & Capitol	Milwaukee River

There are 19 water quality constituents to be evaluated in CSO data as follows:

1) Ammonia Nitrogen (NH_3)
2) Arsenic (As)
3) 5-day biochemical oxygen demand (BOD-5)
4) Cadmium (Cd),
5) Calcium (Ca)
6) Chromium (Cr)
7) Copper (Cu)
8) E-coli QT
9) Fecal coliform (FC)
10) Hardness (Hard)
11) Lead (Pb)
12) Magnesium (Mg)
13) Mercury (Hg)
14) Nickel (Ni)
15) Selenium (Se)
16) Silver (Ag)
17) Total Phosphorus (TP)
18) Total suspended solids (TSS)
19) Zinc (Zn)

5. WATER QUALITY CONSTITUENTS AND LIMITS

There are 33 water quality constituents (MMSD, 2003; WDNR, NR216, 2002) to be evaluated in stormwater data. Table 5 shows the list of constituents with their limits and criteria. It should be noted that these limits are used as guidelines and not required limits.

Table 5 List of stormwater monitoring constituents and their data evaluation limits

	Constituent	Limit	Unit of Measure	Limit Reference and Source
1	Silver (Ag)	0.0318	mg/L	NPDES (US EPA, 2000)
2	Alkalinity (Alk)	400	mg/L	National Water Quality Criteria (US EPA, 2004)
3	Arsenic (As)	0.16854	mg/L	NPDES (US EPA, 2000)
4	Beryllium (Be)	0.13	mg/L	NPDES (US EPA, 2000)
5	5-day biochemical oxygen demand (BOD-5)	30	mg/L	WPDES (WDNR, 2003)
6	Calcium (Ca)	- NA -	mg/L	- NA -
7	Cadmium (Cd)	0.0159	mg/L	NPDES (US EPA, 2000)
8	Chloride (Cl)	860	mg/L	NPDES (US EPA, 2000)
9	Chromium (Cr)	0.016	mg/L	National Water Quality Criteria (US EPA, 2004)
10	Copper (Cu)	0.0636	mg/L	NPDES (US EPA, 2000)
11	E-coli	- NA -	MPN/100 mL	- NA -
12	Fecal coliform (FC)	400	CFU/100 mL	WPDES (WDNR, 2003)
13	Hardness (Hard)	120	mg/L	EPA Gold Book (US EPA, 1986)
14	Mercury (Hg)	2.4	μg/L	NPDES (US EPA, 2000)
15	Magnesium (Mg)	- NA -	mg/L	- NA -
16	Ammonia Nitrogen (NH3)	19	mg/L	NPDES (US EPA, 2000)
17	Nickel (Ni)	1.417	mg/L	NPDES (US EPA, 2000)
18	Nitrite Nitrogen (NO2)	1	mg/L	EPA Gold Book (US EPA, 1986)
19	Nitrate Nitrogen (NO3)	10	mg/L	National Water Quality Criteria (US EPA, 2004)
20	Nitrate and Nitrite (NO5)	0.68	mg/L	NPDES (US EPA, 2000)
21	Lead (Pb)	0.0816	mg/L	NPDES (US EPA, 2000)
22	Antimony (Sb)	0.636	mg/L	NPDES (US EPA, 2000)
23	Selenium (Se)	0.2385	mg/L	NPDES (US EPA, 2000)
24	Total Dissolved solids (TDS)	- NA -	mg/L	- NA -
25	Total Kjeldahl nitrogen (TKN)	1.5	mg/L	NPDES (US EPA, 1999)
26	Thallium (Tl)	0.048	mg/L	EPA Gold Book (US EPA, 1986)
27	Total organic carbon (TOC)	50	mg/L	NPDES (US EPA, 1999)
28	Total Phosphorus (TP)	1	mg/L	WPDES (WDNR, 2003)
29	Total solids (TS)	- NA -	mg/L	- NA -

30	Total soluble phosphorus (TSP)	0.05	mg/L	EPA Gold Book (US EPA, 1986)
31	Total suspended solids (TSS)	30	mg/L	WPDES (WDNR, 2003)
32	Turbidity	5	NTU	NPDES (US EPA, 1999)
33	Zinc (Zn)	0.117	mg/L	NPDES (US EPA, 2000)

- NA - : Limits not available

6. STORMWATER METHODOLOGY

6.1 SAMPLING METHODOLOGY

This methodology (MMSD, 2003) was adopted using recommendations found in WDNR (2002). The first flush sample (4-32 oz. bottles) is taken at a specified time triggered by level in the sewer and is combined into a single sample for analysis. The trigger point level is at 0.4 feet for sewers greater than or equal to 36 inches in diameter and 0.3 feet for sewers less than 36 inches in diameter and it may vary from site to site due to adjustments to triggered points based on baseline flow. The second flush (4-32 oz. bottles) is taken two hours later.

The following criteria (WDNR, 2002) are used for MMSD stormwater event:

1. The runoff event sampling is 72 hours after any previous measurable storm greater than 0.1 inch of rainfall.
2. The runoff event sampling has been at least 4 weeks since last storm event sampling.
3. The average precipitation accumulated over the MMSD service area is greater than or equal to 0.1 inch.
4. A minimum of eight first flush samples with at least 2 liters of sample volume are collected in one event.

Area velocity (AV) sensors, which measure level and velocity, have been used to derive flow data at all sampling sites.

6.2 STATISTICAL ANALYSIS

6.2.1 Descriptive statistics of stormwater and combined sewer overflow data

6.2.1.1 Stormwater Data

Stormwater data were analyzed statistically using SPSS software. Minimum, maximum, median, mean, standard deviation, standard error, variance and confidence interval have been provided for each constituent.

Data has been categorized by year and date for each constituent as compared to evaluation limits. Plotting can be done in Microsoft Excel but statistical box charting of this data has been completed using SigmaPlot software.

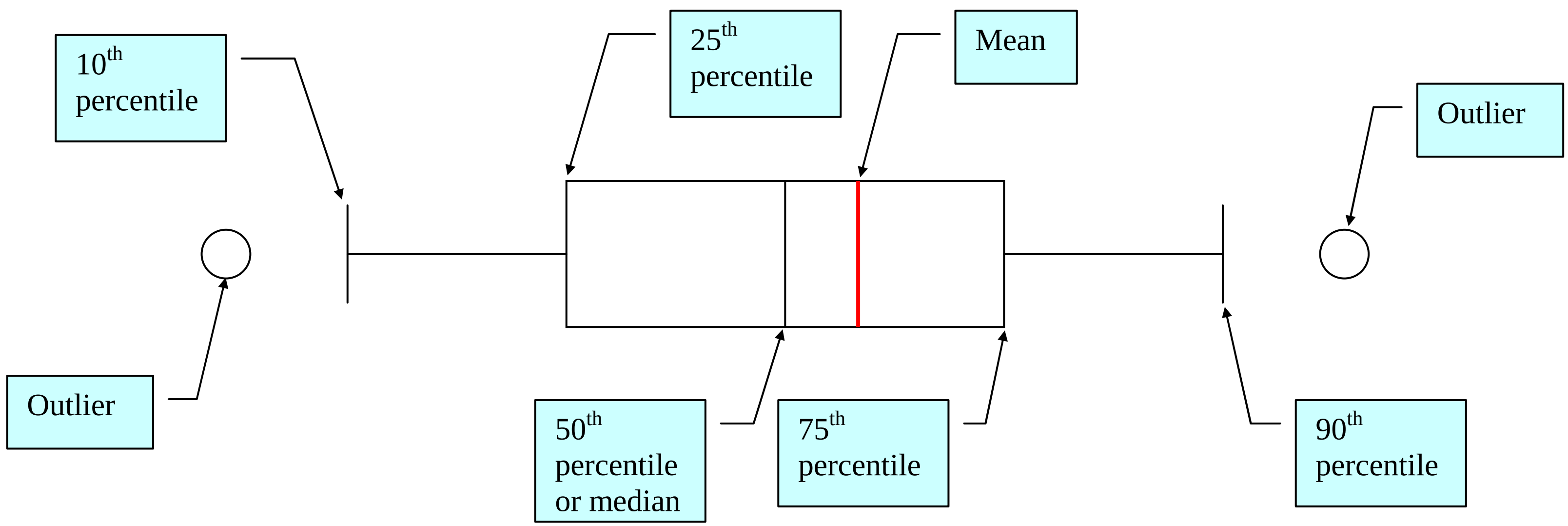
The box chart (Kottegoda and Rosso, 1997) is highly useful in data presentation. It displays the five percentiles (10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th}) and arithmetic mean as shown in Fig.5.

Runoff flows were categorized by date, and then averaged by sampling location using the PivotTable command in Microsoft Excel.

6.2.1.2 Combined sewer overflow (CSO) Data

CSO data were analyzed statistically using SPSS software. Minimum, maximum, median, mean, standard deviation, standard error, variance and confidence interval have been provided for each constituent. Statistical box charting of this data has been completed using SigmaPlot software.

Figure 5 Box chart illustration



6.2.2 Time trends using seasonal Kendall test

There are variables (e.g. temperature, precipitation, vegetative cover, or lack of cover, use of fertilizers, salting, etc.) or pollutants for which changes between seasons of the year are a major source of variation in many constituents. A seasonal trend analysis was used to remove these effects, in order to represent the true trends. The seasonal Kendall test will be used in this study.

The seasonal Kendall test (Gilbert, 1987) consists of calculating of the Mann-Kendall test statistic, *S* and its variance, VAR(*S*), separately for each season with data collected over years. These seasonal statistics are then combined, and the Z statistic is computed. The Z value may be referred to the standard normal distribution to test for a statistically significant trend.

Let x_{il} be the datum for the *i*th season for *l*th year, x_{ik} be the datum for the *i*th season for *k*th season, *K* the number of seasons, and L the number of years.

For each season the data collected over years (5 years) are used to compute the Mann-Kendall statistic, *S*. Let S_i be this statistic computed for season i, then

$$S_i = \sum_{k-1}^{n_i-1} \sum_{l=k+1}^{n_i} \operatorname{sgn}(x_{il} - x_{ik}) \tag{15}$$

where $l>k$, n_i is the number of data (over years) for season *i*, and

$$\begin{aligned} \operatorname{sgn}(x_{il} - x_{ik}) &= 1 \quad \text{if } x_{il} - x_{ik} > 0 \\ \operatorname{sgn}(x_{il} - x_{ik}) &= 0 \quad \text{if } x_{il} - x_{ik} = 0 \\ \operatorname{sgn}(x_{il} - x_{ik}) &= -1 \quad \text{if } x_{il} - x_{ik} < 0 \end{aligned} \tag{16}$$

VAR(S_i) can be computed as:

$$\begin{aligned} \operatorname{VAR}(S_i) = \frac{1}{18}\left[n_i(n_i-1)(2n_i+5) - \sum_{p=1}^{g_i} t_{ip}(t_{ip}-1)(2t_{ip}+5) - \sum_{q=1}^{h_i} u_{iq}(u_{iq}-1)(2u_{iq}+5) \right] \\ + \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1)(t_{ip}-2) \sum_{q=1}^{h_i} u_{iq}(u_{iq}-1)(u_{iq}-2)}{9n_i(n_i-1)(n_i-2)} + \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1) \sum_{q=1}^{h_i} u_{iq}(u_{iq}-1)}{2n_i(n_i-1)} \end{aligned} \tag{17}$$

where g_i is the number of groups of tied data in season *i*, t_{ip} is the number of tied data in the *p*th group for season *i*, h_i is the number of sampling times in season *i* that contain multiple data, and u_{iq} is the number of multiple data in *q*th time period in season *i*.
After getting S_i and VAR(S_i),

$$S^{'} = \sum_{i=1}^{K} S_i \tag{18}$$

$$\mathrm{VAR}(S^{'}) = \sum_{i=1}^{K} \mathrm{VAR}(S_i) \tag{19}$$

Next,

$$\begin{aligned} Z &= \frac{(S^{'} - 1)}{\left[\mathrm{VAR}(S^{'})\right]^{1/2}} && \text{if } S^{'} > 0 \\ Z &= 0 && \text{if } S^{'} = 0 \\ Z &= \frac{(S^{'} + 1)}{\left[\mathrm{VAR}(S^{'})\right]^{1/2}} && \text{if } S^{'} < 0 \end{aligned} \tag{20}$$

To test the null hypothesis, H_o, of no trend versus the alternative hypothesis, H_A, of either an upward of downward trend;

Two tailed test: reject H_o, no trend if absolute value of Z is greater than $Z_{1-\alpha/2}$ (Standard normal distribution table).

One tailed test: reject H_o, no trend in favor of an upward trend if value of Z is greater than $Z_{1-\alpha}$ and reject H_o, no trend in favor of a downward trend if value of Z is negative and absolute value of Z is greater than $Z_{1-\alpha}$.

To compute seasonal kendall slope:

$$Q_i = \frac{x_{il} - x_{ik}}{l - k} \tag{21}$$

where x_{il} is the datum for ith season of lth year, and x_{ik} is the datum for the ith season of kth year, where $l>k$. Rank the $N_1^{'} + N_2^{'} + N_3^{'} + ... + N_k^{'} = N^{'}$ individual slope estimates and find their median. This median is the seasonal Kendall slope estimator.

To compute the upper limit and lower limit values of the seasonal Kendall slope:

1) choose the desired confidence level, α and find $Z_{1-\alpha}$
2) compute $C_\alpha = Z_{1-\alpha/2}[\mathrm{VAR}(S^{'}]^{1/2}$
3) compute $M_1 = (N^{'} - C_\alpha)/2$ and $M_2 = (N^{'} + C_\alpha)/2$
4) the lower and upper confidence limits are the M_1th largest and the (M_2+1)th largest of ranked $N^{'}$

Table 6 shows an example of all computations in seasonal Kendall test. The seasonal Kendall test is described in detail in Gilbert (1987).

Table 6 Illustration of seasonal Kendall test

	Season 1							Season 2						
Year	1	1	2	3				1	2	2	3			
Data	8	10	12	15				15	20	18	20			
		-	+4	+3.5	2	0			+5	+3	+2.5	3	0	
			+2	+2.5	2	0				-	0	0	0	
				+3	1	0					+2	1	0	
				S_1 =	5 +	0	= 5				S_2 =	4 +	0	= 4

Ranking of seasonal slope estimates: 0, 2, 2, 2.5, 2.5, 3, 3, 3.5, 4, 5
Median of seasonal slope estimates: 2.75

$n_1 = 4$ $n_2 = 4$ $g_1 = 0$ $g_2 = 1$, $t_{21} = 2$ $h_1 = 1$, $u_{11} = 2$ $h_2 = 1$, $u_{21} = 2$ $N_1^{'} = 5$ $N_2^{'} = 5$, $N^{'} = 10$

$\mathrm{VAR}(S_1) = 7.667$
$\mathrm{VAR}(S_2) = 6.834$
$[\mathrm{VAR}(S_1)]^{1/2} = 2.8$
$[\mathrm{VAR}(S_2)]^{1/2} = 2.6$
$S^{'} = S_1 + S_2 = 9$
$\mathrm{VAR}(S^{'}) = 14.5$
$[\mathrm{VAR}(S^{'})]^{1/2} = 3.808$
$Z = 2.1 > Z_{0.95} = 1.645$ (one-tailed: 0.05 level of significance) → Reject H_o (no trend) and accept an upward trend (increasing)

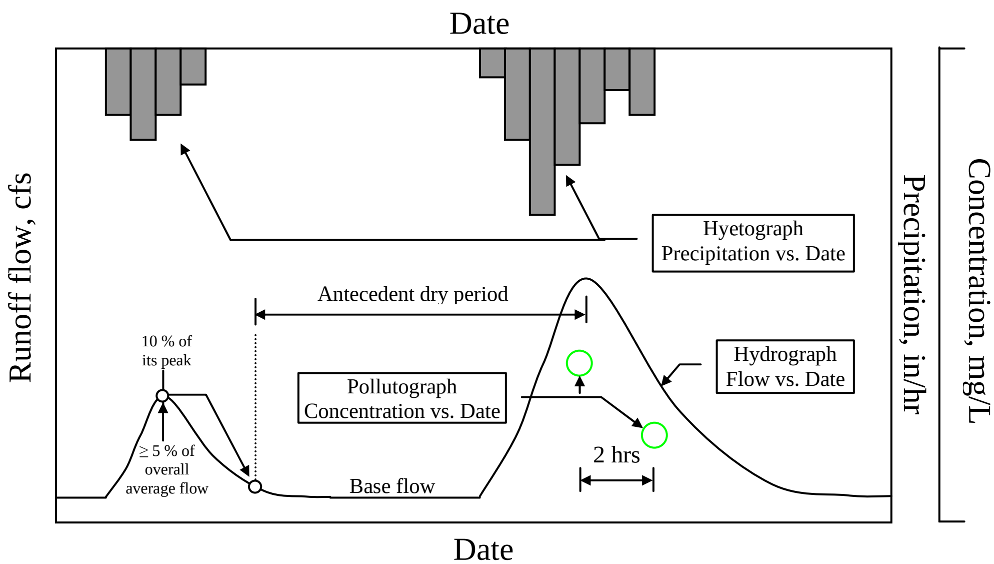
For 90 % confidence interval
$C_\alpha = 1.645\, [\mathrm{VAR}(S^{'})]^{1/2} = 6.264$
$M_1 =$ 1.868, lower confidence limit = 1.7
$M_2 + 1 = 9.132$, upper confidence limit = 4.1

Source: Gilbert, 1987 (Example 17.1, p. 228)

6.3 HYETOGRAPHS, HYDROGRAPHS AND POLLUTOGRAPHS

A hyetograph is a graph of the rainfall intensity as a function of time. The time sequence of stormwater runoff is called a hydrograph. The time sequence of pollutant concentration is called a pollutograph. Figure 6 shows the combination of hyetograph, hydrograph, and pollutograph in one chart.

Figure 6 Illustrations of hyetograph, hydrograph, and pollutograph



6.4 ANTECEDENT DRY PERIOD

The antecedent dry period (t_d) is the time of no rainfall before a rainfall event. It relates to pollutant build-up for stormwater analysis. In this report, the dry period (Fig. 6) starts from 10 percent of maximum value of runoff discharge peak and ends at the maximum value of next runoff discharge peak (maximum value of peak ≥ 5 percent of overall average runoff discharge for 2000-2004). Then, first-flush concentration and load versus t_d can be plotted. The correlation coefficient (R) can be obtained (Gilbert, 1987).

6.5 POLLUTANT LOAD CALCULATION

In the current stormwater monitoring program (2000-2004), the first and second flush for each water quality constituent are mainly considered. Thus, only two concentrations were measured for each storm event.

The mean of first flush and second flush load, W(t=1) and W(t=2) may be considered to be constant throughout each storm event, i. The load equations then become

$$W_i = \frac{Q_{1i}C_{1i} + Q_{2i}C_{2i}}{2},$$

$$Mass_i = \left(\frac{Q_{1i}C_{1i} + Q_{2i}C_{2i}}{2}\right)\Delta t_i,$$

$$\text{Total Mass} = \sum_{i=1}^{N_S}\left(\frac{Q_{1i}C_{1i} + Q_{2i}C_{2i}}{2}\right)\Delta t_i$$

where Q_{1i} is the first flush discharge, Q_{2i} is the second flush discharge, C_{1i} is the first-flush concentration, C_{2i} is the second flush concentration, Δt_i is the time of runoff or storm duration and N_S is the annual number of storm events.

Not all storm events are measured so that the annual number of monitored storm events N'_S, is less than the actual annual number of storm events N_S, which can lead to underestimation of total annual constituent load. In this report, the mass per area per storm event and the mass per storm event will be presented.

The storm duration Δt_i for each runoff event is measured from the starting point of the storm event of the runoff hydrograph through the 5 percent of maximum value of individual runoff discharge peak relative to the base flow of the hydrograph.

7. RESULTS

7.1 DESCRIPTIVE STATISTICAL RESULTS OF STORMWATER QUALITY

Various plots of stormwater data (2000-2005) in Appendix E show concentrations of 33 water quality constituents (first flush, second flush, snowmelt, and background snowmelt) along with their limits. Results indicate that soluble constituents had the least tendency toward first-flush effect, which was high initial concentration.

Box plots of concentrations of 33 water quality constituents in stormwater (2000-2005) by sampling locations are presented in Appendix E. Table 7 shows the summary of sampling sites that give the highest average concentration for each water quality constituent. The average concentration of antimony (Sb) was highest at SWMI01. The average concentration of alkalinity (Alk) was highest at SWMI02 (soil erosion). The average concentration of total dissolved solids (TDS) was highest at SWMI07. The highest average concentration of nitrate nitrogen (NO3) was found at SWMI08 (fertilizer). The highest average concentrations of nitrate/nitrite nitrogen (NO5) and thallium (Tl) were found at SWWB09. The highest average concentration of turbidity (Turb) was found at SWGF10. The highest average concentrations of total phosphorus (TP) and total suspended solids (TSS) were found at SWMI12 (fertilizer). The highest average concentrations of fecal coliform (FC) and total Kjeldahl nitrogen (TKN) were found at SWWA13 (animal feces and bird droppings). According to geometric mean calculation in Appendix G (CDs), FC was highest at SWWB09 (pet excrement and bird droppings) and E-coli (EC) was highest at SWWA17. The highest average concentrations of arsenic (As), beryllium (Be), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), hardness (Hard), magnesium (Mg), nickel (Ni), lead (Pb), and zinc (Zn) were found at SWMI15 (traffic). The highest average concentrations of silver (Ag), chloride (Cl), mercury (Hg), selenium (Se), and total solids (TS) were found at SWMI16 (deicing salt, freeway, and corroded metals). The highest average concentrations of 5-day biochemical oxygen demand (BOD-5), EC, nitrite nitrogen (NO2), total organic carbon (TOC), and total soluble phosphorus (TSP) were found at SWWA17 (fertilizer). The highest average concentration of ammonia nitrogen (NH3) was found SWMI18 (decomposing organic matter). See page 56 for further discussion of these results.

Table 7 Summary of sampling sites that give the highest average concentration for each constituent in stormwater

Constituent \ Site No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Ag																X		
Alk		X																
As															X			
Be															X			
BOD																	X	
Ca															X			
Cd															X			
Cl																X		
Cr															X			
Cu															X			
EC																	X	
FC									O				X					
Hardness															X			
Hg																X		
Mg															X			
NH3																		X
Ni															X			
NO2																	X	
NO3								X										
NO5									X									
Pb															X			
Sb	X																	
Se																X		
TDS							X											
TKN													X					
Tl									X									
TOC																	X	
TP												X						
TS																X		
TSP																	X	
TSS												X						
TURB										X								
Zn															X			

O: Highest value of geometric mean
X: Highest value of arithmetic mean

SWMI01	Lincoln Memorial Dr & Carferry Dr, Milwaukee
SWMI02	1700 N. Lincoln Memorial Dr @ Lafayette Hill, Milwaukee
SWFR03	54th & Ashland, Franklin
SWMI04	3500 S. Lake Dr @ Bayview Park, Milwaukee
SWMI05*	1200 E. Singer Circle, Milwaukee
SWMI06	Milwaukee County Zoo, Milwaukee
SWMI07	4345 N. 47th St, Milwaukee
SWMI08*	Hampton & Lincoln Crk Pkwy, Milwaukee
SWWB09	4939 N. Newhall, Whitefish Bay
SWGF10	Boerner Botanical Gardens, Hales Corners (10007 W. Meadow Dr), Greenfield
SWNB11	13380 Eagle Trace & Timber Ridge, New Berlin
SWMI12	3275 S. 72nd St, Milwaukee
SWWA13	Ridge Blvd & Harding, Wauwatosa
SWSF14*	Lake Dr and Tesch Av, St Francis
SWMI15	42nd St & Mt Vernon (I-94 & Menominee River), Milwaukee
SWMI16	Marquette interchange, Milwaukee
SWWA17	71st and Chestnut St, Wauwatosa
SWMI18	Miller park east parking lot at sausage house, Milwaukee

The runoff discharges (Table 8) were found high at SWMI06 (Milwaukee County Zoo), SWMI07 (4345 N. 47th St.), SWMI04 (3500 S. Lake Dr. and Bay view Pk.), and SWMI08 (Hampton and Lincoln Creek Parkway).

Table 8 Average storm discharge (cfs) in each stormwater sampling location (2000-2004)

Sampling Locations	Location	Average Flow (cfs)
SWMI01	Lincoln Memorial Dr & Carferry Dr, Milwaukee	0.035
SWMI02	1700 N. Lincoln Memorial Dr @ Lafayette Hill, Milwaukee	0.014
SWFR03	54th & Ashland, Franklin	0.040
SWMI04	3500 S. Lake Dr @ Bayview Park, Milwaukee	0.978
SWMI05	1200 E. Singer Circle, Milwaukee	0.018(a)
SWMI06	Milwaukee County Zoo, Milwaukee	1.261
SWMI07	4345 N. 47th St, Milwaukee	1.205
SWMI08	Hampton & Lincoln Crk Pkwy, Milwaukee	0.883(a)
SWWB09	4939 N. Newhall, Whitefish Bay	0.085
SWGF10	Boerner Botanical Gardens, Hales Corners (10007 W. Meadow Dr), Greenfield	0.034
SWNB11	13380 Eagle Trace & Timber Ridge, New Berlin	0.048
SWMI12	3275 S. 72nd St, Milwaukee	0.080
SWWA13	Ridge Blvd & Harding, Wauwatosa	0.092
SWSF14	Lake Dr and Tesch Av, St Francis	0.042(a)
SWMI15	42nd St & Mt Vernon (I-94 & Menominee River), Milwaukee	0.061
SWMI16	Marquette interchange, Milwaukee	0.046
SWWA17	71st and Chestnut St, Wauwatosa	0.123
SWMI18	Miller park east parking lot at sausage house, Milwaukee	0.108

(a) stations 5, 8, and 14 were inactive for water quality sampling.
1 cfs = 0.02832 m^3/s

7.2 RESULTS FOR COMBINED SEWER OVERFLOW

Results from Table 9 indicate that the average concentrations of various water quality constituents in CSOs were generally higher than those in stormwater. However, the average concentrations of some water quality constituents in stormwater were higher than those in CSO, i.e. Calcium (Ca), Copper (Cu), Hardness (Hard), Magnesium (Mg), Selenium (Se), total phosphorus (TP), total suspended solids (TSS), and Zinc (Zn).

Box plots of CSO data (2000-2004) are presented in Appendix F. The descriptive statistical results of concentrations of various water quality constituents in CSO (2000-2004) by sampling stations are summarized in Appendix H.

Table 9 Comparison of the descriptive statistics between stormwater and combined sewer overflow data in mg/L (*μg/L)

	Stormwater Data 2000-2005										Combined Sewer Overflow Data 2000-2004									
	N	Mean	Std. Error of Mean	Median	Std. Deviation	Maximum	Minimum	Geometric Mean	95% Confidence upper	95% Confidence lower	N	Mean	Std. Error of Mean	Median	Std. Deviation	Maximum	Minimum	Geometric Mean	95% Confidence upper	95% Confidence lower
Ag	917	0.00089	0.000047	0.000075	0.0014	0.03	0.000075	0.000295	0.00098	0.000796	175	0.0039	0.0022	0.00018	0.029	0.28	0.00015	0.00038	0.0082	-0.00046
Alk	291	46.9	3.38	27.0	57.7	330	2.25	26.1	53.6	40.3										
As	910	0.0033	0.0002	0.0018	0.0075	0.20	0.0005	0.0017	0.0037	0.0028	176	0.0062	0.0017	0.001	0.023	0.26	0.00035	0.0018	0.01	0.0029
Be	230	0.0011	0.00024	0.0001	0.0036	0.037	0.000085	0.00023	0.0015	0.0006										
BOD	1025	22.8	0.93	12.0	29.7	250	1.00	12.4	24.6	20.9	176	25.1	6.84	13.0	90.7	1200	3	14.2	38.5	11.7
Ca	918	38.2	1.86	26.0	56.2	1300	2.80	26.6	41.9	34.6	136	27.0	1.94	19.0	22.6	110	4.6	21.3	30.8	23.2
Cd	918	0.00085	0.000042	0.0005	0.0013	0.024	0.000025	0.00039	0.00093	0.00076	175	0.0039	0.0021	0.00061	0.028	0.28	0.00005	0.00062	0.0081	-0.00025
Cl	494	79.4	12.8	23.0	285	5100	0.8	22.7	105	54.3										
Cr	918	0.012	0.001	0.006	0.041	1.1	0.00055	0.006	0.015	0.010	176	0.016	0.0023	0.005	0.03	0.27	0.0018	0.009	0.02	0.012
Cu	918	0.044	0.004	0.022	0.108	2.4	0.0023	0.023	0.051	0.037	176	0.029	0.0029	0.02	0.038	0.3	0.006	0.022	0.035	0.024
EC	971	4.56E+04	2536	6000	7.90E+04	7.30E+05	50.0	5543	5.06E+04	4.07E+04	38	1.43E+05	1.81E+04	1.20E+05	1.11E+05	4.60E+05	1.80E+04	1.02E+05	1.79E+05	1.08E+05
FC	1008	1.49E+05	1.39E+04	9300	4.40E+05	2.40E+06	10.0	8206	1.76E+05	1.22E+05	44	9.34E+05	5.43E+05	2.30E+05	3.60E+06	2.40E+07	2.30E+04	2.17E+05	2.00E+06	-1.30E+05
Hard	918	154	7.61	100	231	5100	8.30	103	169	139	136	105	7.96	71.0	92.9	490	18	81.4	121	89.3
Hg*	931	0.043	0.005	0.023	0.148	4	0.007	0.025	0.052	0.033	135	0.06	0.0072	0.05	0.08	0.68	0.01	0.05	0.08	0.05
Mg	918	14.3	0.76	8.70	23.0	480	0.62	8.66	15.8	12.8	136	10.1	0.82	6.50	9.51	52	1.6	7.54	11.7	8.55
NH3	996	0.62	0.04	0.38	1.27	34	0.002	0.25	0.70	0.54	40	0.92	0.06	0.95	0.39	2.10	0.28	0.83	1.04	0.80
Ni	918	0.0078	0.00045	0.0036	0.014	0.29	0.0002	0.0053	0.0087	0.007	176	0.012	0.0021	0.007	0.027	0.28	0.002	0.0077	0.016	0.0077
NO2	975	0.10	0.0048	0.06	0.15	2.2	0.01	0.06	0.11	0.09										
NO3	976	1.01	0.03	0.79	0.86	12	0.0015	0.67	1.07	0.96										
NO5	228	1.14	0.08	0.91	1.18	13	0.02	0.80	1.30	0.99										
Pb	910	0.033	0.0035	0.02	0.11	1.9	0.000475	0.012	0.04	0.026	176	0.05	0.004	0.031	0.056	0.43	0.001	0.03	0.054	0.038
Sb	230	0.016	0.0023	0.0059	0.04	0.28	0.00055	0.0048	0.021	0.012										
Se	910	0.007	0.00045	0.00065	0.014	0.18	0.00065	0.002	0.0079	0.0061	175	0.0051	0.0016	0.0013	0.021	0.260	0.00035	0.0018	0.0083	0.002
TDS	218	197	18.1	125	267	3100	0.5	107	233	162										
TKN	999	3.32	0.12	2.30	3.86	60	0.025	2.32	3.56	3.08										
Tl	230	0.0026	0.00018	0.002	0.0028	0.028	0.000425	0.002	0.003	0.0023										
TOC	678	25.5	0.97	16.0	25.4	190	2.8	17.9	27.4	23.6										
TP	998	0.92	0.12	0.55	3.69	110	0.01	0.56	1.15	0.69	175	0.85	0.06	0.59	0.85	8.4	0.2	0.68	0.97	0.72
TS	801	532	35.1	330	994	2.20E+04	16	329	601	463										
TSP	269	0.41	0.02	0.25	0.37	2.2	0.05	0.30	0.45	0.37										
TSS	1005	221	30.9	77.0	978	2.90E+04	0.5	71.2	281	160	173	91.0	7.60	63.0	99.9	680	4	58.6	106	76.2
Turb	174	144	39.5	34.8	520	4800	4.45	38.4	221	66.2										
Zn	918	0.18	0.02	0.09	0.52	14	0.0094	0.10	0.22	0.15	176	0.11	0.0056	0.09	0.07	0.70	0.02	0.09	0.12	0.10

7.3 TIME TRENDS

Table 10 lists the values of seasonal slopes for 33 constituents estimated by the seasonal Kendall test. An estimate of the seasonal slope was computed as the median of all slopes between data pairs of four years (2000-2004) within the same season (spring, summer, and fall). Upward trend is positive seasonal slope (increasing). In contrast, downward trend is negative seasonal slope (decreasing).

In Table 10, an upward trend can be found for silver (Ag) with seasonal slope of 5.4×10^{-4} mg/L/year, alkalinity (Alk) with seasonal slope of 8.75 mg/L/year, arsenic (As) with seasonal slope of 1.5×10^{-3} mg/L/year, cadmium (Cd) with seasonal slope of 1.6×10^{-4} mg/L/year, chloride (Cl) with seasonal slope of 1 mg/L/year, copper (Cu) with seasonal slope of 1×10^{-3} mg/L/year, mercury (Hg) with seasonal slope of 2.8×10^{-3} μg/L/year, nickel (Ni) with seasonal slope of 5×10^{-5} mg/L/year, lead (Pb) with seasonal slope of 4.4×10^{-3} mg/L/year, selenium (Se) with seasonal slope of 1.8×10^{-3} mg/L/year, total organic carbon (TOC) with seasonal slope of 2 mg/L/year, total phosphorus (TP) with seasonal slope of 0.08 mg/L/year, and total soluble phosphorus (TSP) with seasonal slope of 0.05 mg/L/year.

Figure 7 shows the seasonal snowfall data in Milwaukee (1899/1990-2004/2005) from Wisconsin state climatology office (2005). Total snowfall of each year is the amount of snowfall accumulated from July of that indicated year to June of next year. Seasonal snowfall data (Fig. 7) are consistent with the upward trend of Chloride (Cl) since Cl samples were colleted from 2002 to 2004 and a primary source of Cl is deicing salt.

A study of urban mobility from Texas Transportation Institute, Texas A&M University System (2005) shows an increase versus year in daily freeway vehicle-miles of travel on freeways in Milwaukee (Fig. 8), which may explain the upward trends for Cd, Cu, Ni, and Pb because the automobile traffic is a primary source of these constituents (McCuen, 2004).

Due to exceedances of the guideline limits along with occurrences of upward trends, stations of special concern for metals (Cu and Pb) are SWMI15 (42nd St & Mt Vernon, I-94 & Menominee River, Milwaukee), SWMI16 (Marquette interchange, Milwaukee), and SWMI18 (Miller park east parking lot at sausage house, Milwaukee) (Table 10 and Figs. E-22, E-30, and E-66). Stations of special concern for TP include SWMI07 (4345 N. 47th St, Milwaukee), SWWB09 (4939 N. Newhall, Whitefish Bay), SWMI12 (3275 S. 72nd St, Milwaukee), SWWA17 (71st and Chestnut St, Wauwatosa), and SWMI18 (Table 10 and Fig. E-56). Because of high TSP values, all 15 stations with TSP measurements (station 1-4, 6, 7, 9-13, and 15-18) (Table 10 and Fig. E-60) should be monitored carefully.

Table 10 Seasonal Kendall slope estimations

Stormwater Data 2000 - 2004

				Seasonal Kendall Slope Confidence Intervals		
Constituent	% Confidence Interval	Seasonal Trend		Lower Limit	Slope mg/L/year (*µg/L/year)	Upper limit
		Two-tailed	One-tailed			
Ag	95	Upward/Downward	<u>Upward</u>	0.00044	**0.00054**	0.00071
Alk	95	Upward/Downward	<u>Upward</u>	3	**8.75**	15
As	95	Upward/Downward	<u>Upward</u>	0.0013	**0.0015**	0.0018
Be	95	Upward/Downward	Downward	-0.000015	-0.000015	-0.000015
BOD	95	Upward/Downward	Downward	0	-0.6	-1.2
Ca	70	Upward/Downward	Downward	-1.2	-0.67	0
Cd	95	Upward/Downward	<u>Upward</u>	0.00016	**0.00016**	0.00026
Cl	75	Upward/Downward	<u>Upward</u>	0	**1**	2.34
Cr	85	Upward/Downward	Downward	-0.0001	-0.00005	0
Cu	85	Upward/Downward	<u>Upward</u>	0	**0.001**	0.0017
EC	95	No trend	No trend	-300	0	75
FC	95	Upward/Downward	Downward	-1145	-370	-1.67
Hardness	65	Upward/Downward	Downward	-4.33	-2	0
Hg	95	Upward/Downward	<u>Upward</u>	0.0028*	**0.0028***	0.0028*
Mg	45	Upward/Downward	Downward	-0.25	-0.1	0
NH3	95	No trend	No trend	-0.02	0	0.023
Ni	95	Upward/Downward	<u>Upward</u>	0	**0.00005**	0.000067
NO2	95	Upward/Downward	Downward	-0.0083	-0.0057	-0.0033
NO3	90	Upward/Downward	Downward	-0.06	-0.03	0
NO5	95	(a)	(a)	(a)	(a)	(a)
Pb	95	Upward/Downward	<u>Upward</u>	0.0025	**0.0044**	0.0063
Sb	95	Upward/Downward	Downward	-0.078	-0.053	-0.012
Se	95	Upward/Downward	<u>Upward</u>	0.00073	**0.0018**	0.0031
TDS	70	Upward/Downward	Downward	-39.5	-20	0
TKN	95	Upward/Downward	Downward	-0.3	-0.22	-0.13
Tl	95	Upward/Downward	Downward	-0.0011	-0.0011	-0.0011
TOC	90	Upward/Downward	<u>Upward</u>	0	**2**	3.5
TP	95	Upward/Downward	<u>Upward</u>	0.05	**0.08**	0.11
TS	55	Upward/Downward	Downward	-10.67	-6.67	0
TSP	95	Upward/Downward	<u>Upward</u>	0.02	**0.05**	0.05
TSS	95	Upward/Downward	Downward	-8.75	-4.4	-0.5
TURB	95	(a)	(a)	(a)	(a)	(a)
Zn	95	No trend	No trend	-0.0043	0	0.005

(a) not sufficient data to compute seasonal slope

Figure 7 Seasonal snowfall at Milwaukee, WI (Wisconsin Climatology Office)

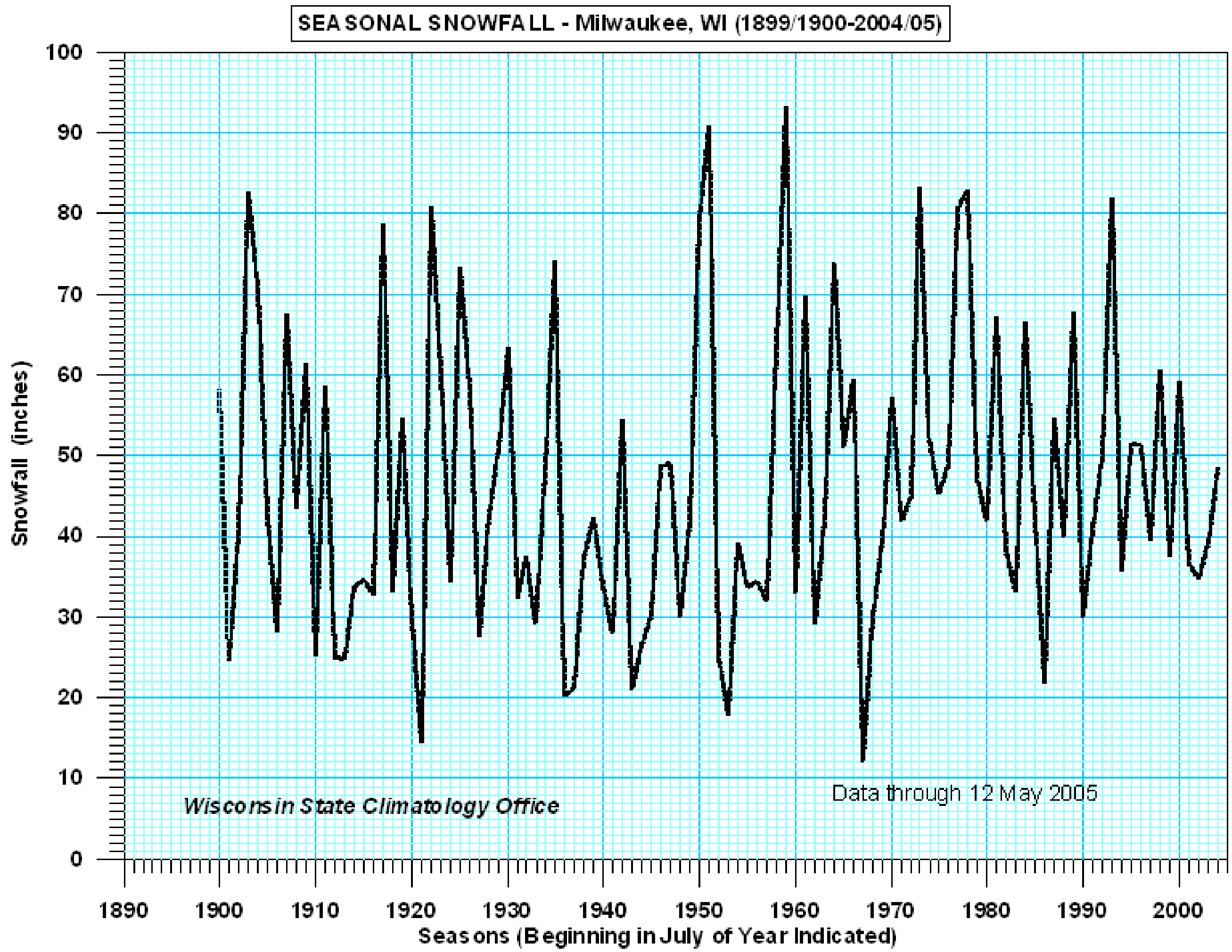
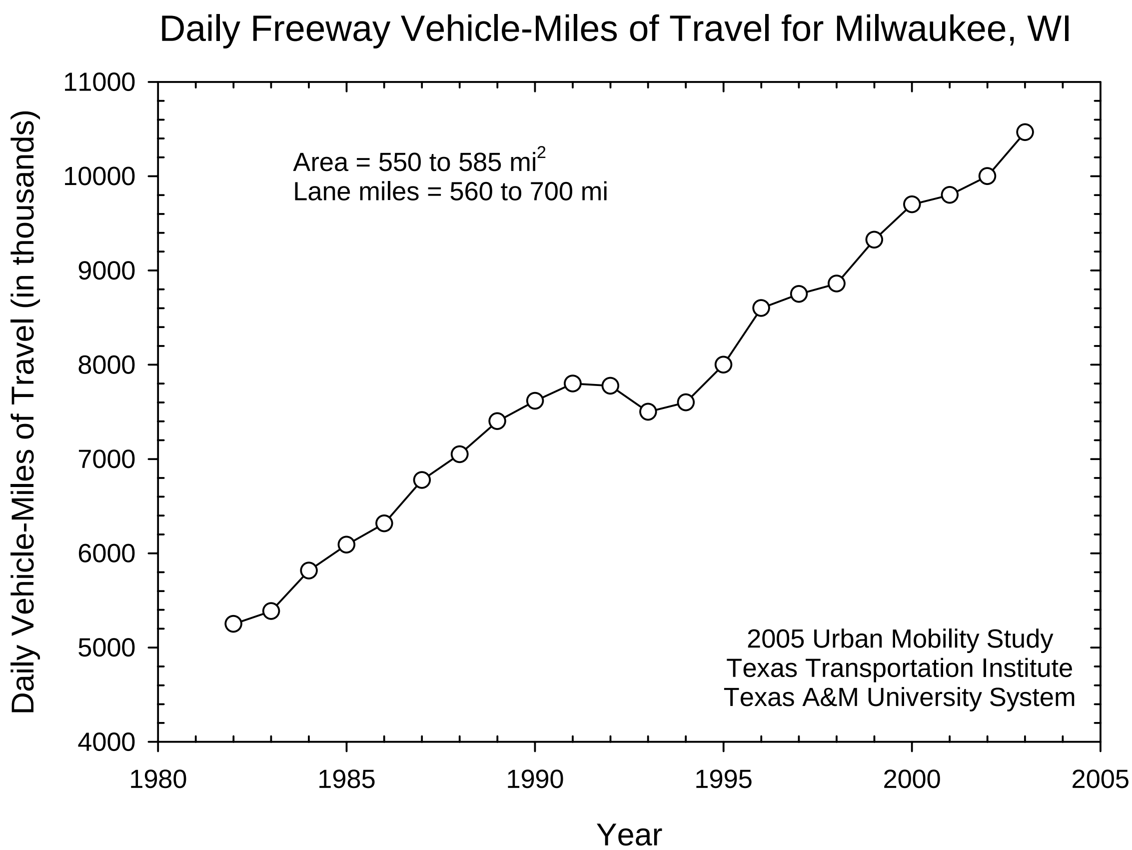


Figure 8 Daily freeway vehicle-miles of travel on freeways for Milwaukee, WI (Texas Transportation Institute, Texas A&M University System)



7.4 HYETOGRAPHS, HYDROGRAPHS, AND POLLUTOGRAPHS

Examples of some typical hyetographs, hydrographs and pollutographs of BOD during the June 11-14, 2001, runoff event at 3500 S. Lake Dr @ Bayview Park, Milwaukee (SWMI04), during the June 11-13, 2001, runoff event at 4939 N. Newhall, Whitefish Bay (SWWB09), during the June 11-14, 2001, runoff event at 4345 N. 47th St, Milwaukee (SWMI07), and during the June 11-12, 2001, runoff event at 42nd St & Mt. Vernon (I-94 & Menomonee River), Milwaukee (SWMI15), are presented in Figure 9 through Figure 12. Hyetographs, hydrographs and pollutographs of all other constituents (Ag, Alk, As, Be, BOD-5, Ca, Cd, Cl, Cr, Cu, EC, FC, Hardness, Hg, Mg, NH_3, Ni, NO_2, NO_3, NO_5, Pb, Sb, Se, TDS, TKN, Tl, TOC, TP, TS, TSP, TSS, Turb and Zn) are shown in Appendix I (attached CDs). Examples of hyetographs and hydrographs (2000-2004) at SWMI07 are shown in Figure 13 through 22.

Runoff hydrographs (Appendix I: CDs) show high base flow among high flow stations (e.g. SWMI06 and SWMI07). The high base flow in runoff hydrograph usually indicates extraneous flow or groundwater infiltration. Extraneous flow may result from illegal connection of untreated sanitary sewage or industrial discharge (Adams and Papa, 2000). Groundwater infiltration results from groundwater seeping into storm sewer pipes through cracks, holes, and old pipe joints (Adams and Papa, 2000). This high base flow case requires more investigation.

Additionally, runoff hydrographs (Appendix I: CDs) show similarity with intermittent streams (e.g. Fig. 9, 10, and 11) and ephemeral streams (e.g. Fig. 12). Intermittent streams have limited groundwater storage and release stored waters at a fast rate (Wanielista et al., 1997). Base flow or interflow in intermittent streams exists only during and shortly after heavy rainfall periods (Wanielista et al., 1997). Ephemeral streams have no interflow and base flow due to impervious sidewalls and bed of the stream channel (Wanielista et al., 1997).

Figure 9   A hyetograph, hydrograph and pollutograph of BOD during the June 11-14, 2001, runoff event: 3500 S. Lake Dr @ Bayview Park, St Francis (SWMI04)

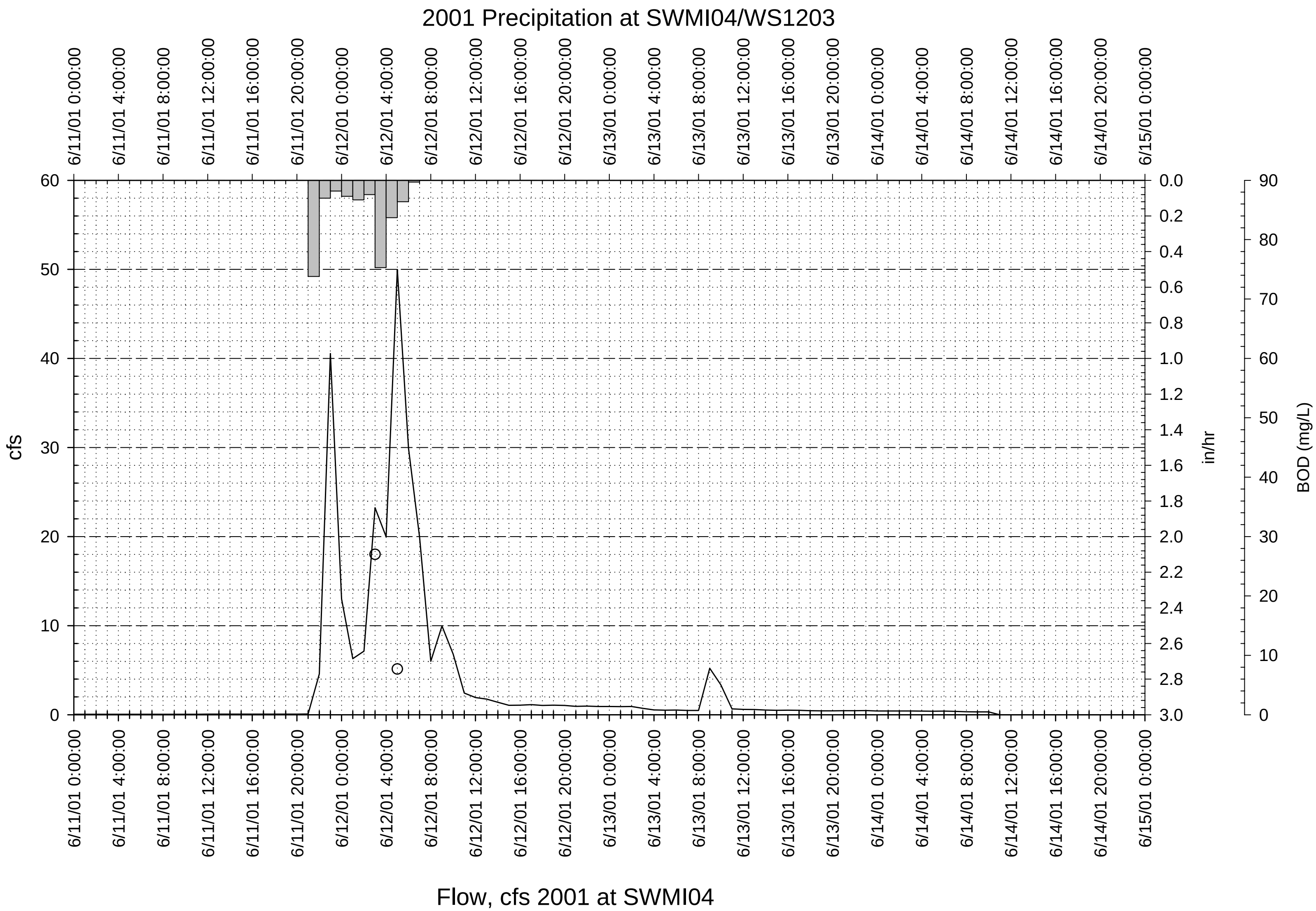


Figure 10 A hyetograph, hydrograph and pollutograph of BOD during the June 11-13, 2001, runoff event: 4939 N. Newhall, Whitefish Bay (SWWB09)

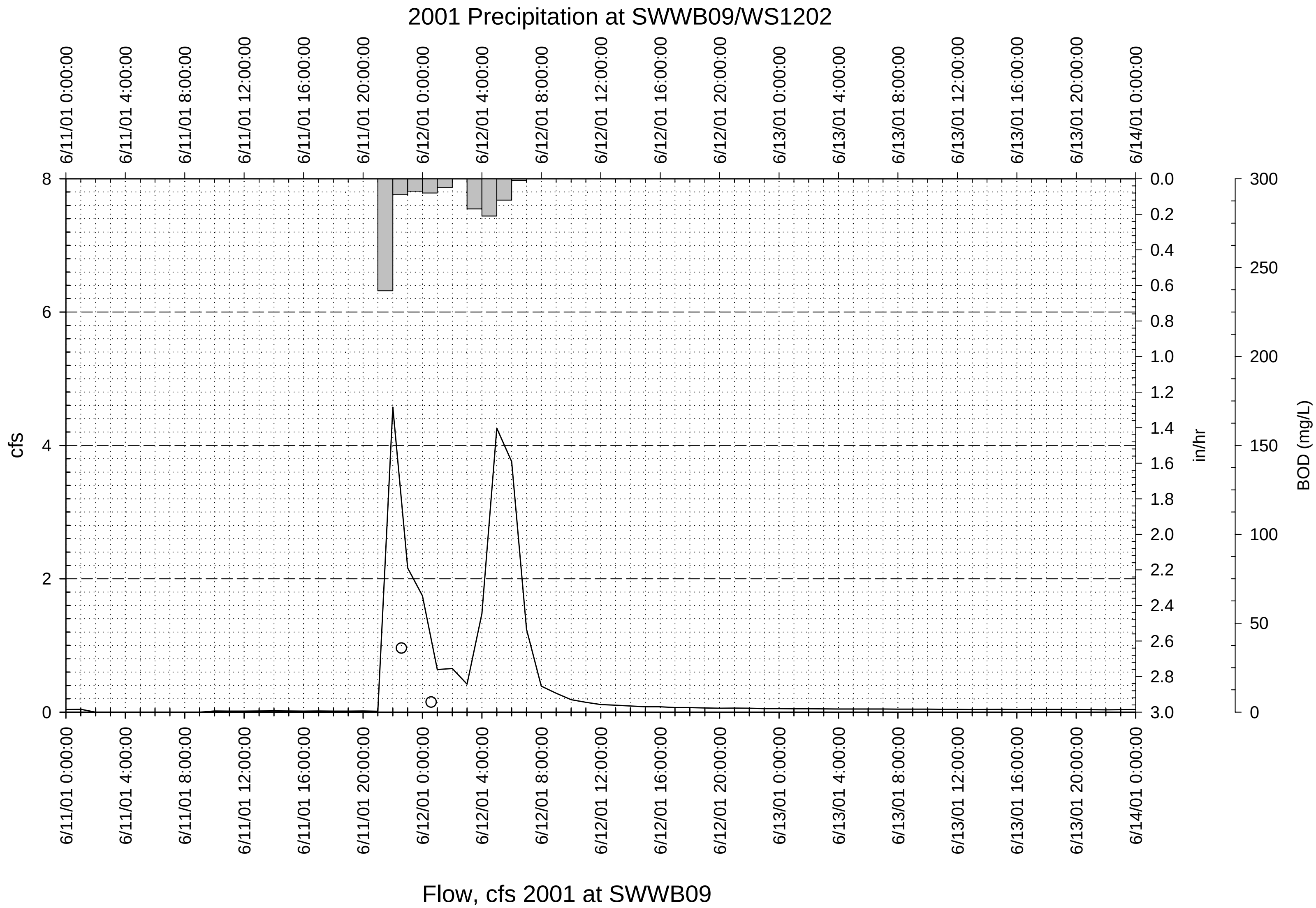


Figure 11 A hyetograph, hydrograph and pollutograph of BOD during the June 11-14, 2001, runoff event: 4345 N. 47th St, Milwaukee (SWMI07)

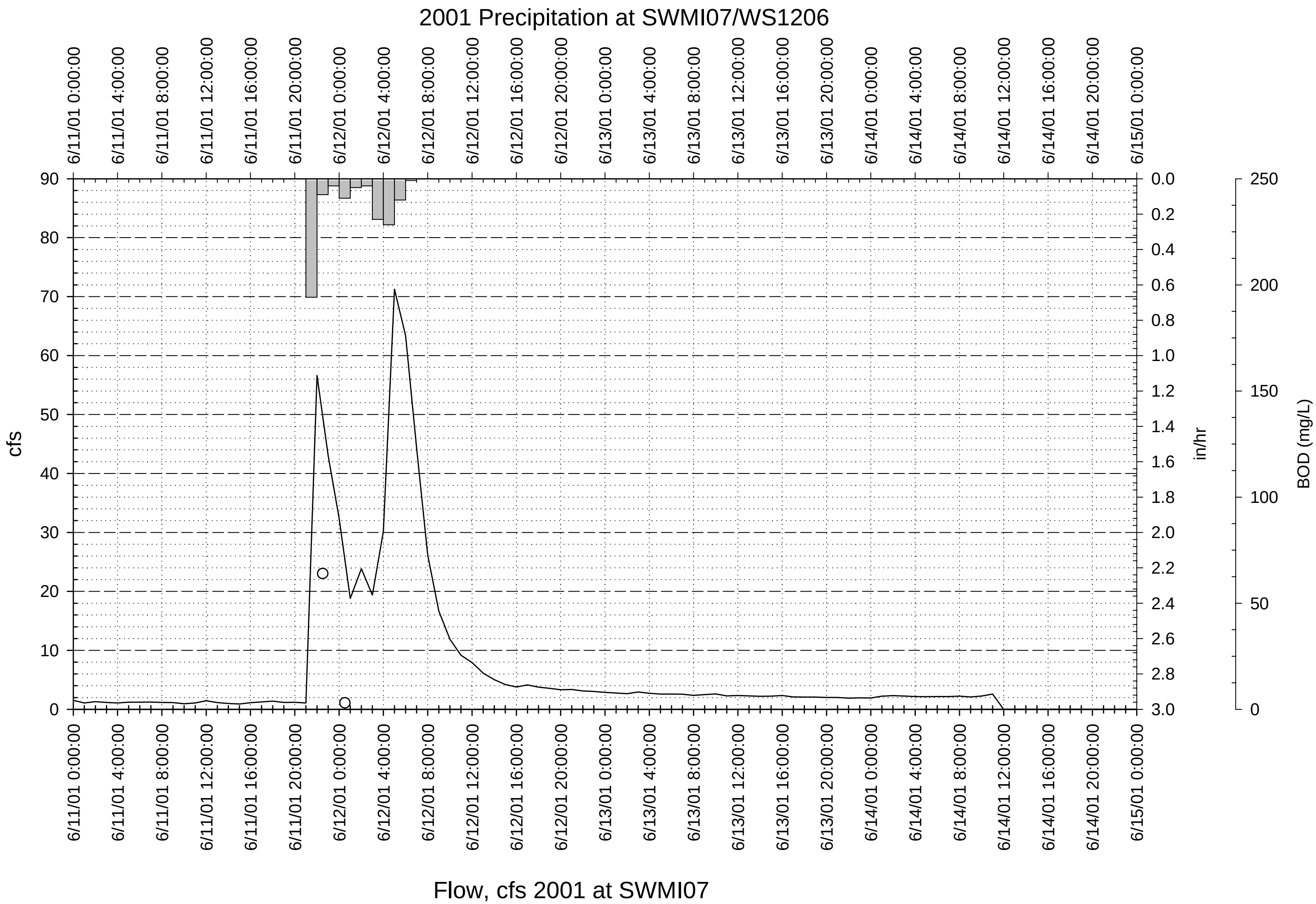


Figure 12 A hyetograph, hydrograph and pollutograph of BOD during the June 11-12, 2001, runoff event: 42nd St & Mt Vernon (I-94 & Menominee River), Milwaukee (SWMI15)

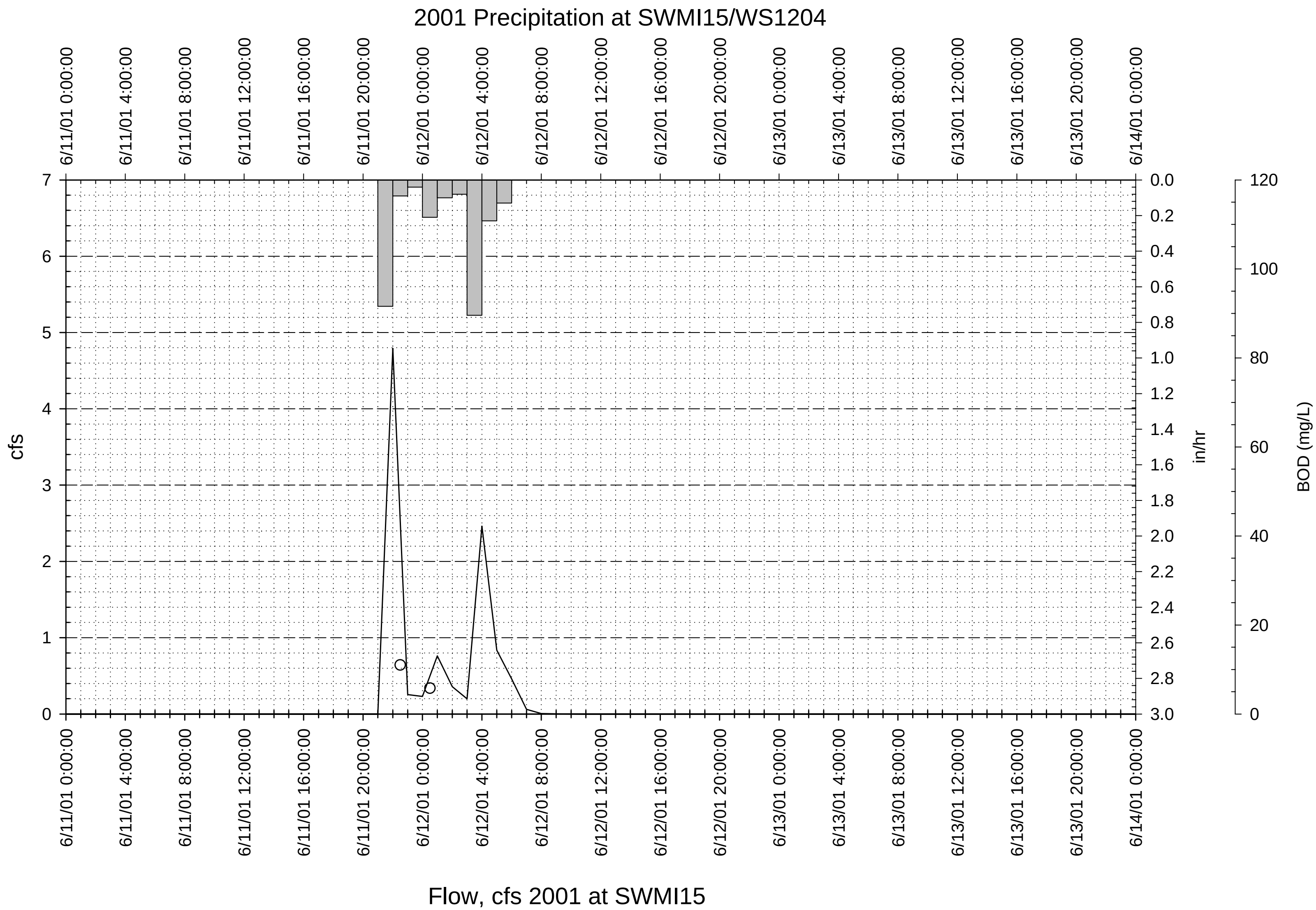


Figure 13 Hyetographs and hydrographs (Oct, 2000 to Dec, 2000) at 4345 N. 47th St, Milwaukee (SWMI07)

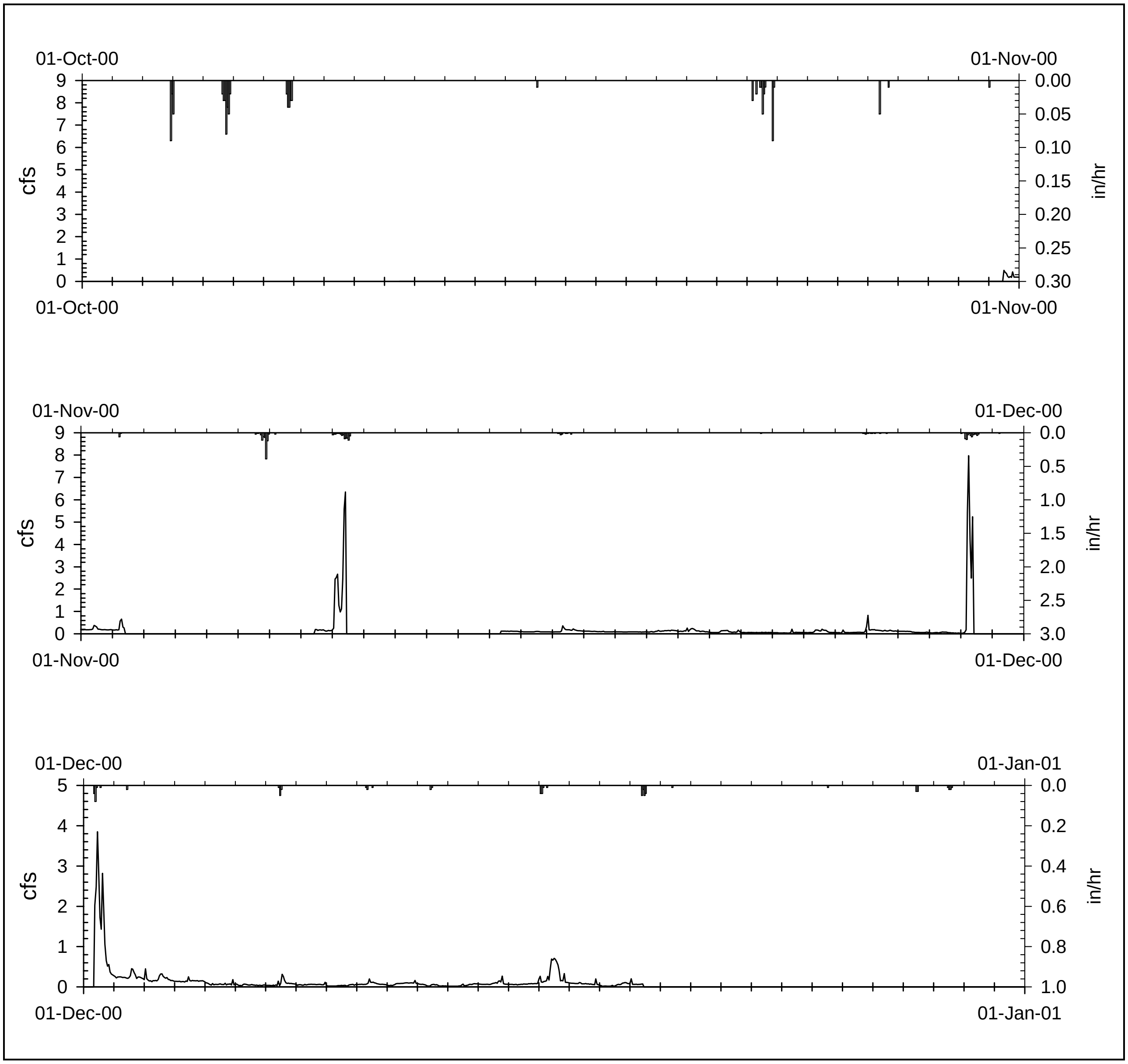


Figure 14 Hyetographs and hydrographs (Mar, 2001 to Jun, 2001) at 4345 N. 47th St, Milwaukee (SWMI07)

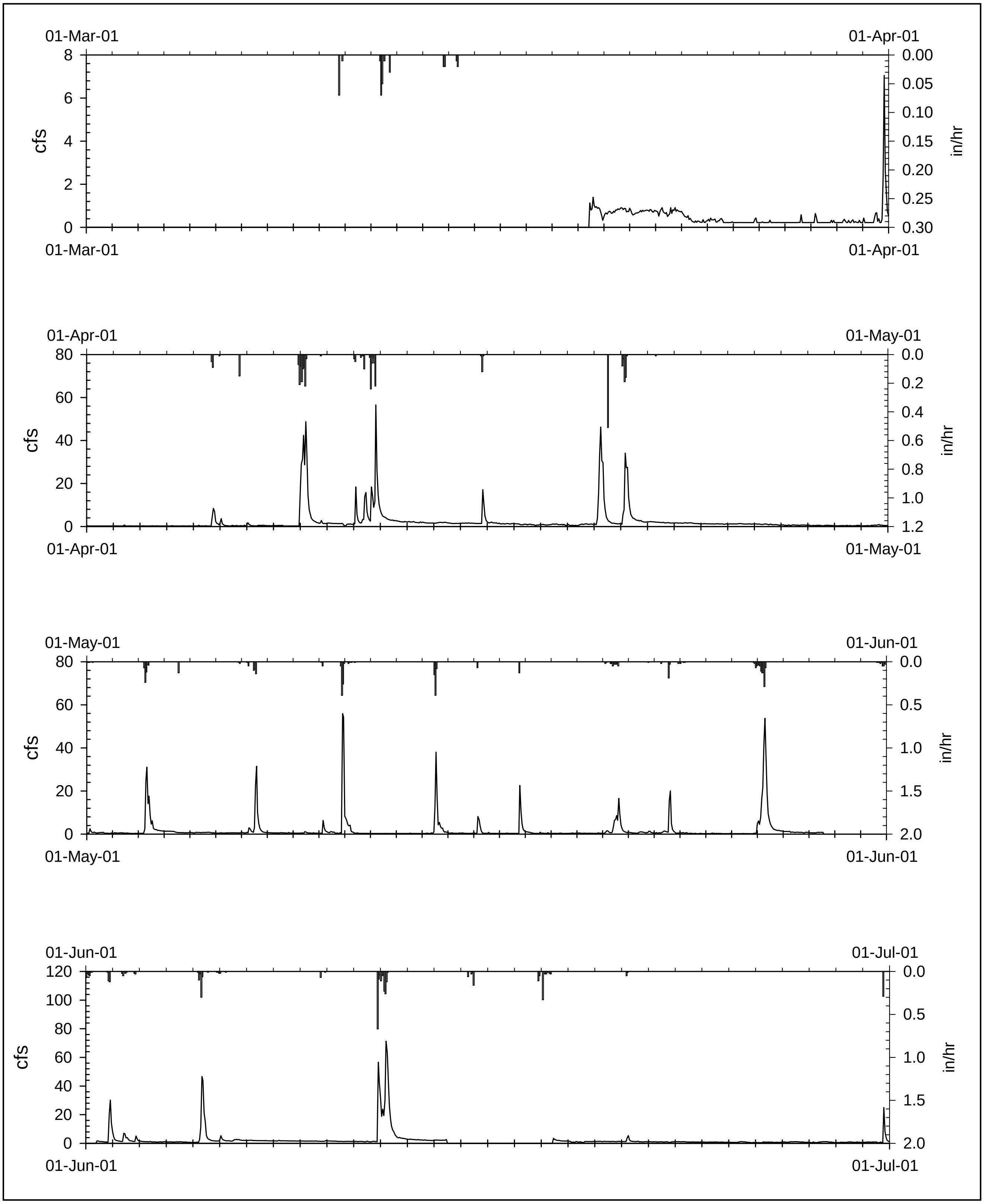


Figure 15 Hyetographs and hydrographs (July, 2001 to Oct, 2001) at 4345 N. 47th St, Milwaukee (SWMI07)

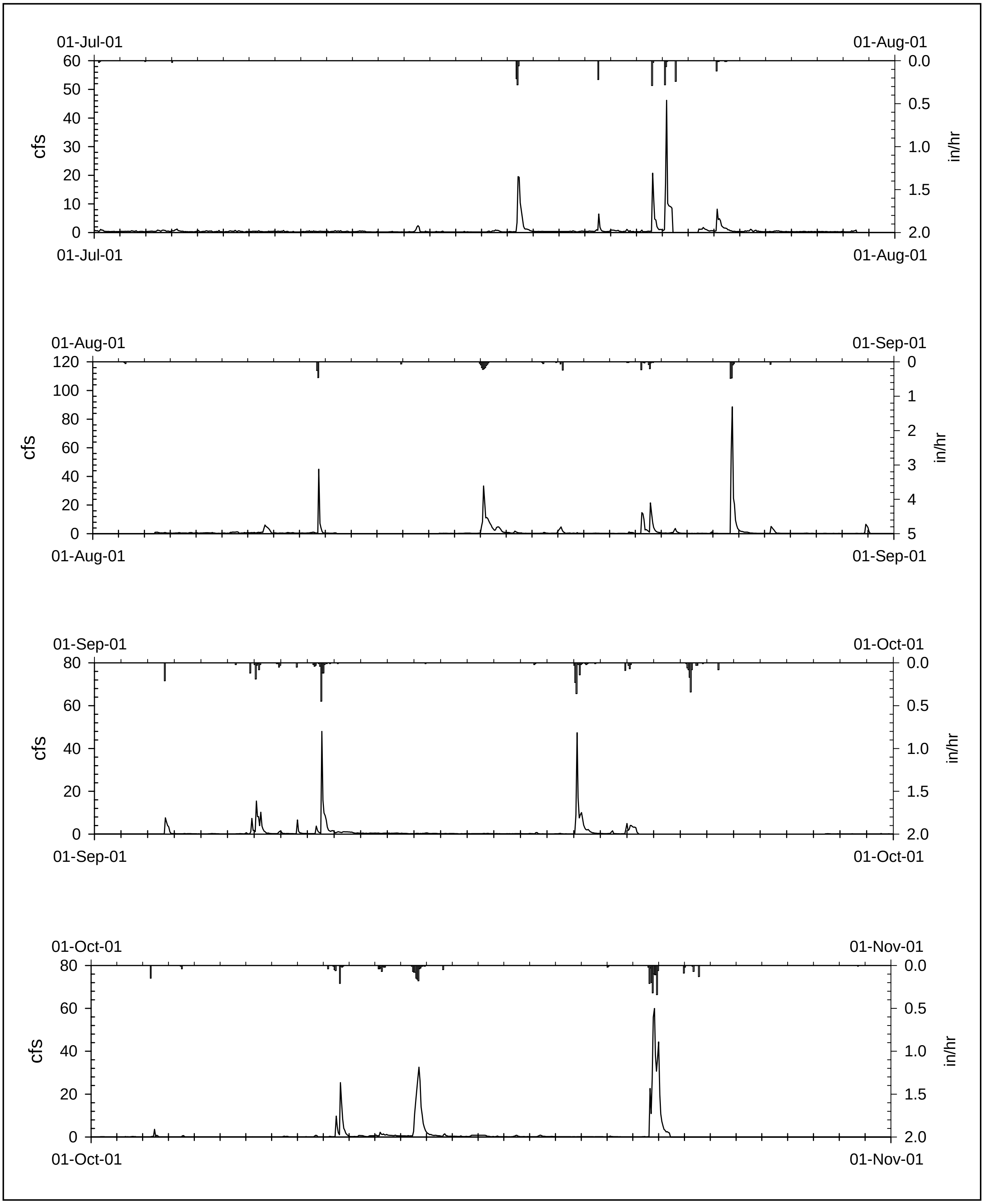


Figure 16 Hyetographs and hydrographs (Apr, 2002 to July, 2002) at 4345 N. 47th St, Milwaukee (SWMI07)

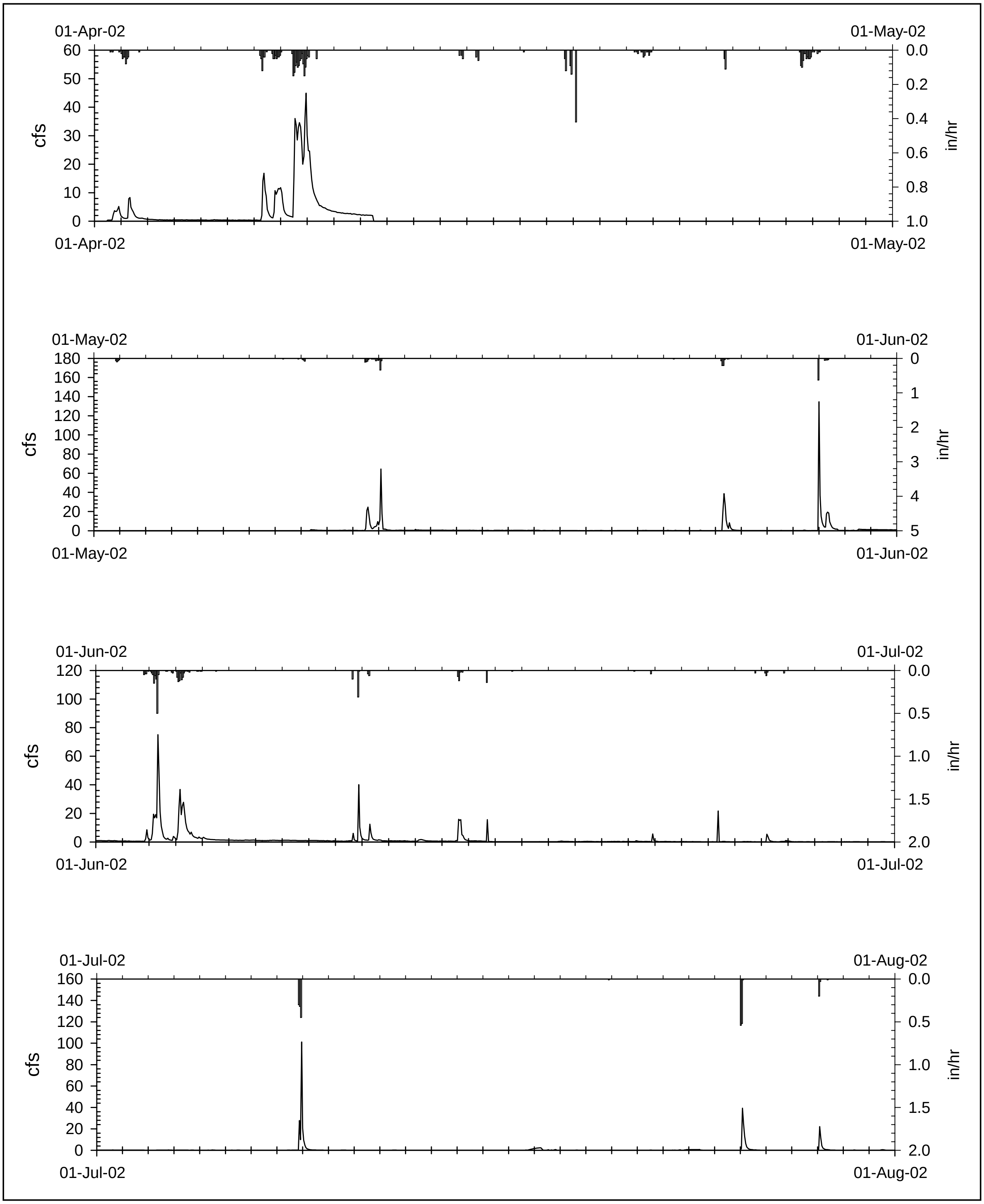


Figure 17 Hyetographs and hydrographs (Aug, 2002 to Oct, 2002) at 4345 N. 47th St, Milwaukee (SWMI07)

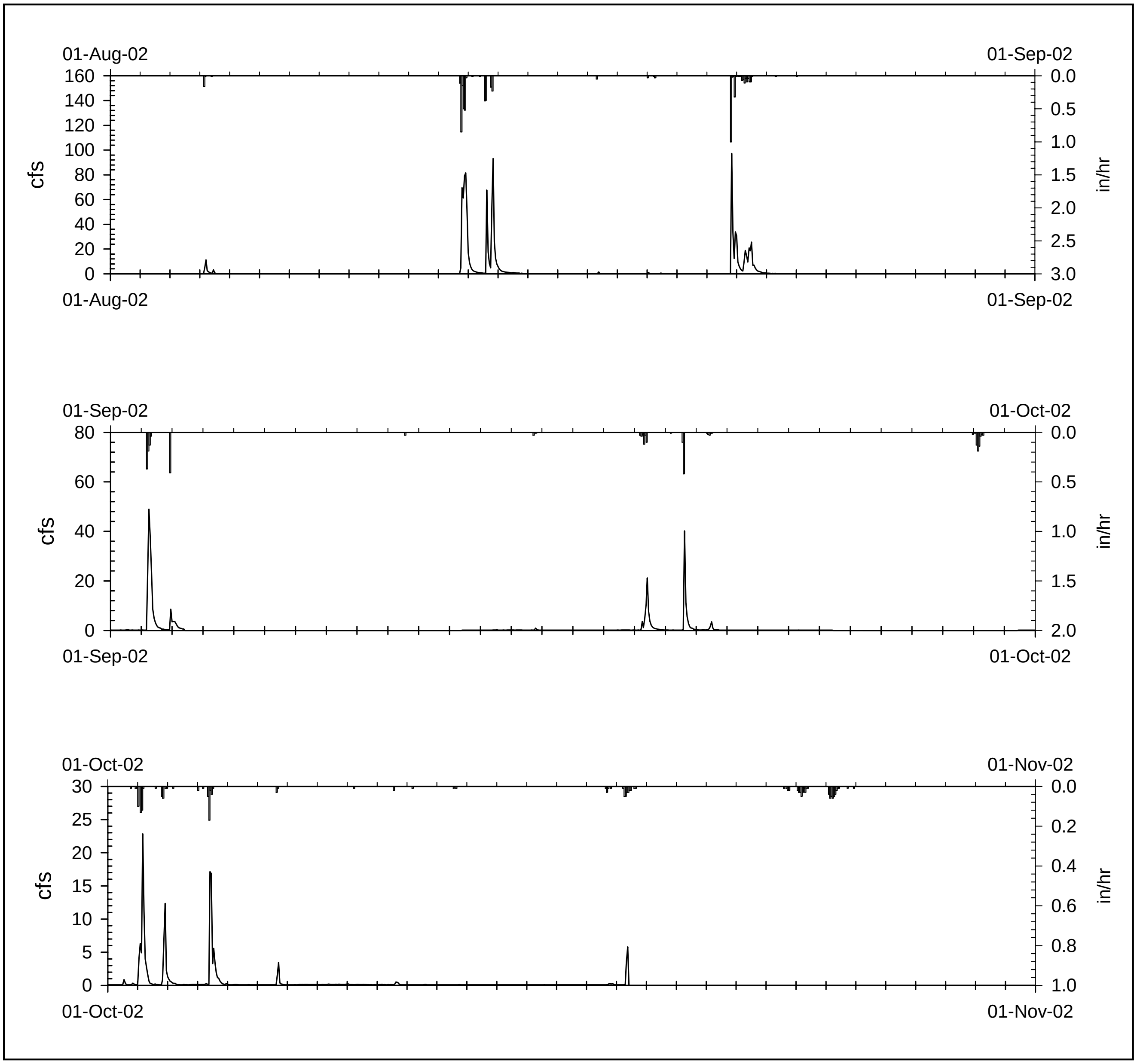


Figure 18   Hyetographs and hydrographs (Mar, 2003 to May, 2003) at 4345 N. 47th St, Milwaukee (SWMI07)

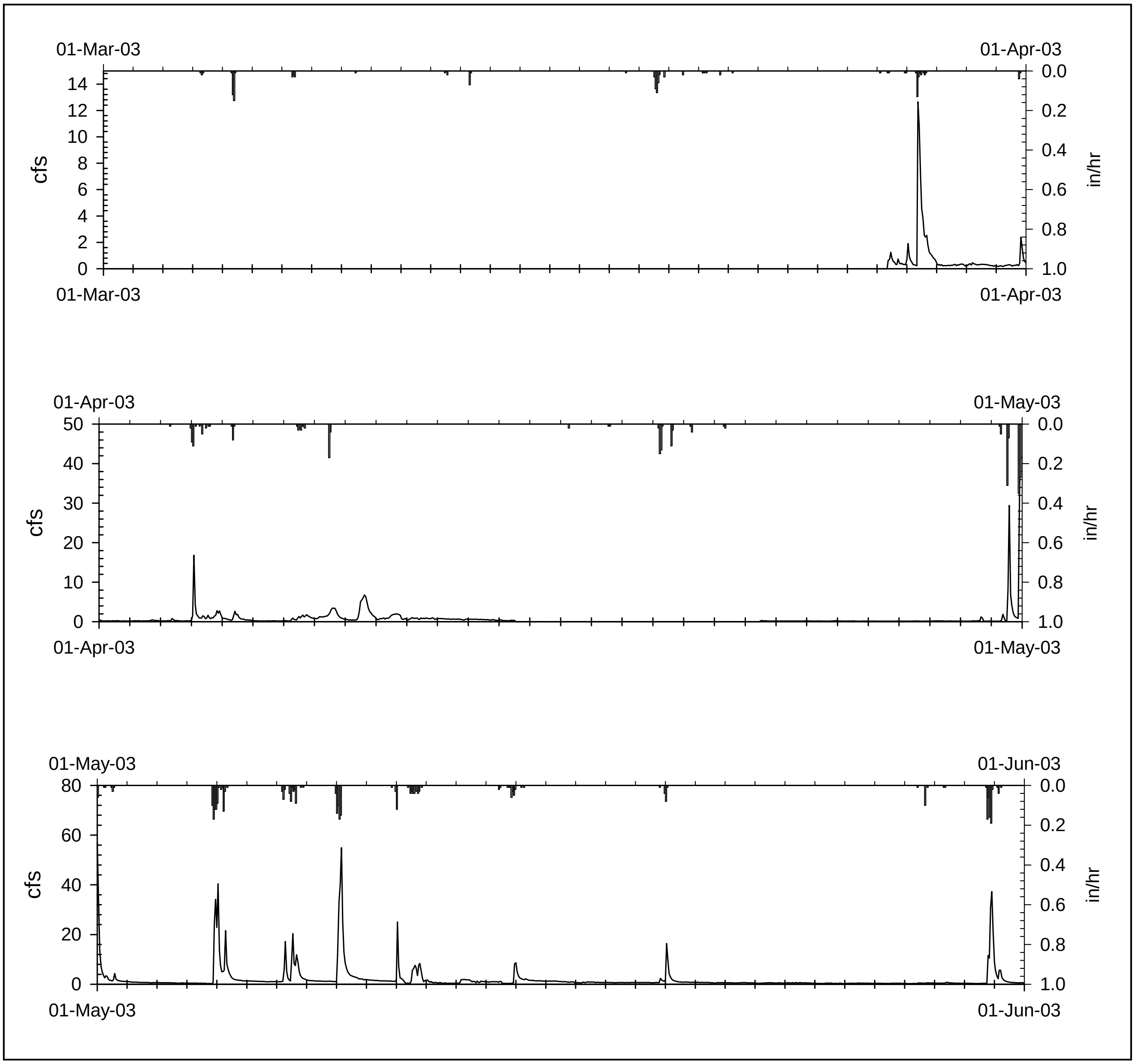


Figure 19 Hyetographs and hydrographs (Jun, 2003 to Sep, 2003) at 4345 N. 47th St, Milwaukee (SWMI07)

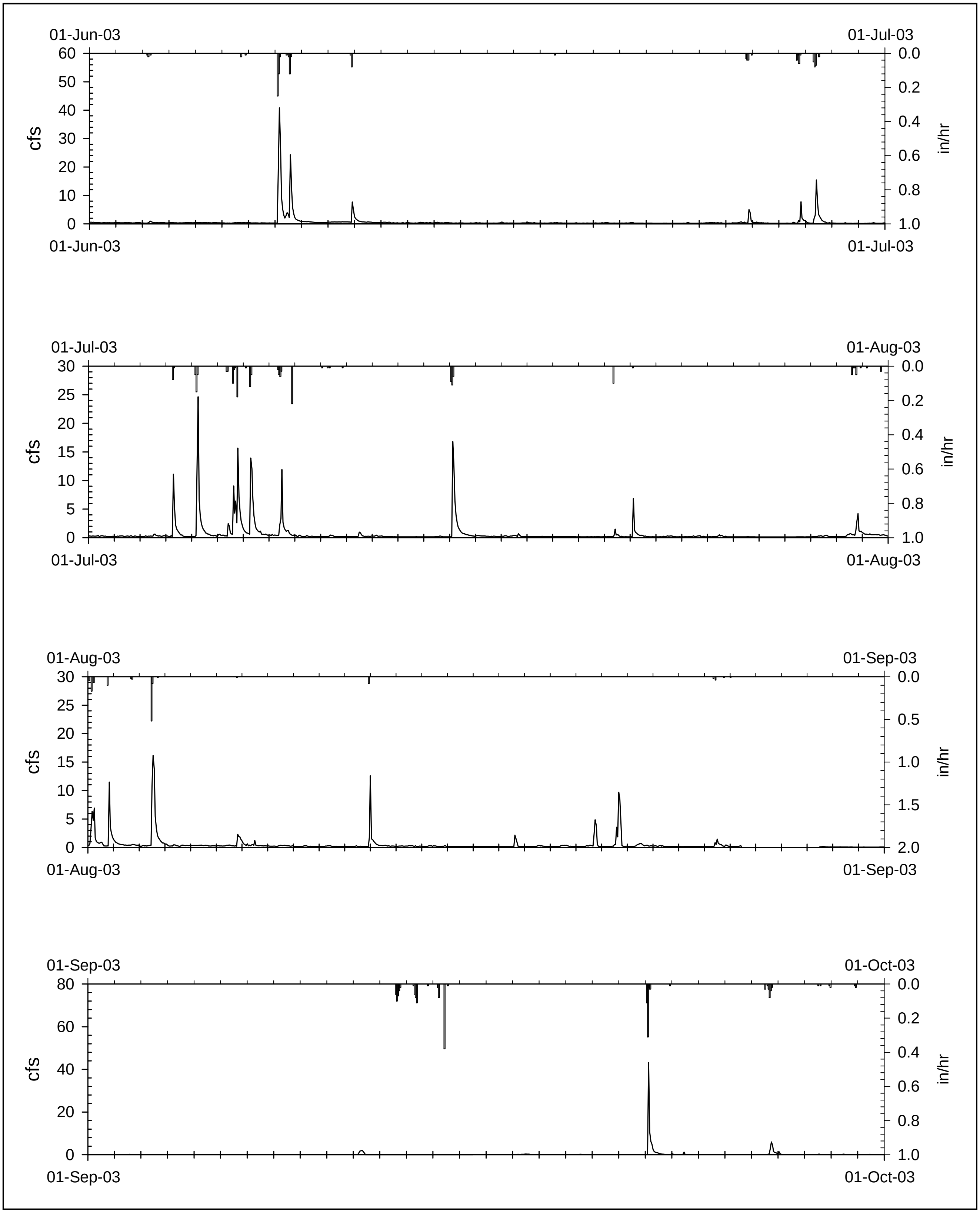


Figure 20 Hyetographs and hydrographs (Oct, 2003 to Nov, 2003) at 4345 N. 47th St, Milwaukee (SWMI07)

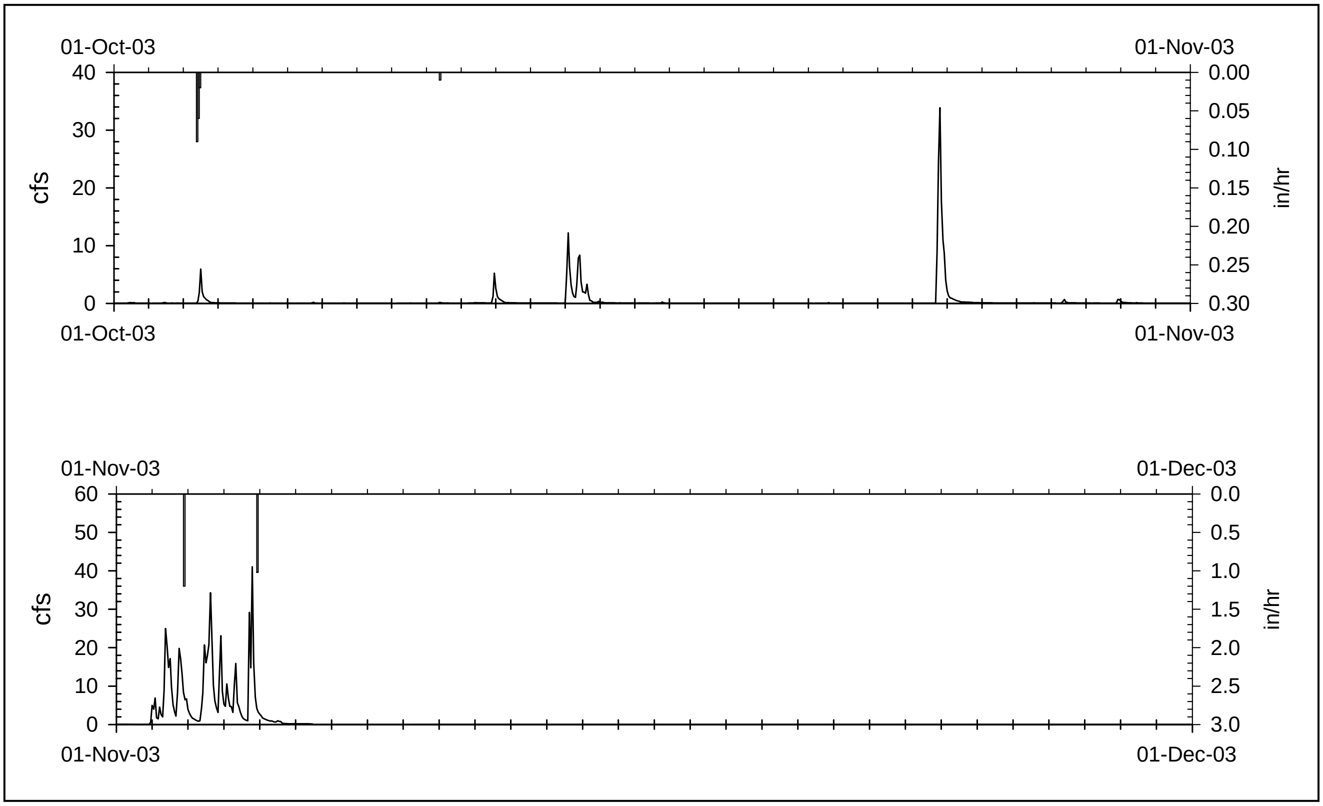


Figure 21 Hyetographs and hydrographs (Apr, 2004 to Jul, 2004) at 4345 N. 47th St, Milwaukee (SWMI07)

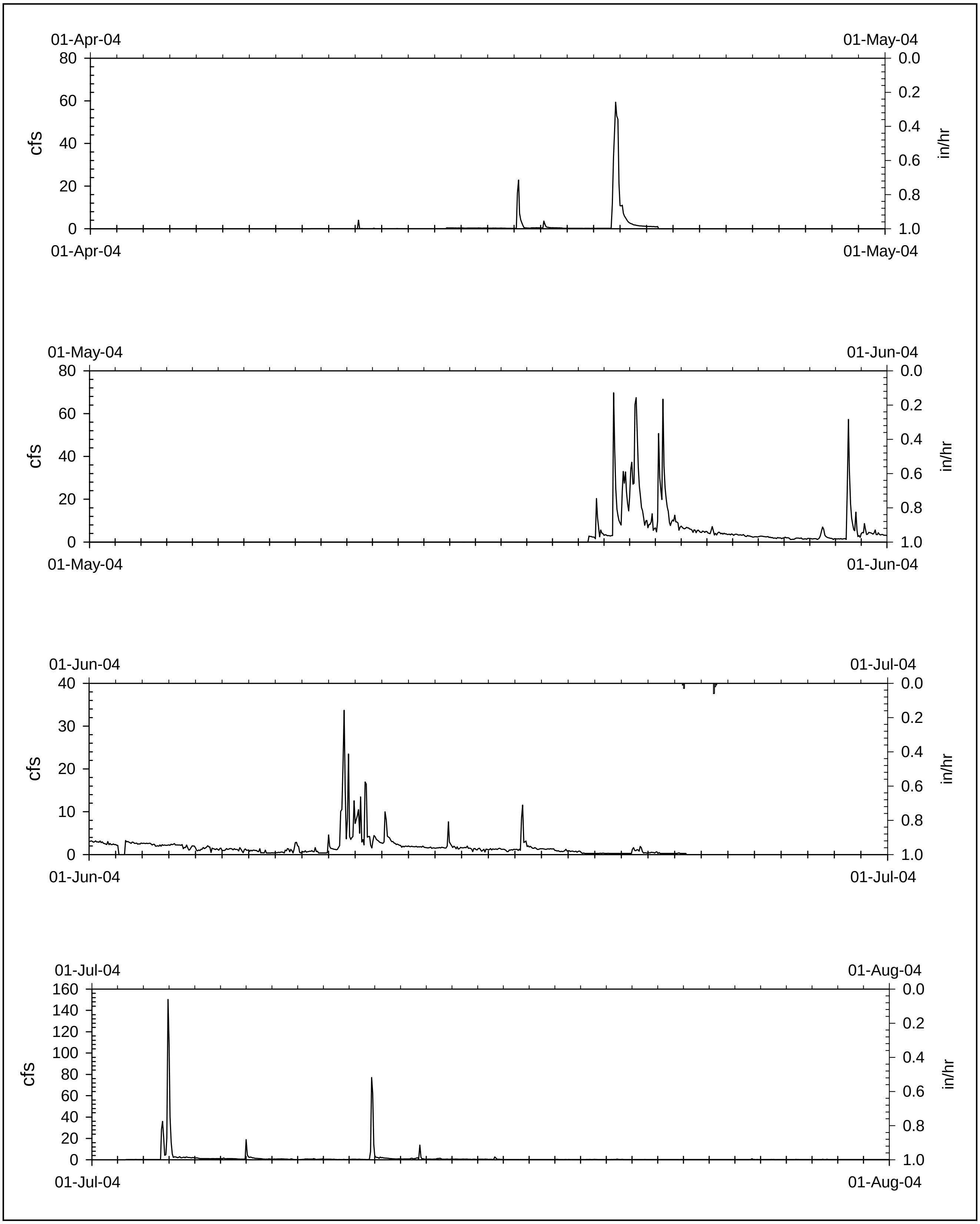
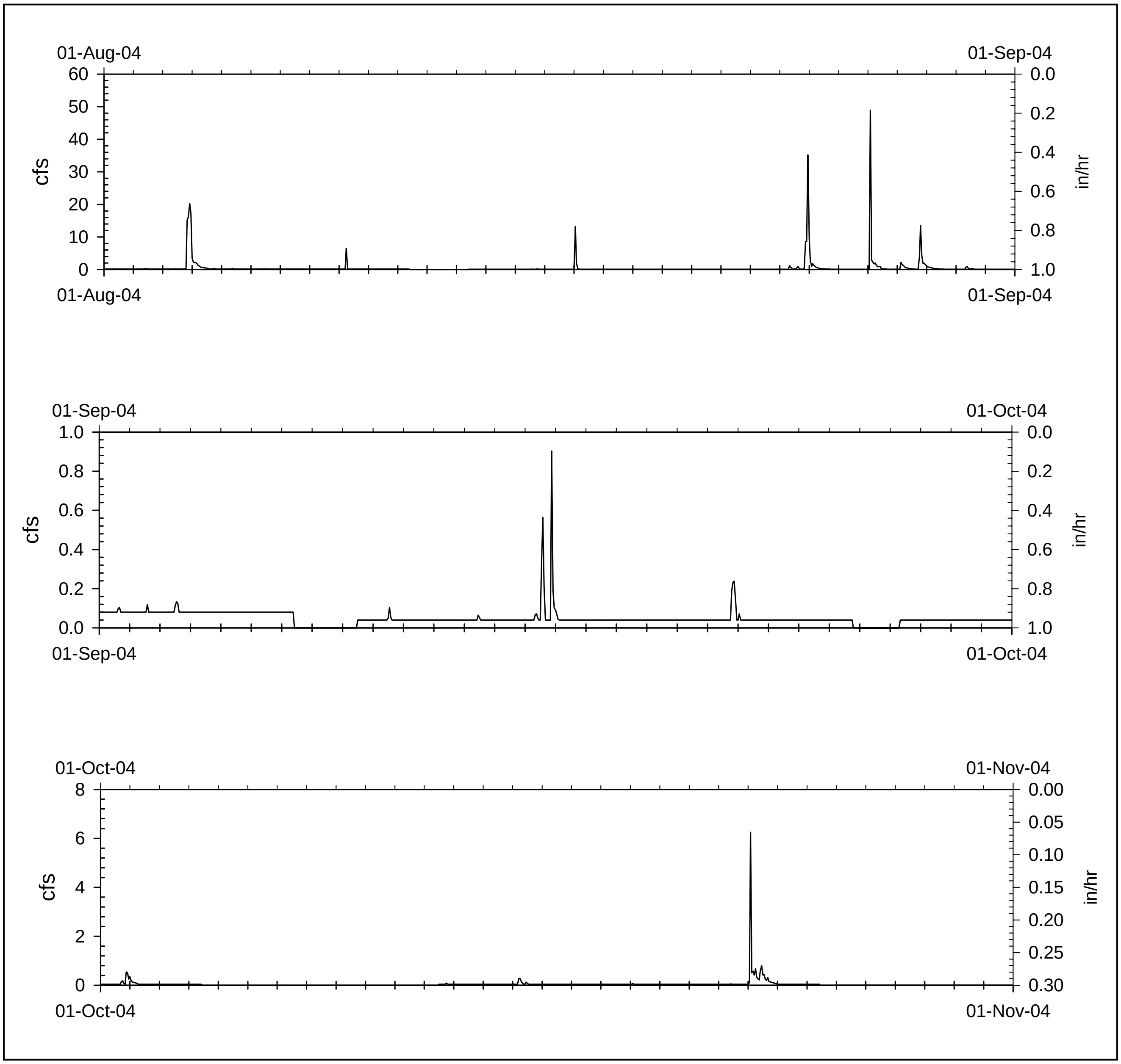


Figure 22 Hyetographs and hydrographs (Aug, 2004 to Oct, 2004) at 4345 N. 47th St, Milwaukee (SWMI07)



7.5 FIRST-FLUSH CONCENTRATION AND ANTECEDENT DRY PERIOD

First-flush concentrations (high initial pollutant concentrations) occur in small storm catchments with high impervious areas. Sediment wash off in pervious areas may not have this first-flush effect because of unlimited supply of soil particles. The short time but high intensity rainfall along with long antecedent dry period can cause this first-flush effect (Appendix I: hyetographs, hydrographs, and pollutographs).

Correlation analysis was carried out to determine the degree of association among constituents. The correlation can identify relationships between individual constituents and between different categories of constituents. The correlation coefficient R ranges between –1 to 1. Positive R values indicate a relationship between the constituents so that as one increases, so does the other. Negative R values mean that the relationship between the constituents is such that as values for one increases, values for the other decreases. A R value near zero means that there is no correlation between the constituents.

Correlations between first-flush concentrations in mg/L (E-coli in MPN/100mL and fecal coliforms in CFU/100mL) of 13 constituents (Table 11 and 13) were evaluated along with antecedent dry period in days. Loads in lb/storm of nine constituents were evaluated along with antecedent dry period in days (Table 12 and 14).

The antecedent dry period had positive correlations with BOD-5, total suspended solids (TSS), chloride (Cl), zinc (Zn), copper (Cu), bacteria, and nutrients (Tables 11 and 13). From the magnitude of the correlation coefficients, it is seen that copper (Cu), zinc (Zn), BOD-5, and total soluble phosphorus (TSP) were more influenced by antecedent dry period than other constituents.

The first-flush concentration of Zn had high correlation ($R = 0.819$) at significance level of 0.01 with first-flush concentration of Cu. This supports a common source, traffic, of these metals. The first-flush concentration of total suspended solids (TSS) had high correlation ($R = 0.624$) at significance level of 0.01 with first-flush concentration of TSP.

Other significant correlations are listed below. The first-flush concentrations of BOD-5 and total nitrogen (TN) had a correlation of 0.553 at significance level of 0.01. The first-flush concentrations of BOD-5 and total soluble phosphorus (TSP) had a correlation of 0.507 at significance level of 0.01. The first-flush concentrations of BOD-5 and total Kjeldahl nitrogen (TKN) had a correlation of 0.510 at significance level of 0.01. The first-flush concentrations of total soluble phosphorus (TSP) and Copper (Cu) had a correlation of 0.536 at significance level of 0.01. The first-flush concentrations of total soluble phosphorus (TSP) and Zinc (Zn) had a correlation of 0.544 at significance level of 0.01. The first-flush concentrations of total soluble phosphorus (TSP) and total nitrogen (TN) had a correlation of 0.514 at significance level of 0.01. This would occur when both come from the same source such as fertilizer. In addition, the first-flush concentrations of total nitrogen (TN) and total Kjeldahl nitrogen (TKN) had high correlation of 0.986 at significance level of 0.01. Thus, the total nitrogen from stormwater runoff may be from TKN (ammonia nitrogen (NH3)+organic nitrogen). The first-flush concentrations of E-coli (EC) and Fecal coliform (FC) had a high correlation of 0.635 at significance level of 0.01 indicating common origin of some of these bacteria.

Most of these correlations are consistent with the findings of Adams and Papa (2000) who reported that for separated sewer catchments total suspended solids (TSS) are positively correlated with nutrients and heavy metals, and nutrients are positively correlated with heavy metals. The constituents within the bacteriological and heavy metal categories are highly correlated among themselves.

Table 13 shows that the antecedent dry period and first-flush concentrations of Zinc (Zn) had the highest average correlation of 0.438. The antecedent dry period and first-flush concentrations of total suspended solids (TSS) had an average correlation of 0.342. Table 12 shows that antecedent dry period and loads (lb/storm) are not correlated considering all stations. However, Table 14 shows that antecedent dry period and loads (lb/storm) of TSS for individual stations had the highest average correlation of 0.295.

Figure 23 and 24 show charts of antecedent dry period as compared to first-flush concentration of Zinc (Zn) at SWFR03 and SWMI16 with the values of the square of the correlation coefficient (R^2) of 0.448 and 0.920, respectively. Figure 25 and 26 show charts of antecedent dry period as compared to first-flush concentration of total suspended solids (TSS) at SWMI08 and Copper (Cu) at SWMI18 with the values of square correlation coefficient (R^2) of 0.490 and 0.960, respectively. These correlations are quite significant.

Charts of antecedent dry period versus first-flush concentration by sampling stations for BOD, TSS, TP, Cl, Cu, Zn, EC, FC, TKN, NH3, NO3, TSP, and TN can be found in Appendix K (attached CDs).

Table 11   Correlations (R) among first-flush concentrations of 13 constituents (mg/L) and antecedent dry period, t_d (day) (2000-2004)

	t_d	BOD	TSS	TP	Cl	Cu	Zn	FC	EC	TKN	NH3	NO3	TSP	TN
t_d	1 n = 447	.250(**) n = 443	.170(**) n = 436	.054 n = 415	.027 n = 156	.250(**) n = 384	.362(**) n = 384	.140(**) n = 413	.155(**) n = 415	.150(**) n = 416	.178(**) n = 414	-.029 n = 410	.332(**) n = 81	.149(**) n= 424
BOD		1 n = 451	.078 n = 438	.108(*) n = 418	.245(**) n = 159	.277(**) n = 390	.255(**) n = 390	.262(**) n = 417	.424(**) n = 419	.510(**) n = 419	.487(**) n = 417	.154(**) n = 416	.507(**) n = 82	.553(**) n = 423
TSS			1 n = 442	.067 n = 420	-.016 n = 160	.147(**) n = 390	.212(**) n = 390	.028 n = 409	.131(**) n = 411	.054 n = 421	.033 n = 419	-.027 n = 416	.624(**) n = 84	.049 n = 424
TP				1 n = 499	-.021 n = 215	.062 n = 463	.078 n = 463	.199(**) n = 481	.163(**) n = 465	.081 n = 499	.070 n = 498	-.005 n = 491	.053 n = 104	.073 n = 407
Cl					1 n = 218	.192(**) n = 191	.243(**) n = 191	-.098 n = 209	-.011 n = 190	.062 n = 216	.276(**) n = 215	.233(**) n = 218	.335(**) n = 97	.086 n = 156
Cu						1 n = 465	.819(**) n = 465	.088 n = 447	.120(*) n = 431	.207(**) n = 463	.300(**) n = 463	.029 n = 465	.536(**) n = 80	.185(**) n = 383
Zn							1 n = 465	.071 n = 447	.106(*) n = 431	.180(**) n = 463	.317(**) n = 463	.057 n = 465	.544(**) n = 80	.155(**) n = 383
FC								1 n = 501	.635(**) n = 471	.225(**) n = 482	-.016 n = 480	-.106(*) n = 478	.025 n = 97	.203(**) n = 392
EC									1 n = 485	.266(**) n = 466	.125(**) n = 464	-.042 n = 462	.247(*) n = 104	.242(**) n = 394
TKN										1 n = 500	.447(**) n = 498	.235(**) n = 492	.483(**) n = 104	.986(**) n = 408
NH3											1 n = 498	.252(**) n = 490	.379(**) n = 103	.468(**) n = 407
NO3												1 n = 496	.141 n = 98	.441(**) n = 408
TSP													1 n = 104	.514(**) n = 74
TN														1 n = 429

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 12 Correlations (R) among loads (lb/storm) of nine constituents and antecedent dry period, t_d (day) (2000-2004)

	t_d	BOD	TSS	TP	Cl	Cu	Zn	NH3	TSP	TN
t_d	1 n = 447	.026 n = 444	.044 n = 438	.026 n = 434	-.046 n = 164	.029 n = 410	.022 n = 410	-.013 n = 434	-.039 n = 83	-.009 n = 429
BOD		1 n = 453	.850(**) n = 442	.510(**) n = 442	.843(**) n = 170	.819(**) n = 417	.925(**) n = 417	.692(**) n = 442	.758(**) n = 87	.853(**) n = 437
TSS			1 n = 445	.775(**) n = 439	.579(**) n = 169	.842(**) n = 417	.929(**) n = 417	.826(**) n = 439	.695(**) n = 86	.759(**) n = 436
TP				1 n = 442	.185(*) n = 169	.579(**) n = 416	.666(**) n = 416	.805(**) n = 442	.560(**) n = 87	.480(**) n = 436
Cl					1 n = 170	.766(**) n = 150	.813(**) n = 150	.482(**) n = 169	.647(**) n = 84	.589(**) n = 169
Cu						1 n = 417	.888(**) n = 417	.706(**) n = 416	.776(**) n = 68	.772(**) n = 415
Zn							1 n = 417	.814(**) n = 416	.790(**) n = 68	.882(**) n = 415
NH3								1 n = 442	.689(**) n = 87	.658(**) n = 436
TSP									1 n = 87	.819(**) n = 84
TN										1 n = 437

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 13 Correlations (R) among first-flush concentration of 13 constituents (mg/L) and antecedent dry period, t_d (day) (2000-2004) in each sampling station

	t_d	BOD	TSS	TP	Cl	Cu	Zn	FC	EC	TKN	NH3	NO3	TSP	TN
SWMI01	1	.064	.481(**)	.173	.160	***.494(*)***	.430(*)	.101	-.097	.009	-.023	-.094	.488	-.067
n	28	28	28	26	11	22	22	25	25	26	26	26	5	28
SWMI02	1	.580(**)	.590(**)	***.664(**)***	.296	.530(*)	.463(*)	.331	-.005	.152	-.144	-.018	-.307	.249
n	23	23	23	21	7	21	21	21	21	21	21	21	3	23
SWFR03	1	.149	.312	-.021	-.097	.490(**)	***.669(**)***	-.004	.198	.002	.067	-.116	-.185	-.025
n	35	35	35	33	14	32	32	31	31	33	33	33	7	35
SWMI04	1	.113	-.150	.090	-.125	***.121***	.095	.032	.020	-.064	-.087	-.224	-.311	-.105
n	24	23	24	24	10	20	20	23	24	24	24	23	7	23
SWMI05	1	.341	.169	.296	***.801***	.290	.199	.673(**)	.173	.424(*)	.171	-.047	.(a)	.369
n	24	24	22	22	4	20	20	23	23	22	22	22	0	22
SWMI06	1	.103	.343(*)	.263	.500	.226	.368(*)	.039	-.125	.041	.047	-.129	***.693***	.001
n	35	34	35	32	15	32	32	31	32	33	32	33	7	35
SWMI07	1	***.349***	.209	.221	.331	-.064	.260	.189	.265	.327	.272	-.011	-1.000(**)(b)	.327
n	30	30	30	30	10	30	30	29	28	30	30	30	2	30
SWMI08	1	.596(**)	.700(**)	.550(**)	.(a)	.424	.529(*)	***.733(**)***	.618(**)	.484(*)	-.075	-.283	.(a)	.291
n	21	21	21	21	0	21	21	21	21	21	21	21	0	21
SWWB09	1	.581(**)	.662(**)	.478(**)	.262	.377(*)	.486(**)	.553(**)	.483(**)	.293	.392(*)	-.006	***.739***	.268
n	32	32	31	29	10	28	28	31	30	29	29	30	4	30
SWGF10	1	***.393(*)***	.111	.337	-.079	.332	.182	.371	.383(*)	.370(*)	.297	.169	.322	.357
n	30	30	29	29	14	26	26	28	29	29	29	29	8	29
SWNB11	1	.364(*)	-.103	.084	.413	-.048	.237	.264	.257	.034	.207	.173	***.609***	.044
n	37	36	37	34	12	32	32	32	33	34	34	33	7	36
SWMI12	1	.324	.418(*)	.025	-.284	.552(**)	***.553(**)***	.138	.214	.209	.054	-.057	-.463	.214
n	31	31	30	27	10	27	27	27	26	27	27	27	4	30
SWWA13	1	.285	.004	.206	-.419	.093	.630(**)	.245	.594(**)	.392	.248	-.016	***.983***	.376
n	27	26	23	22	8	22	22	27	26	22	22	22	3	21
SWSF14	1	.030	-.131	.070	.276	-.046	-.148	.489(*)	***.573(*)***	.312	.041	-.075	.(a)	.333
n	20	20	20	20	4	20	20	19	19	20	20	20	0	20
SWMI15	1	.238	.601(**)	***.696(**)***	.117	.512(*)	.597(**)	.058	.090	-.148	.068	-.152	.248	-.118
n	26	26	24	24	9	19	19	24	26	24	24	21	8	21
SWMI16	1	.050	.374	-.589	-.263	-.602	***.959(**)***	.137	-.046	.048	.005	.010	-.808	.047
n	10	10	10	9	8	5	5	9	8	9	9	8	4	9
SWWA17	1	.665	***.875(*)***	-.281	.732	1.000(**)(b)	1.000(**)(b)	-.748	.093	.910	***.911***	.847	.936	.889(*)
n	6	6	6	4	4	2	2	5	5	4	4	4	4	5
SWMI18	1	.132	.685	.249	.858(*)	***.980(**)***	.937(*)	-.167	.569	-.152	.062	.514	.594	-.156
n	8	8	8	8	6	5	5	7	8	8	7	7	8	6
	AVG	0.298	0.342	0.195	0.205	0.274	***0.438***	0.191	0.236	0.202	0.140	0.027	0.253	0.183

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.
b Not included in computing of arithmetic average due to insufficient number of data.
Bold number: The highest value of R in each station

Table 14 Correlations (R) among loads (lb/storm) of nine constituents and antecedent dry period, t_d (day) (2000-2004) in each sampling station

	t_d	BOD	TSS	TP	Cl	Cu	Zn	NH3	TSP	TN
SWMI01	1	.034	.335	.165	***.408***	.321	.288	.064	.260	-.033
n	28	28	28	28	12	27	27	28	6	28
SWMI02	1	***.659(**)***	.533(**)	.592(**)	.316	.589(**)	.548(**)	.499(*)	-.836	.572(**)
n	23	23	23	23	7	23	23	23	3	23
SWFR03	1	.182	.042	-.012	-.360	.127	***.391(*)***	.081	-.294	.065
n	35	35	35	35	14	34	34	35	7	35
SWMI04	1	.140	-.029	***.201***	.105	-.050	-.048	-.035	-.202	-.034
n	24	23	24	23	10	20	20	23	6	23
SWMI05	1	***.356***	.014	.310	.234	.048	.011	.110	.(a)	.249
n	24	24	22	22	4	20	20	22	0	22
SWMI06	1	-.069	.070	.133	.281	.070	.125	-.006	***.682***	.038
n	35	35	35	34	16	34	34	34	8	35
SWMI07	1	.275	.223	.222	***.337***	.124	.261	.257	-1.000(**)(b)	.283
n	30	30	30	30	10	30	30	30	2	30
SWMI08	1	.671(**)	***.814(**)***	.595(**)	.(a)	.553(**)	.597(**)	.222	.(a)	.475(*)
n	21	21	21	21	0	21	21	21	0	21
SWWB09	1	.304	.359(*)	.176	.529	.356(*)	.355	.271	***.876***	.189
n	32	32	32	31	11	31	31	31	5	31
SWGF10	1	.214	.116	.278	-.287	.223	.170	***.311***	-.142	.126
n	30	30	29	29	14	26	26	29	8	29
SWNB11	1	***.441(**)***	.119	.305	.376	.289	.363(*)	.379(*)	-.104	.397(*)
n	37	36	37	36	12	35	35	36	6	36
SWMI12	1	.265	.437(*)	.022	.082	.477(**)	***.499(**)***	.313	-.729	.270
n	31	31	30	30	10	30	30	30	4	30
SWWA13	1	.226	.221	.244	-.212	.389	***.676(**)***	.221	.813	.365
n	27	27	24	25	8	23	23	25	4	23
SWSF14	1	.254	.023	.295	***.835***	.179	.024	.131	.(a)	.393
n	20	20	20	20	4	20	20	20	0	20
SWMI15	1	.091	***.373***	.319	-.180	.100	.125	.060	.249	.040
n	26	26	24	24	9	19	19	24	8	21
SWMI16	1	***.425***	.286	.008	.353	.095	.143	.353	-.423	.298
n	10	10	10	10	10	9	9	10	4	9
SWWA17	1	.042	***.732***	-.065	.443	-.812	-.862	.711	.677	.320
n	6	5	6	5	5	3	3	5	4	5
SWMI18	1	.017	***.642***	-.009	-.190	.490	.470	.260	.256	-.098
n	8	8	8	8	8	5	5	8	8	8
	AVG	0.251	***0.295***	0.210	0.181	0.198	0.230	0.233	0.077	0.217

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.
b not included in computing of arithmetic average due to less number of data
Bold number: The highest value of R in each station

Figure 23 Correlation of antecedent dry period versus first-flush concentration of Zinc (2000-2004) at 54th & Ashland, Franklin (SWFR03).

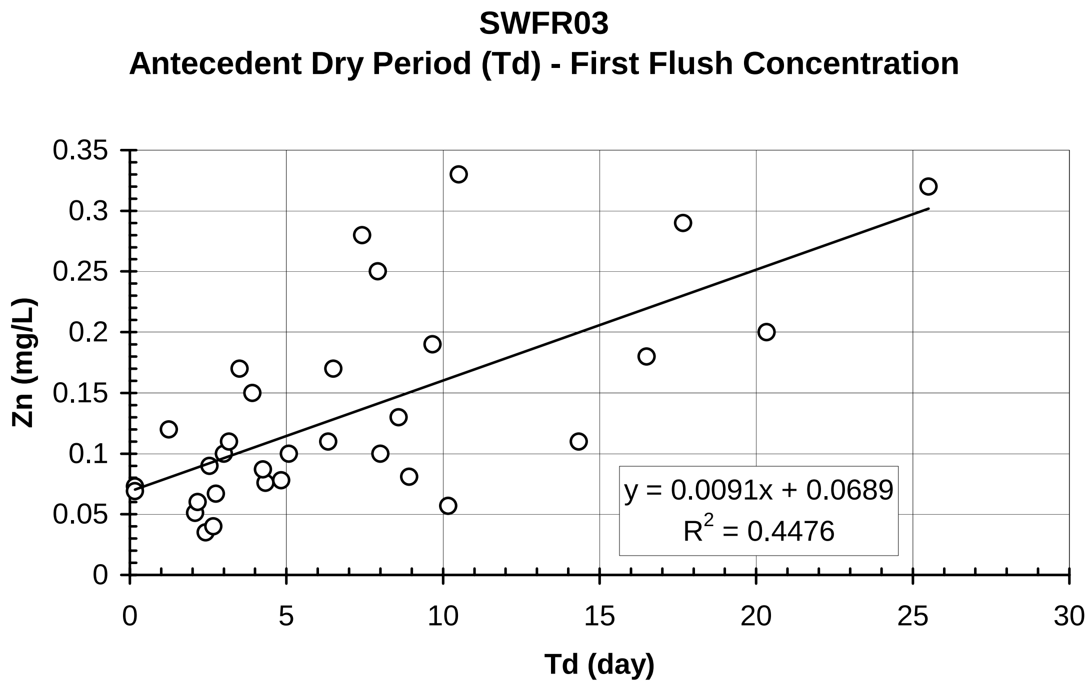


Figure 24 Correlation of antecedent dry period versus first-flush concentration of Zinc (2000-2004) at Marquette interchange, Milwaukee (SWMI16)

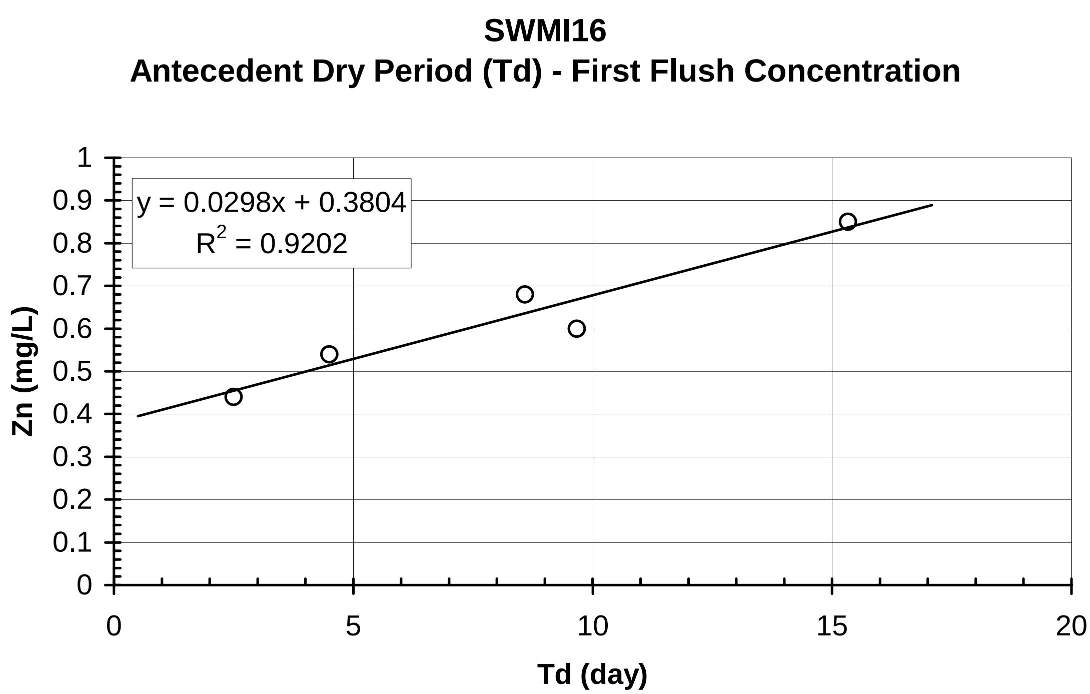


Figure 25 Correlation of antecedent dry period versus first-flush concentration of total suspended solids (2000-2004) at Hampton Avenue & Lincoln Creek Parkkway, Milwaukee (SWMI08)

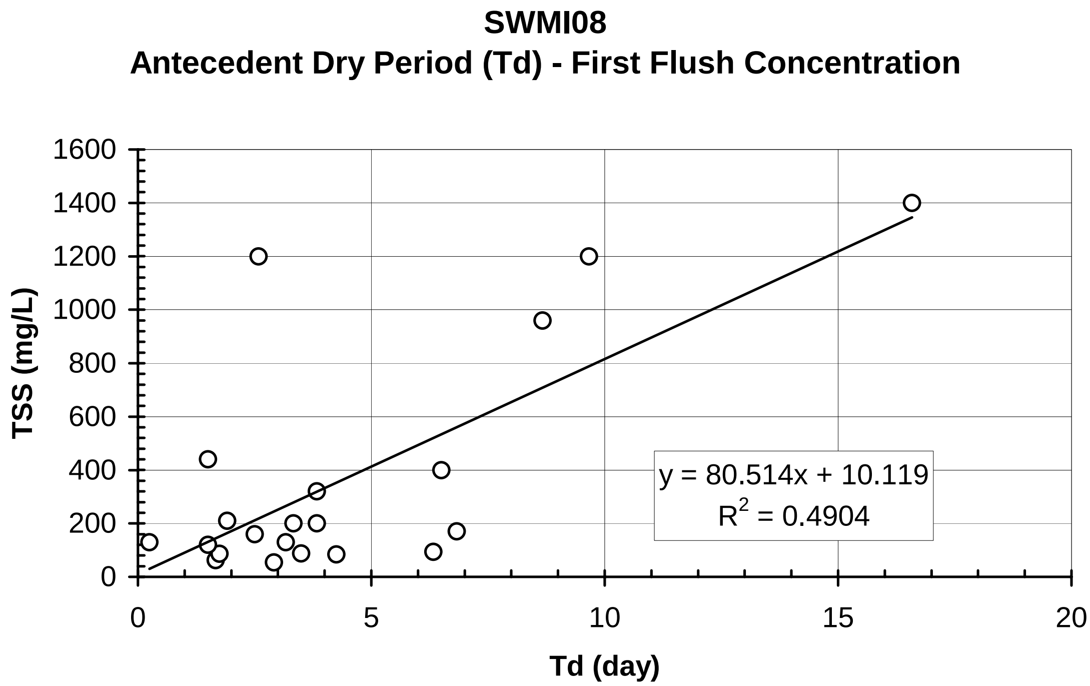
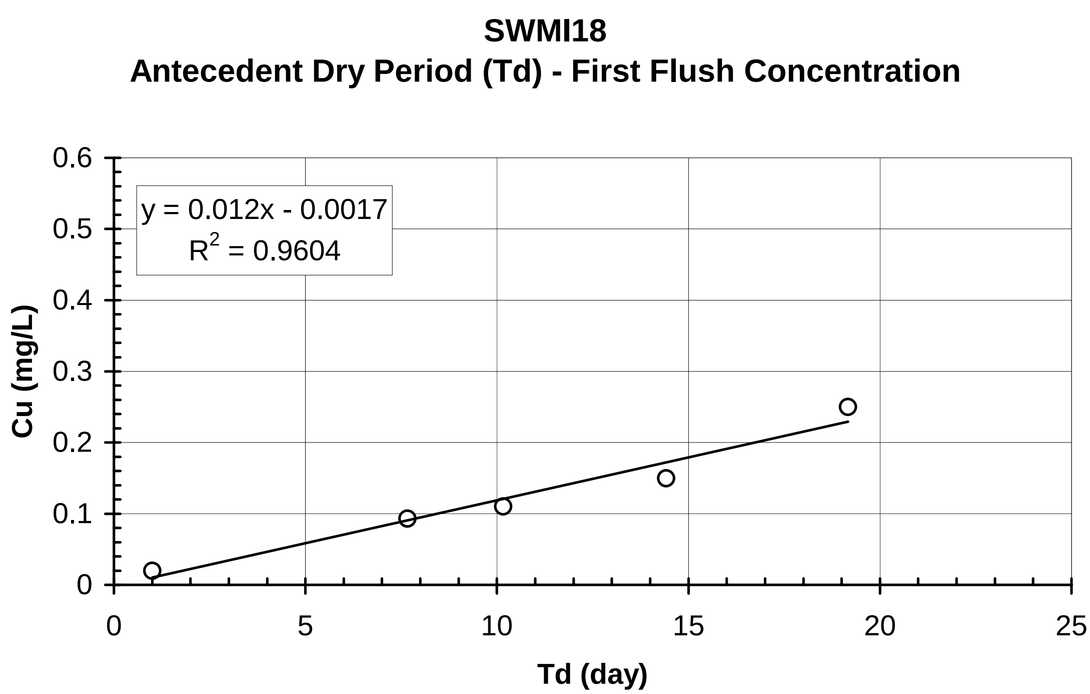


Figure 26 Correlation of antecedent dry period versus first-flush concentration of Copper (2000-2004) at Miller Park east parking lot at sausage house, Milwaukee (SWMI18)



7.6 COMPARISON OF RESULTS WITH STANDARDS AND LITERATURE VALUES

Table G –1 shows the average concentrations of 33 water quality constituents in stormwater for each sampling station. Total phosphorus (TP) exceeds the limit (1 mg/L) at SWMI07 (4345 N. 47th St, Milwaukee), SWWB09 (4939 N. Newhall, Whitefish Bay), SWMI12 (3275 S. 72nd St, Milwaukee), SWWA17 (71st and Chestnut St, Wauwatosa), and SWMI18 (Miller park east parking lot at sausage house, Milwaukee). In the soil TP is rapidly immobilized as calcium or iron phosphates (WATERSHEDSS, 2003). Most of the phosphorus in soils is adsorbed to soil particles or incorporated into organic matter (WATERSHEDSS, 2003). Phosphate is only freely soluble in acid solutions and under reducing conditions (WATERSHEDSS, 2003). Calcium can be also considered high at SWMI07, SWWB09, and SWWA17. Other sources of TP are synthetic detergent and commercial fertilizer (Sawyer et al., 2003). Total soluble phosphorus (TSP) exceeds the limit (0.05 mg/L) for all 15 measured stations. Two main sources of TSP are synthetic detergent and commercial fertilizer (Sawyer et al., 2003). The increased TP and TSP levels (discussed earlier in 7.3) could at least in part be explained by increased detergent and fertilizer usage.

Total Kjeldahl nitrogen (TKN) exceeds the limit (1.5 mg/L) for all stations. TKN is the sum of Ammonia (NH3) and Organic nitrogen. The discharge of Ammonia nitrogen (NH3) and its oxidation can rapidly reduce the dissolved-oxygen (DO) levels in rivers and estuaries (Sawyer et al., 2003). The amount of NH3 never exceeds the limit (19 mg/L). Nitrite and Nitrate (NO5) exceed the limit (0.68 mg/L) for all stations. Automobiles in dense urban areas and commercial fertilizer are primary sources of NO5 (Sawyer et al., 2003).

Calcium (Ca) and Magnesium (Mg) are high at SWMI15 (42nd St & Mt Vernon, I-94 & Menominee River, Milwaukee). Chloride (Cl) is found high at SWMI16 (Marquette interchange, Milwaukee). The primary source of these constituents is soil erosion and deicing salts. Both of these sites are transportation corridors which may link deicing salts to the high Ca, Mg and Cl concentrations at these two sites.

The 5-day biochemical oxygen demand (BOD-5) exceeds the limit (30 mg/L) at SWMI08 (Hampton & Lincoln Crk Pkwy, Milwaukee), SWWB09 (4939 N. Newhall, Whitefish Bay), SWMI12 (3275 S. 72nd St, Milwaukee), SWWA13 (Ridge Blvd & Harding, Wauwatosa), SWWA17 (71st and Chestnut St, Wauwatosa), and SWMI18 (Miller park east parking lot at sausage house, Milwaukee). BOD is the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions (Sawyer et al., 2003). High BOD reflects high-strength domestic and industrial wastes in terms of the oxygen that will be required under aerobic conditions (Sawyer et al., 2003).

Total suspended solids (TSS) exceed the limit (30 mg/L) for all stations. TSS are materials that will be retained by a filter with 2.0-μm nominal average pore size. High TSS deposition is expected to occur through biological and chemical flocculation (Sawyer et al., 2003).

Fecal coliforms (FC) exceed the limit (400 CFU/100mL) for all stations. FC are from dogs, cats, rodents in urban areas, from geese, seagulls, and waterfowls in open lands, from farm animals and wild life in rural areas (Burton and Pitt, 2002). FC enter the drainage system by wash-off of feces (Adams and Papa, 2000) or bird droppings from catchment surfaces.

Chromium (Cr) exceeds the limit (0.016 mg/L) at SWMI15 (42nd St & Mt Vernon, I-94 & Menominee River, Milwaukee) and SWMI16 (Marquette interchange, Milwaukee). The sources of Cr are from metal plating, moving engine parts, and brake lining wear (McCuen, 2004). Copper (Cu) exceeds the limit (0.0636 mg/L) at SWMI15 (42nd St & Mt Vernon, I-94 & Menominee River, Milwaukee), SWMI16 (Marquette interchange, Milwaukee), and SWMI18 (Miller park east parking lot at sausage house, Milwaukee). The primary sources of Cu are metal plating, bearing and bushing wear, moving engine parts, brake lining wear, and fungicides and insecticides applied by maintenance operations (McCuen, 2004). Lead (Pb) exceeds the limit (0.0816 mg/L) at SWMI15 (42nd St & Mt Vernon, I-94 & Menominee River, Milwaukee). The sources of Pb are tire wear, batteries, lubricating oil and grease, and bearing wear (McCuen, 2004). Zinc (Zn) exceeds the limit (0.117 mg/L) for 12 stations including SWMI15 (42nd St & Mt Vernon, I-94 & Menominee River, Milwaukee), SWMI16 (Marquette interchange, Milwaukee), and SWMI18 (Miller park east parking lot at sausage house, Milwaukee). The sources of Zn are tire wear, motor oil, and grease (McCuen, 2004).

Hardness (Hard) exceeds the limit (120 mg/L: maximum hardness levels accepted by textile industry) for 14 stations. The hardness in water is derived largely form contact with the soil and rock formations. The hard waters also originate in areas where topsoil is thick and limestone formations are present (Sawyer et al., 2003).

7.7 CHARACTERISTICS OF DRAINAGE AREAS

The drainage area is the total surface area of the catchment in question. A large drainage area generally gives the high runoff discharges. However, the results show that even some small drainage areas (SWMI06: 26 acres and SWMI07: 45 acres) exhibit high runoff discharges (discussed earlier in 7.4). The pollution load from each drainage area depends on area, runoff coefficient, land use, antecedent dry period, rainfall intensity, and storm duration.

7.8 POLLUTANT LOADS

Table 15 shows an example of load computations for measured storm events from 2000 to 2004 for Zinc (Zn) at SWMI07 (4345 N. 47th St, Milwaukee). There were 32 storm events (2000-2004) where Zinc (Zn) samples were collected. Calculations for other eight constituents (BOD-5, TSS, TP, Cl, Cu, TN, NH3, and TSP) can be found in Appendix J (attached CDs).

Table 15 Storm events and Zn loads at 4345 N. 47th St, Milwaukee (SWMI07)

Event No.[a]	Statistics	Storm Start	Storm End	Storm Duration (hr)	lb/hr/storm	lb/storm
1		11/2/2000 5:00	11/2/2000 9:00	4	0.16	0.64
2		11/9/2000 0:00	11/9/2000 6:00	6	0.03	0.17
3		11/16/2000 6:00	11/16/2000 11:00	5	0.01	0.06
4		11/29/2000 4:00	11/29/2000 10:00	6	0.31	1.85
5		4/5/2001 16:00	4/5/2001 21:00	5	0.41	2.03
6		4/8/2001 23:00	4/9/2001 10:00	11	1.22	13
7		4/11/2001 1:00	4/11/2001 5:00	4	0.16	0.64
8		4/20/2001 2:00	4/20/2001 11:00	9	0.83	7.51
9		5/3/2001 6:00	5/3/2001 14:00	8	0.7	5.64
10		5/7/2001 6:00	5/7/2001 10:00	4	0.12	0.46
11		5/10/2001 3:00	5/10/2001 7:00	4	0.11	0.45
12		5/14/2001 10:00	5/14/2001 15:00	5	0.33	1.65
13		5/17/2001 18:00	5/17/2001 23:00	5	1.13	5.64
14		5/21/2001 9:00	5/21/2001 19:00	10	0.22	2.16
15		5/23/2001 13:00	5/23/2001 18:00	5	0.62	3.09
16		5/26/2001 23:00	5/27/2001 14:00	15	0.15	2.29
17		6/11/2001 21:00	6/12/2001 16:00	19	2.53	48
18		7/17/2001 8:00	7/17/2001 15:00	7	1.49	10
19		8/16/2001 0:00	8/16/2001 13:00	13	0.02	0.28
20		10/22/2001 15:00	10/23/2001 6:00	15	3.01	45
21		6/2/2002 20:00	6/3/2002 1:00	5	0.2	1.01
22		8/4/2002 3:00	8/4/2002 8:00	5	0.43	2.15
23		8/12/2002 17:00	8/13/2002 3:00	10	1.29	13
24		8/21/2002 19:00	8/22/2002 2:00	7	1.82	13
25		9/18/2002 5:00	9/18/2002 14:00	9	0.62	5.55
26		10/2/2002 0:00	10/2/2002 8:00	8	0.22	1.75
27		10/4/2002 9:00	10/4/2002 15:00	6	0.32	1.93
28		4/30/2003 12:00	4/30/2003 17:00	5	1.04	5.18
29		5/20/2004 16:00	5/20/2004 20:00	4	0.24	0.96
30		6/10/2004 10:00	6/10/2004 16:00	6	0.47	2.84
31		8/24/2004 7:00	8/24/2004 10:00	3	0.09	0.27
32		10/23/2004 1:00	10/23/2004 3:00	2	0.14	0.27
Total	N				32	32
	Mean				0.64	6.22
	Std. Error of Mean				0.13	2

[a] Events are only listed when simultaneous measurement of pollutant concentration were made.

Results from Pie charts in Appendix K indicate that the percentages of BOD, TSS, TP, Cl, Cu, Zn, TN, and NH3 load (lb/storm/acre) are high at SWMI06 (Milwaukee County Zoo, Milwaukee), SWMI07 (4345 N. 47th St, Milwaukee), SWMI08 (Hampton & Lincoln Crk Pkwy, Milwaukee), and SWMI18 (Miller park east parking lot at sausage house, Milwaukee). High loads (lb/storm/acre) at SWMI06 (Milwaukee County Zoo, Milwaukee), SWMI07 (4345 N. 47th St, Milwaukee), and SWMI08 (Hampton & Lincoln Creek Parkway, Milwaukee) result in part from high runoff discharges (Fig. 27). A small catchment area with high concentrations (Fig. 28) may cause highs load (lb/storm/acre) as for example at SWMI18 (Miller park east parking lot at sausage house, Milwaukee) (Fig. K-11). The percentage of TSP load (lb/storm/acre) is high at SWWA17 (71st and Chestnut St, Wauwatosa) (Fig. K-17). This may be from the high concentrations of TSP measured at this location.

Figure 27 % Runoff discharge for all sampling stations

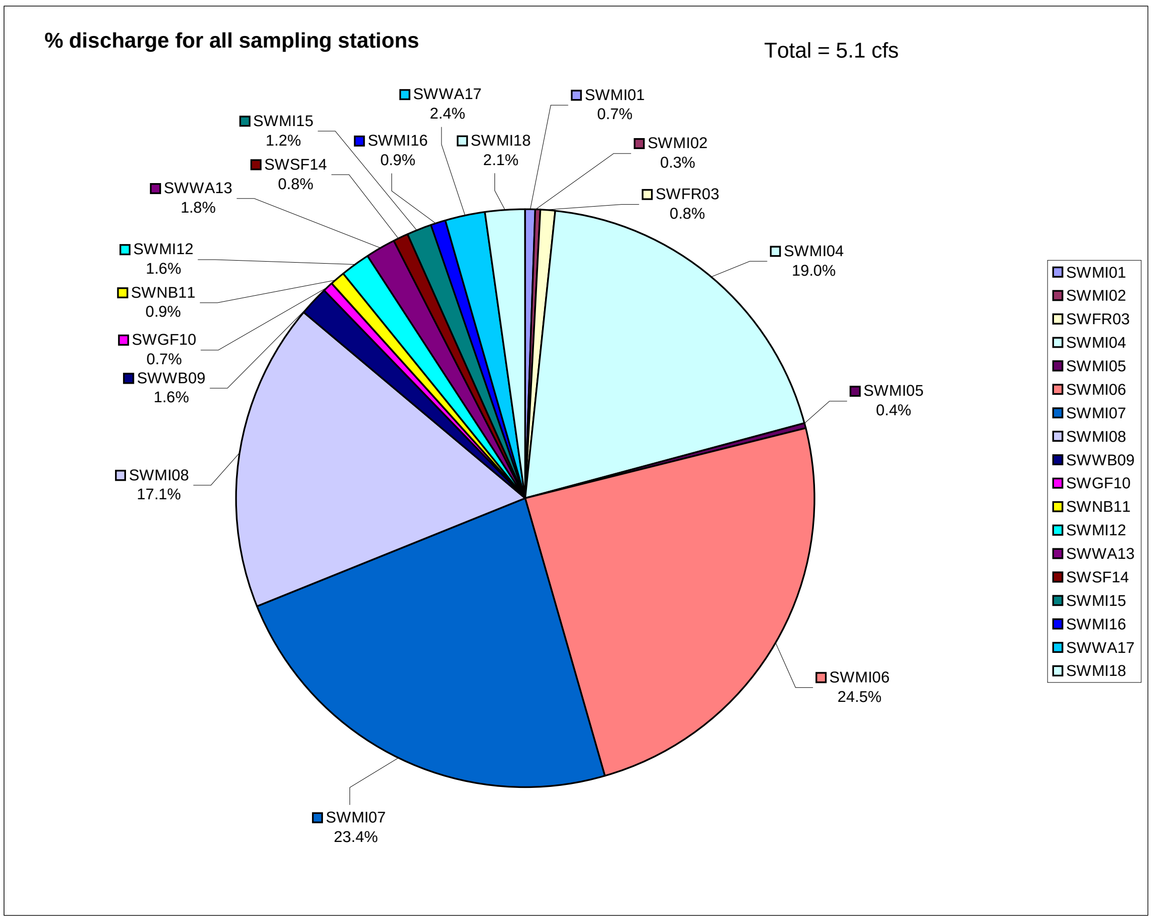
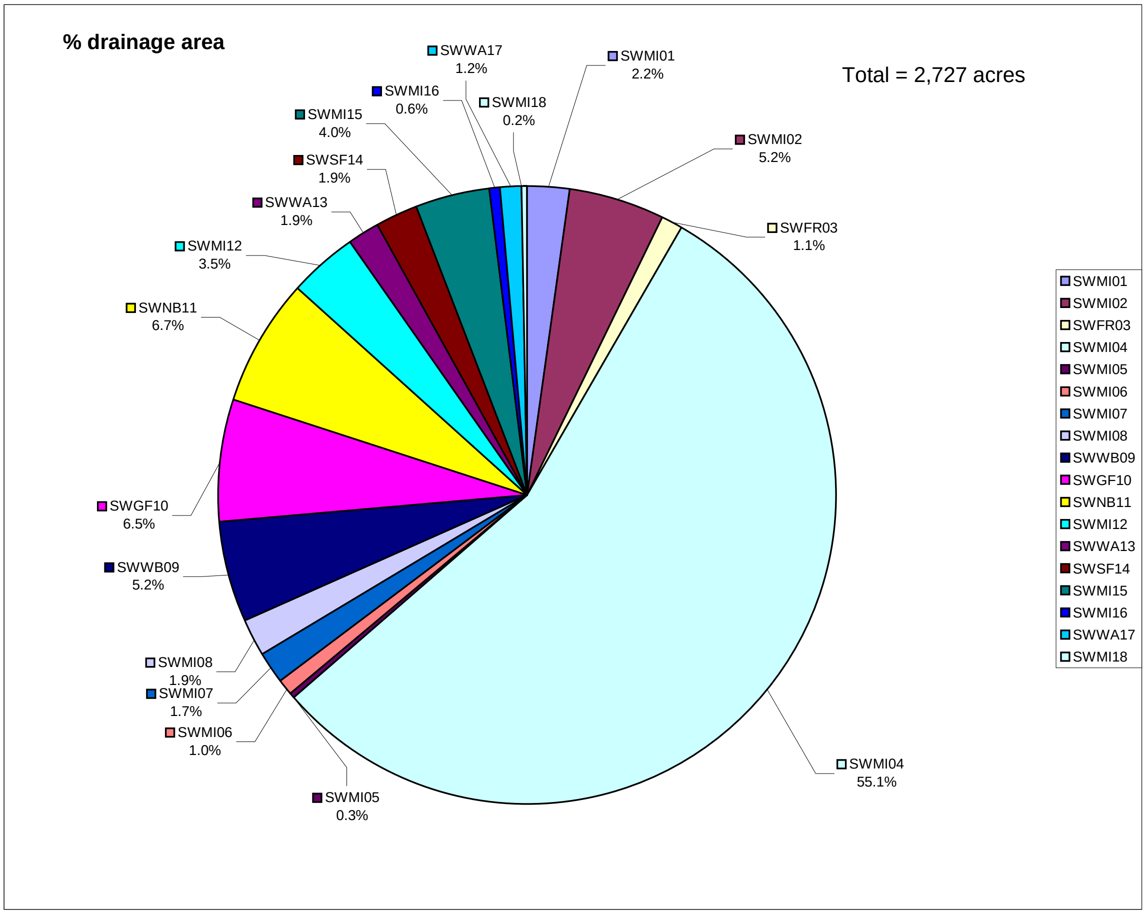


Figure 28 % Drainage area for all sampling stations



8. CONCLUSIONS

1. Stormwater samples were found to be significantly higher in pollutant concentration than either State derived Surface Water Quality Standards or other guideline levels established for many parameters.

2. The length of the antecedent dry period (t_d) was found to be significant parameter determining pollutant concentrations and loadings due to the gradual accumulation of pollutants during the dry period prior to a storm.

3. First and second flush pollutant concentrations are dependent on the duration and intensity of rainfall but are also highly dependent on the solubility of the pollutant. Soluble pollutants (chloride, E-coli, and fecal coliforms) tend to have a more uniform or homogeneous concentrations over the duration of the runoff event while insoluble pollutants (total suspended solids, BOD-5, copper, and zinc) tend to runoff with the first flush. Knowing the runoff nature of the pollutant of concern will help determine the best management practice to control that pollutant.

4. High correlations between antecedent dry period (t_d) and first flush concentrations of fecal coliforms and nutrients were found in residential areas, whereas high correlations between copper and zinc were found associated with areas of high automobile traffic. Of note is that daily freeway vehicle-miles of travel for Milwaukee have nearly doubled in the time period from 1985 to 2003 (from approximately 6000 to 10,400 thousands of vehicle-miles/day) according to a 2005 Urban Mobility Study done by Texas Transportation Institute at Texas A&M University System.

5. Many pollutants were found to have higher concentrations in stormwater than in combined sewer overflow (CSO). These include calcium, magnesium and hardness (from soil erosion), copper and zinc (from automobile traffic), total phosphorus and total suspended solids (from agricultural and urban runoff).

6. Fecal coliforms were found to be very high in stormwater ($1.49 \pm 1.39 \cdot 10^5$) but lower than CSO's ($9.34 \pm 5.43 \cdot 10^5$). Levels of bacteria, however, were within the same order of magnitude whether from stormwater or CSO's.

7. Pollutant loadings are dependent on the drainage area, runoff coefficient, land use, antecedent dry period, and duration and intensity of the rainfall.

8. The largest loads of pollutants as a percentage (lbs/storm) are carried by four of the eighteen monitored sewersheds (below). These four sewersheds represent: 82% of the zinc (Zn) loading; 86% of the total suspended solids (TSS) loading; 77% of the ammonia (NH_3) loading; and 77% of the total phosphorus (TP). These loading are

most likely a result of the combination of the drainage area and impervious cover within each of the four sewershed.

a. Bayview Park/Lake Michigan (SWMI04 - 30% Zn, 21%TSS, 29% NH_3, and 17% TP)
b. N.47th Street/Lincoln Creek (SWMI07- 32% Zn, 40% TSS, 25% NH_3, and 43% TP)
c. Hampton Ave /Lincoln Creek (SWMI08 - 16% Zn, 19% TSS, 15% NH_3 and 11% TP)
d. Milwaukee County Zoo (SWMI06 – 4% Zn, 6% TSS, 10% NH_3 and 6% TP)

9. With regards to time trends, hardness, magnesium, calcium, total Kjehdal nitrogen, thallium and total suspended solids are decreasing over time; total phosphorus, fecal coliforms, copper and lead are increasing over time, and zinc appears to be steady.

10. Any future effort that includes the separation of sewers (combined sewers into separate sanitary and stormsewer sewers) should require stormwater management options to reduce pollutant concentrations because some concentrations in stormwater are higher than what is found in combined sewer overflow (CSOs), and stormwater runoff events occur much more frequently than overflows.

9. RECOMMENDATIONS

Recommendations from this study are:

1. Evaluate stormwater data compared to CSO data from time period 2000-2006. Evaluate how stormwater data from both a defined first and second flush condition compares to CSO data in terms of both pollutant concentration and loading and develop an estimate as to the fraction (%) of stormwater in CSO's.

2. Evaluate stormwater hydrographs with multiple data points throughout the duration of the storms. The duration and intensity of rainfall should be used with estimates of pollutant build up in the various storm sewersheds/watersheds to develop a better estimate of unit loading for the drainage area.

3. Evaluate seasonality of stormwater constituents; determine when concentrations are expected to be highest; evaluate how snowmelt/thaw differs or compares to other types of runoff events and evaluate rainfall/precipitation data to determine the link between the length of antecedent dry deposition period and ground saturation to pollutant load.

4. Homogeneity of trends of water quality constituents in different seasons and stations needs to be considered. This analysis will look at individual stations and seasons in order to gain a better understanding of increases in pollutants that are station specific. This applies for example to zinc that is closely associated with traffic drainage areas and to phosphorus that is associated with residential areas and summer or fall season.

5. First and second flush pollutant concentrations are dependent on the antecedent dry period, rainfall duration, and rainfall intensity but are also highly dependent on the solubility of the pollutant. Soluble pollutants (chloride, E-coli, and fecal coliforms) tend to have a more uniform or homogeneous concentrations over the duration of the runoff event while insoluble pollutants (total suspended solids, BOD-5, copper, and zinc) tend to runoff with the first flush. The existence of this first-flush effect provides an opportunity for controlling pollutants of high initial concentration. Many detention facilities are designed to capture and treat the first-flush pollutants in the first 0.47 to 0.98 inches of rainfall.

6. Determine significant sources and contaminants of concern within each storm sewershed using GIS (geographic information system). Investigate the accuracy of

drainage areas by examining sewer pipe networks, and compute the percentage of impervious area for each catchment by categorizing subareas by land use. Using the GIS, potential BMPs (best management practices) will be evaluated and alternative scenarios for drainage/catchment areas and possible treatment scenarios should be developed.

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Appendix A : Wisconsin Department of Natural Resources Criteria

Chapter NR 102
[Water Quality Standards for Wisconsin Surface Waters]
&
Chapter NR 105
[Surface Water Quality Criteria and Secondary Values for Toxic Substances]

(1) Standards for Fish and Aquatic Life

Criteria	Cold Water	Warm Water
Dissolved Oxygen (DO)	≥ 5 mg/L ≥ 6 mg/L - in trout streams at any time ≥ 7 mg/L - in trout streams during spawning season ≥ natural background - in great lakes used by salmonids during spawning	≥ 5 mg/L
Temperature	≈ natural background - in trout streams	≤ 89 ^{o}F
Maximum Temperature Rise (above the existing natural temperature at the edge of the mixing zone)	≤ 5 ^{o}F - for streams ≤ 3 ^{o}F - for lakes	≤ 5 ^{o}F - for streams ≤ 3 ^{o}F - for lakes
pH	6.0 (± 0.5) ≤ pH ≤ 9.0 (± 0.5)	6.0 (± 0.5) ≤ pH ≤ 9.0 (± 0.5)
Phosphorus	1 mg/L	1 mg/L

Acute Toxicity Criteria for Substances With Toxicity Unrelated to Water Quality

(in μg/L except where indicated)

Substance	Cold Water	Warm Water Sport Fish, Warm Water Forage, and Limited Forage Fish	Limited Aquatic Life
Arsenic (+3)*	339.8	339.8	339.8
Chromium (+6)*	16.02	16.02	16.02
Mercury (+2)*	0.83	0.83	0.83
Cyanide, free	22.4	45.8	45.8
Chlorine*	19.03	19.03	19.03
Gamma – BHC	0.96	0.96	0.96
Dieldrin	0.24	0.24	0.24
Endrin	0.086	0.086	0.12
Toxaphene	0.73	0.73	0.73
Chlorpyrifos	0.041	0.041	0.041
Parathion	0.057	0.057	0.057

Note:* - Criterion listed is applicable to the "total recoverable" form except for chlorine which is applicable to "total residual" form.

Acute Toxicity Criteria for Substances With Toxicity Related to Water Quality

(all in μg/L)

Water Quality Parameter: Hardness (in ppm as $CaCO_3$)

ATC = $e^{(V\ (hardness)\ +\ \ln ACI)}$			ATC at Various Hardness (ppm) Levels		
Substance	V	ln ACI	50	100	200
Total Recoverable Cadmium:					
Cold Water/	1.147	-3.8104	1.97	4.36	9.65
Warm Water Sport Fish, Warm Water Forage, and Limited Forage Fish/	1.147	-2.9493	4.65	10.31	22.83
Limited Aquatic Life	1.147	-1.9195	13.03	28.87	63.92
Total Recoverable Chromium (+3): All surface Waters	0.819	3.7256	1022	1803	3181
Total Recoverable Copper: All surface Waters	0.8561	-1.1199	9.29	16.82	30.45
Total Recoverable Lead: All surface Waters	0.9662	0.2226	54.73	106.92	208.90
Total Recoverable Nickel: All surface Waters	1.083	2.2289	642.7	1361	2434
Total	0.8745	0.7634	65.66	120.4	220.7

Recoverable Zinc: All surface Waters					

Water Quality Parameter: pH

$ATC = e^{(V\,(pH) + \ln ACI)}$

Substance	V	ln ACI	506.5	7.8	8.8
Pentachlorophenol All surface Waters	1.0054	-4.877	5.25	19.40	53.01

Water Quality Parameter Ranges for Substances With Acute Toxicity Related to Water Quality

Substance	Parameter	Applicable Range
Cadmium	Hardness (ppm)	6 - 457
Chromium (+3)	Hardness (ppm)	13 - 301
Copper	Hardness (ppm)	14 - 427
Lead	Hardness (ppm)	12 - 356
Nickel	Hardness (ppm)	19 - 157
Zinc	Hardness (ppm)	12 - 333
Pentachlorophenol	pH (s.u.)	6.6 - 8.8

Secondary Acute Factors

Number of minimum data requirements satisfied	Adjustment factor
1	21.9
2	13.0
3	8.0
4	7.0
5	6.1
6	5.2
7	4.3

Chronic Toxicity Criteria for Substances With Toxicity Related to Water Quality

(all in μg/L)

Water Quality Parameter: Hardness (in ppm as $CaCO_3$)

$CTC = e^{(V\,(hardness) + \ln CCI)}$

			CTC at Various Hardness (ppm) Levels		
Substance	V	ln CCI	50	100	200
Total Recoverable Cadmium: All surface	0.7852	-2.7150	1.43	2.46	3.82

Water Quality Parameter Ranges for Substances With Chronic Toxicity Related to Water Quality

Substance	Parameter	Applicable Range
Cadmium	Hardness (ppm)	18 - 175

Chronic Toxicity Criteria Using Acute-Chronic Ratios for Substances With Toxicity Unrelated to Water Quality

(all in μg/L)

Substance	Cold Water	Warm Water Sport Fish, Warm Water Forage, and Limited Forage Fish	Limited Aquatic Life
Arsenic (+3)*	148	152.5	152.2
Chromium (+6)*	10.98	10.98	10.98
Mercury (+2)*	0.44	0.44	0.44
Cyanide, free	5.22	11.47	11.47
Chlorine*	7.28	7.28	7.28
Dieldrin	0.055	0.077	0.077
Endrin	0.072	0.072	0.10
Parathion	0.011	0.011	0.011

Note:* - Criterion listed is applicable to the “total recoverable” form except for chlorine which is applicable to “total residual” form.

Chronic Toxicity Criteria Using Acute-Chronic Ratios for Substances With Toxicity Related to Water Quality

(all in μg/L)

Water Quality Parameter: Hardness (in ppm as $CaCO_3$)

CTC = $e^{(V\ (hardness)\ +\ \ln CCI)}$			CTC at Various Hardness (ppm) Levels		
Substance	V	ln CCI	50	100	200
Total Recoverable Chromium (+3):					
Cold Water/	0.819	0.6851	48.86	86.21	152.1
Warm Water Sport Fish/	0.819	1.112	74.88	132.1	233.1
All others	0.819	1.112	74.88	132.1	233.1
Total Recoverable Copper: All surface Waters	0.8561	-1.4647	6.58	11.91	21.57
Total Recoverable Lead: All surface Waters	0.9662	-1.1171	14.33	28.01	54.71
Total Recoverable Nickel: All surface Waters	1.083	0.033	71.50	151.5	270.8
Total Recoverable Zinc: All surface Waters	0.8745	0.7634	65.66	120.4	220.7

Water Quality Parameter: pH

CTC = $e^{(V (pH) + \ln CCI)}$			CTC at Various pH (s.u.) Levels		
Substance	V	ln CCI	506.5	7.8	8.8
Pentachlorophenol: Cold Water	1.0054	-5.1468	4.43	14.81	40.48
All other surface Waters	1.0054	-4.9617	5.33	12.82	48.70

(2) Standards for recreational use

Parameter	Cold water	Warm water
Fecal Coliform	≤ 200 #/100 ml (≥ 5 samples/month) ≤ 400 #/100 ml (≥ 10% of all samples/month)	≤ 200 #/100 ml (≥ 5 samples/month) ≤ 400 #/100 ml (≥ 10% of all samples/month)

Note: also should meet the NR 103 WATER QUALITY STANDARDS FOR WETLANDS and NR 104 USES AND DESIGNATED STANDARDS.

(3) Standards for public health and welfare

Threshold Concentration (TC_W) for Substance Causing Taste and Odor in Water

Substance	Threshold Concentration (ug/L)[1]
Acenaphthene	20
Chlorobenzene	20
2-Chlorophenol	0.1
3-Chlorophenol	0.1
4-Chlorophenol	0.1
Copper	1000
2,3-Dichlorophenol	0.04
2,4-Dichlorophenol	0.3
2,5-Dichlorophenol	0.5
2,6-Dichlorophenol	0.2
3,4-Dichlorophenol	0.3
2,4-Dimethylphenol	400
Hexachlorocyclopentadiene	1
2-Methyl-4-Chlorophenol	1800
3-Methyl-4-Chlorophenol	3000
3-Mehtyl-6-Chlorophenol	20
Nitrobenzene	30
Pentachlorophenol	30
Phenol	300
2,3,4,6-Tetrachlorophenol	1
2,4,5-Trichlorophenol	1
2,4,6-Trichlorophenol	2
Zinc	5000

[1] A threshold concentration expresses in micrograms per liter (µg/L) can be converted to milligrams per liter (mg/L) by dividing the threshold concentration by 1000.

Human Threshold Criteria

(µg/L unless specified otherwise)

Substance	Public Water Supply: Warm Water Sport Fish Communities	Public Water Supply: Cold water[4] Communities	Non-public Water Supply: Warm Water Sport Fish, Warm Water Forage, and Limited Forage Fish Communities	Non-public Water Supply: Cold water Communities	Non-public Water Supply: Limited Aquatic Life
Acrolein	7.2	3.4	15	4.4	2800
Antimony[2]	10	10	2200	2200	2200
Benzene[2]	5	5	610	260	4000
Bis(2-chloroisoproprыl) ether	1100	1100	55000	34000	220000
Cadmium[2]	10	10	1200	1200	2800
*Chlordane (ng/L)	2.4	0.70	2.4	0.70	310000
Chlorobenzene[2]	100	100	4900	1600	110000
Chromium(3+)	28000	28000	2500000	2500000	5600000
Chromium(6+)	140	140	13000	13000	28000
Cyanide, Total[2]	200	200	40000	40000	120000
*4,4'-DDT (ng/L)	3.0	0.88	3.0	0.88	2800000
1,2-Dichlorobenzene[2]	600	600	6400	1900	500000
1,3-Dichlorobenzene	1400	710	3300	1000	500000
Cis-1,2 Dichloroethene[2]	70	70	14000	9000	56000
Tran-1,2 Dichloroethene[2]	100	100	24000	13000	110000
Dichloromethane[2] (methylene chloride)	5	5	95000	72000	328000
2,4-Dichlorophenol	74	58	580	180	17000
Dichloropropenes[3] (1,3-Dichloropropene)	8.3	8.2	420	260	1700
*Dieldrin (ng/L)	0.59	0.17	0.59	0.17	280000
2,4-Dimethylphenol	450	430	11000	4500	94000
Diethyl phthalate[2]	5000	5000	68000	21000	4500000
Dimethyl phthalate (mg/L)	241	184	1680	530	56000
4,6-Dinitro-o-cresol	100	96	1800	640	22000
Dinitrophenols[3] (2,4-Dinitrophenol)	55	55	2800	1800	11000
2,4-Dinitrotoluene	0.51	0.48	13	5.3	110
Endosulfan	87	41	181	54	33600
Ethybenzene[2]	700	700	12000	3700	560000
Fluoranthene	890	610	4300	1300	220000
*Hexachlorobenzene	0.075	0.022	0.075	0.022	4500
Hexachlorocyclopentadiene	50	50	980	310	39000
Hexachloroethane	8.7	3.3	13	3.7	5600
*gamma-BHC (lindane)	0.20	0.20	0.84	0.25	1900
Isophorone	5500	5300	180000	80000	1100000
Lead	10	10	140	140	2240
*Mercury[5]	0.0015	0.0015	0.0015	0.0015	336
Nickel2	100	100	43000	43000	110000

*Pentachlorobenzene	0.46	0.14	0.47	0.14	4500
Selenium[2]	50	50	2600	2600	28000
Silver	140	140	28000	28000	28000
*2,3,7,8-TCDD (pg/L)	0.11	0.032	0.11	0.032	7300
*1,2,4,5-Tetrachlorobenzene	0.54	0.17	0.58	0.17	1700
Tetrachloroethene	5.8	4.6	46	15	1300
Toluene[2]	1000	1000	760100	26000	1200000
1,1,1-Trichloroethane[2]	200	200	270000	110000	2000000
2,4,5-Trichlorophenol	1600	830	3900	1200	560000

* Indicates substances that are Bioaccumulative chemicals of concern (BCCs).

[1] A human threshold criterion expresses in micrograms per liter (µg/L) can be converted to milligrams per liter (mg/L) by dividing the criterion by 1000.

[2] For this substance that human threshold criteria for public water supply receiving water classifications equal the maximum contaminant level pursuant to s.NR 105.08 (3) (b).

[3] The human threshold criteria for this chemical class are applicable to each isomer.

[4] For BCCs, these criteria apply to all water of Great Lakes Systems.

[5] The mercury criteria were calculated using 20 g/day fish consumption and the human non-cancer criteria derivation procedure in 40 CFR Part 132, Appendix C. For these criteria, 40 CFR Part 132, Appendix C as stated on September 1, 1997 is incorporated by reference.

Human Cancer Criteria

(µg/L unless specified otherwise)

Substance	Public Water Supply: Warm Water Sport Fish Communities	Public Water Supply: Cold water[4] Communities	Non-public Water Supply: Warm Water Sport Fish, Warm Water Forage, and Limited Forage Fish Communities	Non-public Water Supply: Cold water Communities	Non-public Water Supply: Limited Aquatic Life
Acrylonitrile	0.57	0.45	4.6	1.5	130
Arsenic[2]	0.185	0.185	50	50	50
*alpha-BHC	0.012	0.0037	0.013	0.0039	11
*gamma-BHC (lindane)	0.052	0.018	0.064	0.019	54
*BHC, technical grade	0.038	0.013	0.047	0.014	39
Benzene[2]	5	5	140	45	1300
Benzidine (ng/L)	1.5	1.5	81	55	300
Beryllium	0.054	0.054	0.33	0.33	16
Bis(2-chloroethyl) ether	0.31	0.29	7.6	3.0	64
Bis(chloromethyl) ether (ng/L)	1.6	1.6	96	79	320
Carbon tetrachloride	2.5	2.1	29	9.5	540
*Chlordane (ng/L)	0.41	0.12	0.41	0.12	54000
Chloroethene (vinyl chloride)	0.18	0.18	10	6.8	37
Chloroform (trichloromethane)	55	53	1960	922	11200
*4,4[1]-DDT (ng/L)	0.22	0.065	0.22	0.065	206000
1,4-Dichlorobenzene	14	12	163	54	2940
3,3[1]-Dichlorobenzidine	0.51	0.29	1.5	0.46	154
1,2-Dichloroethane	3.8	3.8	217	159	770
Dichloromethane[2] (methylene chloride)	5	5	2700	2100	9600
*Dieldrin (ng/L)	0.0091	0.0027	0.0091	0.0027	4400
2,4-Dinitrotoluene	0.51	0.48	13	5.3	110
1,2-Diphenylhydrazine	0.38	0.31	3.3	1.04	88
Halomethanes3	55	53	1960	922	11200
*Hexachlorobenzene (ng/L)	0.73	0.22	0.73	0.22	44000
*Hexachlorobutadiene	0.59	0.19	0.69	0.2	910
Hexachloroethane	7.7	2.9	11	3.3	5000
N-Nitrosodiethylamine	2.3	2.3	150	140	460
N-Nitrosodimethylamine	0.0068	0.0068	0.46	0.46	1.4
N-Nitrosodi-n-butylamine	0.063	0.062	2.5	1.3	13
N-Nitrosodiphenylamine	44	23	116	34	13
N-Nitrosopyrrolidine	0.17	0.17	11	11	34
*Polychlorinated biphenyls (ng/L)	0.01	0.003	0.01	0.003	9100
*2,3,7,8-Tetrachlorodibenzo-p-dioxin (pg/L)	0.014	0.0041	0.014	0.0041	930
1,1,2,2-Tetrachloroethane	1.7	1.6	52	22	350
Tetrachloroethene	5.8	4.6	46	15	1300
*Toxaphene (ng/L)	0.11	0.034	0.14	0.034	63600

1,1,2-Trichloroethane[2]	6.0	6.0	195	87	1200
Trichlorothene[2]	5	5	539	194	6400
2,4,6-Trichlorophenol	29	24	30	97	6400

* Indicates substances that are Bioaccumulative chemicals of concern (BCCs).

[1] A human cancer criterion expresses in micrograms per liter (μg/L), nanograms per liter (ηg/L) or picograms per liter (ρg/L) can be converted to milligrams per liter (mg/L) by dividing the criterion by 1000, 1,000,000, 1,000,000,000, repectively.

[2] For this substance that human cancer criteria for public water supply receiving water classifications equal the maximum contaminant level pursuant to s.NR 105.08 (4) (b).

[3] The human cancer criteria for halomethanes are applicable to any combination of the following chemicals: bromomethane (methyl bromide), chloromethane (methyl chloride), tribromomethane (bromoform), bromodichloromethane (dichloromethyl bromide), dochlorodifluoromethane (fluorocarbon 12) and trichlorofluoromethane (fluorocarbon 11).

[4] For BCCs, these criteria apply to all water of Great Lakes Systems.

(4) Standards for wildlife

Substance	Criteria (in ηg/L, except where indicated
DDT & Metabolite	0.011
Mercury	1.3
Polychlorinated Biphenyls	0.12
2,3,7,8 – TCDD	0.003 (ρg/L)

Appendix B : Wisconsin Pollutant Discharge Elimination System (WPDES)

<table>
<tr><th>Parameter</th><th>Limits and Units</th></tr>
<tr><td>BOD_5, Total (weekly avg)</td><td>30 mg/L</td></tr>
<tr><td>BOD_5, Total (monthly avg)</td><td>45 mg/L</td></tr>
<tr><td>Suspended solids, Total (weekly avg)</td><td>30 mg/L</td></tr>
<tr><td>Suspended solids, Total (monthly avg)</td><td>45 mg/L</td></tr>
<tr><td>Chlorine, Total Residual (daily max)</td><td>38 μg/L</td></tr>
<tr><td>Chlorine, Total Residual (weekly max)</td><td>80 μg/L</td></tr>
<tr><td>Fecal Coliform</td><td>400 #/100 ml</td></tr>
<tr><td>Phosphorus, Total</td><td>1.0 mg/L</td></tr>
<tr><td>pH Field (daily)</td><td>6 < pH< 9</td></tr>
<tr><td>Nitrogen, Ammonia (weekly) (NH_3-N) Total</td><td>
<table>
<tr><th>Month</th><th>pH=7</th><th>pH=7.1</th><th>pH=7.2</th><th>pH=7.3</th><th>pH=7.4</th><th>pH=7.5</th></tr>
<tr><td>June</td><td>16.7</td><td>16.7</td><td>13.1</td><td>13.1</td><td>13.1</td><td>13.1</td></tr>
<tr><td>July</td><td>11.3</td><td>8.8</td><td>8.8</td><td>8.8</td><td>6.8</td><td>6.8</td></tr>
<tr><td>August</td><td>11.1</td><td>8.7</td><td>8.7</td><td>6.7</td><td>6.7</td><td>6.7</td></tr>
<tr><td>September</td><td>12.7</td><td>12.7</td><td>10.0</td><td>10.0</td><td>10.0</td><td>10.0</td></tr>
</table>
mg/L</td></tr>
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Note: __ this number is not available on web.

Appendix C : Stormwater NPDES Permit
(attached CDs)

Table C - 1 NPDES constituent benchmark values

Constituent name	Benchmark level, mg/L
Biochemical Oxygen Demand (5 days)	30
Chemical Oxygen Demand	120
TSS	100
Oil and Grease	15
Nitrate and Nitrite Nitrogen	0.68
Total Phosphorus	2.0
pH	6.0-9.0 s.u.
Acrylonitrile	7.55
Aluminum, Total	0.75
Ammonia	19
Antimony, Total	0.636
Arsenic, Total	0.16854
Benzene	0.01
Beryllium, Total	0.13
Butylbenzyl Phthalate	3
Cadmium, Total	0.0159
Chloride	860
Copper, Total	0.0636
Cyanide, Total	0.0636
Dimethyl Phthalate	1.0
Ethylbenzene	3.1
Fluoranthene	0.042
Fluoride	1.8
Iron, Total	1.0
Lead, Total	0.0816
Magnesium, Total	0.0636
Manganese	1.0
Mercury, Total	0.0024
Nickel, Total	1.41
PCB-1016	0.000127
PCB-1221	0.1
PCB-1232	0.000318
PCB-1242	0.0002
PCB-1248	0.002544
PCB-1254	0.10
PCB-1260	0.000477
Phenols, Total	1.0
Pyrene	0.01
Selenium, Total*	0.2385

Silver, Total	0.0318
Toluene	10.0
Trichloroethylene	0.0027
Zinc, Total	0.117

Notes: * Limit established for oil and gas exploration and production facilities only

Appendix D : EPA National Water Quality Criteria

(attached CDs)

Appendix E : Stormwater Data Charts

Figure E - 1 Alkalinity (Alk) 1st and 2nd flush in stormwater

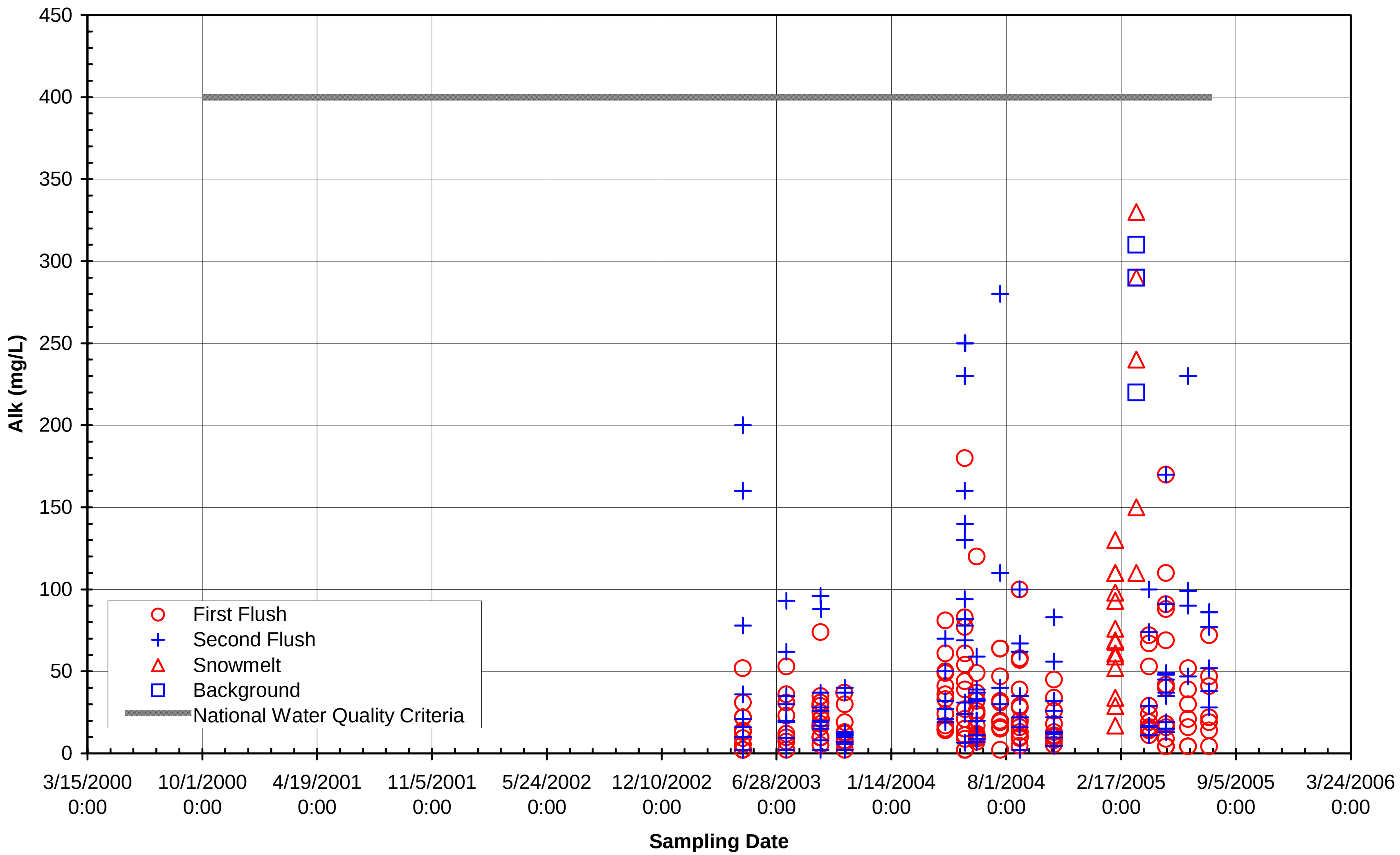


Figure E - 2   Alkalinity (Alk) box chart in stormwater

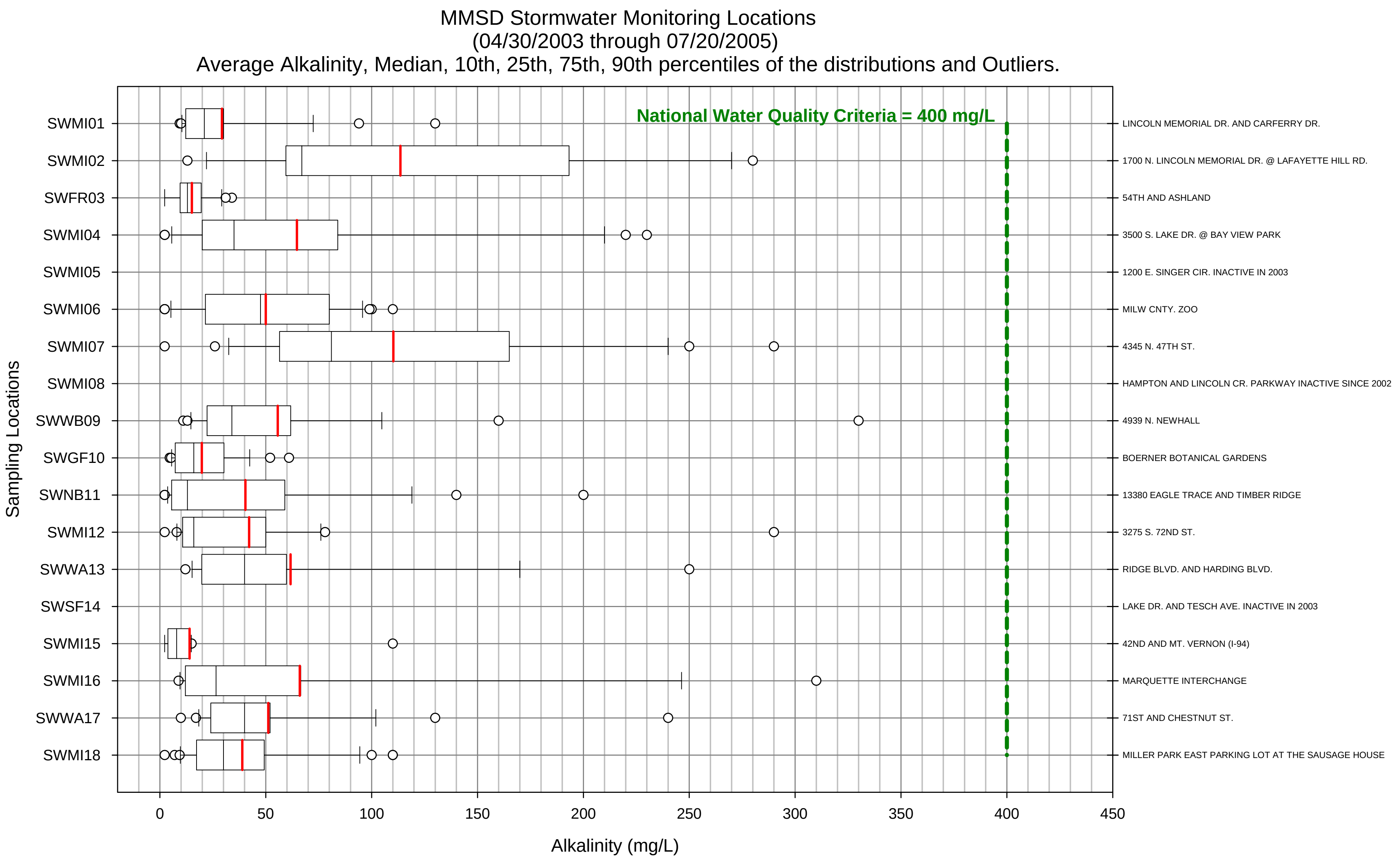


Figure E - 3 Ammonia Nitrogen (NH3) 1st and 2nd flush in stormwater

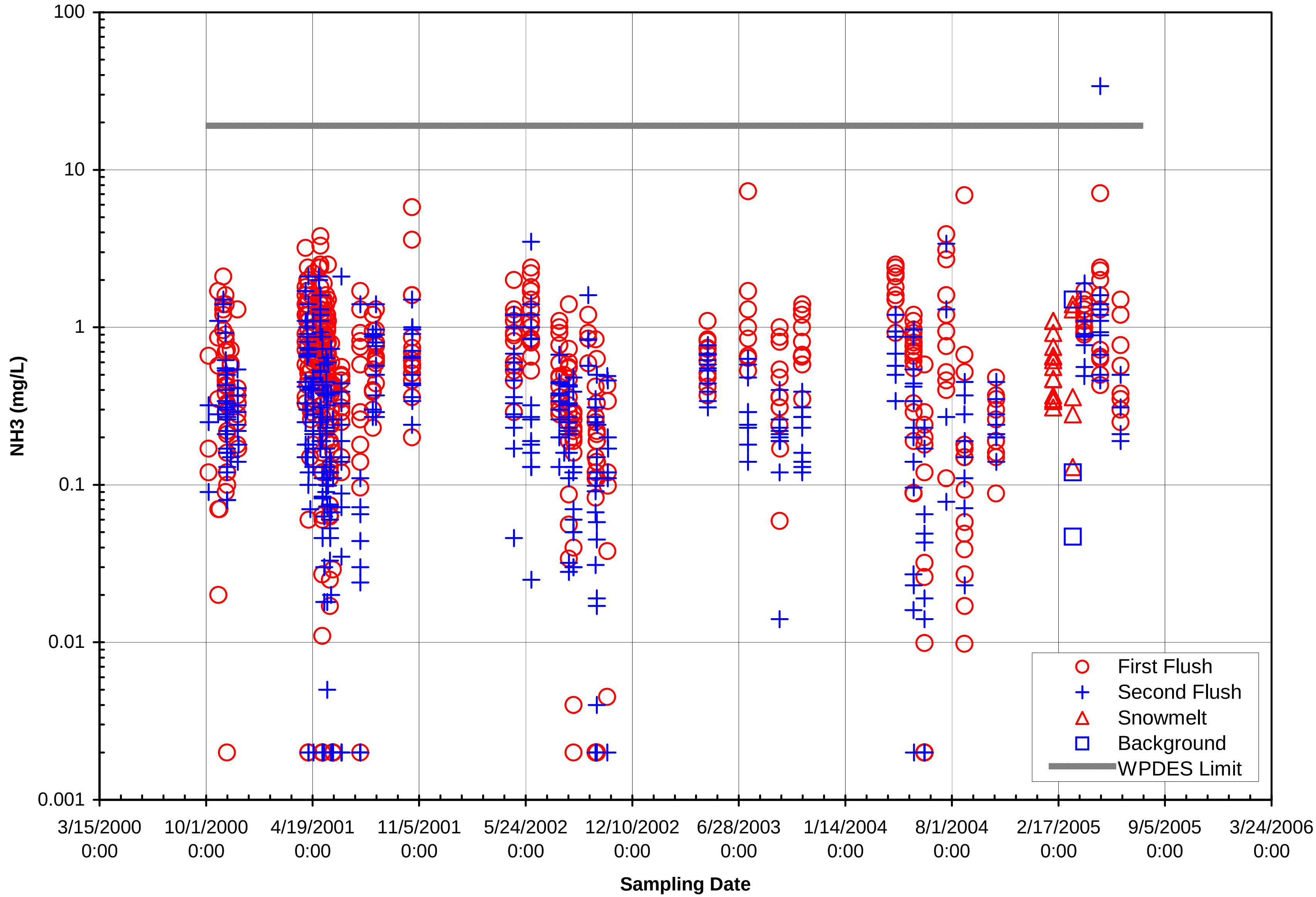


Figure E - 4 Ammonia Nitrogen (NH3) box chart in stormwater

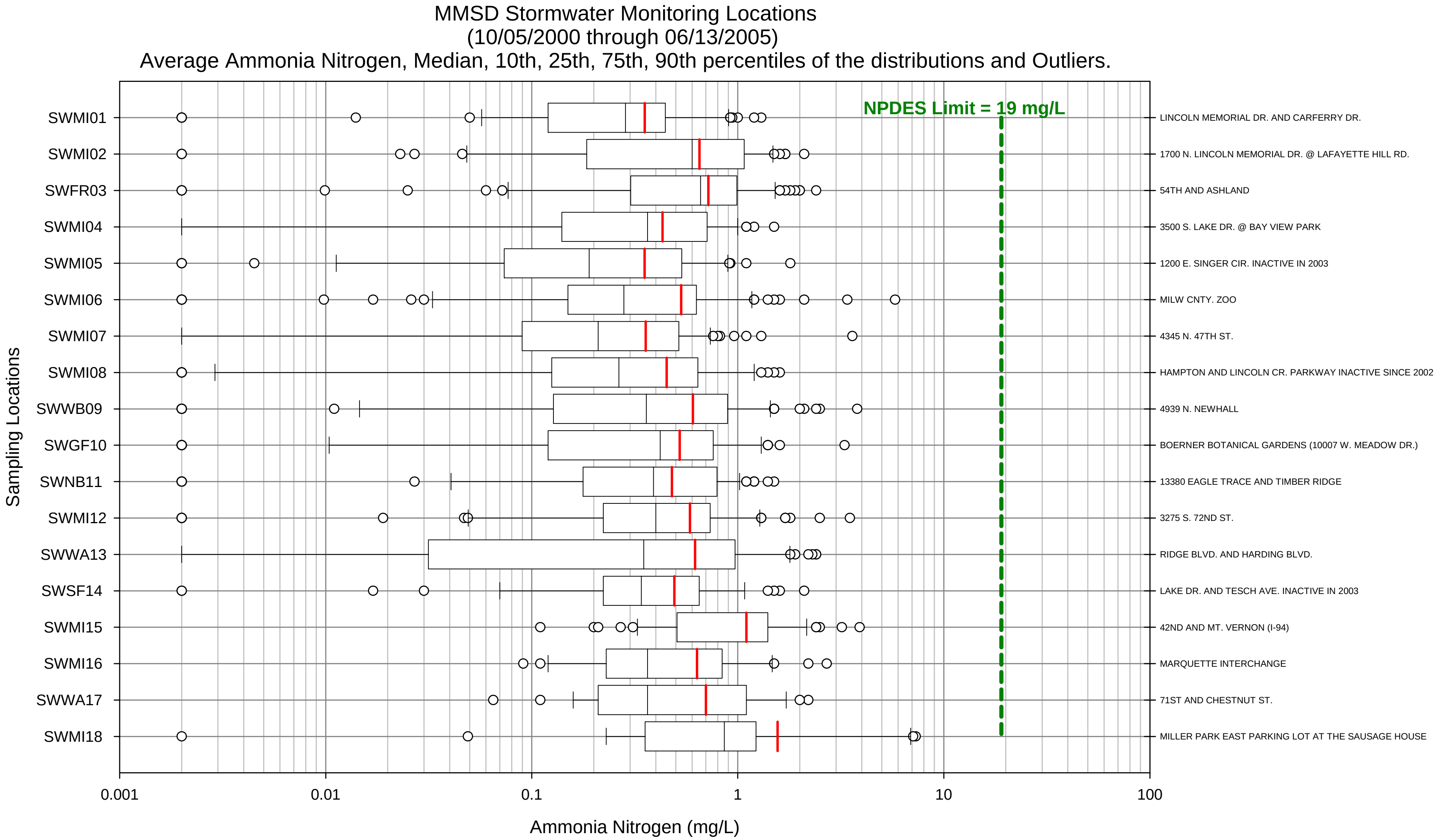


Figure E - 5 Antimony (Sb) 1st and 2nd flush in stormwater

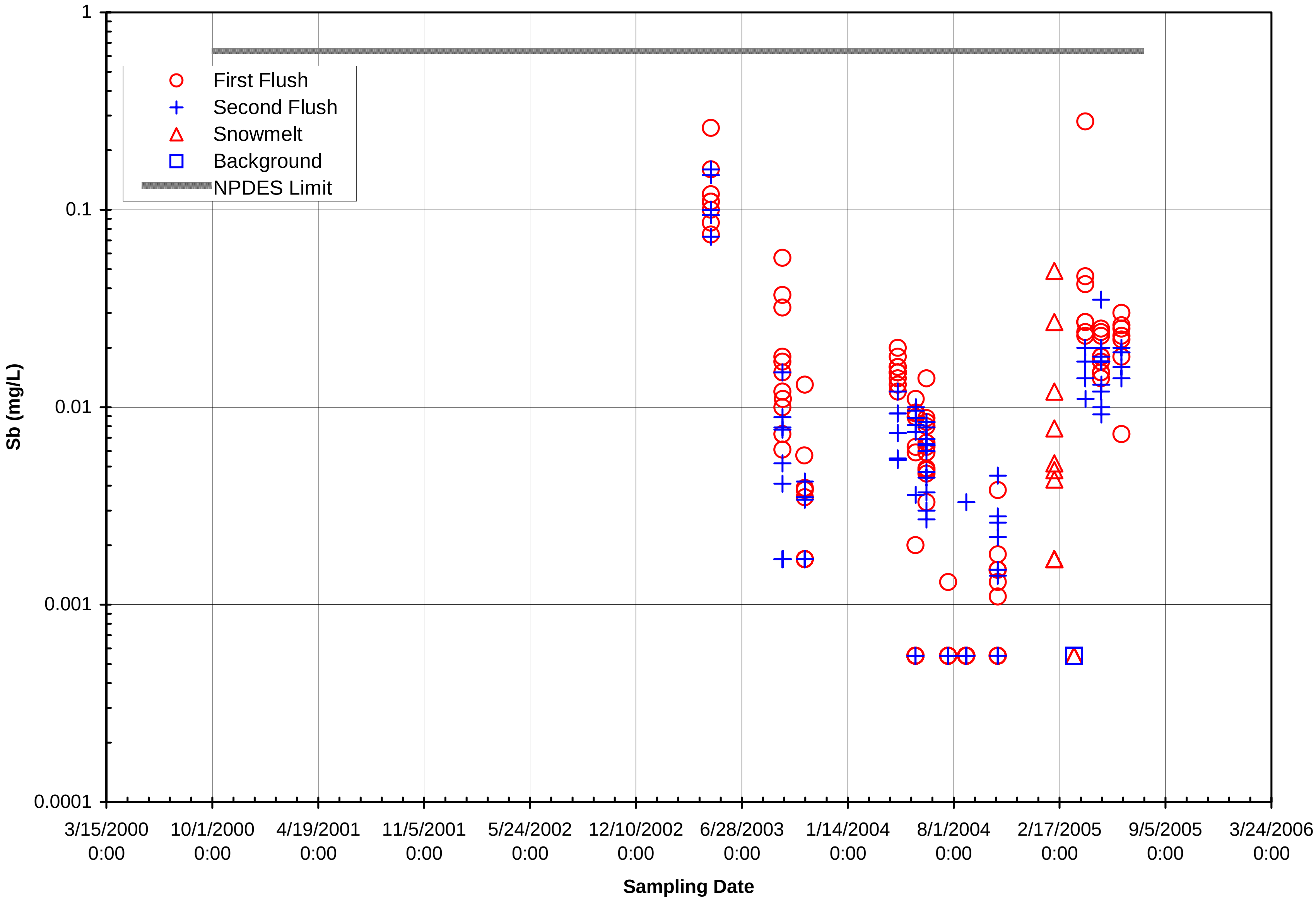


Figure E - 6 Antimony (Sb) box chart in stormwater

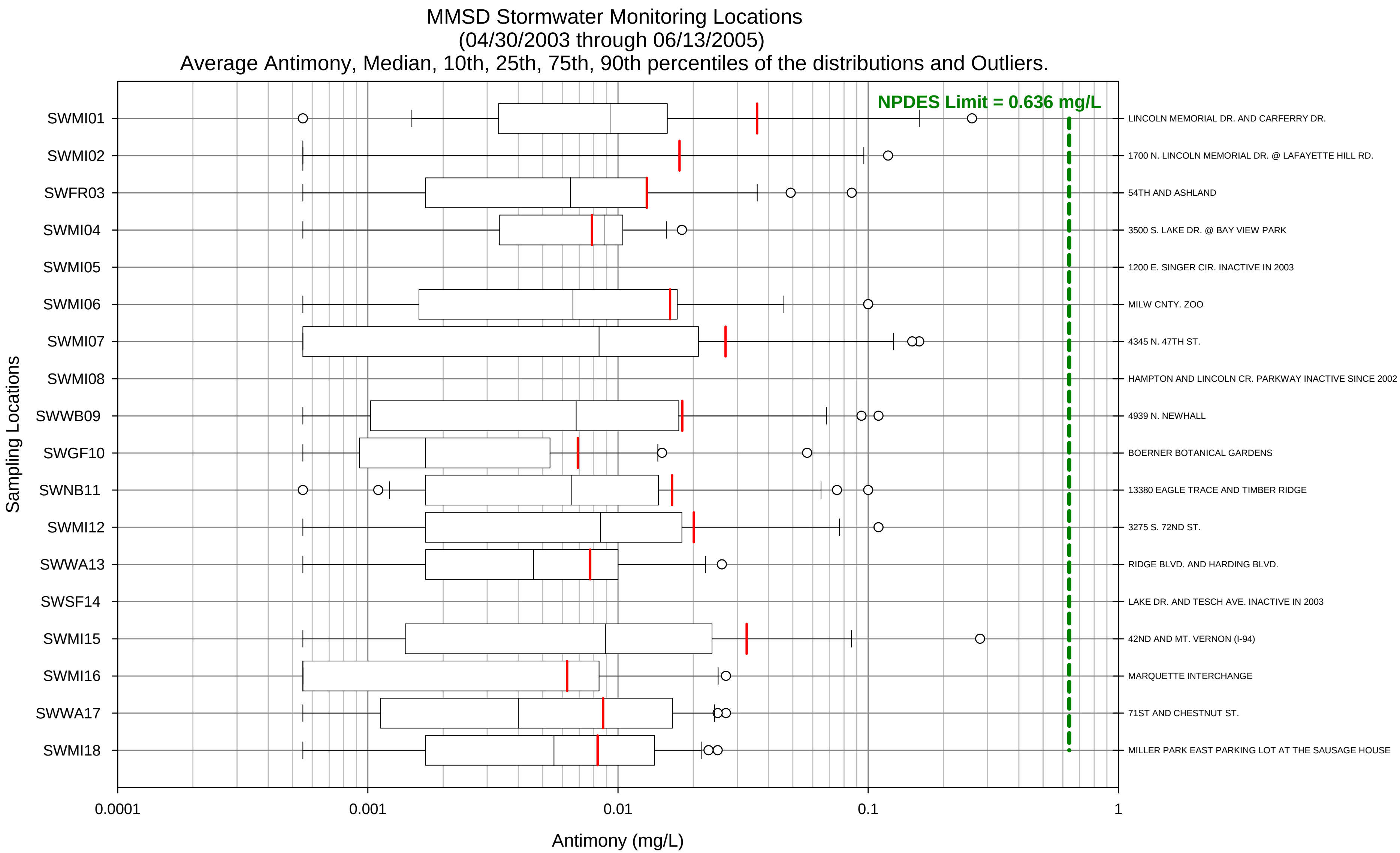


Figure E - 7 Arsenic (As) 1st and 2nd flush in stormwater

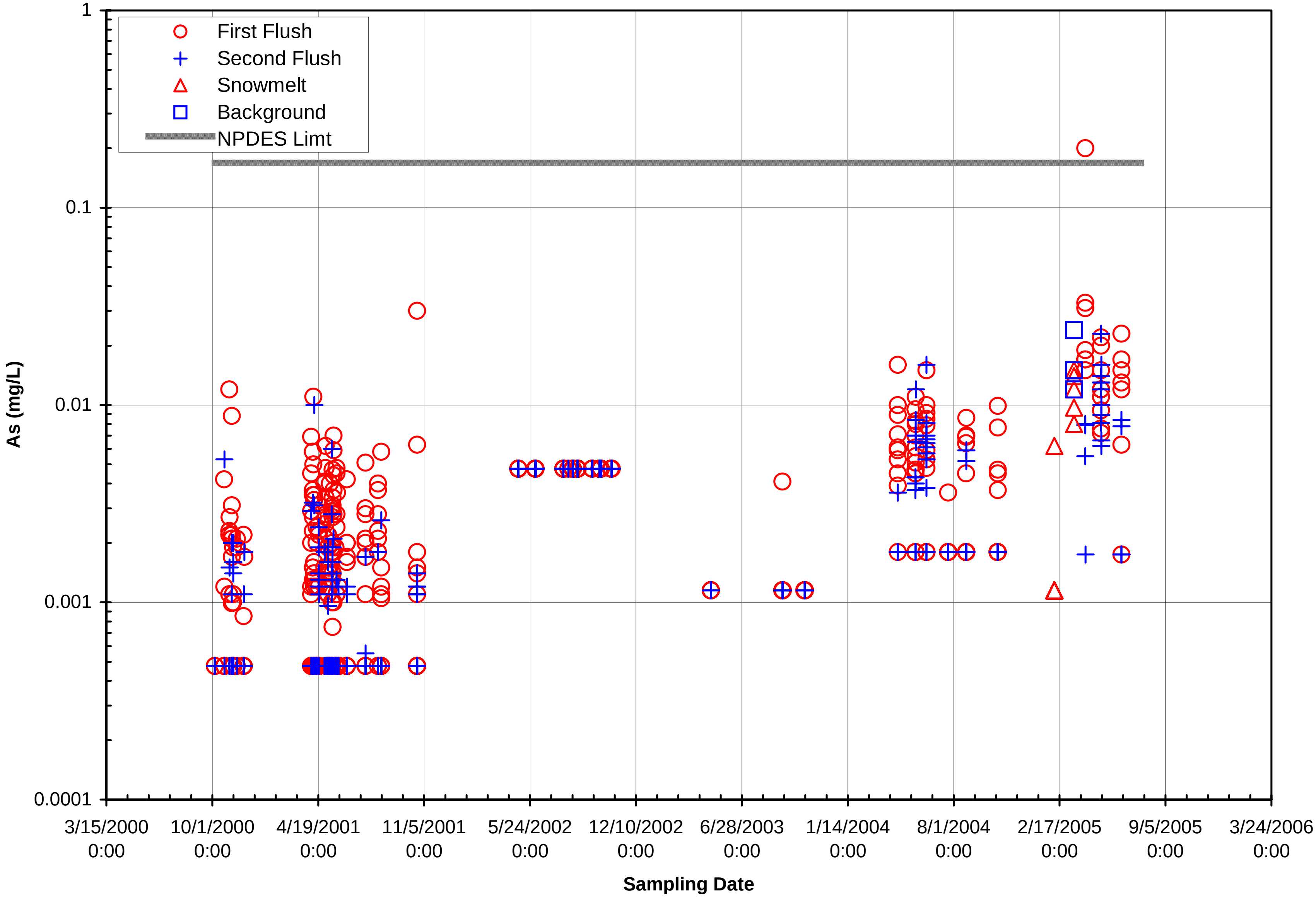


Figure E - 8 Arsenic (As) box chart in stormwater

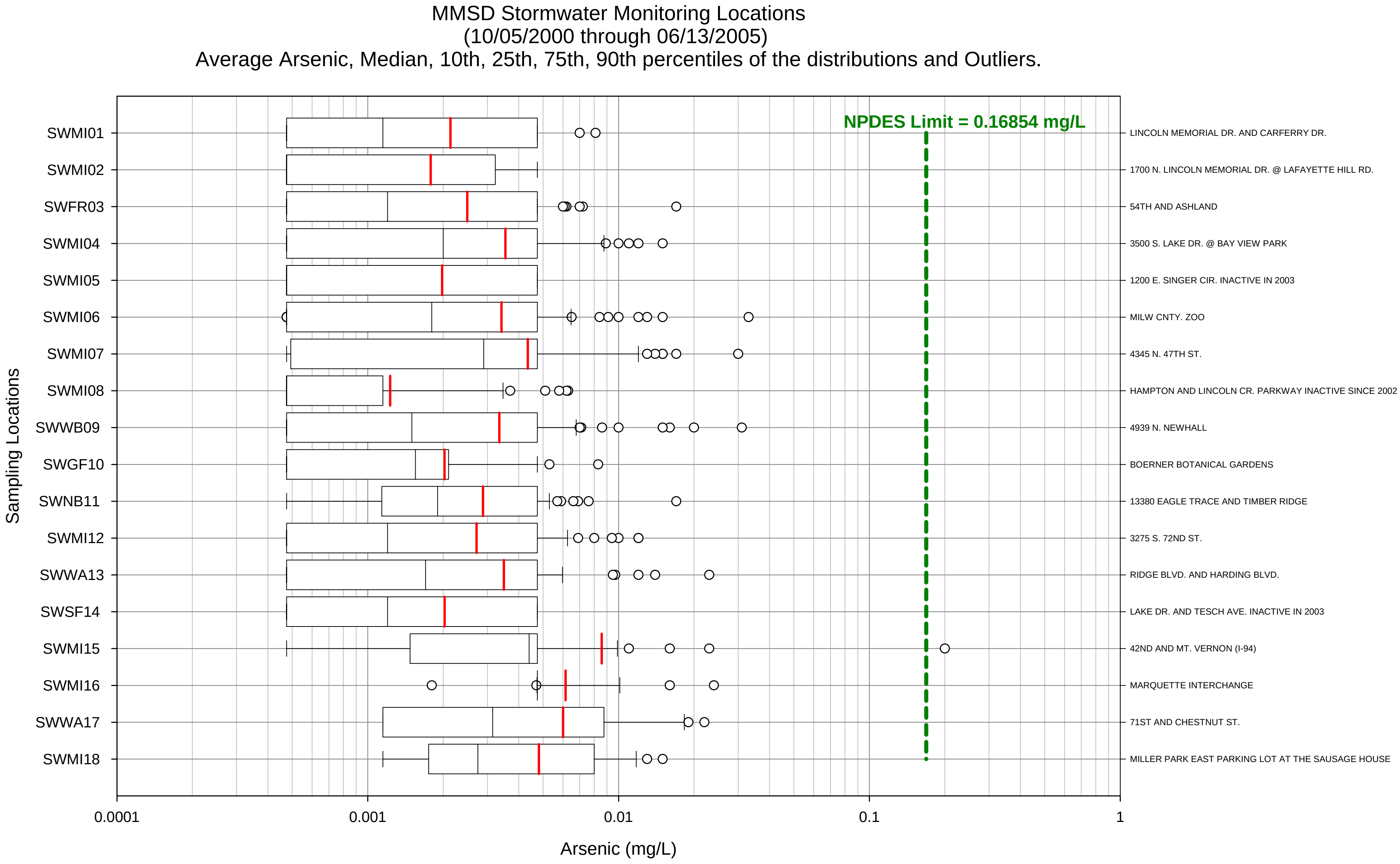


Figure E - 9 Beryllium (Be) 1st and 2nd flush in stormwater

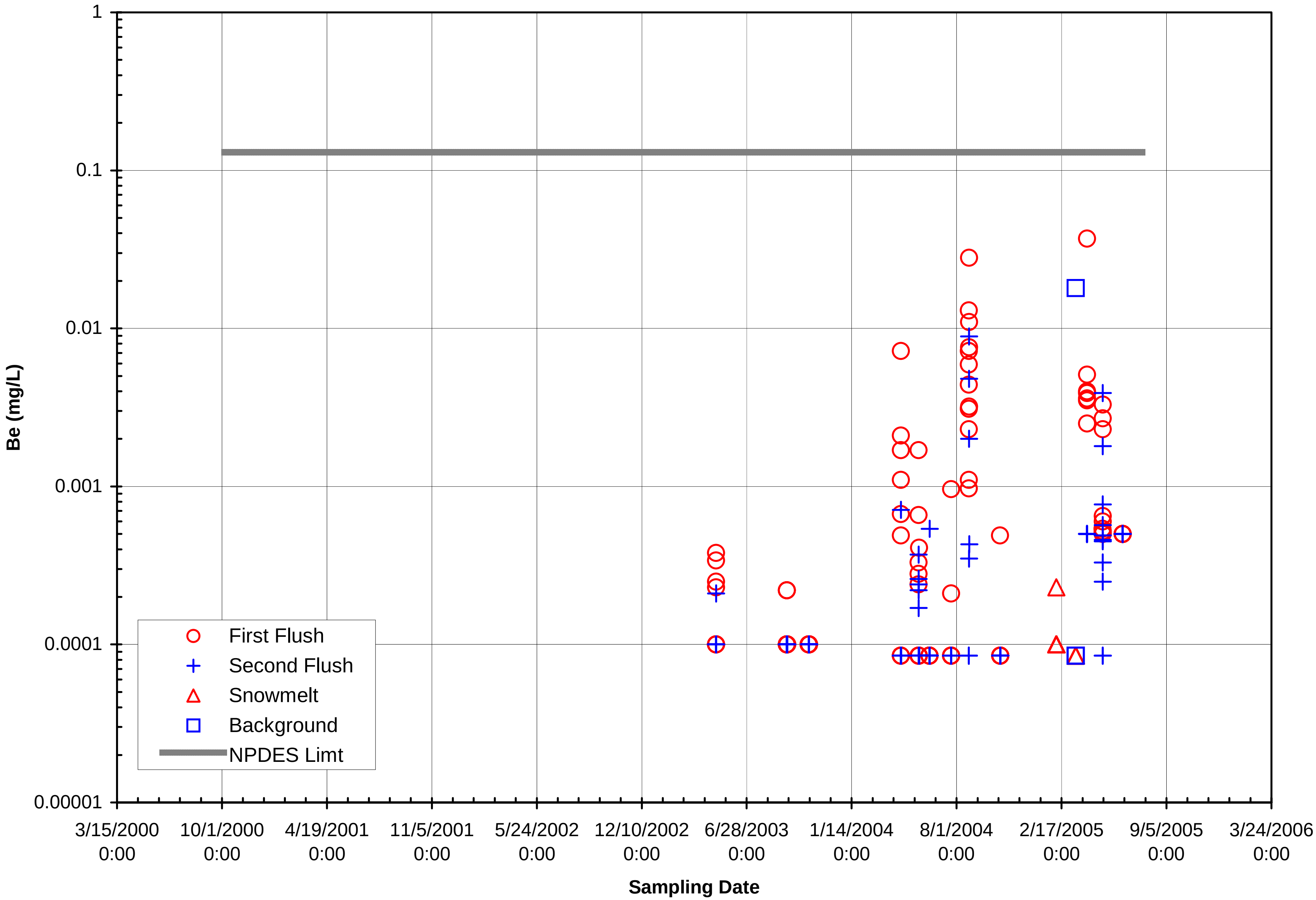


Figure E - 10 Beryllium (Be) box chart in stormwater

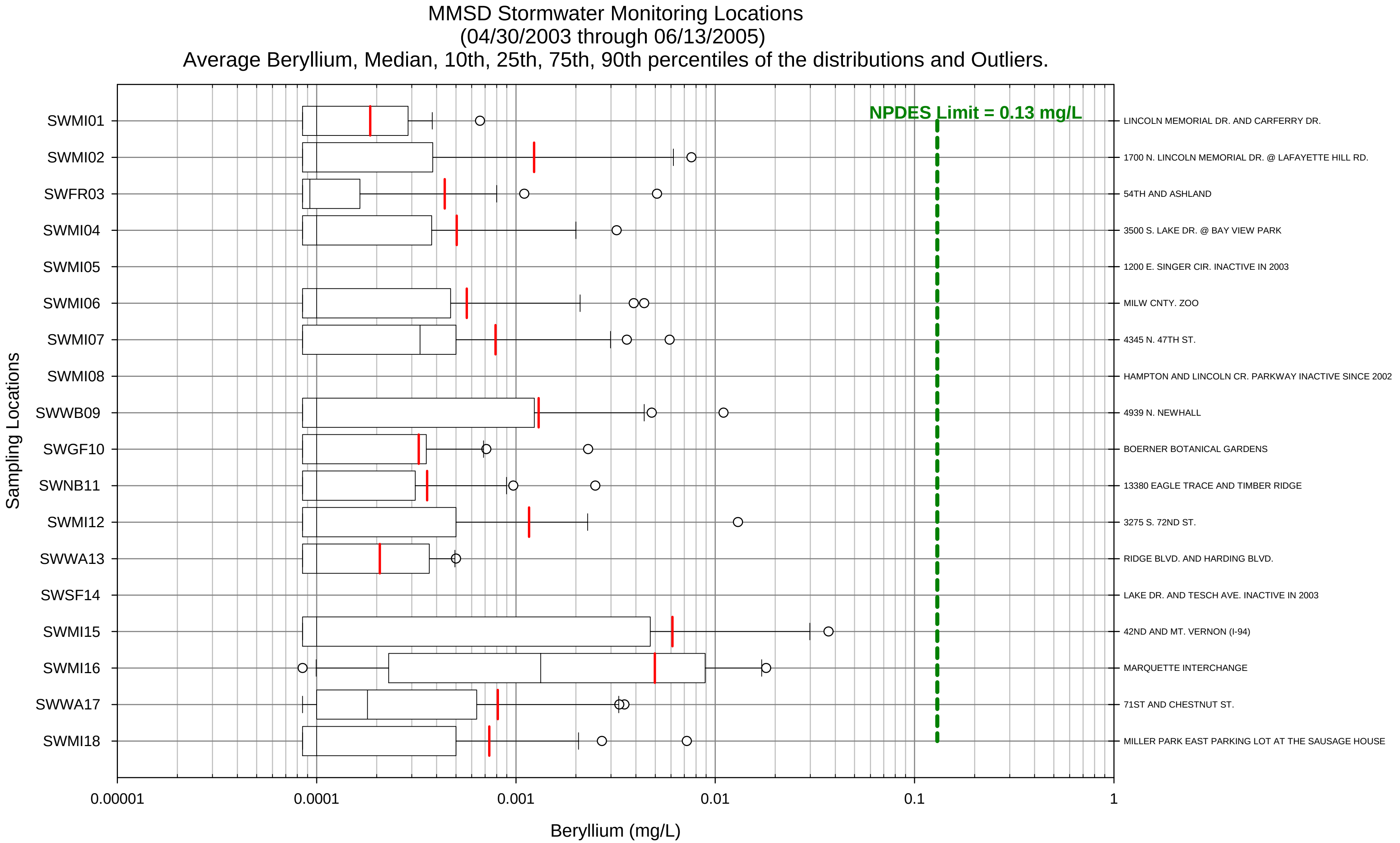


Figure E - 11   BOD-5 1st and 2nd flush in stormwater

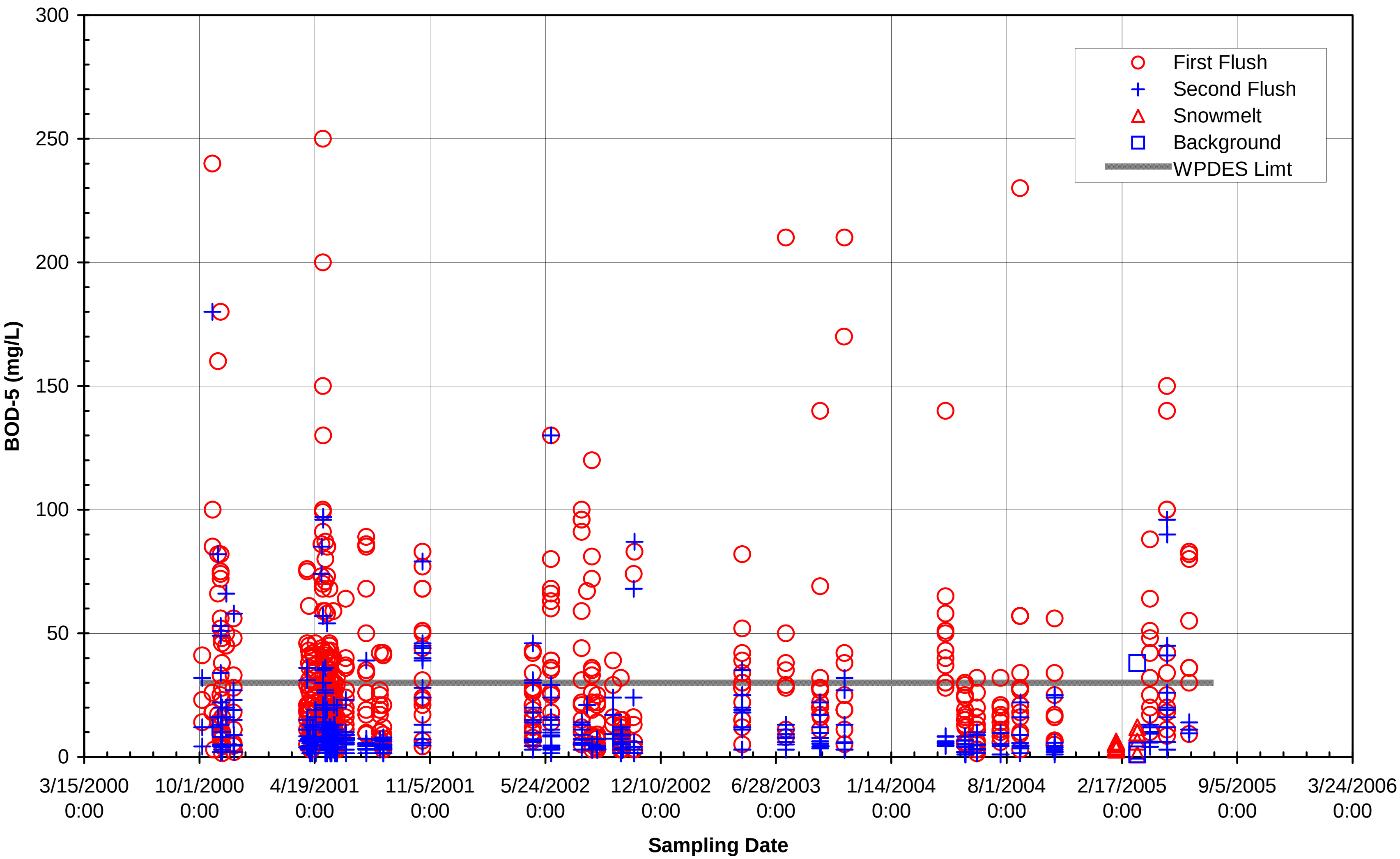


Figure E - 12 BOD-5 box chart in stormwater

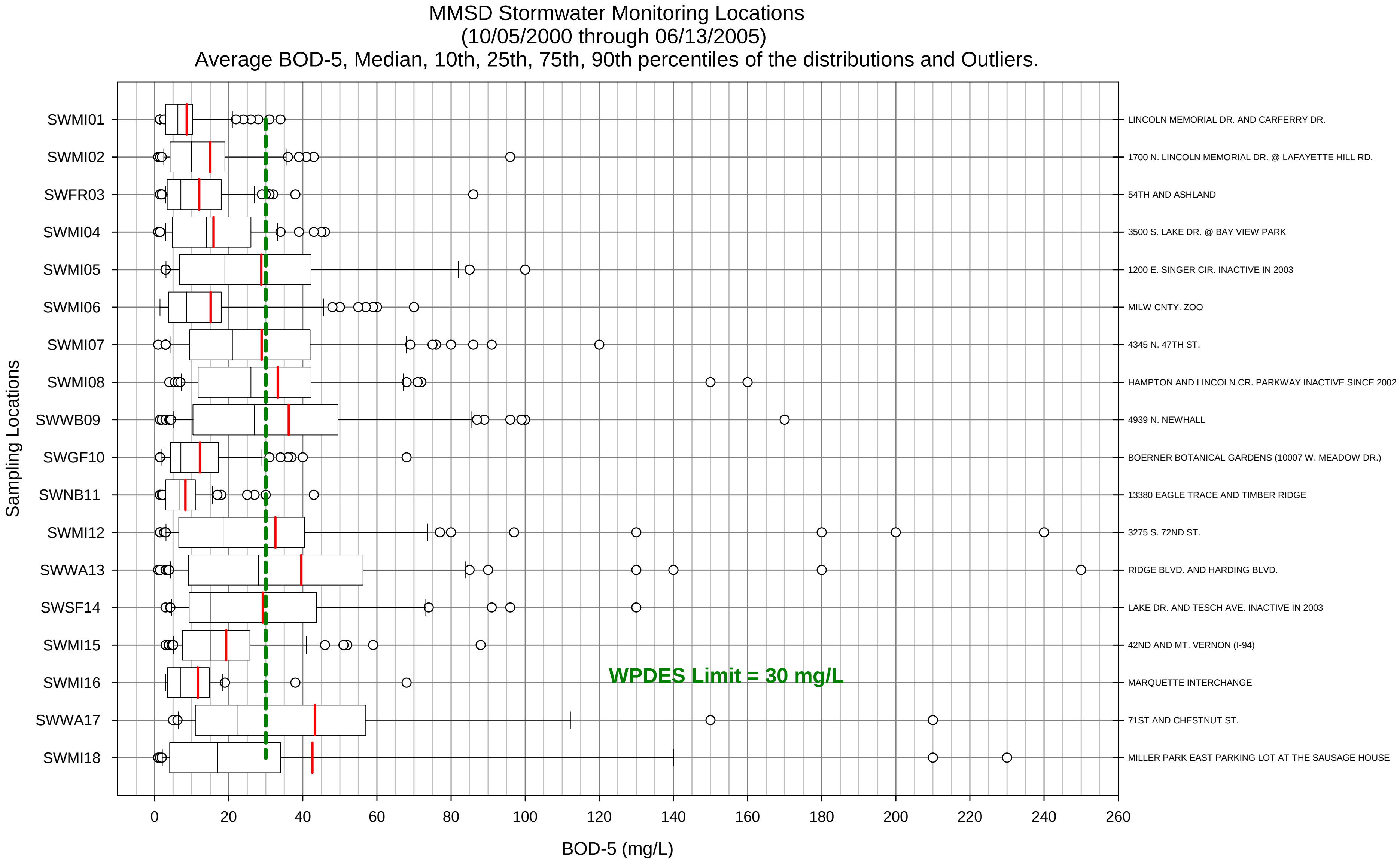


Figure E - 13 Cadmium (Cd) 1st and 2nd flush in stormwater

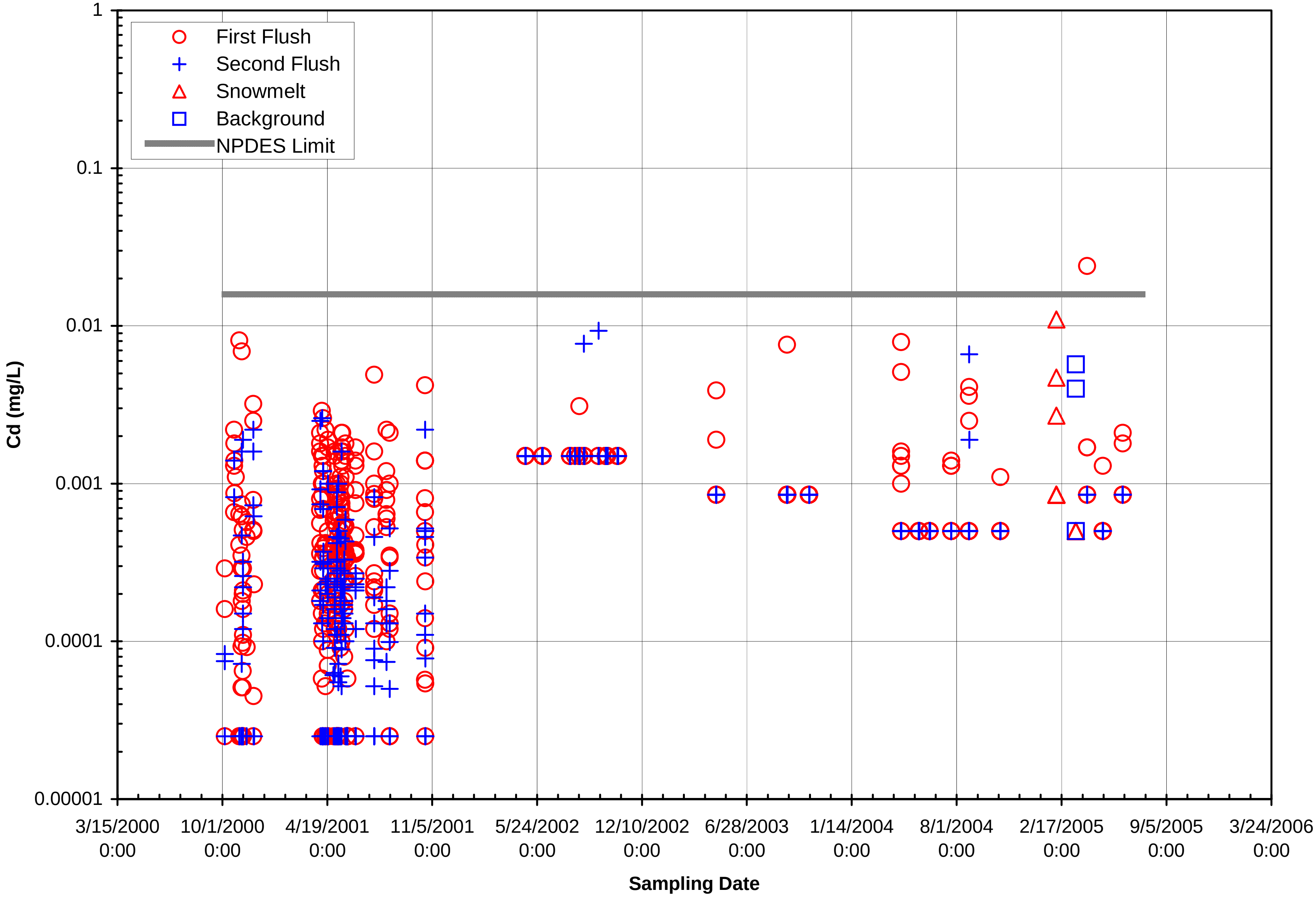


Figure E - 14 Cadmium (Cd) box chart in stormwater

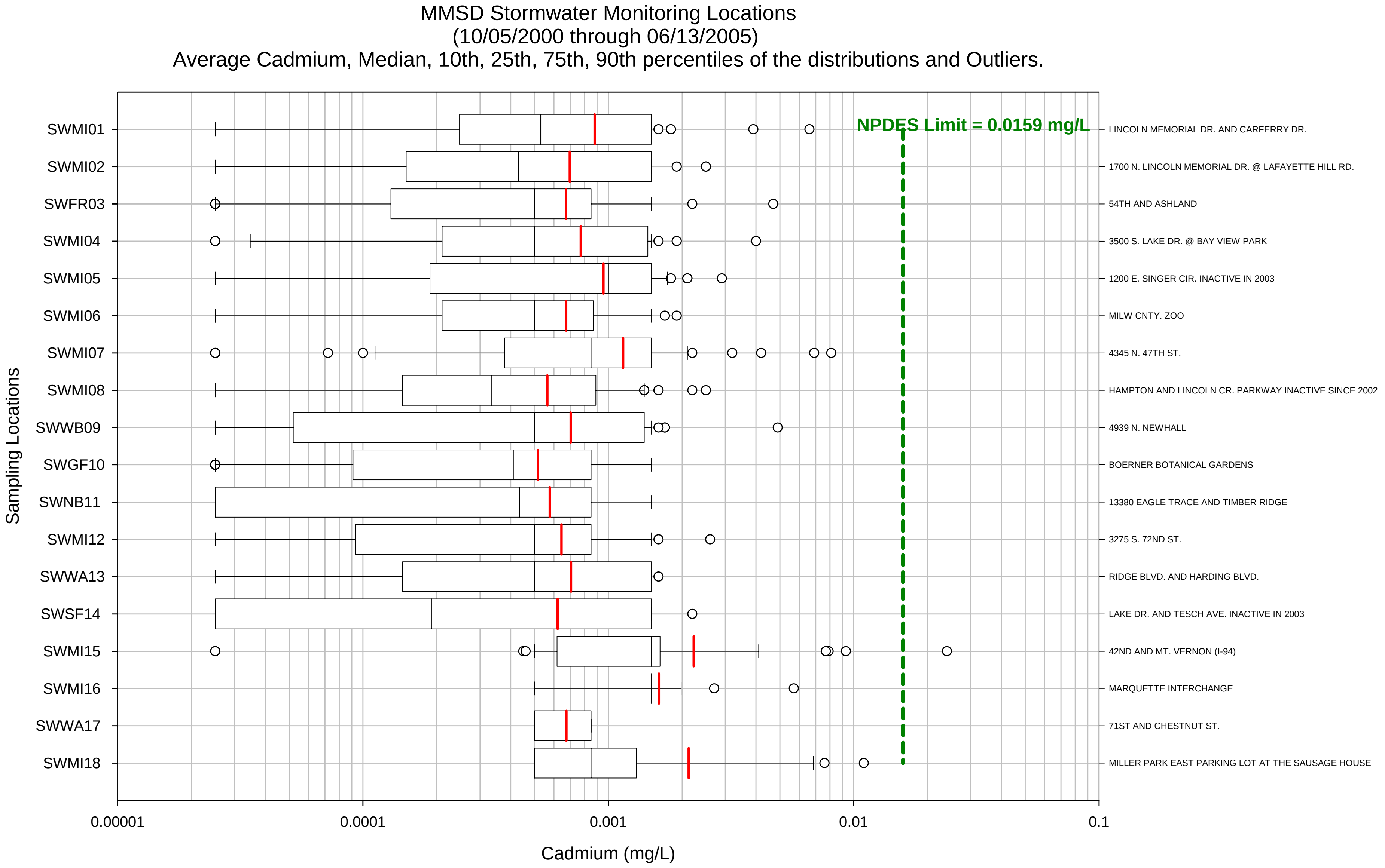


Figure E - 15   Calcium (Ca) 1st and 2nd flush in stormwater

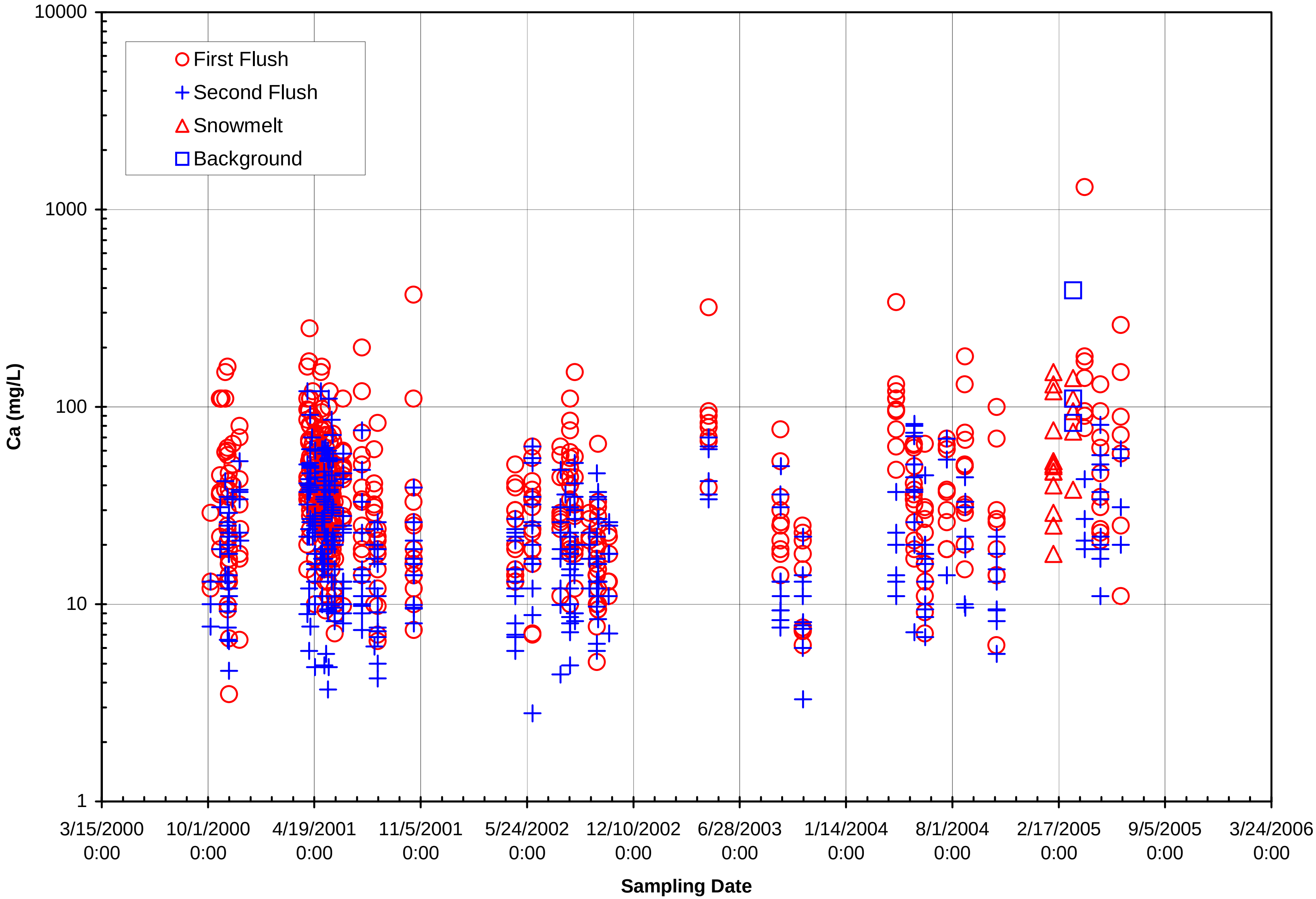


Figure E - 16 Calcium (Ca) box chart in stormwater

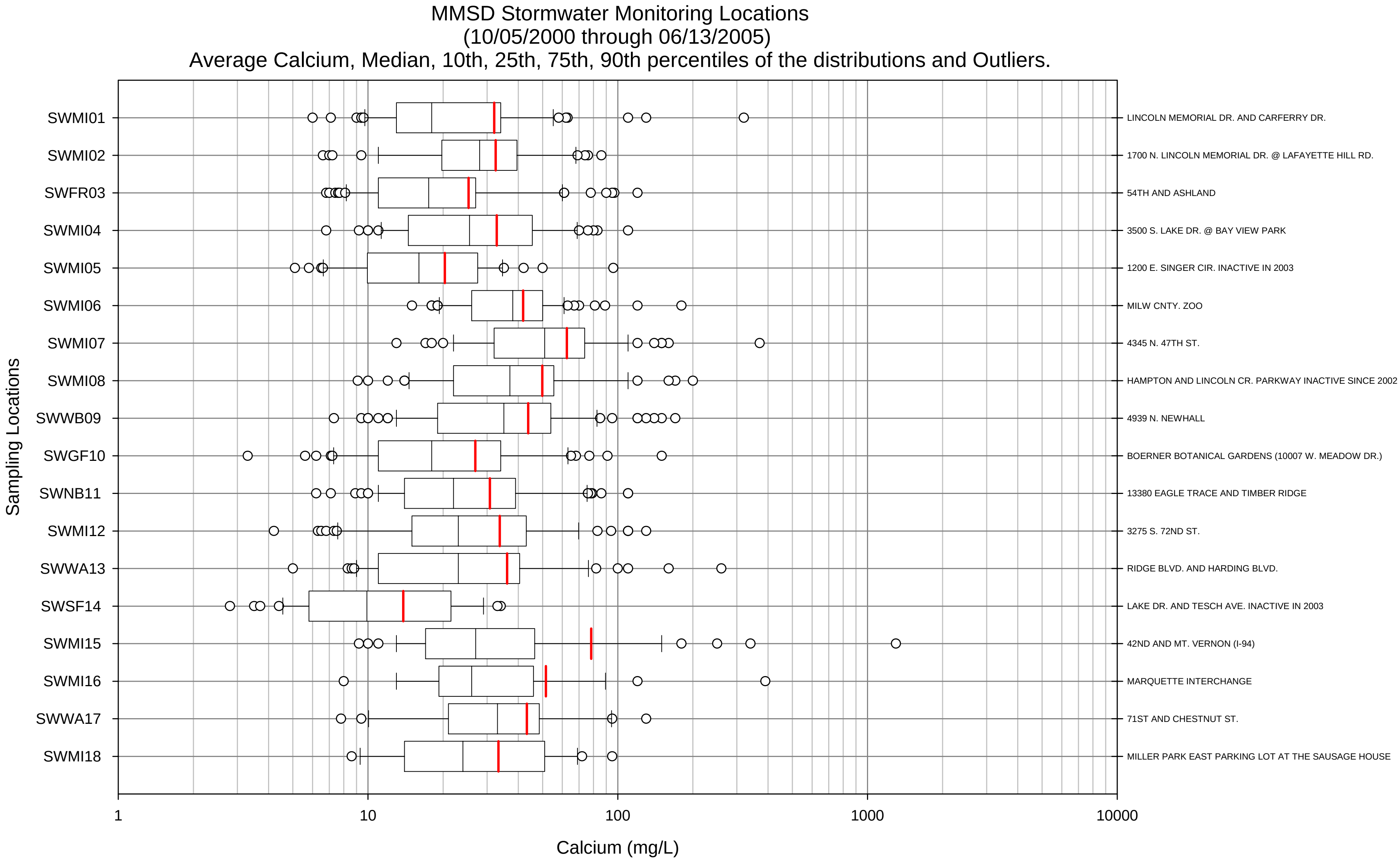


Figure E - 17 Chloride (Cl^-) 1st and 2nd flush in stormwater

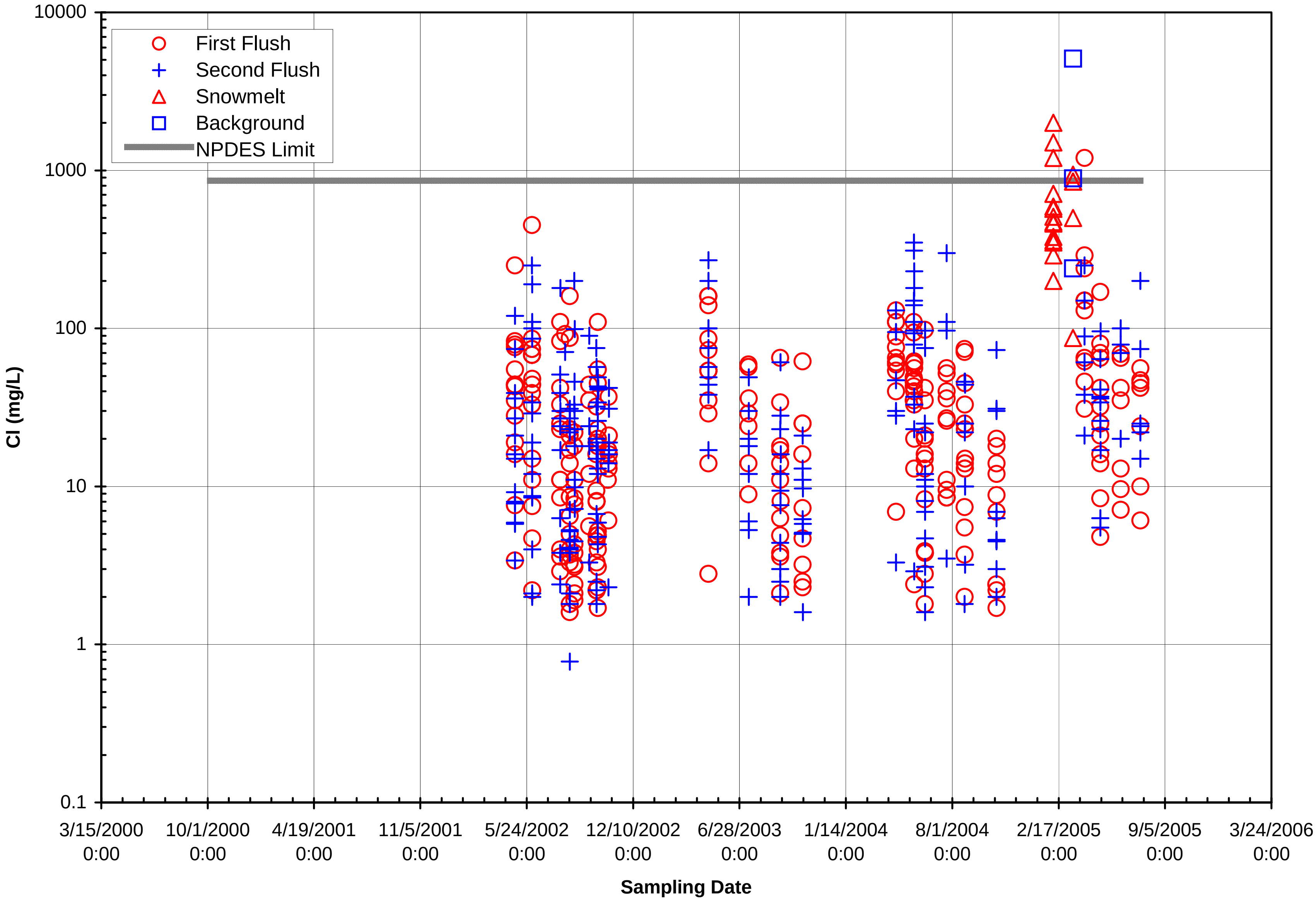


Figure E - 18 Chloride (Cl^-) box chart in stormwater

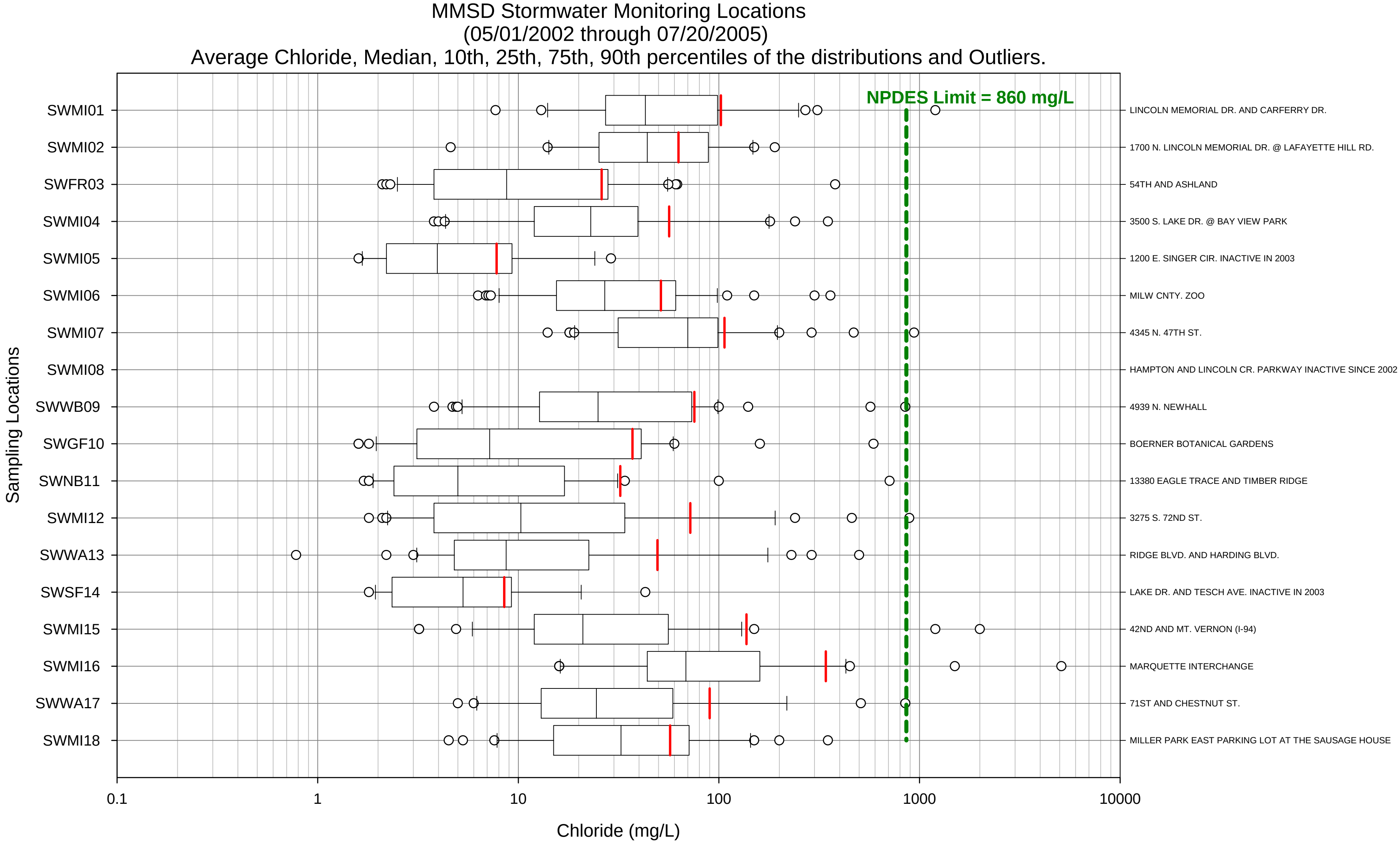


Figure E - 19 Chromium (Cr) 1st and 2nd flush in stormwater

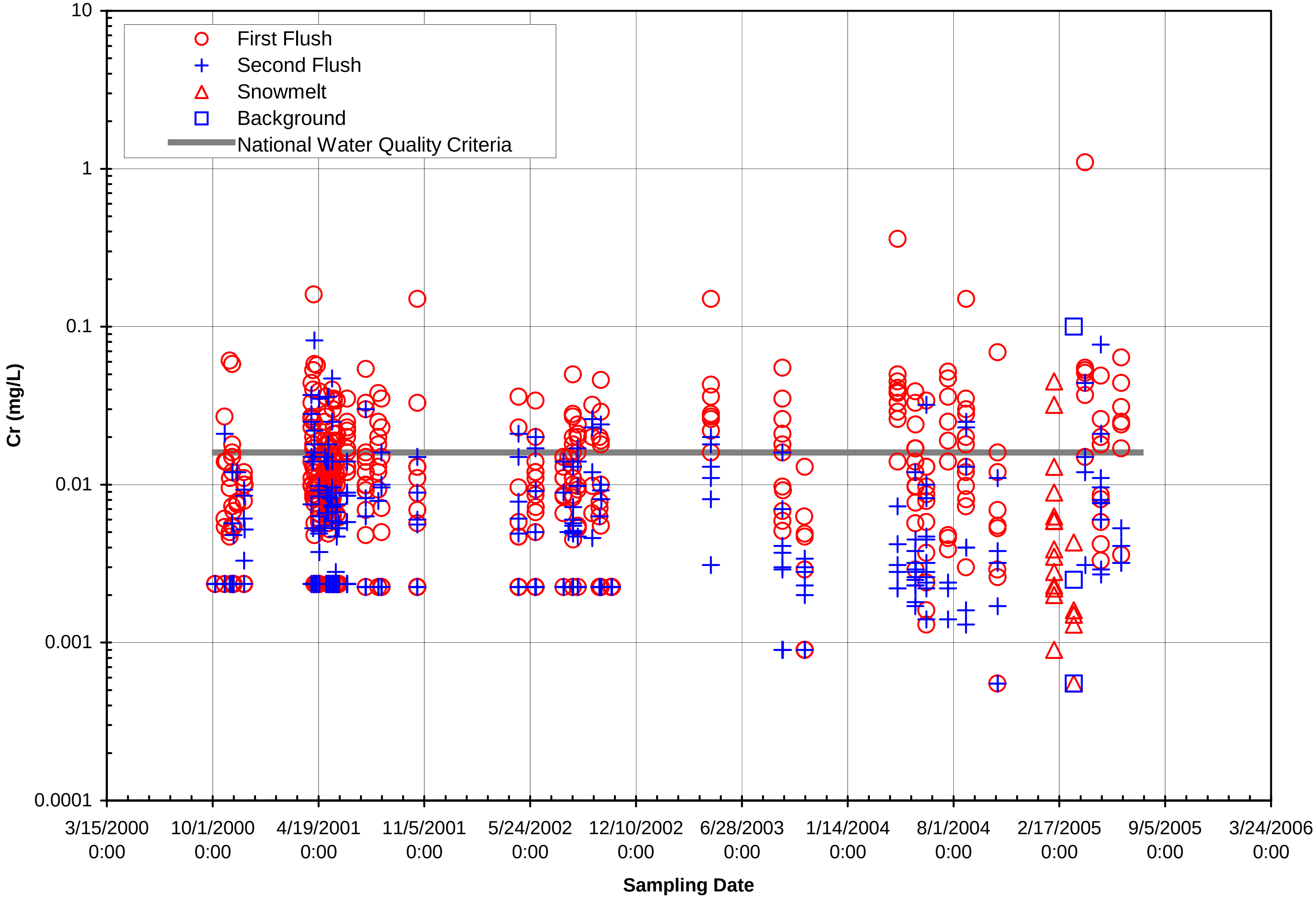


Figure E - 20   Chromium (Cr) box chart in stormwater

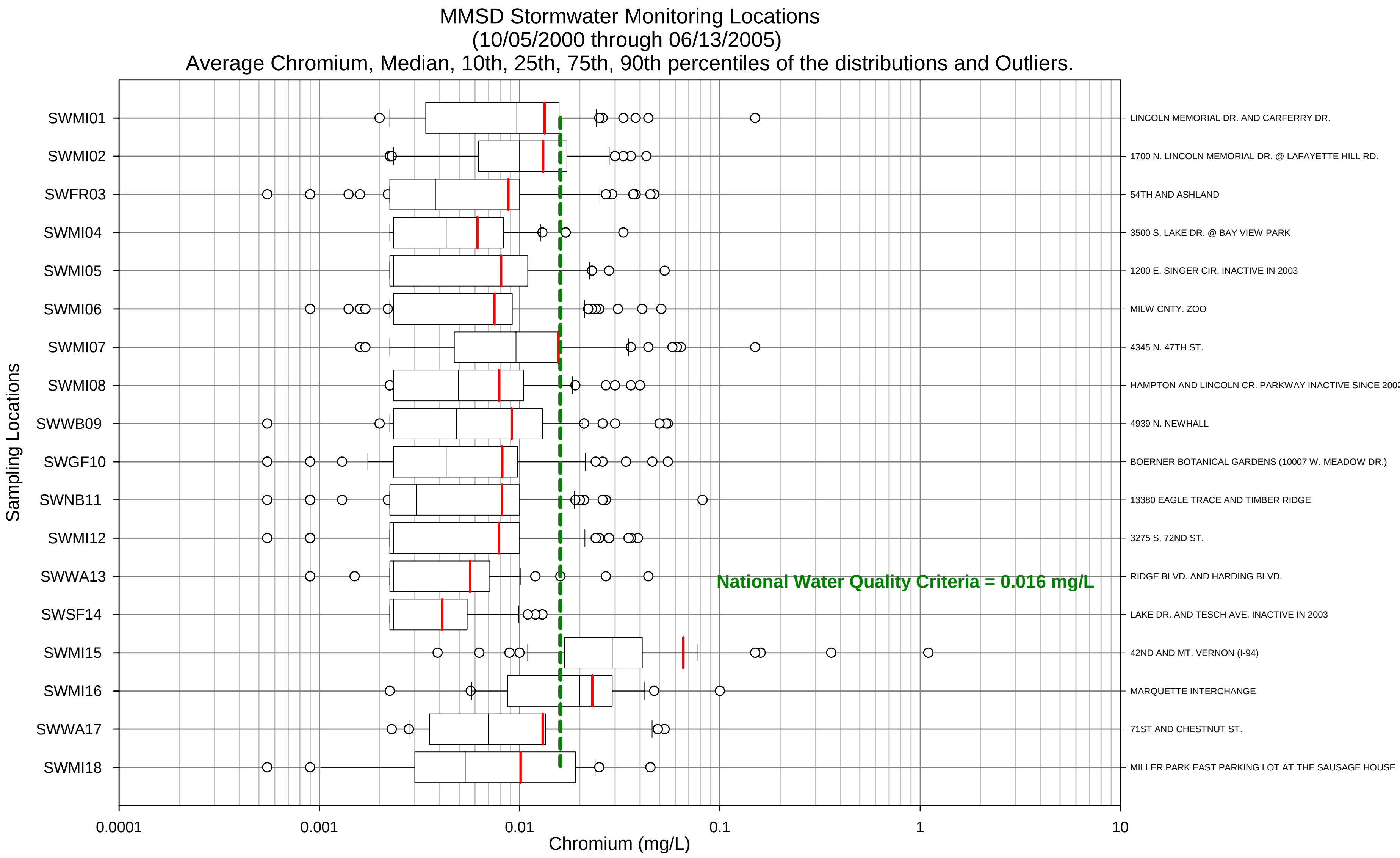


Figure E - 21 Copper (Cu) 1st and 2nd flush in stormwater

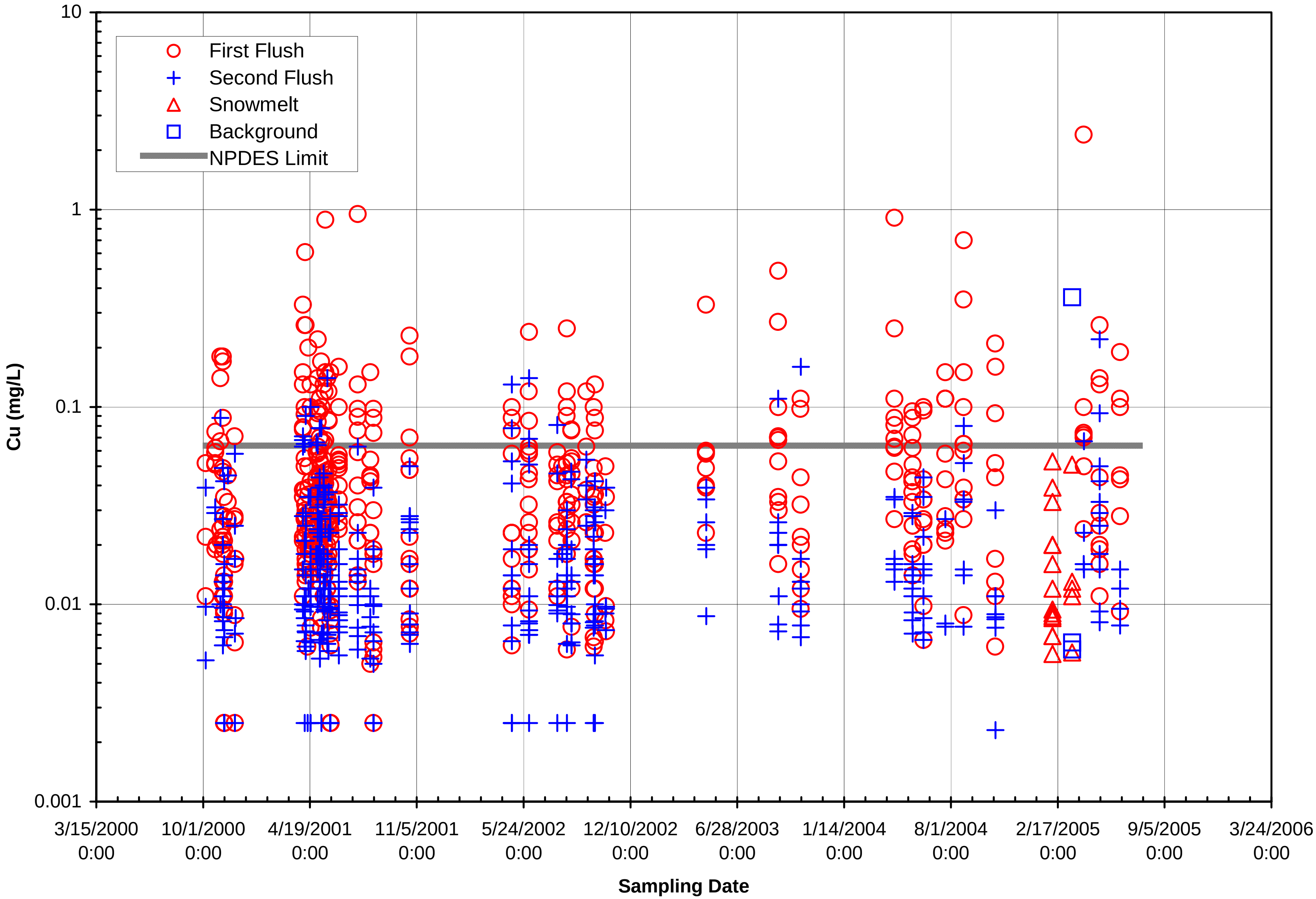


Figure E - 22 Copper (Cu) box chart in stormwater

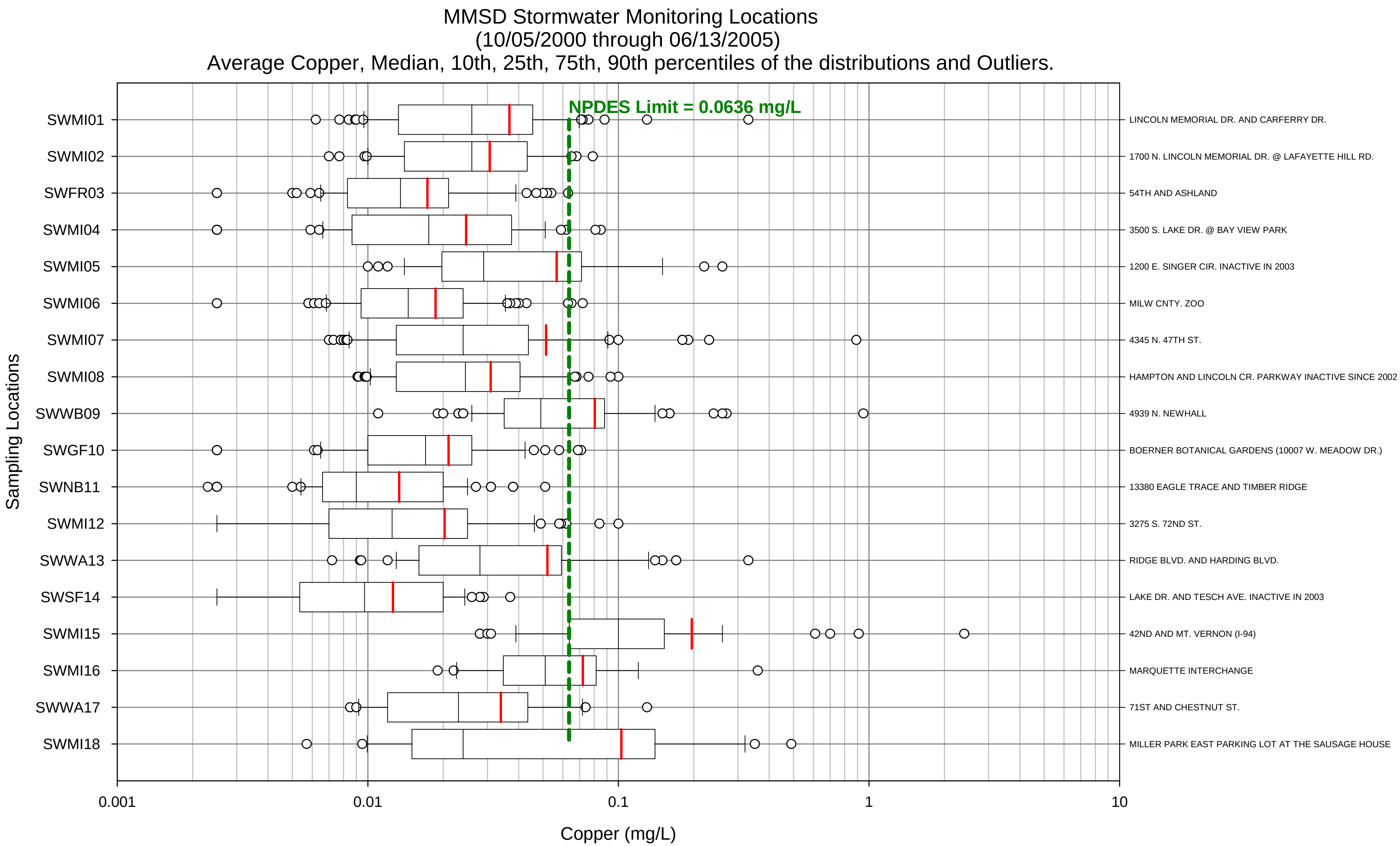


Figure E - 23 E-coli QT 1st and 2nd flush in stormwater

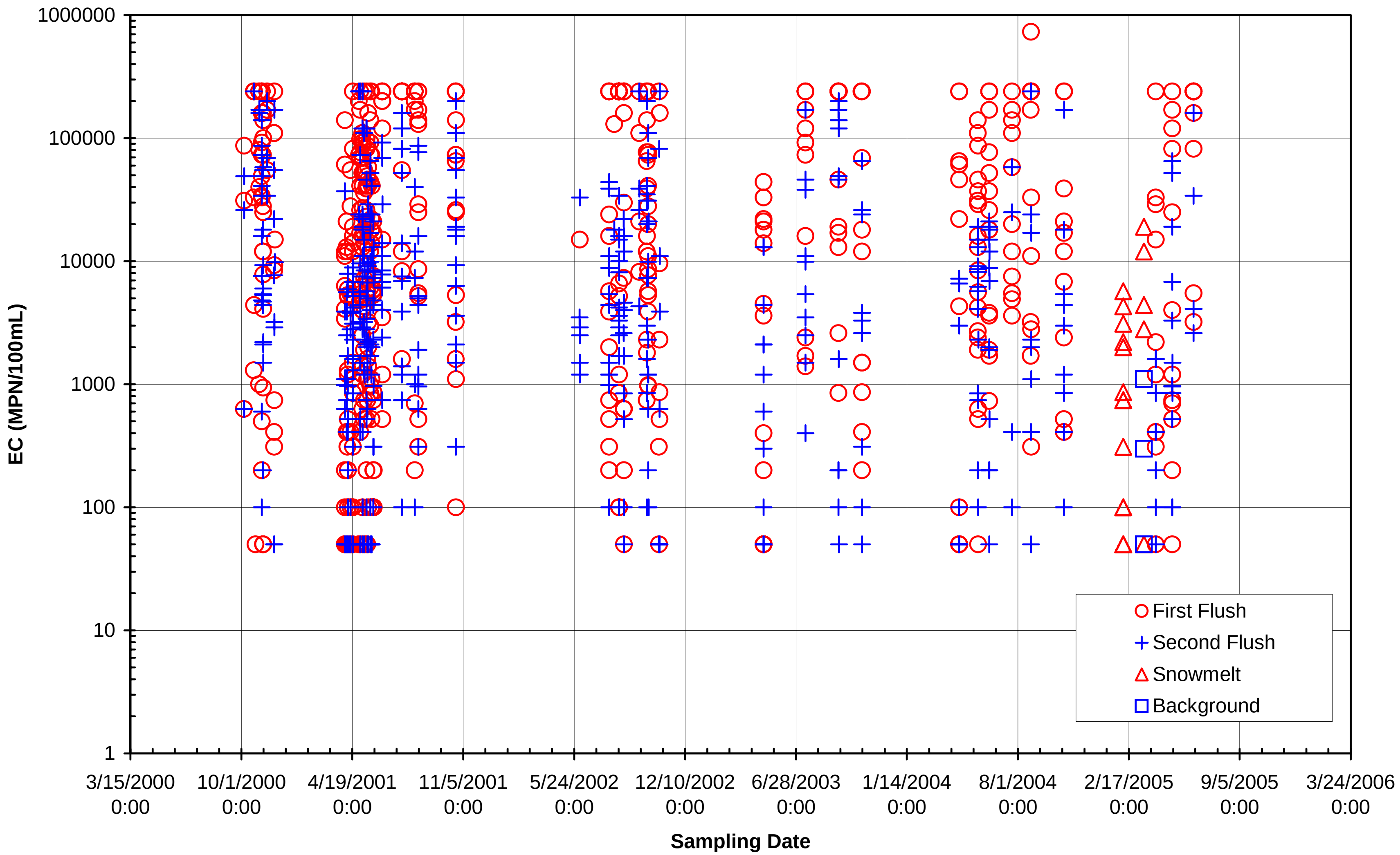


Figure E - 24   E-coli QT box chart in stormwater

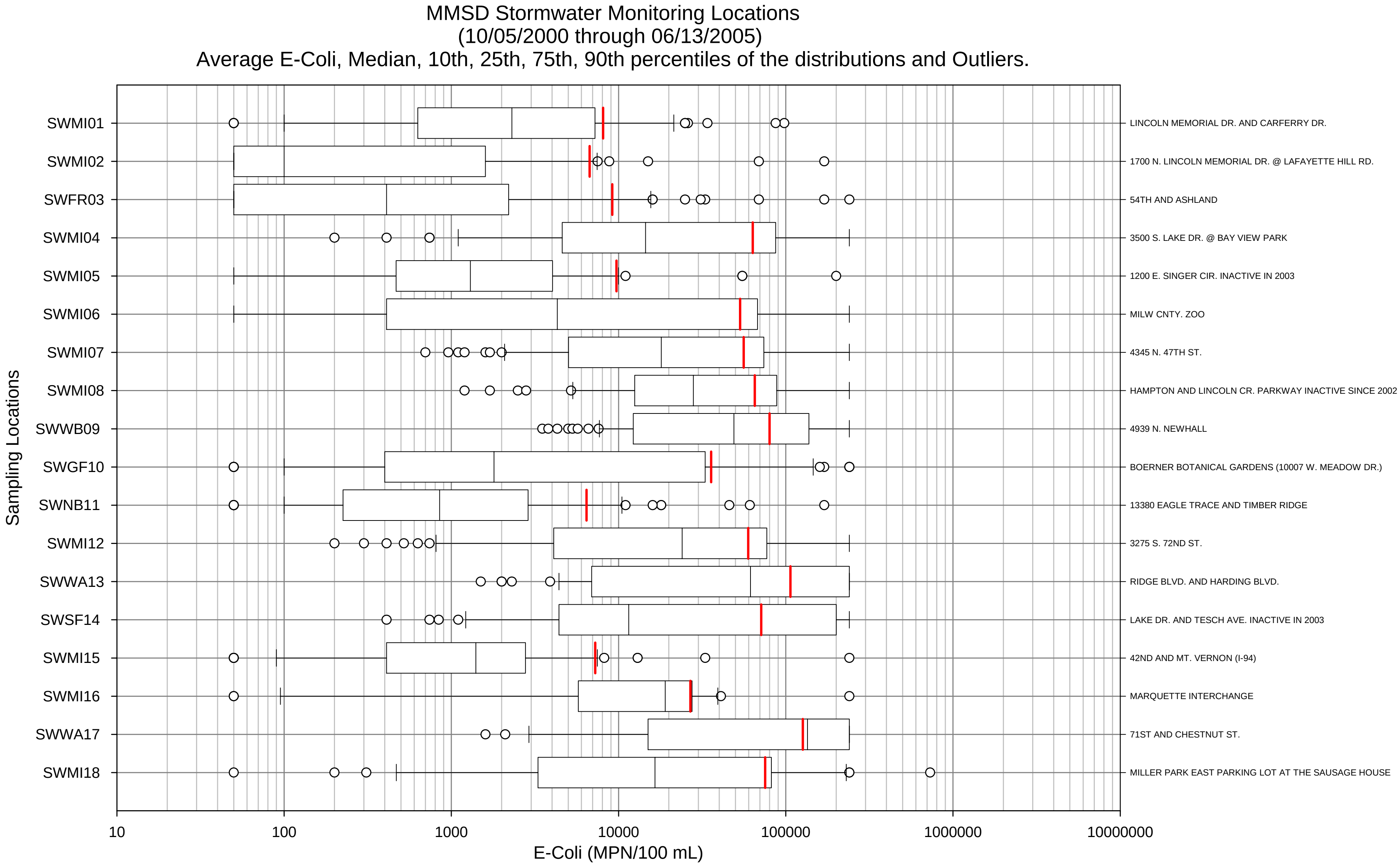


Figure E - 25 Fecal coliform (FC) 1st and 2nd flush in stormwater

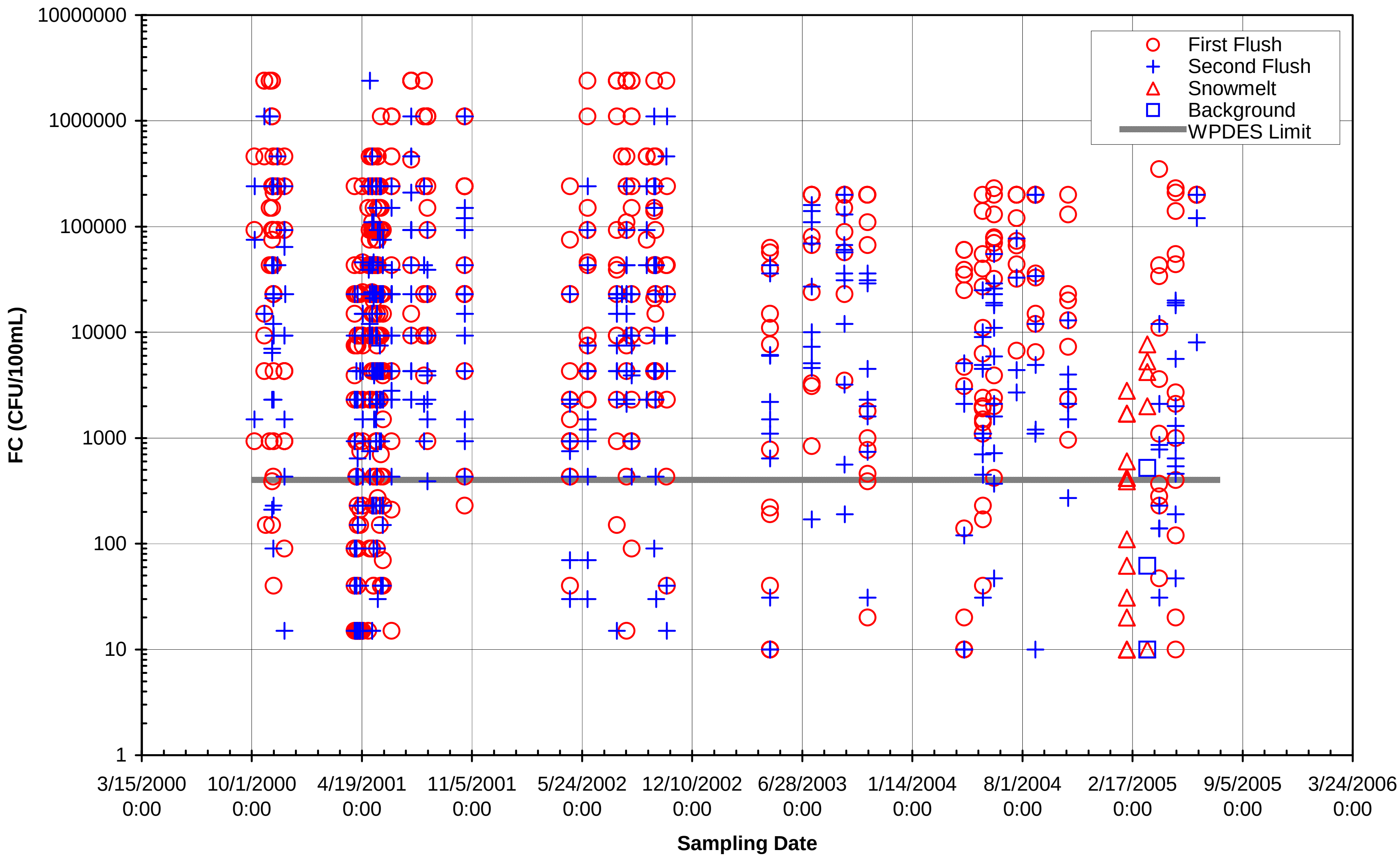


Figure E - 26 Fecal coliform (FC) box chart in stormwater

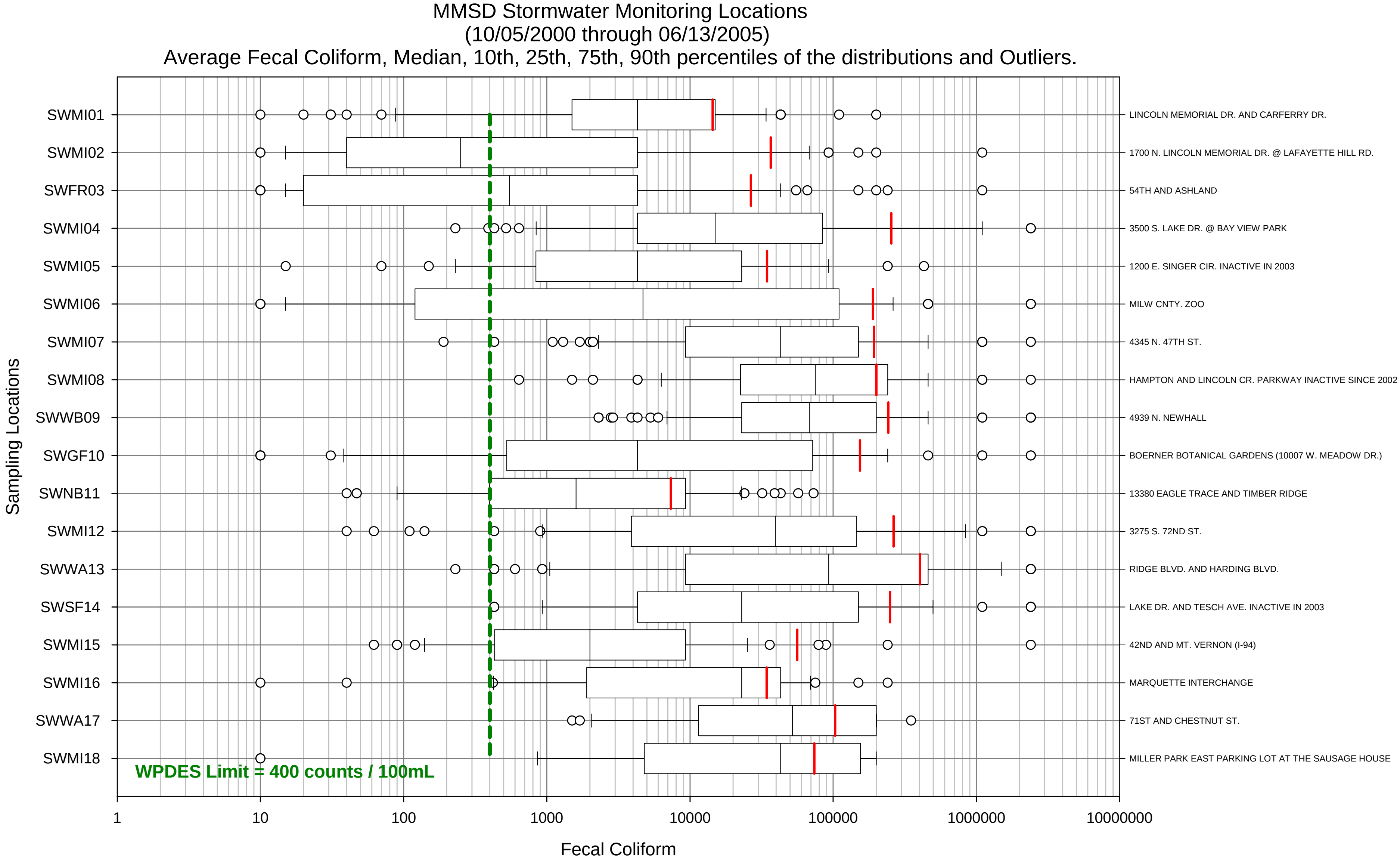


Figure E - 27   Hardness (Hard) 1st and 2nd flush in stormwater

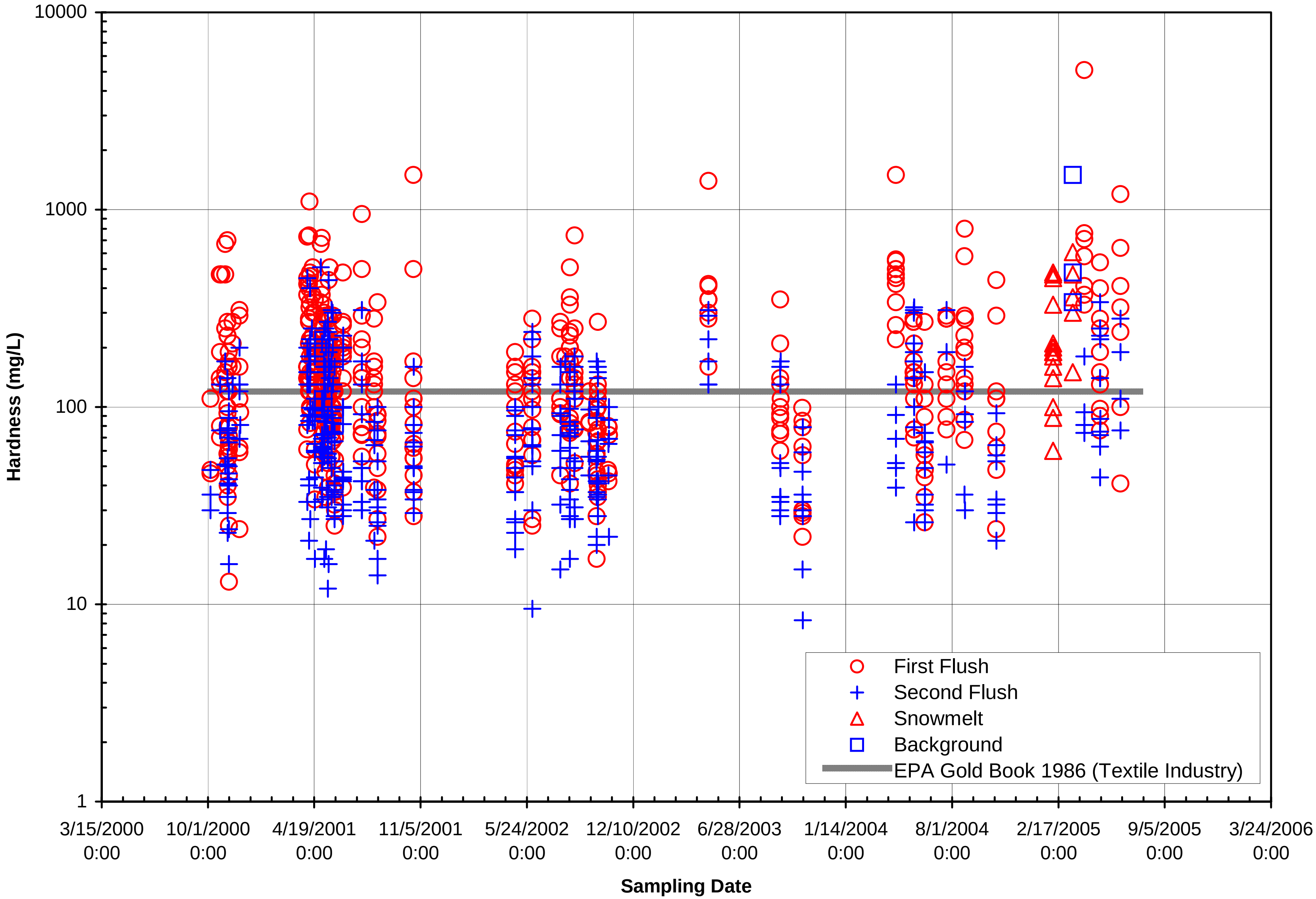


Figure E - 28   Hardness (Hard) box chart in stormwater

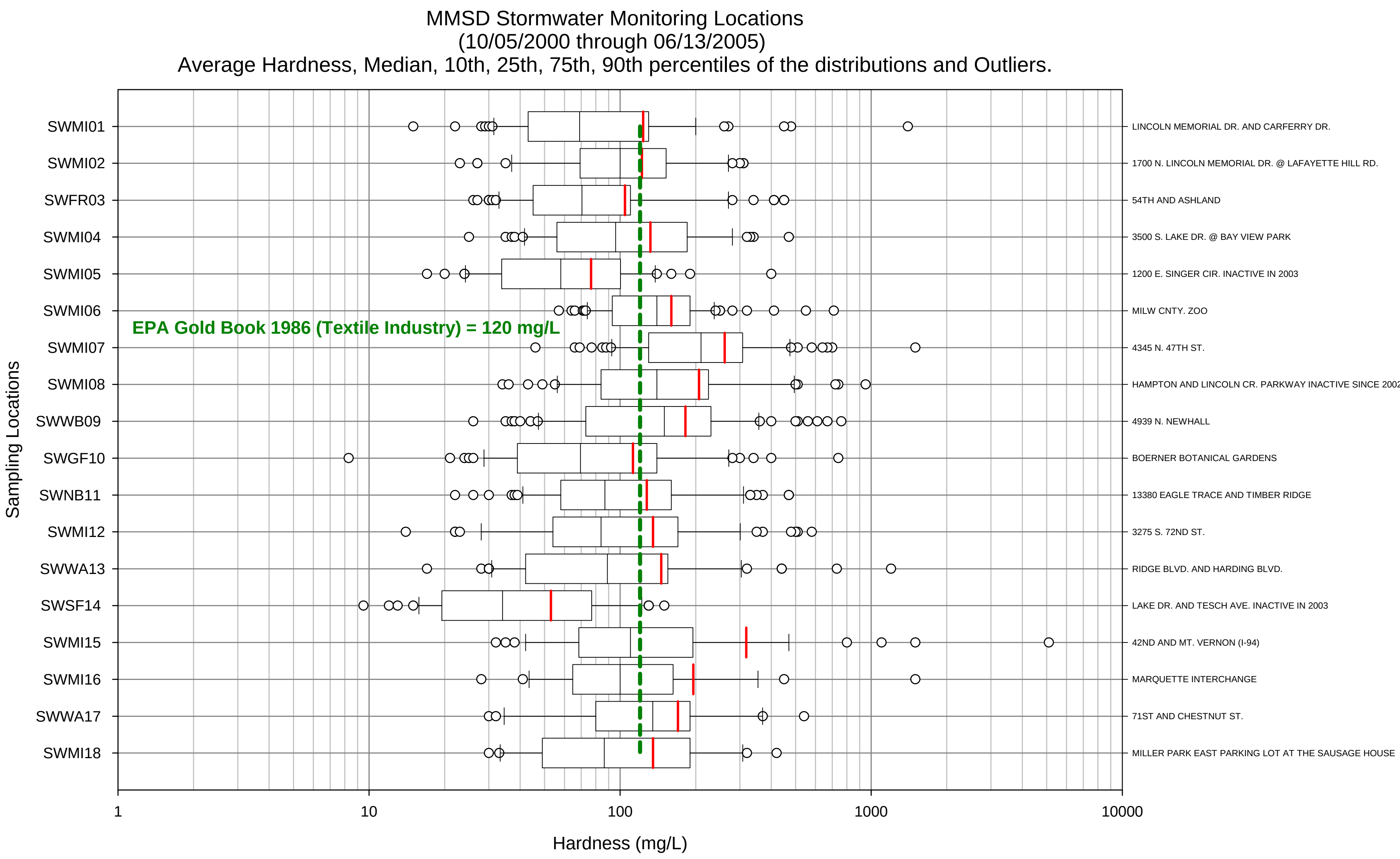


Figure E - 29 Lead (Pb) 1st and 2nd flush in stormwater

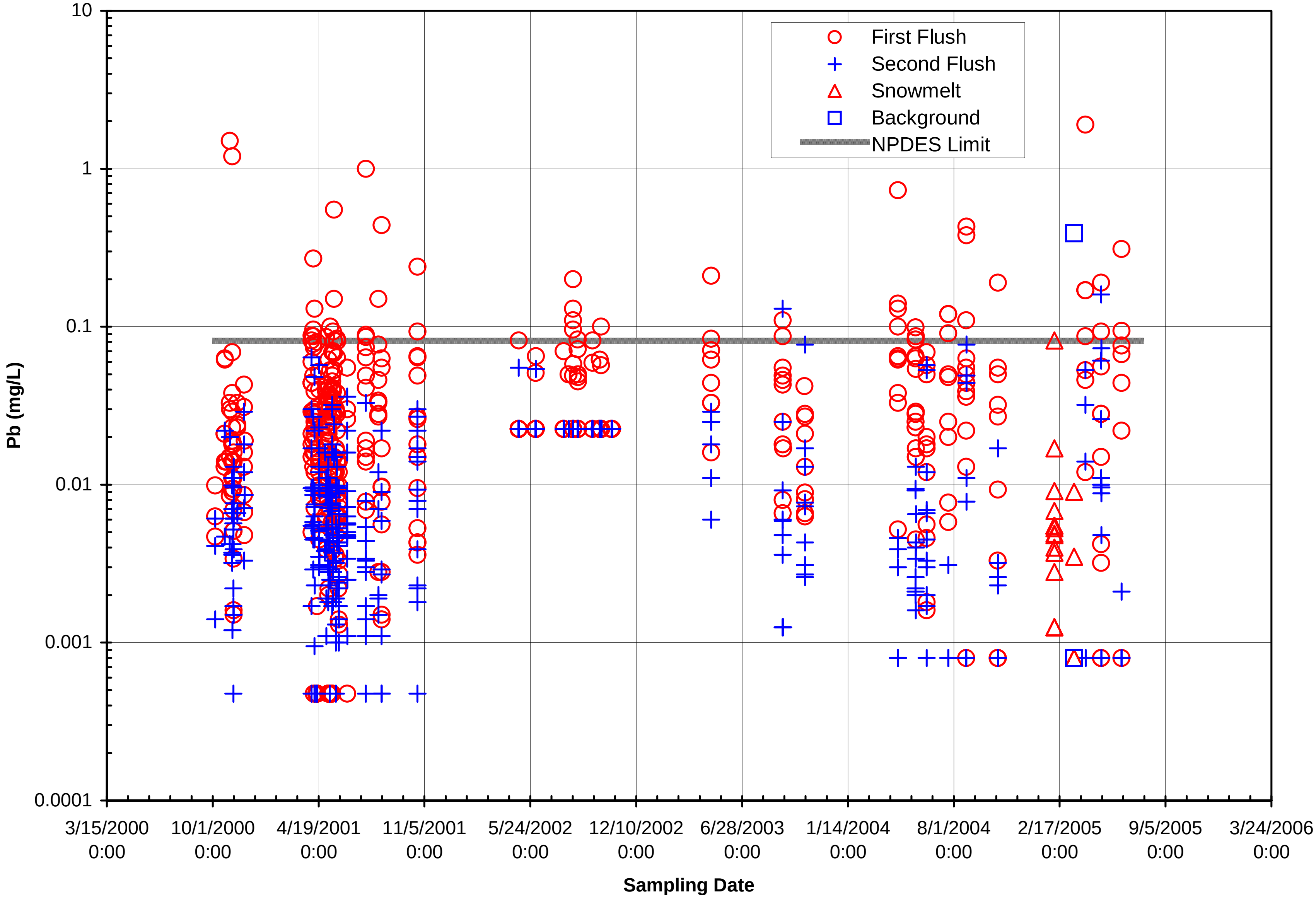


Figure E - 30 Lead (Pb) box chart in stormwater

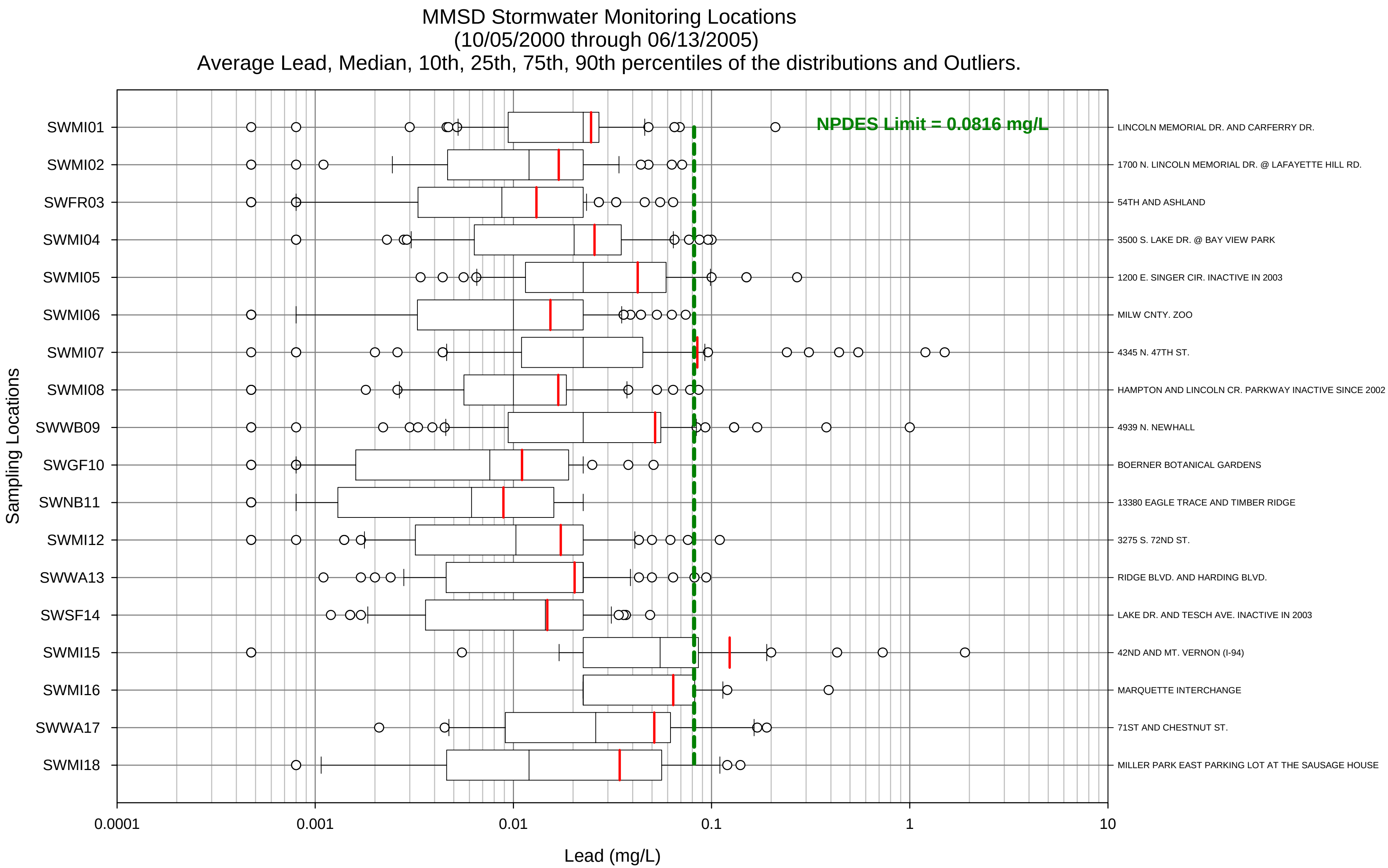


Figure E - 31 Magnesium (Mg) 1st and 2nd flush in stormwater

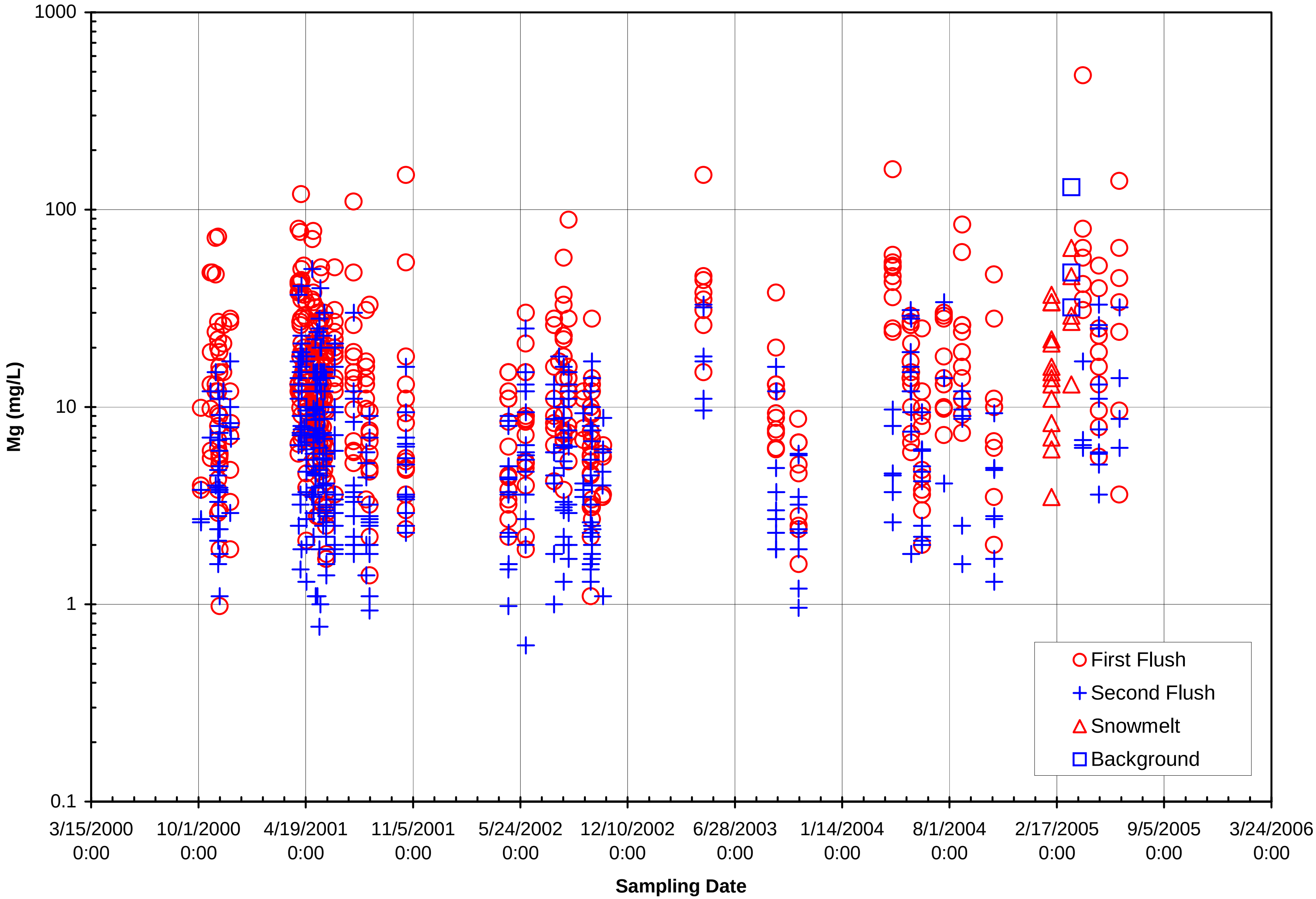


Figure E - 32 Magnesium (Mg) box chart in stormwater

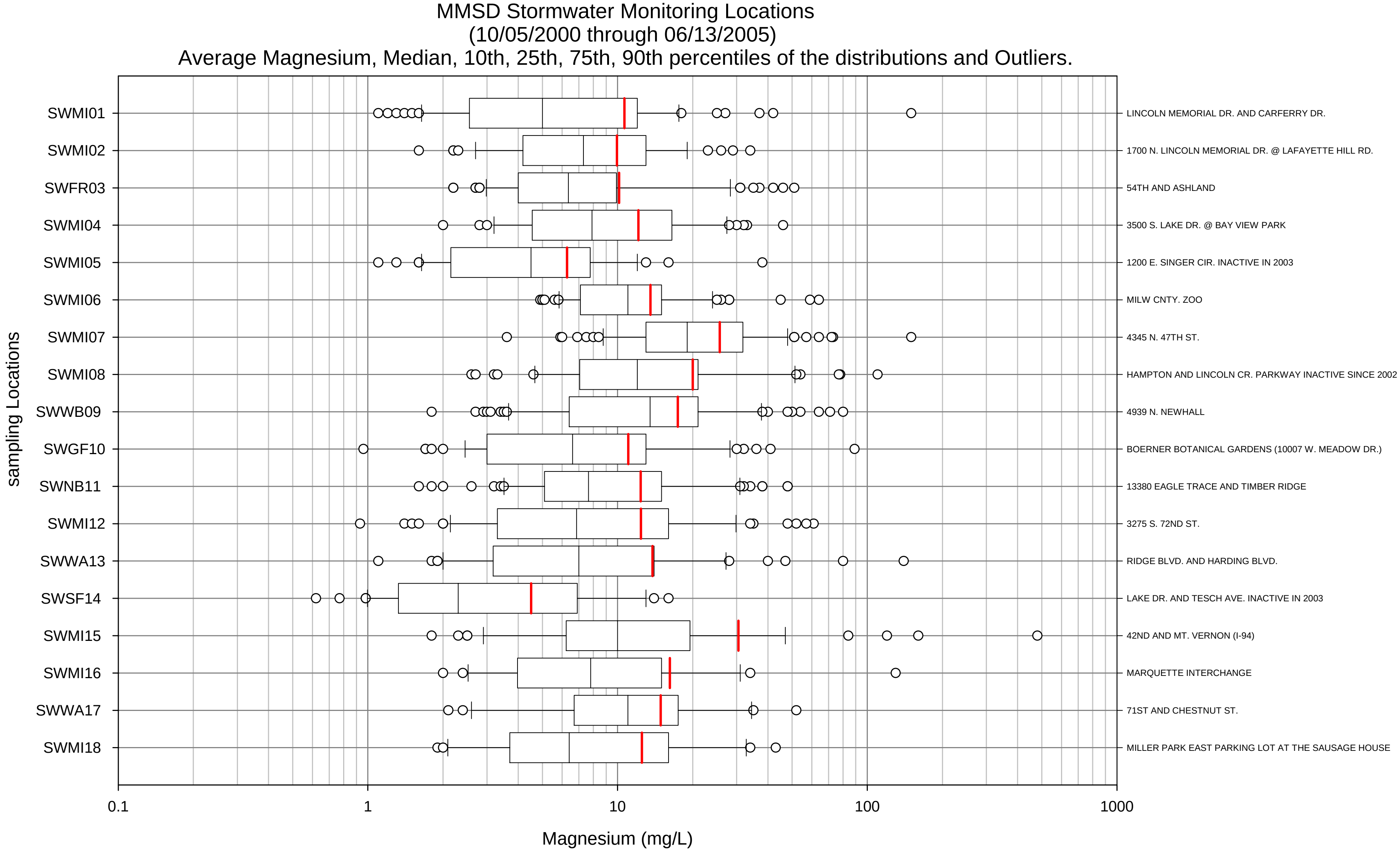


Figure E - 33 Mercury (Hg) 1st and 2nd flush in stormwater

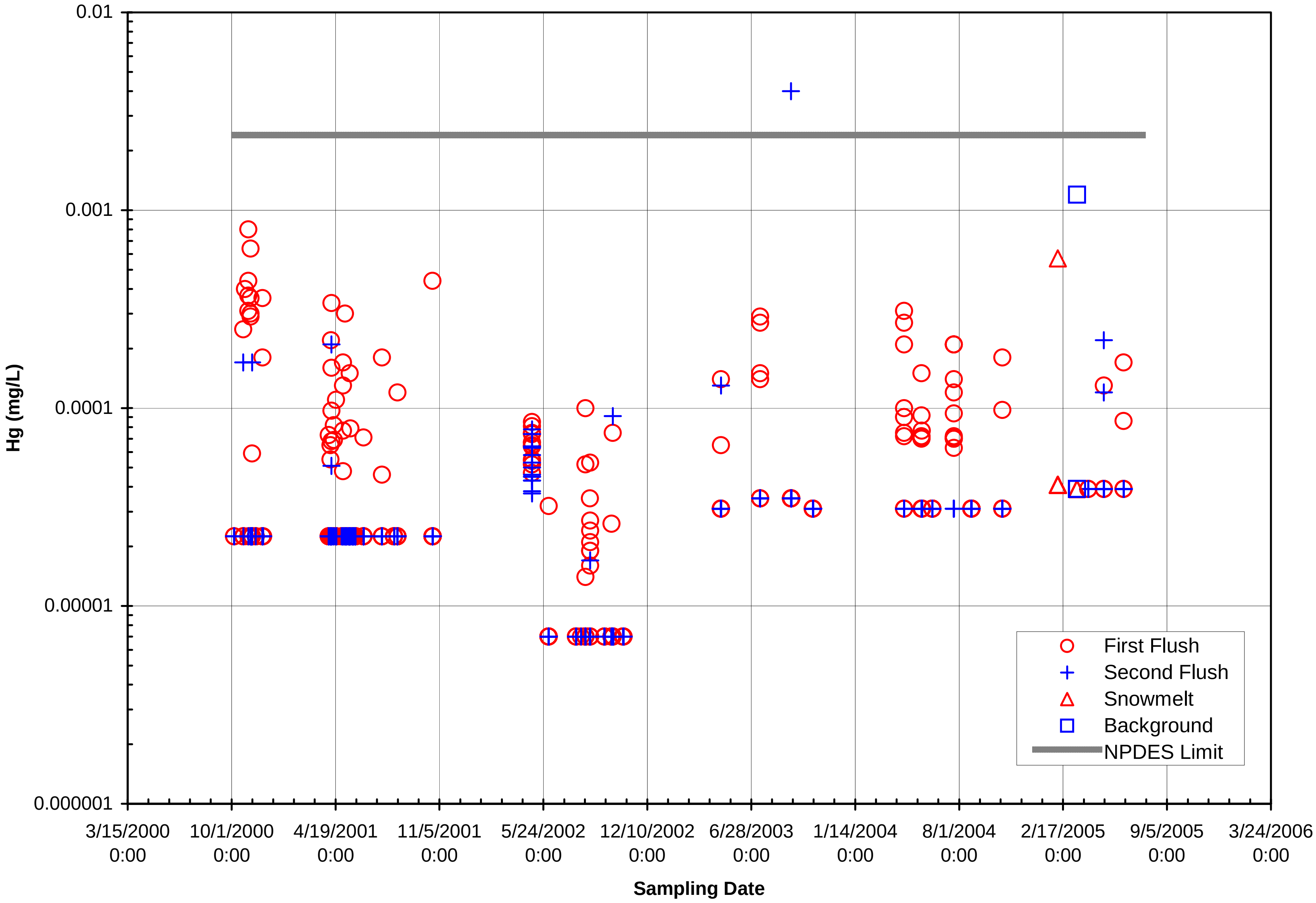


Figure E - 34   Mercury (Hg) box chart in stormwater

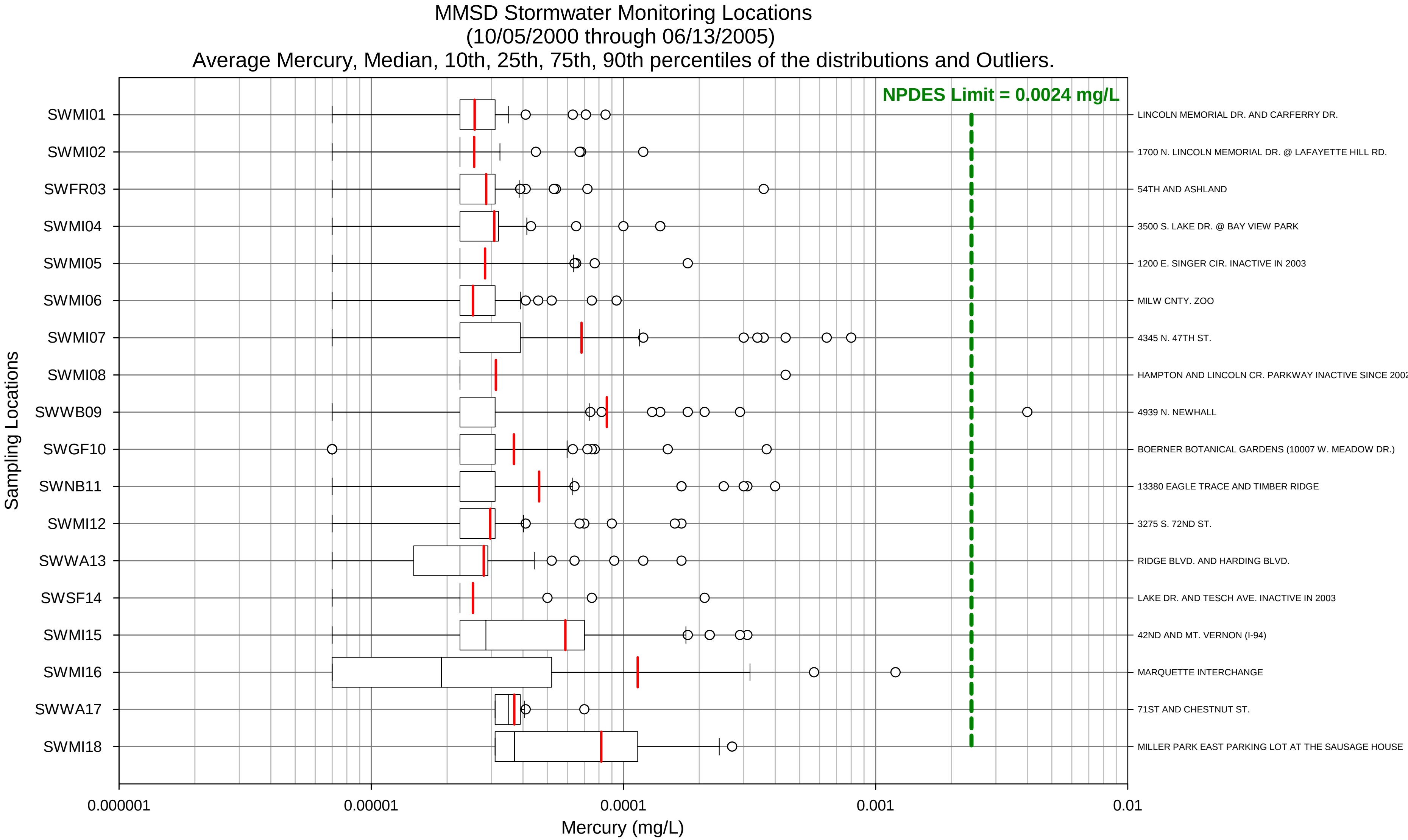


Figure E - 35 Nickel (Ni) 1st and 2nd flush in stormwater

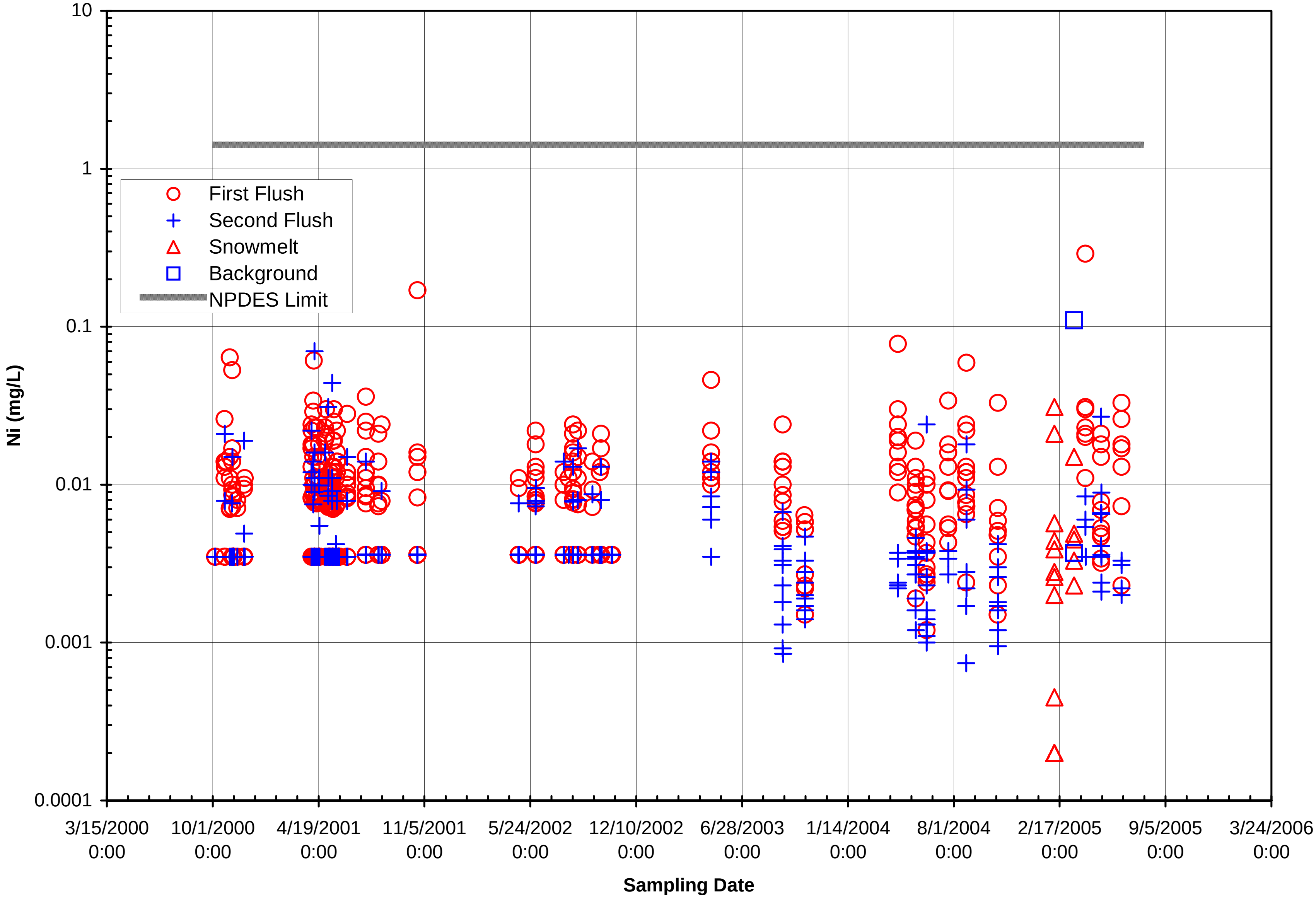


Figure E - 36   Nickel (Ni) box chart in stormwater

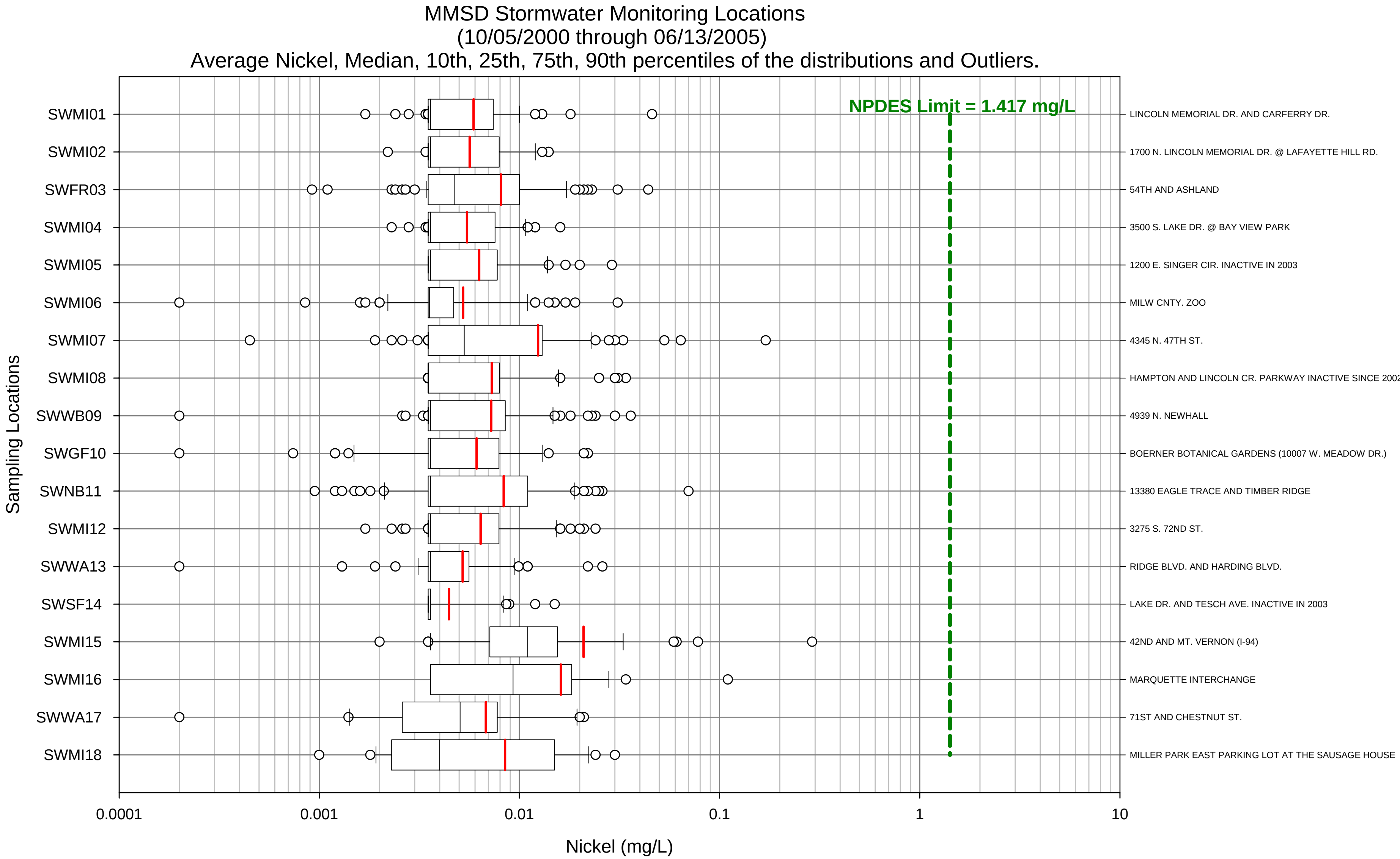


Figure E - 37 Nitrate and Nitrite (NO5) 1st and 2nd flush in stormwater

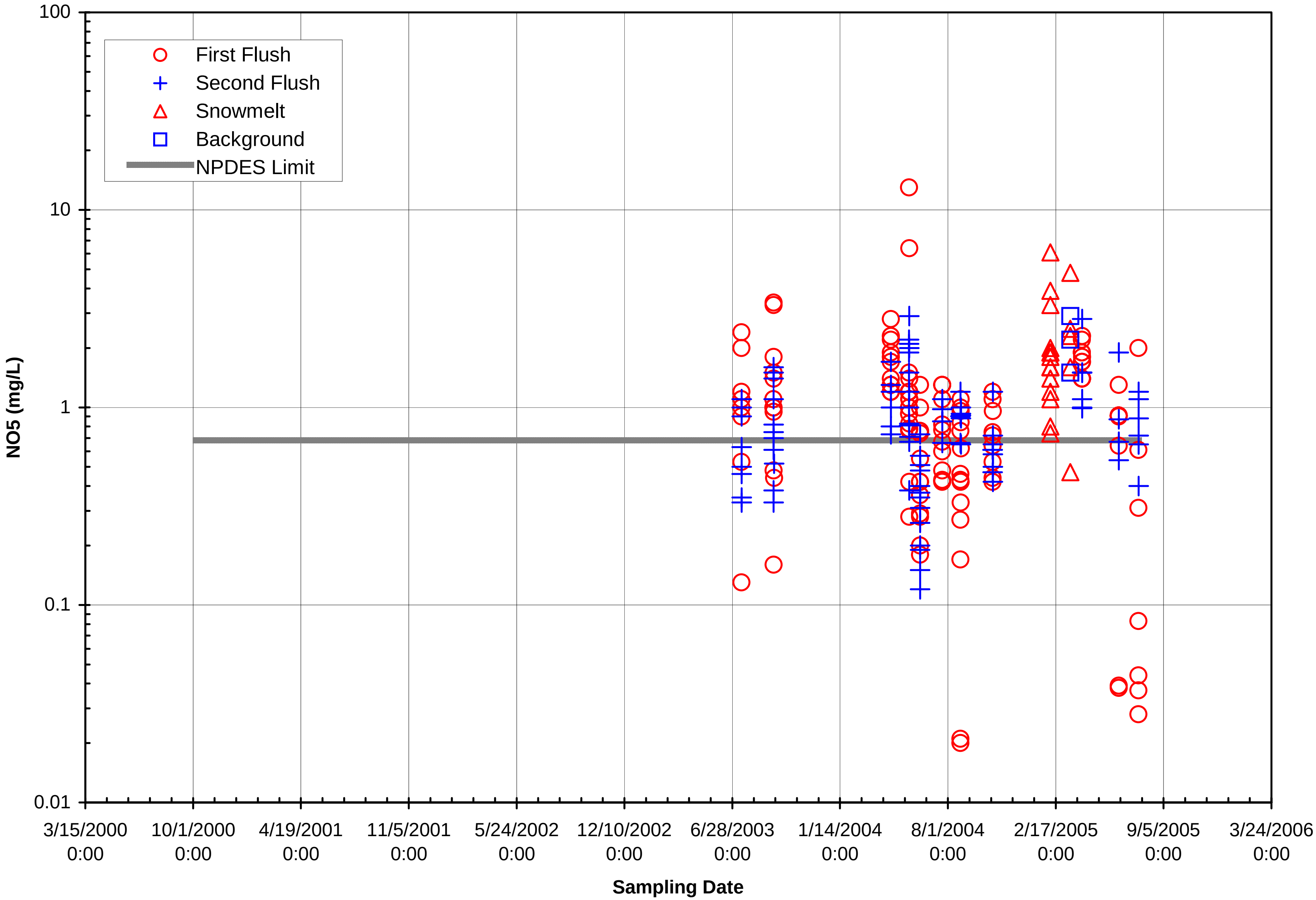


Figure E - 38   Nitrate and Nitrite (NO5) box chart in stormwater

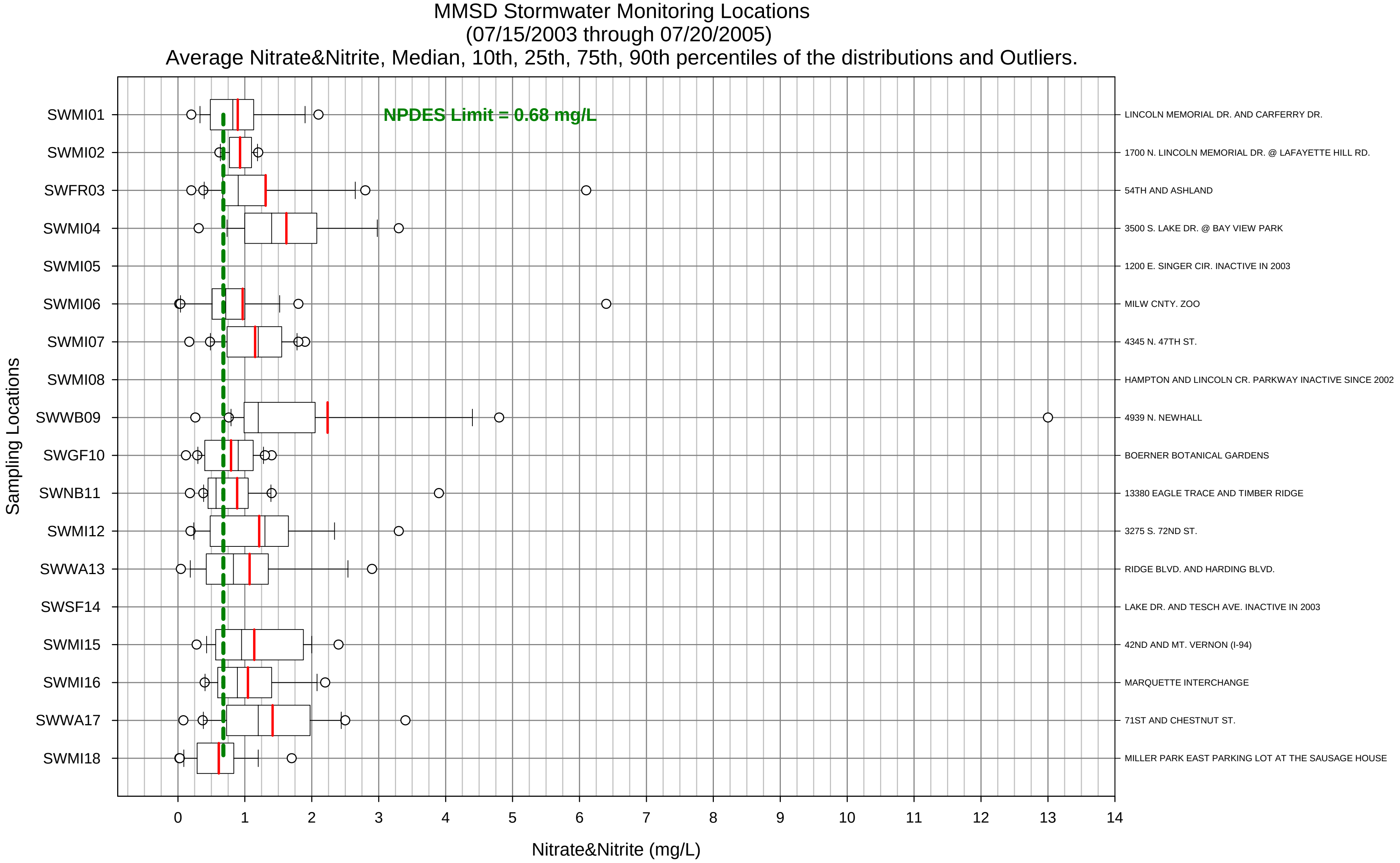


Figure E - 39 Nitrate nitrogen (NO3) 1st and 2nd flush in stormwater

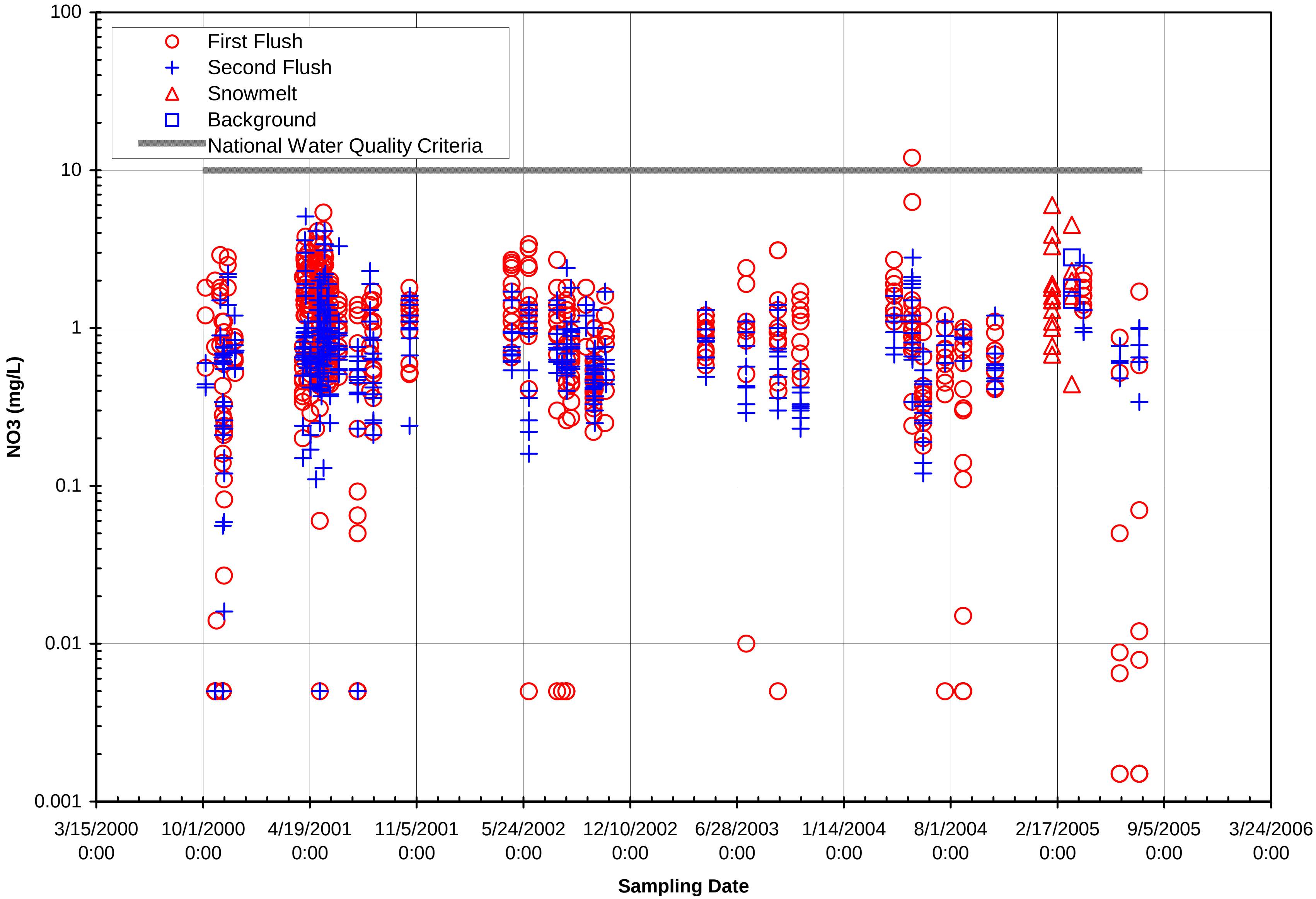


Figure E - 40   Nitrate nitrogen (NO3) box chart in stormwater

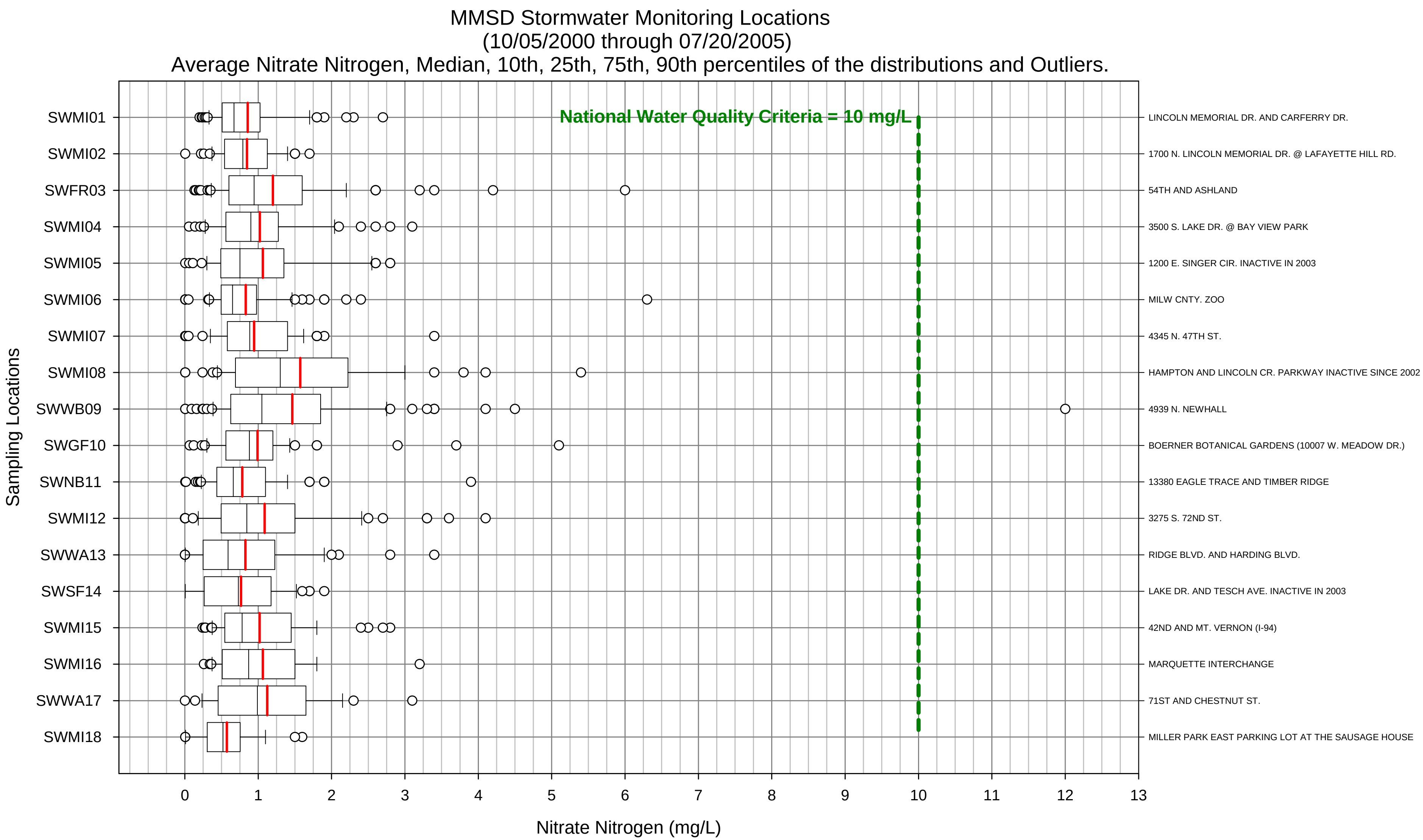


Figure E - 41   Nitrite nitrogen (NO2) 1st and 2nd flush in stormwater

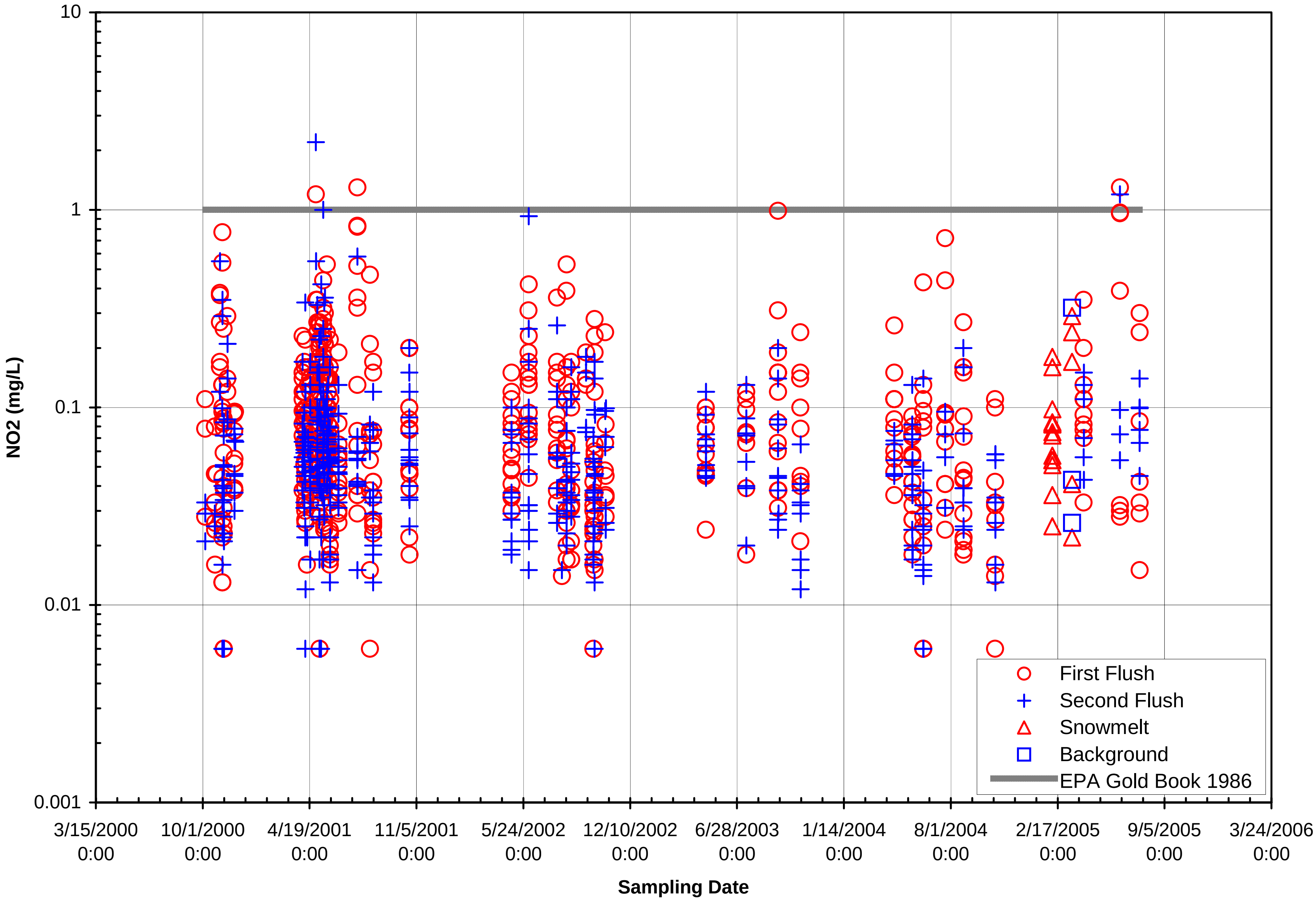


Figure E - 42   Nitrite nitrogen (NO2) box chart in stormwater

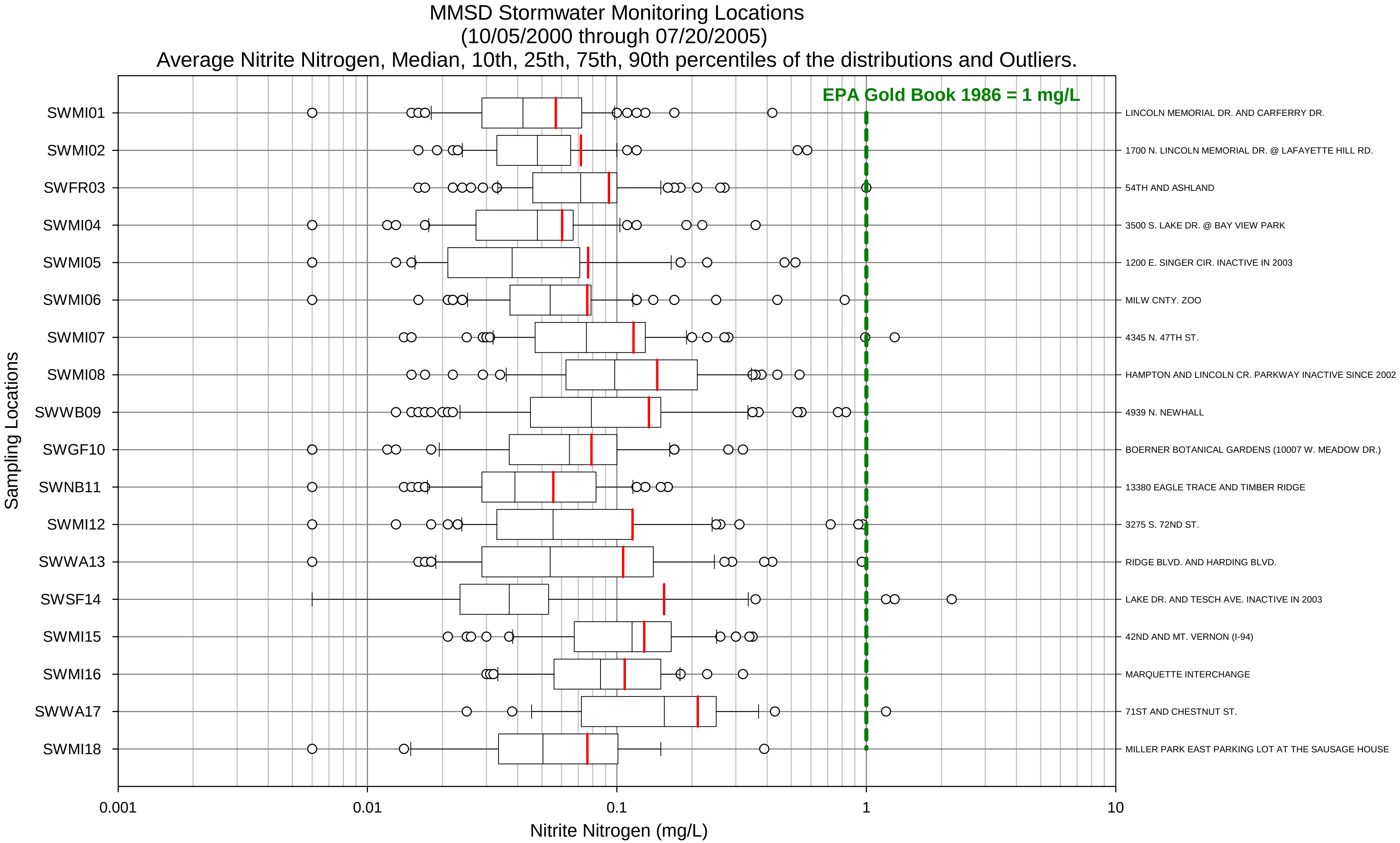


Figure E - 43   Selenium (Se) 1st and 2nd flush in stormwater

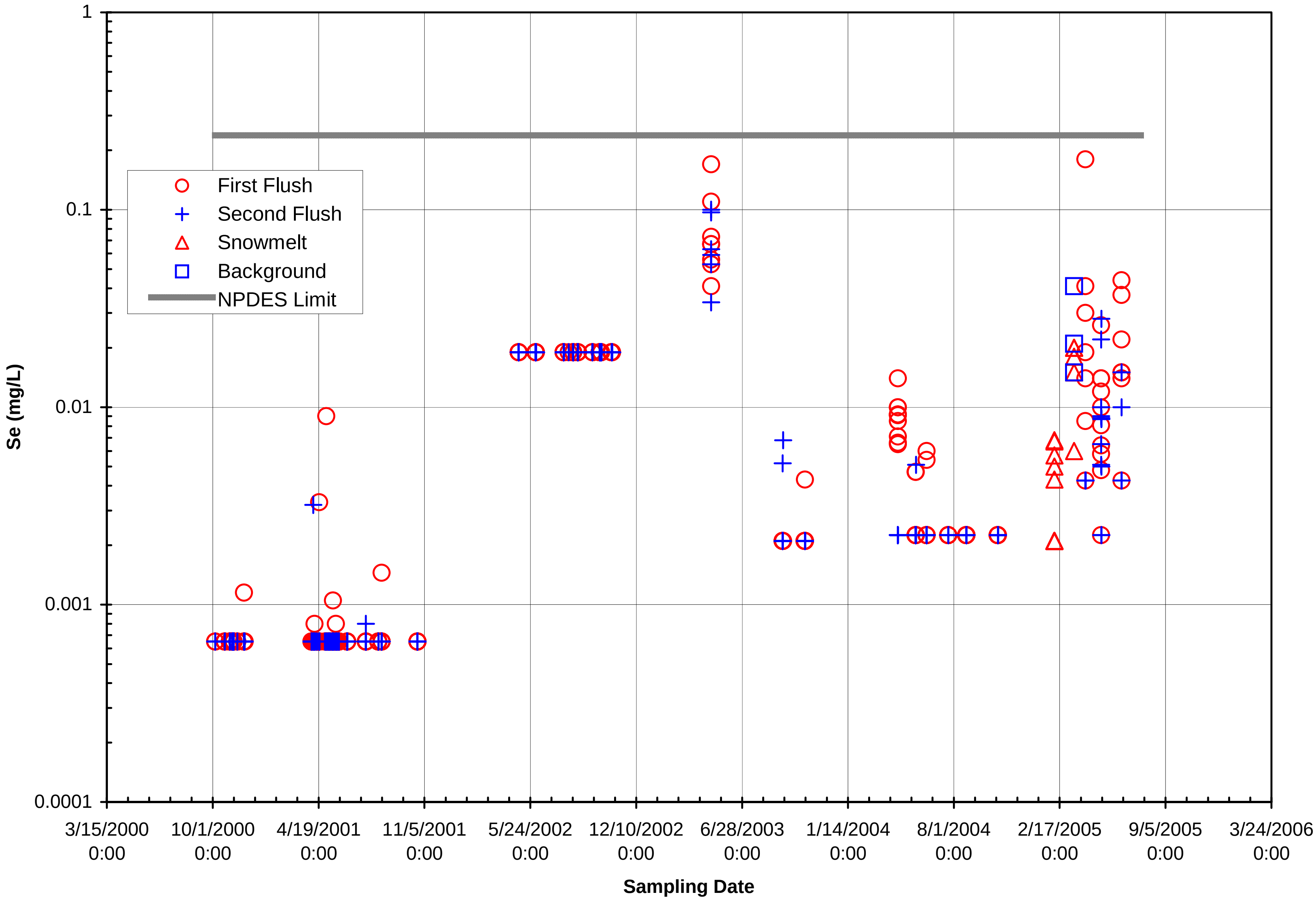


Figure E - 44 Selenium (Se) box chart in stormwater

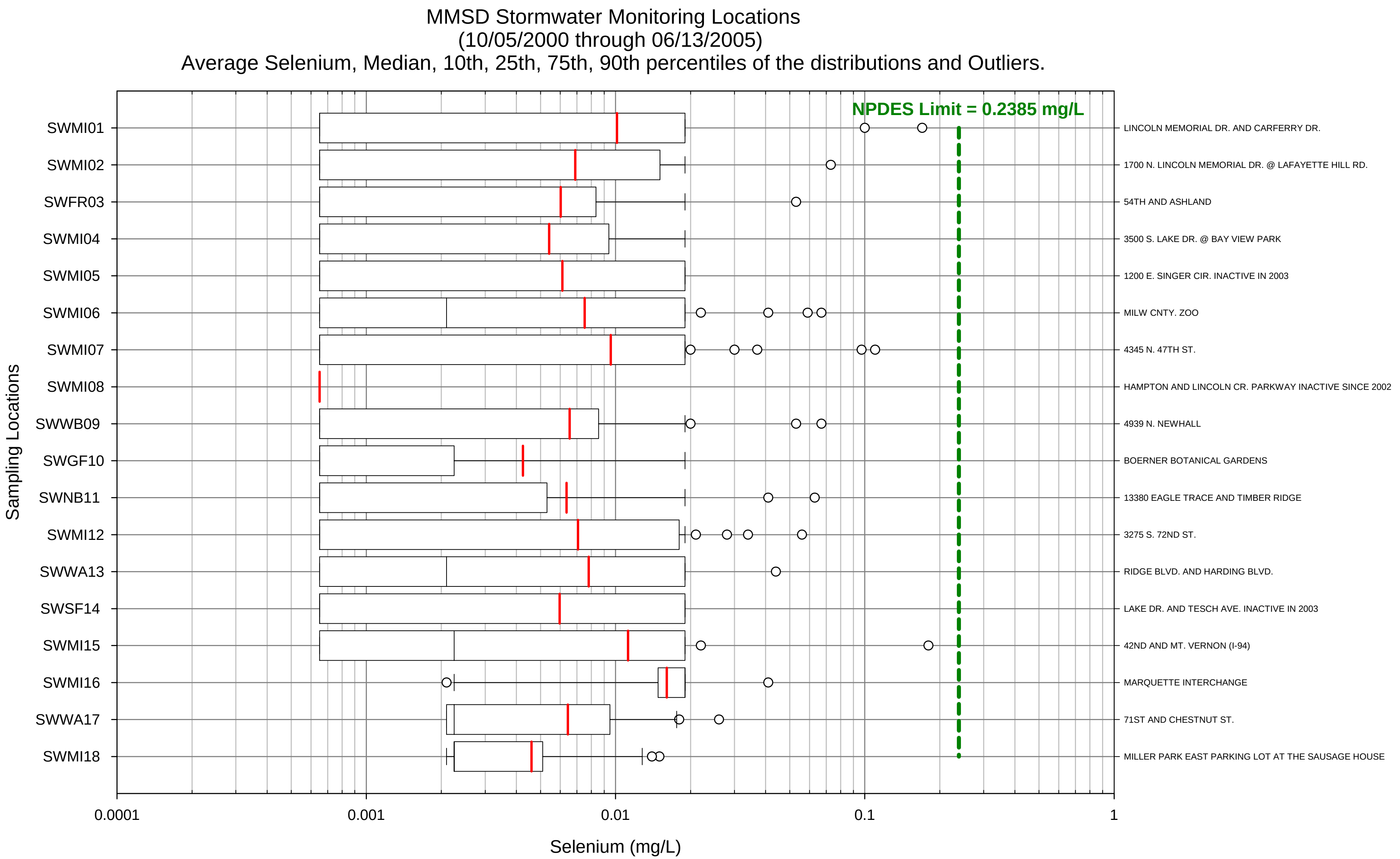


Figure E - 45 Silver (Ag) 1st and 2nd flush in stormwater

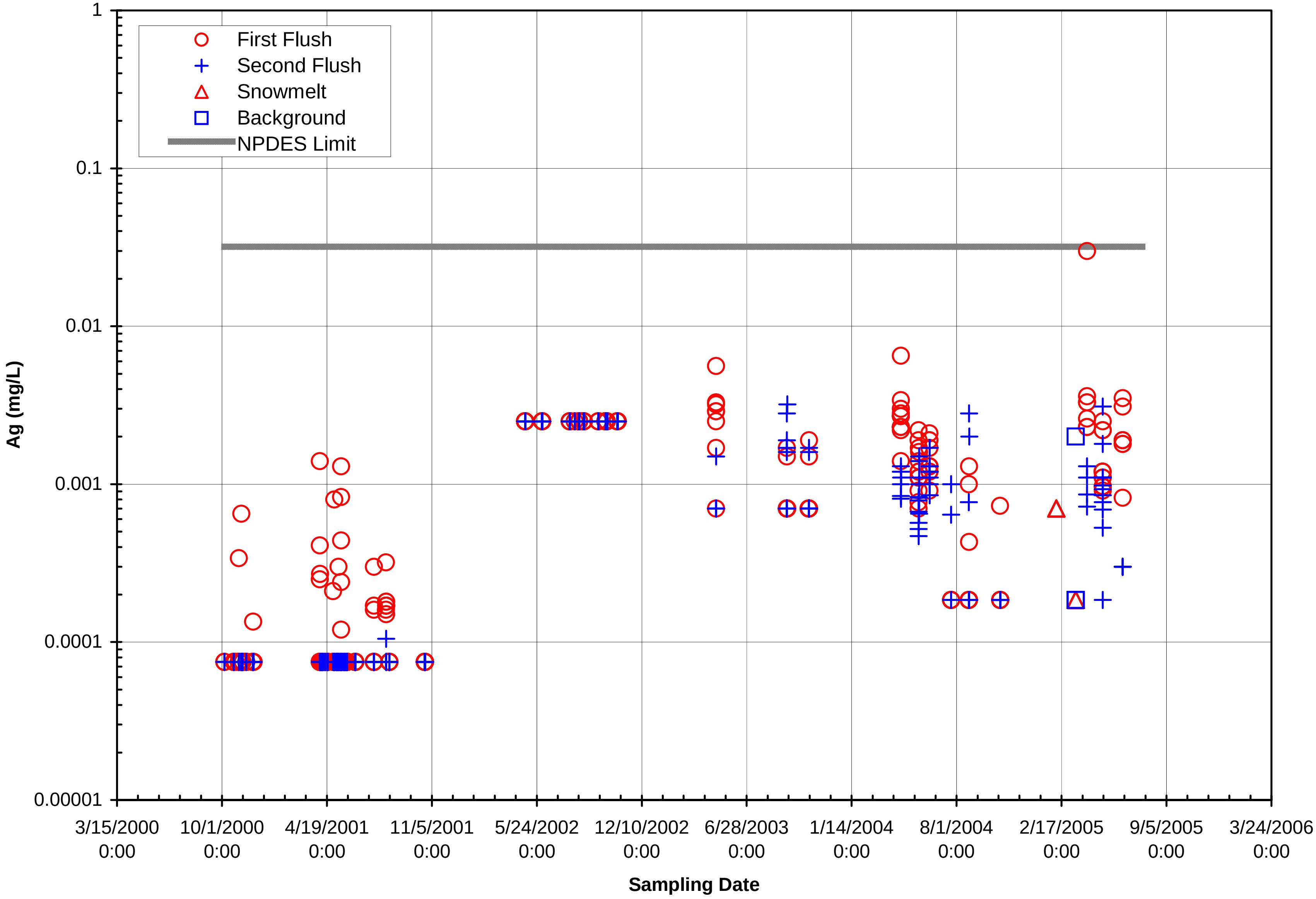


Figure E - 46   Silver (Ag) box chart in stormwater

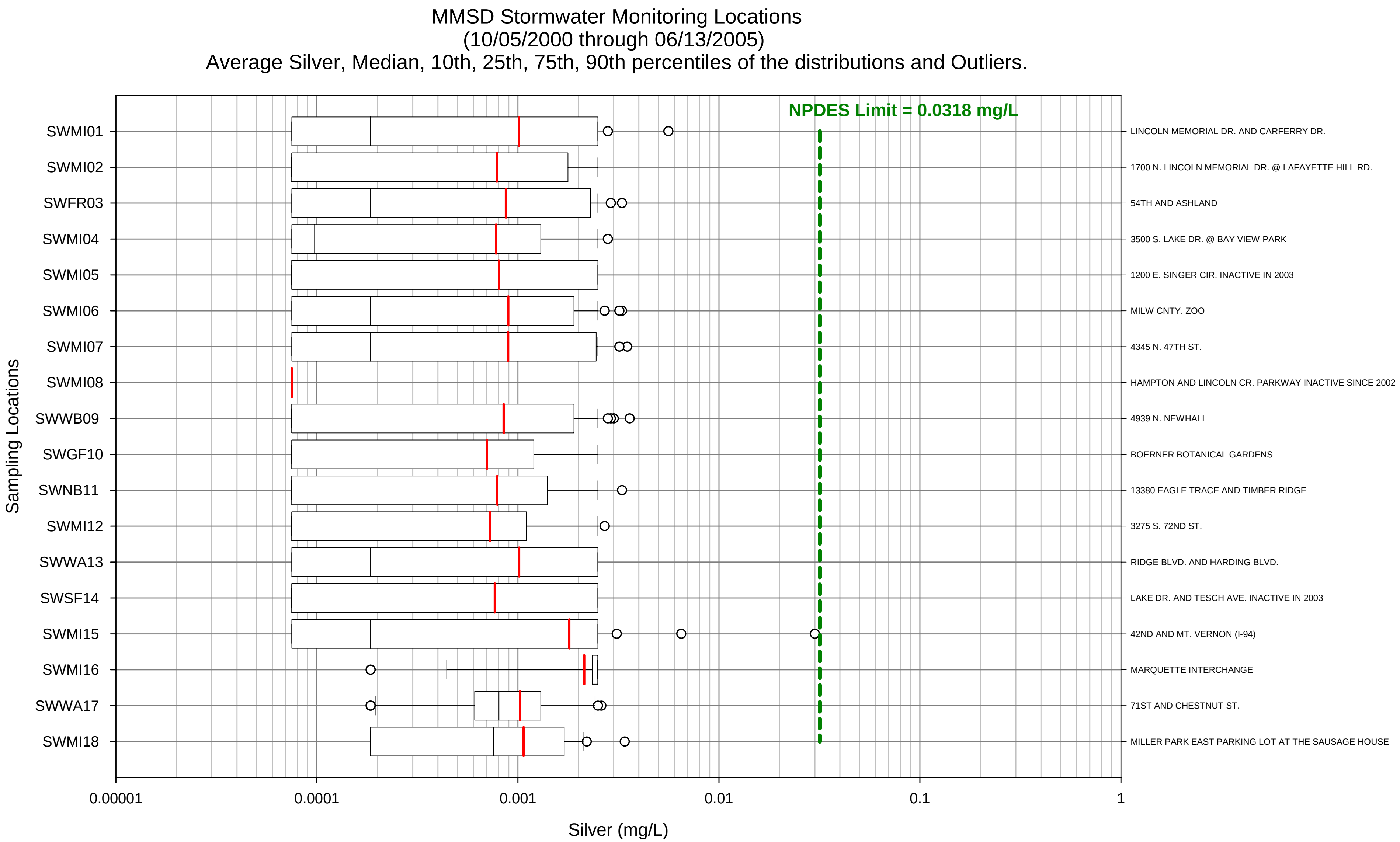


Figure E - 47 Thallium (Tl) 1st and 2nd flush in stormwater

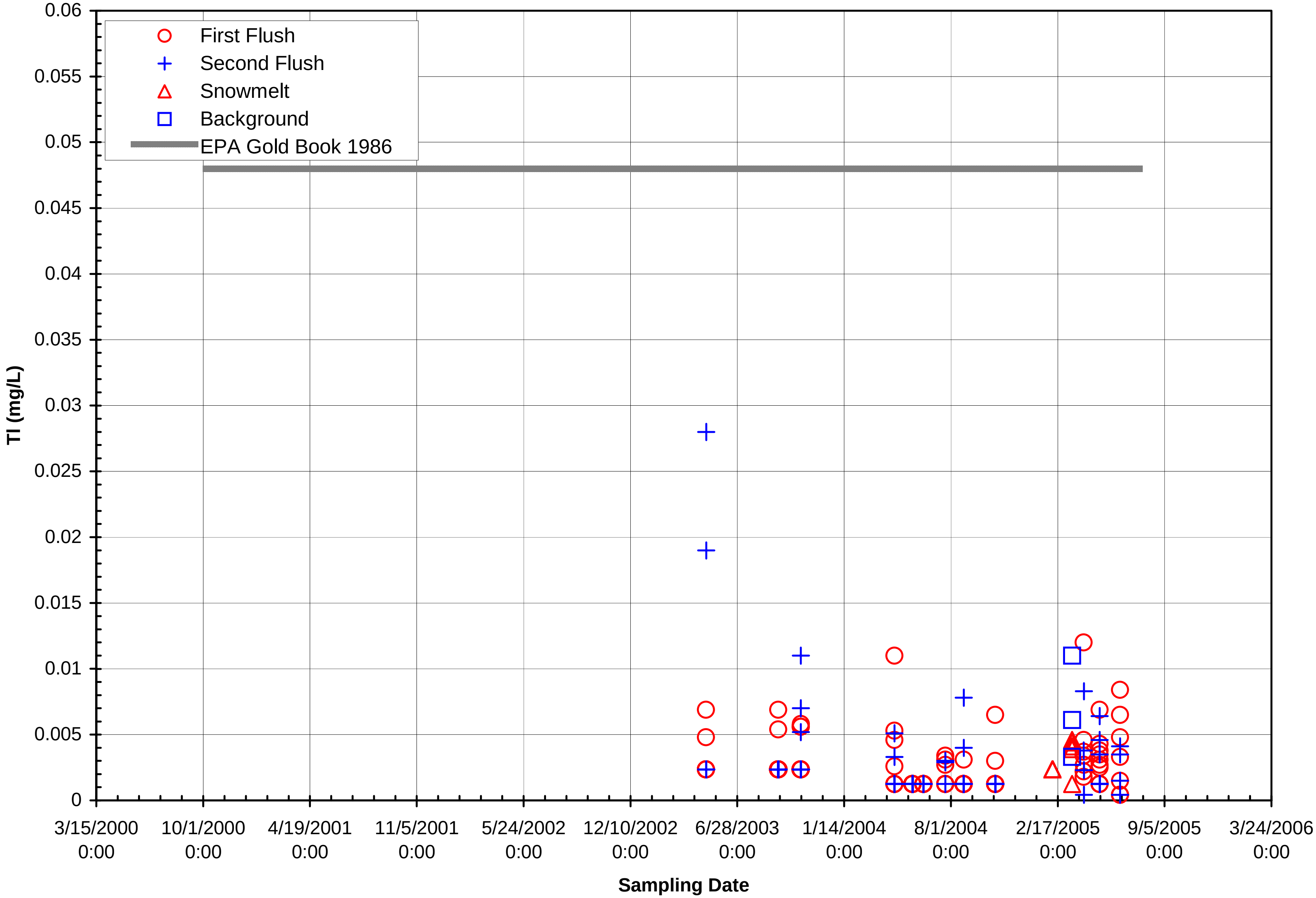


Figure E - 48 Thallium (Tl) box chart in stormwater

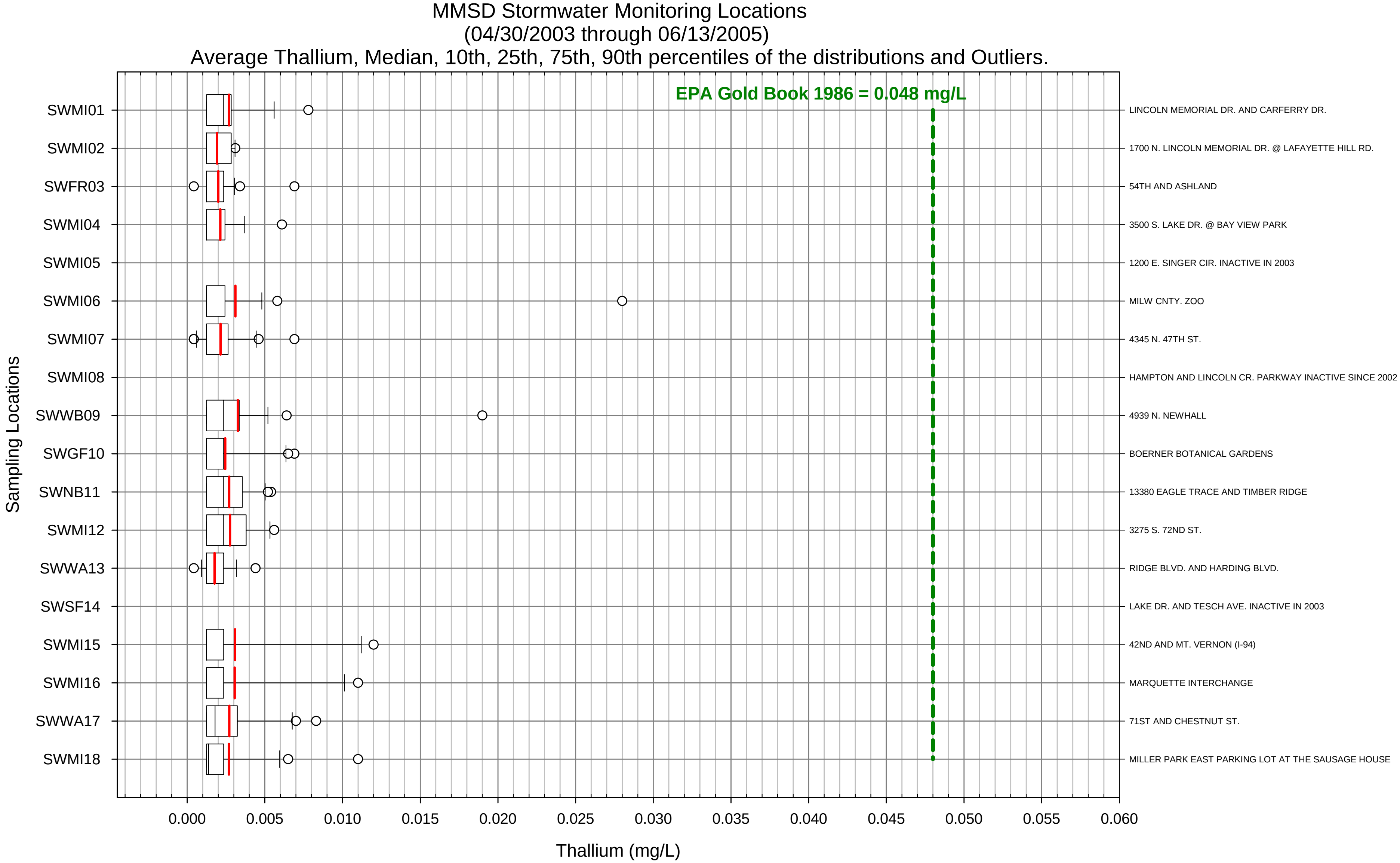


Figure E - 49 TKN 1st and 2nd flush in stormwater

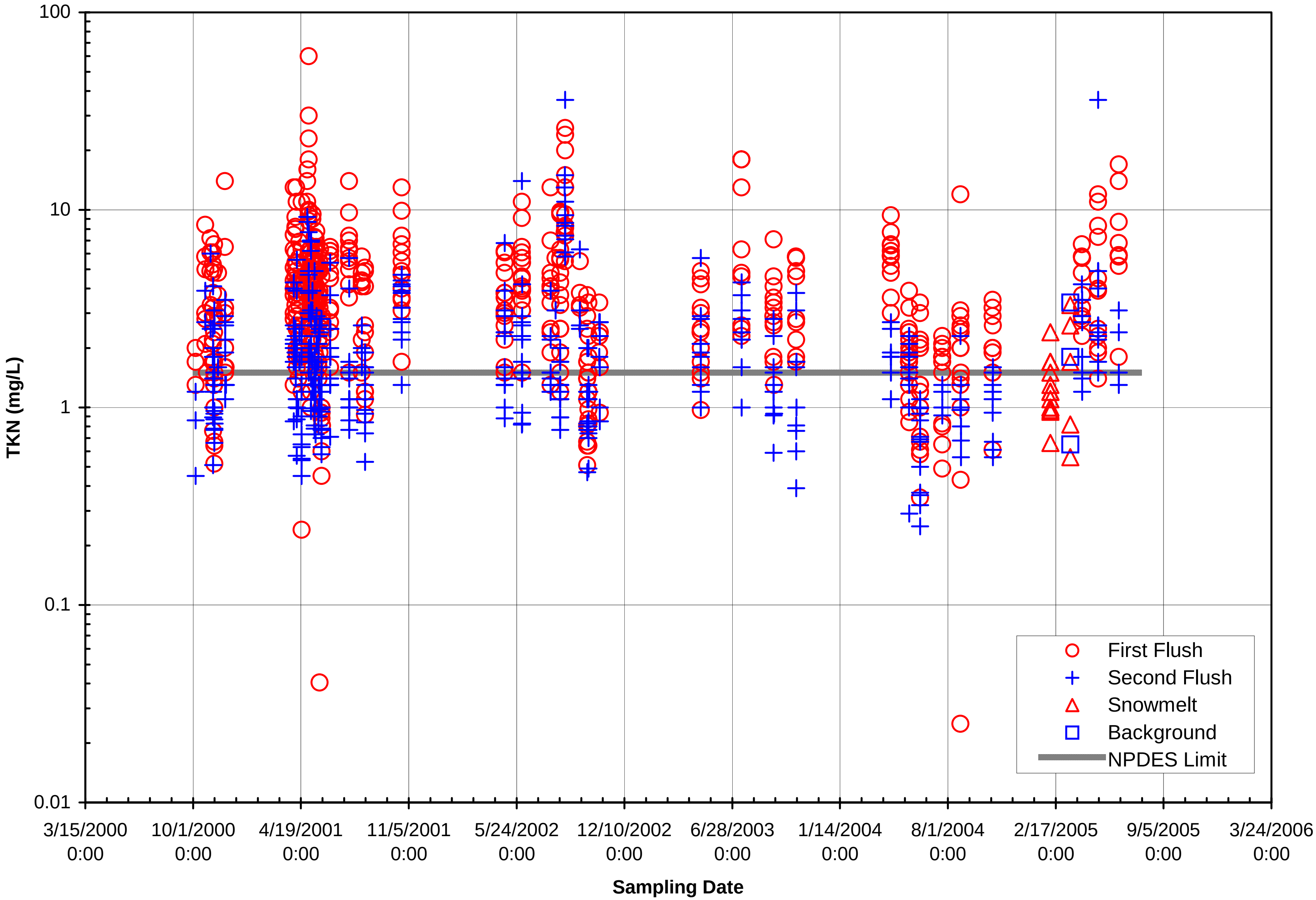


Figure E - 50 TKN box chart in stormwater

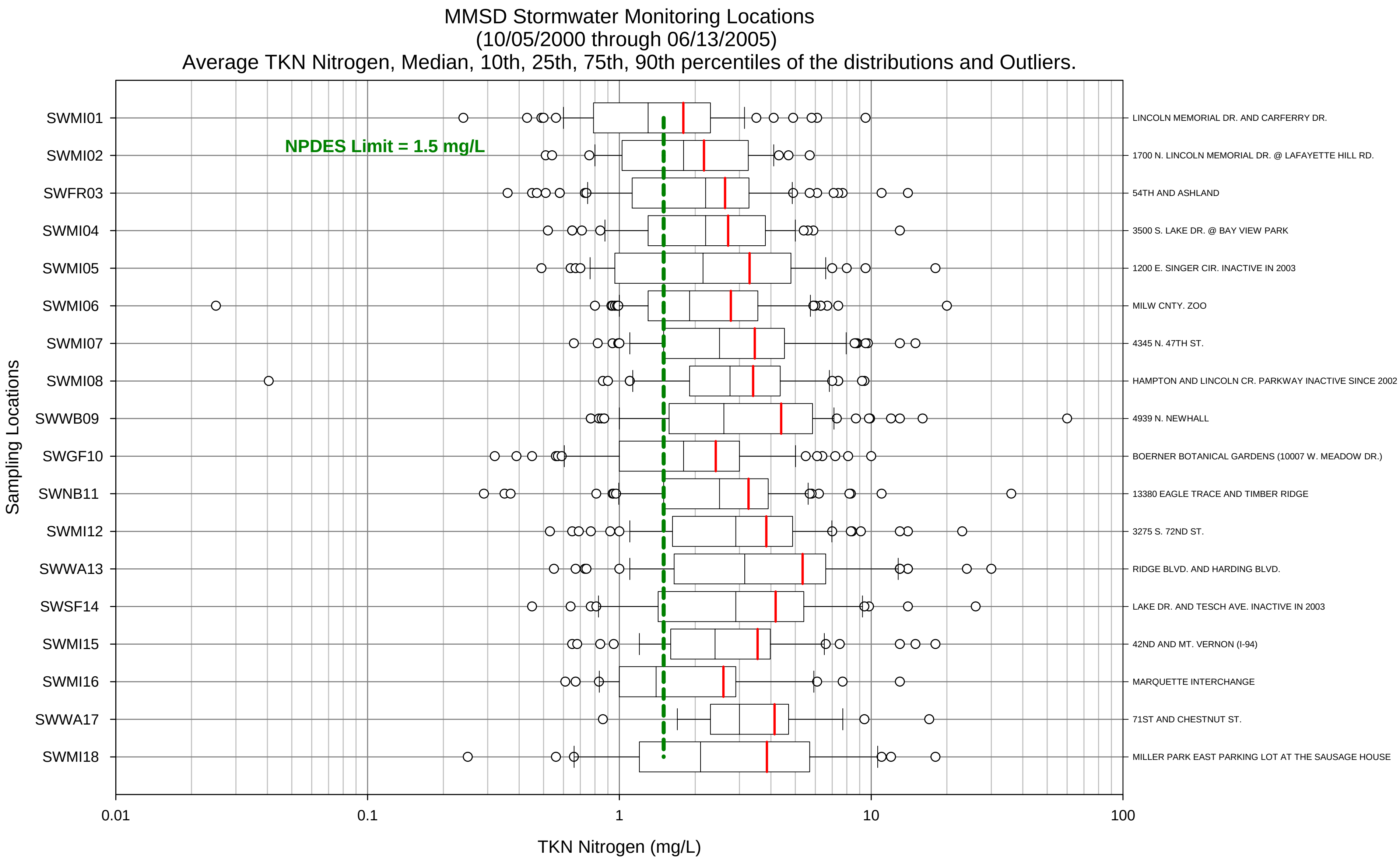


Figure E - 51   Total dissolved solids (TDS) 1st and 2nd flush in stormwater

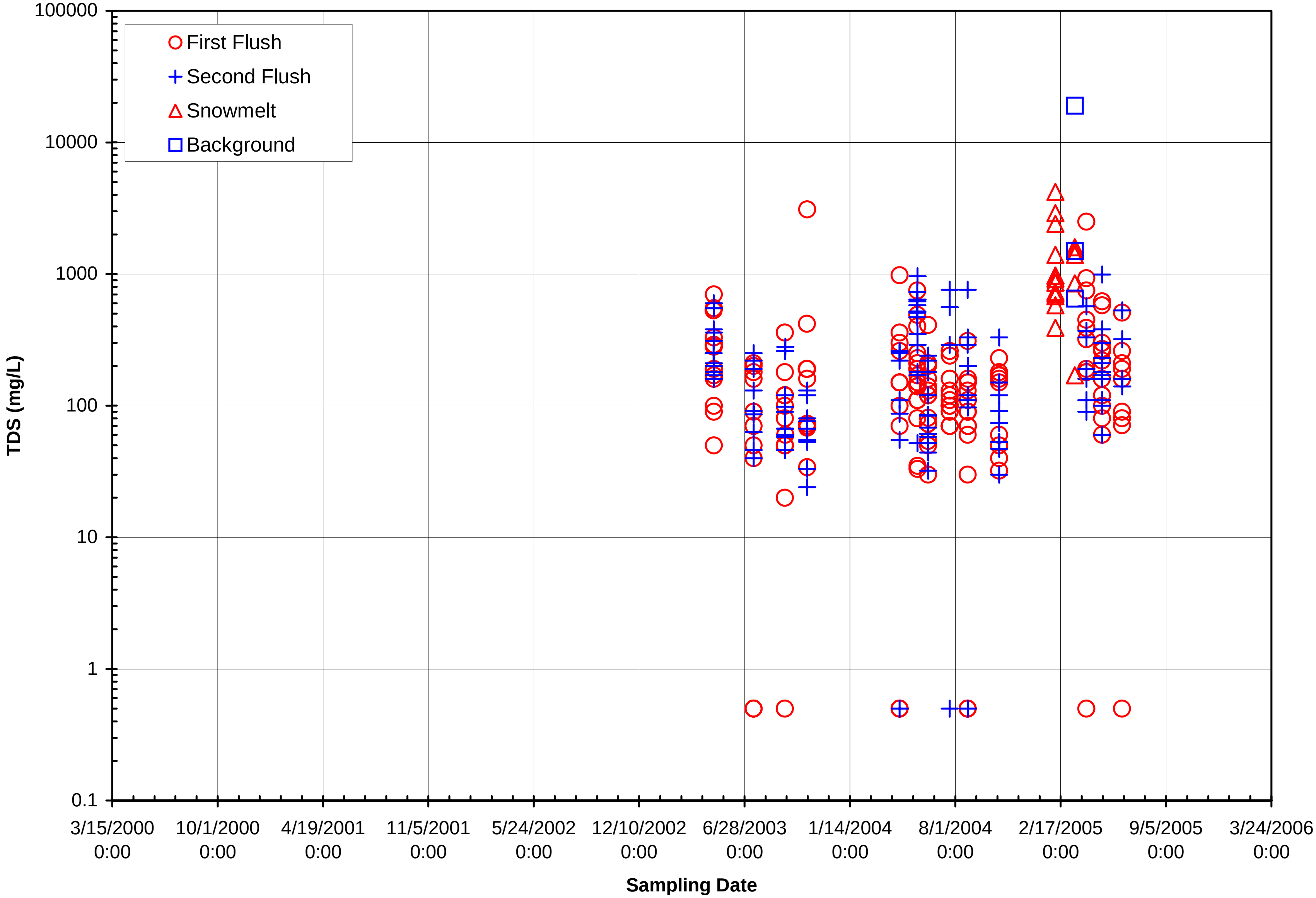


Figure E - 52   Total dissolved solids (TDS) box chart in stormwater

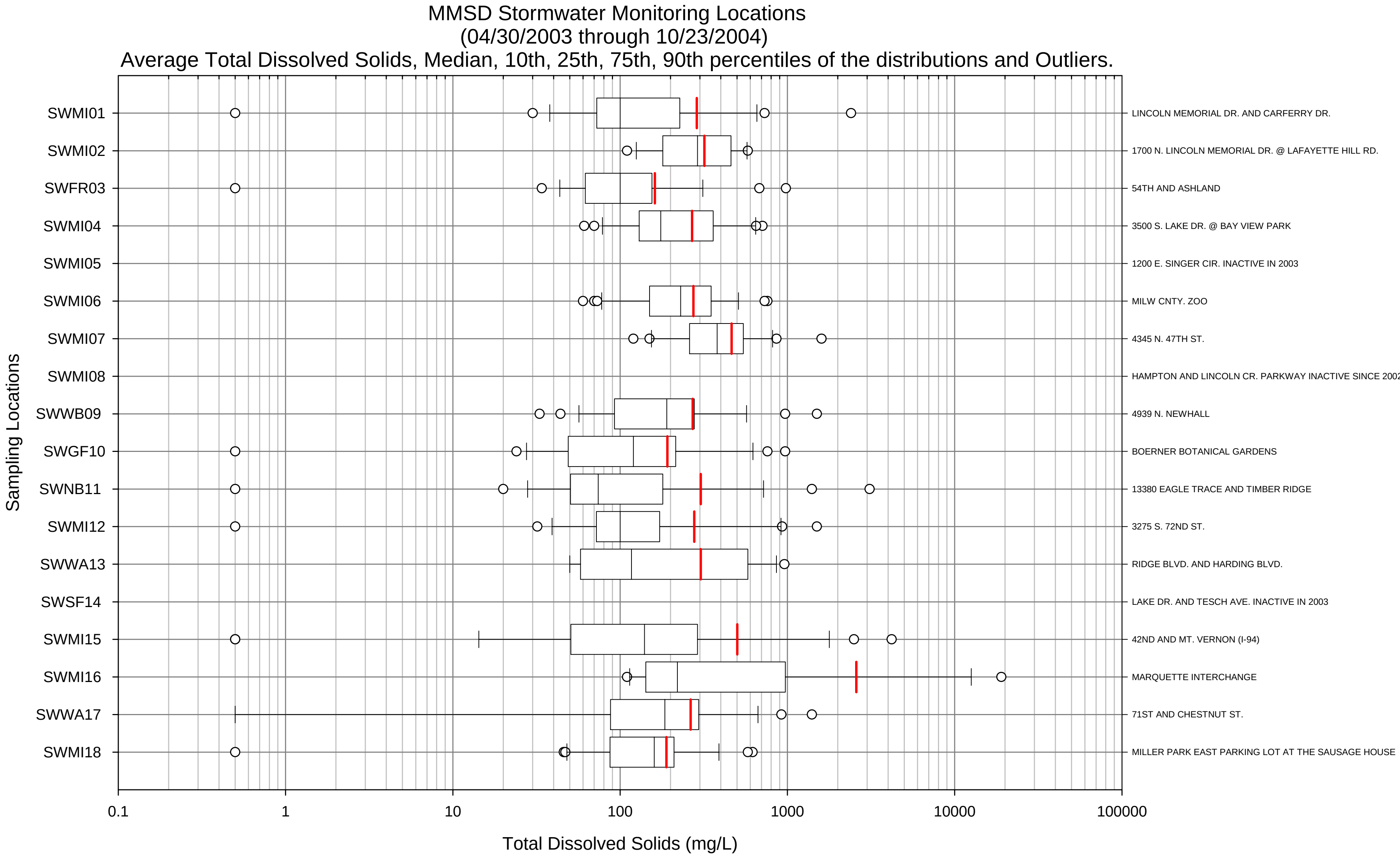


Figure E - 53 Total organic carbon (TOC) 1st and 2nd flush in stormwater

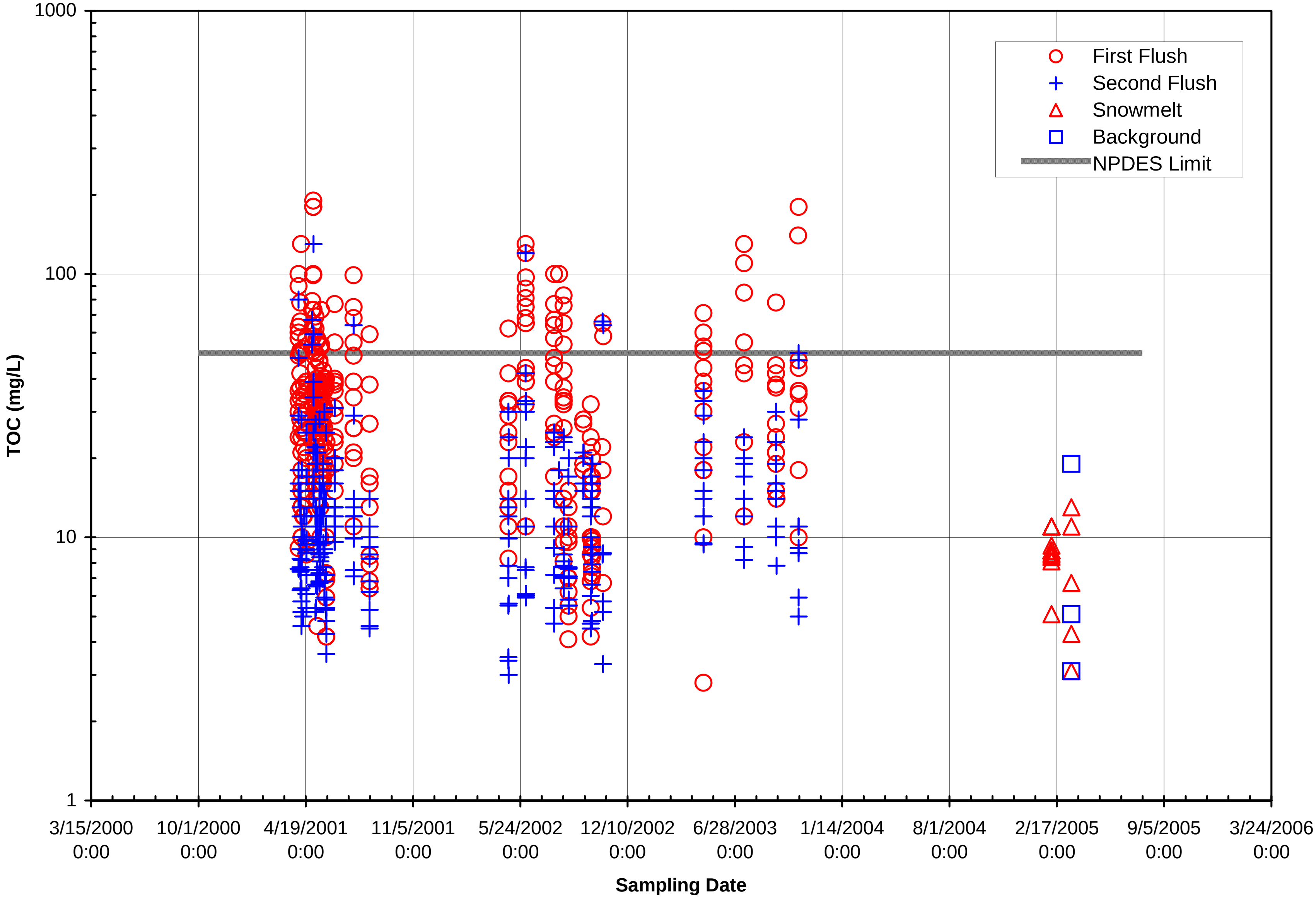


Figure E - 54   Total organic carbon (TOC) box chart in stormwater

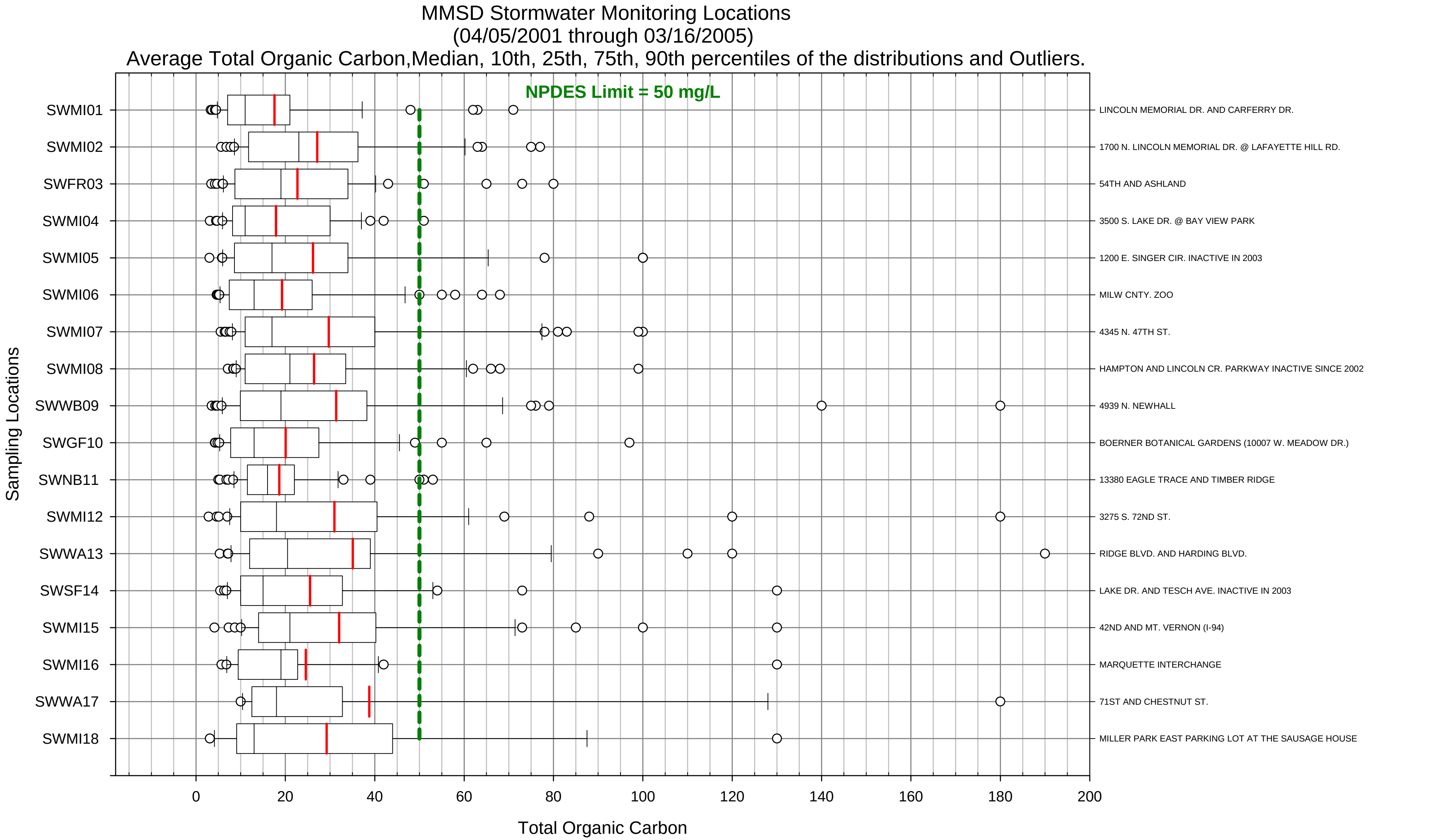


Figure E - 55 Total phosphorus (TP) 1st and 2nd flush in stormwater

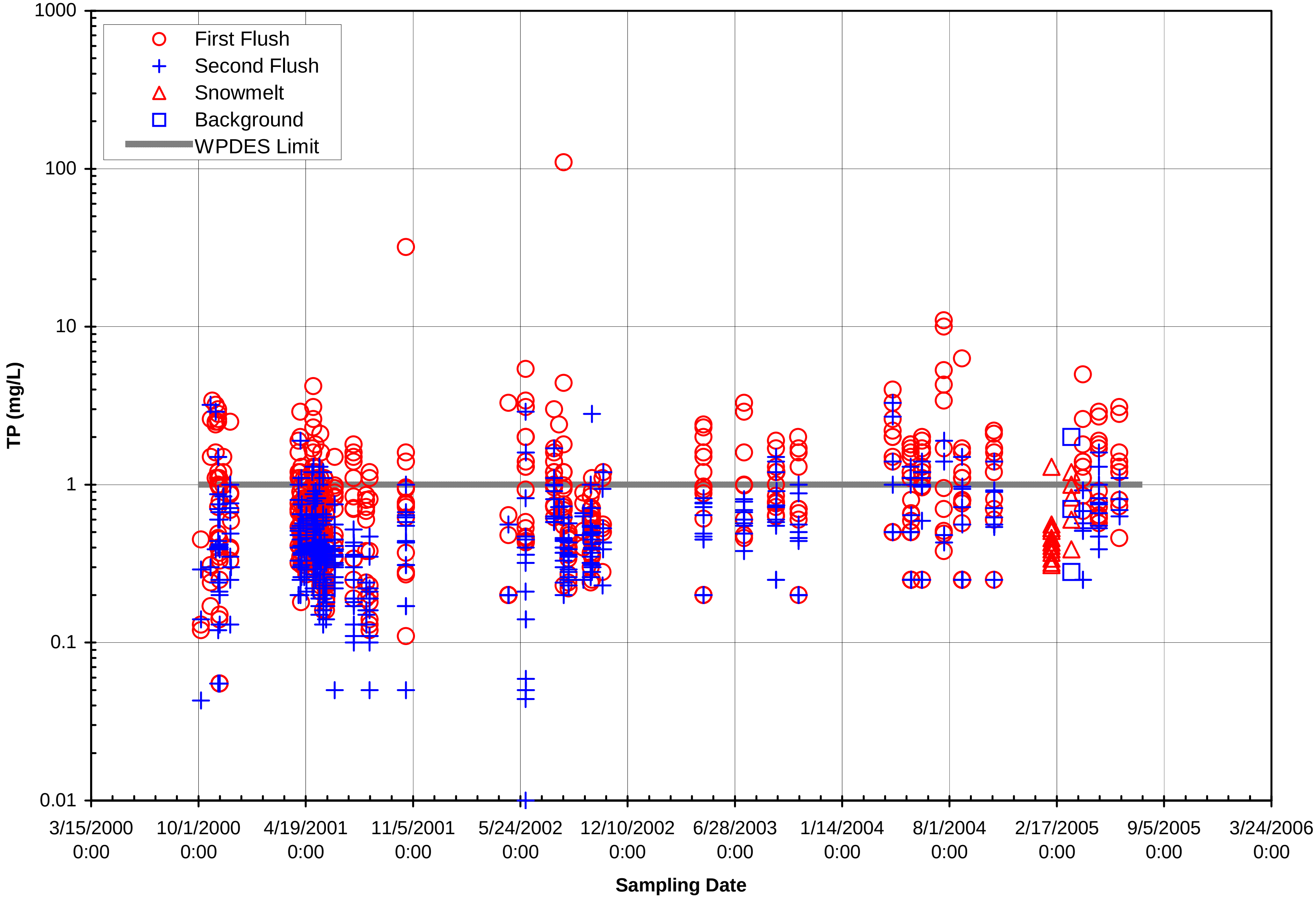


Figure E - 56 Total phosphorus (TP) box chart in stormwater

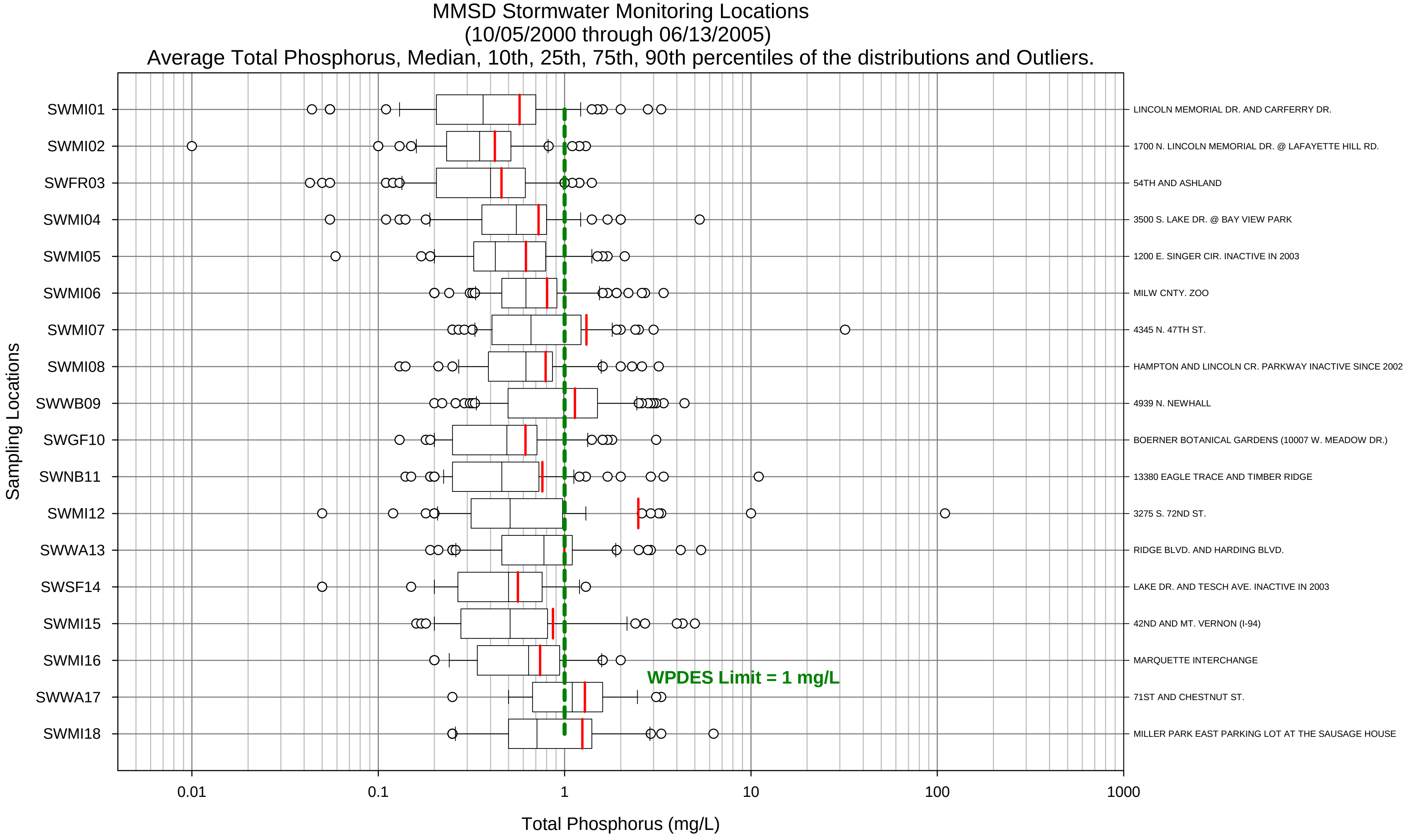


Figure E - 57   Total solids (TS) 1st and 2nd flush in stormwater

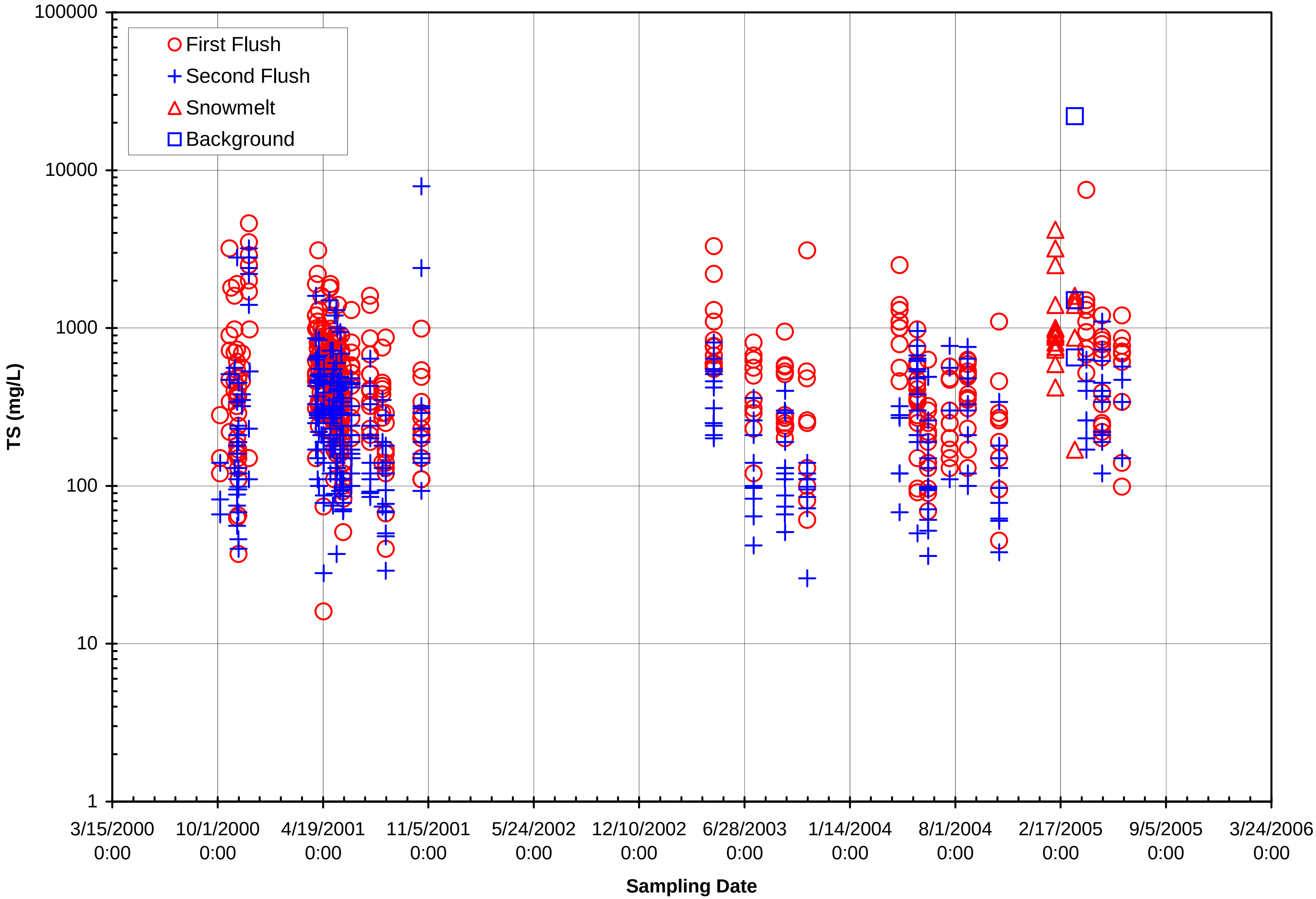


Figure E - 58 Total solids (TS) box chart in stormwater

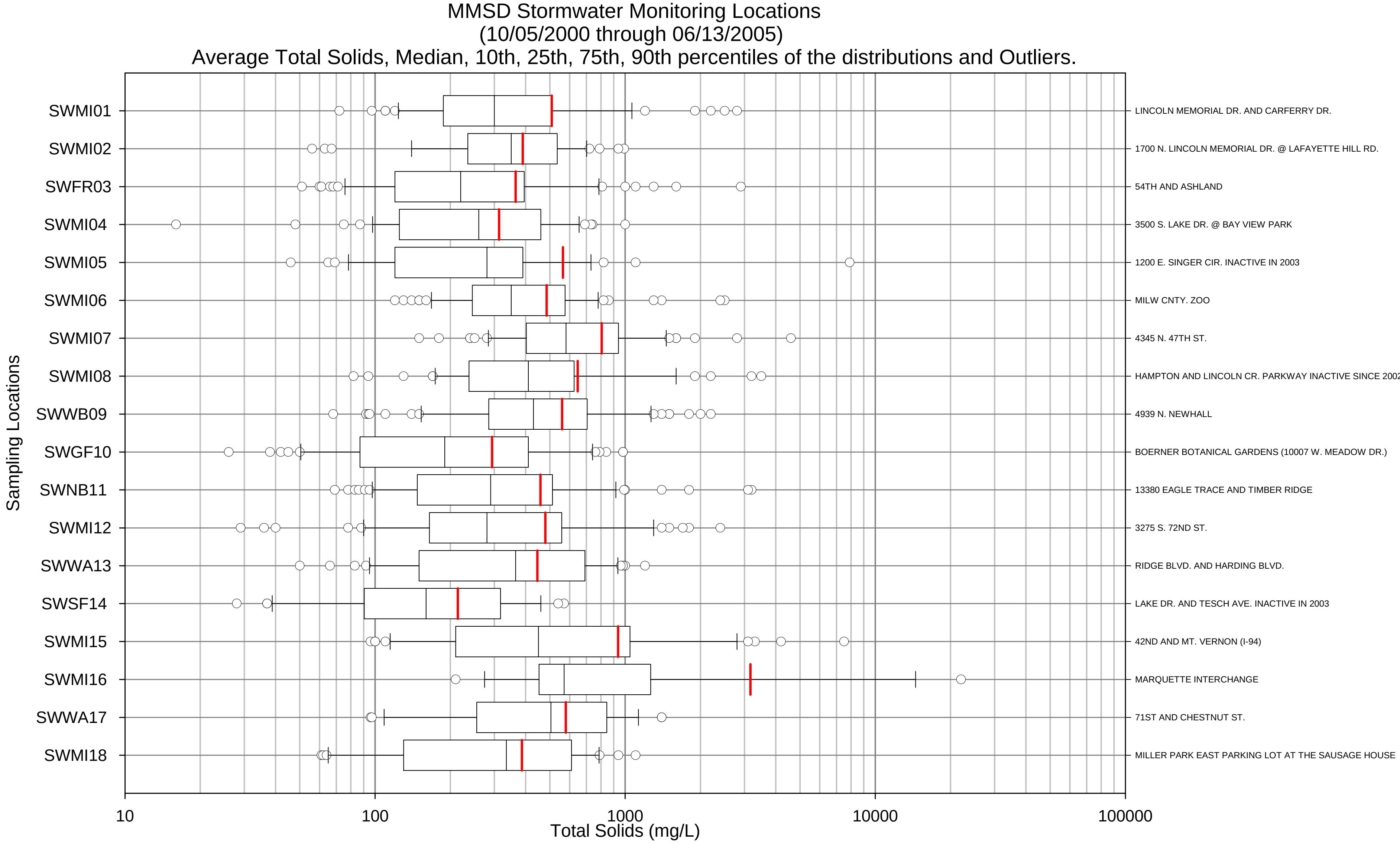


Figure E - 59 Total soluble phosphorus (TSP) 1st and 2nd flush in stormwater

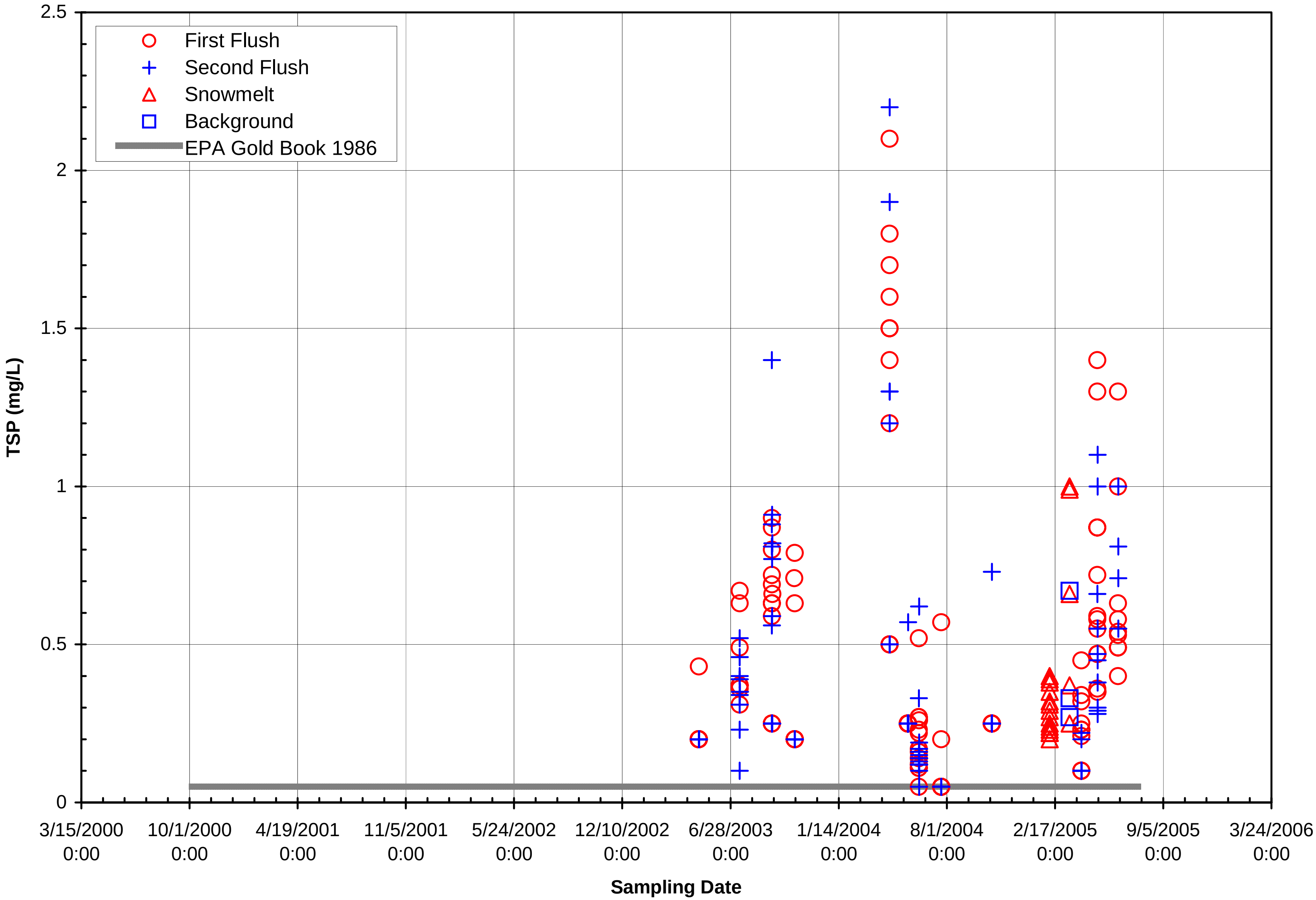


Figure E - 60 Total soluble phosphorus (TSP) box chart in stormwater

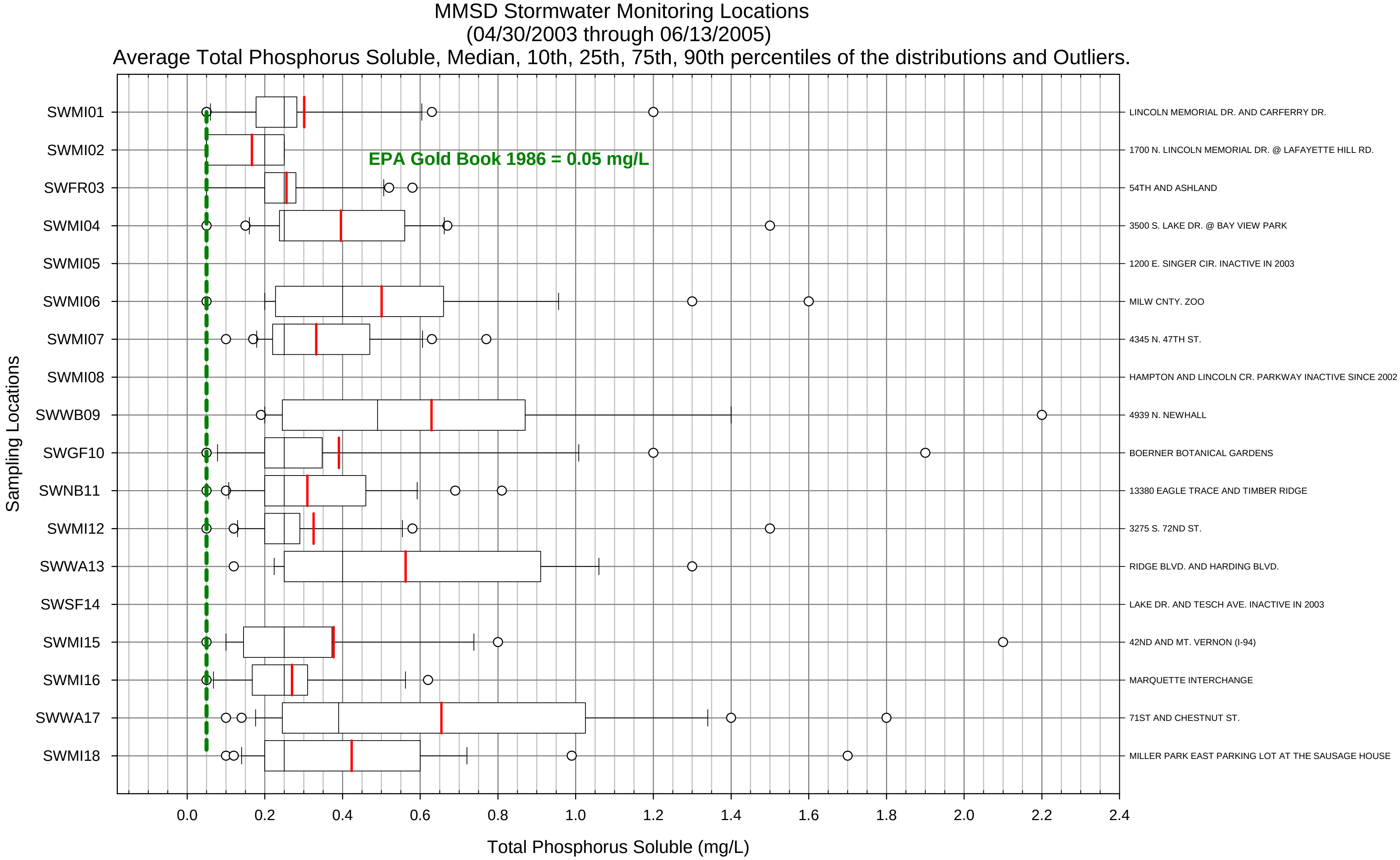


Figure E - 61 Total suspended solids (TSS) 1st and 2nd flush in stormwater

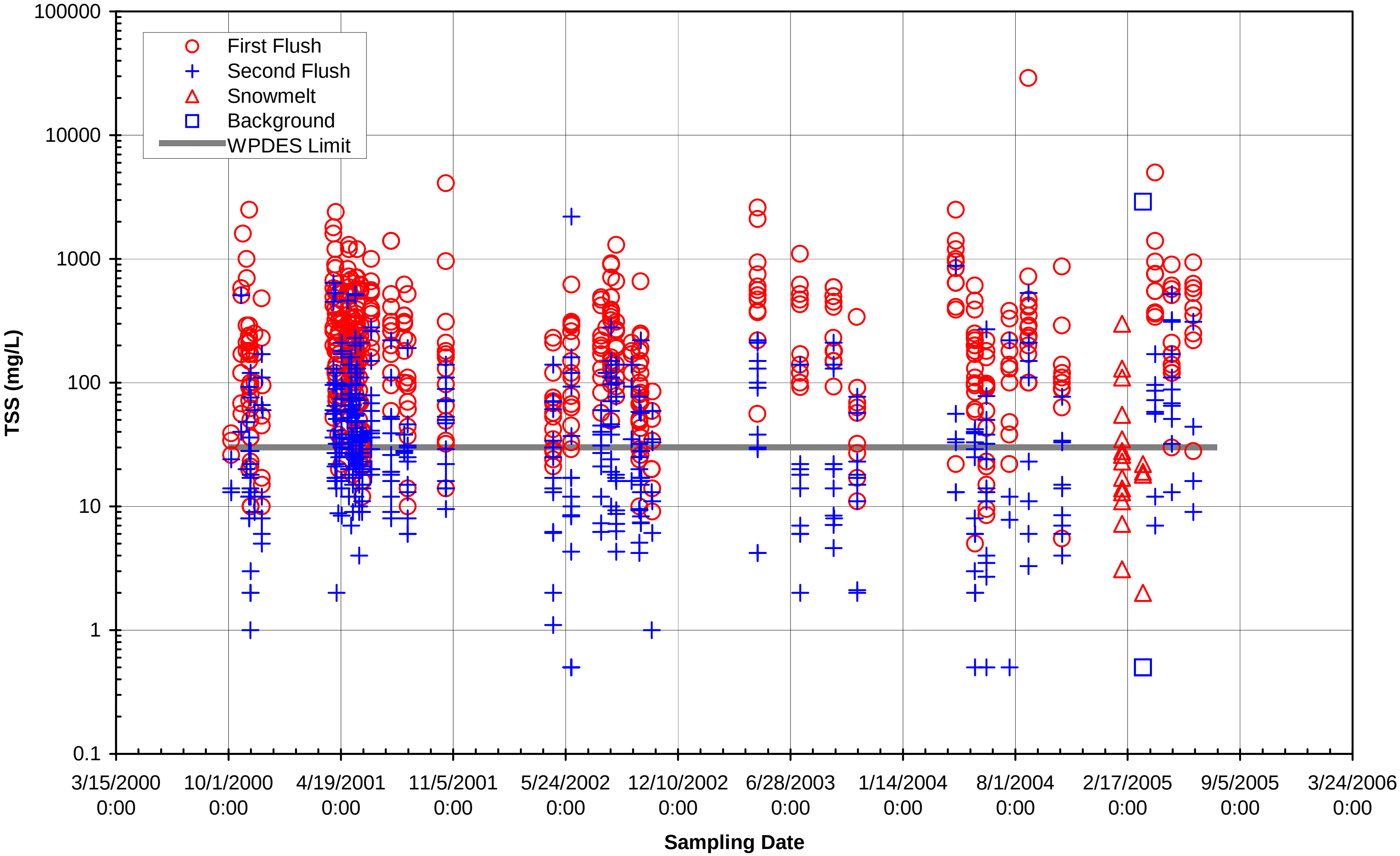


Figure E - 62 Total suspended solids (TSS) box chart in stormwater

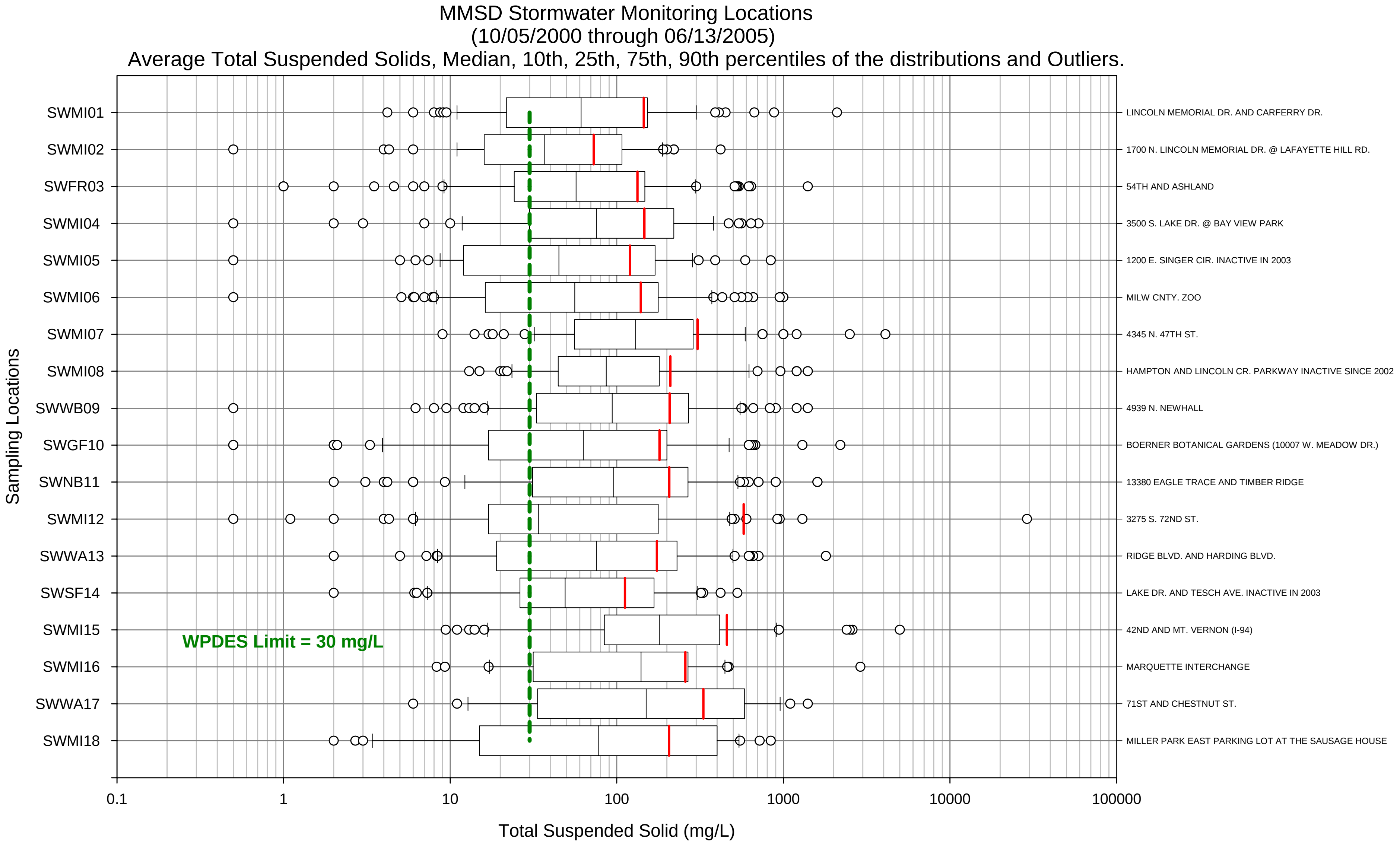


Figure E - 63 Turbidity 1st and 2nd flush in stormwater

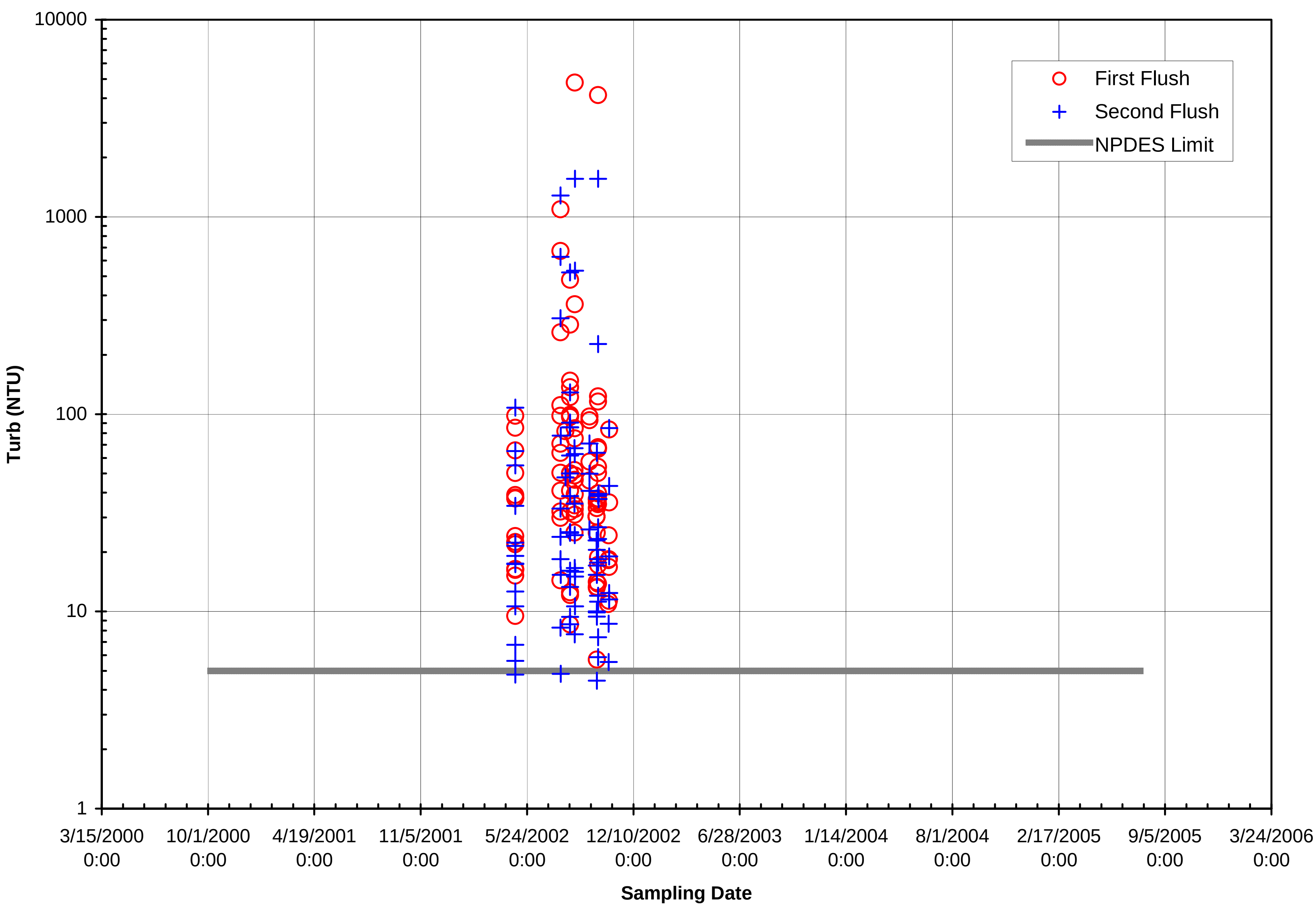


Figure E - 64 Turbidity box chart in stormwater

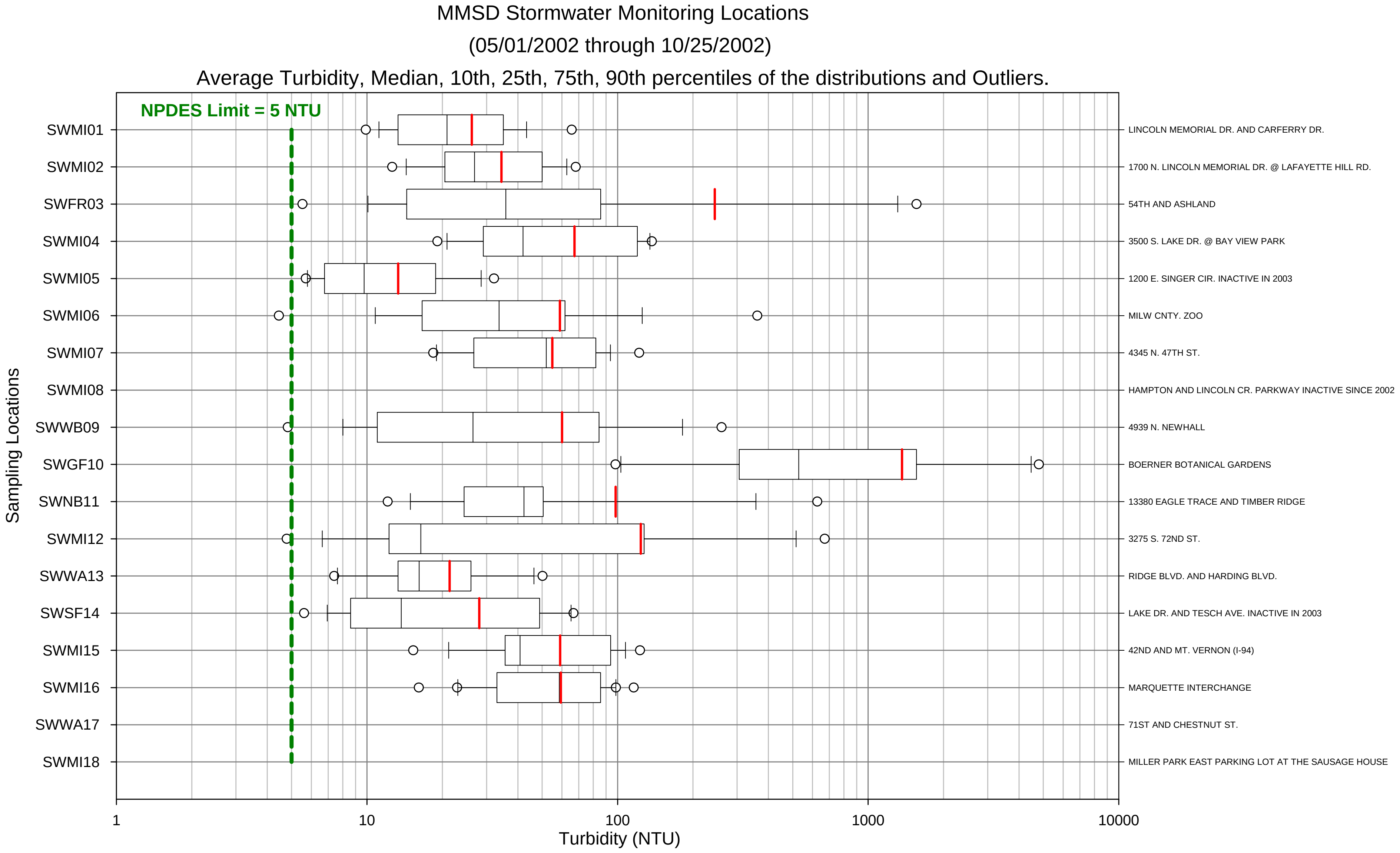


Figure E - 65 Zinc (Zn) 1st and 2nd flush in stormwater

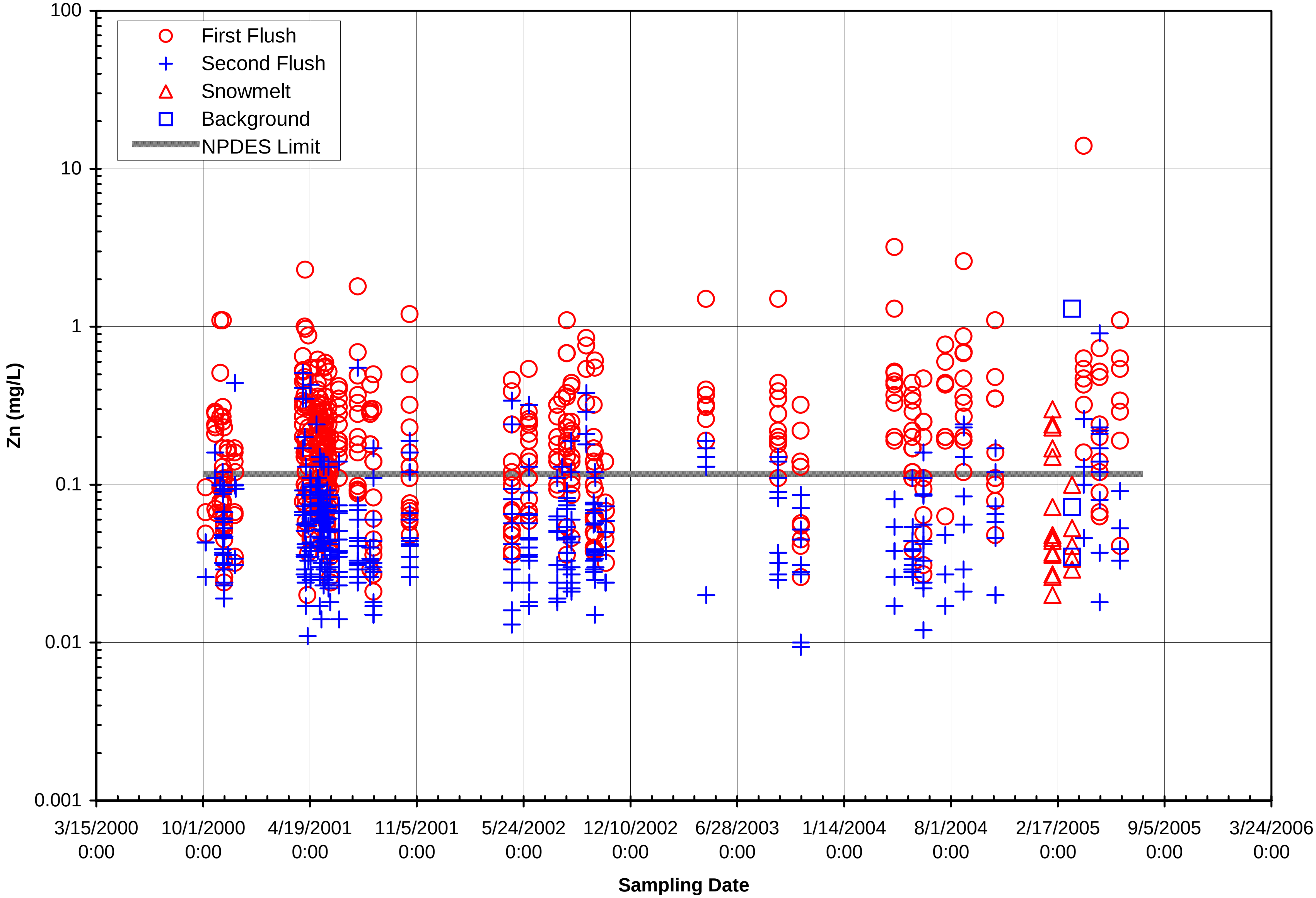
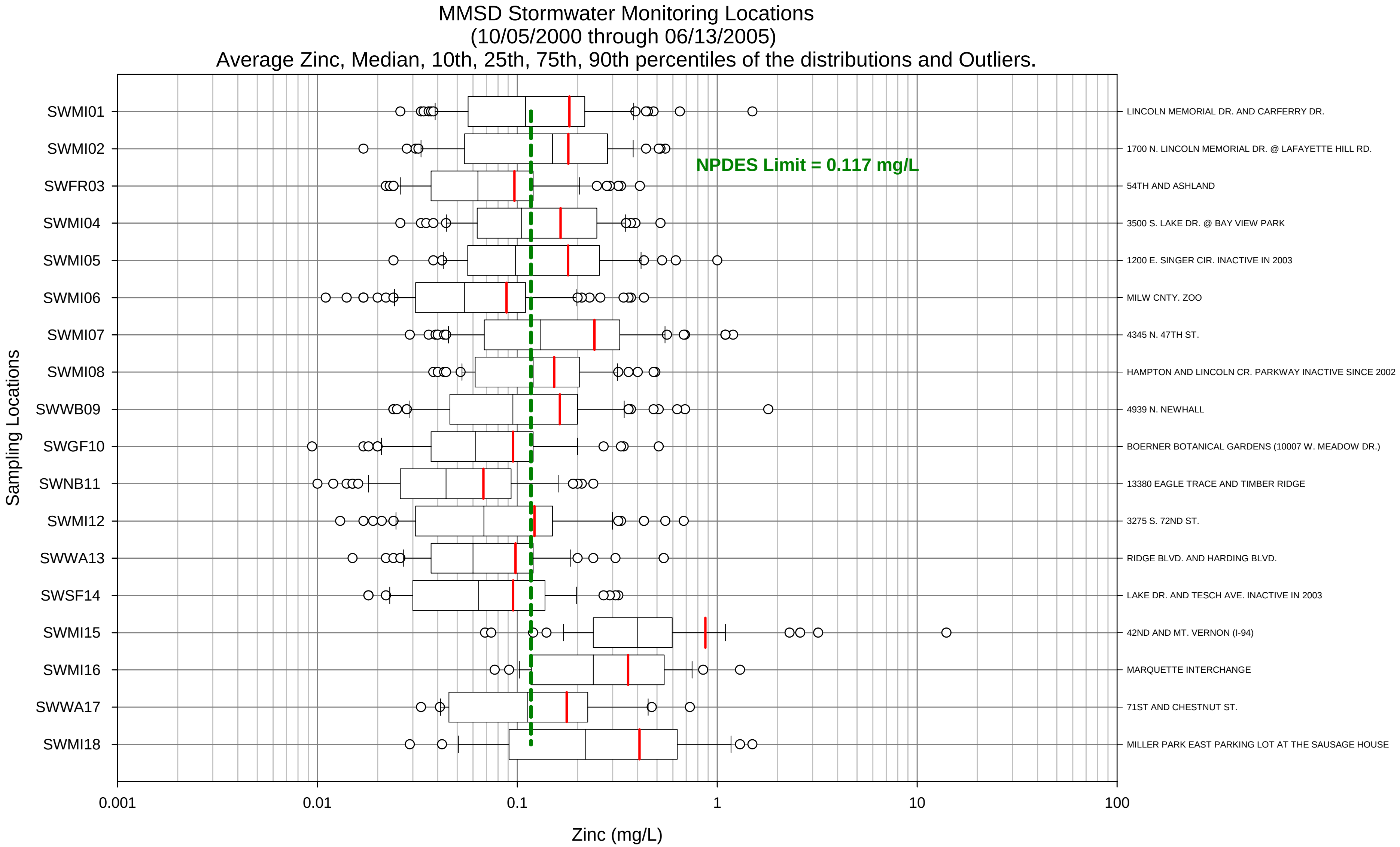


Figure E - 66   Zinc (Zn) box chart in stormwater



Appendix F : Combined Sewer Overflow Charts

Figure F - 1 Ammonia Nitrogen (NH_3) all data by time in combined sewer overflow

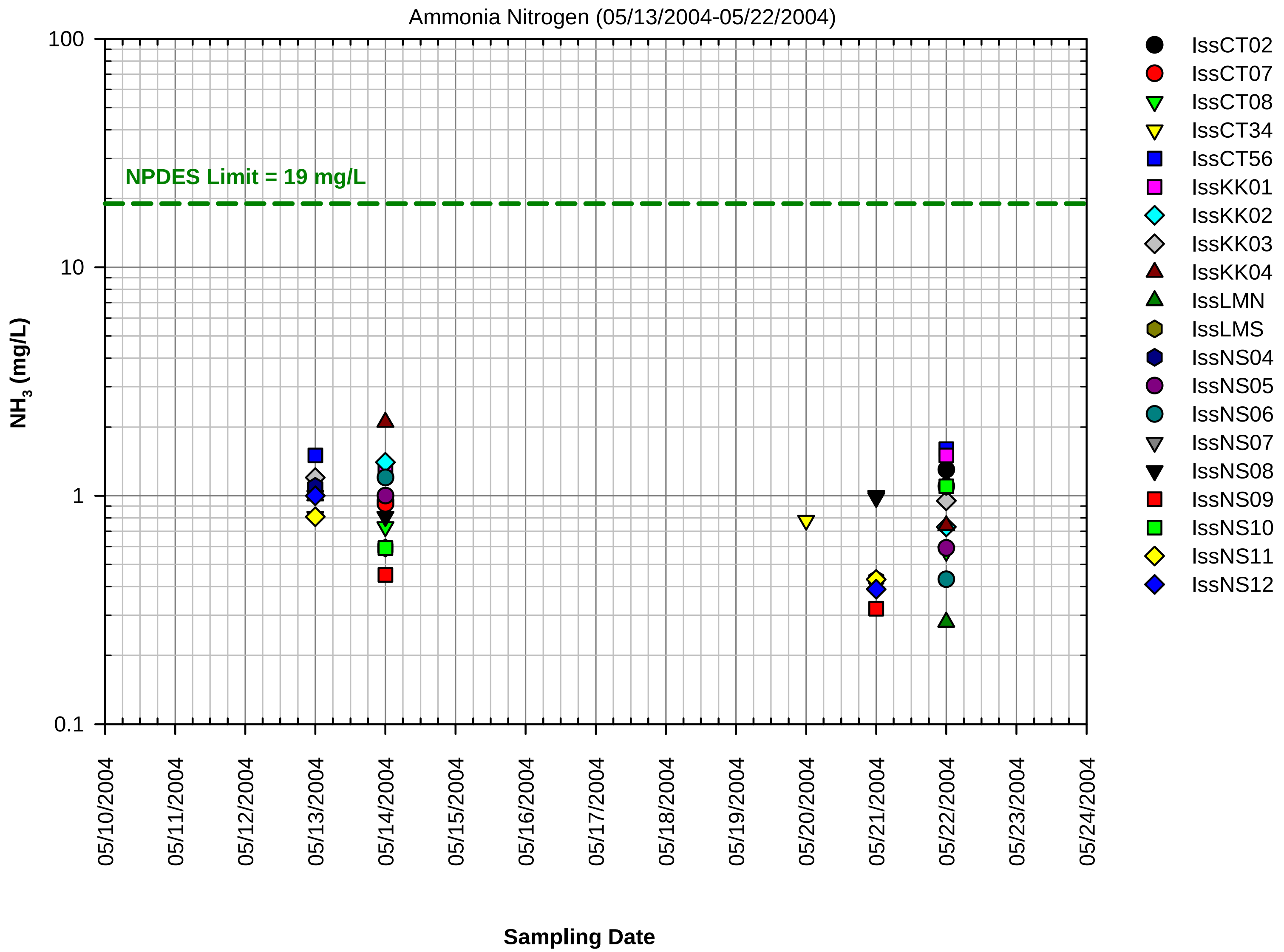


Figure F - 2 Ammonia Nitrogen (NH_3) box chart in combined sewer overflow

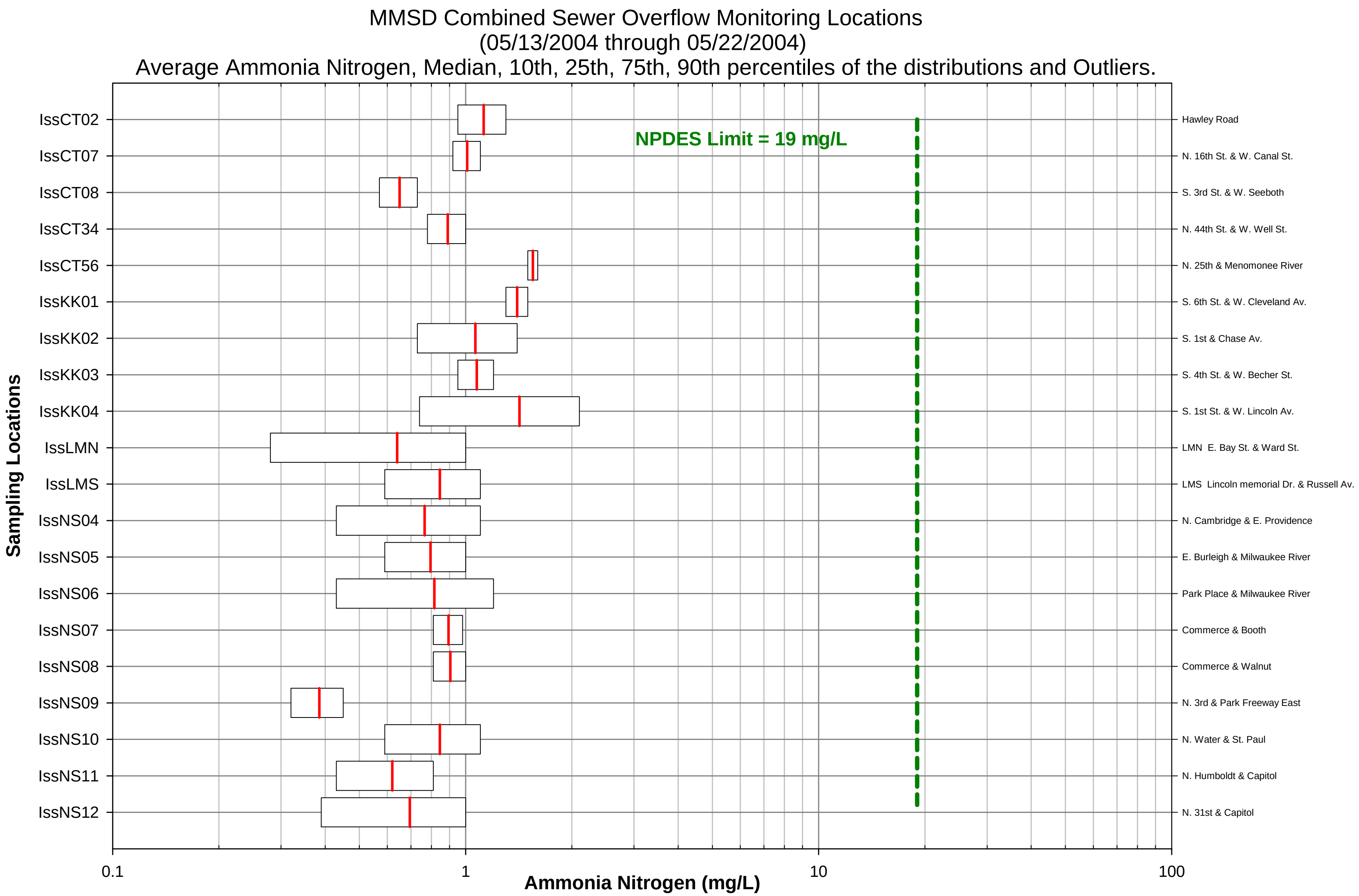


Figure F - 3 Arsenic (As) all data by time in combined sewer overflow

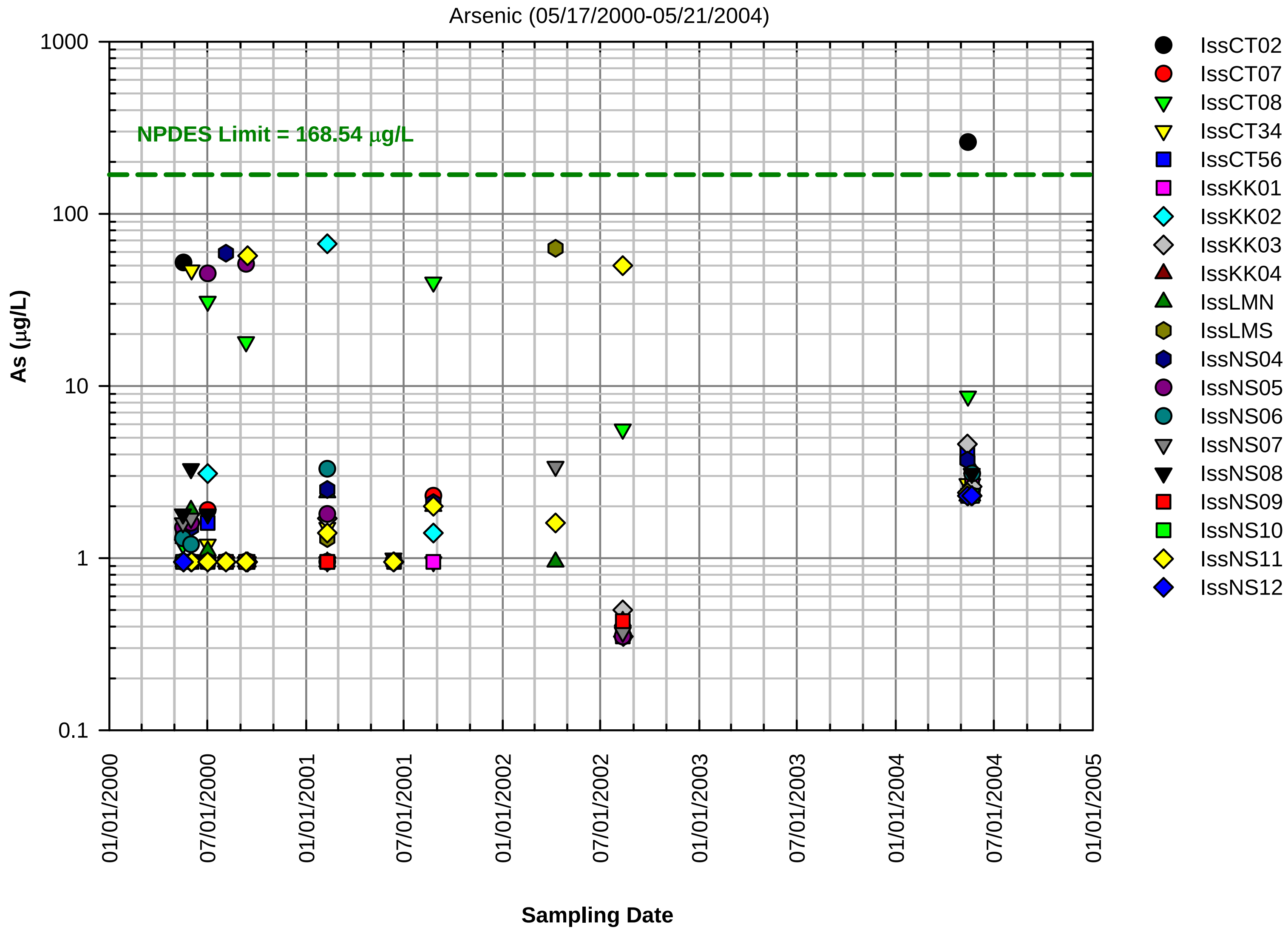


Figure F - 4 Arsenic (As) box chart in combined sewer overflow

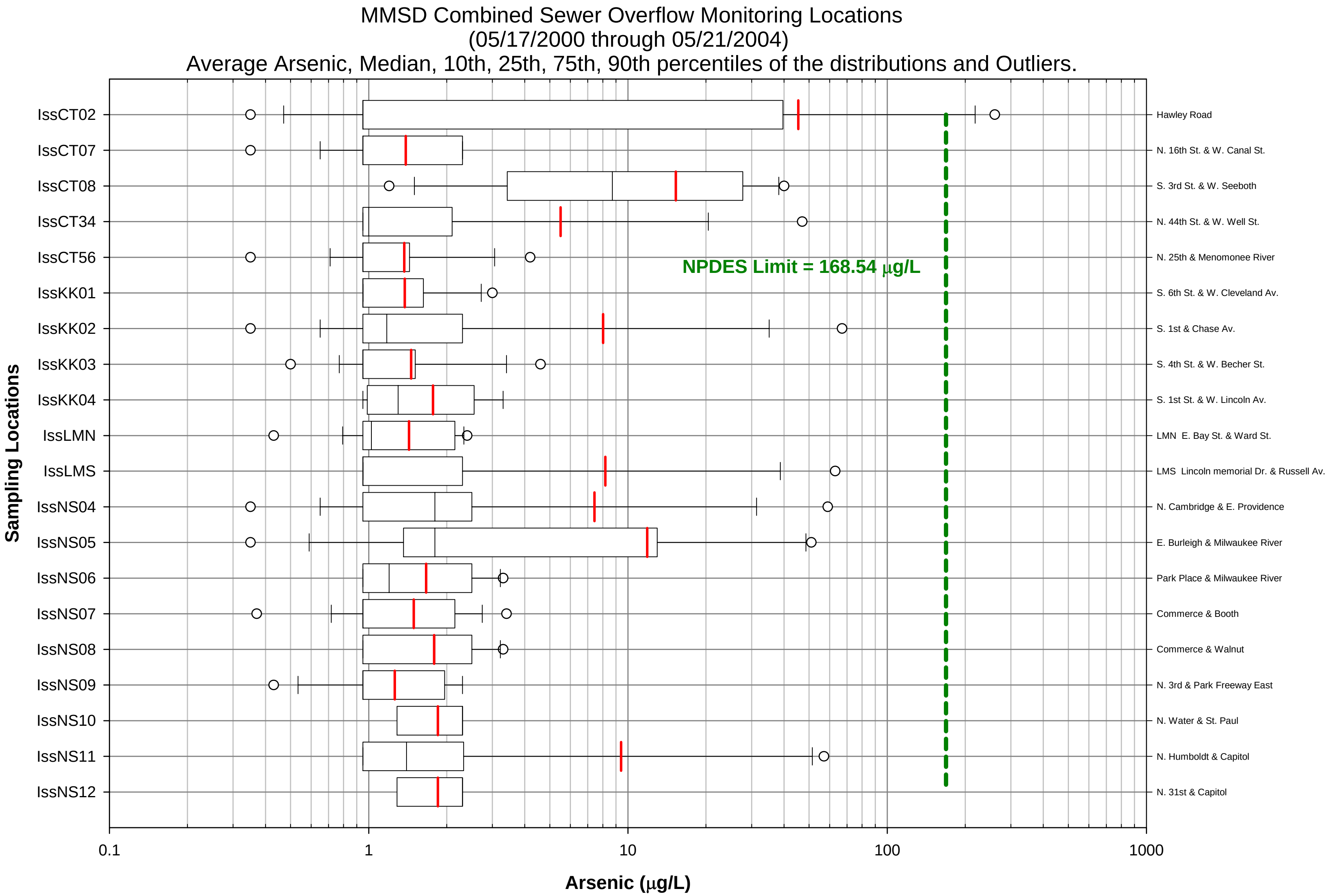


Figure F - 5   BOD-5 all data by time in combined sewer overflow

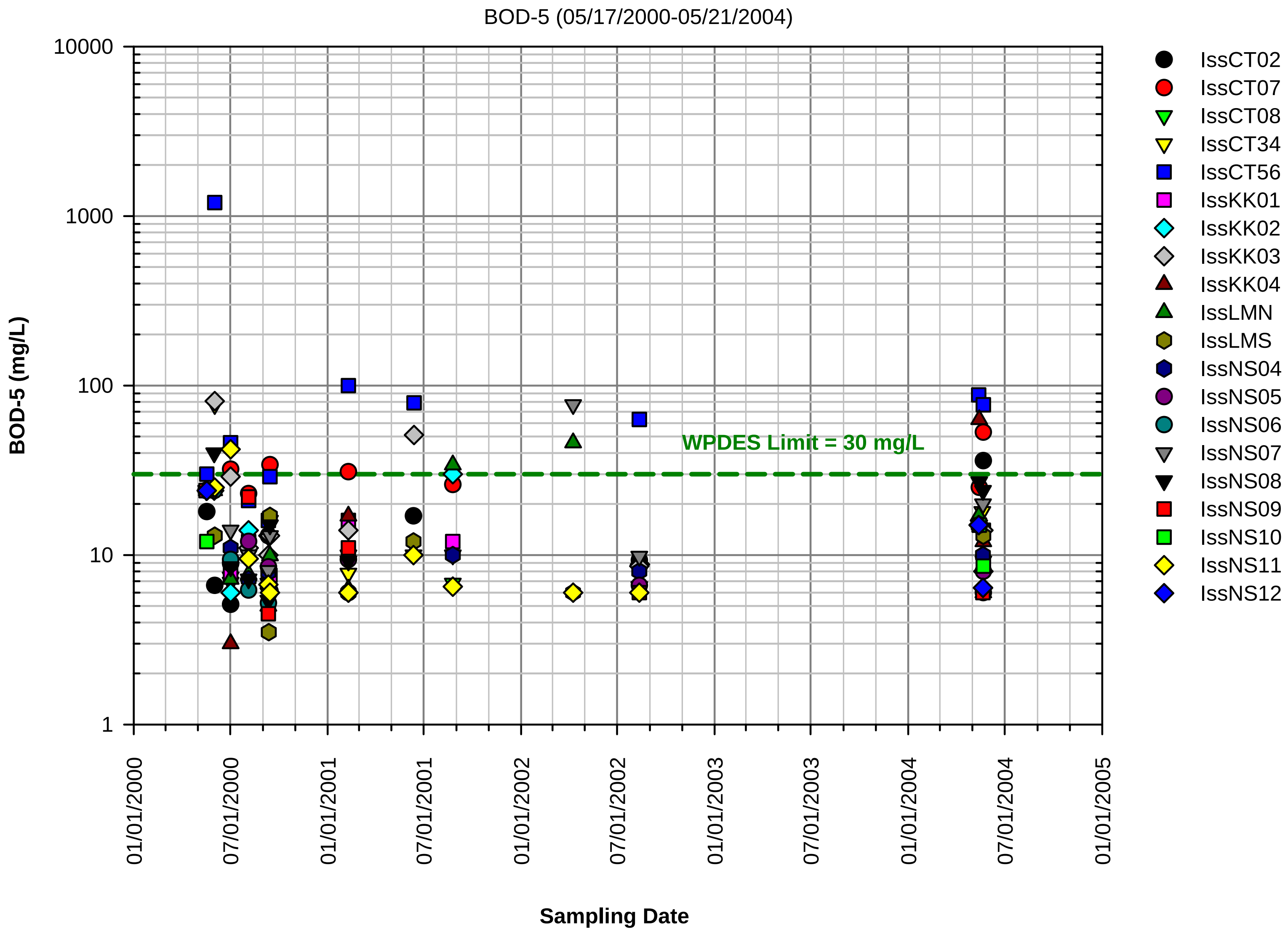


Figure F - 6   BOD-5 box chart in combined sewer overflow

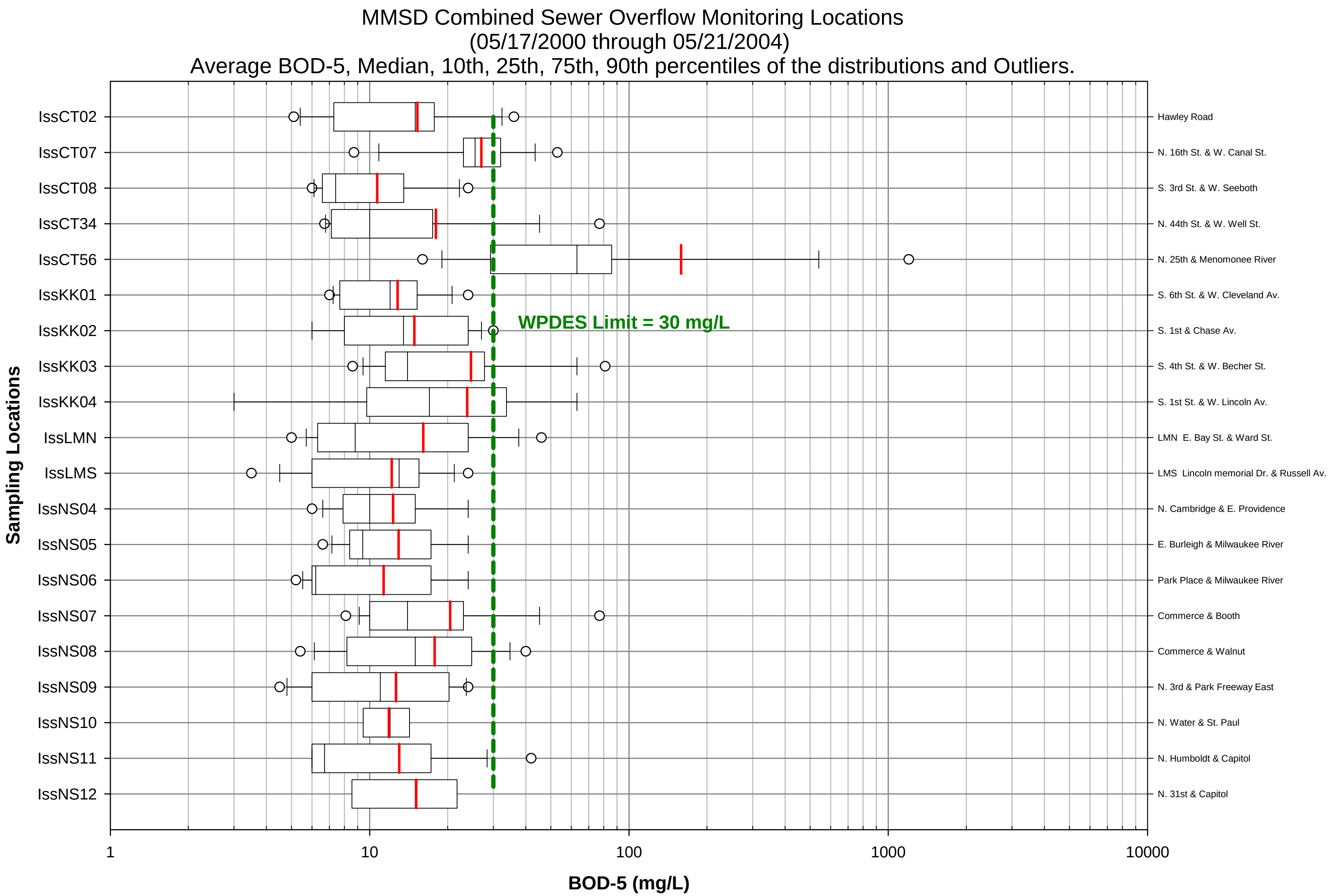


Figure F - 7   Cadmium (Cd) all data by time in combined sewer overflow

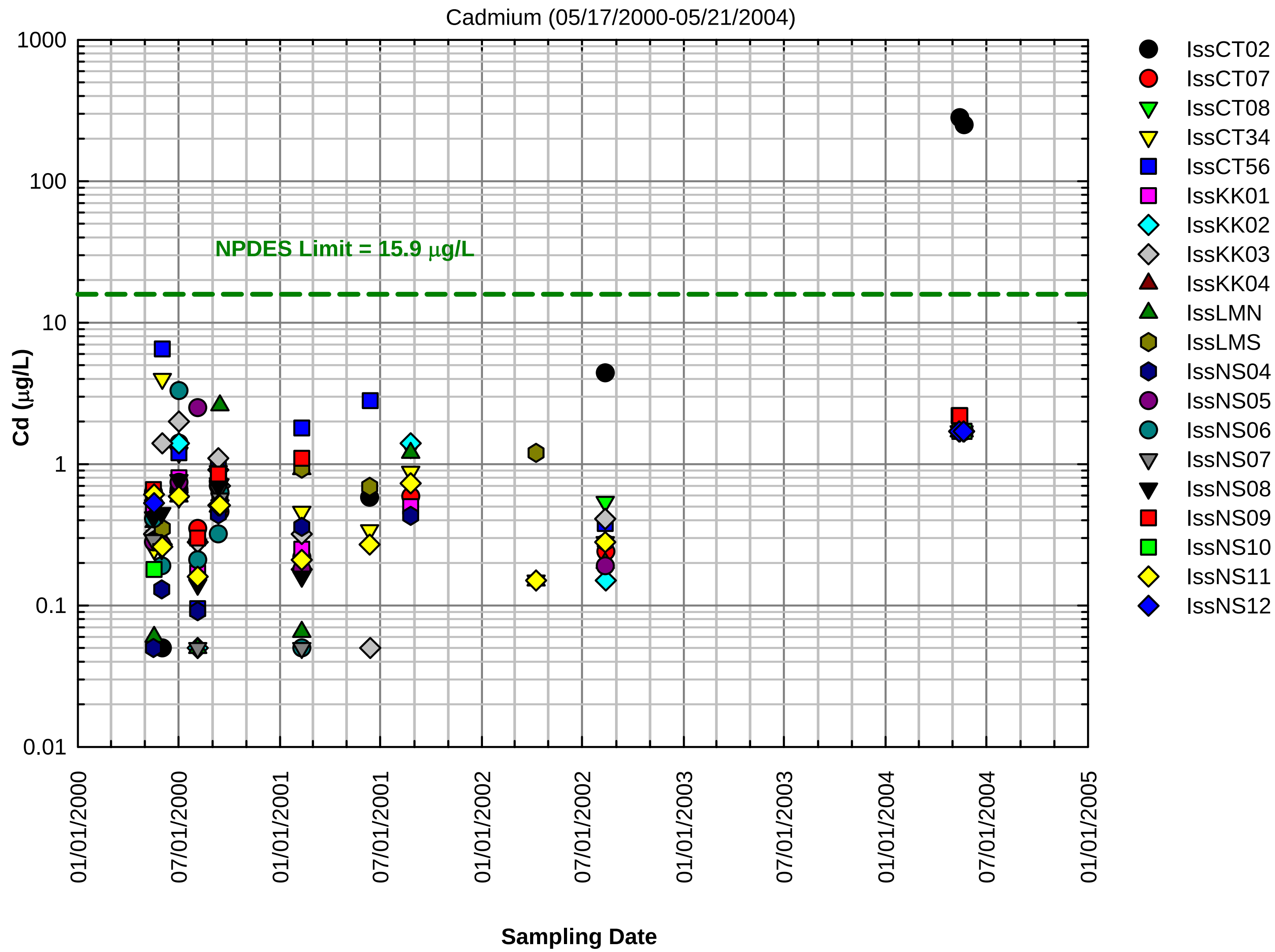


Figure F - 8 Cadmium (Cd) box chart in combined sewer overflow

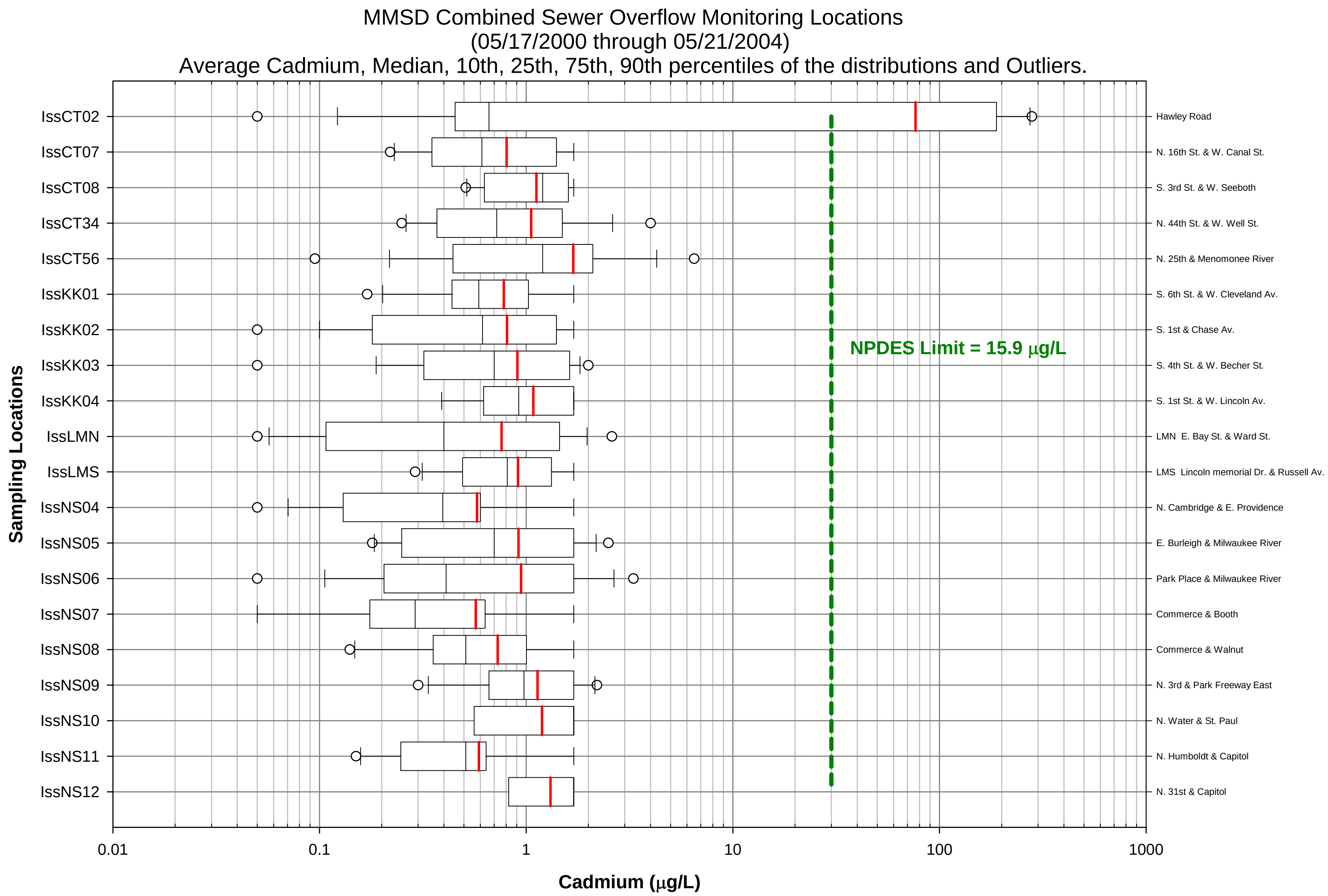


Figure F - 9   Calcium (Ca) all data by time in combined sewer overflow

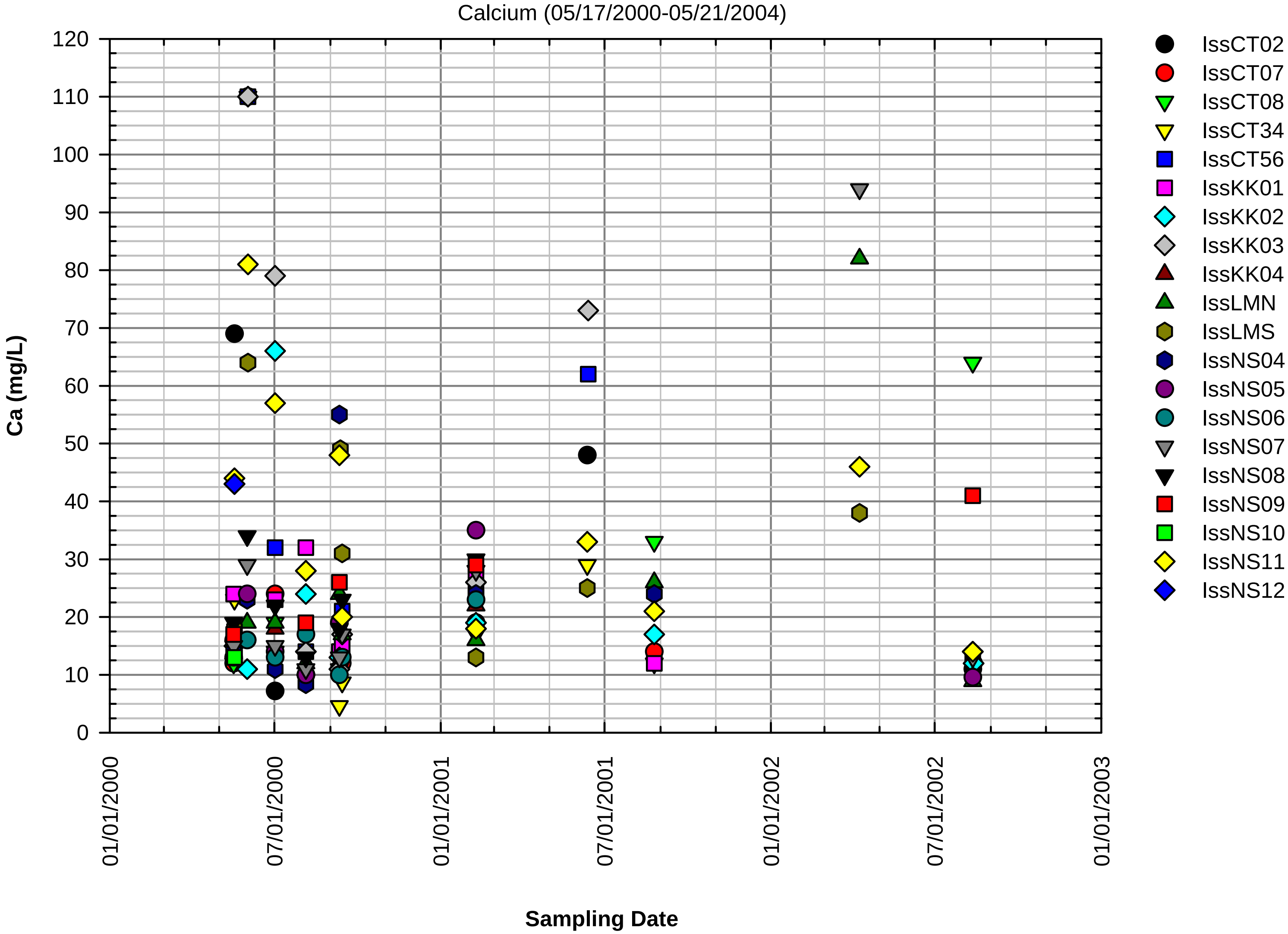


Figure F - 10   Calcium (Ca) box chart in combined sewer overflow

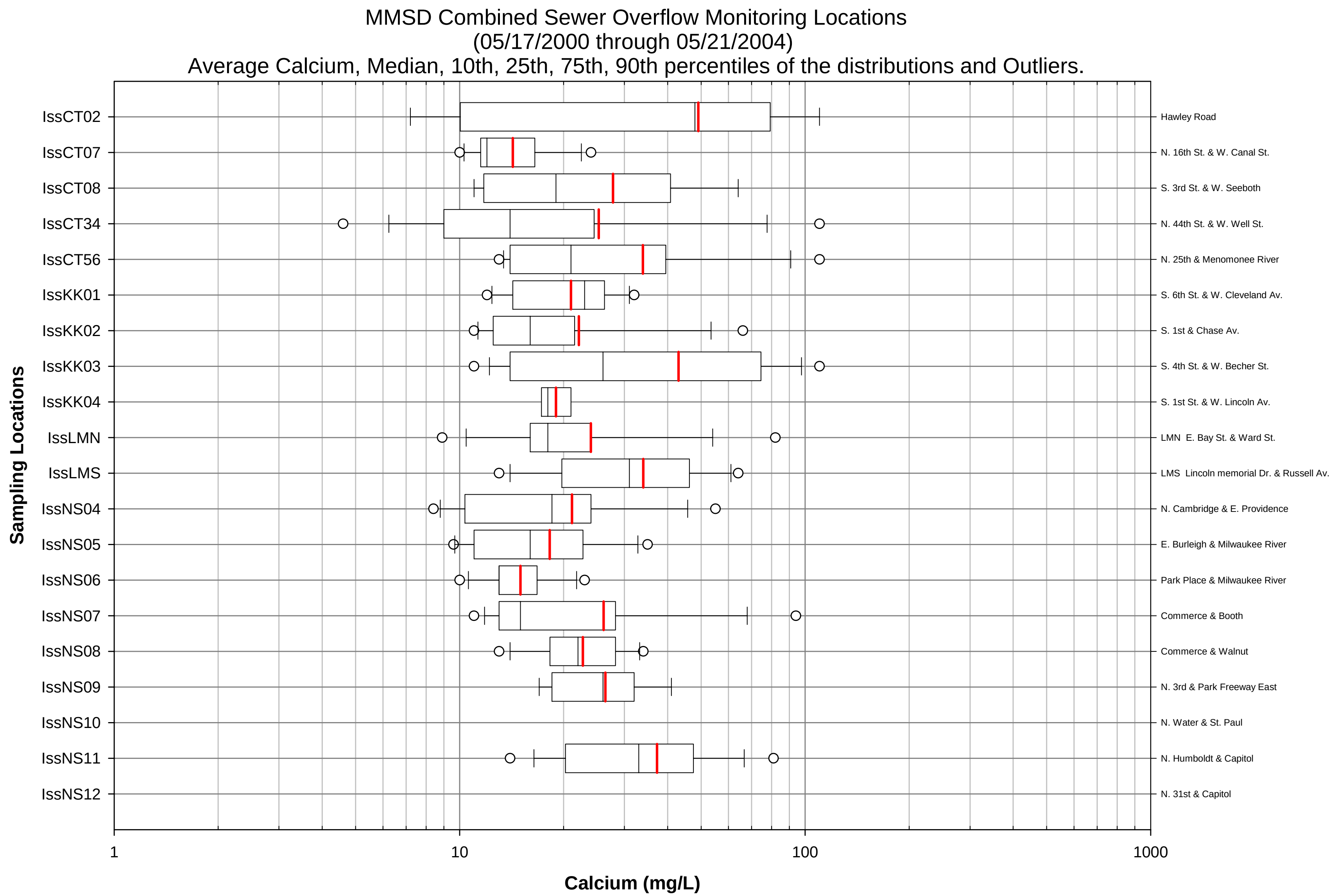


Figure F - 11   Chromium (Cr) all data by time in combined sewer overflow

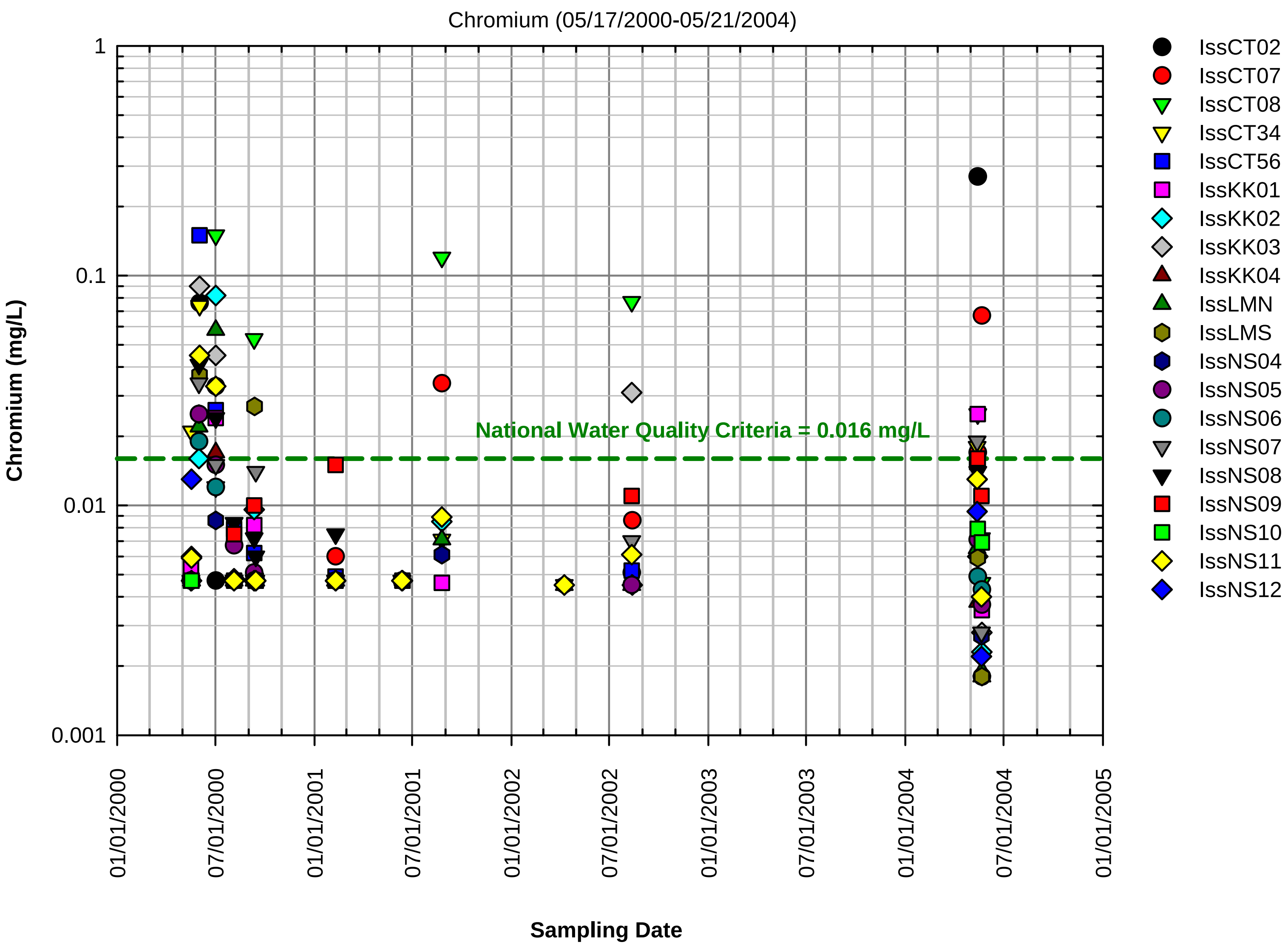


Figure F - 12   Chromium (Cr) box chart in combined sewer overflow

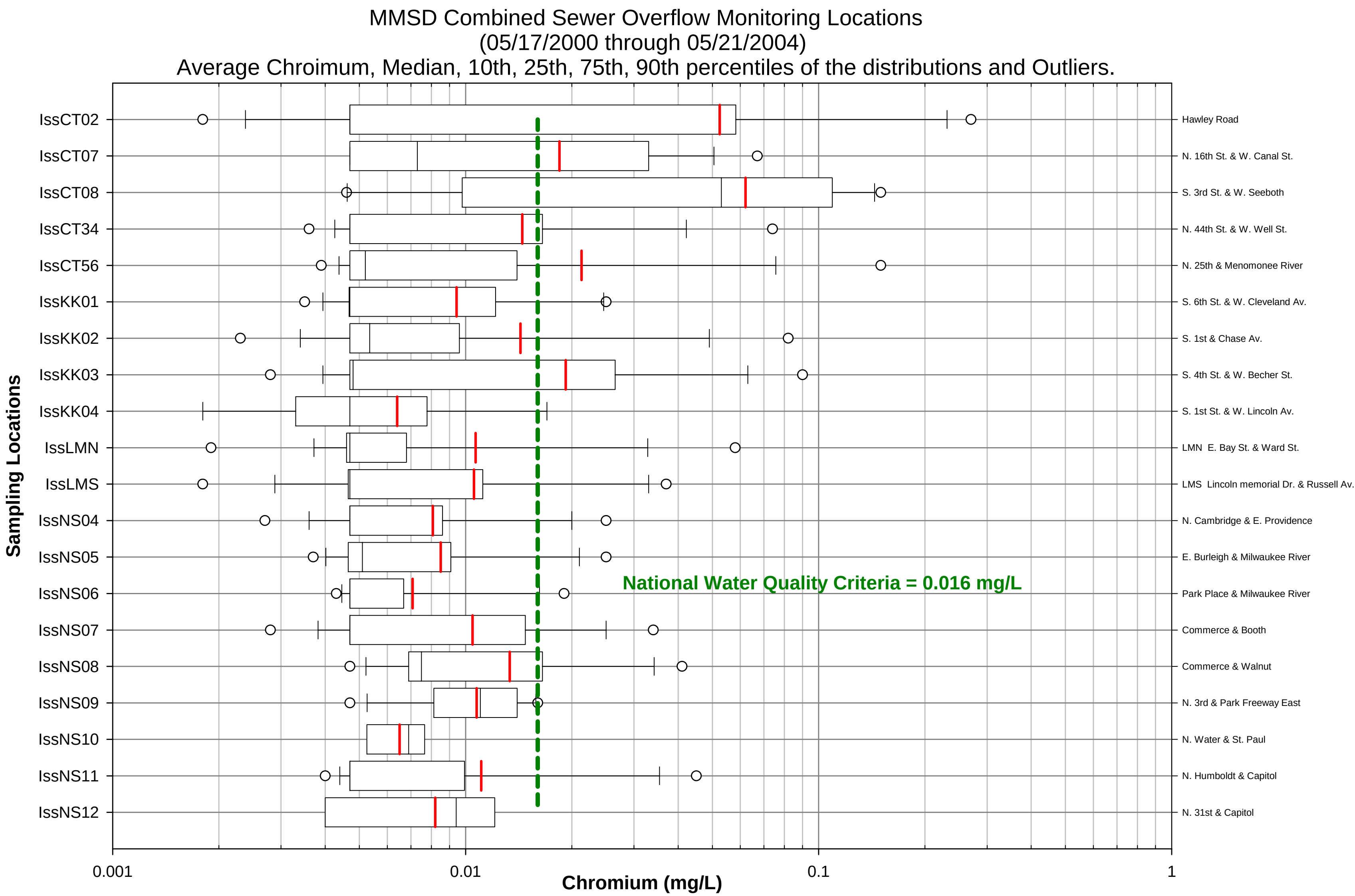


Figure F - 13   Copper (Cu) all data by time in combined sewer overflow

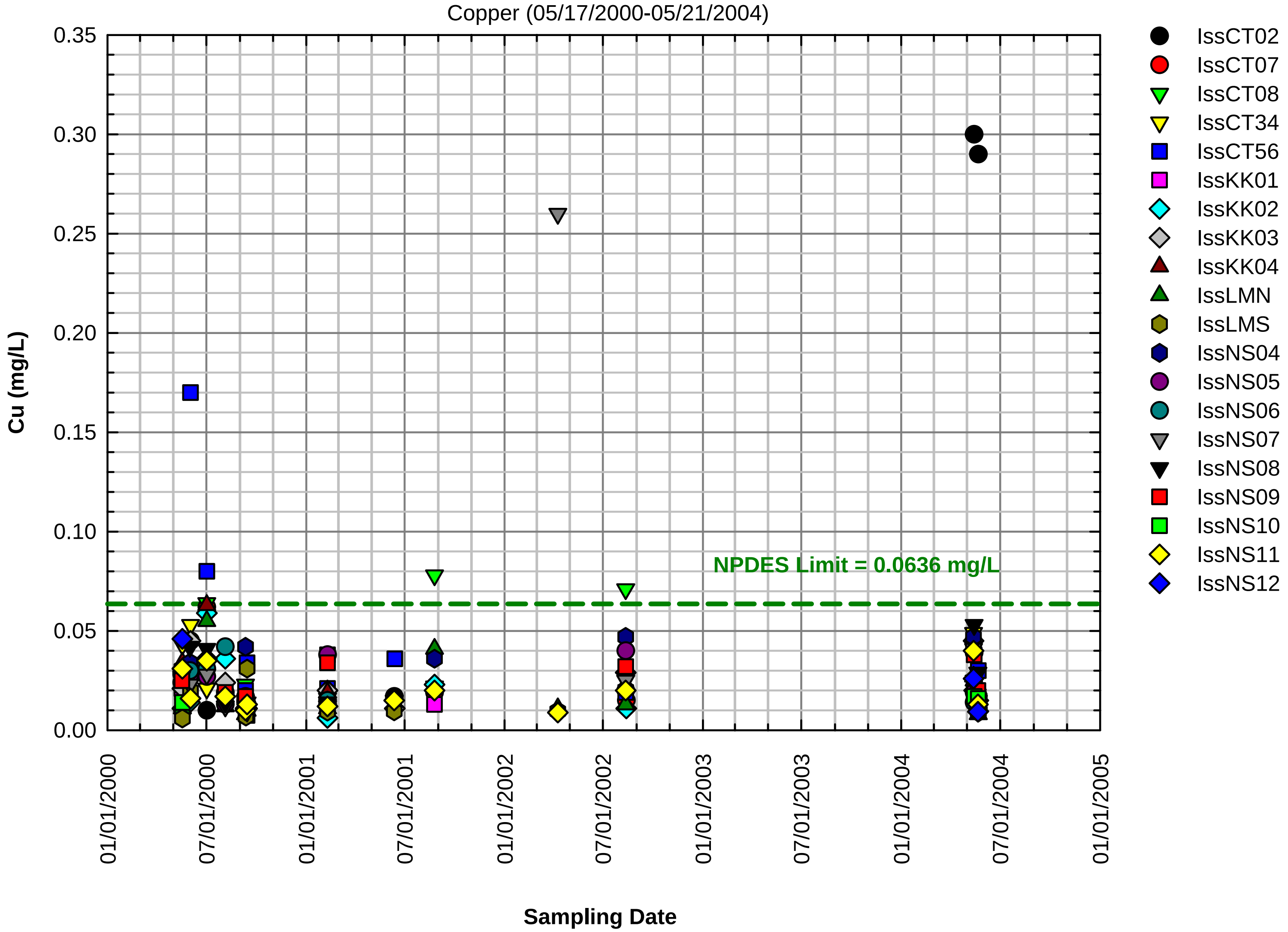


Figure F - 14   Copper (Cu) box chart in combined sewer overflow

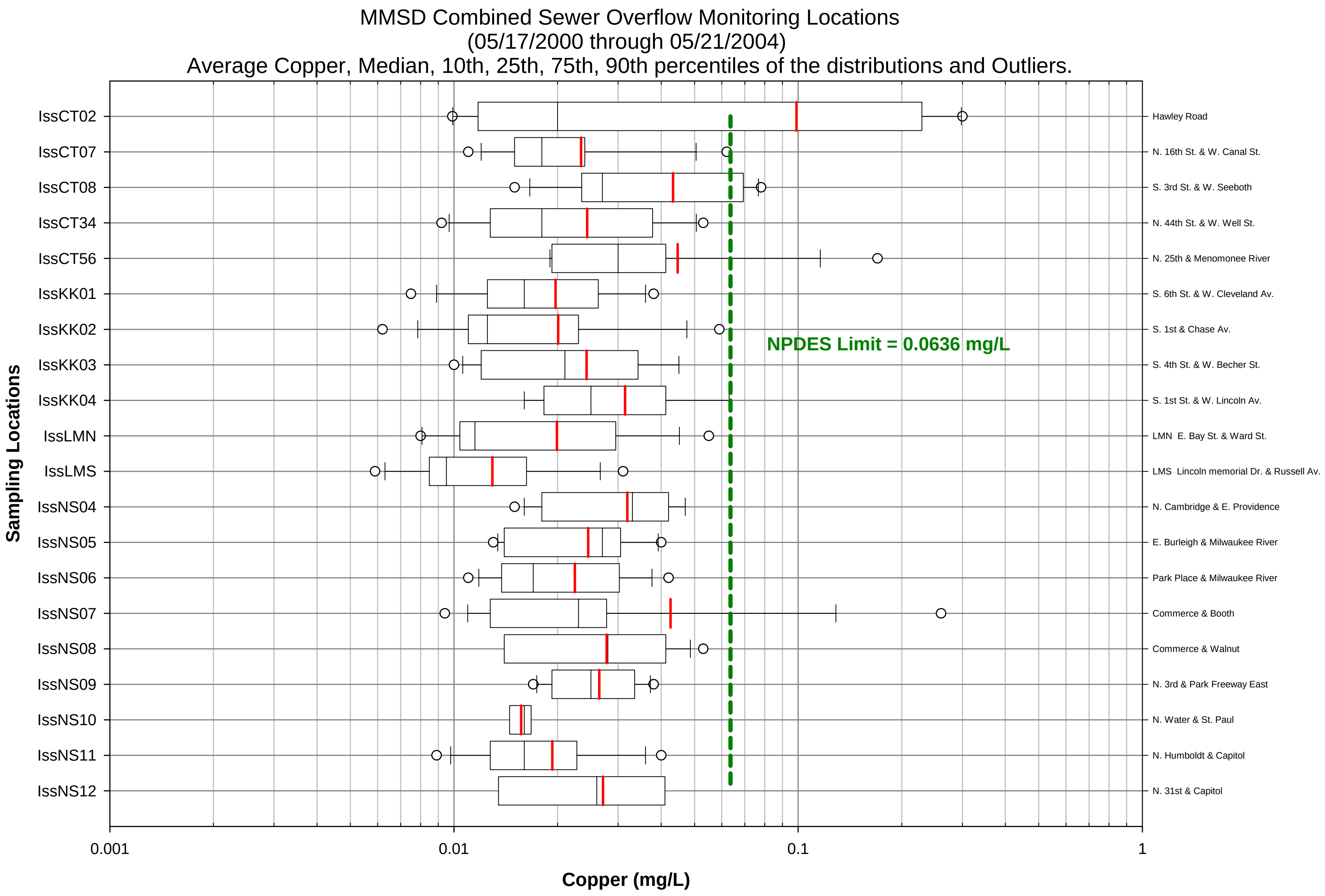


Figure F - 15   E-coli QT all data by time in combined sewer overflow

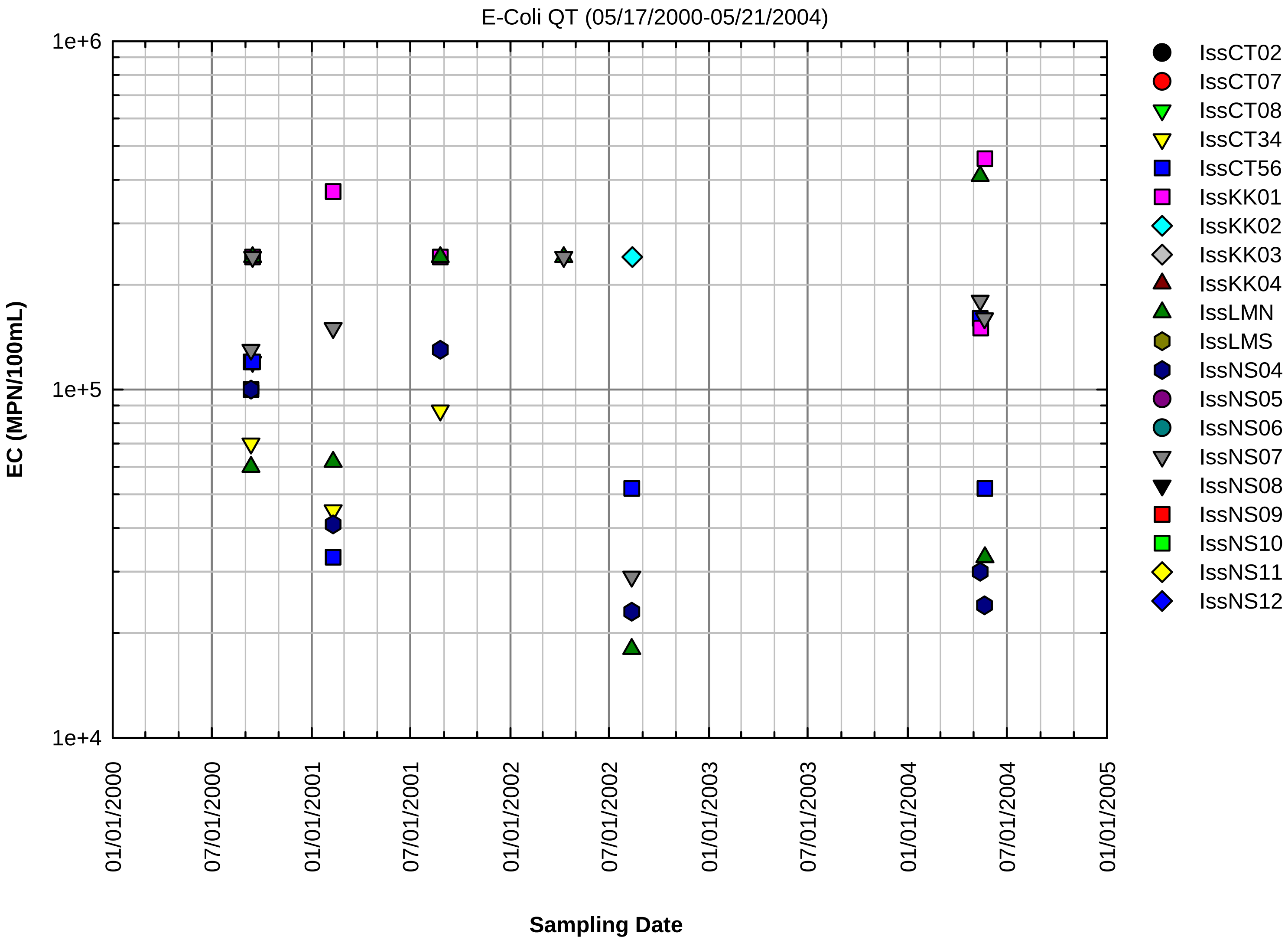


Figure F - 16   E-coli QT box chart in combined sewer overflow

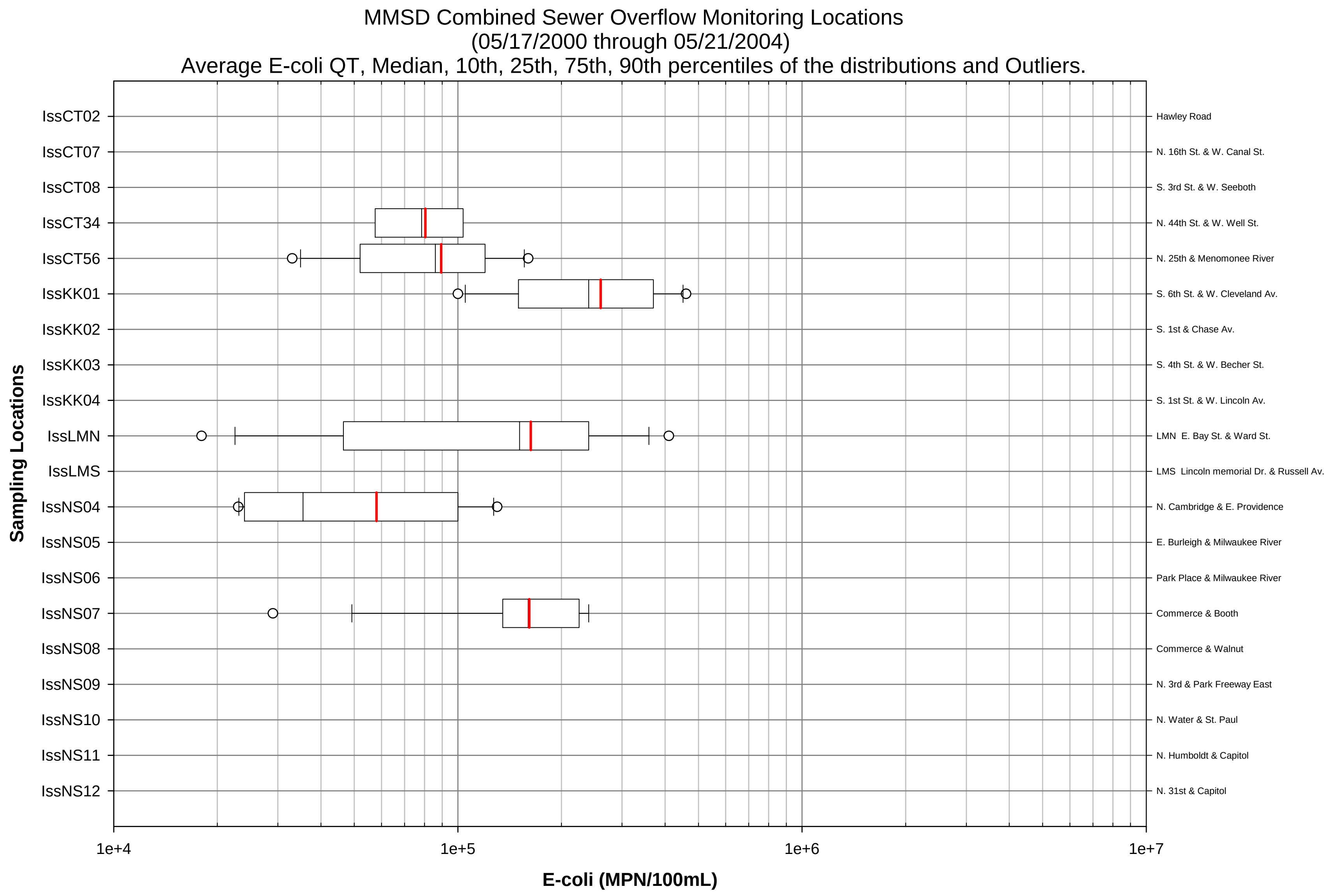


Figure F - 17   Fecal coliform (FC) all data by time in combined sewer overflow

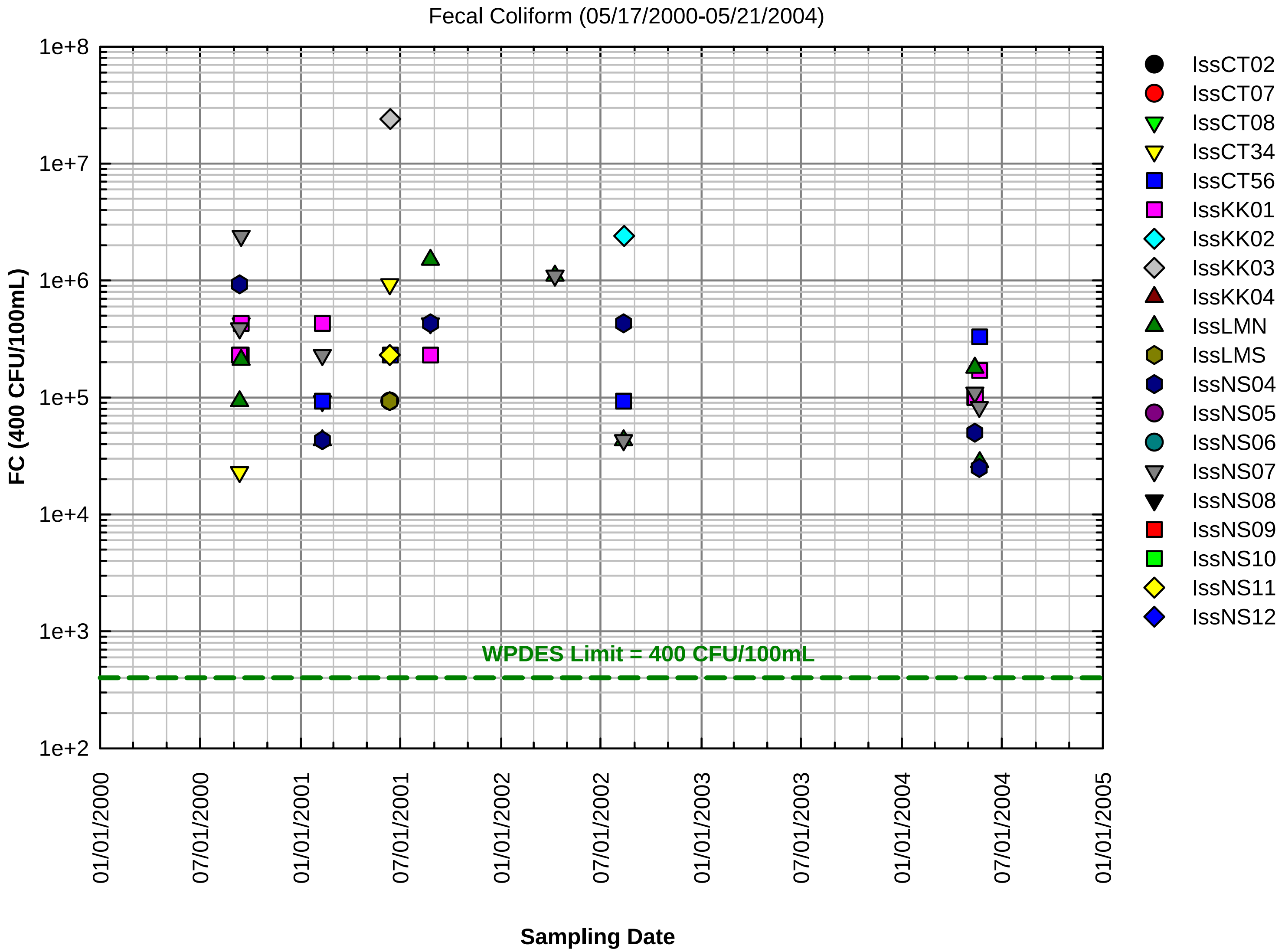


Figure F - 18 Fecal coliform box chart in combined sewer overflow

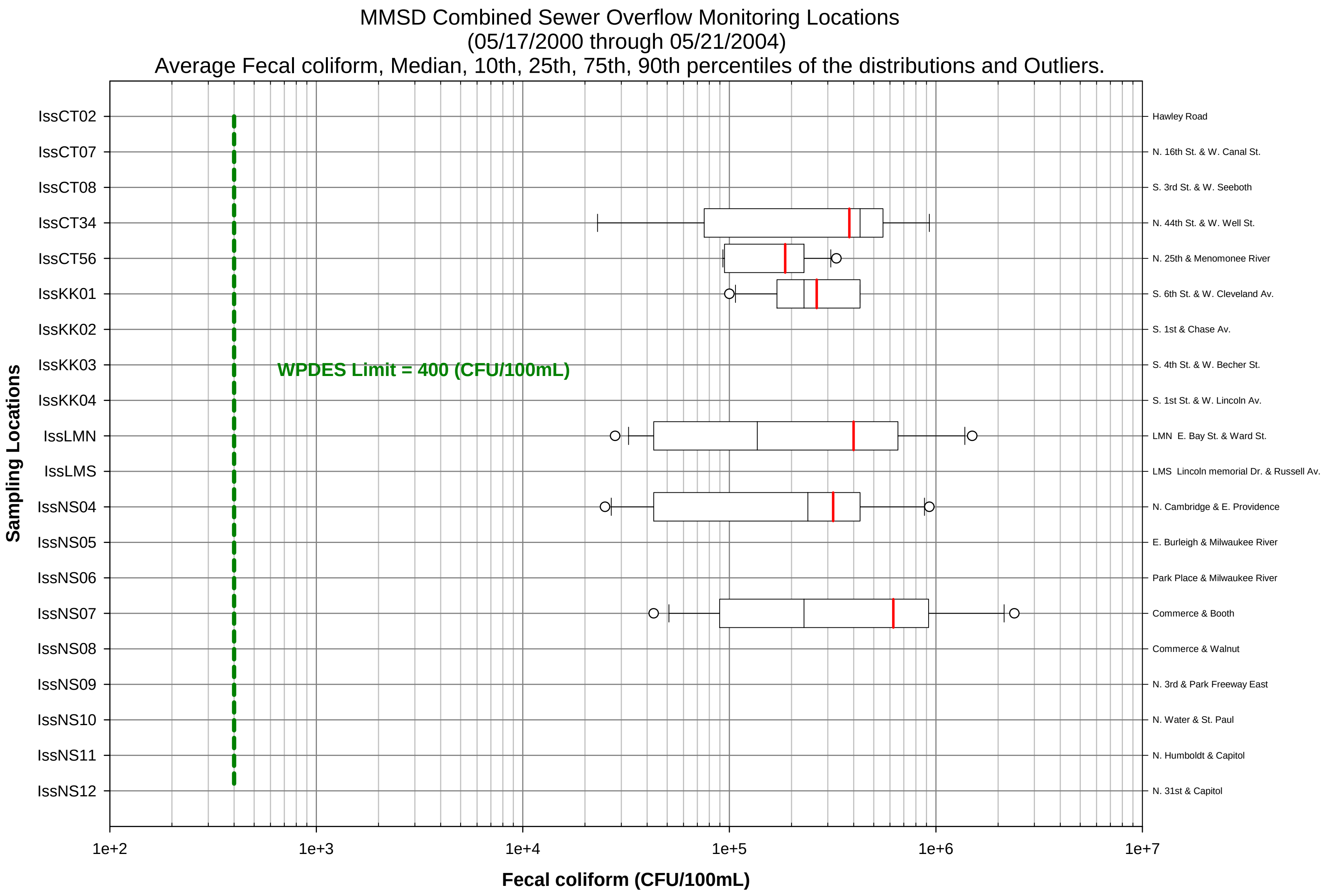


Figure F - 19   Hardness (Hard) all data by time in combined sewer overflow

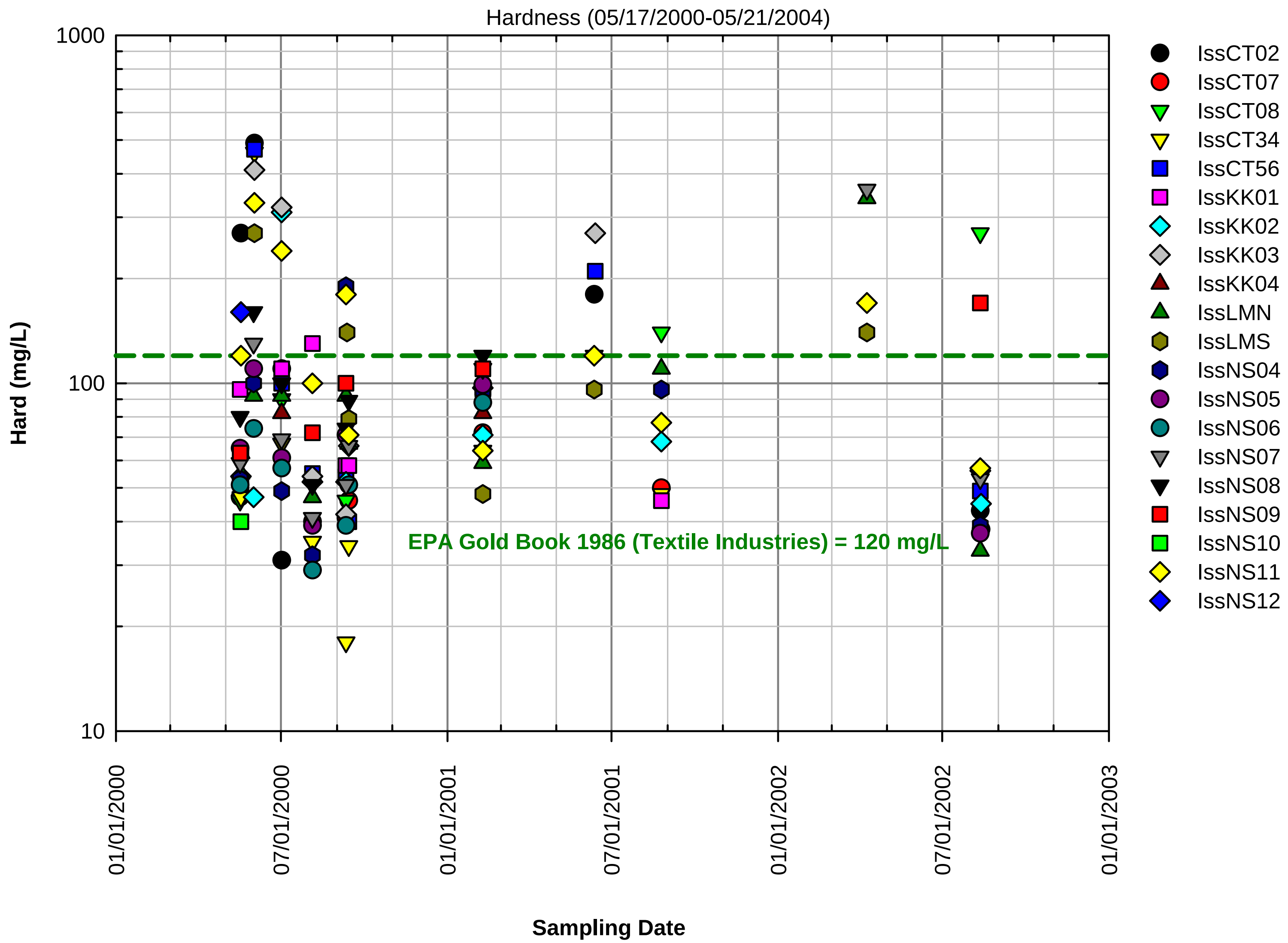


Figure F - 20 Hardness (Hard) box chart in combined sewer overflow

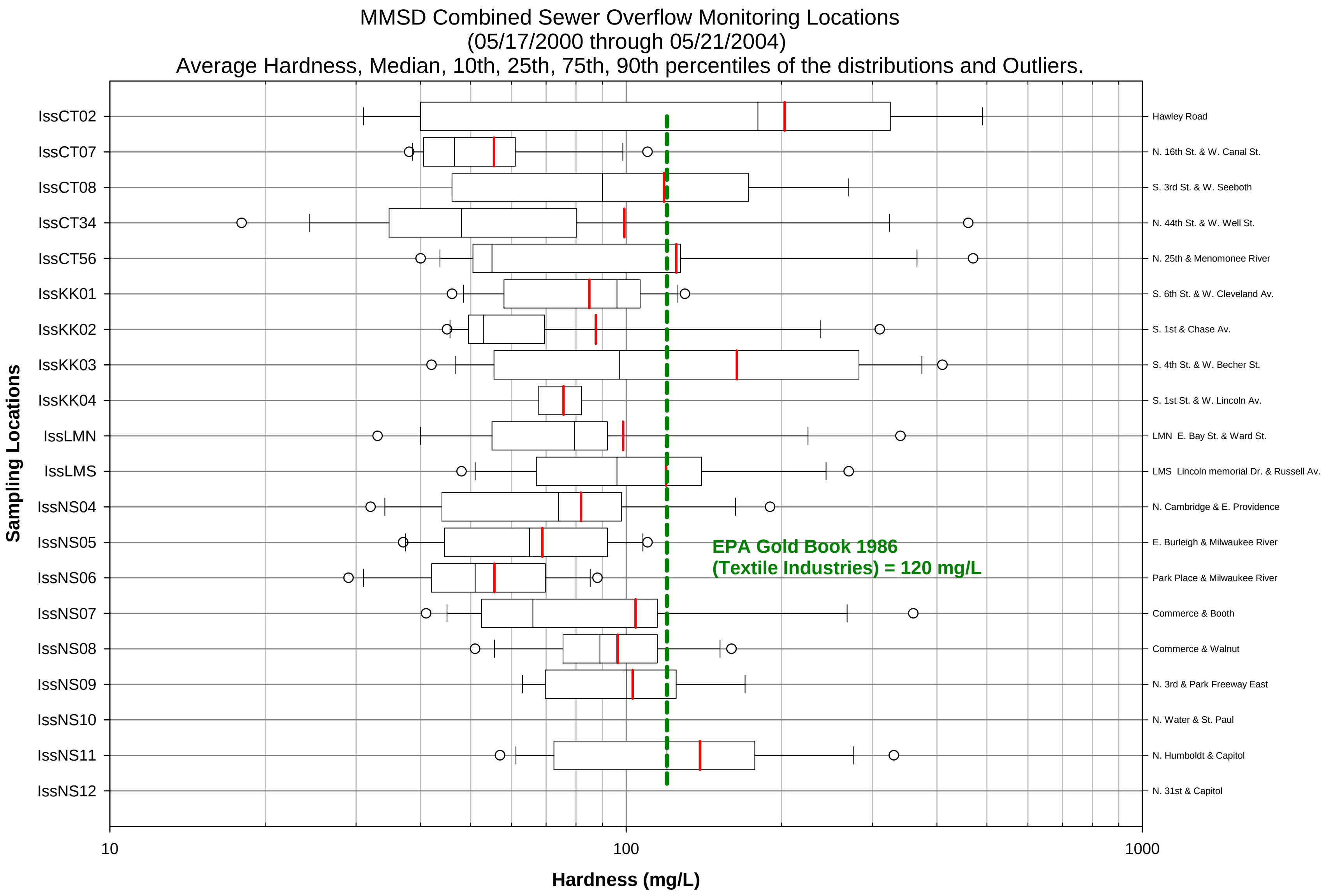


Figure F - 21 Lead (Pb) all data by time in combined sewer overflow

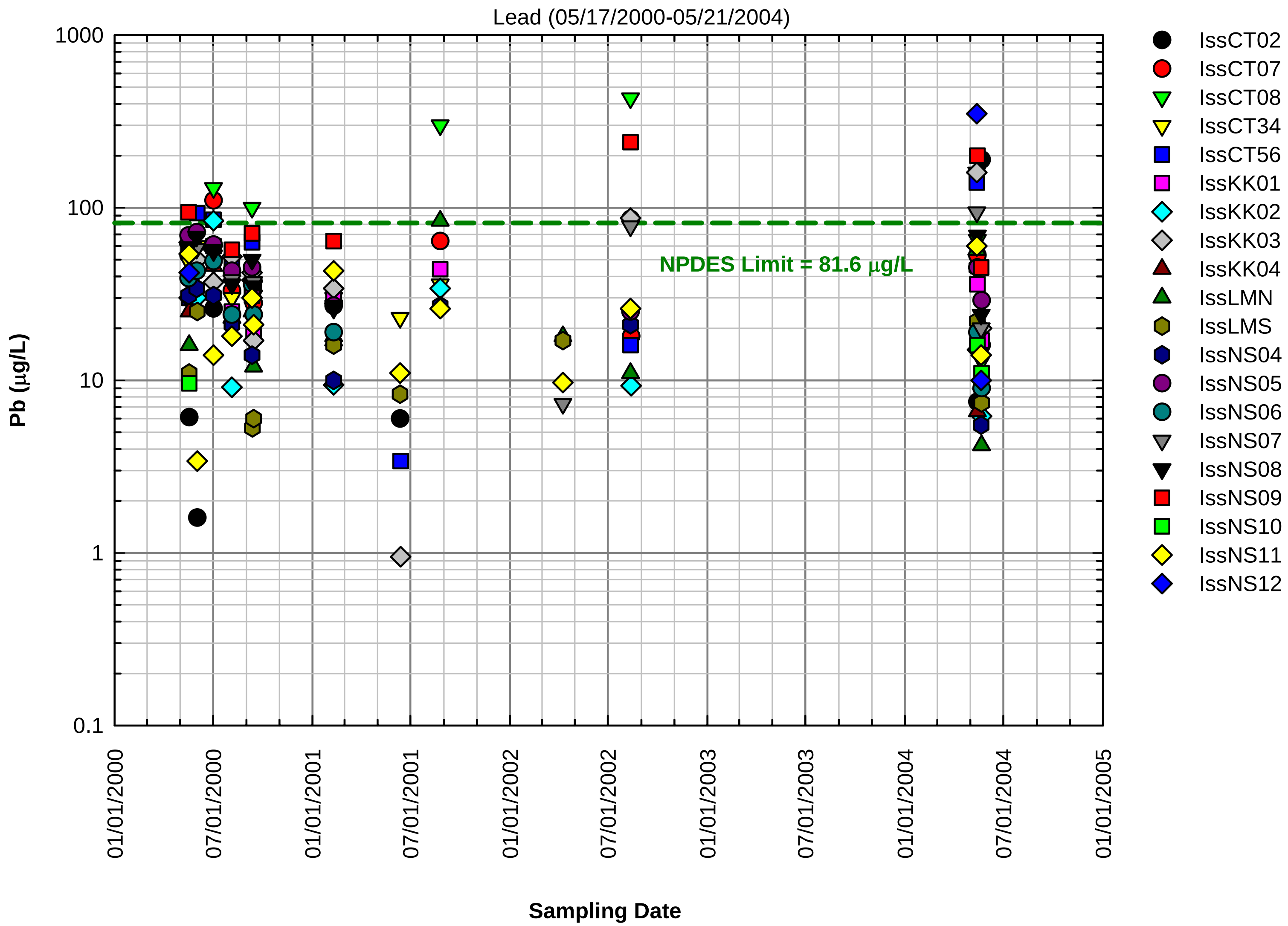


Figure F - 22 Lead (Pb) box chart in combined sewer overflow

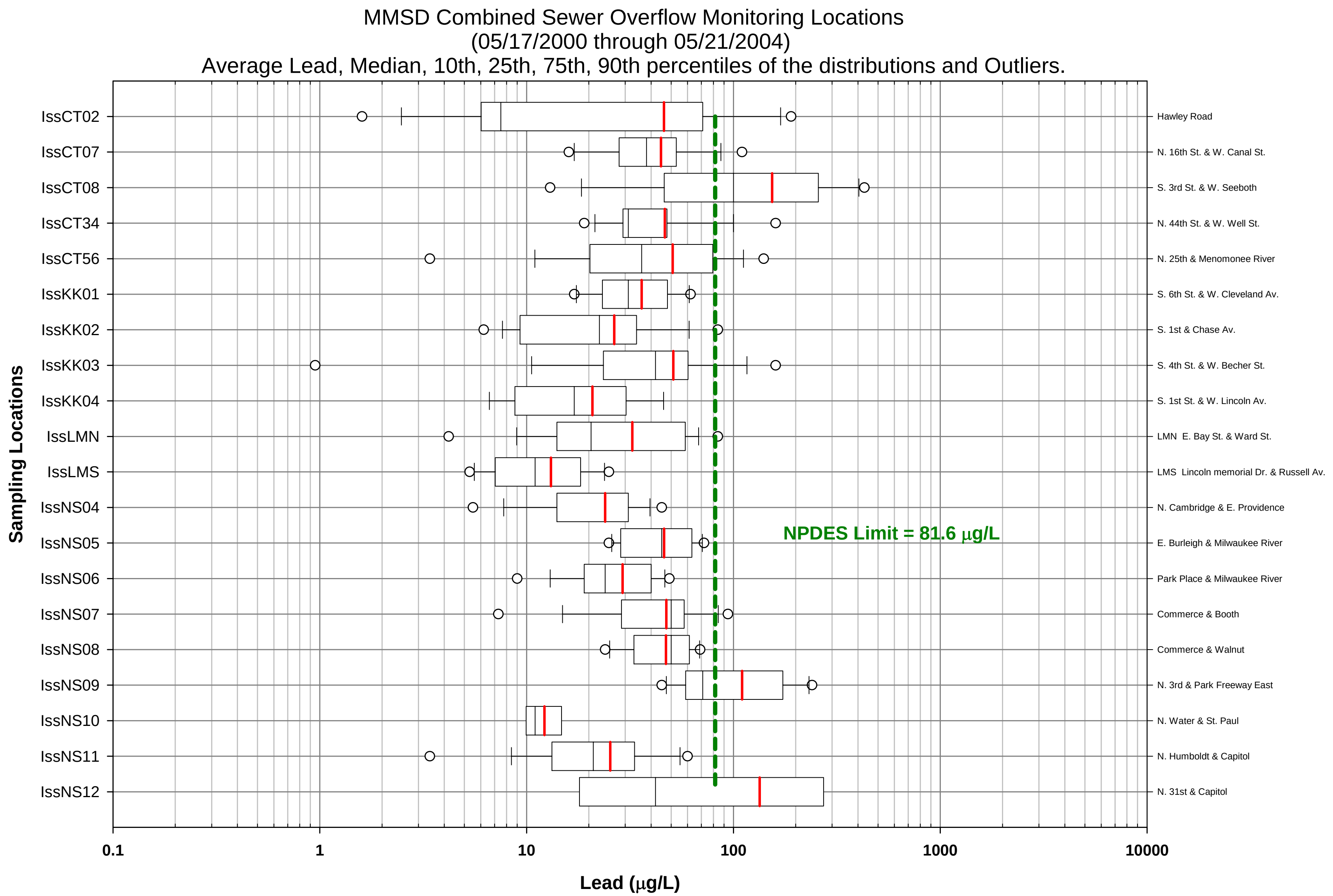


Figure F - 23 Magnesium (Mg) all data by time in combined sewer overflow

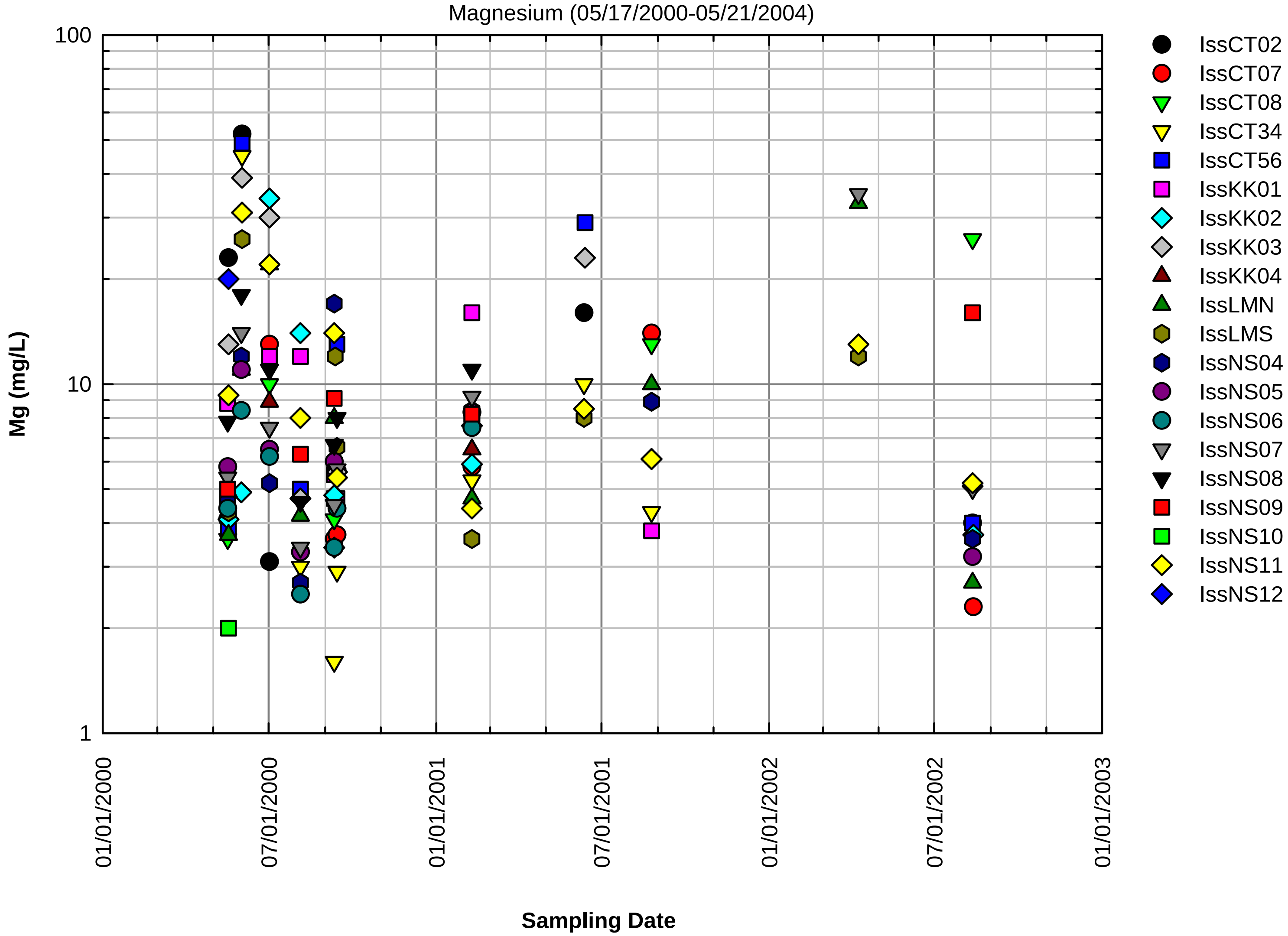


Figure F - 24 Magnesium (Mg) box chart in combined sewer overflow

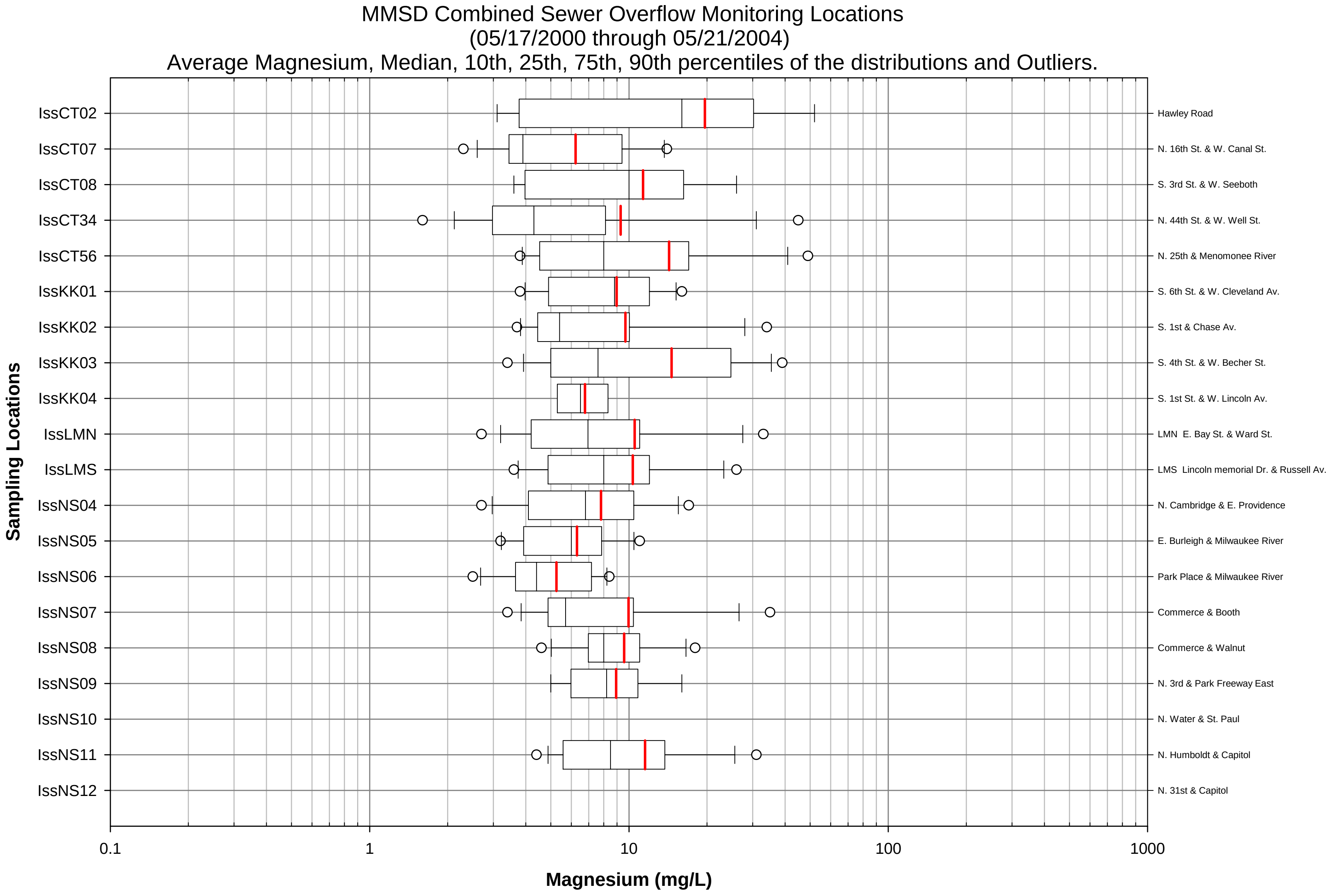


Figure F - 25 Mercury (Hg) all data by time in combined sewer overflow

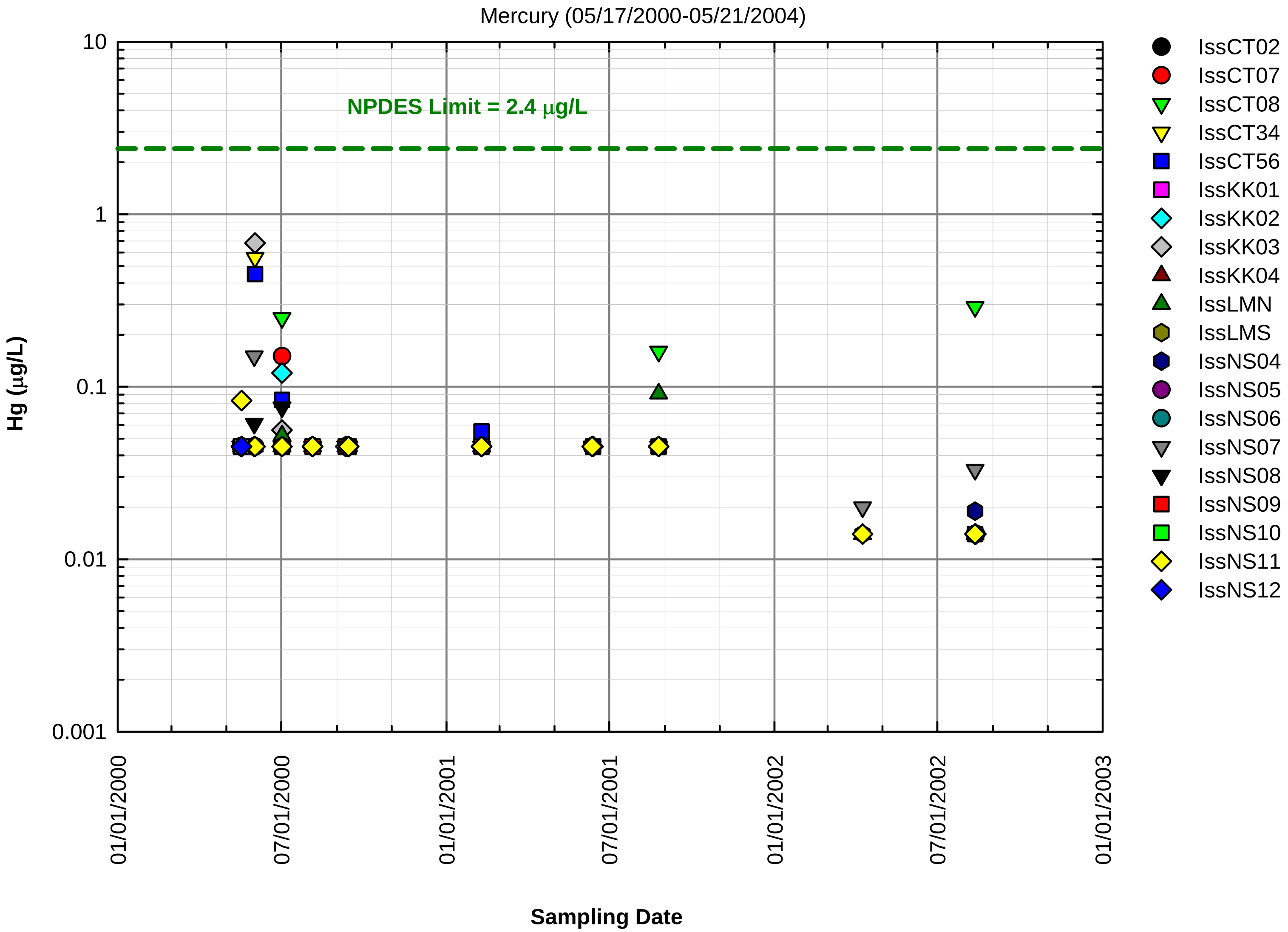


Figure F - 26 Mercury (Hg) box chart in combined sewer overflow

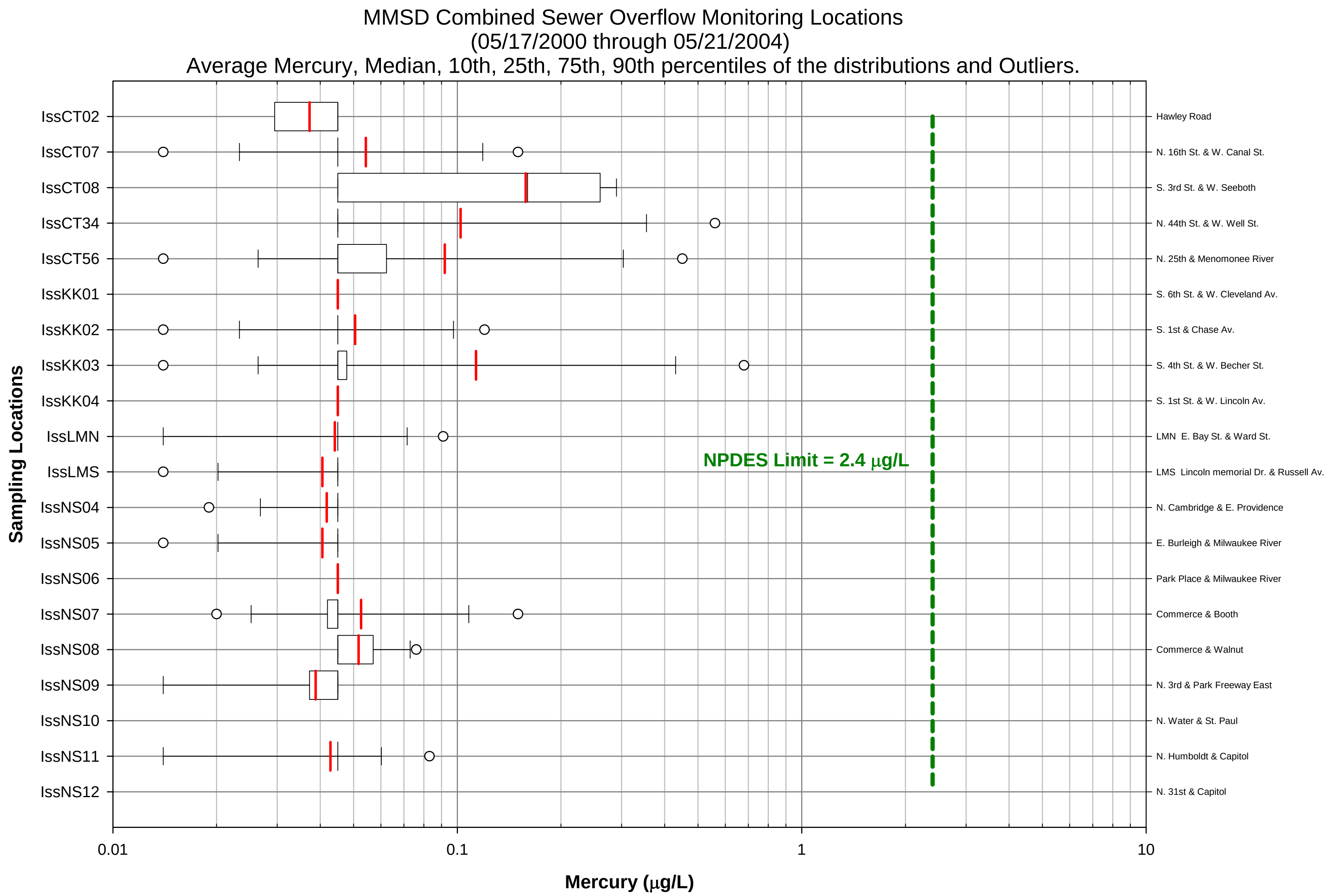


Figure F - 27   Nickel (Ni) all data by time in combined sewer overflow

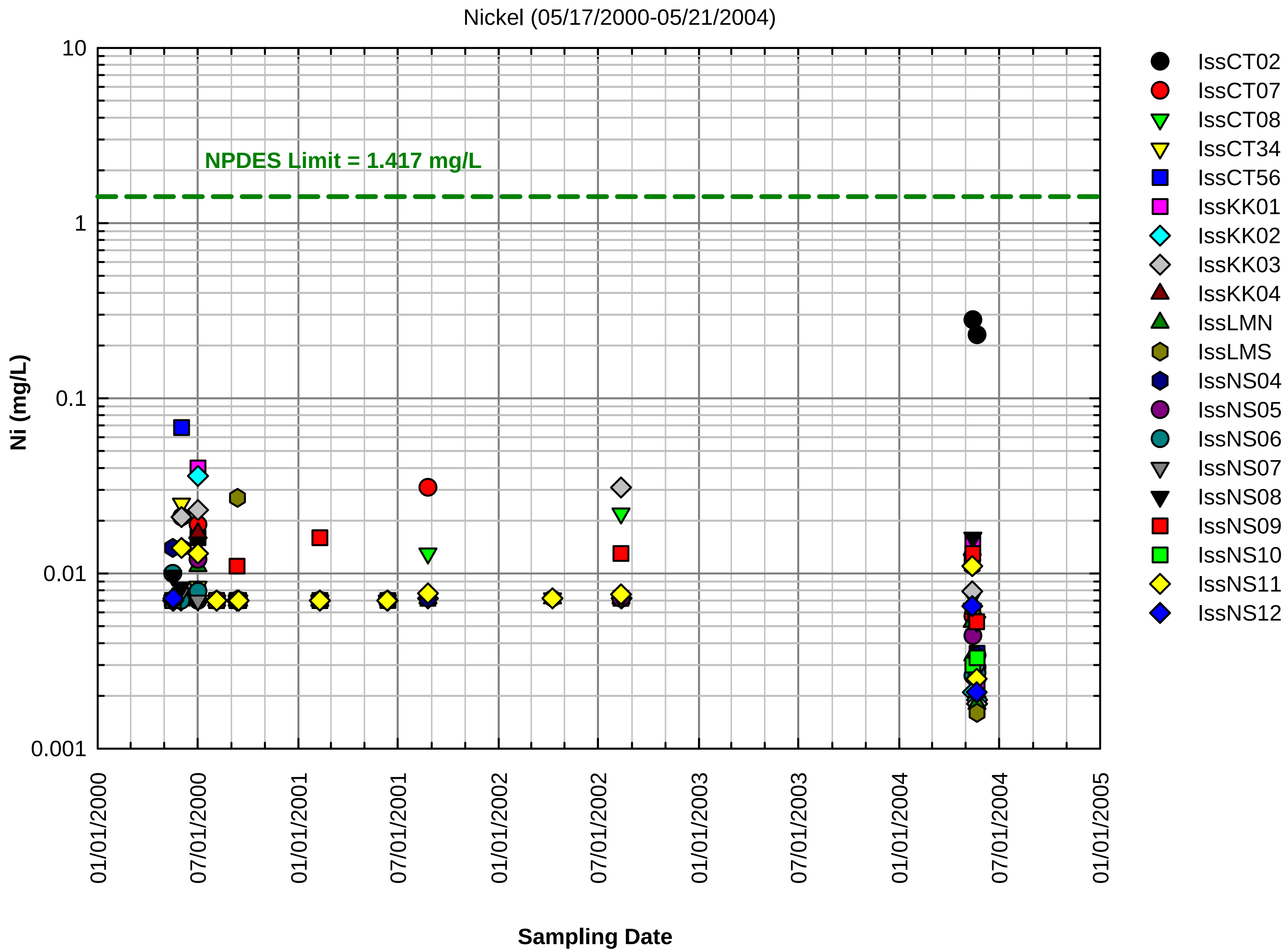


Figure F - 28 Nickel (Ni) box chart in combined sewer overflow

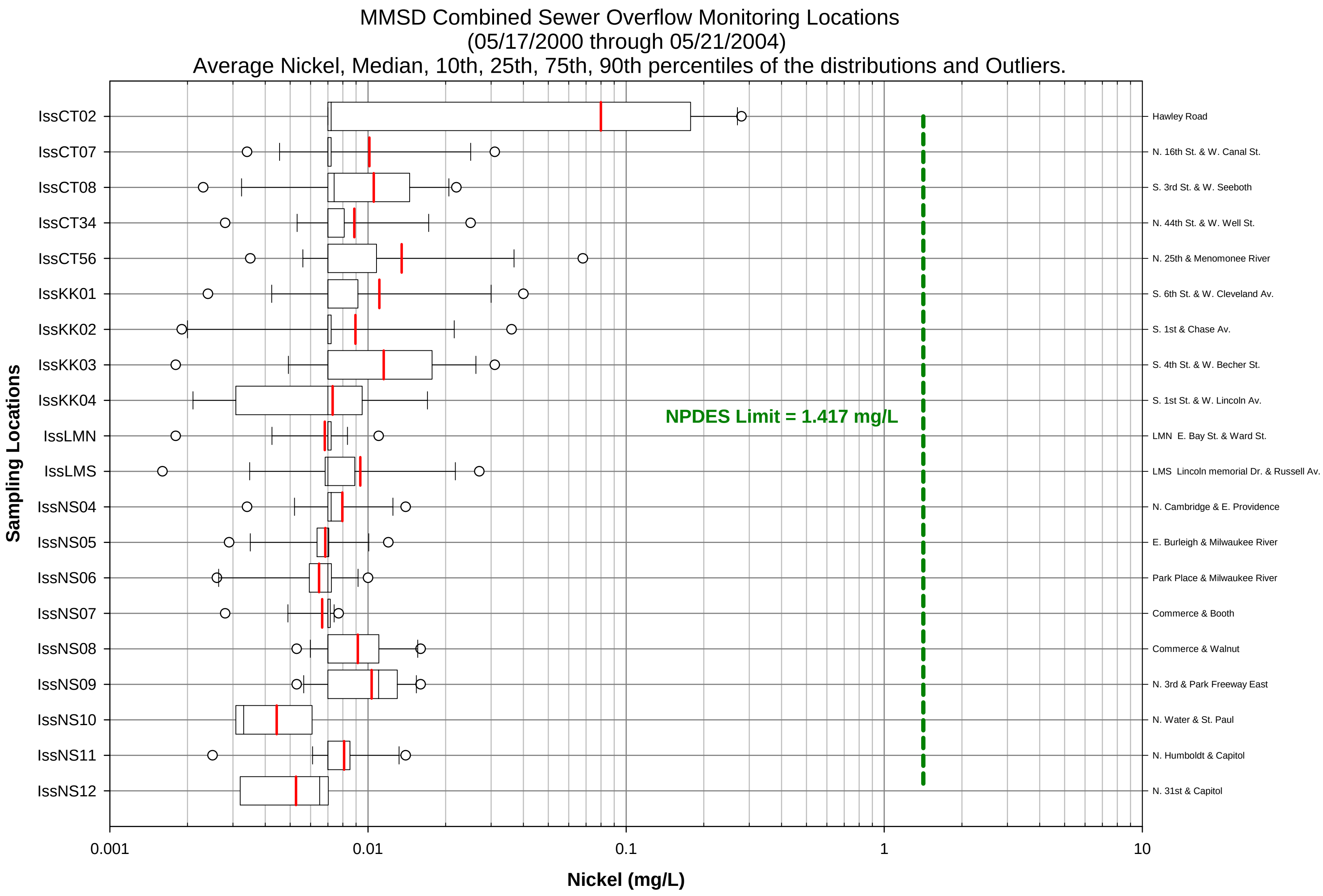


Figure F - 29 Selenium (Se) all data by time in combined sewer overflow

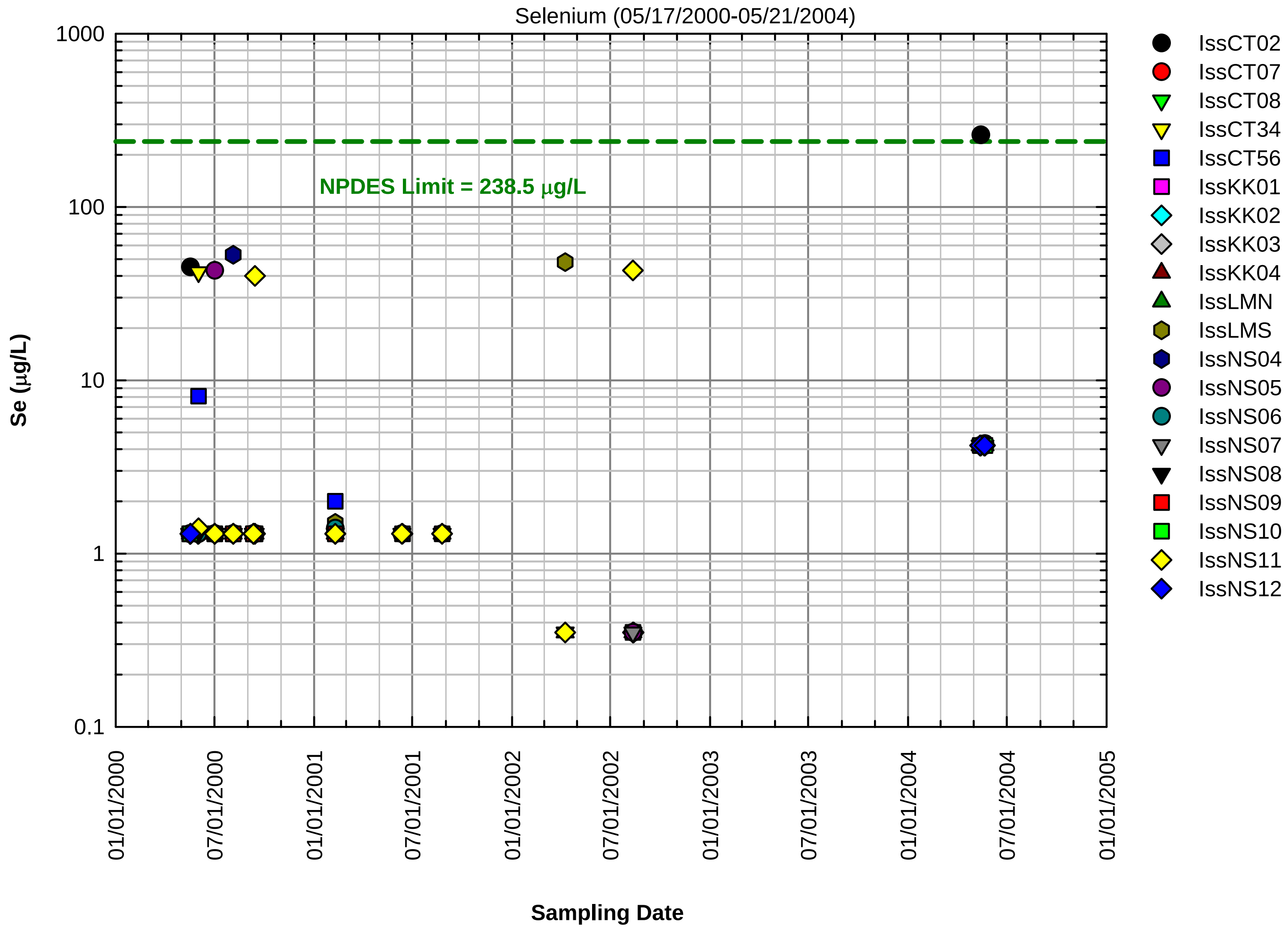


Figure F - 30 Selenium (Se) box chart in combined sewer overflow

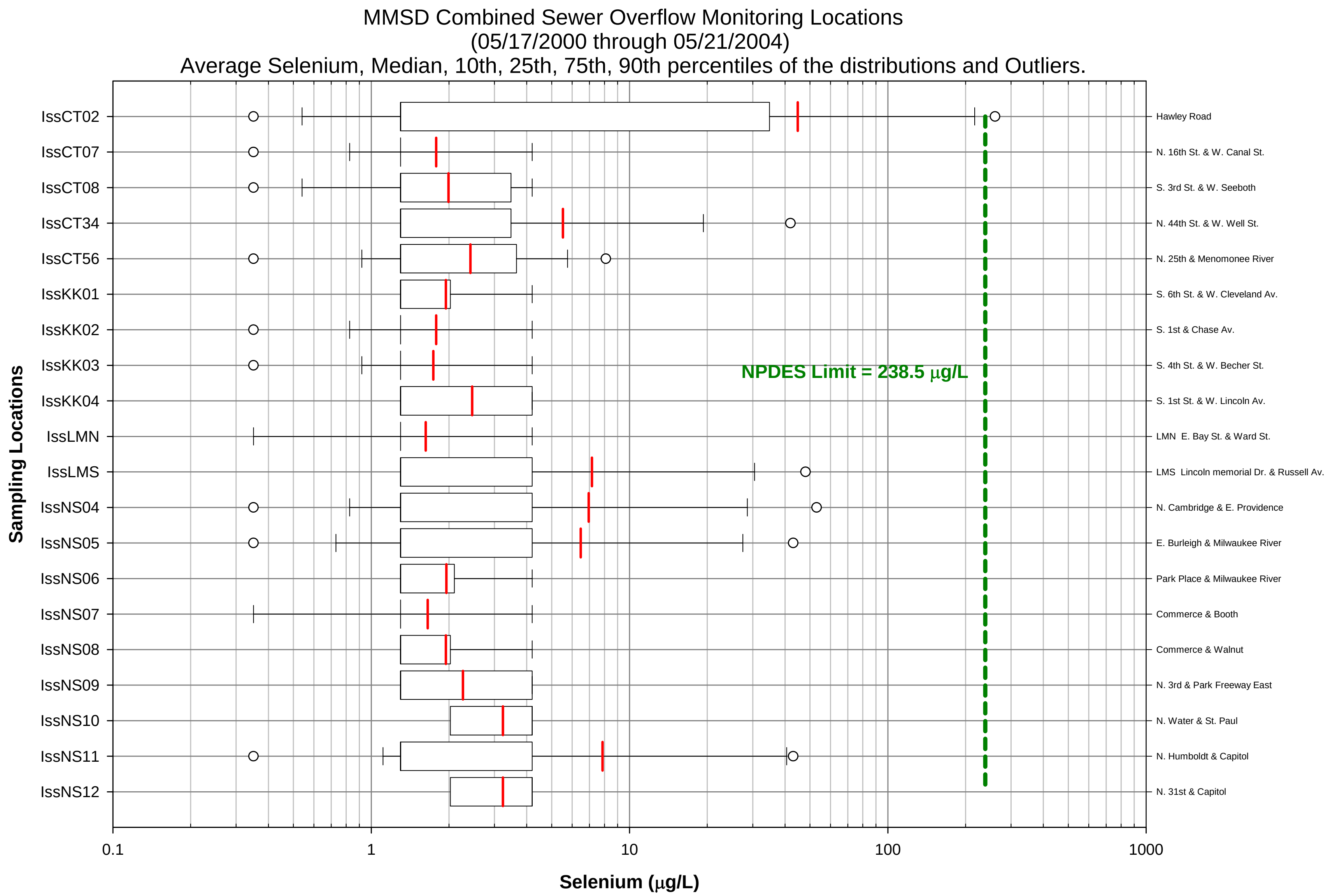


Figure F - 31 Silver (Ag) all data by time in combined sewer overflow

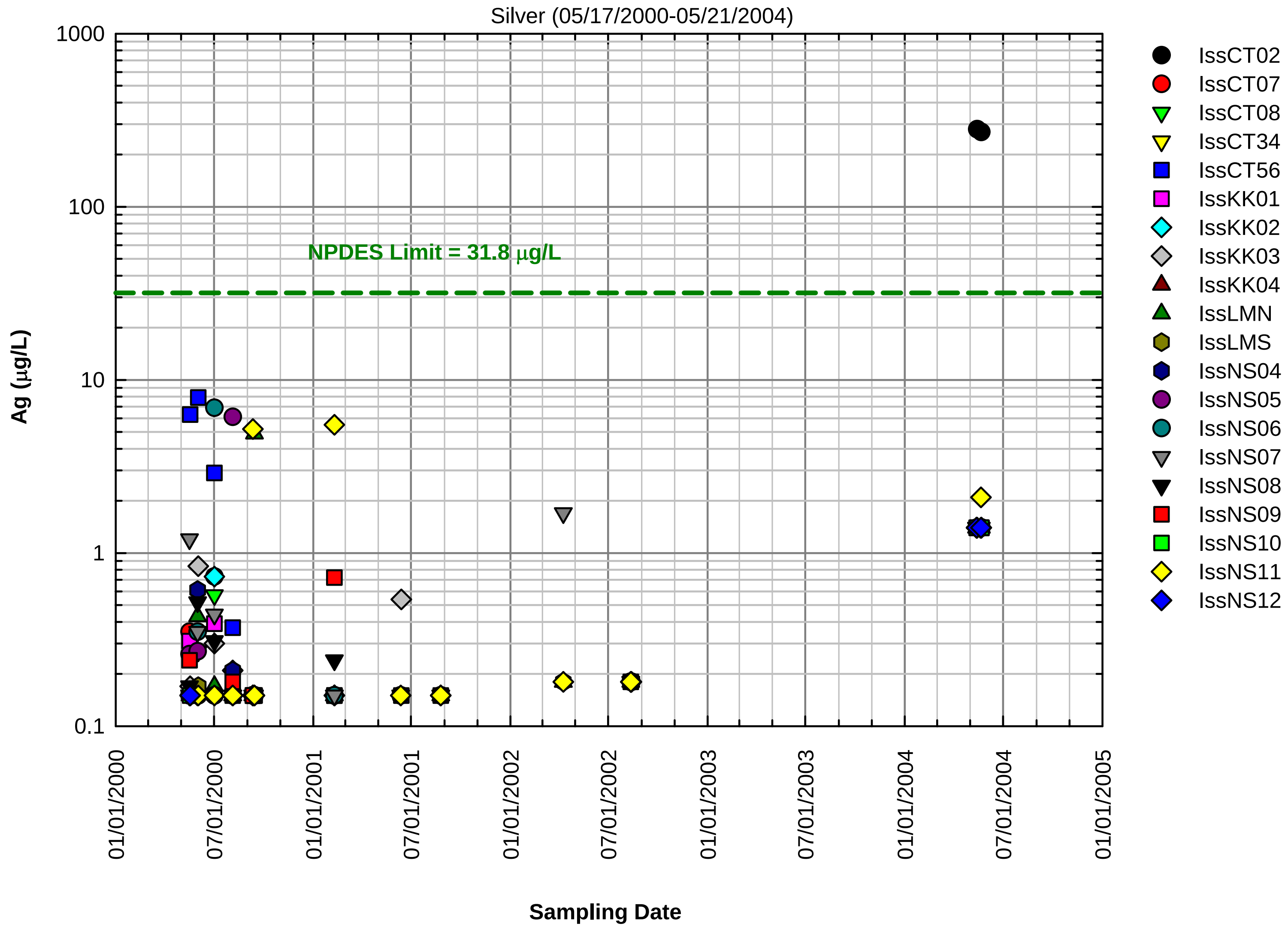


Figure F - 32 Silver (Ag) box chart in combined sewer overflow

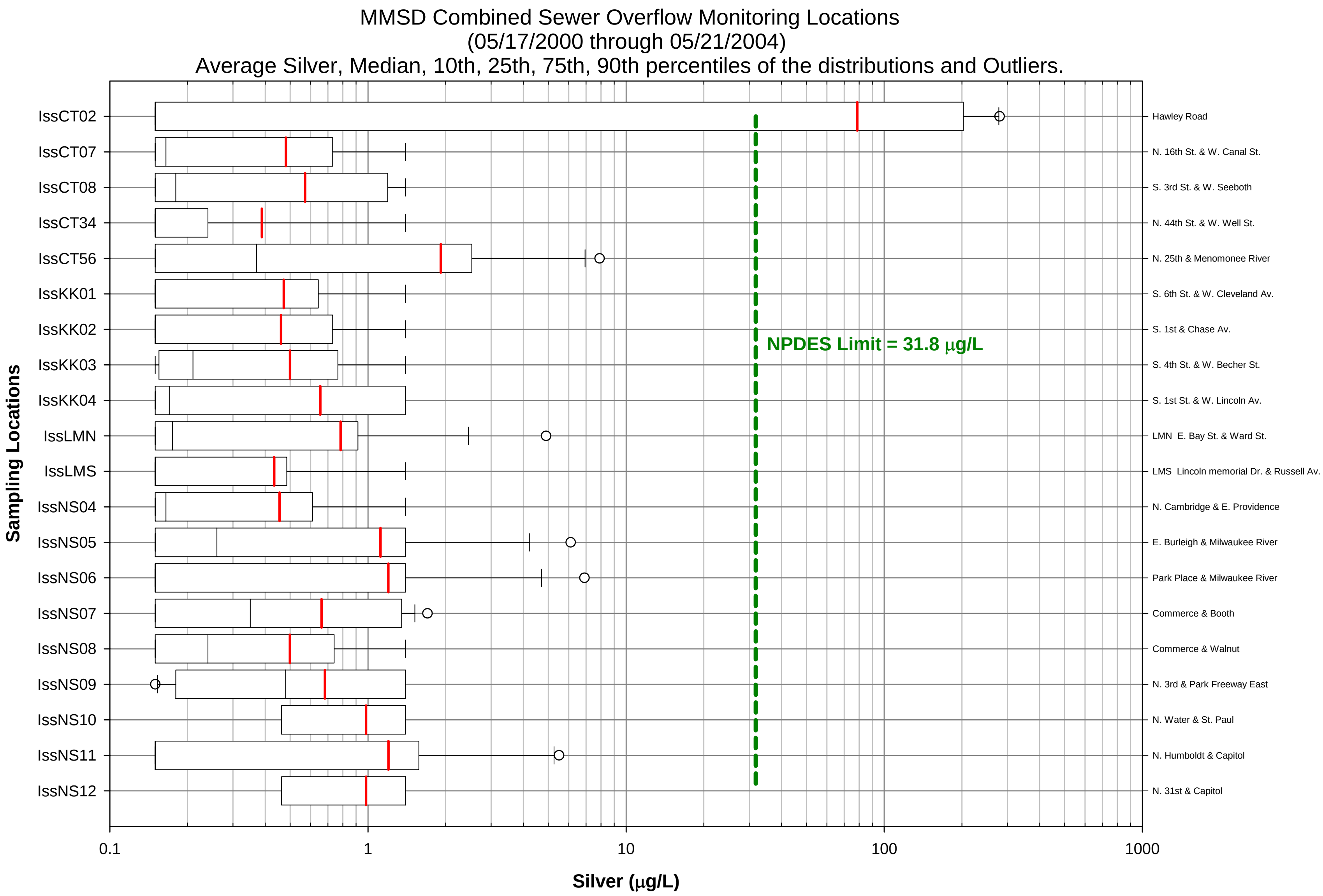


Figure F - 33   Total Phosphorus (TP) all data by time in combined sewer overflow

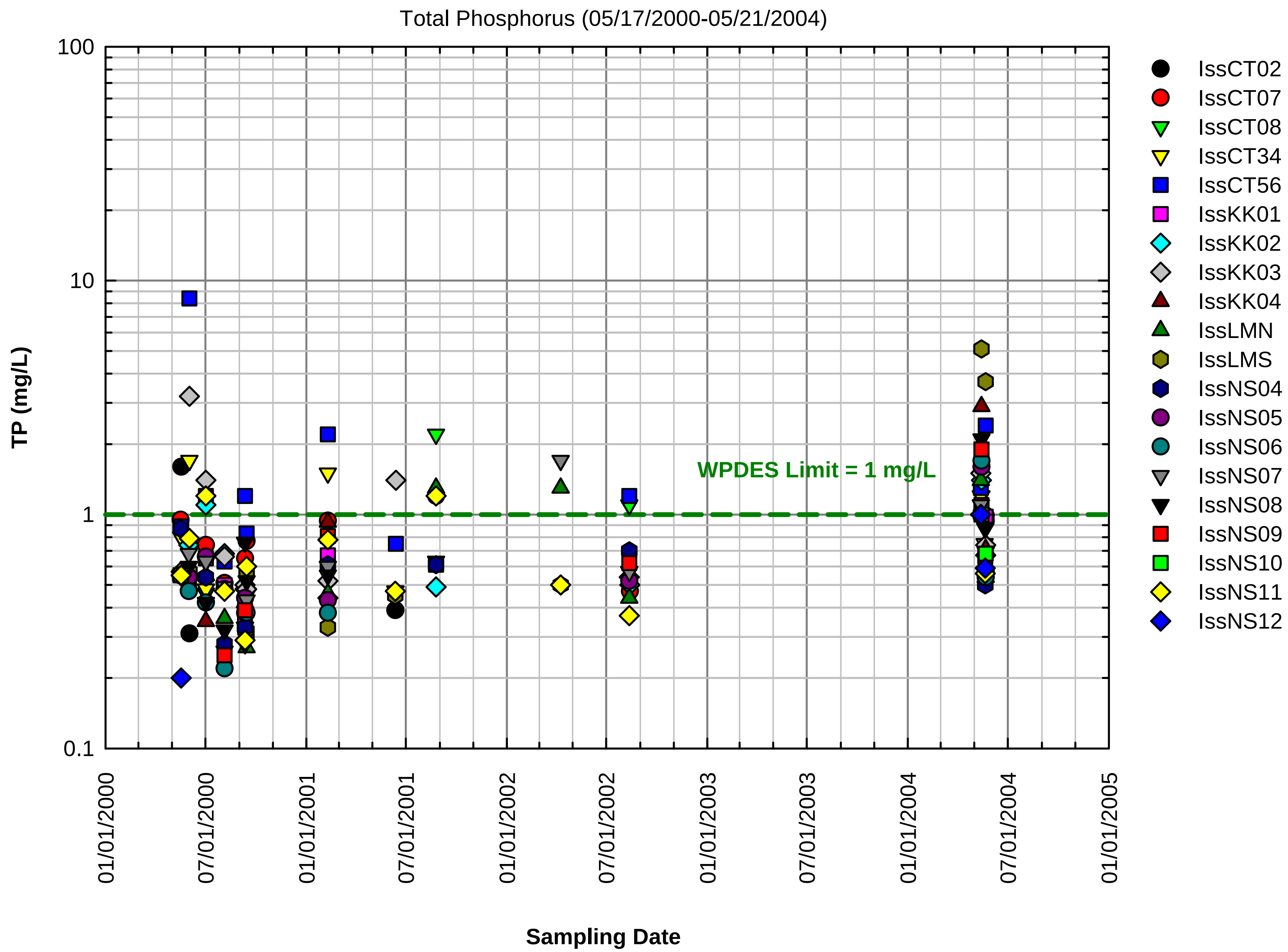


Figure F - 34   Total Phosphorus (TP) box chart in combined sewer overflow

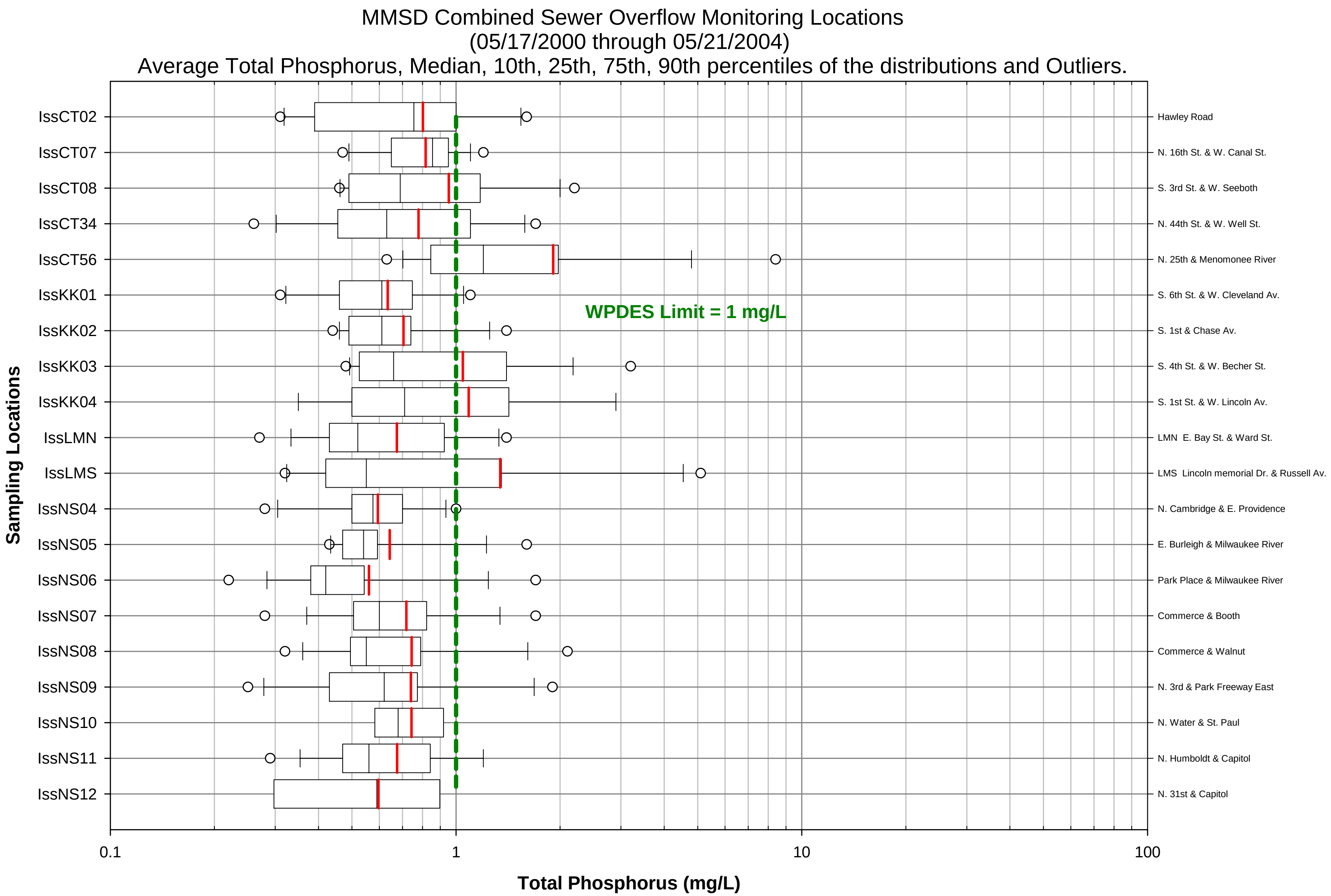


Figure F - 35 Total suspended solids (TSS) all data by time in combined sewer overflow

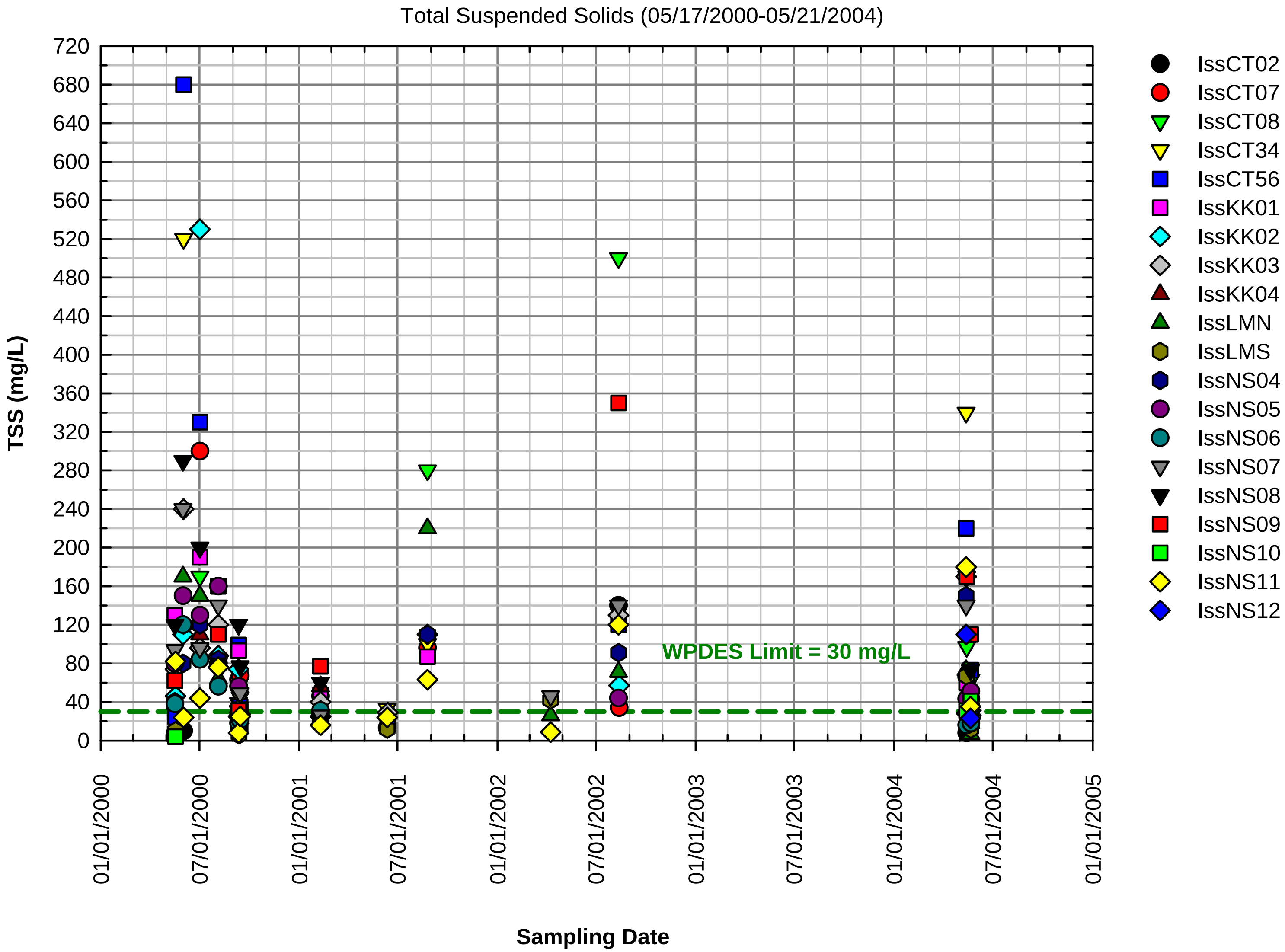


Figure F - 36 Total suspended solids (TSS) box chart in combined sewer overflow

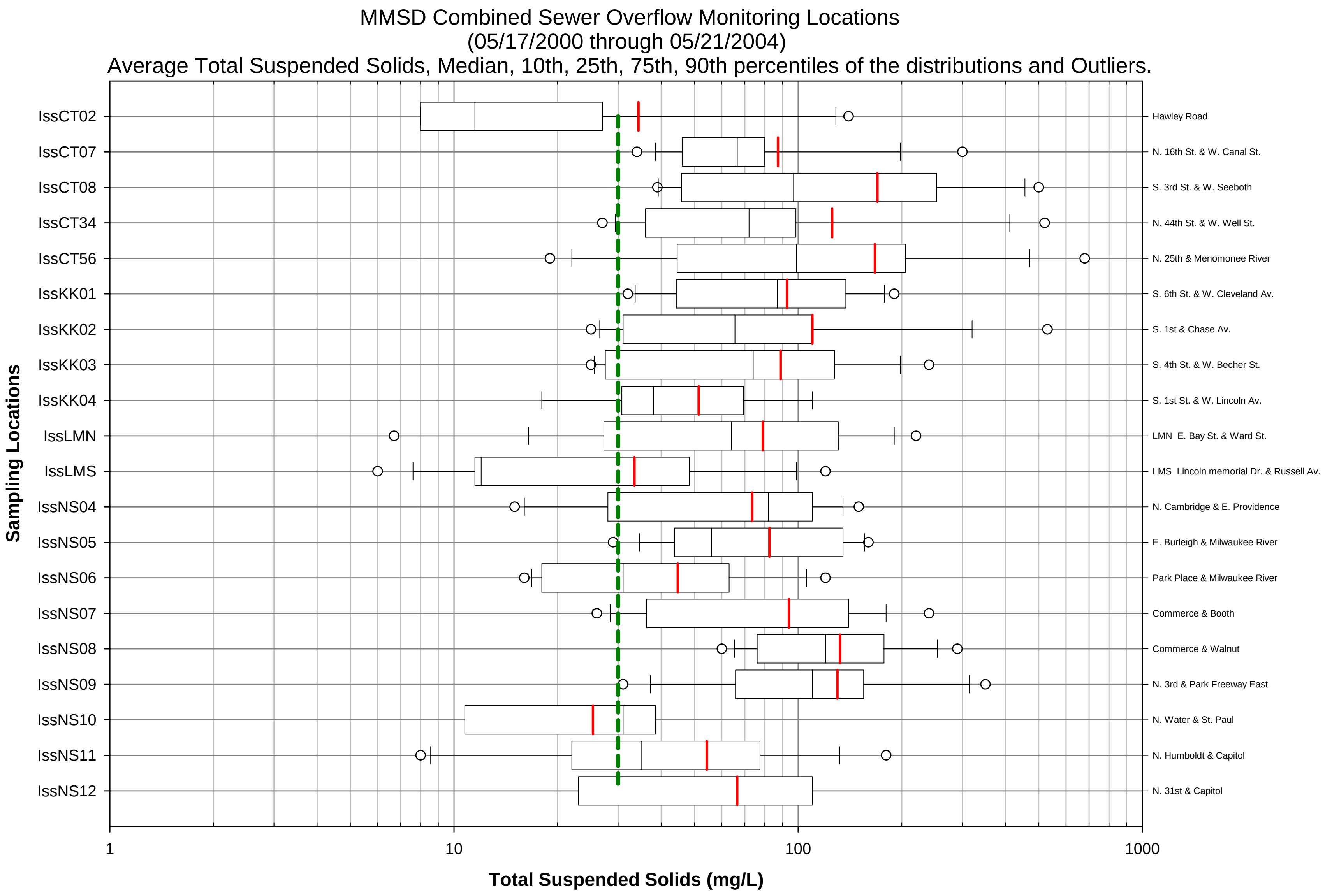


Figure F - 37   Zinc (Zn) all data by time in combined sewer overflow

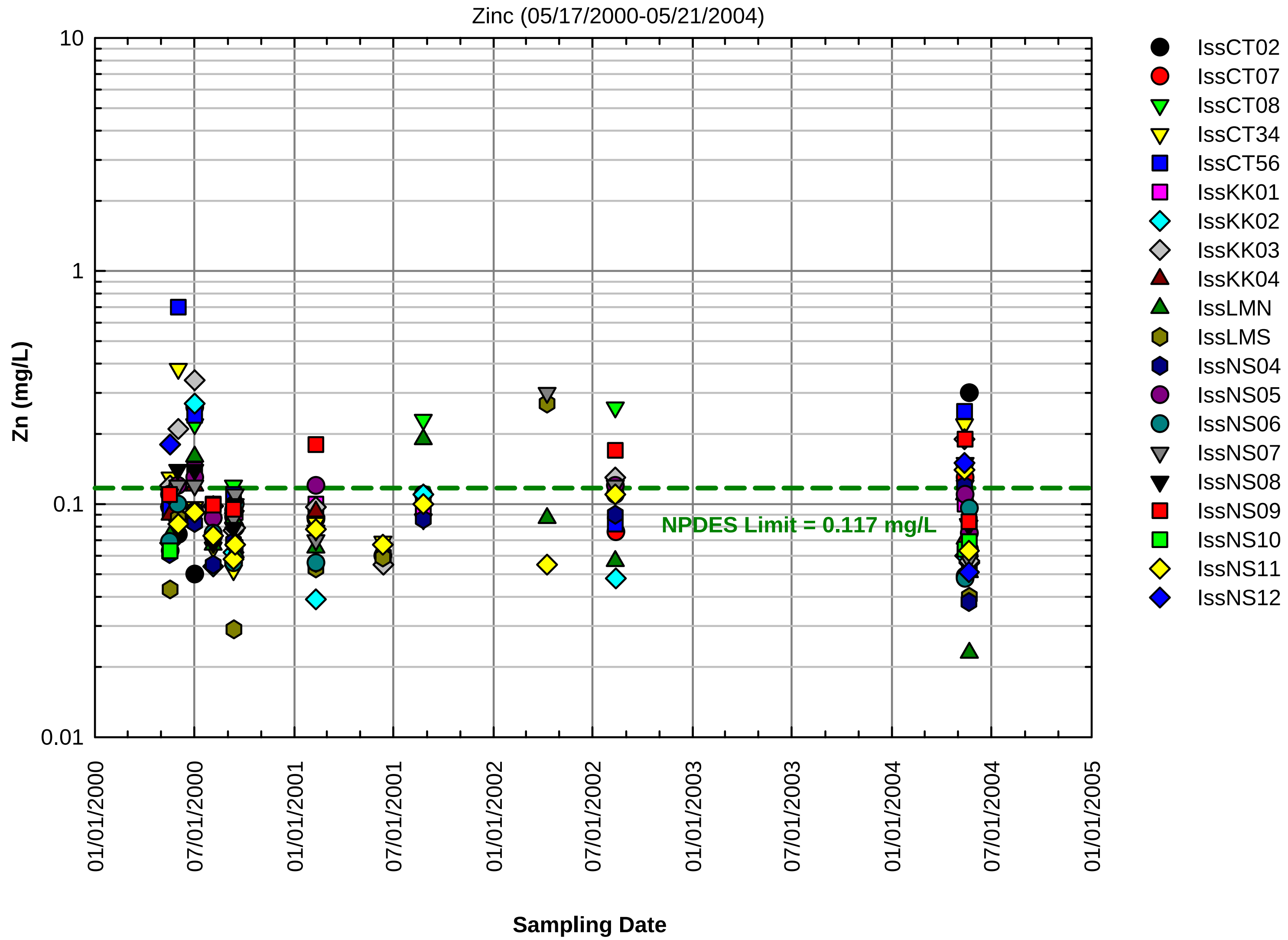
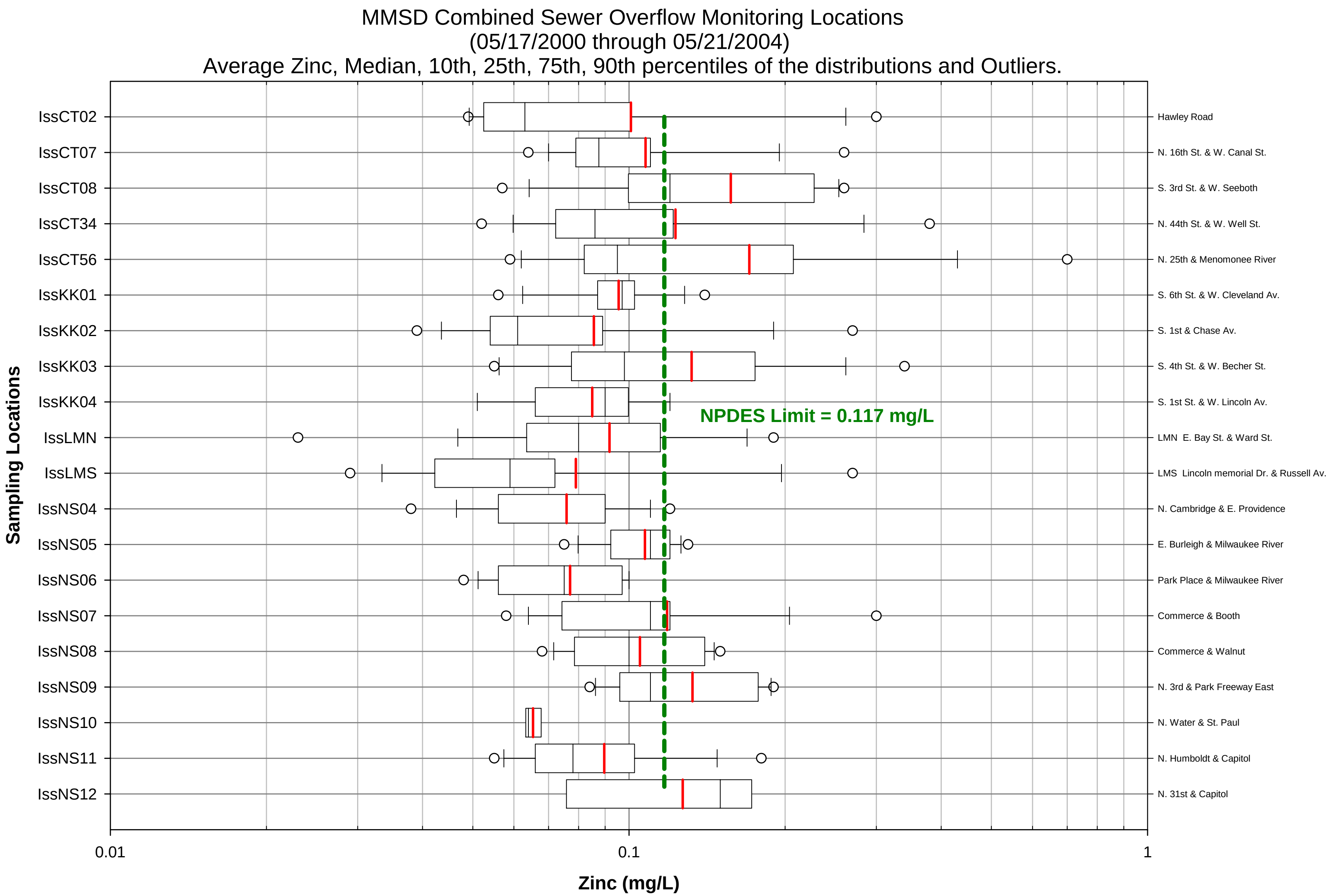


Figure F - 38 Zinc (Zn) box chart in combined sewer overflow



Appendix G : Stormwater Statistical Data

(regardless of event, precipitation, landuse, and sewershed)
(attached CDs – Appendix G.xls)

Table G - 1 Stormwater average values (2000-2005) with their limits by sampling stations

	Ag mg/L	Alk mg/L	As mg/L	Be mg/L	BOD mg/L	Ca mg/L	Cd mg/L	Cl mg/L	Cr mg/L	Cu mg/L	EC MPN/100 mL	FC CFU/100 mL	Hardness mg/L	Hg ug/L	Mg mg/L	NH3 mg/L	Ni mg/L	NO2 mg/L	NO3 mg/L	NO5 mg/L	Pb mg/L	Sb mg/L	Se mg/L	TDS mg/L	TKN mg/L	Tl mg/L	TOC mg/L	TP mg/L	TS mg/L	TSP mg/L	TSS mg/L	TURB NTU	Zn mg/L
SWMI01	0.0010	29.3	0.0021	0.0002	8.70	32.0	0.0009	102	0.013	0.037	8082	14379	124	0.026	10.7	0.35	0.0059	0.06	0.86	0.89	0.025	0.036	0.010	170	1.80	0.0027	17.6	0.57	509	0.30	145	26.2	0.18
												Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	Exceed
SWMI02	0.0008	114	0.0018	0.0012	15.0	32.4	0.0007	62.9	0.013	0.031	6716	36686	122	0.026	9.94	0.65	0.0056	0.07	0.85	0.93	0.017	0.018	0.007	319	2.17	0.0019	27.1	0.42	389	0.17	72.7	34.4	0.18
												Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	Exceed
SWFR03	0.0009	15.1	0.0025	0.0004	12.1	25.3	0.0007	26.0	0.009	0.017	9165	26633	105	0.029	10.1	0.72	0.0081	0.09	1.20	1.31	0.013	0.013	0.006	146	2.63	0.0020	22.7	0.46	365	0.26	133	244	0.10
												Exceed								Exceed					Exceed					Exceed	Exceed	Exceed	
SWMI04	0.0008	64.7	0.0035	0.0005	15.9	32.8	0.0008	56.5	0.006	0.025	63479	254571	132	0.031	12.1	0.43	0.0055	0.06	1.02	1.62	0.026	0.008	0.005	193	2.70	0.0021	17.9	0.72	313	0.40	147	67.3	0.16
												Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	Exceed
SWMI05	0.0008		0.0020		28.8	20.3	0.0010	7.8	0.008	0.057	9704	34498	76.6	0.028	6.28	0.35	0.0063	0.08	1.06		0.042		0.006		3.29		26.2	0.62	564		120	13.3	0.18
												Exceed													Exceed						Exceed	Exceed	Exceed
SWMI06	0.0009	50.0	0.0034	0.0006	15.2	41.8	0.0007	51.4	0.007	0.019	53264	189683	160	0.025	13.5	0.53	0.0052	0.08	0.83	0.97	0.015	0.016	0.008	248	2.77	0.0031	19.2	0.81	485	0.50	139	58.9	0.09
												Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	
SWMI07	0.0009	110	0.0043	0.0008	28.9	62.6	0.0011	107	0.016	0.051	56036	193048	261	0.068	25.7	0.36	0.0124	0.12	0.94	1.15	0.085	0.027	0.010	358	3.45	0.0022	29.7	1.31	805	0.33	305	54.9	0.24
												Exceed	Exceed							Exceed	Exceed				Exceed			Exceed		Exceed	Exceed	Exceed	Exceed
SWMI08	0.0001		0.0012		33.2	49.9	0.0006		0.008	0.031	65288	200266	206	0.031	20.0	0.45	0.0073	0.15	1.57		0.017		0.001		3.40		26.4	0.79	646		210		0.15
					Exceed							Exceed	Exceed												Exceed						Exceed		Exceed
SWWB09	0.0008	55.7	0.0033	0.0013	36.2	43.8	0.0007	75.5	0.009	0.081	80000	242726	182	0.086	17.4	0.61	0.0072	0.13	1.46	2.24	0.052	0.018	0.007	181	4.39	0.0033	31.4	1.14	559	0.63	208	60.1	0.16
					Exceed					Exceed		Exceed	Exceed							Exceed					Exceed			Exceed		Exceed	Exceed	Exceed	Exceed
SWGF10	0.0007	19.8	0.0020	0.0003	12.3	26.9	0.0005	37.1	0.008	0.021	35785	153993	112	0.037	11.0	0.52	0.0061	0.08	0.99	0.79	0.011	0.007	0.004	153	2.42	0.0024	20.1	0.62	294	0.39	181	1365	0.10
												Exceed								Exceed					Exceed					Exceed	Exceed	Exceed	
SWNB11	0.0008	40.4	0.0029	0.0004	8.32	30.8	0.0006	32.2	0.008	0.013	6426	7356	128	0.046	12.4	0.48	0.0083	0.06	0.78	0.89	0.009	0.016	0.006	290	3.26	0.0027	18.6	0.76	459	0.31	207	98.3	0.07
												Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	
SWMI12	0.0007	42.2	0.0027	0.0012	32.6	33.7	0.0006	72.0	0.008	0.020	59652	264246	135	0.030	12.4	0.59	0.0064	0.12	1.09	1.21	0.017	0.020	0.007	105	3.84	0.0028	31.0	2.48	479	0.33	578	124	0.12
					Exceed							Exceed	Exceed							Exceed					Exceed			Exceed		Exceed	Exceed	Exceed	Exceed
SWWA13	0.0010	61.7	0.0035	0.0002	39.6	36.1	0.0007	49.4	0.006	0.052	106640	403362	146	0.028	13.8	0.62	0.0052	0.11	0.83	1.07	0.020	0.008	0.008	246	5.34	0.0018	35.1	1.00	446	0.56	174	21.4	0.10
					Exceed							Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	
SWSF14	0.0008		0.0020		29.2	13.8	0.0006	8.5	0.004	0.013	71268	249469	53.0	0.025	4.50	0.49	0.0044	0.15	0.77		0.015		0.006		4.17		25.5	0.56	214		112	28.1	0.10
												Exceed													Exceed						Exceed	Exceed	
SWMI15	0.0018	14.0	0.0086	0.0061	19.3	78.3	0.0022	137	0.066	0.196	7250	56070	318	0.059	30.5	1.10	0.0209	0.13	1.02	1.14	0.123	0.033	0.011	130	3.54	0.0031	32.0	0.87	937	0.38	458	59.0	0.87
									Exceed	Exceed		Exceed	Exceed							Exceed	Exceed				Exceed					Exceed	Exceed	Exceed	Exceed
SWMI16	0.0021	66.1	0.0062	0.0050	11.7	51.6	0.0016	341	0.023	0.072	26913	34336	196	0.114	16.2	0.63	0.0161	0.11	1.06	1.05	0.064	0.006	0.016	194	2.59	0.0031	24.6	0.74	3168	0.27	258	59.4	0.36
									Exceed	Exceed		Exceed	Exceed							Exceed					Exceed					Exceed	Exceed	Exceed	Exceed
SWWA17	0.0010	51.2	0.0060	0.0008	43.3	43.3	0.0007	90.1	0.013	0.034	126417	103213	170	0.037	14.9	0.70	0.0068	0.21	1.12	1.42	0.051	0.009	0.006	171	4.13	0.0027	38.8	1.28	579	0.65	331		0.18
					Exceed							Exceed	Exceed							Exceed					Exceed			Exceed		Exceed	Exceed		Exceed
SWMI18	0.0011	38.9	0.0048	0.0007	42.6	33.3	0.0021	57.2	0.010	0.103	75237	73871	135	0.082	12.5	1.56	0.0085	0.08	0.57	0.61	0.034	0.008	0.005	154	3.85	0.0027	29.2	1.24	386	0.42	206		0.41
					Exceed					Exceed		Exceed	Exceed												Exceed			Exceed		Exceed	Exceed		Exceed
Limit	0.0318	400	0.16854	0.13	30		0.0159	860	0.016	0.0636		400	120	2.4		19	1.417	1	10	0.68	0.0816	0.636	0.2385		1.5	0.048	50	1		0.05	30	5	0.117

Exceed: Constituent concentration exceed its limit

Appendix H : Combined Sewer Overflow Statistical Data

(regardless of event, precipitation, landuse, and sewershed) viation of concentration in each constituent for each sampling location

		IssCT08						IssCT34					
STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN
0.13	0.09	2	0.65	0.73	0.57	0.11	0.08	2	0.89	1	0.78	0.16	0.11
0.001	0.0002	7	0.02	0.04	0.001	0.02	0.01	11	0.01	0.05	0.001	0.01	0.004
12.1	3.84	7	10.70	24	6	6.63	2.50	11	18	77	6.7	20.3	6.13
0.58	0.18	7	1.12	1.7	0.51	0.50	0.19	11	1.06	4	0.25	1.1	0.33
4.8	1.7	5	27.80	64	11	22.06	9.87	9	25.3	110	4.6	32.7	10.9
0.02	0.01	7	0.062	0.15	0.005	0.06	0.02	11	0.01	0.07	0.004	0.02	0.01
0.02	0.005	7	0.043	0.08	0.015	0.03	0.01	11	0.02	0.05	0.01	0.02	0.005
								4	80500	120000	45000	31480	15740
								5	381200	930000	23000	359622	160828
24.5	8.65	5	118	270	46	93.2	41.7	9	99.2	460	18	138	46.1
27.9	8.82	7	154	430	13	154	58.1	11	46.6	160	19	39.5	11.9
4.6	1.63	5	11.3	26	3.6	9.11	4.07	9	9.29	45	1.6	13.6	4.54
0.04	0.01	5	0.16	0.29	0.05	0.11	0.05	9	0.1	0.56	0.05	0.17	0.06
0.01	0.003	7	0.01	0.02	0.002	0.01	0.002	11	0.01	0.03	0.003	0.01	0.002
0.23	0.07	7	0.95	2.2	0.46	0.63	0.24	11	0.78	1.7	0.26	0.48	0.15
1.31	0.41	7	1.99	4.2	0.35	1.55	0.58	11	5.53	42	1.30	12.2	3.66
0.52	0.16	7	0.57	1.4	0.15	0.59	0.22	11	0.39	1.4	0.15	0.5	0.15
77.04	24.4	7	170	500	39	169	64	11	125	520	27	158	47.6
0.06	0.02	7	0.16	0.26	0.06	0.08	0.03	11	0.12	0.38	0.05	0.1	0.03

on of concentration in each constituent for each sampling location (cont'd)

		IssKK02						IssKK03					
DEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN
.14	0.1	2	1.07	1.4	0.73	0.47	0.34	2	1.08	1.2	0.95	0.18	0.13
.001	0.0003	10	0.01	0.07	0.0004	0.02	0.01	11	0.001	0.005	0.001	0.001	0.0004
.36	1.79	10	14.9	30	6	8.44	2.67	11	24.6	81	8.6	22.4	6.74
.56	0.19	10	0.81	1.7	0.05	0.69	0.22	11	0.91	2	0.05	0.7	0.21
.48	2.83	8	22.1	66	11	18.2	6.44	9	43	110	11	36	12
.01	0.003	10	0.01	0.08	0.002	0.02	0.01	11	0.02	0.09	0.003	0.03	0.01
.01	0.003	10	0.02	0.06	0.01	0.02	0.01	11	0.02	0.05	0.01	0.01	0.004
4611	54955	1	240000	240000	240000		0						
6492	55723	1	2400000	2400000	2400000		0	1	24000000	24000000	24000000		0
31.3	11.8	8	87.4	310	45	90.4	32	9	164	410	42	136	45.5
6.5	5.49	10	26.5	84	6.2	23.5	7.42	11	51.2	160	0.95	43	13
.56	1.72	8	9.69	34	3.7	10.36	3.66	9	14.6	39	3.4	13	4.33
0	0	8	0.05	0.12	0.01	0.03	0.01	9	0.11	0.68	0.01	0.21	0.07
.01	0.004	10	0.01	0.04	0.002	0.01	0.003	11	0.01	0.03	0.002	0.01	0.003
.26	0.09	10	0.71	1.4	0.44	0.31	0.10	11	1.05	3.2	0.48	0.82	0.25
.28	0.43	10	1.79	4.2	0.35	1.31	0.41	11	1.74	4.2	0.35	1.25	0.38
.53	0.18	10	0.46	1.4	0.15	0.53	0.17	11	0.5	1.4	0.15	0.49	0.15
56.4	18.8	10	110	530	25	151	47.8	11	88.8	240	25	70.8	21.4
.02	0.01	10	0.09	0.27	0.04	0.07	0.02	11	0.13	0.34	0.06	0.09	0.03

on of concentration in each constituent for each sampling location (cont'd)

		IssLMS						IssNS04					
STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN
0.51	0.36	2	0.85	1.1	0.59	0.36	0.26	2	0.77	1.1	0.43	0.47	0.34
0.001	0.0002	9	0.01	0.06	0.001	0.02	0.01	10	0.01	0.06	0.0004	0.02	0.01
13.3	3.84	9	12.2	24	3.5	6.36	2.12	10	12.3	24	6	6.64	2.1
0.84	0.24	9	0.91	1.7	0.29	0.53	0.18	10	0.58	1.7	0.05	0.62	0.19
21	6.64	7	34	64	13	17.9	6.78	8	21.1	55	8.4	15.2	5.37
0.02	0.005	9	0.01	0.04	0.002	0.01	0.004	10	0.01	0.03	0.003	0.01	0.002
0.02	0.004	9	0.01	0.03	0.01	0.01	0.003	10	0.03	0.05	0.02	0.01	0.004
140169	49557							6	58000	130000	23000	45611	18621
569715	201425	1	93000	93000	93000		0.00	6	318000	930000	25000	355789	145250
88.2	27.9	7	119	270	48	75.3	28.4	8	81.8	190	32	51.6	18.2
25.8	7.46	9	13.1	25	5.3	7.21	2.40	10	24	45	5.5	12	3.81
9.7	3.07	7	10.4	26	3.6	7.66	2.90	8	7.80	17	2.7	4.85	1.71
0.02	0.01	7	0.04	0.05	0.01	0.01	0.004	8	0.04	0.05	0.02	0.01	0.003
0.002	0.001	9	0.01	0.03	0.00	0.01	0.002	10	0.008	0.014	0.003	0.003	0.001
0.41	0.12	9	1.34	5.10	0.32	1.77	0.59	10	0.59	1.00	0.28	0.22	0.07
1.26	0.36	9	7.16	48	1.30	15.4	5.12	10	6.96	53	0.35	16.2	5.13
1.38	0.40	9	0.43	1.4	0.15	0.55	0.18	10	0.46	1.4	0.15	0.52	0.16
70	21.1	9	33.4	120	6	38	12.7	10	73.5	150	15	46.7	14.8
0.05	0.01	9	0.08	0.27	0.03	0.07	0.02	10	0.08	0.12	0.04	0.02	0.01

on of concentration in each constituent for each sampling location (cont'd)

		IssNS07						IssNS08					
STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN
0.54	0.39	2	0.9	0.98	0.81	0.12	0.09	2	0.91	1	0.81	0.13	0.1
0.001	0.0003	11	0.001	0.003	0.0004	0.001	0.0003	9	0.002	0.003	0.001	0.001	0.0003
7.8	2.6	11	20.4	77	8.1	19.6	5.9	9	17.8	40	5.4	11.67	3.89
1.08	0.36	11	0.57	1.7	0.05	0.60	0.18	9	0.73	1.7	0.14	0.59	0.20
4.2	1.59	9	26.1	94	11	26.3	8.76	7	22.7	34	13	7.2	2.72
0.01	0.002	11	0.01	0.03	0.003	0.01	0.003	9	0.01	0.04	0.005	0.01	0.004
0.01	0.004	11	0.04	0.26	0.01	0.07	0.02	9	0.03	0.05	0.01	0.01	0.005
		7	161286	240000	29000	72284	27321						
		7	622286	2400000	43000	864596	326787						
20.1	7.58	9	104	360	41	100	33.4	7	96.3	160	51	35.4	13.4
13.2	4.4	11	47.4	94	7.3	25.3	7.63	9	47.2	69	24	17.2	5.74
2.17	0.82	9	9.97	35	3.40	9.91	3.30	7	9.59	18	4.6	4.35	1.65
0	0	9	0.05	0.15	0.02	0.04	0.01	7	0.05	0.08	0.05	0.01	0.005
0.002	0.001	11	0.01	0.01	0.003	0.001	0.0004	9	0.01	0.02	0.01	0.004	0.001
0.44	0.15	11	0.72	1.7	0.28	0.39	0.12	9	0.74	2.10	0.32	0.53	0.18
1.27	0.42	11	1.65	4.2	0.35	1.31	0.40	9	1.94	4.20	1.30	1.28	0.43
2.2	0.73	11	0.66	1.7	0.15	0.62	0.19	9	0.50	1.40	0.15	0.52	0.17
36	12	11	94	240	26	66.7	20.1	9	132.22	290	60	75.59	25.20
0.02	0.01	11	0.12	0.3	0.06	0.07	0.02	9	0.11	0.15	0.07	0.03	0.01

on of concentration in each constituent for each sampling location (cont'd)

		IssNS11						IssNS12					
STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN	NO. of SAMPLE	ARITH MEAN	MAX	MIN	STDEV	STDEV of MEAN
0.36	0.26	2	0.62	0.81	0.43	0.27	0.19	2	0.7	1	0.39	0.43	0.31
0.001	0.0005	13	0.01	0.06	0.001	0.02	0.01	3	0.002	0.002	0.001	0.0008	0.0005
3	1.85	13	13	42	6	11	3.05	3	15.13	24	6.40	8.80	5.08
0.88	0.51	13	0.59	1.7	0.15	0.53	0.15	3	1.31	1.7	0.53	0.68	0.39
	0	11	37.3	81	14	20.3	6.12	1	43	43	43		0
0.002	0.001	13	0.01	0.05	0.004	0.01	0.004	3	0.01	0.01	0.002	0.01	0.003
0.002	0.001	13	0.02	0.04	0.01	0.01	0.003	3	0.03	0.05	0.01	0.02	0.01
		1	230000	230000	230000		0						
	0	11	139	330	57	85.1	25.7	1	160	160	160		0
3.36	1.94	13	25.39	60	3.4	17.4	4.82	3	134	350	10	188	108
	0	11	11.54	31	4.4	8.26	2.49	1	20	20	20		0
	0	11	0.04	0.08	0.01	0.02	0.01	1	0.05	0.05	0.05		0
0.002	0.001	13	0.01	0.01	0.003	0.003	0.001	3	0.01	0.01	0.002	0.003	0.002
0.23	0.13	13	0.68	1.2	0.29	0.30	0.08	3	0.6	1	0.2	0.4	0.23
1.67	0.97	13	7.87	43	0.35	15	4.16	3	3.23	4.2	1.3	1.67	0.97
0.72	0.42	13	1.20	5.50	0.15	1.94	0.54	3	0.98	1.4	0.15	0.72	0.42
19.14	11.05	13	54.3	180	8	50.2	13.9	2	66.5	110	23	61.5	43.5
0.003	0.002	13	0.09	0.18	0.06	0.04	0.01	3	0.13	0.18	0.05	0.07	0.04

Appendix I : Hyetographs, hydrographs, and pollutographs

(attached CDs)

Appendix J : Pollutant loads (lb/storm/acre and lb/storm)

(attached CDs)

Appendix K : % Load charts

Figure K - 1 % BOD Load (Lb/storm/acre) for all sampling stations

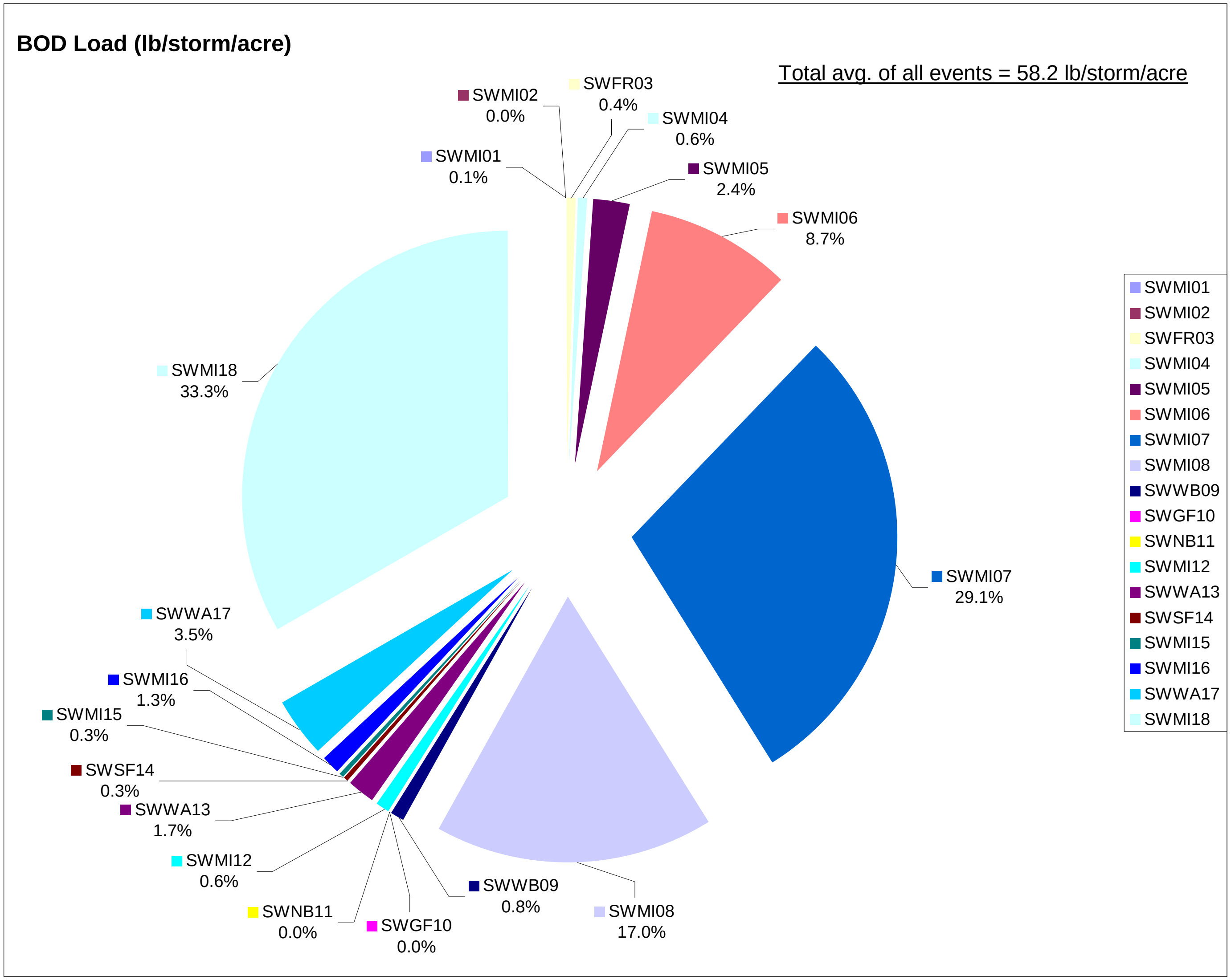


Figure K - 2 % BOD Load (Lb/storm) for all sampling stations

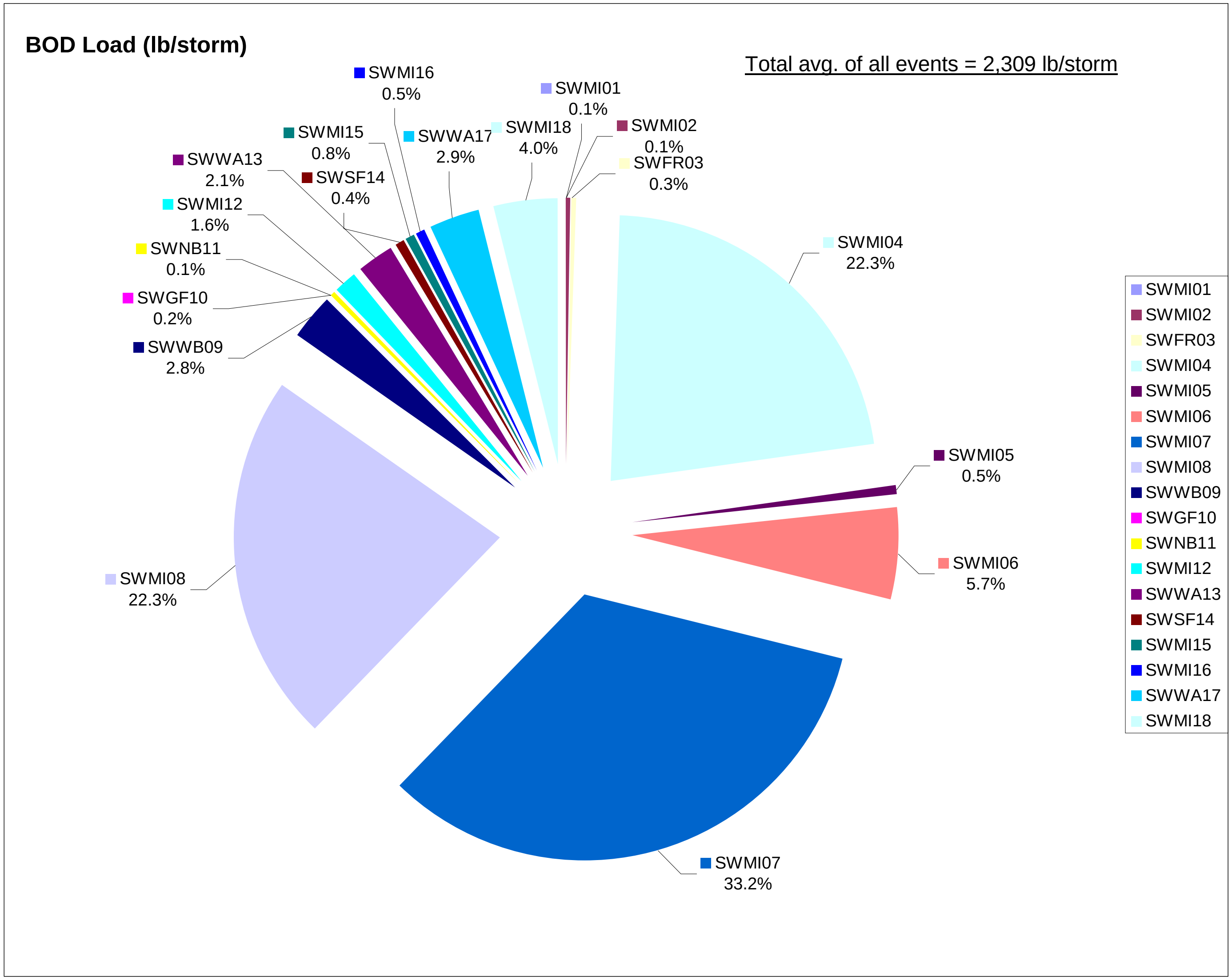


Figure K - 3   % TSS Load (Lb/storm/acre) for all sampling stations

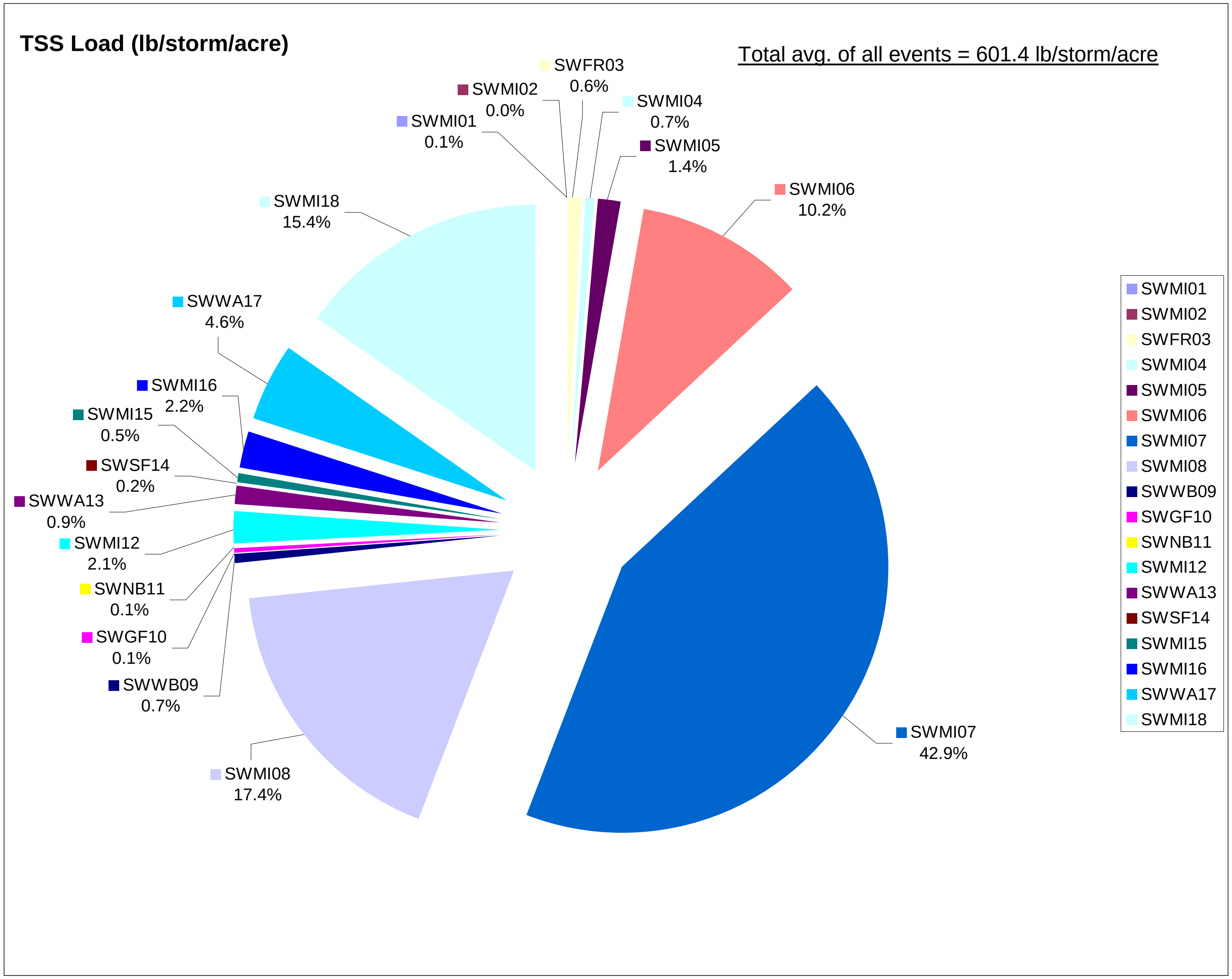


Figure K - 4 % TSS Load (Lb/storm) for all sampling stations

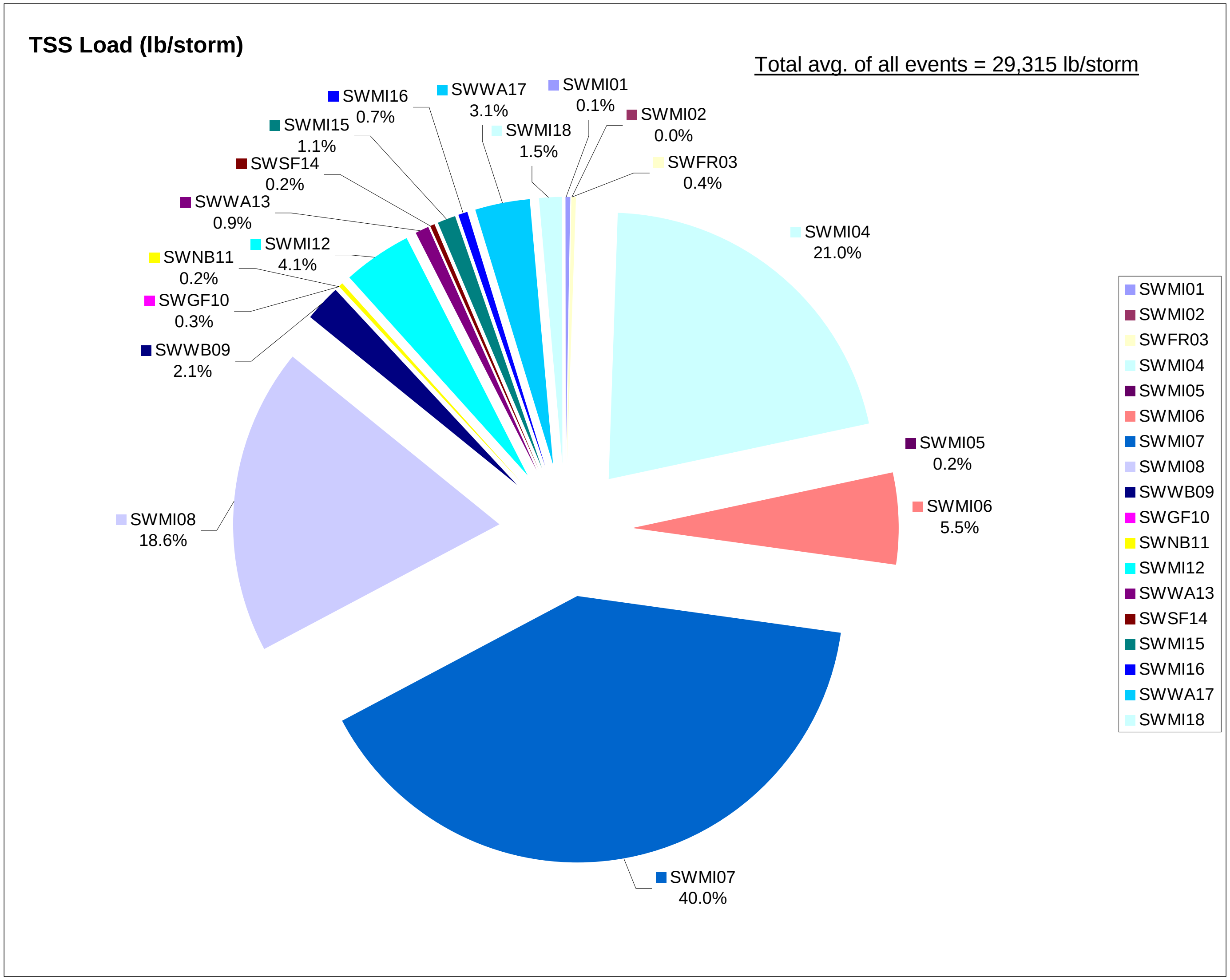


Figure K - 5 % TP Load (Lb/storm/acre) for all sampling stations

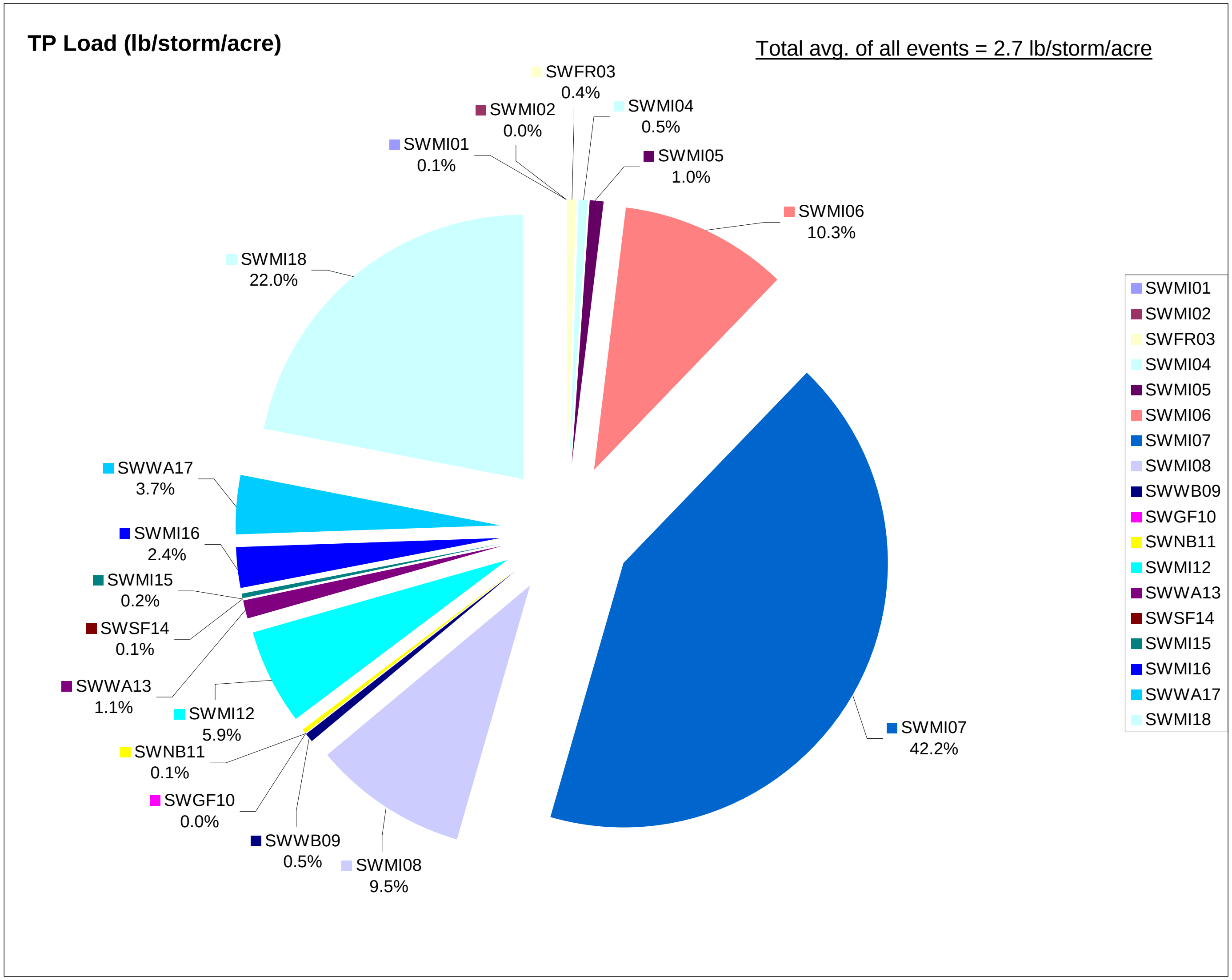


Figure K - 6   % TP Load (Lb/storm) for all sampling stations

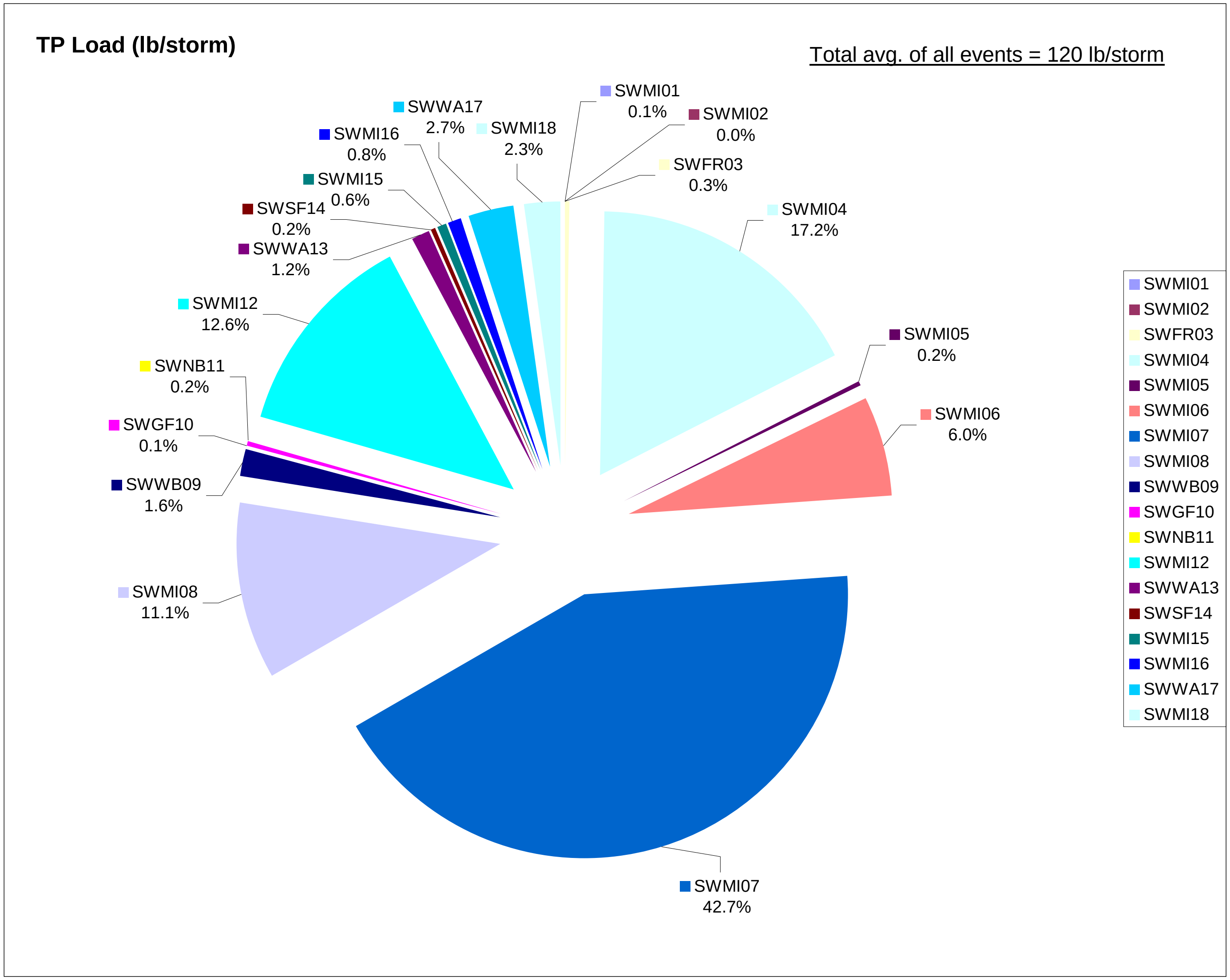


Figure K - 7 % Cl Load (Lb/storm/acre) for all sampling stations

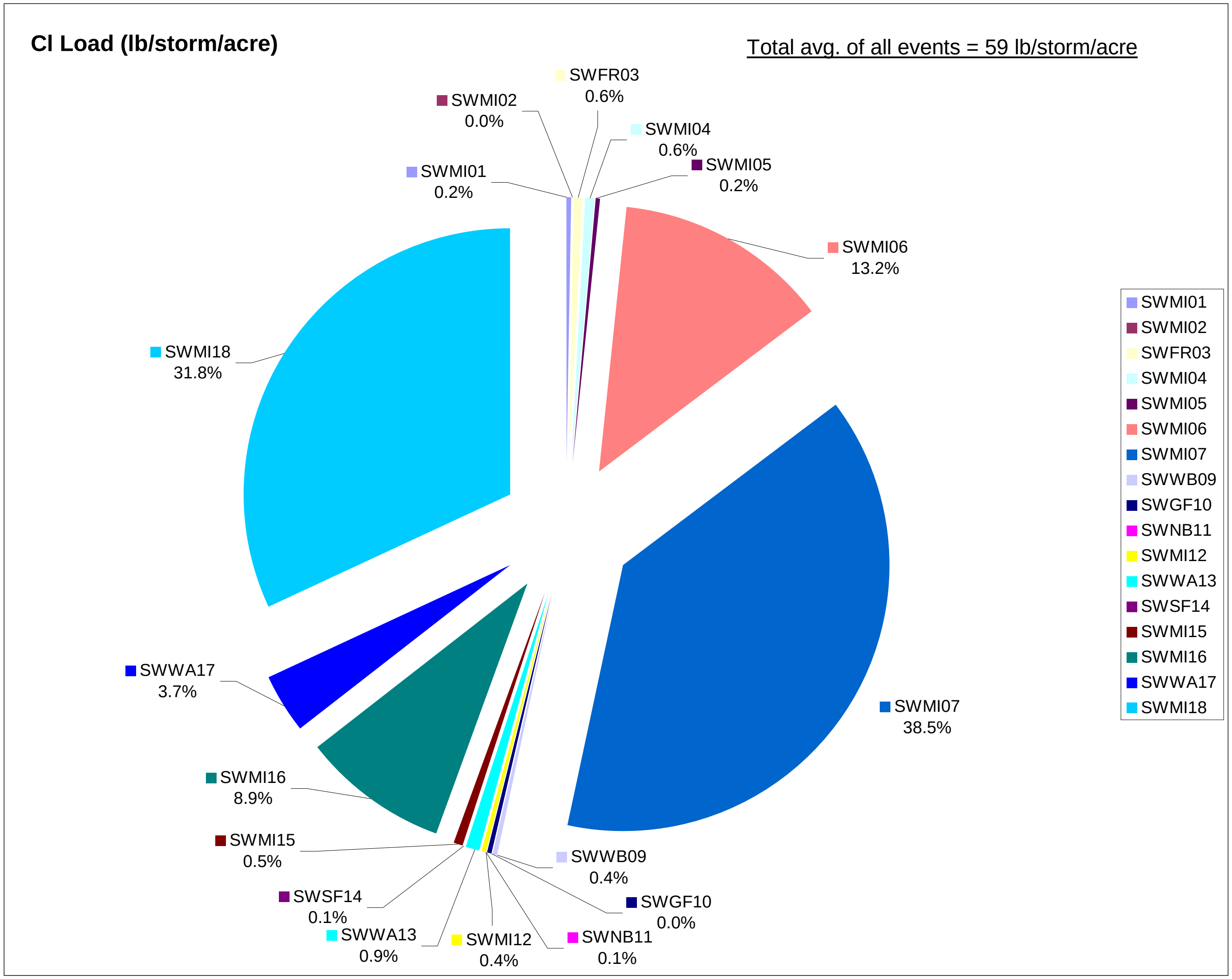


Figure K - 8   % Cl Load (Lb/storm) for all sampling stations

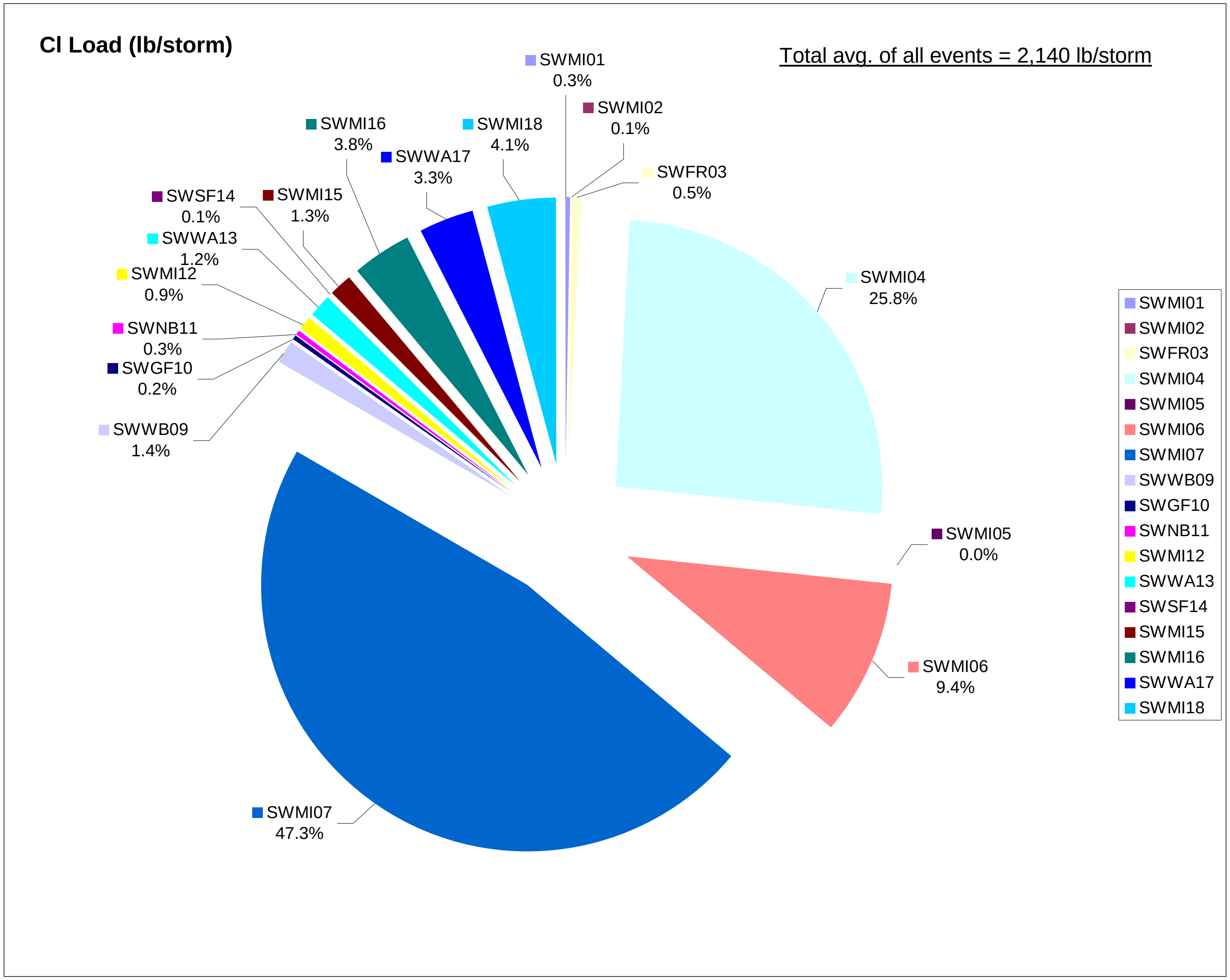


Figure K - 9 % Cu Load (Lb/storm/acre) for all sampling stations

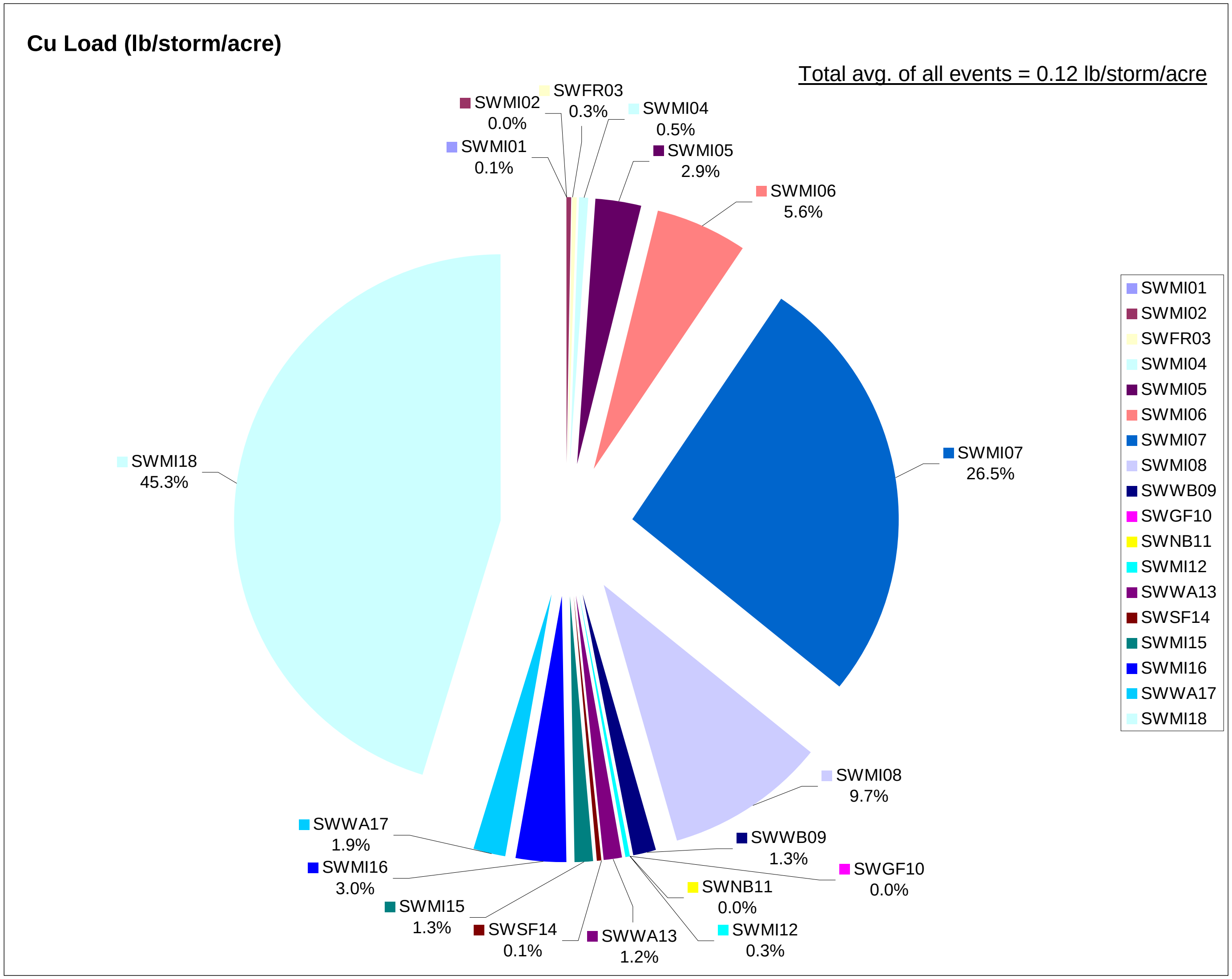


Figure K - 10 % Cu Load (Lb/storm) for all sampling stations

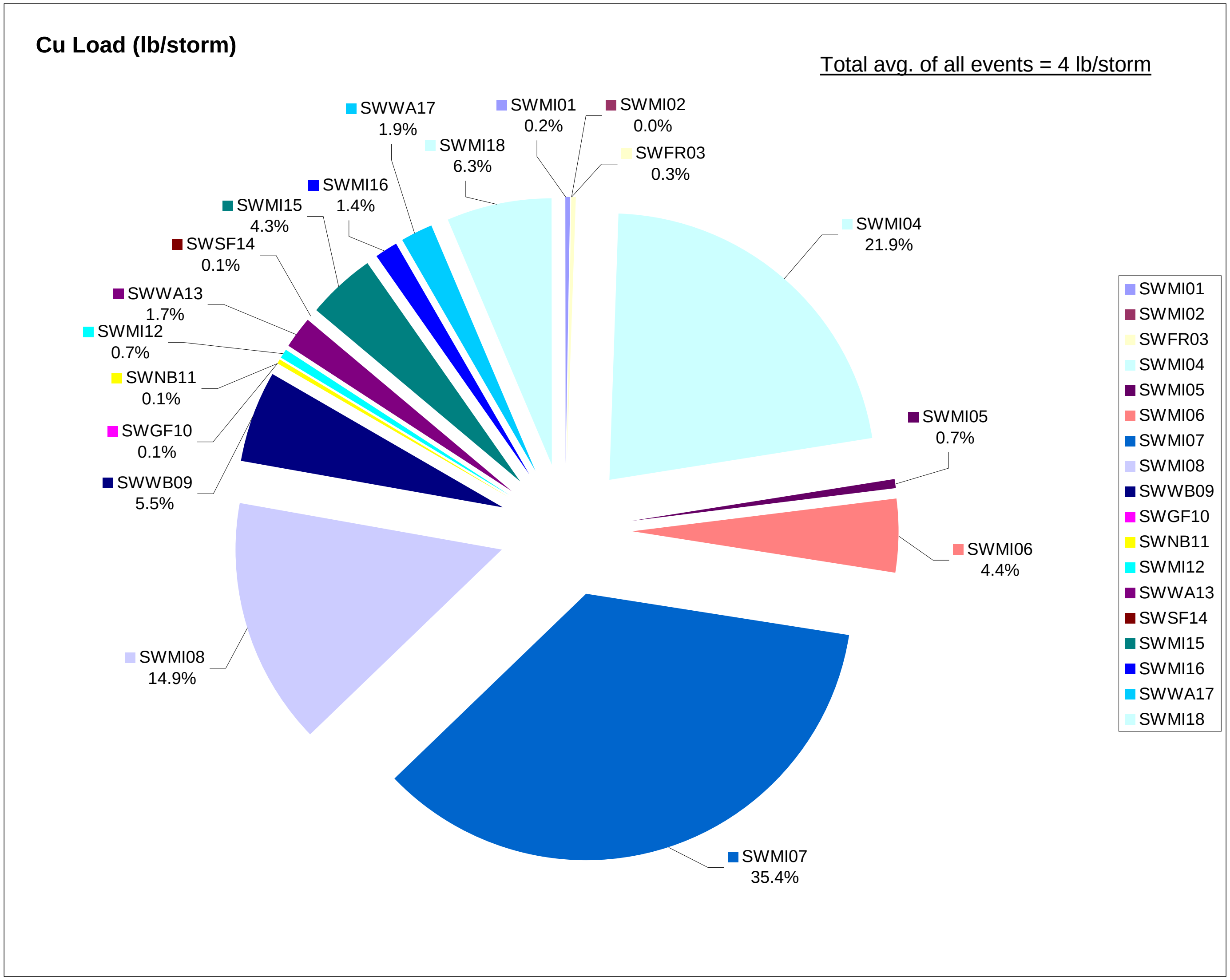


Figure K - 11 % Zn Load (Lb/storm/acre) for all sampling stations

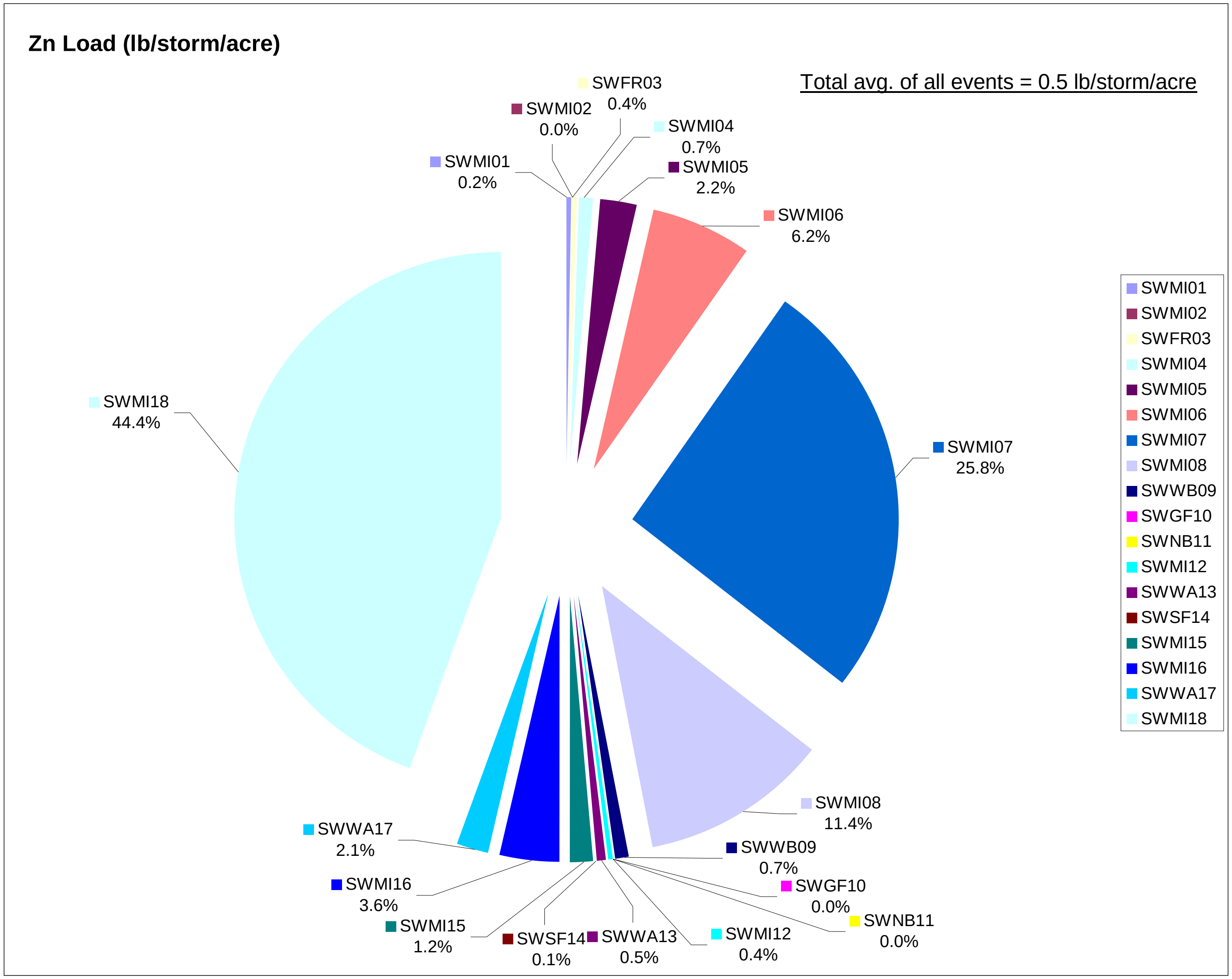


Figure K - 12 % Zn Load (Lb/storm) for all sampling stations

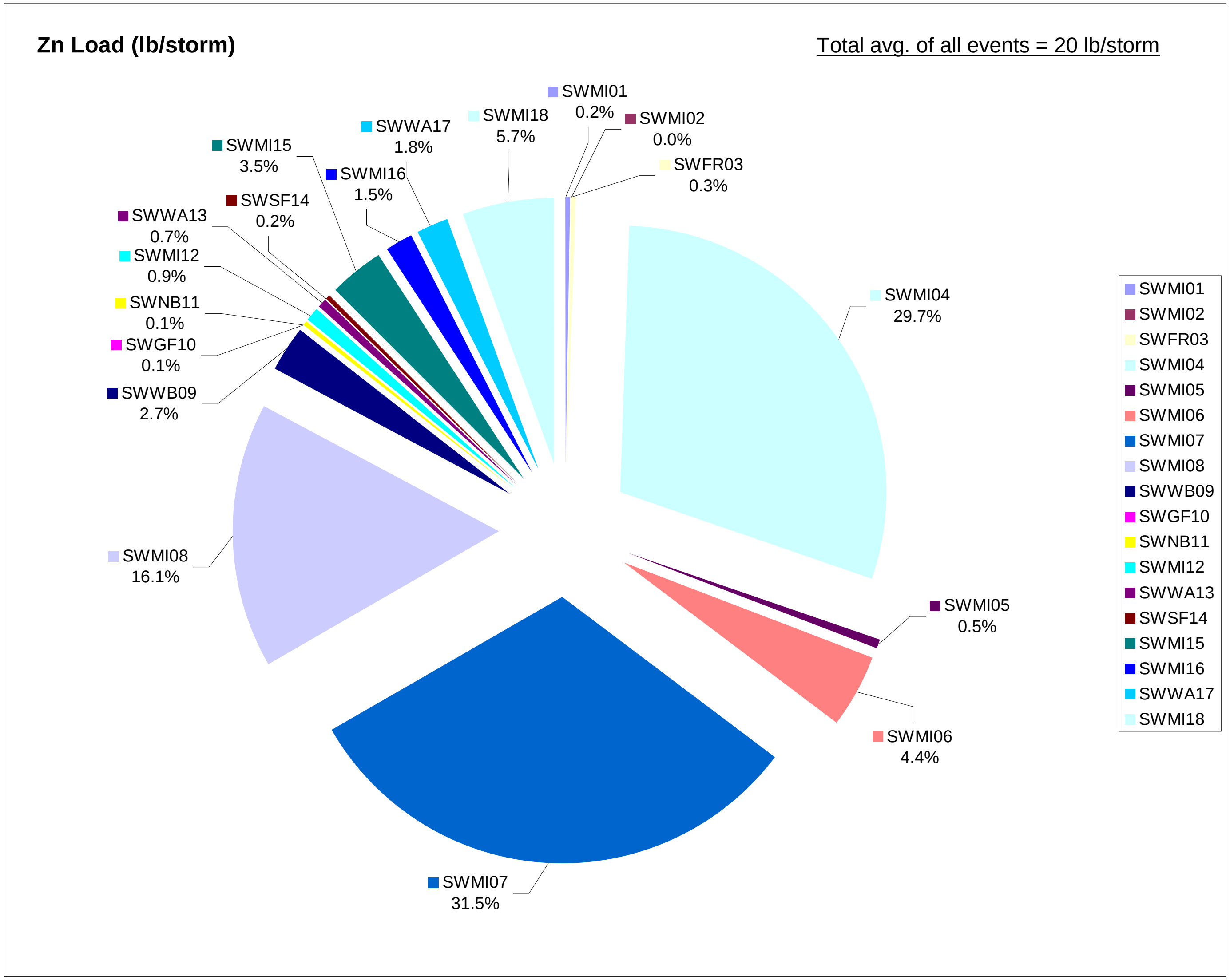


Figure K - 13   % TN Load (Lb/storm/acre) for all sampling stations

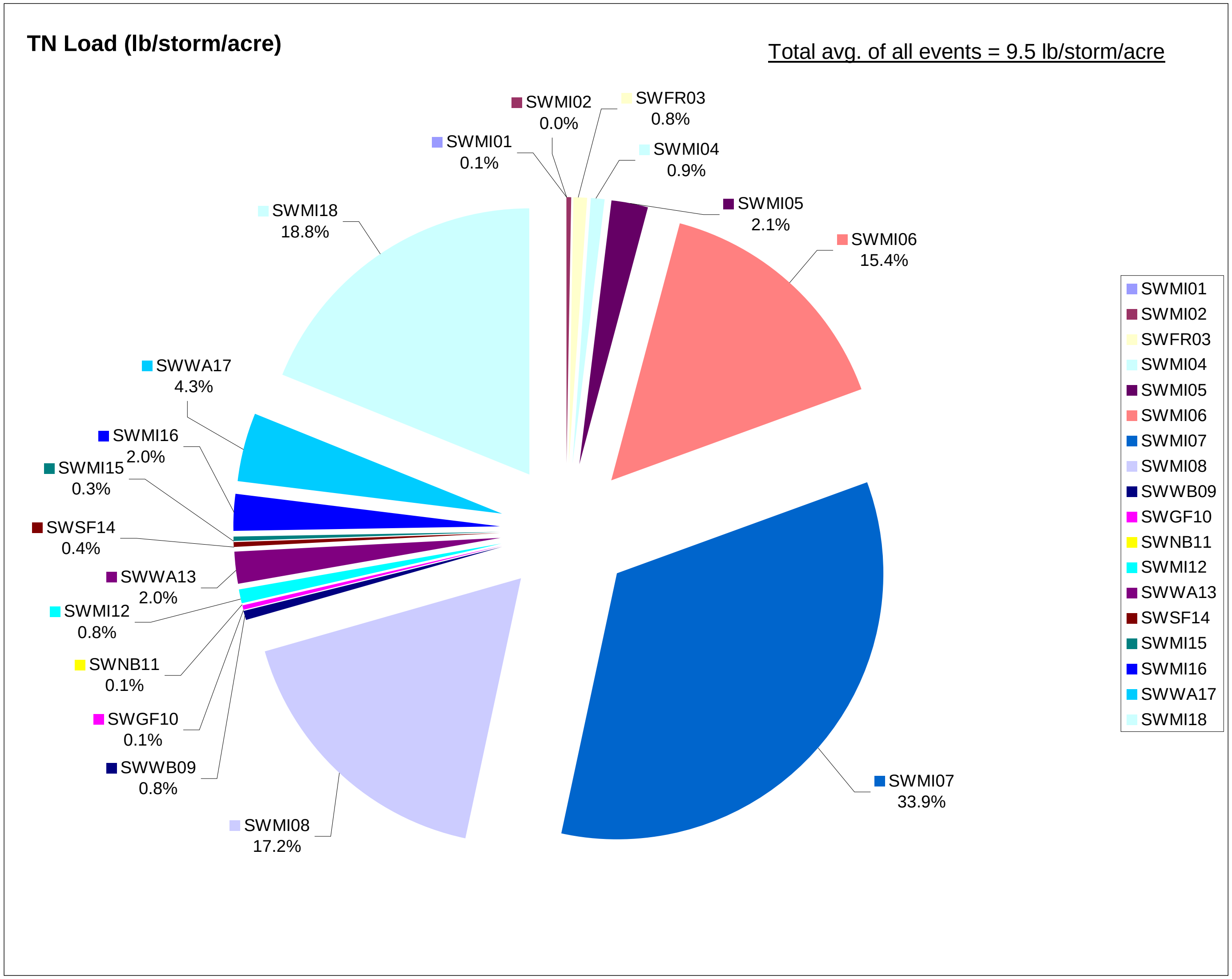


Figure K - 14 % TN Load (Lb/storm) for all sampling stations

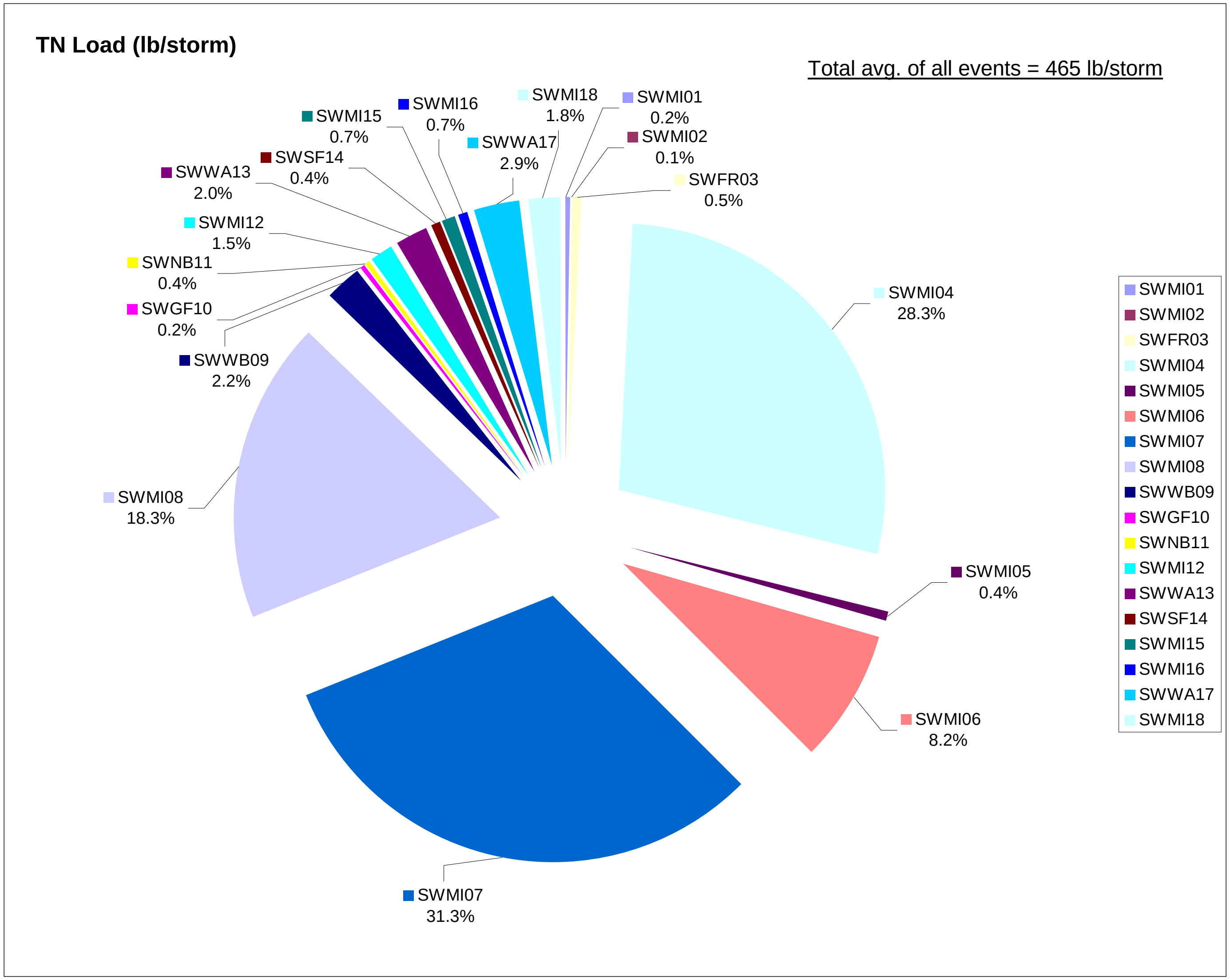


Figure K - 15 % NH3 Load (Lb/storm/acre) for all sampling stations

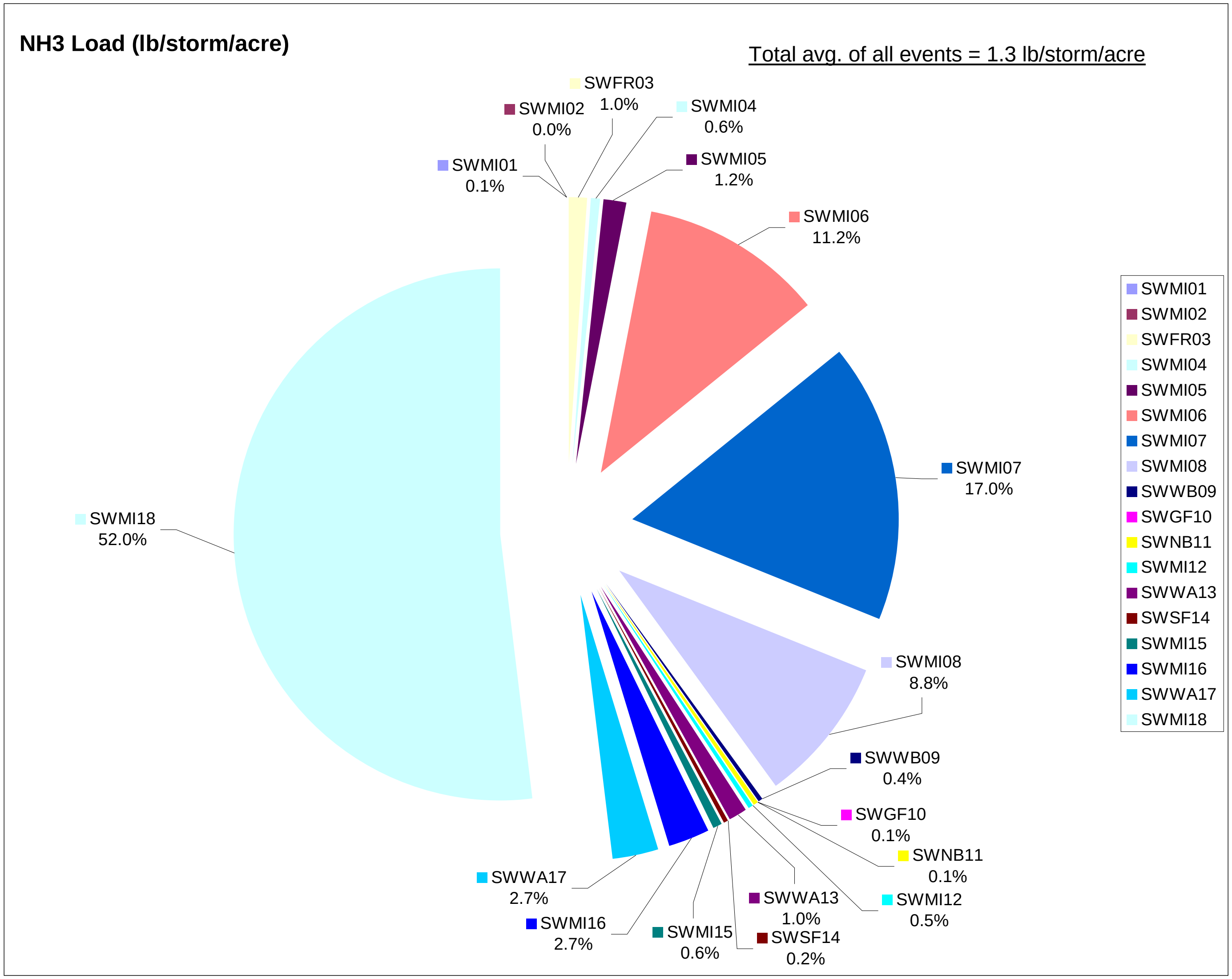


Figure K - 16 % NH3 Load (Lb/storm) for all sampling stations

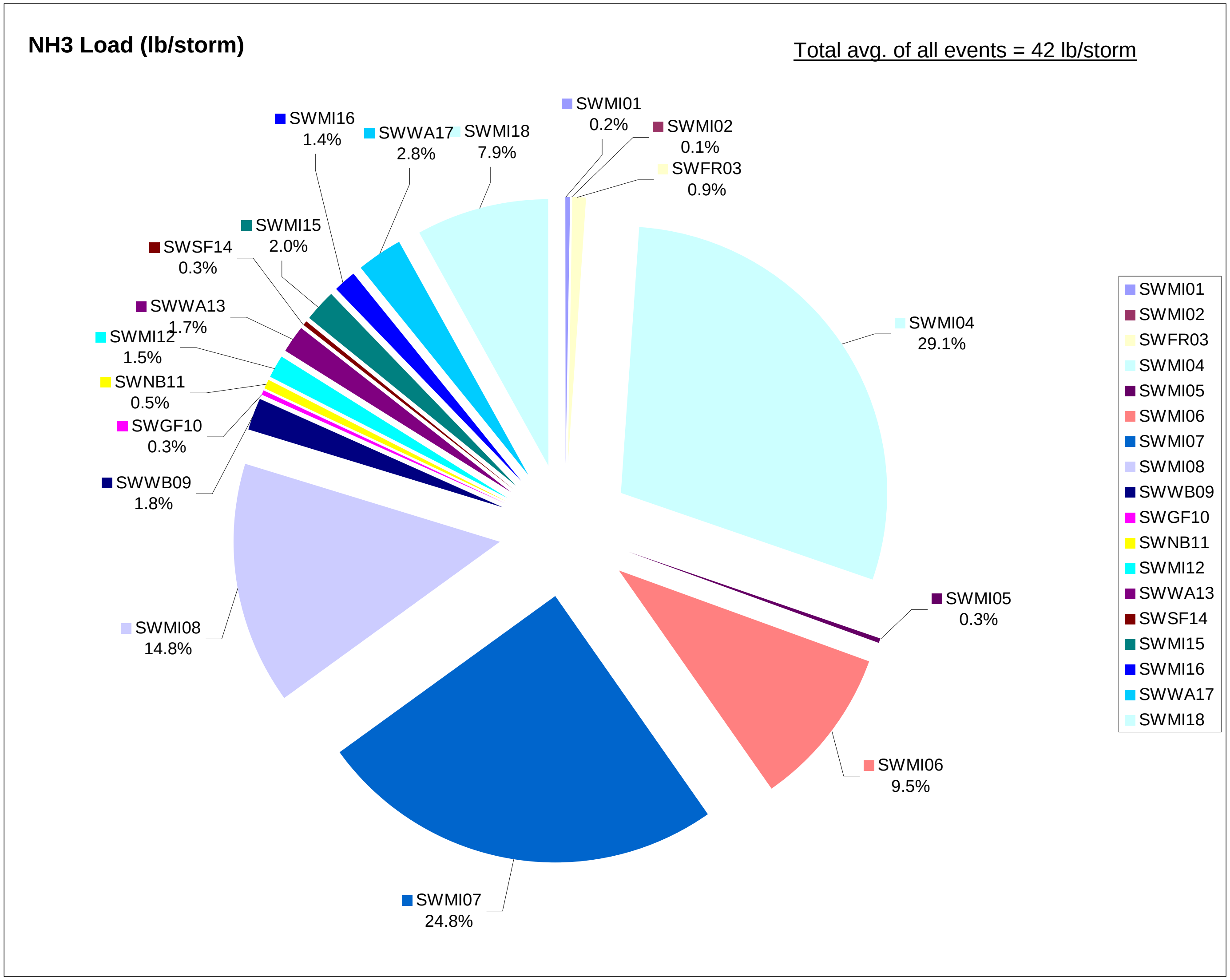


Figure K - 17 % TSP Load (Lb/storm/acre) for all sampling stations

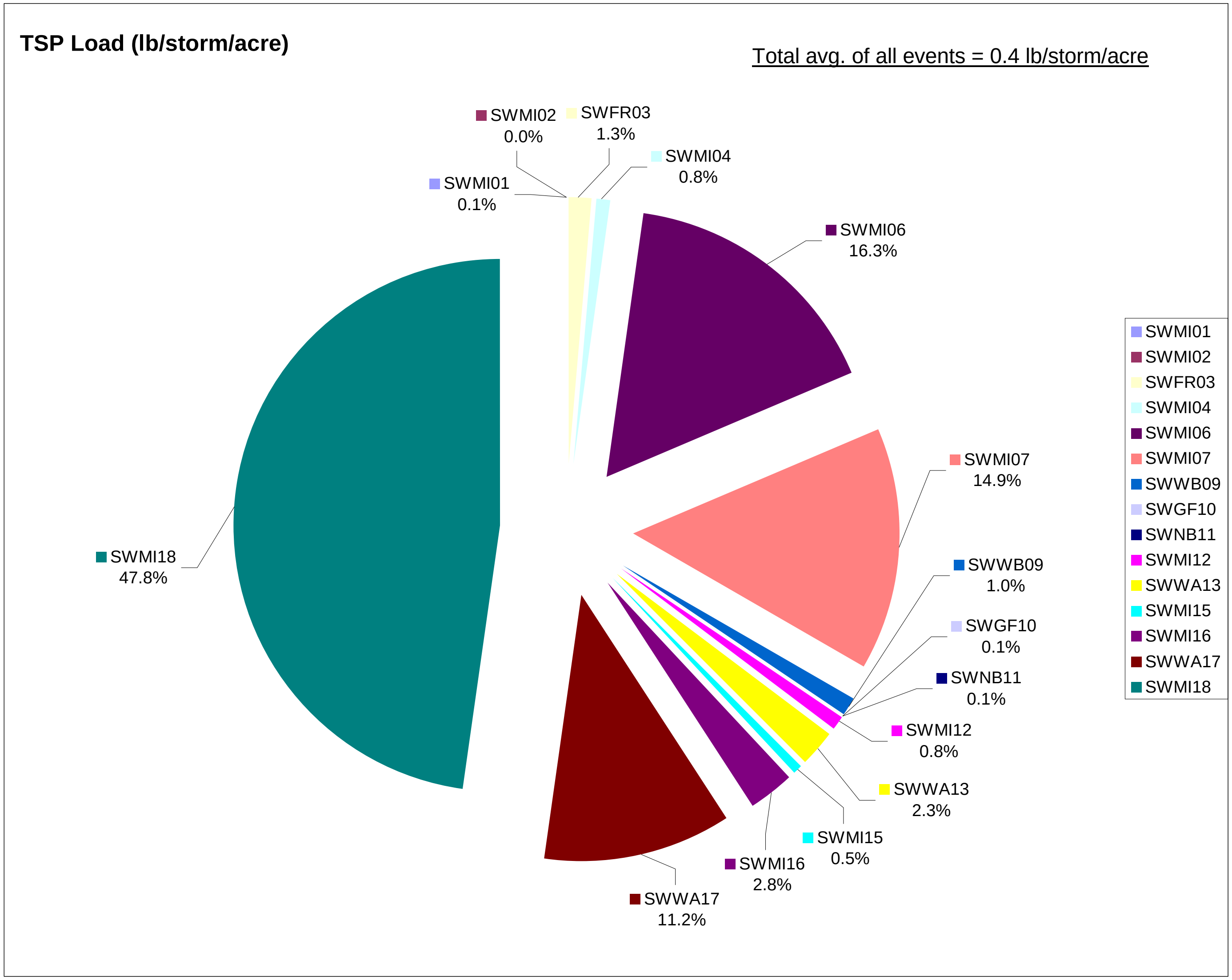
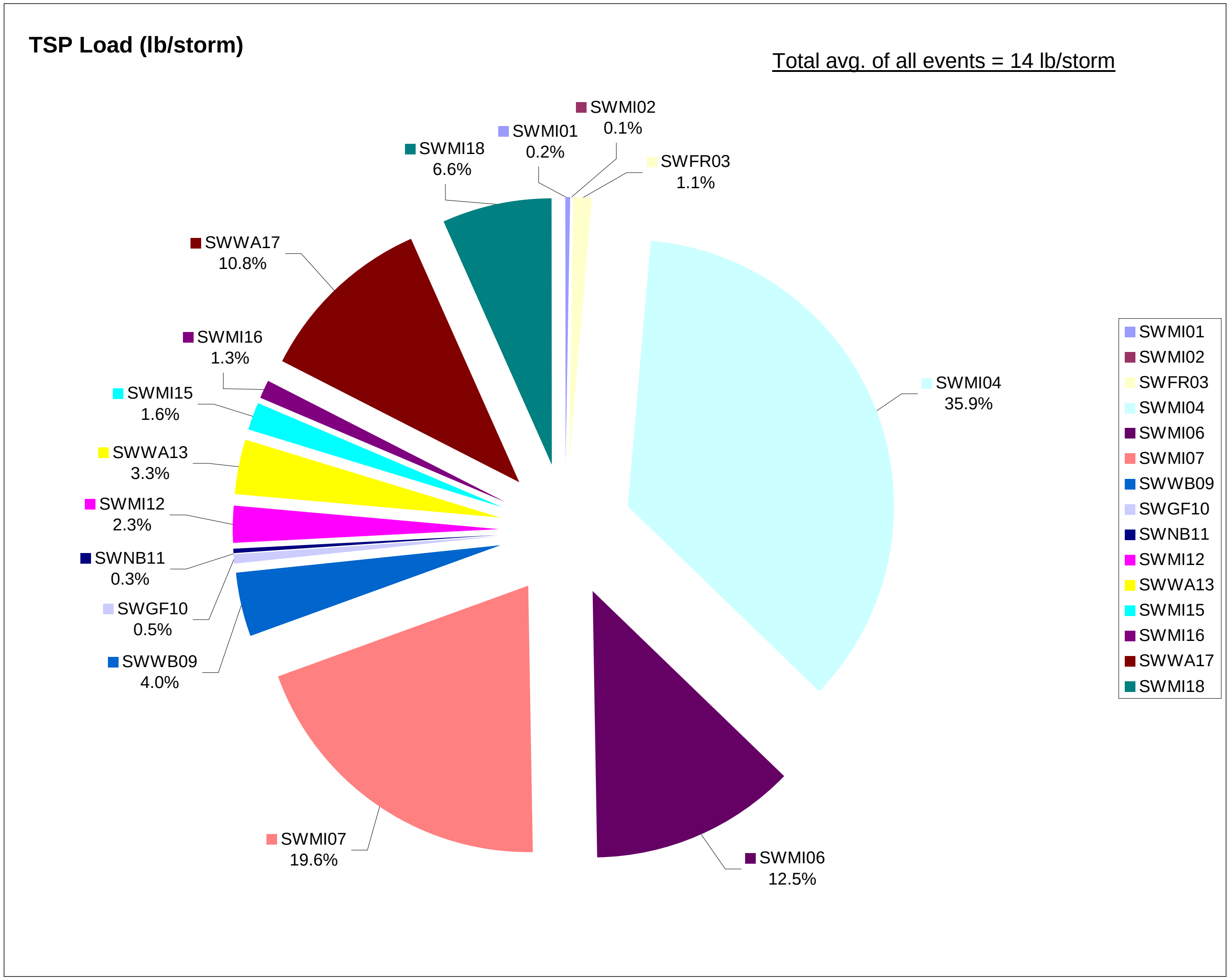


Figure K - 18 % TSP Load (Lb/storm) for all sampling stations



Appendix L : Antecedent dry period VS first-flush concentration charts and antecedent dry period VS load (lb/storm) charts

(attached CDs)