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June 2, 2017

Ms. Brigitte Ann Berger, P.E.
Director of Engineering and Public Works
Village of Wilmette
711 Laramie Avenue
Wilmette, Illinois 60091

SUBJECT: NORTH SHORE INTERCEPTOR SYSTEM (NSIS) FLOW DATA ANALYSIS FINAL REPORT

Dear Ms. Berger,

RJN Group, Inc. (RJN) is pleased to submit this summary of the 2016 flow monitoring program in the Metropolitan Water Reclamation District of Greater Chicago's (MWRD) North Shore Interceptor System (NSIS) to the Village of Wilmette (Village). The flow monitoring was being conducted as part of a joint project between MWRD, the Village of Wilmette, the Village of Winnetka, the Village of Northfield, and the Village of Glencoe, and the findings of this study are intended to aid in the analysis of alternatives for alleviating capacity constraints within the NSIS that affect these communities.

PROJECT BACKGROUND

In 2013, the Village of Wilmette (Village) conducted a 6-month flow monitoring program on its separated sanitary sewer system. As part of this program, the Princeton Region—the portion of the Village's separated system that is tributary to the NSIS—was monitored near the Region's connection to the MWRD system, which is located at the upstream end of the North Shore No. 4 interceptor near the intersection of Princeton Place and Kenilworth Drive. The outflow from the Princeton Region to the NSIS is restricted by a control structure at this location, and flows in excess of the restricted limit are stored upstream in the Wilmette system.

The data collected during the flow monitoring program was used to calibrate a hydraulic model of the Princeton Region. Although restricted outflow from the Region was expected due to the presence of the control structure, the model indicated that outflow was restricted more than could be attributed to the control structure alone. The model predicted that the system, as designed, would provide a 50-year level of protection against basement backups in the Princeton Region. However, when the downstream control observed in the flow monitoring data was replicated in the model, the system only provided a 3-year level of protection. A conclusion of the study, therefore, was that additional downstream control from the NSIS was restricting outflow from the Wilmette system more than was intended by the control structure design.

Based on these findings, RJN recommended that a regional flow monitoring program of the North Shore Interceptor System be conducted to determine the cause and location of this additional downstream control. RJN and the Village brought this information to MWRD for discussion, which led to an understanding that the Villages of Winnetka, Northfield, and Glencoe have also experienced sanitary sewer issues due to downstream control. As a result, the four communities and MWRD agreed to collaborate on a regional flow monitoring study aimed at understanding the causes and locations of bottlenecks in the NSIS and potential solutions to alleviate these capacity constraints.

Project Approach

The flow monitoring was completed by ADS Environmental Services, LLC (ADS) as part of their flow monitoring program for MWRD. Flow meters were installed in 16 locations throughout the NSIS study area, and these are summarized in Table 1. Rainfall was monitored using two rain gauges, one at the Village of Glencoe Public Works building and the other at Kenilworth Village Hall. A map of the flow monitoring and rain gauge locations is attached as Exhibit 1 of Appendix A. On the exhibit, some of the interceptor reaches are designated as secondary outlets because invert elevations on the MWRD atlas indicate that these lines are elevated and therefore do not serve as the primary outlet for tributary dry-day flows.

Table 1
Flow Monitoring Sites

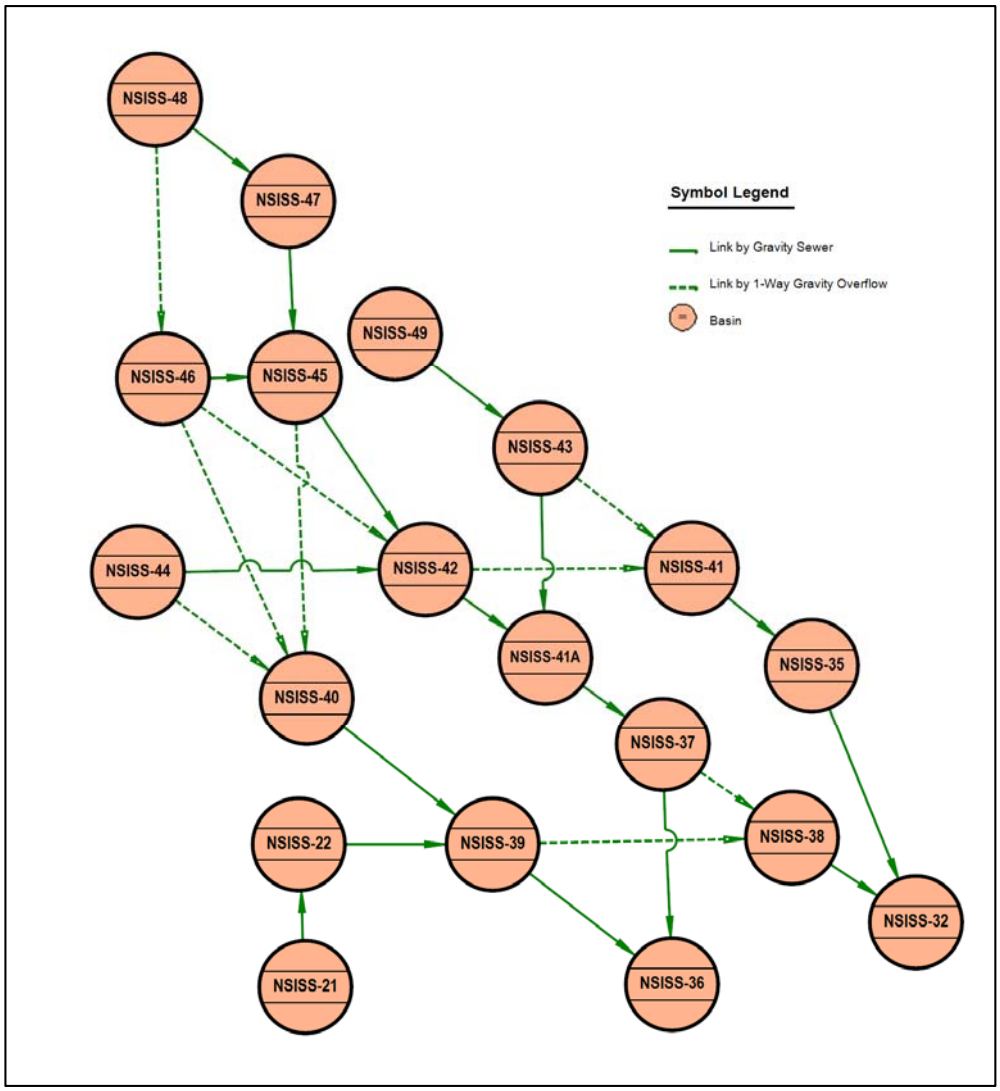
Meter Site	Manhole	Pipe	Width (Inches)	Height (Inches)	Pipe Shape	Pipe Material	Location Description
NSISS-21	6-21	S-In	32	50	Elliptical	Concrete	Indian Hill Golf Course
NSISS-22	6-22	N-Out	32	50	Elliptical	Concrete	Indian Hill Rd.
NSISS-32	6-32	NW-In	72	108	Egg	Concrete	Melrose and Sheridan
NSISS-35	6-35	NW-In	72	96	Egg	Concrete	400 Sheridan Rd.
NSISS-36	6-36	NW-In	78	84	Arch	Concrete	80 Green Bay Rd.
NSISS-37	6-37	NW-In	76.5	85	Arch	Concrete	Green Bay and Sunset
NSISS-38	6-38	W-In	36	54	Elliptical	Lined	Winnetka and Fuller
NSISS-39	6-39	W-In	36	56	Elliptical	Lined	Indian Hill Rd.
NSISS-40	6-40	NW-In	34	40.5	Egg	Lined	139 Birch St.
NSISS-41A	6-41A	SE-Out	79	85	Arch	Concrete	Green Bay and Ash
NSISS-42	6-42	W-In	60	75	Arch	Concrete	Cherry and Rosewood
NSISS-43	6-43	NW-In	54	60	Arch	Concrete	Green Bay and Elm
NSISS-44	6-44	S-In	24	24	Circular	Concrete	Willow and Forest Way
NSISS-45	6-45	N-In	50	55	Arch	Lined	Hibbard and Elm
NSISS-46	6-46	NW-In	31	38	Egg	Lined	Hibbard and Pine
NSISS-47	6-47	W-In	54	60	Arch	Concrete	Tower and Vernon
NSISS-48	6-48	N-In	28	32	Egg	Lined	Prairie and Sycamore
NSISS-49	6-49	N-In	54	60	Arch	Lined	Green Bay and Linden

The flow meters were installed in April 2016, and the flow-monitoring period spanned 107 days in total, ending on July 29. ADS performed all maintenance and calibrations as part of their flow monitoring services with MWRD, and RJN performed quality control and analysis of the data under contract with the Village of Wilmette. The purpose of the flow monitoring was to obtain a detailed

understanding of the flow in the separate sanitary sewer portion of the North Shore Interceptor System, specifically focusing on the impact of excess wet weather flow and the ability of the NSIS to convey this flow. In addition, the NSIS connects to a combined sewer system and also contains a number of multiple-outlet structures. Therefore, a secondary objective of the analysis was to determine how the various branches of the NSIS interact with one another and with the combined sewer area downstream, which has been suspected of imposing downstream control on the separated NSIS interceptors.

The interrelations between the meter basins and interceptors are represented schematically in Figure 1. In the schematic, solid arrows indicate the primary flow path between meter basins, as inferred from the interceptor flow directions and invert elevations. Dotted arrows represent secondary basin interconnections by means of relief lines.

FIGURE 1
BASIN FLOW NETWORK



Data Management

Data was logged every 5 minutes and uploaded to the data server hosted by ADS. A specialized sector of RJN, the Data Group, received the data and the calibrations after the metering period had ended. The Data Group compared calibrations, rain data, and meters in order to finalize the data prior to analysis.

The finalization performed by the Data Group utilized calibrations collected by ADS to validate the flow and rainfall data collected by the monitoring equipment. The "raw" data was edited to eliminate temporary meter malfunctions, or "pops" and "drops" that can distort data analysis, and to adjust the instrument readings as necessary to align with manual calibrations.

Following the QC and finalization processes, the finalized data was campared to the meter basin configurations to ensure proper balancing of flows prior to analysis. The flow data was analyzed in conjunction with rainfall data to establish an Average Dry-Weather Flow (ADWF) baseline and to quantify the response to wet-weather events. Accuracy of the metered level and velocity readings was verified throughout the metering period through onsite calibrations that occurred on a monthly basis.

Data Calibration

In order to verify that the flow monitors and rain gauges were collecting accurate data, ADS collected multiple manual field measurements throughout the monitoring period. Calibration measurements were conducted at least twice at every site. Table 2 summarizes the calibrations done at each site.

Table 2
Calibration Dates

Meter	Calibration 1	Calibration 2	Calibration 3	Calibration 4	Calibration 5
NSISS-21	03/07/16	04/10/16	05/09/16		
NSISS-22	03/03/16	03/09/16	04/10/16	05/09/16	
NSISS-32	03/06/16	04/09/16	05/08/16	06/14/16	
NSISS-35	04/12/16	04/14/16	05/08/16	07/07/16	
NSISS-36	04/13/16	04/14/16			
NSISS-37	03/04/16	04/09/16	04/13/16	05/09/16	
NSISS-38	04/11/16	04/13/16	04/14/16	05/09/16	07/07/16
NSISS-39	04/11/16	04/14/16	05/09/16		
NSISS-40	04/11/16	04/14/16	05/09/16	06/14/16	
NSISS-41A	05/12/16	05/13/16	07/07/16		
NSISS-42	04/12/16	04/14/16			
NSISS-43	04/13/16	04/14/16			
NSISS-44	03/05/16	03/09/16	04/09/16	05/08/16	
NSISS-45	03/04/16	04/09/16	04/13/16	05/08/16	
NSISS-46	03/02/16	04/09/16	05/08/16	07/07/16	
NSISS-47	03/02/16	04/09/16	04/13/16	05/09/16	
NSISS-48	03/05/16	03/09/16	04/09/16	05/08/16	
NSISS-49	03/08/16	04/09/16	04/13/16	05/09/16	

The field confirmations are used to adjust and edit data based on the manual measurements at the time of the calibration. These adjustments are made by the RJN Data Group after the flow monitoring period is completed. All the calibrations are taken into account and adjustments are made when the meter measurements are not in agreement with the manual measurements. Data calibrations and corresponding data editing are essential to obtaining accuracy throughout the metering period.

Dry-Weather Analysis

Flow data collected during dry-weather/low-groundwater periods was analyzed to determine the average daily dry-weather flow (ADWF) for each meter basin. The dry-weather periods used for the ADWF analysis are summarized in Table 3.

Table 3
Dry-Weather Periods

Meter	Dry-Weather Period 1		Dry-Weather Period 2		Dry-Weather Period 3		Dry-Weather Period 4		Total Days
	Start	End	Start	End	Start	End	Start	End	
NSISS-21	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-22	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-32	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-35	04/15/16	04/19/16	05/21/16	05/25/16	07/05/16	07/06/16	07/11/16	07/16/16	14
NSISS-36	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-37	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-38	04/16/16	04/19/16	06/12/16	06/15/16	06/17/16	06/22/16			11
NSISS-39	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-40	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-41A	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-42	07/01/16	07/06/16	07/11/16	07/17/16					11
NSISS-43	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-44	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-45	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-46	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-47	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-48	06/27/16	07/06/16	07/11/16	07/17/16					15
NSISS-49	06/27/16	07/06/16	07/11/16	07/17/16					15

Diurnal Variations and Peaking Factors

Diurnal curves, or plots of typical flow variation throughout a day, were created by averaging data points hourly, separating out weekday and weekend diurnal flow patterns. A typical diurnal curve is shown in Figure 2 while diurnal curves for all meters are in Appendix B.

Wastewater flows during dry-weather periods will vary during the day in response to water consumption, typically cresting in the morning and evening hours and dropping during the overnight and mid-afternoon hours in residential areas. The ADWF and diurnal variation characteristics are summarized in Table 4.

FIGURE 2
TYPICAL DIURNAL FLOW – NSISS-48

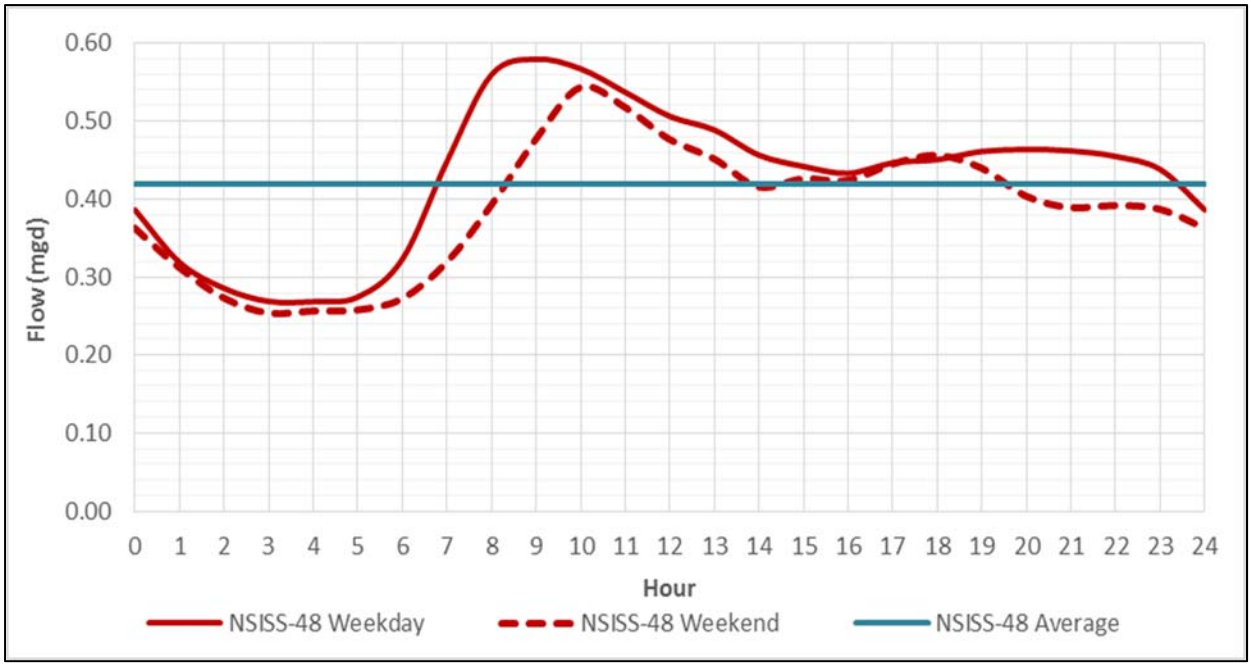


TABLE 4
DRY-WEATHER FLOW CHARACTERISTICS

Meter	Weekday ADWF (mgd)	Peak Hourly Flow (mgd)	Diurnal Peaking Factor (TYP. 1.5-1.8)	Diurnal Trough (mgd)	Percent of Trough to ADWF (TYP. 25%-30%)
NSISS-21	1.425	1.72	1.21	1.05	74%
NSISS-22	1.447	1.817	1.26	0.97	67%
NSISS-32	0.649	0.902	1.39	0.46	70%
NSISS-35	0.480	0.628	1.31	0.34	71%
NSISS-36	5.510	6.700	1.22	3.98	72%
NSISS-37	3.363	4.181	1.24	2.27	67%
NSISS-38	0.211	0.261	1.24	0.16	74%
NSISS-39	1.926	2.368	1.23	1.39	72%
NSISS-40	0.254	0.360	1.42	0.15	59%
NSISS-41A	3.358	3.922	1.17	2.86	85%
NSISS-42	1.422	1.807	1.27	0.92	64%
NSISS-43	0.666	0.839	1.26	0.47	70%
NSISS-44	0.485	0.634	1.31	0.28	58%
NSISS-45	0.655	0.858	1.31	0.41	63%
NSISS-46	0.089	0.116	1.30	0.06	67%
NSISS-47	0.830	1.087	1.31	0.51	62%
NSISS-48	0.486	0.651	1.34	0.31	63%
NSISS-49	0.611	0.774	1.27	0.43	71%

By examining the ADWF diurnal variations in the data, a diurnal peak flow and diurnal trough flow was calculated for each meter basin. The diurnal peak flow is the peak hourly flow rate during a typical dry day, and the diurnal trough is the lowest average hourly flow rate during a typical dry day.

Diurnal variations in ADWF are useful in assessing the prevalence of base infiltration—that is, groundwater that infiltrates the system even during dry periods—within a meter basin. The Diurnal Peaking Factor is the ratio of the peak hourly flow rate to the average daily flow, and low Diurnal Peaking Factors can be indicators of large base infiltration component. Similarly, the Trough-to-ADWF Percentage is a measure of how overnight low flows compare to average flows, and therefore, higher percentages indicate a greater base infiltration component. In a residential meter basin, the Diurnal Peaking Factor is typically in the range of 1.5 to 1.8 with smaller basins tending toward the higher end, and the overnight (diurnal trough) flow is expected to be 15% to 30% of the ADWF (with smaller basins tending toward the lower end) when there is little or no base infiltration.

On these measures, the ADWF of every meter basin appears to have above-average base infiltration components. The Diurnal Peaking Factors are well below the typical range, indicating that the ADWF is elevated by a large base infiltration component. Also, the Trough-to-ADWF percentages are all over 50%, indicating larger than normal flows during overnight hours when water consumption is minimal.

Rain Events

The two rain gauges recorded rainfall every five minutes. Rain events that occurred during the flow metering period are listed in Tables 5A and 5B and are graphically represented in Figure 3. The rain events used in the flow data analysis ranged from a less than a 1-month recurrence interval to as large as an 8-year recurrence interval. The range of data provides a spread of rain event sizes, with most events that occurred being on the small side. However, there is a sufficient spread of data that offers a sufficiently confident prediction of projected storm events.

TABLE 5A
1-HOUR RAIN EVENTS

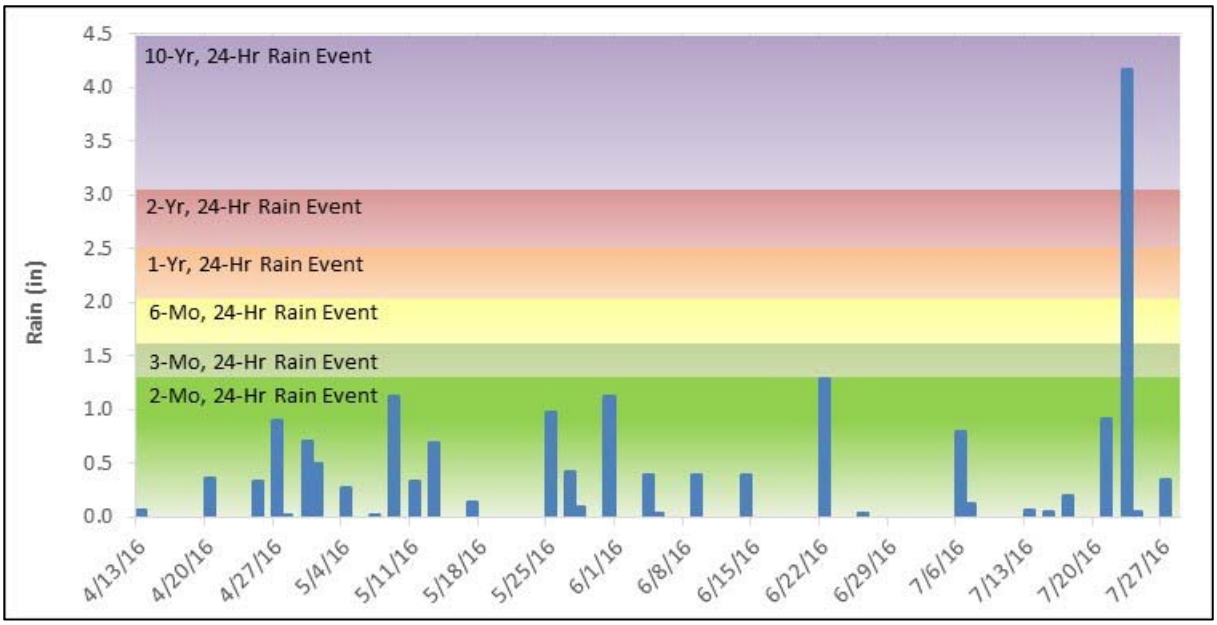
Date	1-Hr Recurrence Interval	1-Hr Rainfall (in)
04/25/16	1-Month	0.34
04/28/16	1-Month	0.35
05/01/16	1-Month	0.32
05/09/16	1-Month	0.26
05/13/16	1-Month	0.24
05/25/16	1-Month	0.38
05/31/16	2-Month	0.54
06/04/16	1-Month	0.30
06/10/16	1-Month	0.17
06/15/16	1-Month	0.20
06/22/16	10-Month	1.14
07/06/16	1-Month	0.35
07/17/16	1-Month	0.20
07/21/16	2-Month	0.68
07/23/16	5-Year	1.81
07/28/16	1-Month	0.19

TABLE 5B
24-HOUR RAIN EVENTS

Date	24-Hr Recurrence Interval	24-Hr Rainfall (in)
04/20/16	1-Month	0.37
04/25/16	1-Month	0.34
04/27/16	1-Month	0.90
04/30/16	1-Month	0.70
05/01/16	1-Month	0.49
05/09/16	2-Month	1.12
05/11/16	1-Month	0.34
05/13/16	1-Month	0.69
05/25/16	1-Month	0.97
05/27/16	1-Month	0.42
05/31/16	2-Month	1.12
06/04/16	1-Month	0.39
06/09/16	1-Month	0.39
06/14/16	1-Month	0.39
06/22/16	2-Month	1.29
07/06/16	1-Month	0.80
07/21/16	1-Month	0.91
07/23/16	8-Year	4.17
07/27/16	1-Month	0.35

Rain events less than a 1-month recurrence were omitted from the summary tables.

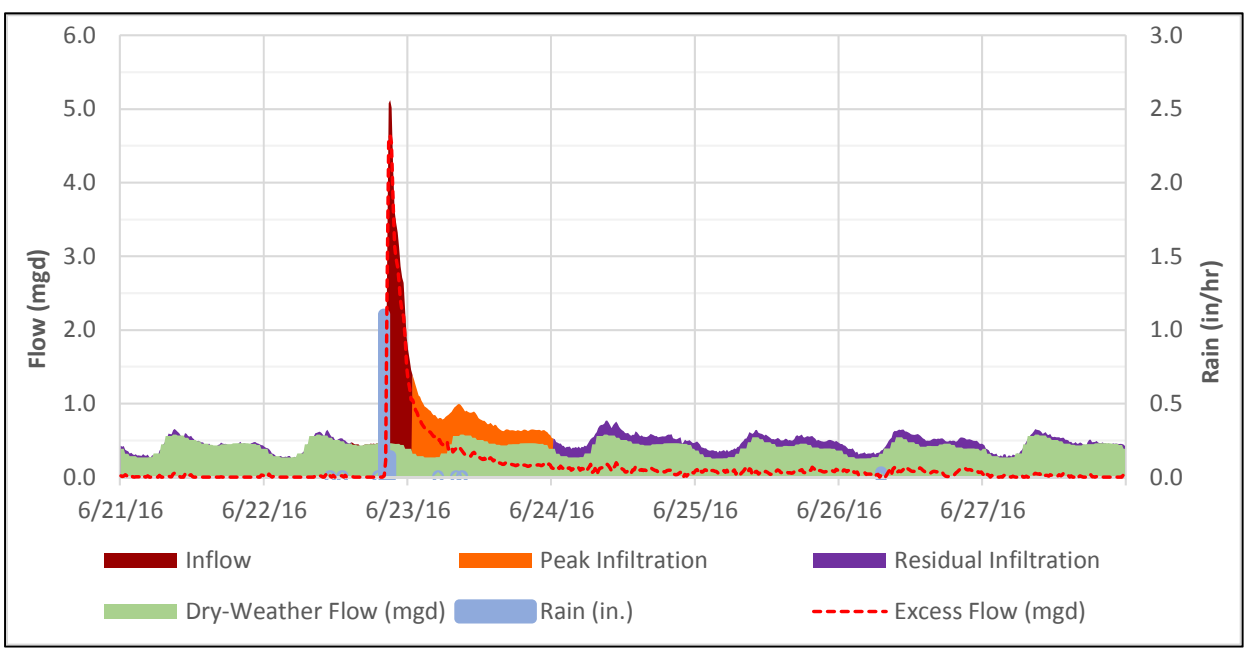
FIGURE 3
24-HR RAINFALL



Stormwater that enters the sanitary sewer system is characterized as rainfall-derived inflow and infiltration (RDII). Inflow is extraneous flow that is a direct result of stormwater runoff. Inflow enters the sanitary system quickly through improper connections, such as directly connected downspouts, area drains, pickhole covers, and cleanouts. Inflow may also enter the system through direct or indirect stormwater connections to the sanitary sewer, as well as through sewer mainline, service laterals, and manhole defects. The large volume and rapid input of inflow to the system can result in system surcharge and in extreme cases, overflows and basement backups. The primary concern of most sewer systems is inflow.

Infiltration is the water entering a sewer system through the ground, from sources such as cracks in mainline sewers and service laterals, pipe joints, and manhole walls. Infiltration occurs during both wet and dry conditions and enters the sewer system more slowly than inflow. Infiltration that occurs during dry-weather periods is called base infiltration and is caused by groundwater entering the sewer system. This flow is included within the dry-weather flow. Rainfall induced infiltration can occur both during and following wet-weather periods, mainly from defective manhole walls, service laterals. Infiltration that occurs within 24 hours of a rain event is commonly referred to as peak infiltration whereas residual infiltration, a primary indicator of how tightly sealed a system is, can linger for days after a storm event. A sample wet-weather hydrograph differentiating the components of RDII is presented in Figure 4. As the figure shows, rain-derived infiltration typically remains in the system for three to five days following significant rain events.

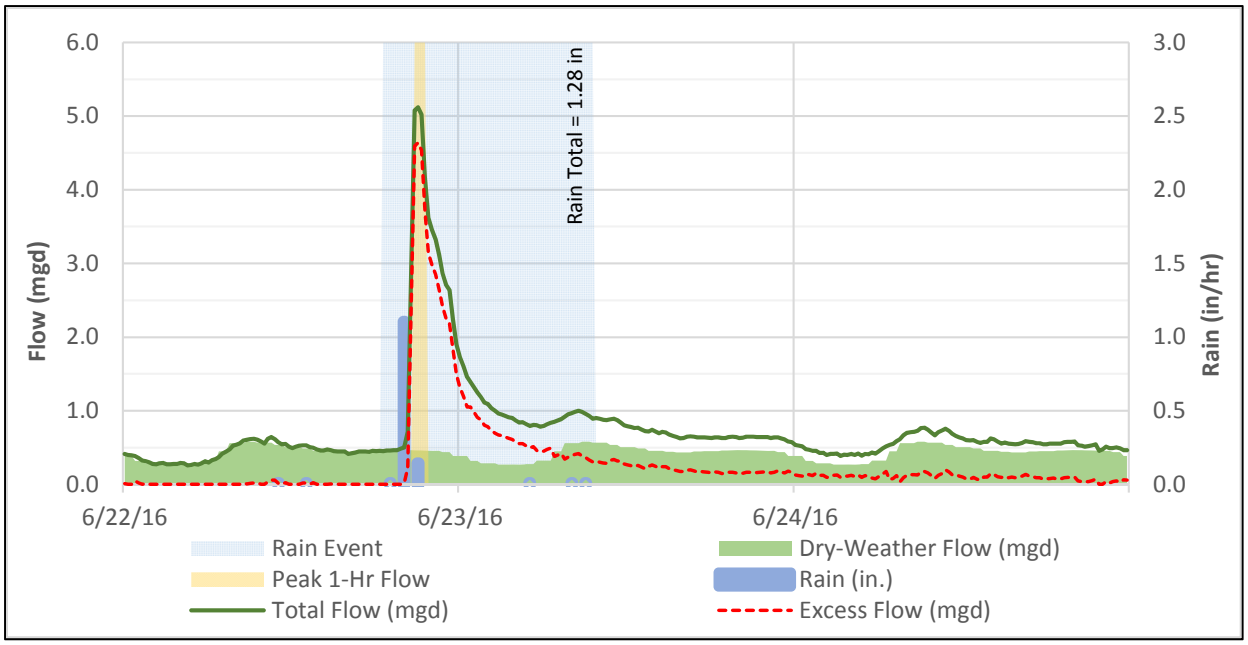
FIGURE 4
NSISS-48 RDII HYDROGRAPH



Wet-Weather Peaking Factors

Rain and flow data were analyzed in conjunction with one another to determine the peak 1-hour excess flow rate resulting from the peak 1-hour rainfall during each of the monitored rain events. In order to isolate the effects of the peak rainfall on peak flows, the dry-weather flow and any lingering infiltration from antecedent rains was subtracted from the total flow in order to calculate a peak excess flow for that rain event. Figure 5 shows an example of the total flow separated into its dry-weather flow, antecedent infiltration, and excess flow components.

FIGURE 5
NSISS-48 PEAK EXCESS FLOW HYDROGRAPH



These peak excess flow (Q) versus peak rainfall intensity (I) data points were plotted and used to calculate a regression line. The regression line was then extrapolated to predict the amount of excess flow that would result from 1-hour events at larger recurrence intervals. An example of the regression analysis is shown in Figure 6 while the results of the regression analysis is presented in Appendix C.

A new sanitary sewer system is typically designed to convey 3 to 4 times the assumed ADWF. Therefore, a peaking factor less than four is generally not considered to be an issue, as the sewer should be able to convey this flow without surcharging or overflows. Older systems such as the areas tributary to the NSIS more often have peaking factors between 4 and 8 in large storm events, and issues are likely to arise in locations where sewers are not sized to accommodate these higher ratios. Most meter sites in the NSIS study area, however, exhibited peaking factors well above this range at even a 1-year storm event and are therefore considered to have very high RDII.

FIGURE 6
REGRESSION ANALYSIS

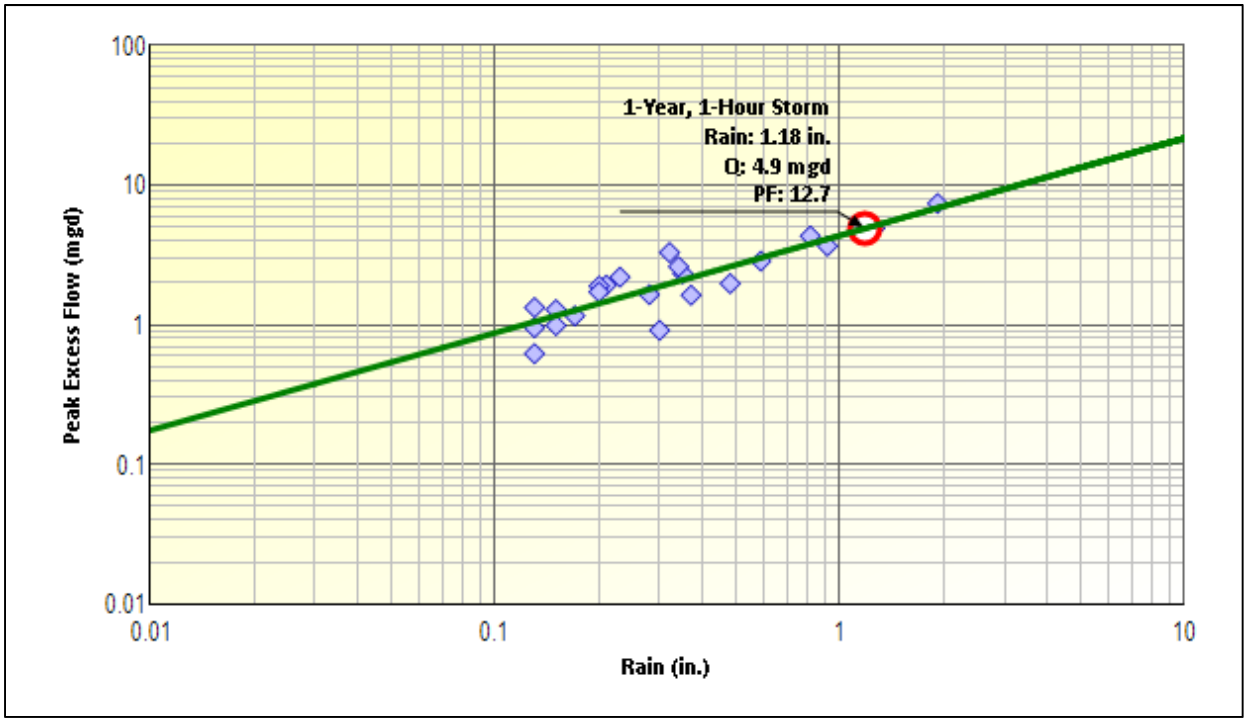


Table 6 summarizes the results of the peak flow analysis. The peaking factors (PF) are the ratio of the total flow (ADWF plus excess flow) to the ADWF. The table also lists the maximum surcharge depth observed at each meter site, as well as the extent of downstream control. Downstream control, discussed further in the following section, is important to note because it can dampen flow peaks. This should be taken into account when considering peaking factors and potential improvements such as capacity increases or flow reduction.

TABLE 6
BASIN CONDITION SUMMARY

Meter	DWF (mgd)	1-Yr, 1-Hr Pred. Excess Flow (mgd)	5-Yr, 1-Hr Pred. Excess Flow (mgd)	10-Yr, 1-Hr Pred. Excess Flow (mgd)	3-Yr, 2-Hr Pred. Excess Flow (mgd)	1-Yr, 1-Hr PF	5-Yr, 1-Hr PF	10-Yr, 1-Hr PF	3-Yr, 2-Hr PF	Surcharging (ft)	Downstream Control
NSISS-21	1.419	4.76	7.29	8.59	5.44	4.4	6.1	7.1	4.8	11.7	MILD
NSISS-22	1.430	5.89	8.95	10.50	7.51	5.1	7.3	8.3	6.3	10.6	MILD
NSISS-32	0.630	12.95	18.12	20.62	10.31	21.5	29.7	33.7	17.4	6.4	SEVERE
NSISS-35	0.490	5.59	10.09	12.65	5.56	12.4	21.6	26.8	12.4	6.3	SEVERE
NSISS-36	5.392	49.62	74.53	87.11	55.49	10.2	14.8	17.2	11.3	9.8	NONE
NSISS-37	3.279	43.11	63.07	72.97	48.18	14.1	20.2	23.3	15.7	10.3	MODERATE
NSISS-38	0.210	5.49	9.26	11.31	4.33	27.1	45.0	54.8	21.6	7.7	SEVERE
NSISS-39	1.894	8.03	12.02	14.02	11.13	5.2	7.3	8.4	6.9	7.0	MILD
NSISS-40	0.245	3.20	4.53	5.17	4.67	14.0	19.4	22.1	20.0	0.0	MILD
NSISS-41A	3.367	21.24	29.31	33.16	21.79	7.3	9.7	10.9	7.5	11.3	MODERATE
NSISS-42	1.383	15.41	21.96	25.16	17.61	12.1	16.9	19.2	13.7	0.0	NONE*
NSISS-43	0.646	9.99	14.00	15.93	10.09	16.5	22.7	25.7	16.6	0.0	MILD
NSISS-44	0.470	2.48	3.26	3.63	2.97	6.3	7.9	8.7	7.3	9.9	MILD
NSISS-45	0.637	12.15	17.40	19.97	15.49	20.1	28.3	32.3	25.3	7.4	SEVERE
NSISS-46	0.087	0.66	0.84	0.92	0.78	8.6	10.6	11.5	9.9	0.0	NONE*
NSISS-47	0.806	8.20	10.80	11.99	9.27	11.2	14.4	15.9	12.5	10.8	SEVERE
NSISS-48	0.474	4.75	6.21	6.88	4.95	11.0	14.1	15.5	11.4	9.3	NONE
NSISS-49	0.596	7.11	10.11	11.56	7.29	12.9	18.0	20.4	13.2	0.00	MODERATE

* While downstream control was not observed at sites NSISS-42 and NSISS-46, these meters were no longer in place during the July 23 event. Based on the response of nearby meters, it is possible that these sites would have been restricted as well.

Shading indicates meter with upstream multiple-outlet structures.

Another consideration that must be taken into account when interpreting peak flows and peaking factors in the NSISS study area is the prevalence of relief lines and multiple-outlet structures. Many of the meter sites, as noted in the table, are downstream of these multiple-outlet structures which can split and divert flows from upstream basins, causing the contributing area to vary by storm intensity. Therefore, a meter could be receiving flows from a larger area during wet-weather conditions than it would during dry-weather conditions, thus inflating the peaking factor. Conversely, other areas may be receiving flows from a smaller area in wet conditions than in dry, thus depressing the peaking factor. It is important that the hydraulic modeling being conducted under MWRD direction evaluates these issues further.

HYDRAULIC ANALYSIS

Scattergraphs are a useful tool for understanding the hydraulics of each flow meter site, particularly the effects of debris and downstream control. On a scattergraph, the flow velocity is plotted versus the flow depth for each collected data point, creating a visualization of how the depth and velocity vary with one another.

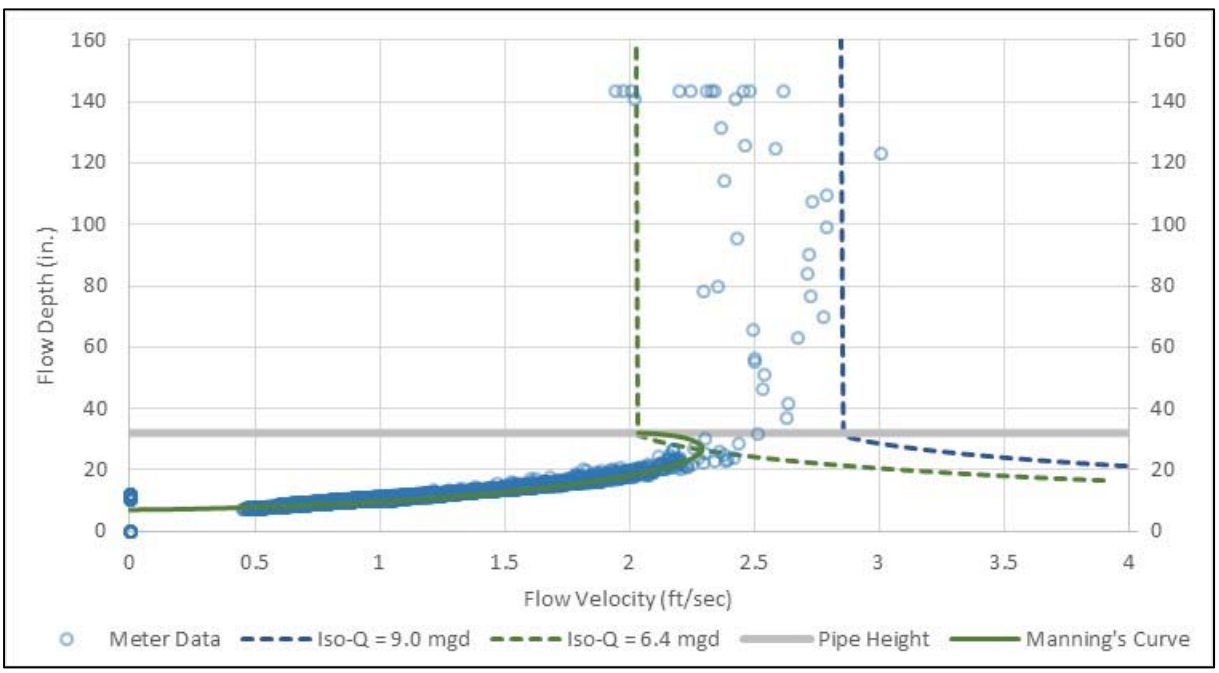
Scattergraphs can be helpful for understanding when flow is limited by the capacity of the pipe at the meter location and when it is limited by downstream control. Downstream control is any condition downstream of the metering point that restricts flow from reaching the potential capacity of the pipe. Downstream control is typically caused by a blockage or a bottleneck in the system, such as a downstream pump station or undersized sewer.

In the example scattergraphs, Figures 7 and 8, the green curve indicates the depth-velocity relationship predicted by Manning's formula in ideal hydraulic conditions based on a best estimate of the pipe roughness and slope at the monitoring location. Points that significantly deviate from this curve indicate hydraulic anomalies such as downstream control or supercritical flow. In addition, if the Manning's curve crosses the depth axis above zero, it indicates a fixed hydraulic head downstream, often referred to as a "dead dog" by flow data analysts, which can be caused by an obstruction (such as debris or an offset pipe joint) or the water level in a downstream sewer.

The dotted lines are Iso-Q lines, so called because any corresponding depth/velocity along an Iso-Q line will represent one flow value through the pipe. A clustering of points along these lines is indicative of a system characteristic or recurring condition that tends to restrict flows to that specific flow limit over the course of multiple events.

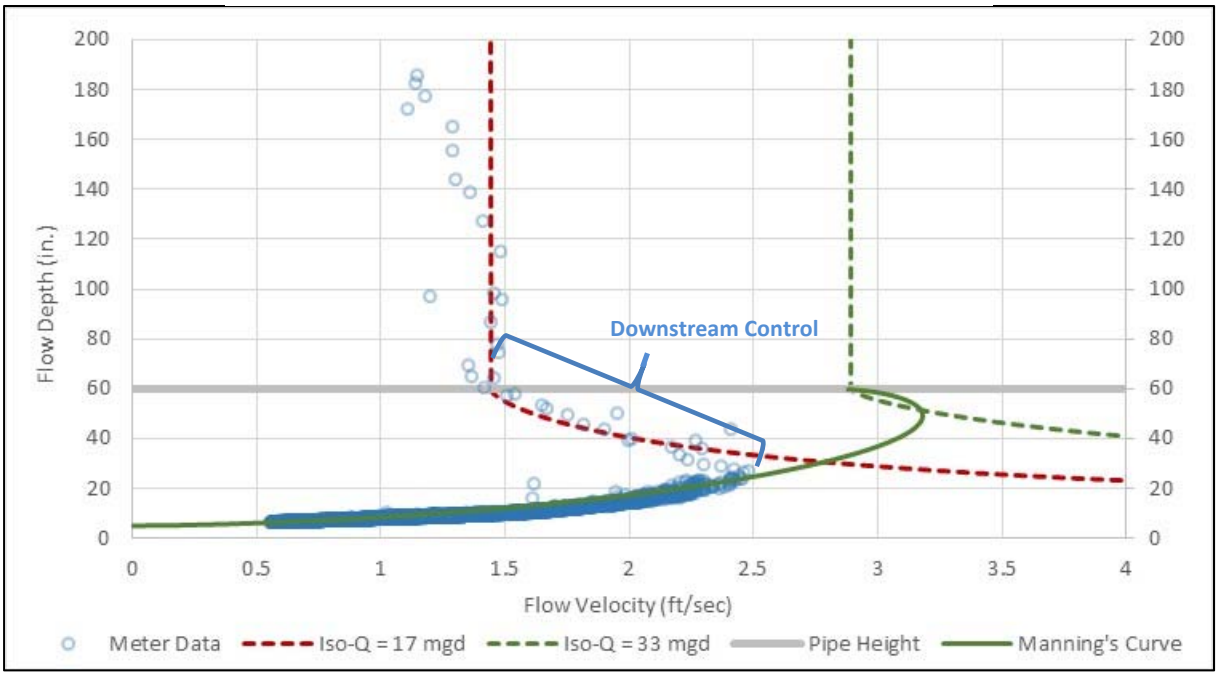
Scattergraphs for all meters are located in Appendix D. Surcharging and downstream control observations are summarized on Exhibit 2, as well as in Table 6.

FIGURE 7
NSISS-48 SCATTERGRAPH



NSISS-48 did not exhibit any flow restrictions, but did exhibit surcharging to the limit of the meter's level sensor range.

FIGURE 8
NSISS-47 SCATTERGRAPH



NSISS-47 exhibited a severe flow restriction in the form of downstream control. The control limited the flow passing through the meter to 17 MGD despite the location having a theoretical full pipe capacity of 33 MGD.

CONCLUSIONS AND RECOMMENDATIONS

The meters installed to monitor the North Shore Interceptor System were largely successful in capturing the key flow characteristics and capacity concerns within the study area. The metering period showed that there was significant infiltration throughout the study area by the diurnal variations. In addition, most meters exhibited very high inflow, as summarized in order of severity in Table 7. The highest peaking factors were observed in meters NSISS-45 and NSISS-38 which both project to having peaking factors over 20 during a 3-year, 2-hour rain event despite experiencing severe downstream control, which can dampen peaking factors by limiting peak flow. The lowest peaking factors were observed at sites NSISS-21 and NSISS-22, which can largely be attributed to the Village of Wilmette restricting its outflow to the NSIS and storing excess flows within its own system. While interpretation of peaking factors throughout the NSIS is complicated by relief lines and multiple-outlet structures, the overarching prevalence of double-digit peaking factors suggests excessive I/I throughout the region.

TABLE 7
INFLOW SEVERITY SUMMARY

Meter	3-Yr, 2-Hr PF	Surcharging (ft)	Downstream Control
NSISS-45	25.3	7.4	SEVERE
NSISS-38	21.6	7.7	SEVERE
NSISS-40	20.0	0.0	MILD
NSISS-32	17.4	6.4	SEVERE
NSISS-43	16.6	0.0	MILD
NSISS-37	15.7	10.3	MODERATE
NSISS-42	13.7	0.0	NONE*
NSISS-49	13.2	0.00	MODERATE
NSISS-47	12.5	10.8	SEVERE
NSISS-35	12.4	6.3	SEVERE
NSISS-48	11.4	9.3	NONE
NSISS-36	11.3	9.8	NONE
NSISS-46	9.9	0.0	NONE*
NSISS-41A	7.5	11.3	MODERATE
NSISS-44	7.3	9.9	MILD
NSISS-39	6.9	7.0	MILD
NSISS-22	6.3	10.6	MILD
NSISS-21	4.8	11.7	MILD

* While downstream control was not observed at sites NSISS-42 and NSISS-46, these meters were no longer in place during the July 23 event. Based on the response of nearby meters, it is possible that these sites would have been restricted as well.

Shading indicates meter with upstream multiple-outlet structures.

The downstream control exhibited during the metering period was mainly seen during the July 23rd rain event. This event had two large peaks separated by roughly two hours. At sites that exhibited downstream control, both spikes in rainfall intensity were large enough to induce flow restriction, as seen in Figure 9.

A general synopsis of the system behavior during wet-weather events is as follows:

- The North Shore No. 1 interceptor exhibited significant downstream control, as evidenced by data at sites NSISS-32, NSISS-35, and NSISS-38. These effects originate from beyond the downstream extents of the study area and were not limited to the July 23 event. Downstream control at these sites generally began to take effect at flows between 5% and 10% of interceptor capacity.

- The North Shore No. 7 interceptor did not exhibit effects of downstream control extending from beyond the study area. While site NSISS-36, the meter furthest downstream on this interceptor, did experience significant surcharging during the July 23 event due to high flows exceeding the interceptor capacity, flows remained in excess of the full-pipe capacity throughout the event, indicating that downstream control did not appreciably contribute to surcharging at this location. However, further upstream on North Shore No. 7 at sites NSISS-

37 and NSISS-41A, some downstream control was observed, lending to the possibility that backwater effects from North Shore No. 1 via North Shore No. 2 could be contributing to surcharging further up along North Shore No. 7.

- Similarly, site NSISS-39 on the North Shore No. 2 interceptor exhibited mild downstream control, potentially originating, at least in part, from backwater effects of North Shore No. 1. However, the effect was not significant, and generally peak wet-weather flows remained near or in excess of full-pipe interceptor capacity at NSISS-39.

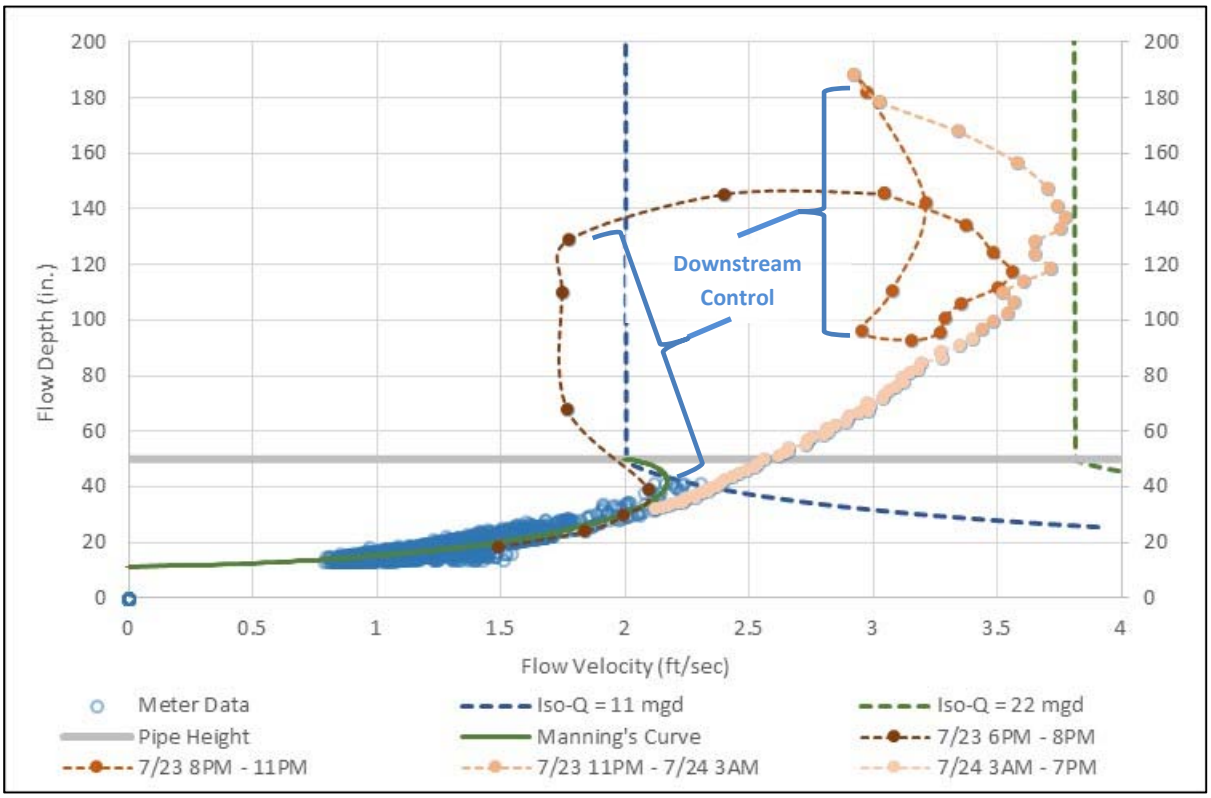
- The junction of North Shore No. 3 and North Shore No. 4 appears to result in a bottleneck toward the upstream end of North Shore No. 2, as evidenced by downstream control in Sites NSISS-40 and NSISS-22 during the July 23 event. This effect did also resonate up to site NSISS-21 at the top end of North Shore No. 4 during this event, as is illustrated in Figure 9.

- The North Shore No. 8 interceptor along Green Bay Road appears to have sufficient excess flow capacity. While the data at sites NSISS-43 and NSISS-49 did indicate some downstream control, it did not result in surcharging, even during the July 23 event.

- Sites NSISS-45 and NSISS-47 indicate significant capacity issues in North Shore No. 5, which resonate upstream through the North Shore No. 8 interceptor along Tower Road and Hibbard Road, resulting in severe downstream control. Site NSISS-44 on the Northfield Outlet interceptor also exhibited the effects of significant downstream capacity restrictions.

- These restrictions observed at NSISS-47 and further downstream did not appreciably resonate to the upstream end of North Shore No. 3, as evidenced by the data at NSISS-48. This site experienced major surcharging during the July 23 event, but flows generally remained above the full-pipe capacity in this location, indicating that the surcharging was foremost the result of excessive wet-weather flows from its tributary area.

FIGURE 9
NSISS-21 DUAL PEAK DOWNSTREAM CONTROL



The July 23rd rain event was not captured in meters NSISS-42 and NSISS-46, two meters that did not exhibit downstream control or surcharging. However, based on data collected at nearby meters NSISS-45 and NSISS-41A and invert elevations on the MWRD interceptor atlas, it is almost certain that both of these sites would have surcharged during the July 23rd event and likely would have exhibited downstream control as well. Nevertheless, without observed data to verify, it is difficult to speculate exactly how the system would have responded, but peak level data from the nearby locations during this event can be useful in projecting July 23rd conditions at these two meter sites.

Exhibit 2 in Appendix A summarizes the observation at each meter site with respect to downstream control, surcharging, and peaking factor assessment. From Exhibit 2, it is evident that there are multiple locations that act as bottlenecks in the MWRD system, most notably just downstream of NSISS-45 and NSISS-32. These two locations and nearby upstream meter sites experience significant surcharging and downstream control. The most severe backwater effects are seen in NSISS-35, NSISS-38 and NSISS-47. The most severe surcharging from these restrictions are seen in NSISS-37, NSISS-41A, and NSISS-47, and they appear to impact sites NSISS-21 and NSISS-22 as well.

Recommendations

The recommendations from this study are comprised of two major components—system-wide modeling and follow-up SSES investigations.

Without a comprehensive model of the interceptor system and its satellite community collection points, it is extremely difficult to disentangle the effects of tributary basin excess flows and diverted flows from partially or contingently tributary basins on wet-weather peaking factors at many of the monitoring sites. Therefore, a primary recommendation of this study is to utilize the collected flow data to calibrate a model of the interceptor system that also incorporates relevant flow monitoring data from satellite communities, as available, to fully understand the origins of and solutions to excessive surcharging contributing to basement backups. The model of the system should aim to achieve the following:

- Understand the causes of downstream control originating from beyond the extents of the flow monitoring study area, specifically those impacting levels in North Shore No. 1 and North Shore No. 2.
- Determine the extents and causes of other significant system bottlenecks, particularly those evident at sites NSISS-44, NSISS-45, and NSISS-47, and understand how these align with satellite community connection points.
- As available, utilize information from satellite communities, including flow monitoring data and basement backup reporting, and reconcile these observations with model results.
- Explore potential solutions including I/I reduction, wet-weather excess flow storage, or modifications to interceptor junctions or relief points to mitigate the risks of overflows and backups in satellite communities.

To achieve these objectives, the findings of this study should be incorporated into modeling efforts as follows:

- Utilize the July 23 data as a critical calibration event. Attempt to replicate this event in the model, emphasizing both peak flows and corresponding peak levels.
- Also utilize smaller but still significant storm events, particularly the May 31 and June 22 events to calibrate the model. These will be especially vital at sites NSISS-42 and NSISS-46, which were not monitored during the July 23 event.
- Conduct investigations as necessary to reconcile modeled conditions with observed conditions, including confirmation of inverts and interceptor sizes at critical locations and/or review of CCTV and cleaning records to identify possible obstructions.

The model will be necessary to determine the excess flow contributions of individual satellite basins due to the complexity of the NSIS hydraulic network. However, even acknowledging the difficulty of interpreting peaking factors in basins impacted by flow splits, the region-wide prevalence of excessive wet-weather flows and surcharging is a clear indication that I/I remains a major concern throughout the North Shore Interceptor System. For instance, sites NSISS-43, NSISS-48, and NSISS-49 all monitored discrete areas with no apparent impact of upstream diversions or flow restrictors, and all three of these sites had 3-year, 2-hour storm peaking factors in excess of 11. While easy to isolate, these basins are by no means exceptional relative to wet-weather peaking factors observed through the region.

To that end, the satellite communities should continue to address I/I sources per the guidelines provided by the MWRD I/I Control Program (IICP). These measures should entail required SSES investigations including smoke testing, manhole inspection, dyed water testing, pipeline condition assessments, and private property inspections.

It has been our pleasure serving the Village of Wilmette on this project, and it is our hope that the findings and recommendations of this study will ultimately benefit each of the communities impacted by them. We appreciate any feedback that the Village might have and look forward to continuing to provide sanitary sewer services to the Village of Wilmette.

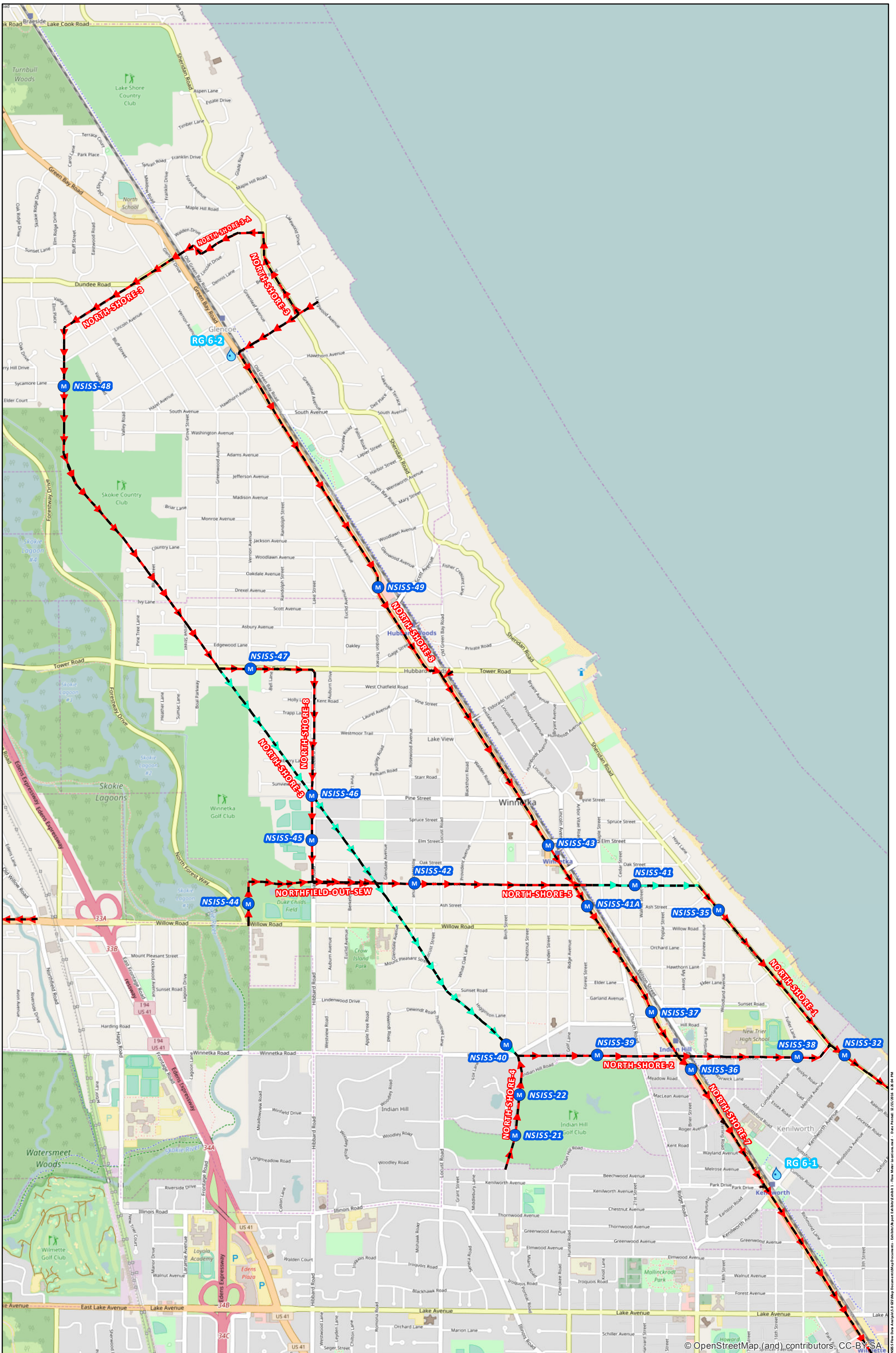
Sincerely,

RJN Group, Inc.

Michael N. Young, P.E
Principal

Thomas J. Romza, P.E.
Project Manager

APPENDIX A – Exhibits



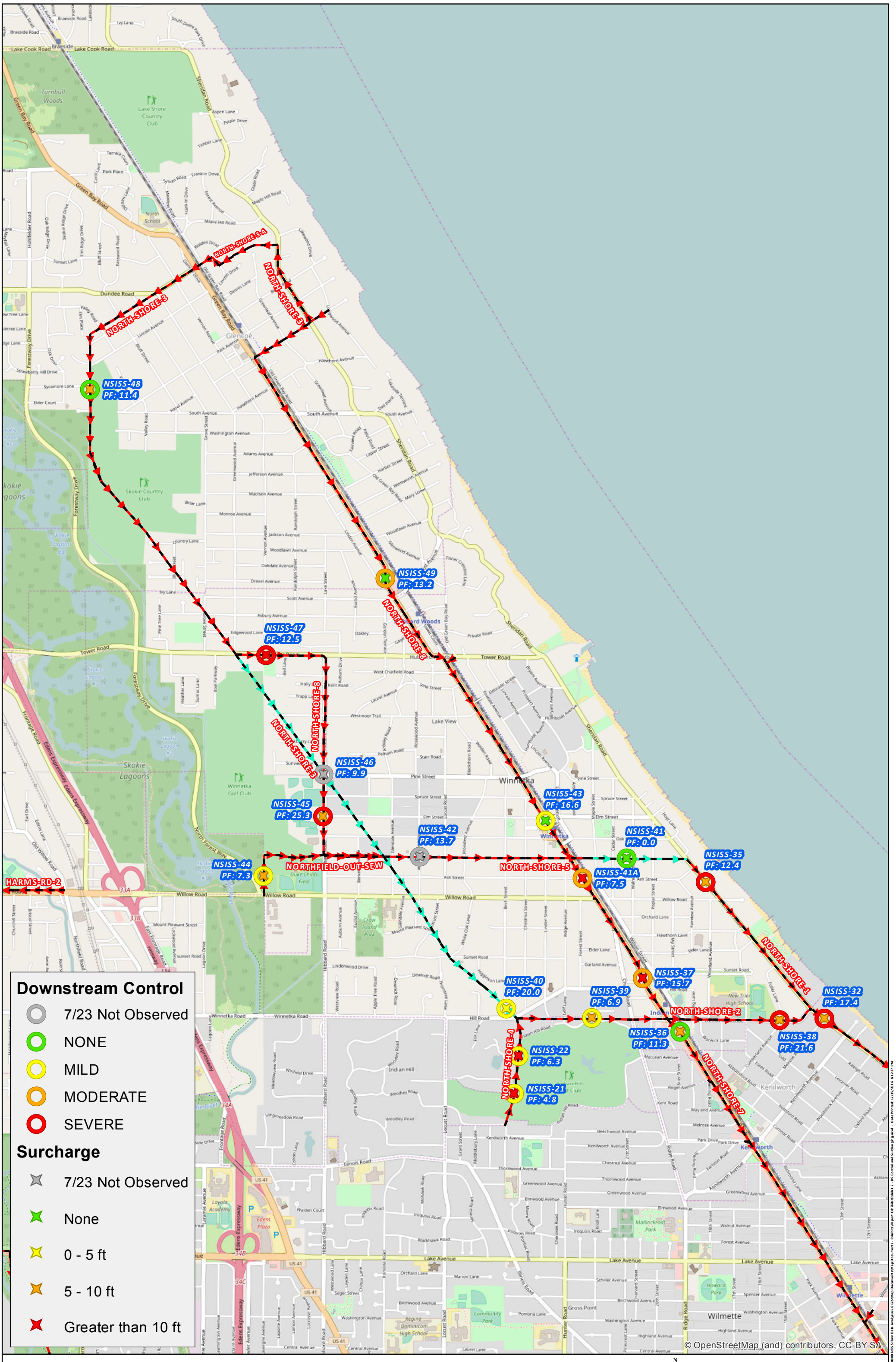
rjngroup
The Choice for Collection System Solutions

2016 NSISS Flow Meters
Rain Gauge Site
MWRD Interceptor
Secondary MWRD Interceptor

N
W E
S

Wilmette NSISS
Exhibit 1 - Meter Locations
December 2016

Q:\Wilmette JL\1130000 NSISS Flow Data Analysis\5.0 GIS\Map Documents\Map Documents - Exhibits\Report Exhibits\Exhibit 1 - Flow Meter Locations.mxd - Date Printed: 12/15/2016 6:28:04 PM



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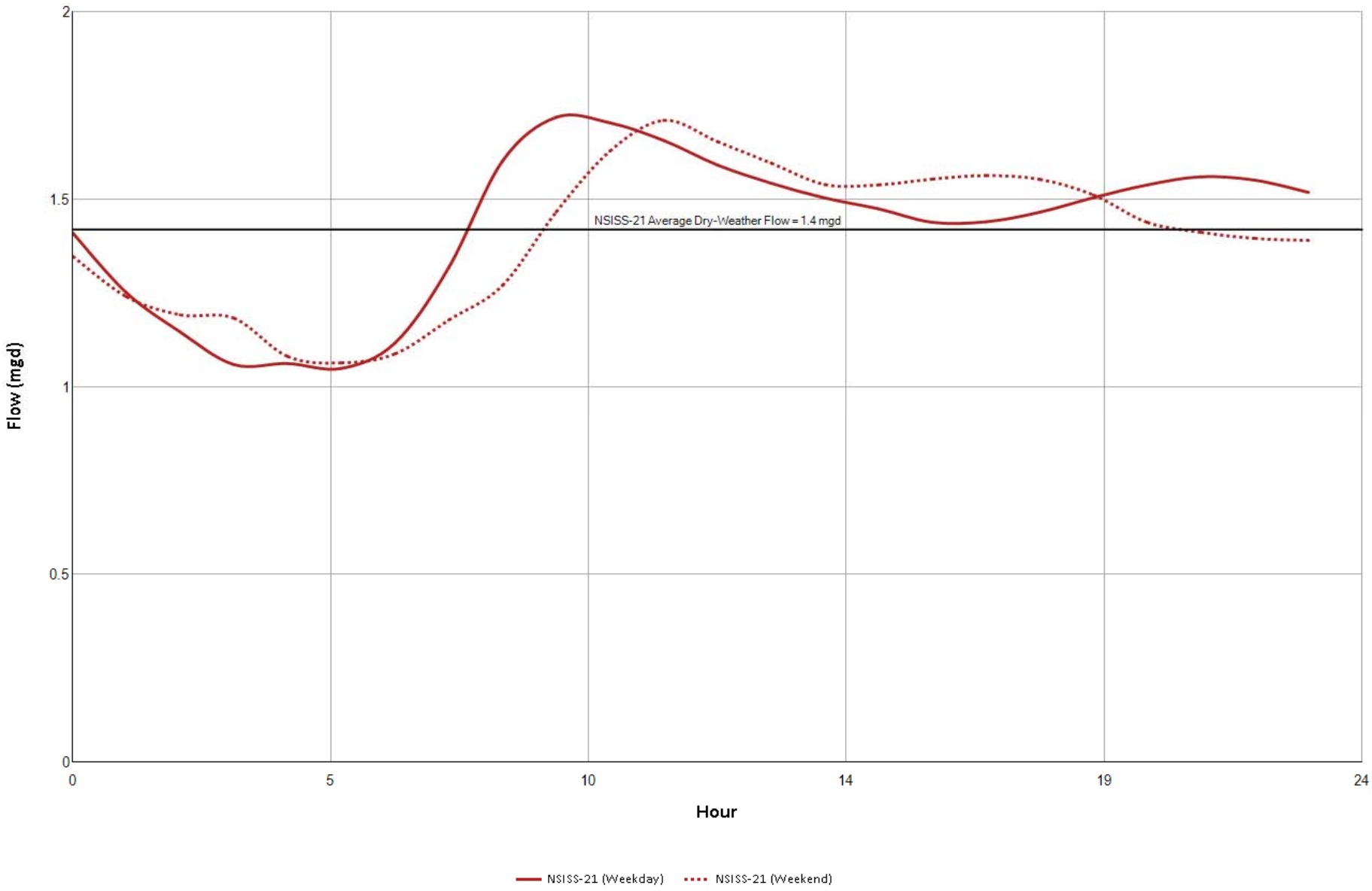
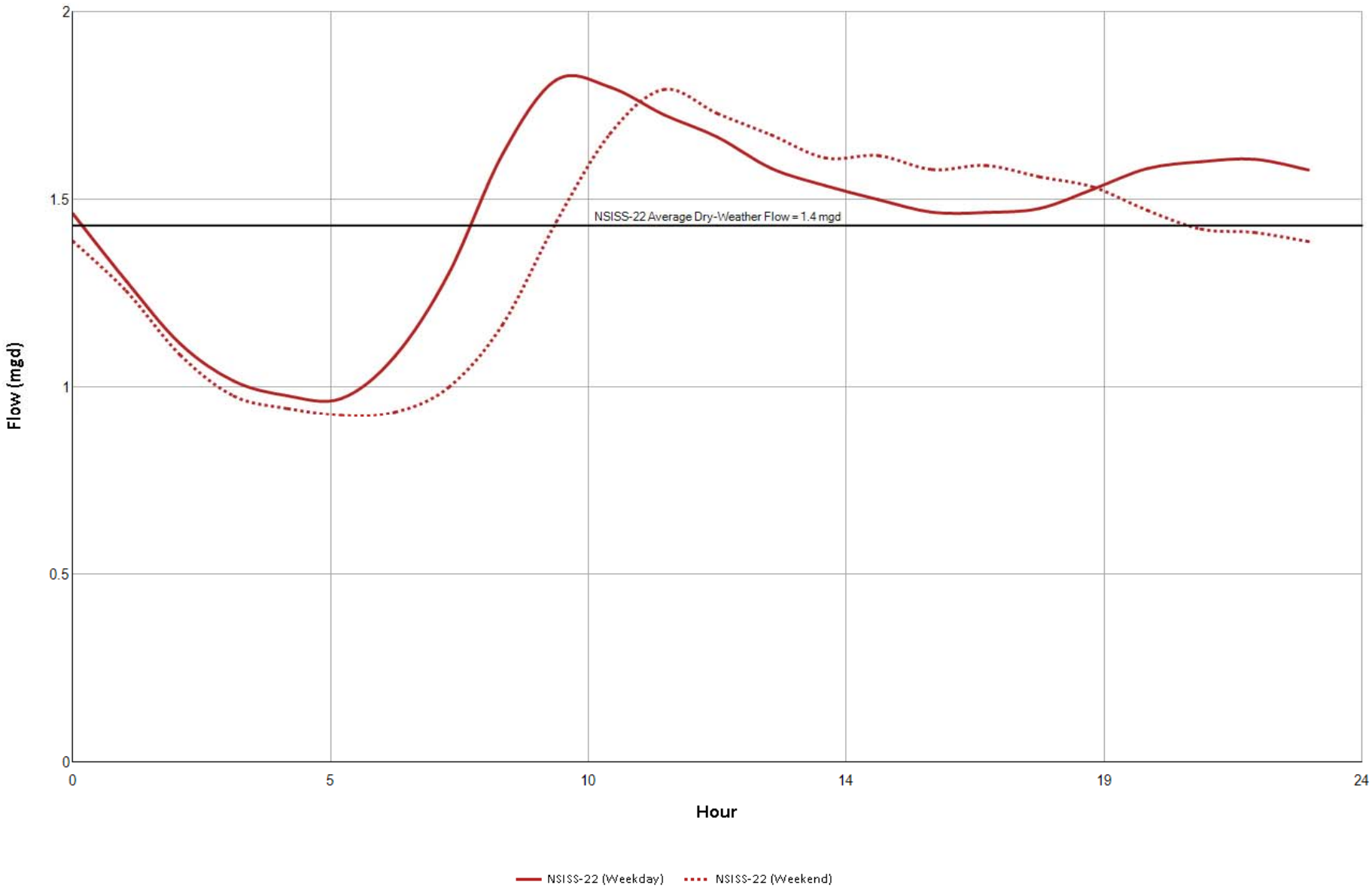
Wilmette NSISS
Exhibit 2 - Meter Characteristics
December 2016

APPENDIX B – Diurnal Curves

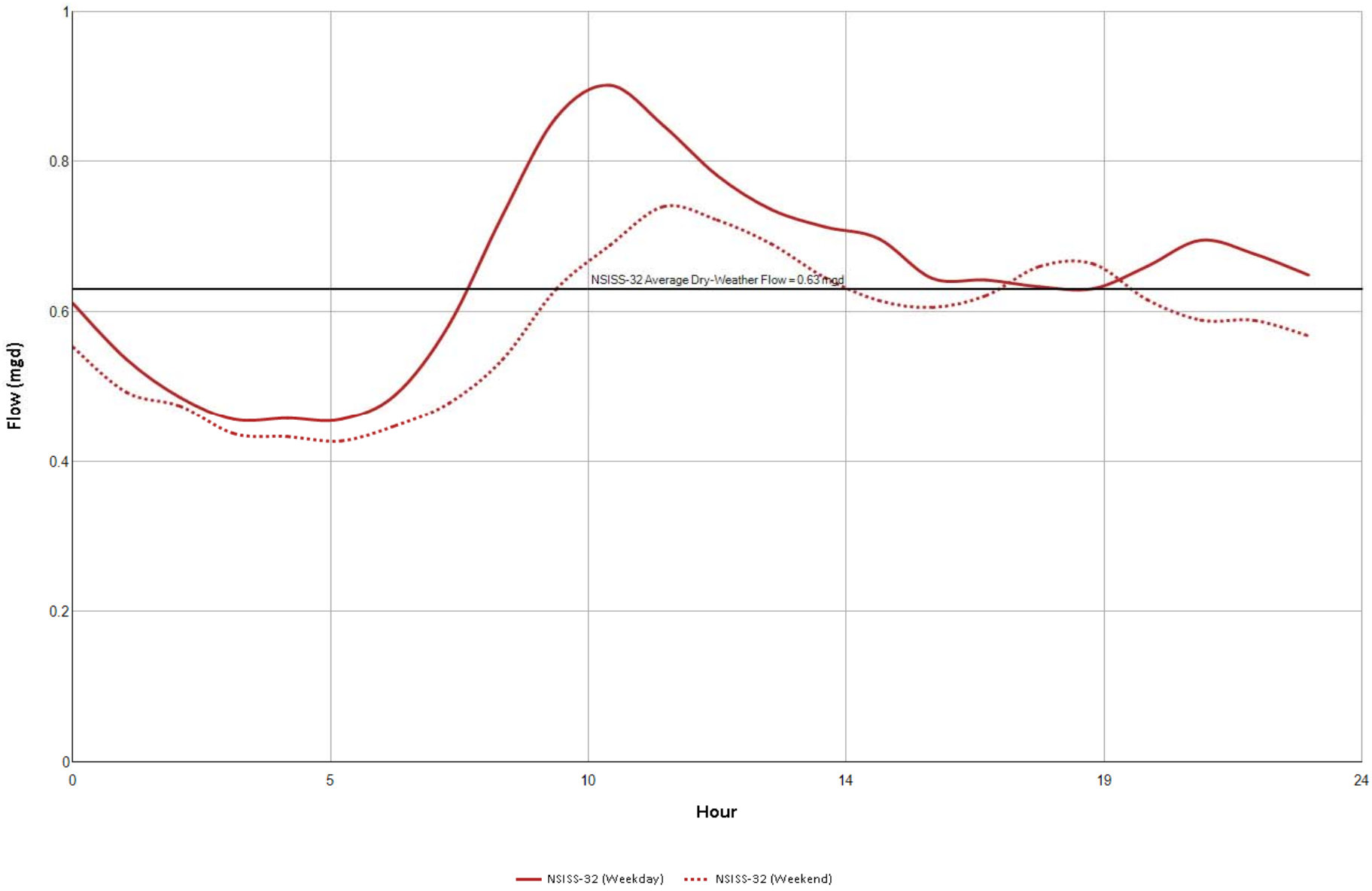
Site: NSISS-21 - Average Dry-Weather Flow

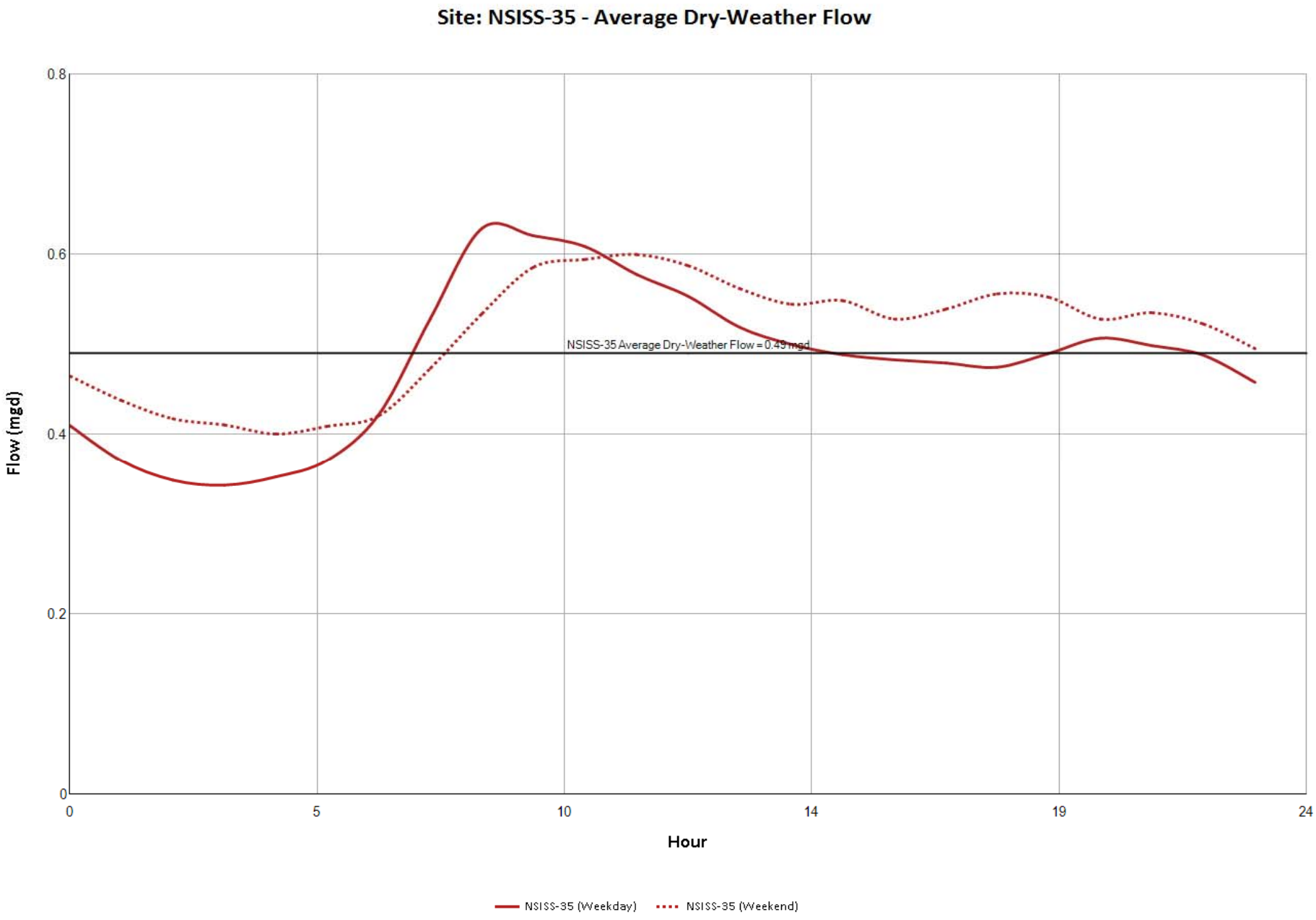


Site: NSISS-22 - Average Dry-Weather Flow

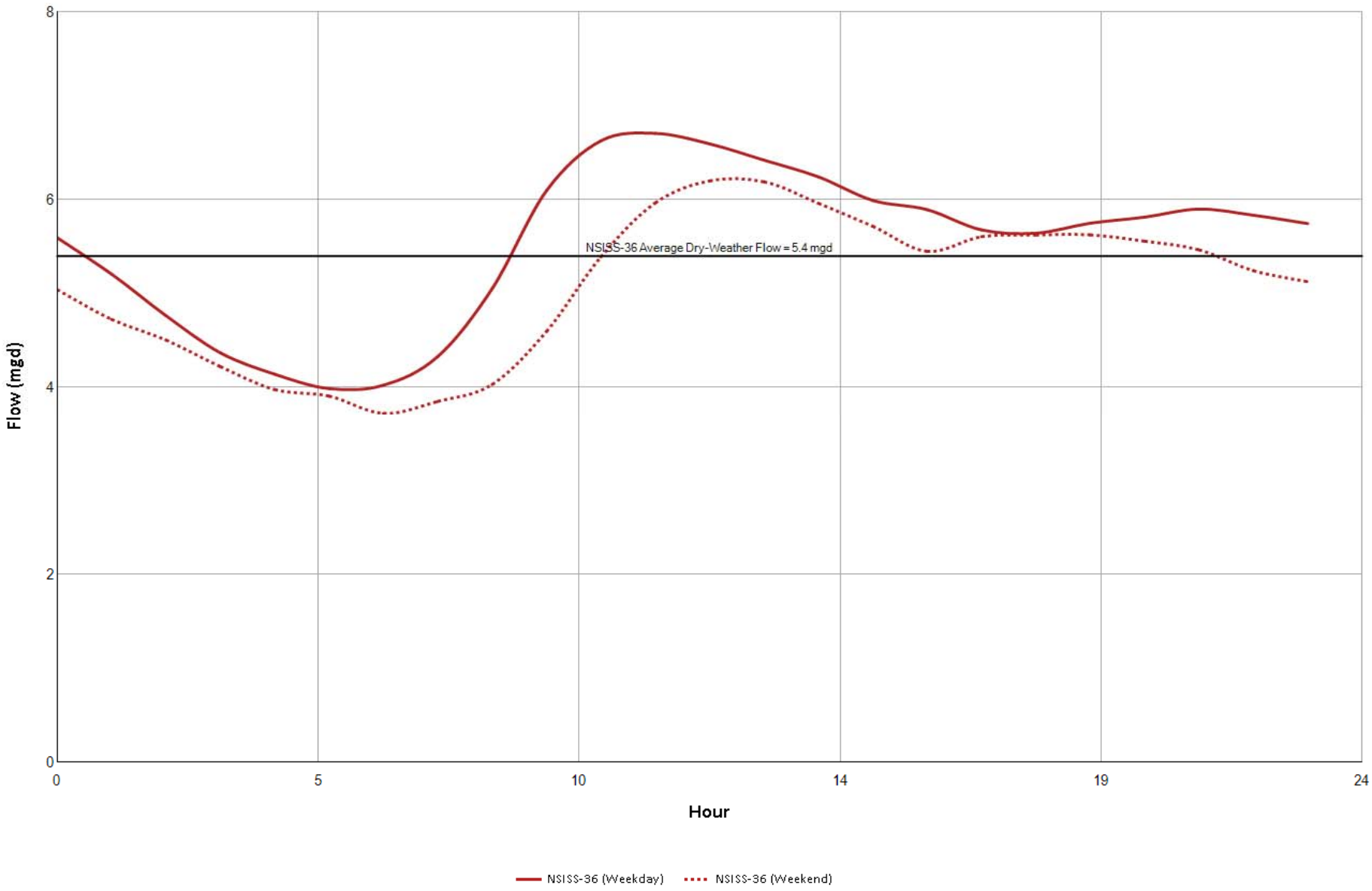


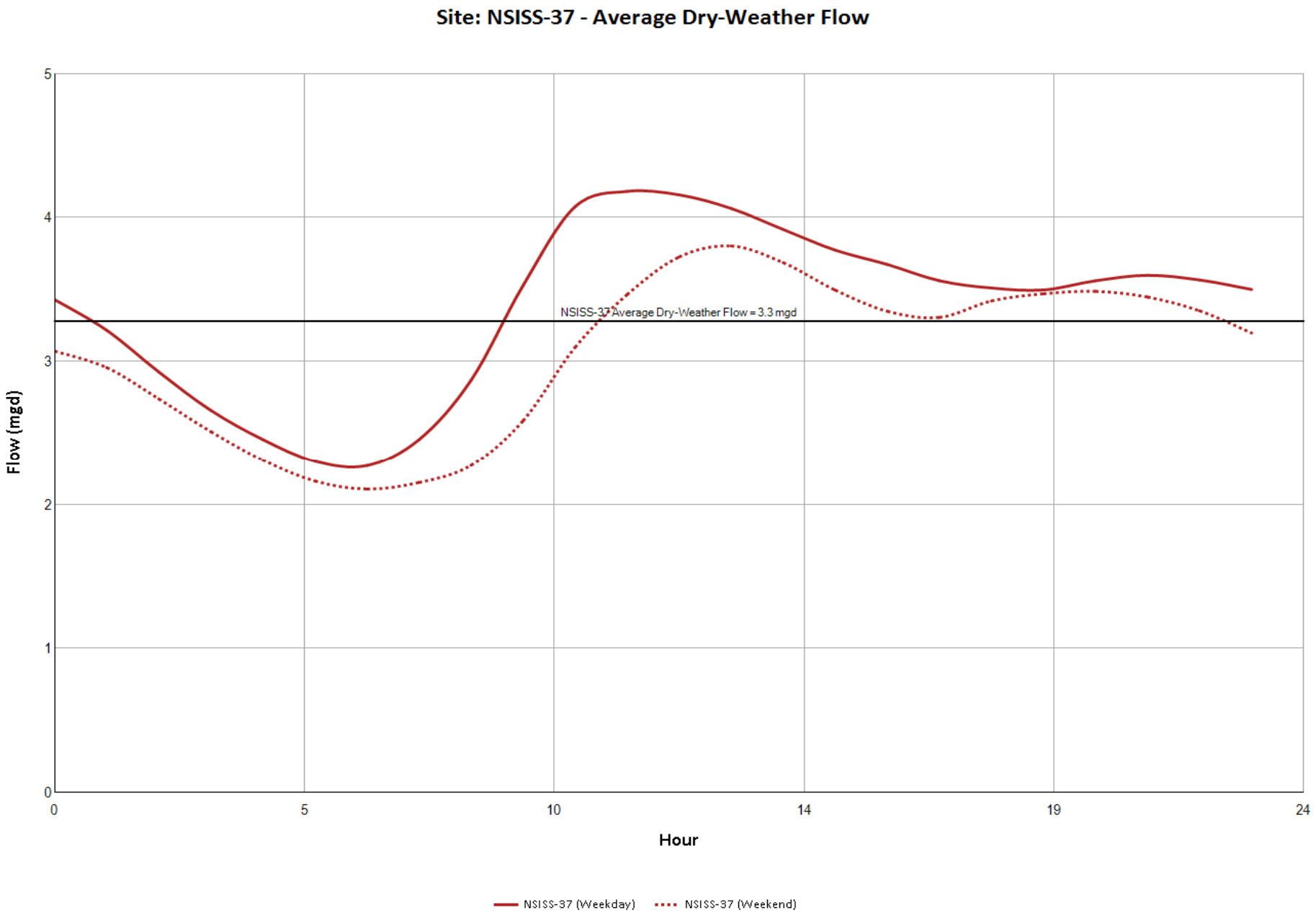
Site: NSISS-32 - Average Dry-Weather Flow

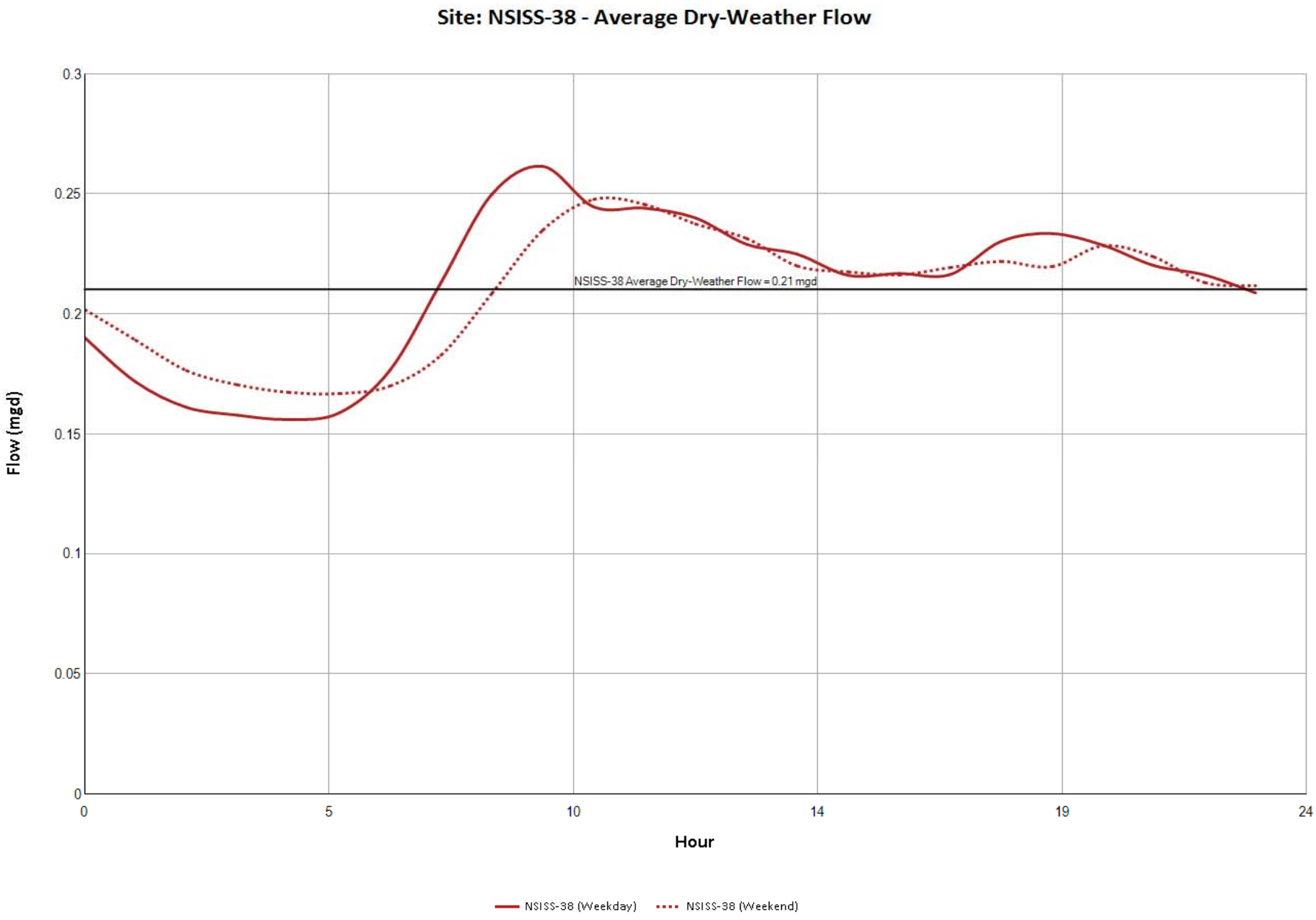


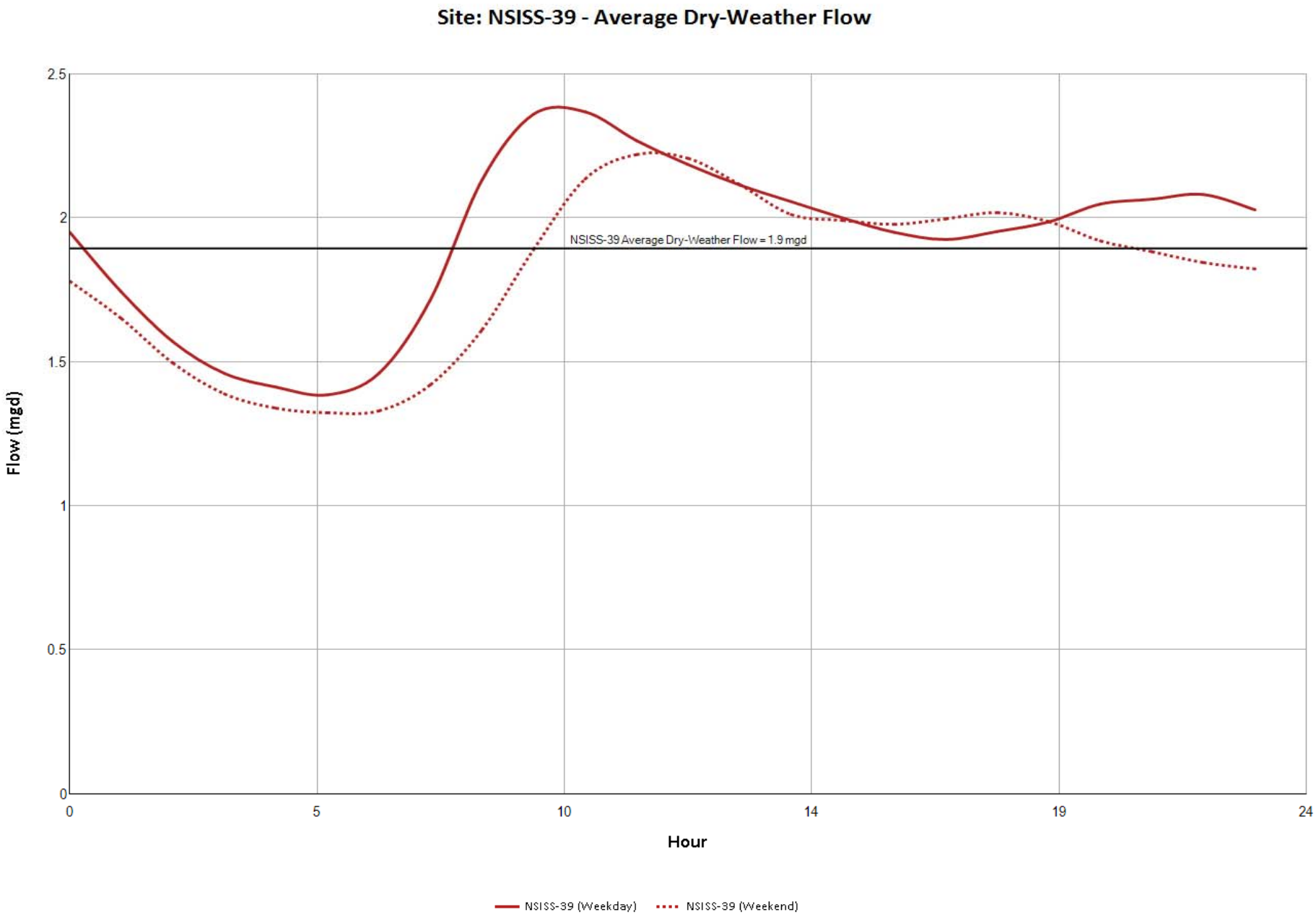

Site: NSISS-35 - Average Dry-Weather Flow
0.8
0.6
0.4
0.2
0
Flow (mgd)
NSISS-35 Average Dry-Weather Flow = 0.49 mgd
0
5
10
14
19
24
Hour
NSISS-35 (Weekday)
NSISS-35 (Weekend)

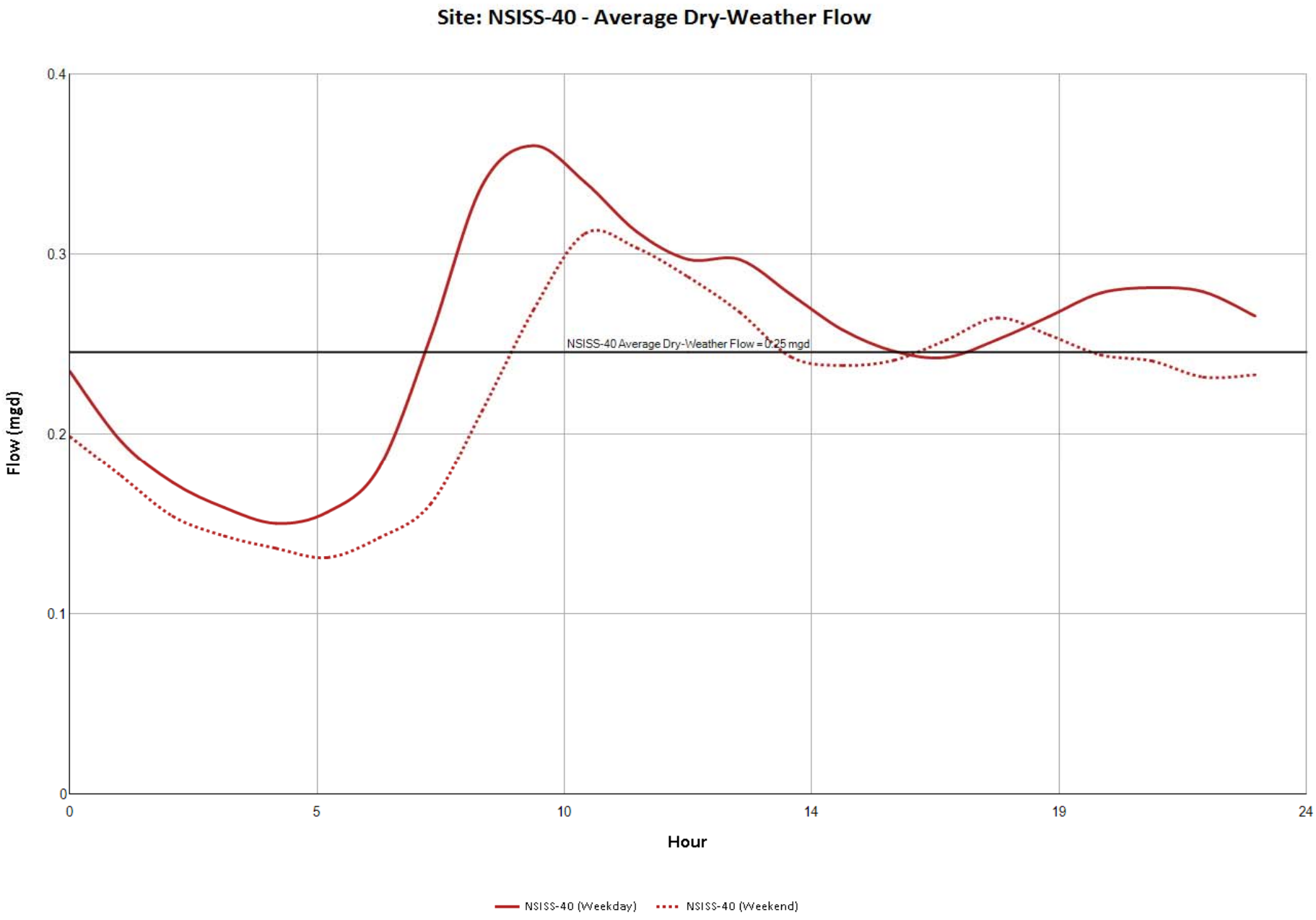
Site: NSISS-36 - Average Dry-Weather Flow



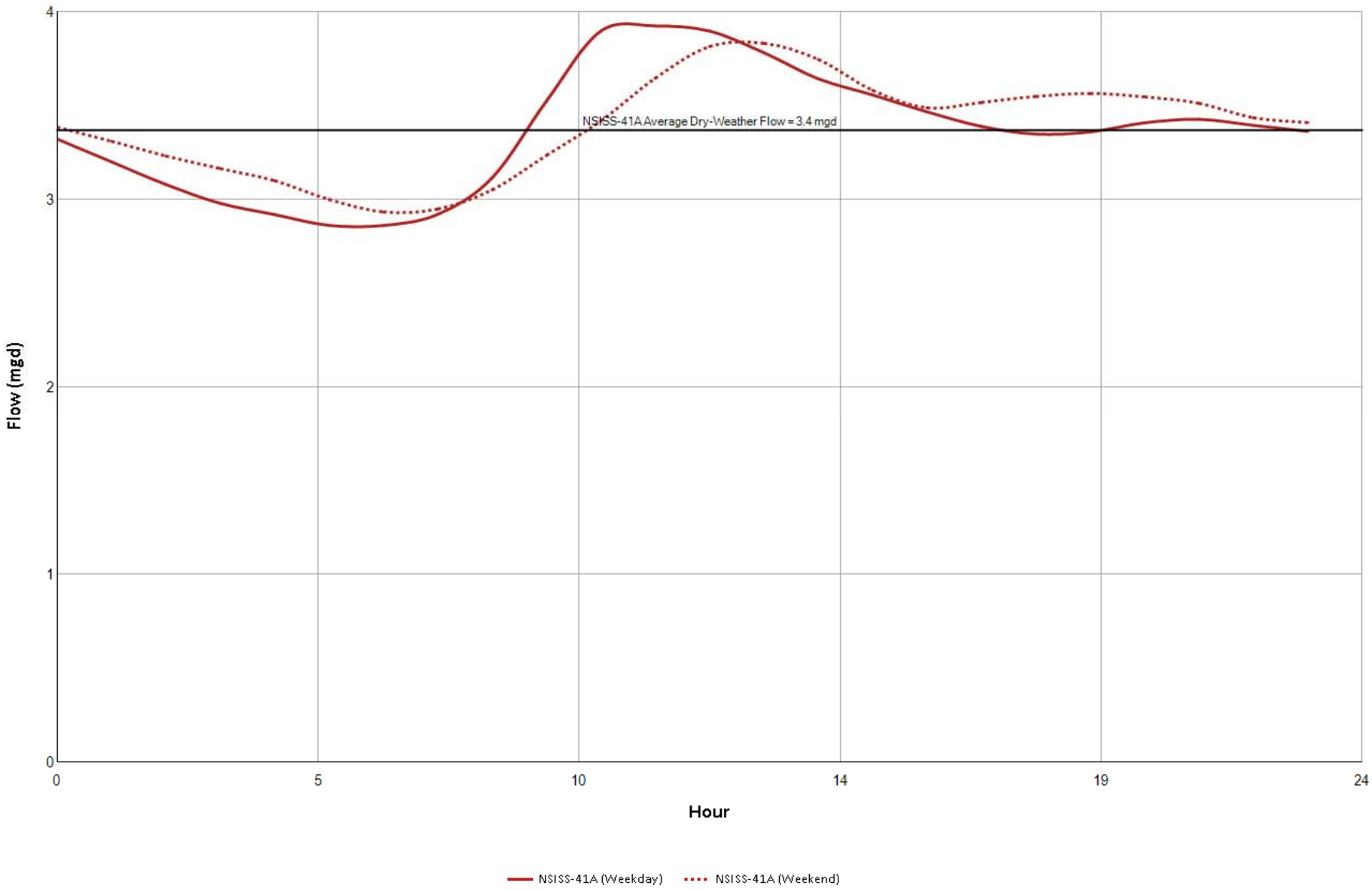

Site: NSISS-37 - Average Dry-Weather Flow
Flow (mgd)
5
4
3
2
1
0
0
5
10
14
19
24
Hour
NSISS-37 Average Dry-Weather Flow = 3.3 mgd
NSISS-37 (Weekday)
NSISS-37 (Weekend)

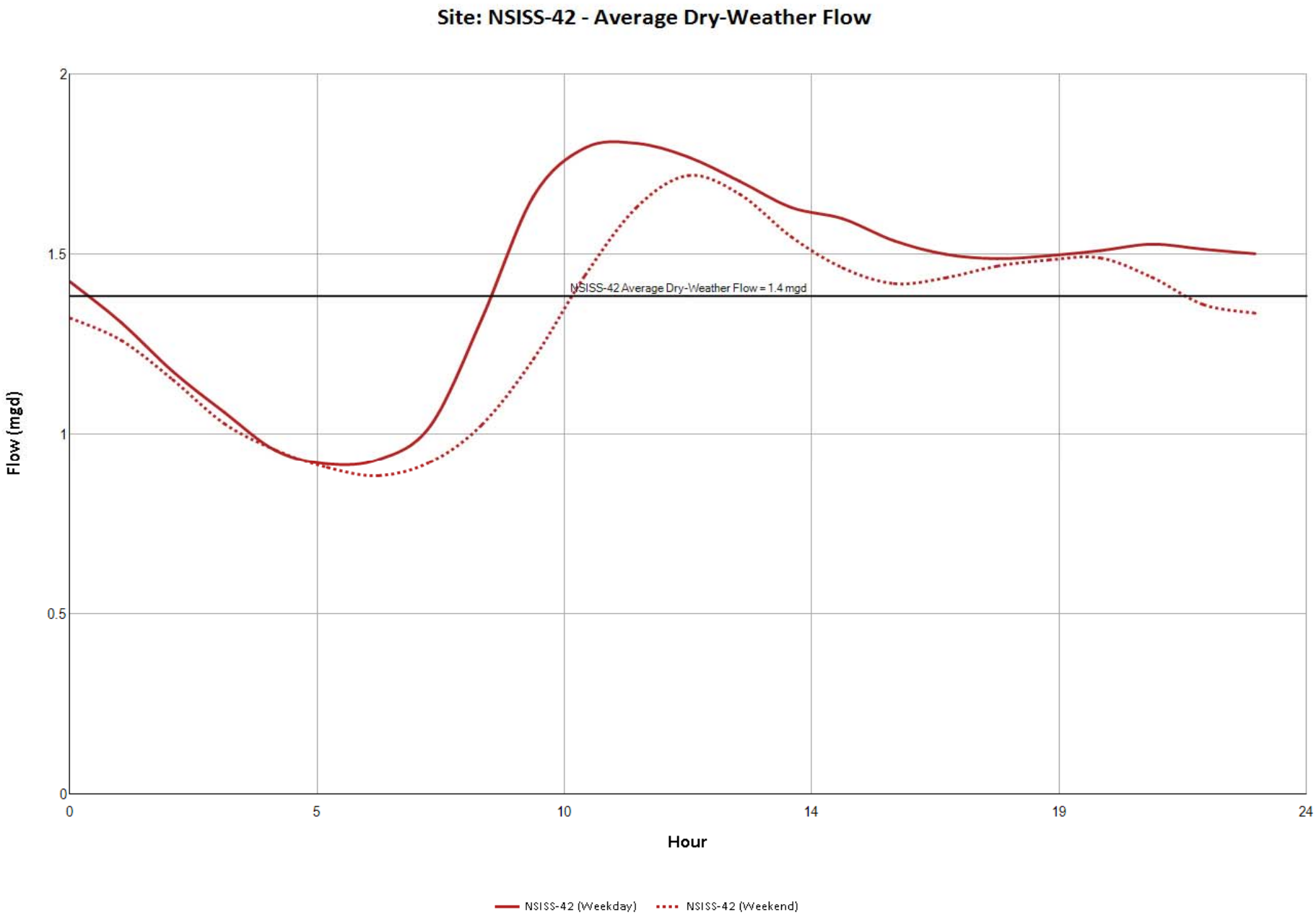

Site: NSISS-38 - Average Dry-Weather Flow
Flow (mgd)
0.3
0.25
0.2
0.15
0.1
0.05
0
NSISS-38 Average Dry-Weather Flow = 0.21 mgd
0
5
10
14
19
24
Hour
NSISS-38 (Weekday)
NSISS-38 (Weekend)


Site: NSISS-39 - Average Dry-Weather Flow
Flow (mgd)
2.5
2
1.5
1
0.5
0
NSISS-39 Average Dry-Weather Flow = 1.9 mgd
0
5
10
14
19
24
Hour
NSISS-39 (Weekday)
NSISS-39 (Weekend)

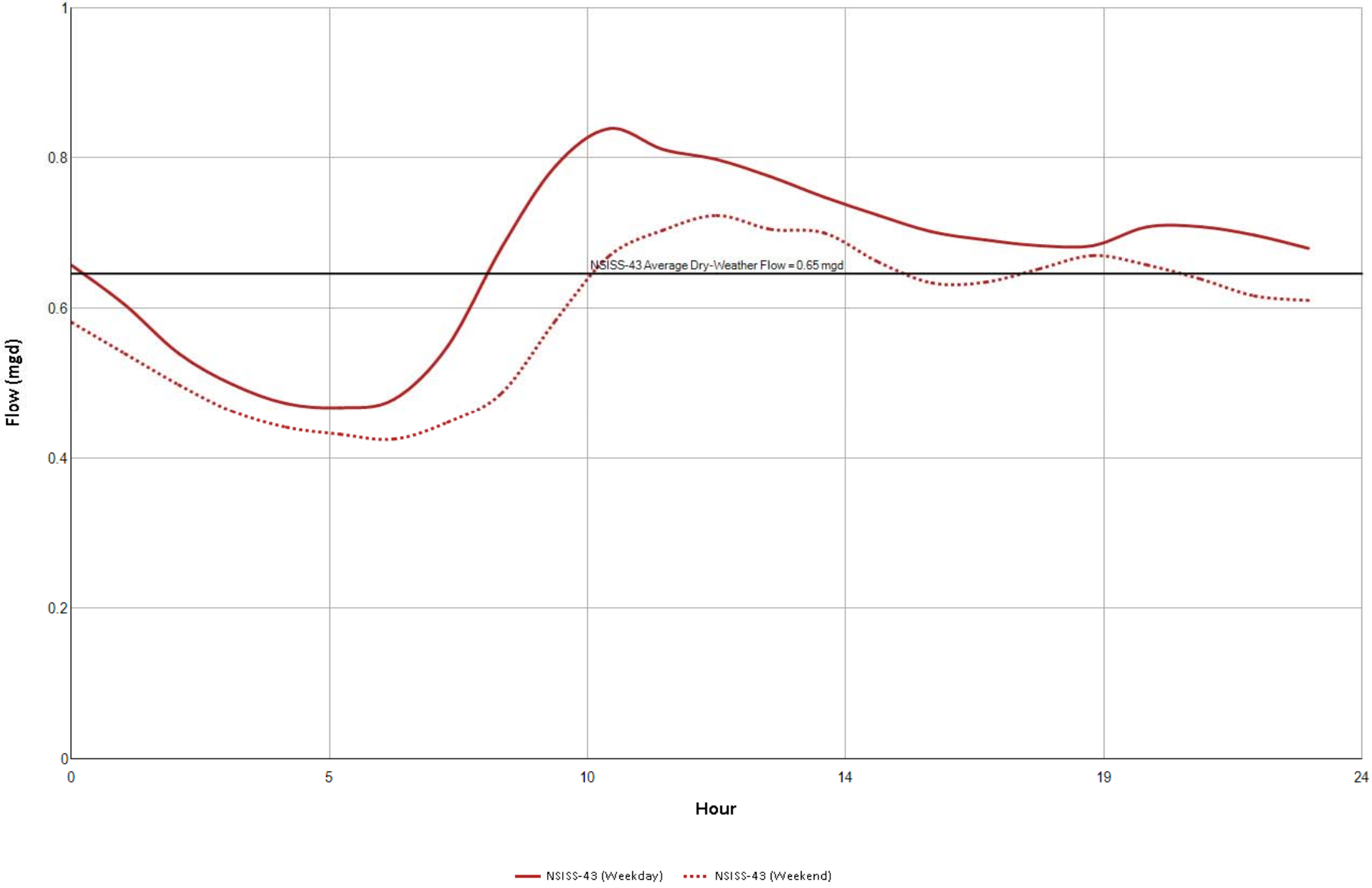

Site: NSISS-40 - Average Dry-Weather Flow
Flow (mgd)
0.4
0.3
0.2
0.1
0
NSISS-40 Average Dry-Weather Flow = 0.25 mgd
0
5
10
14
19
24
Hour
NSISS-40 (Weekday)
NSISS-40 (Weekend)

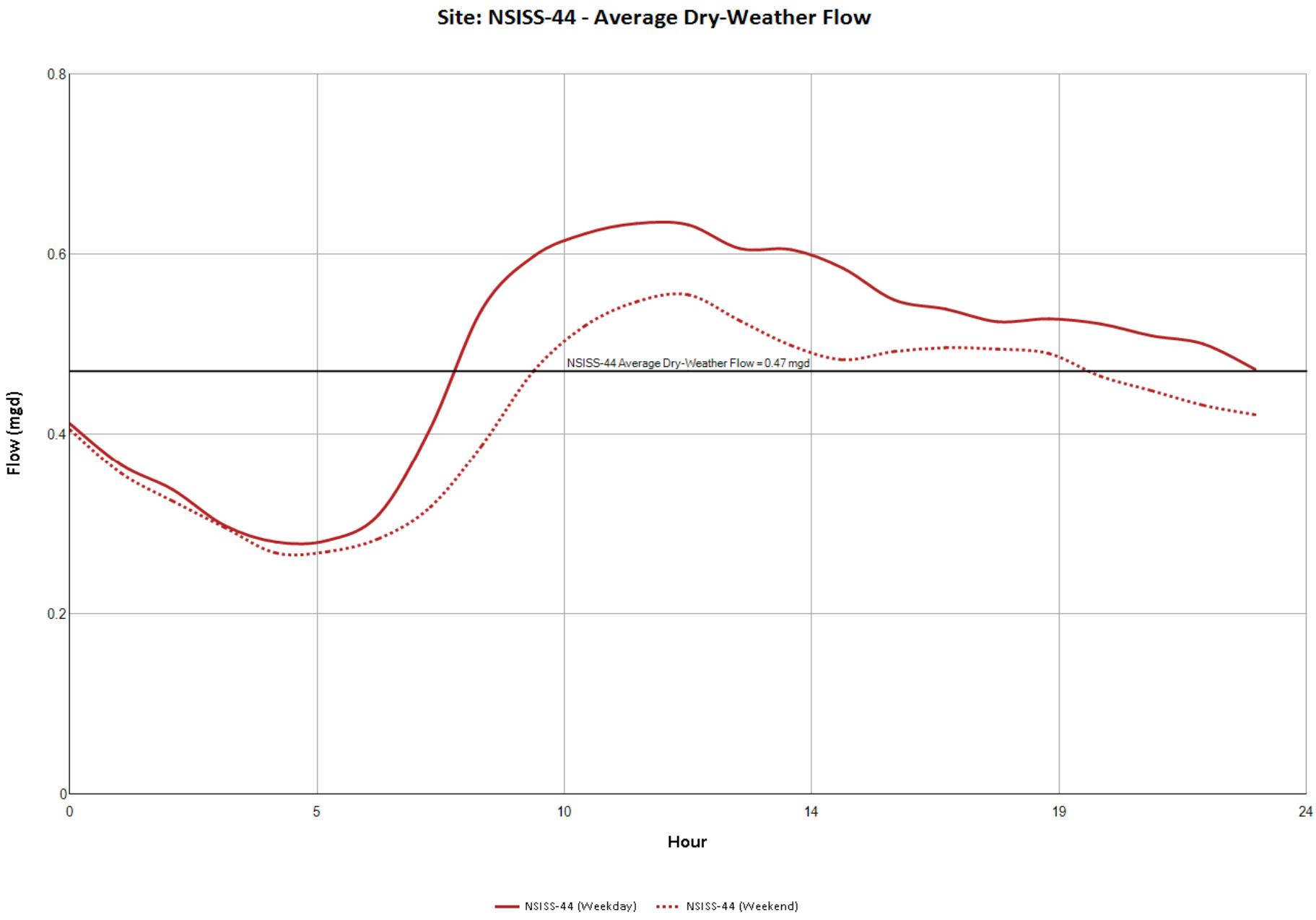
Site: NSISS-41A - Average Dry-Weather Flow

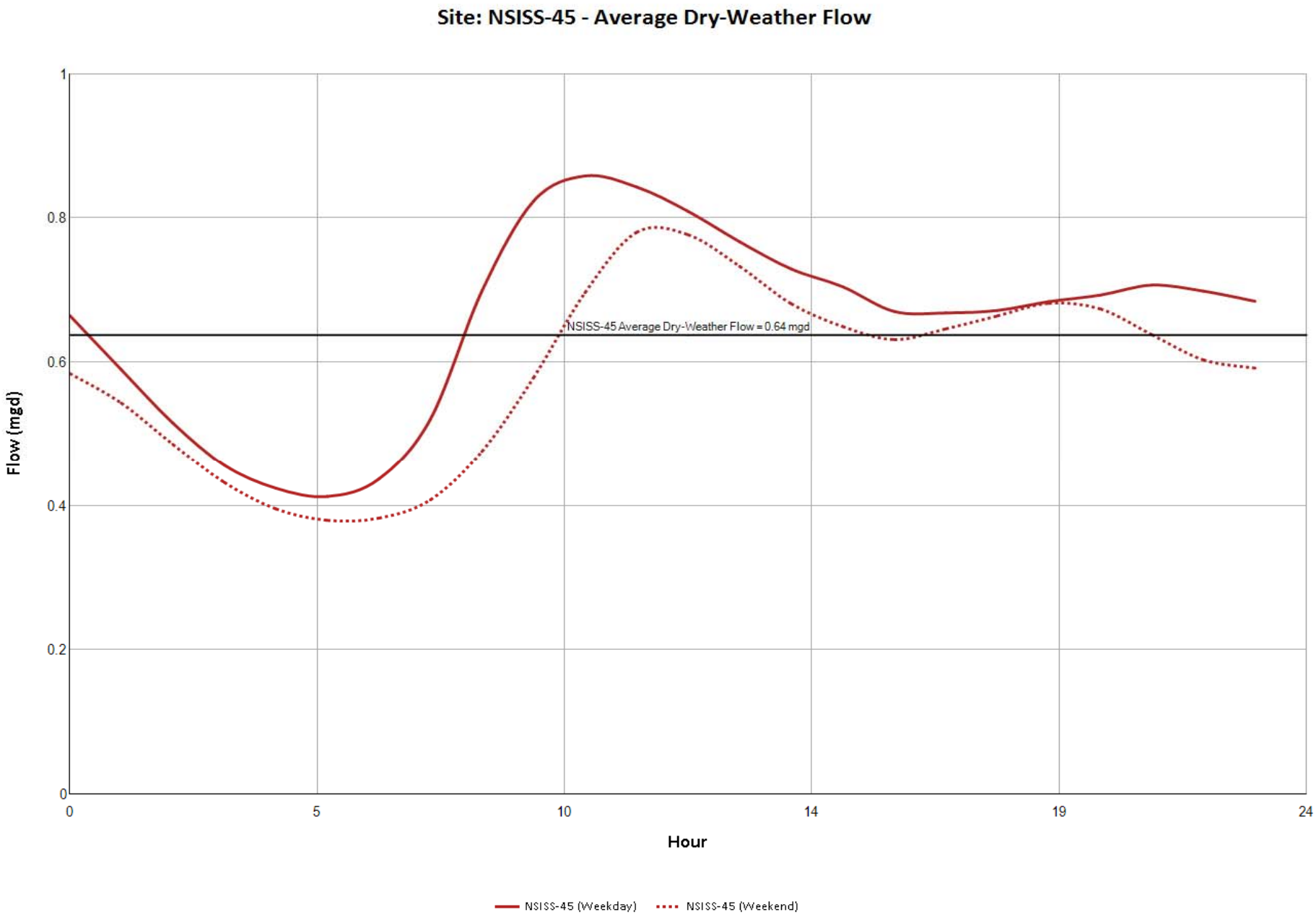


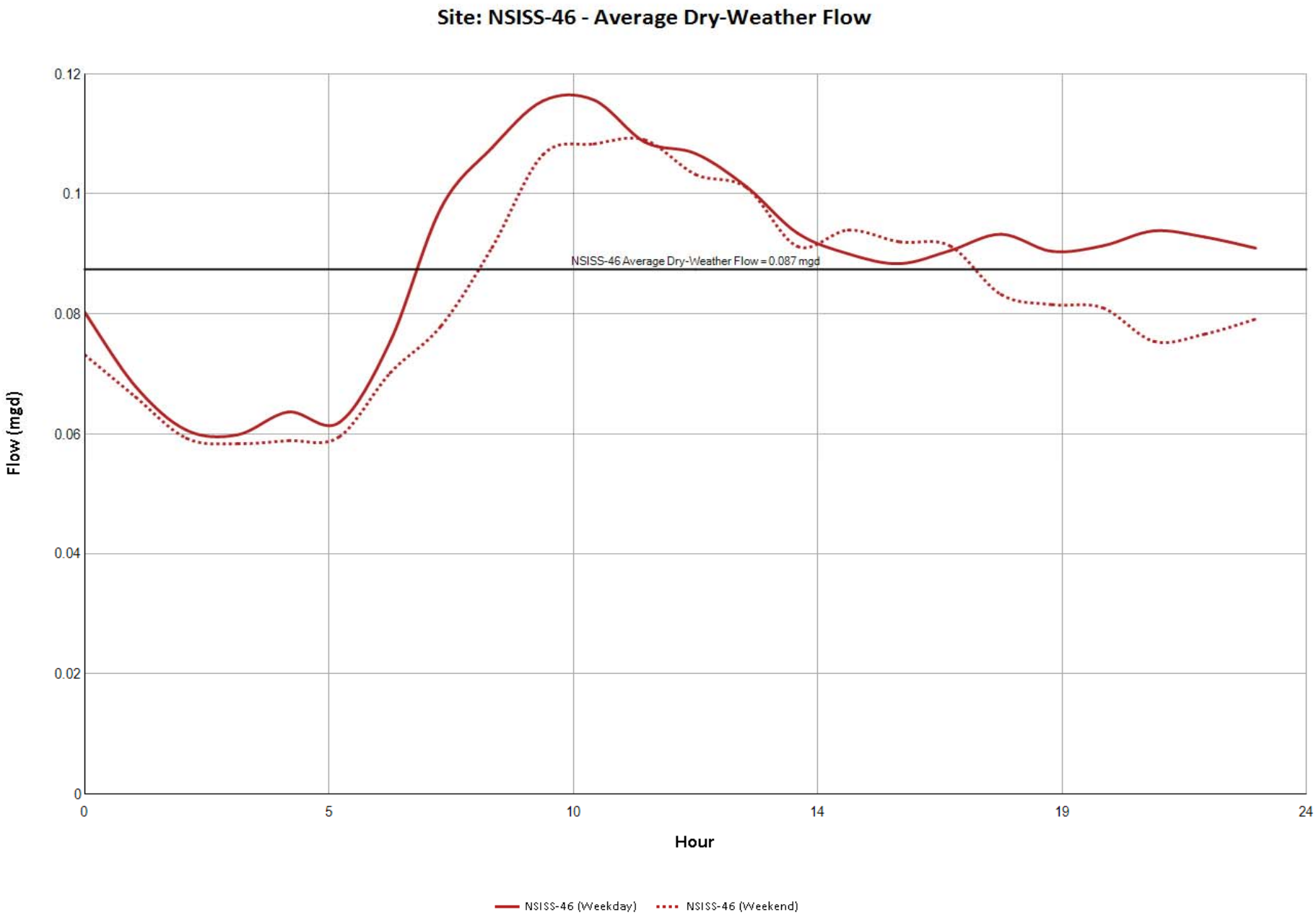

Site: NSISS-42 - Average Dry-Weather Flow
Flow (mgd)
2
1.5
1
0.5
0
NSISS-42 Average Dry-Weather Flow = 1.4 mgd
0
5
10
14
19
24
Hour
NSISS-42 (Weekday)
NSISS-42 (Weekend)

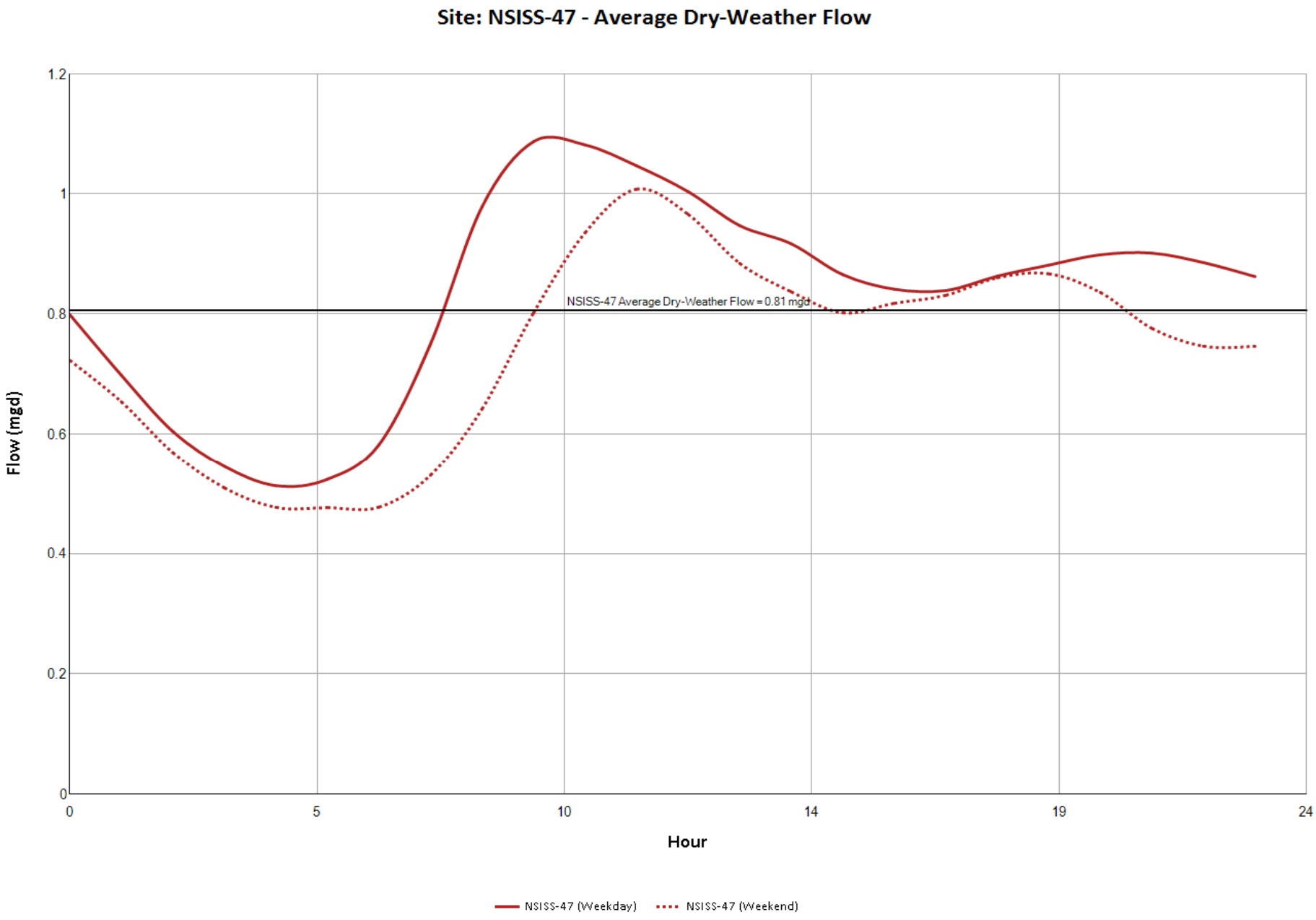
Site: NSISS-43 - Average Dry-Weather Flow

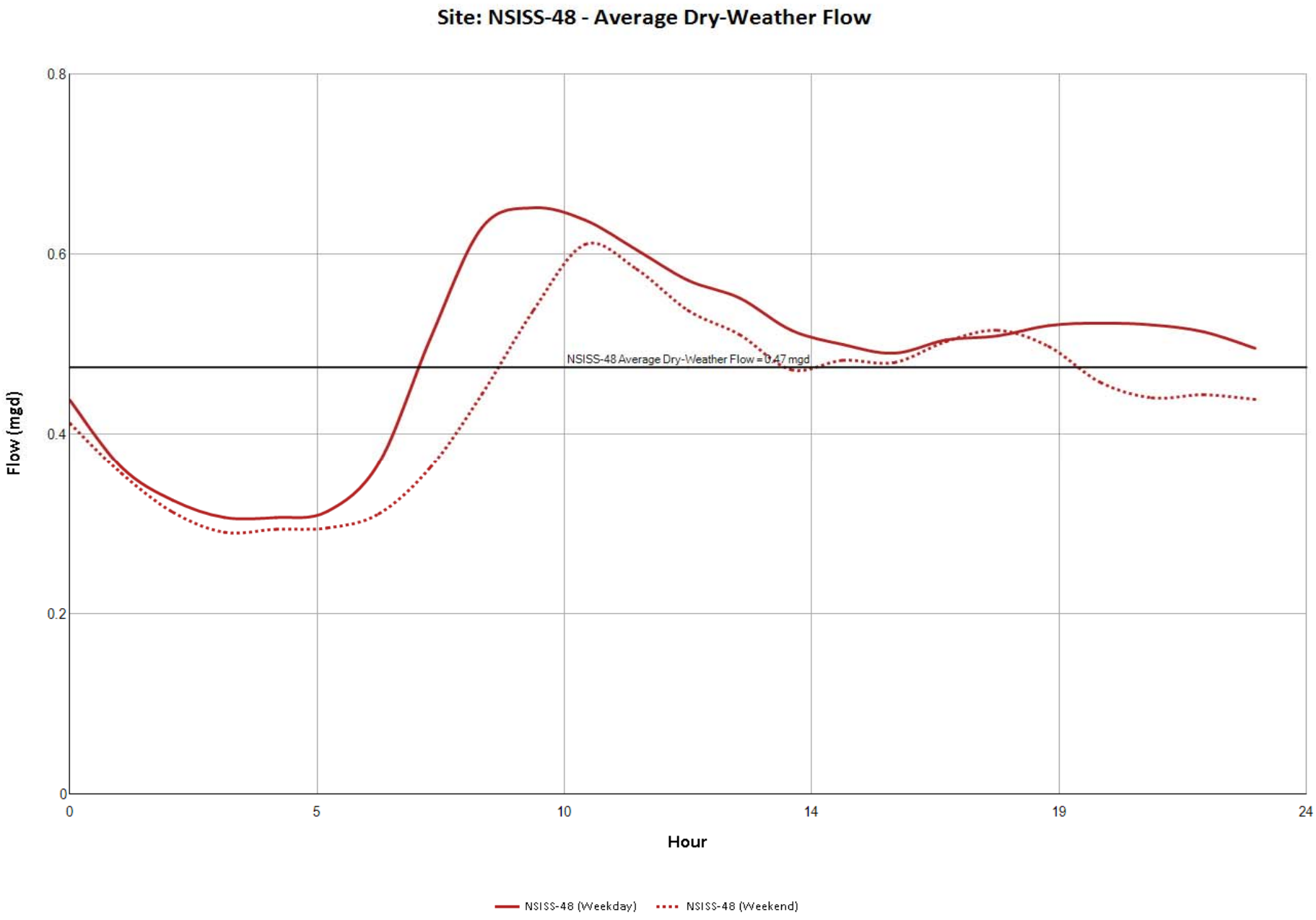


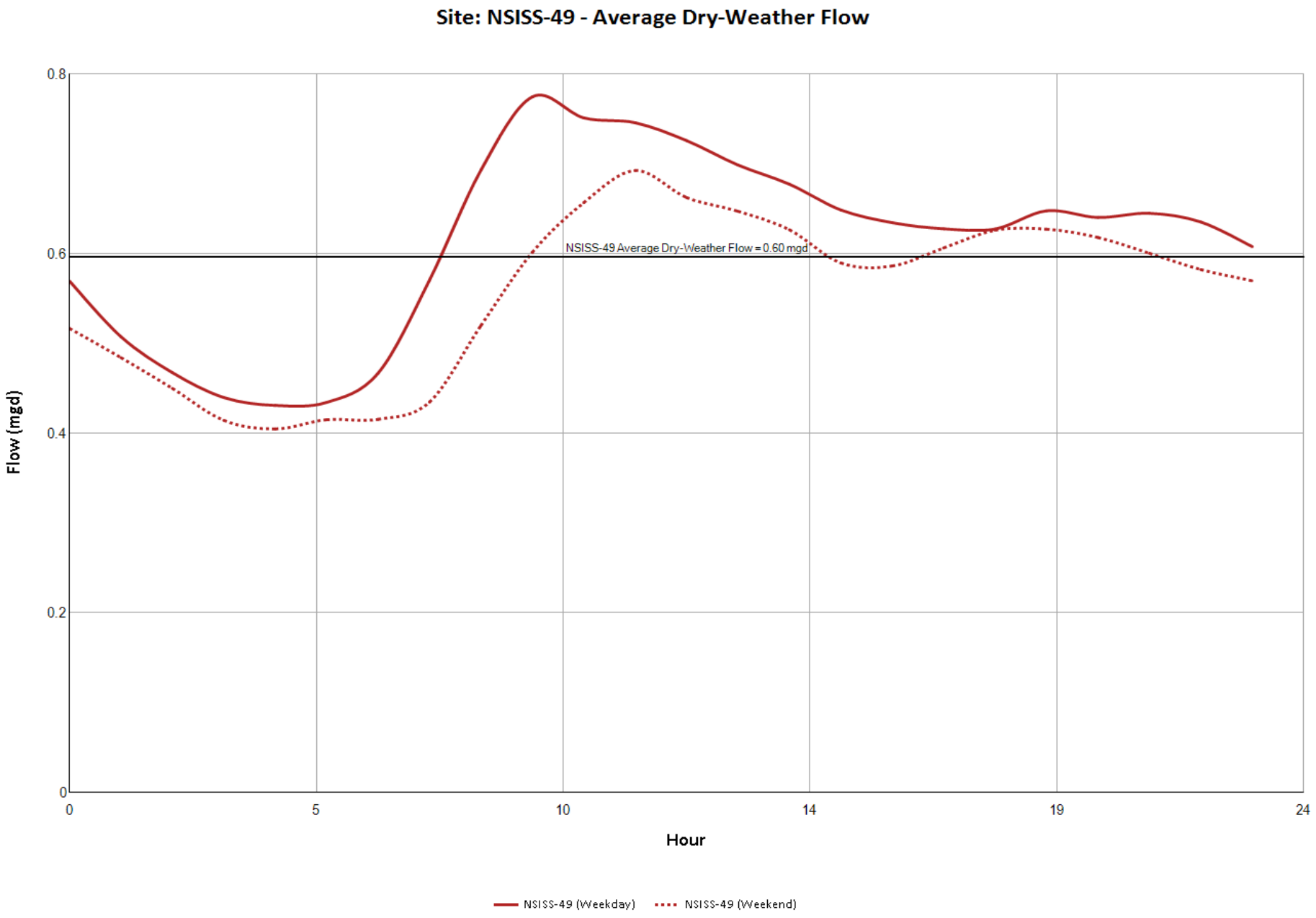

Site: NSISS-44 - Average Dry-Weather Flow
0.8
0.6
0.4
0.2
0
Flow (mgd)
NSISS-44 Average Dry-Weather Flow = 0.47 mgd
0
5
10
14
19
24
Hour
NSISS-44 (Weekday)
NSISS-44 (Weekend)


Site: NSISS-45 - Average Dry-Weather Flow
Flow (mgd)
1
0.8
0.6
0.4
0.2
0
NSISS-45 Average Dry-Weather Flow = 0.64 mgd
0
5
10
14
19
24
Hour
NSISS-45 (Weekday)
NSISS-45 (Weekend)


Site: NSISS-46 - Average Dry-Weather Flow
0.12
0.1
0.08
0.06
0.04
0.02
0
Flow (mgd)
NSISS-46 Average Dry-Weather Flow = 0.087 mgd
0
5
10
14
19
24
Hour
NSISS-46 (Weekday)
NSISS-46 (Weekend)


Site: NSISS-47 - Average Dry-Weather Flow
Flow (mgd)
1.2
1
0.8
0.6
0.4
0.2
0
NSISS-47 Average Dry-Weather Flow = 0.81 mgd
0
5
10
14
19
24
Hour
NSISS-47 (Weekday)
NSISS-47 (Weekend)

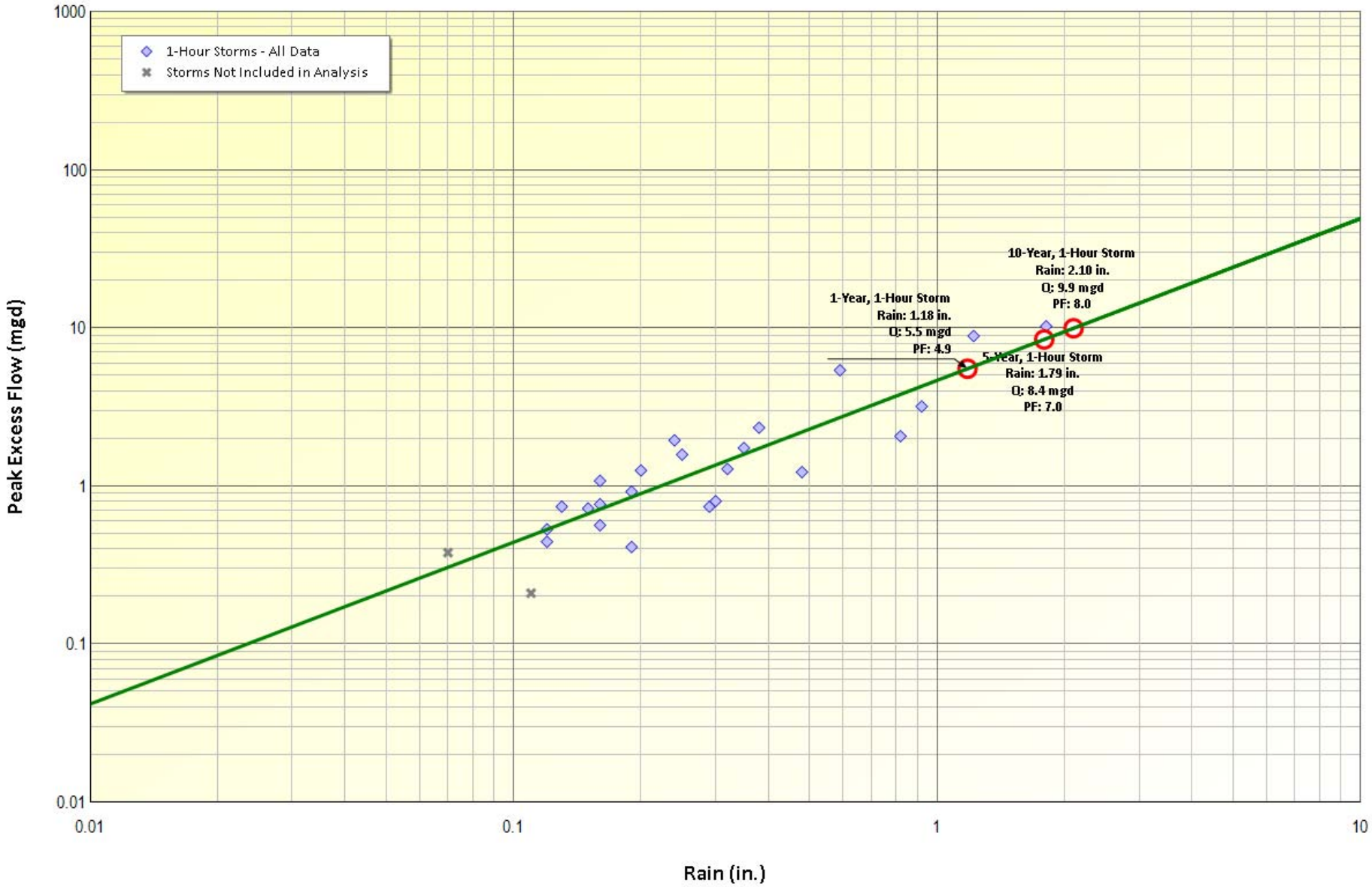

Site: NSISS-48 - Average Dry-Weather Flow
0.8
0.6
0.4
0.2
0
Flow (mgd)
NSISS-48 Average Dry-Weather Flow = 0.47 mgd
0
5
10
14
19
24
Hour
NSISS-48 (Weekday)
NSISS-48 (Weekend)


Site: NSISS-49 - Average Dry-Weather Flow
0.8
0.6
0.4
0.2
0
Flow (mgd)
NSISS-49 Average Dry-Weather Flow = 0.60 mgd
0
5
10
14
19
24
Hour
NSISS-49 (Weekday)
NSISS-49 (Weekend)

APPENDIX C – Regression Analysis

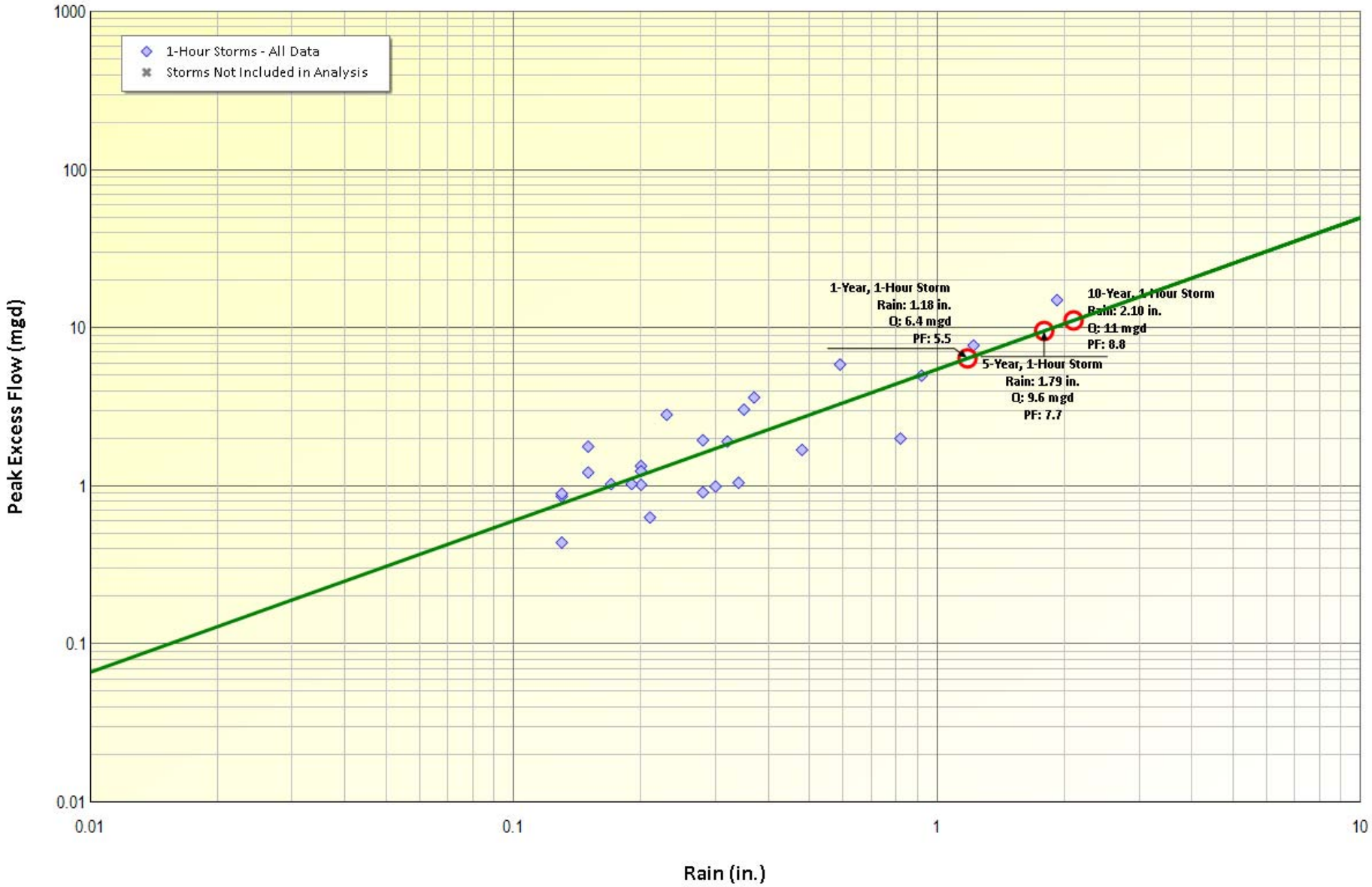
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-21



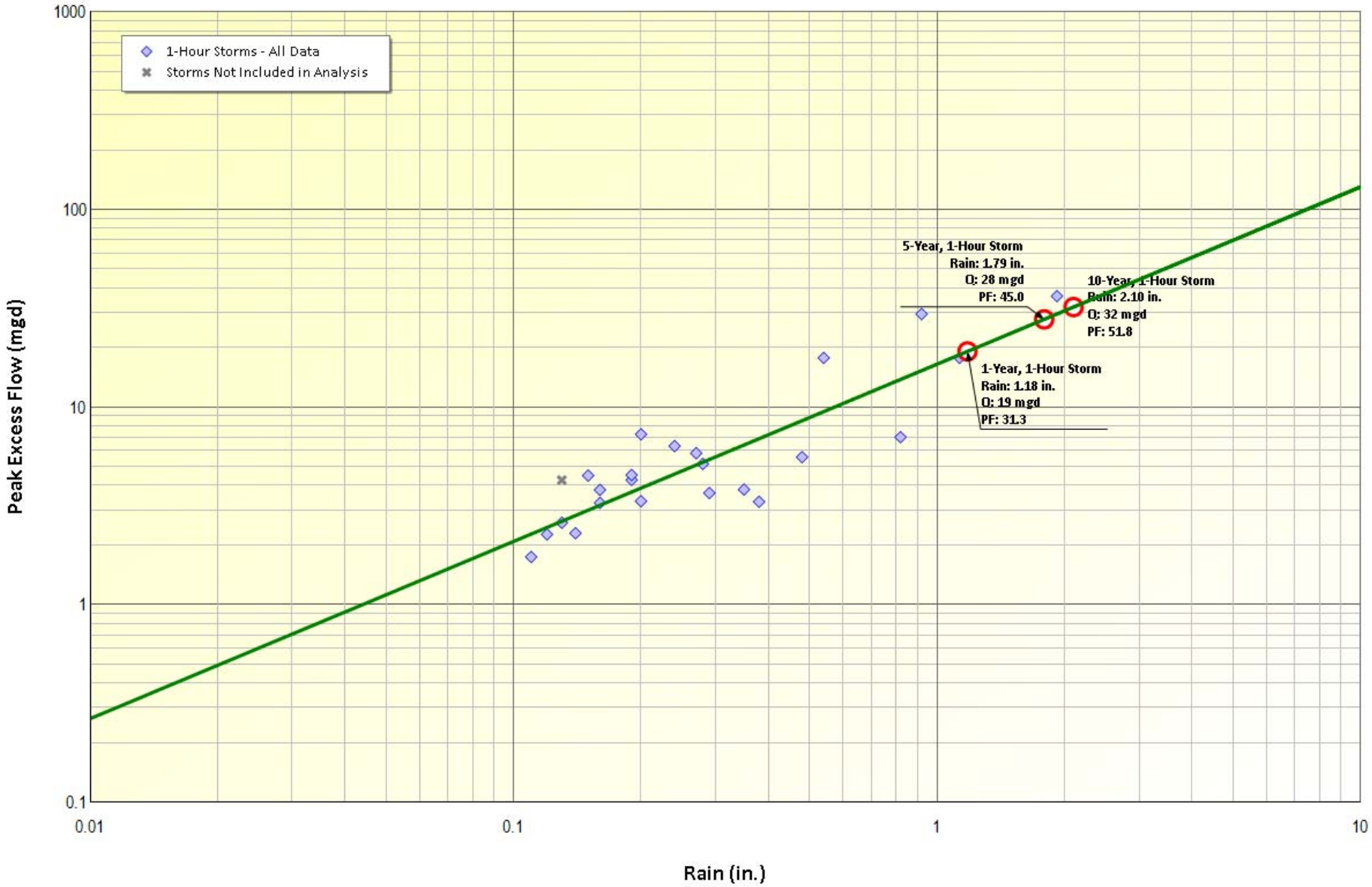
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-22



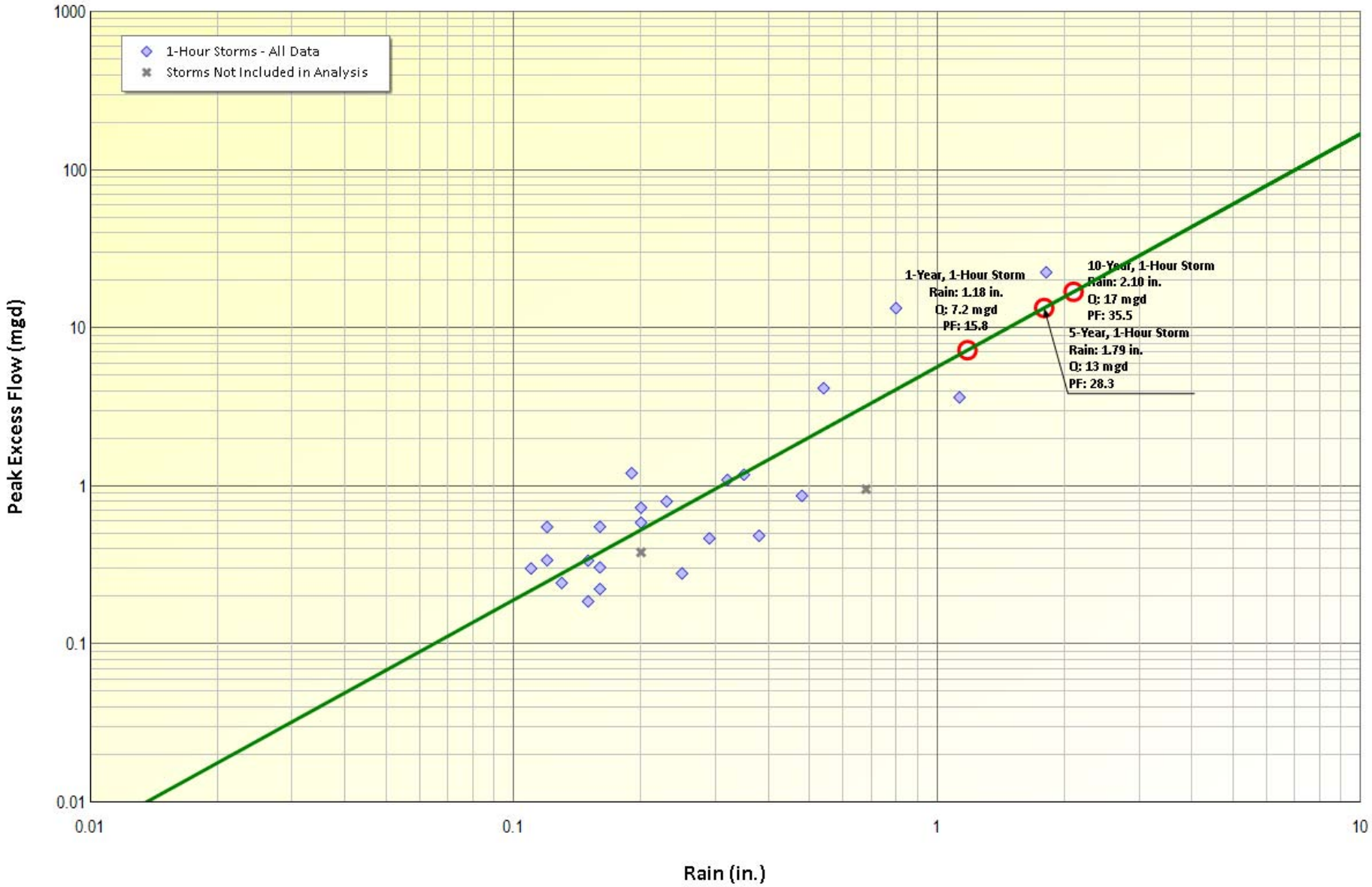
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-32



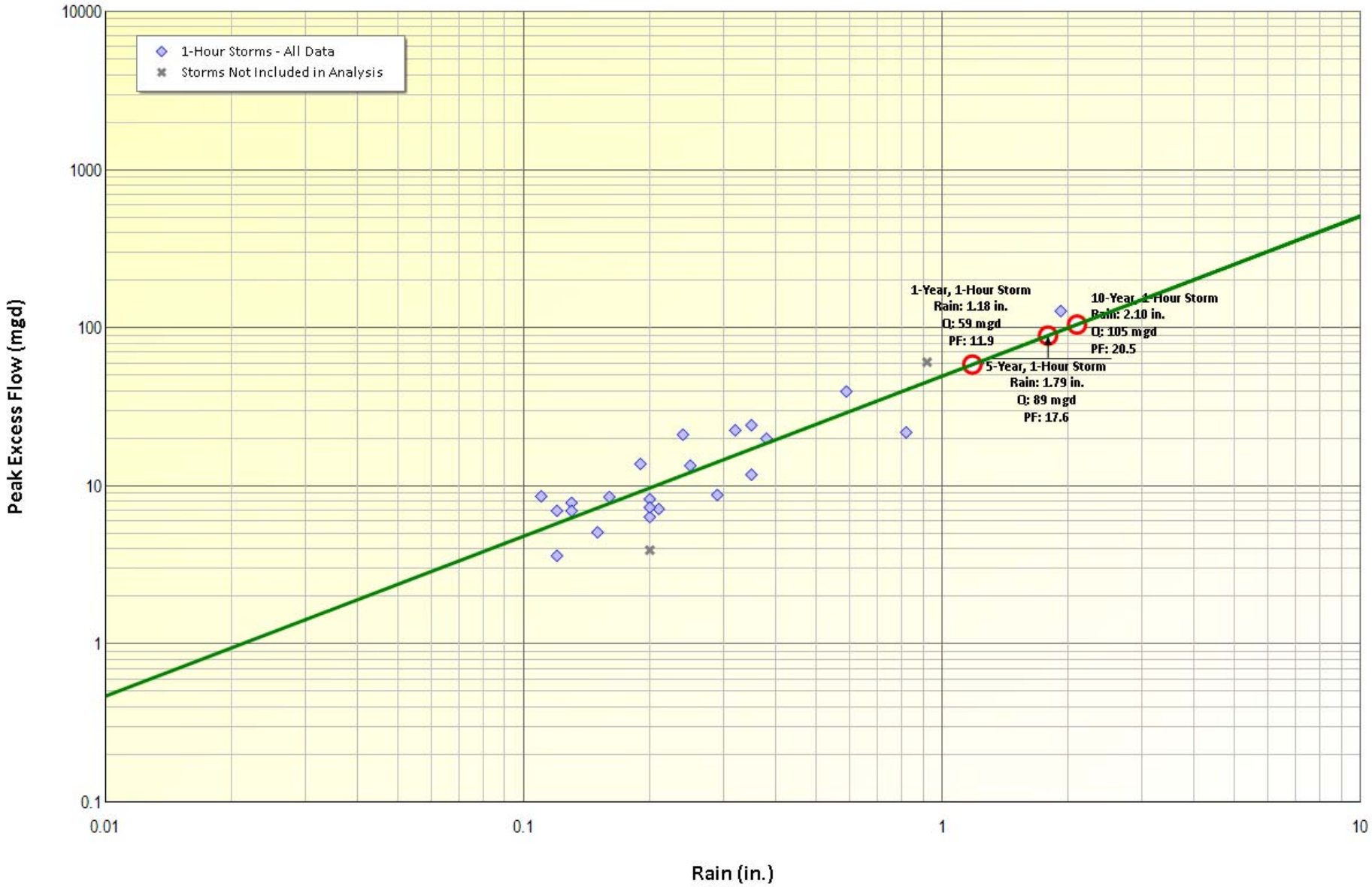
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-35



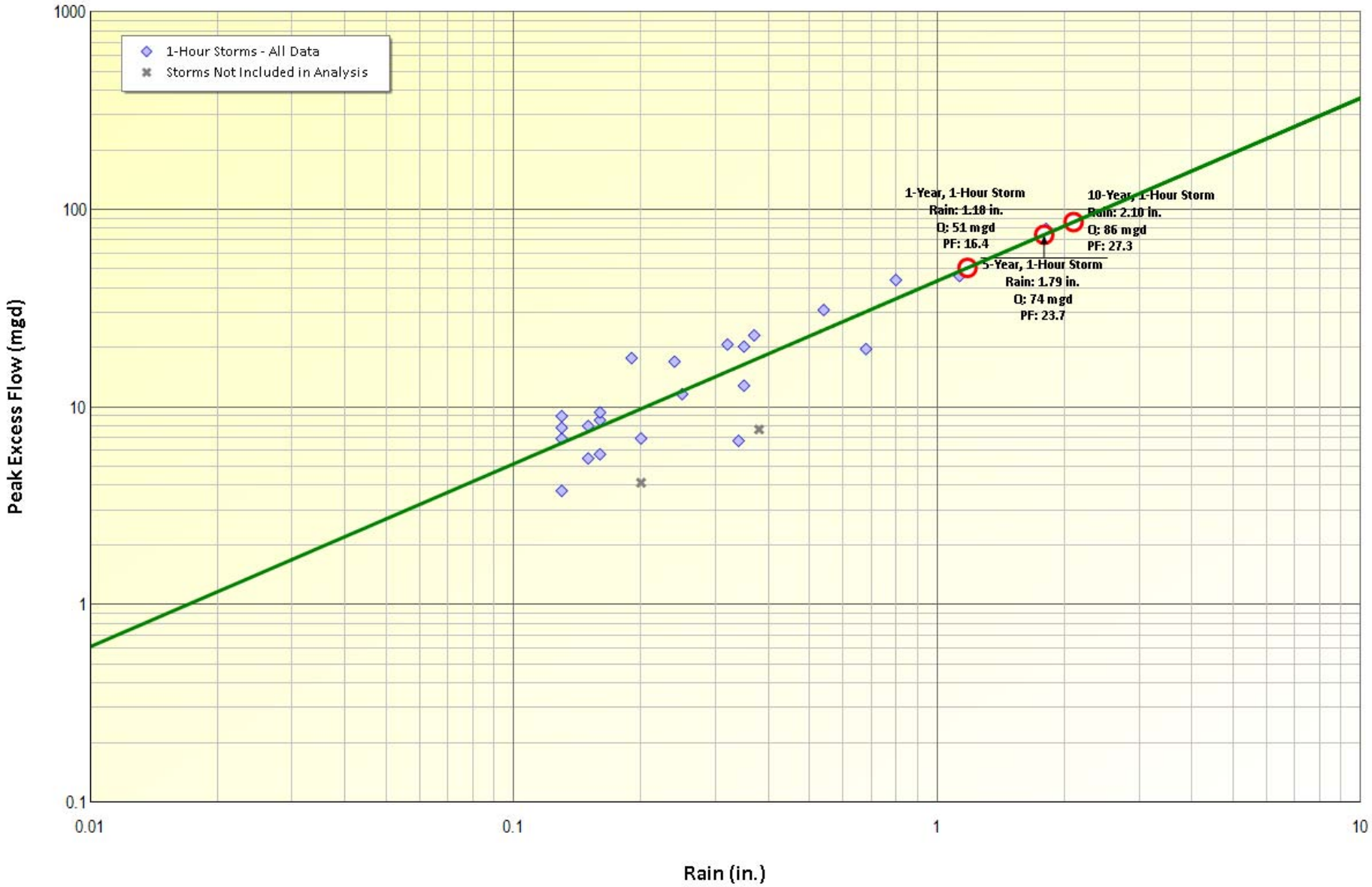
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-36



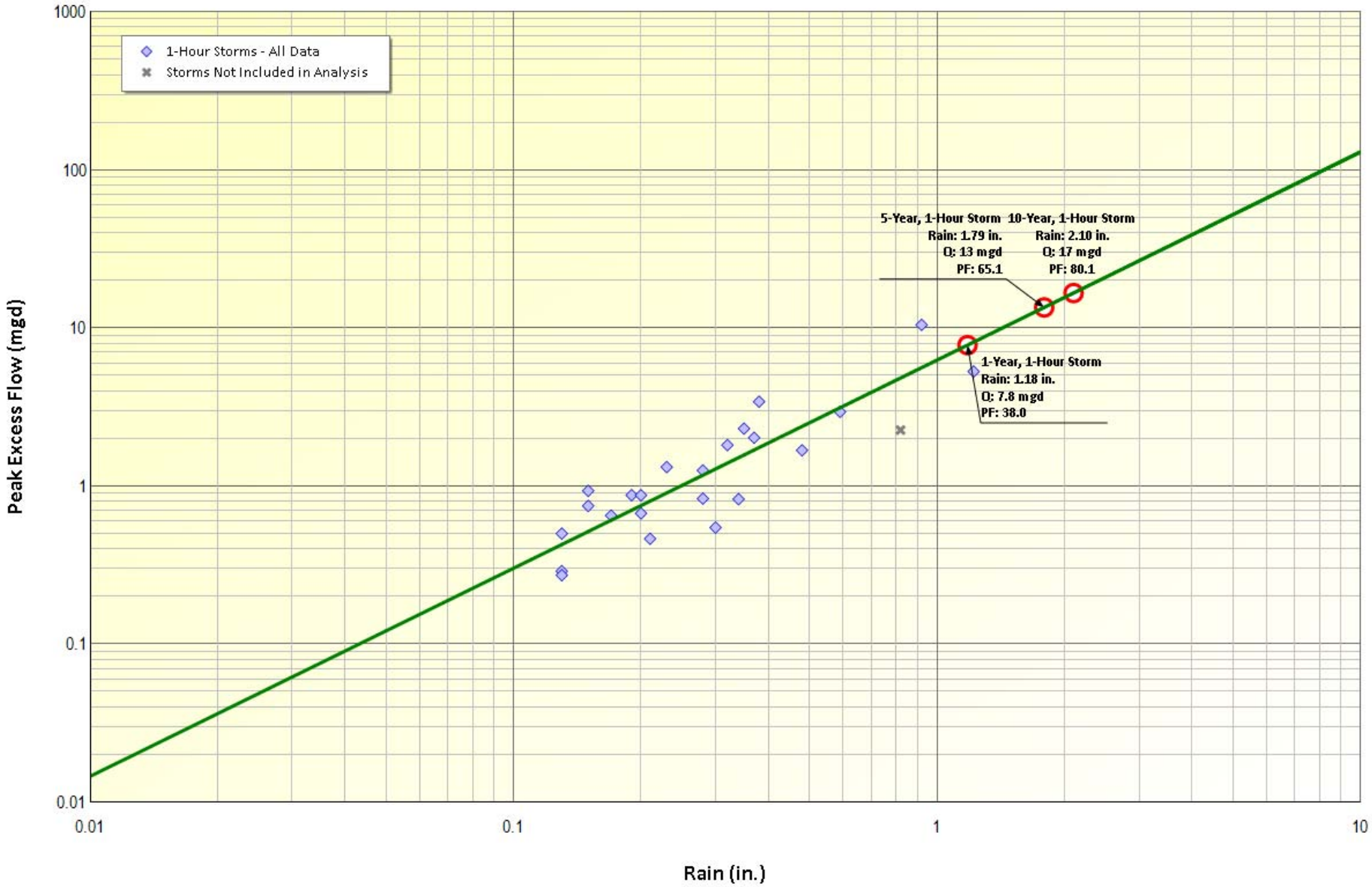
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-37



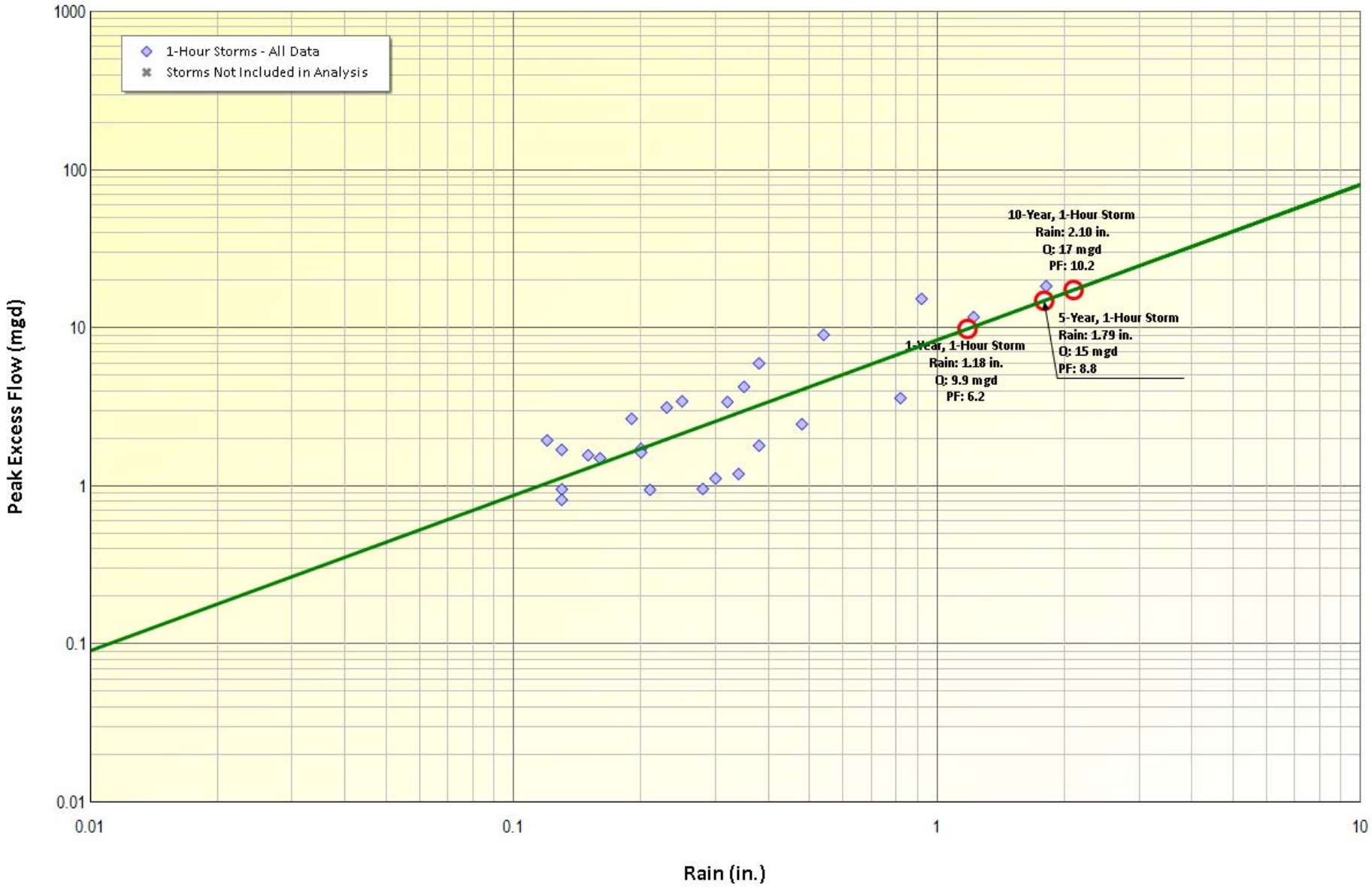
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-38



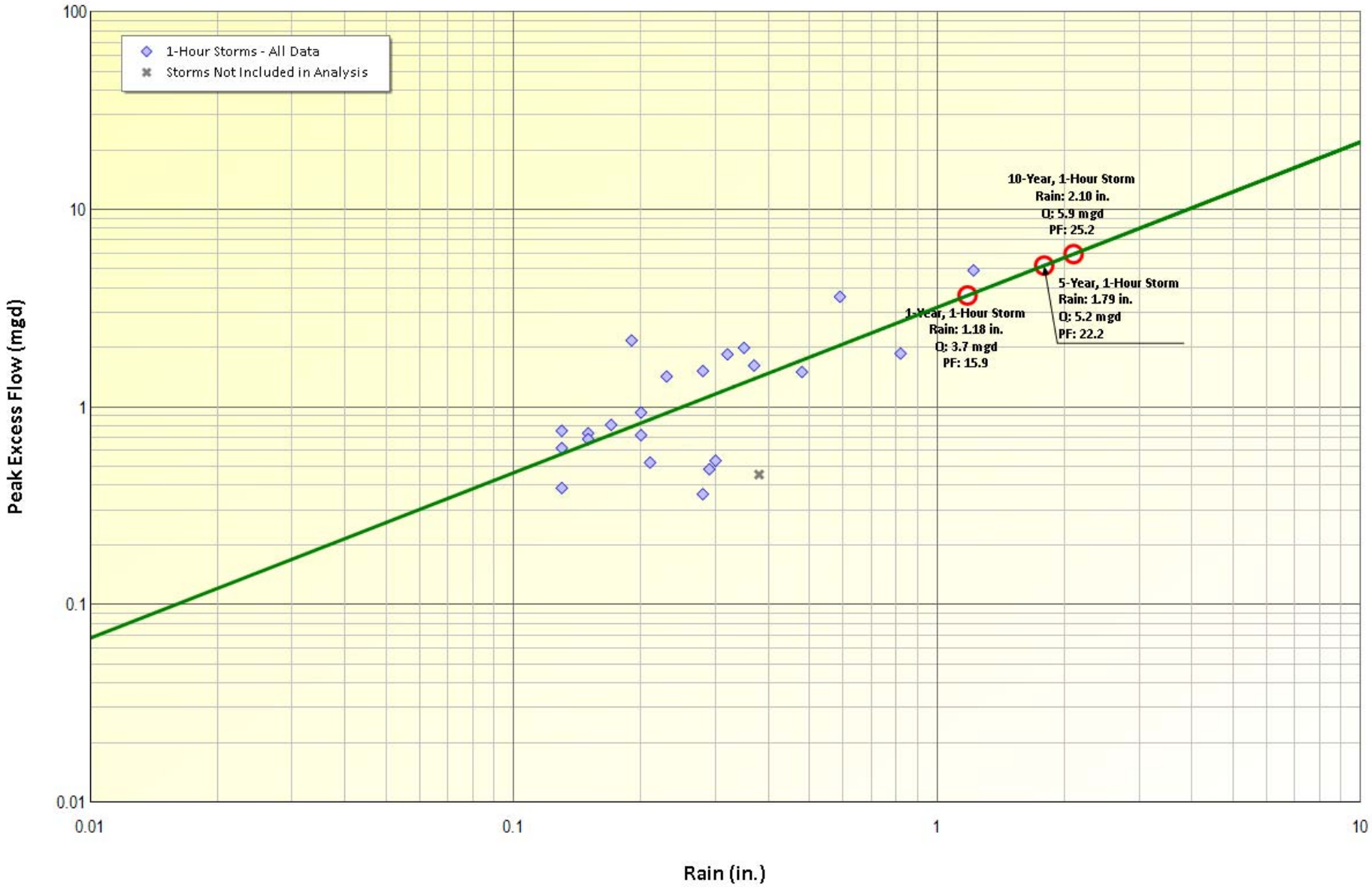
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-39



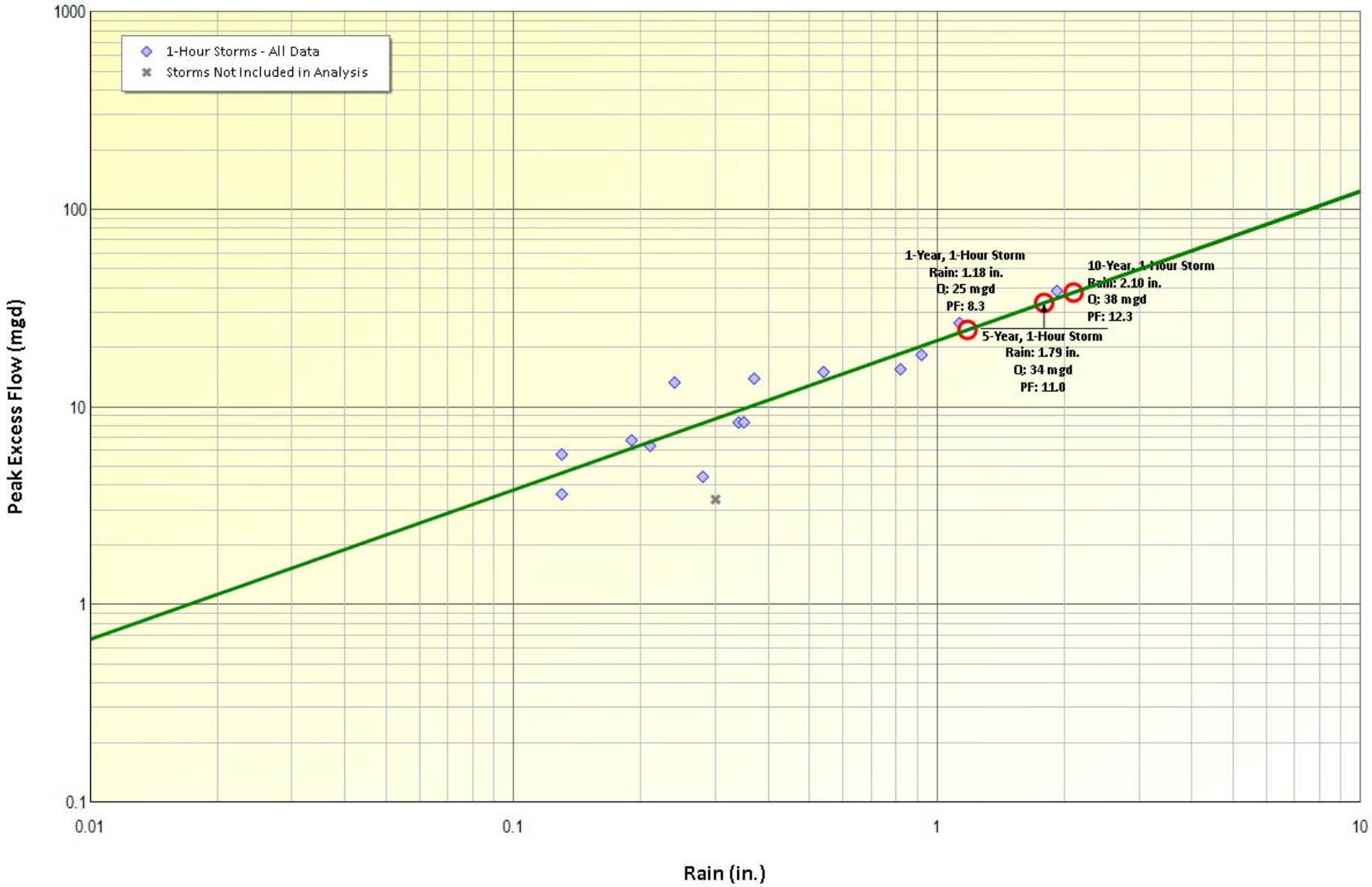
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-40



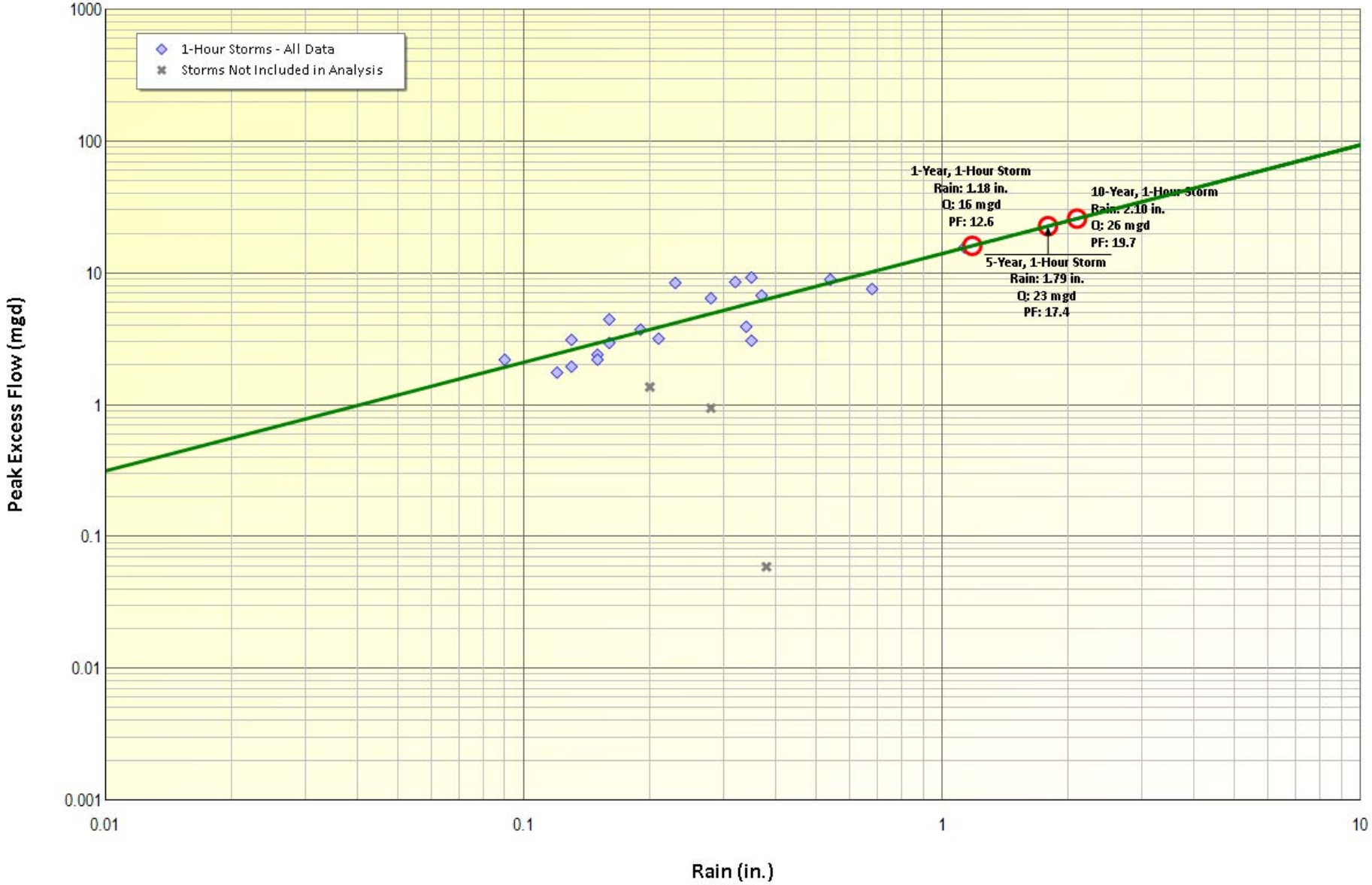
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-41A



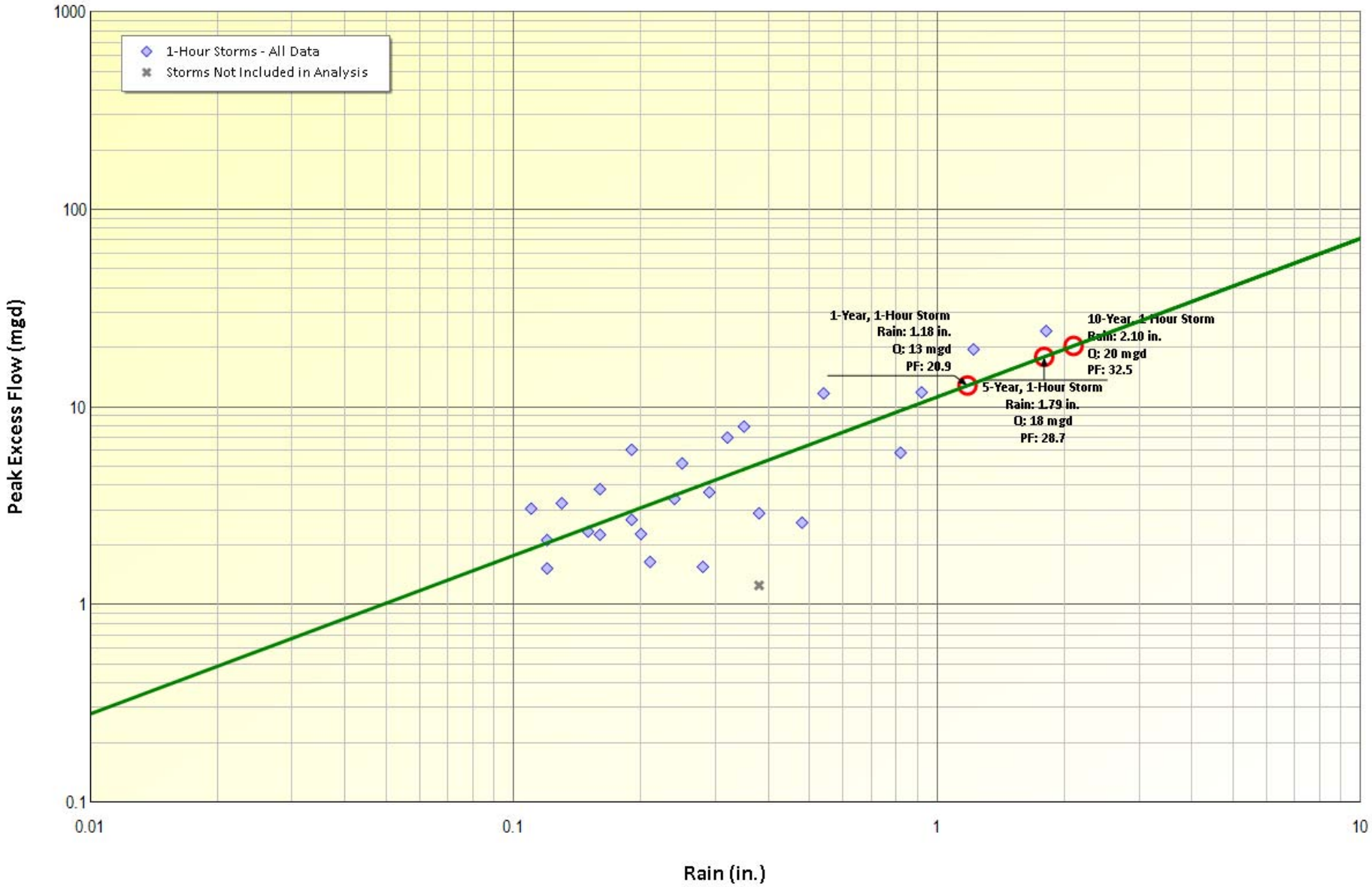
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-42



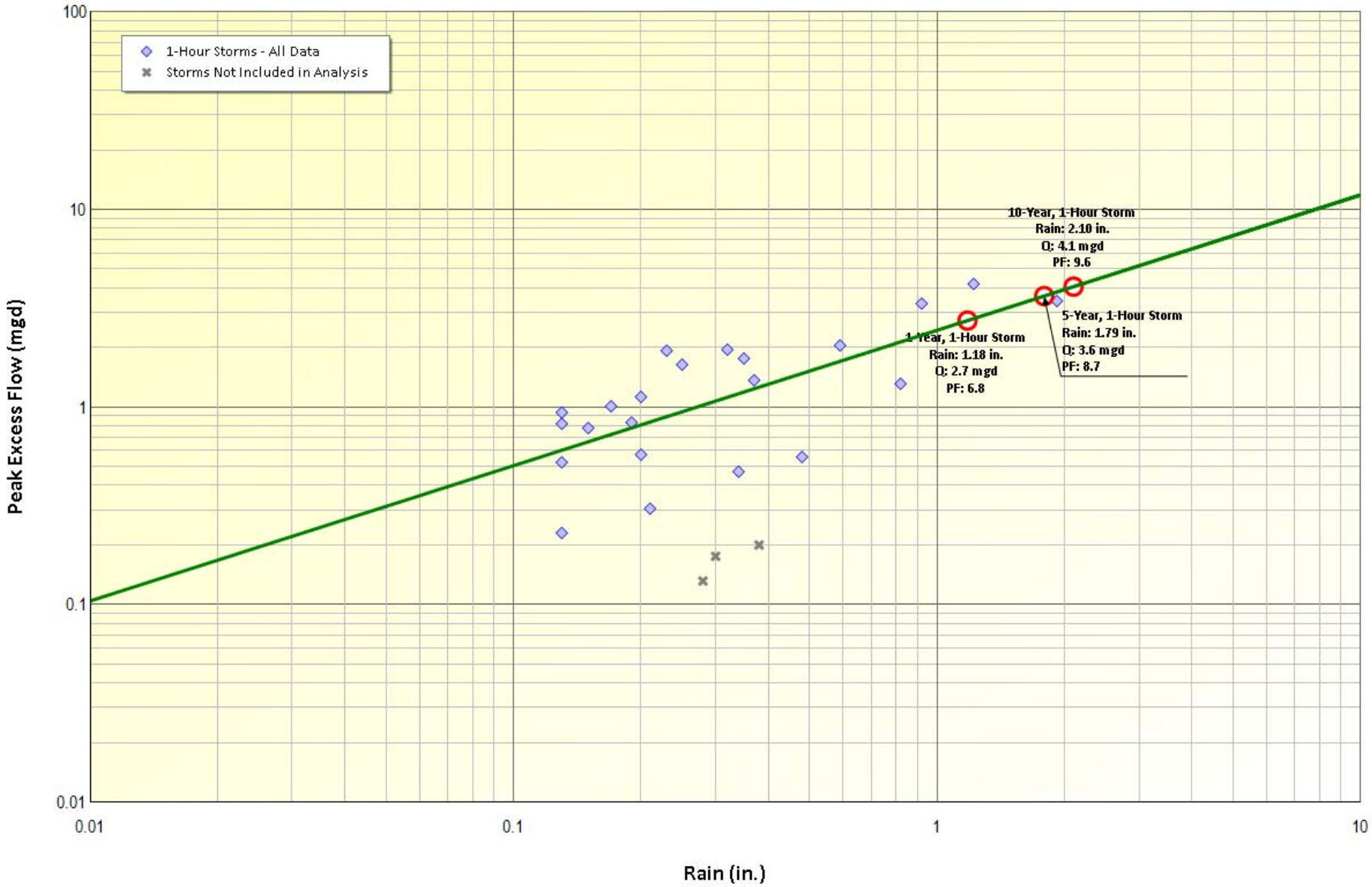
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-43



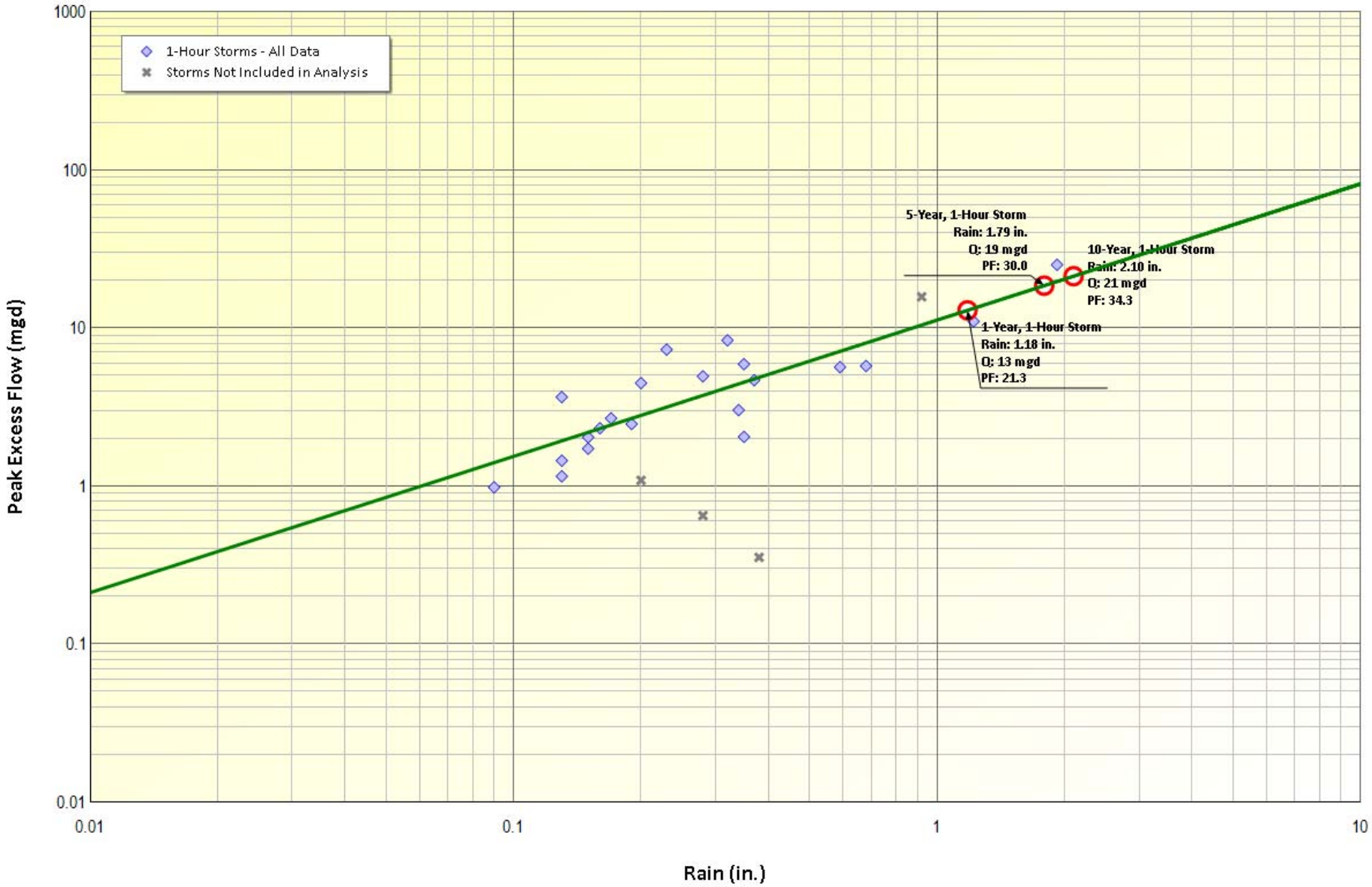
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-44



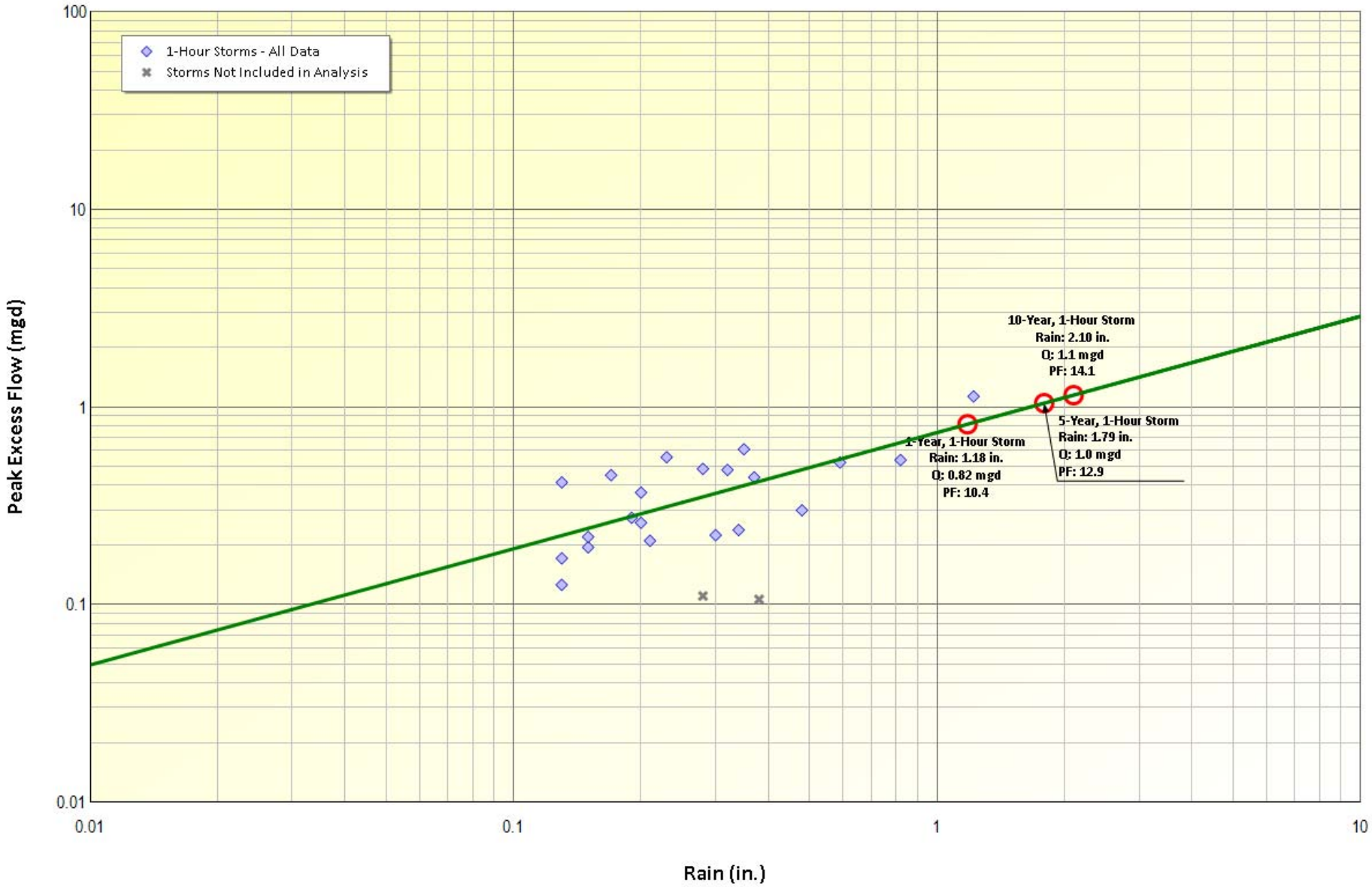
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-45



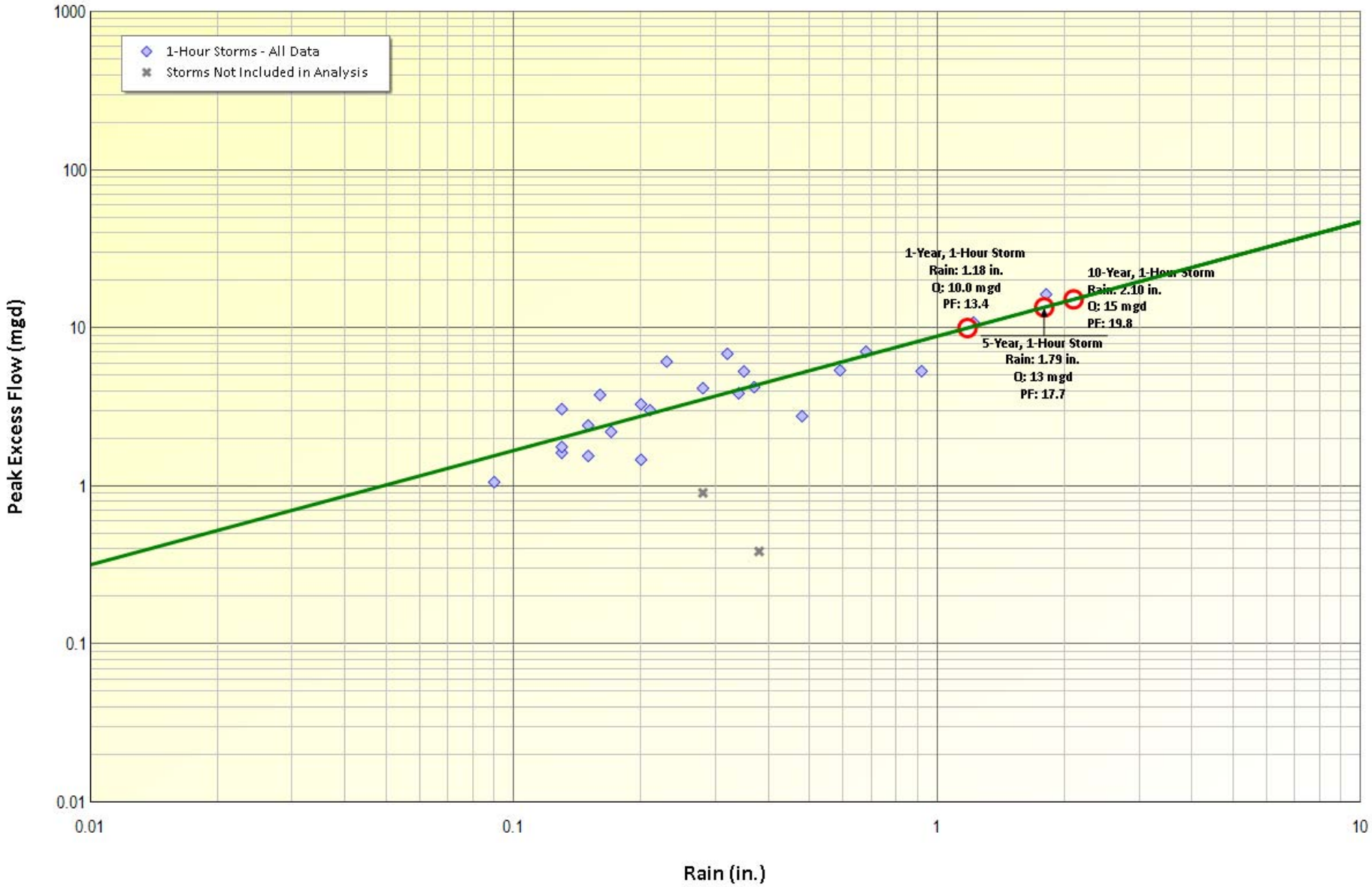
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-46



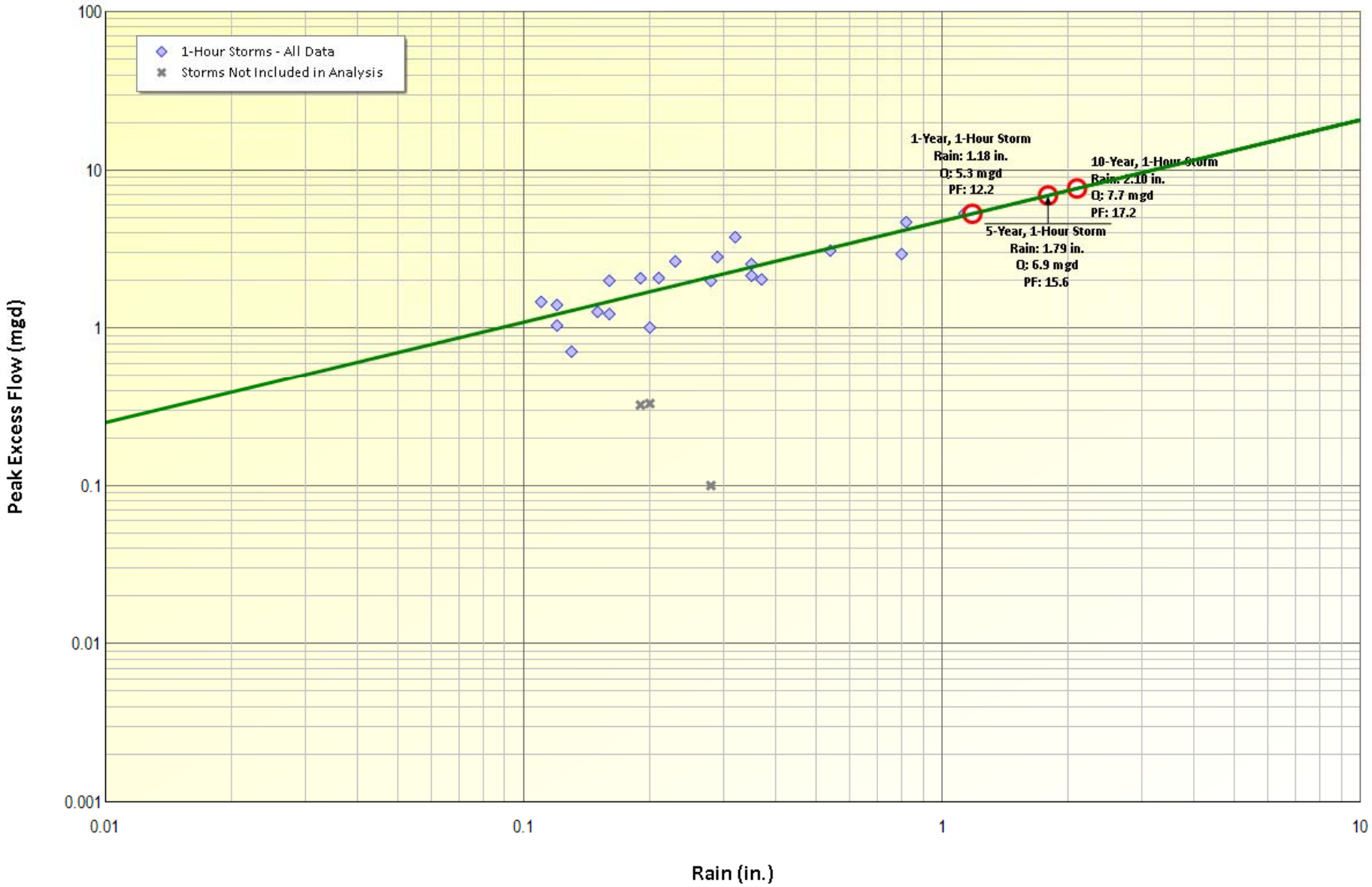
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-47



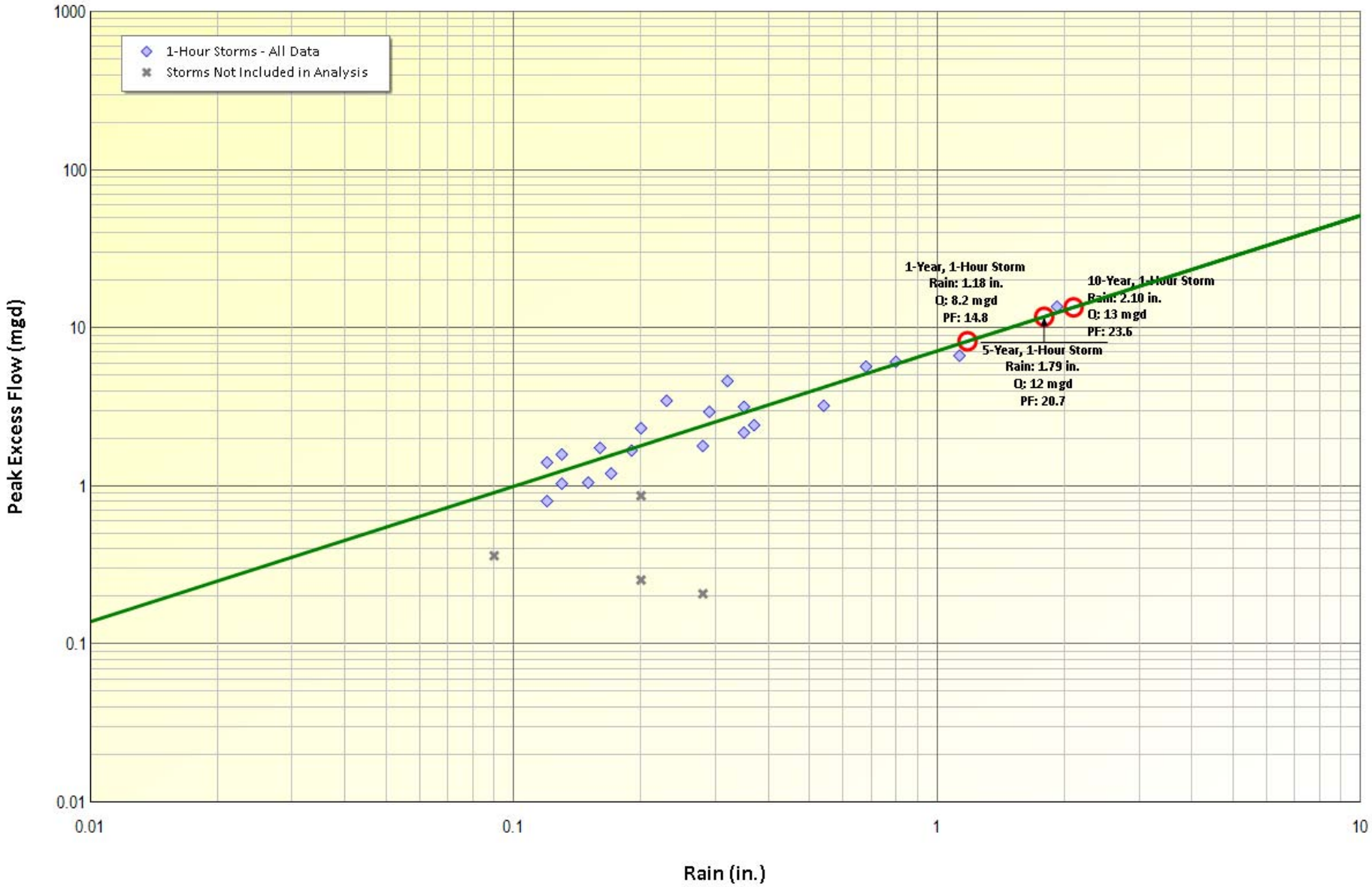
1-Hour Flow vs. Rainfall Regression

Cumulative Basin NSISS-48



1-Hour Flow vs. Rainfall Regression

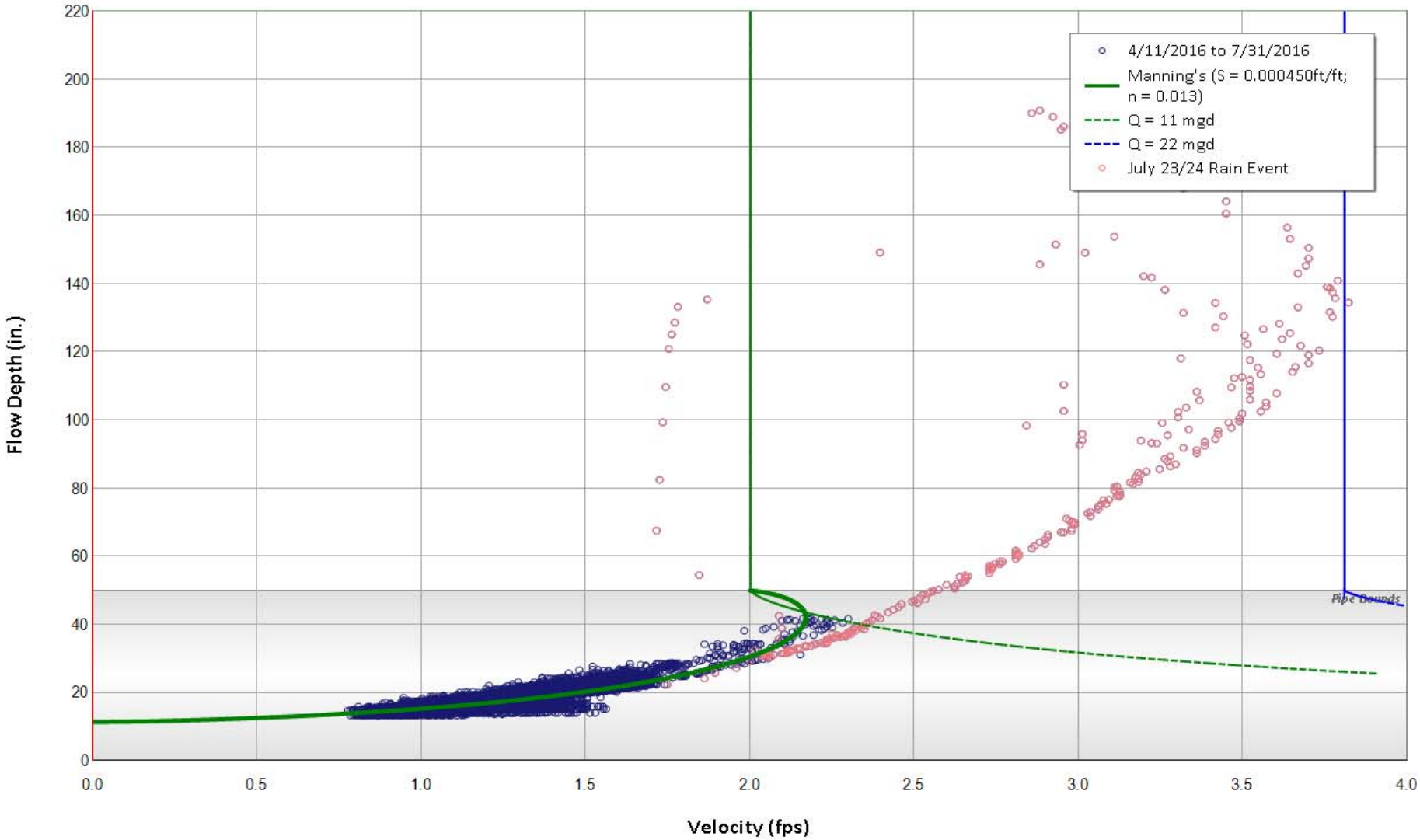
Cumulative Basin NSISS-49



APPENDIX D – Scattergraphs

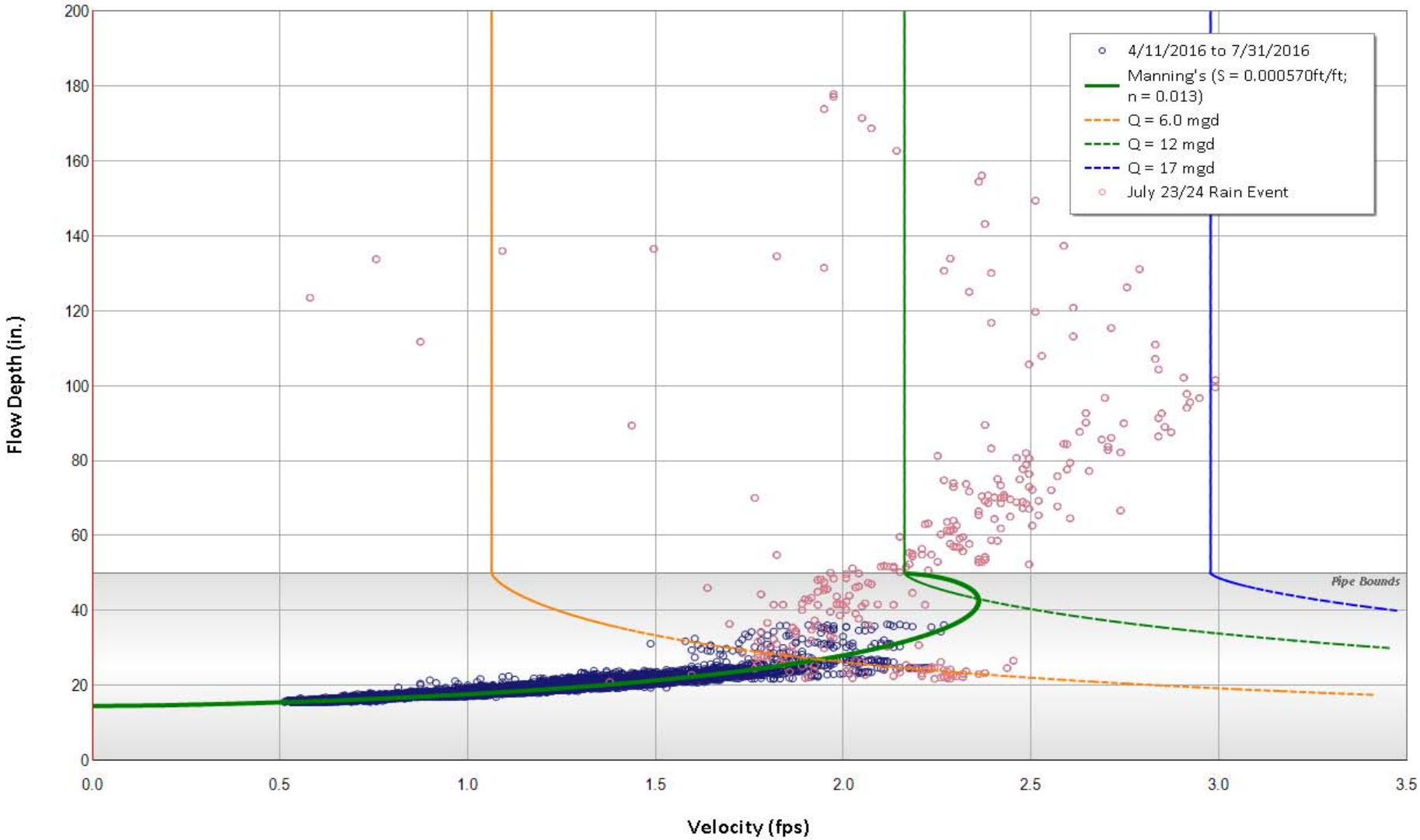
Scattergraph

Meter Site: NSISS-21



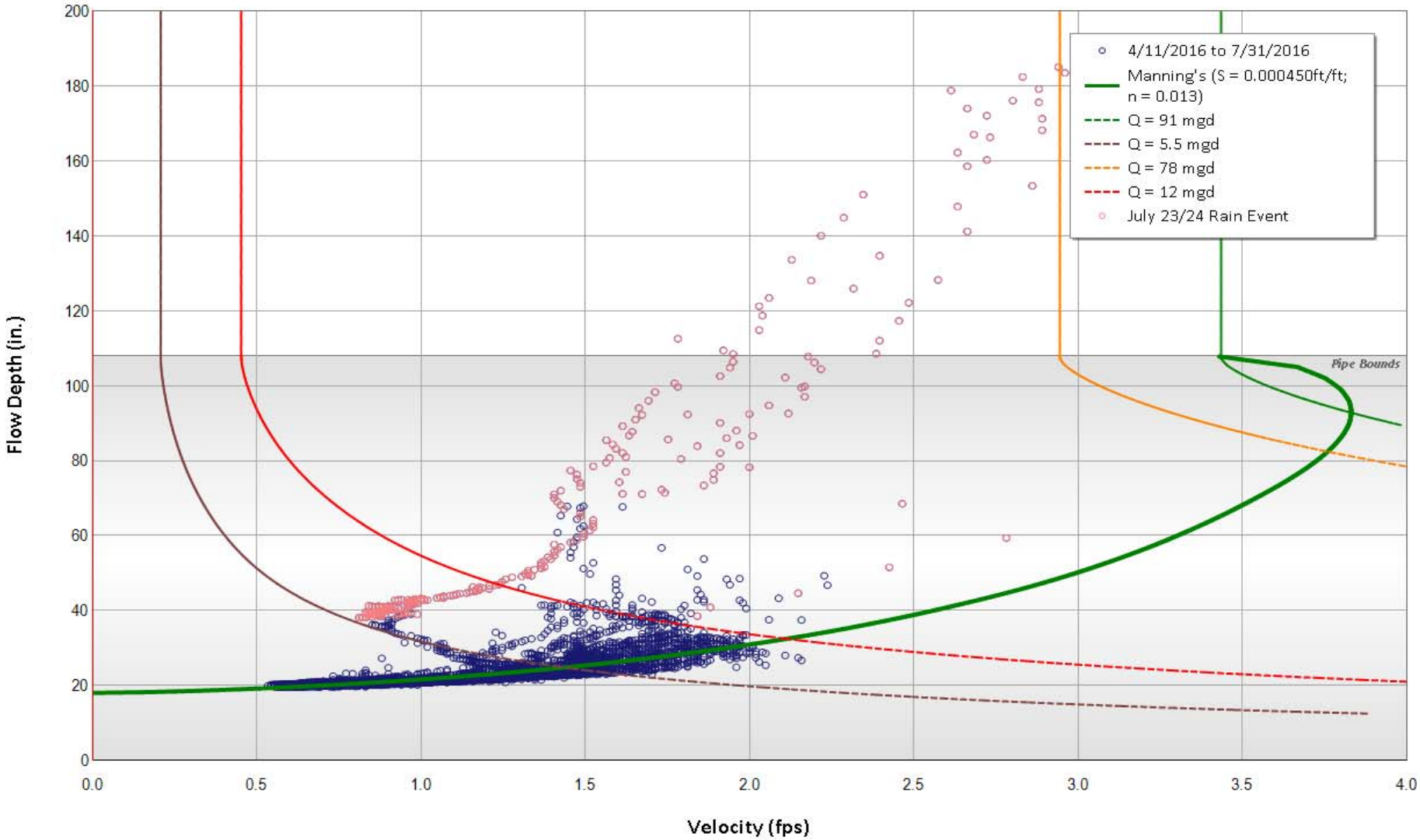
Scattergraph

Meter Site: NSISS-22



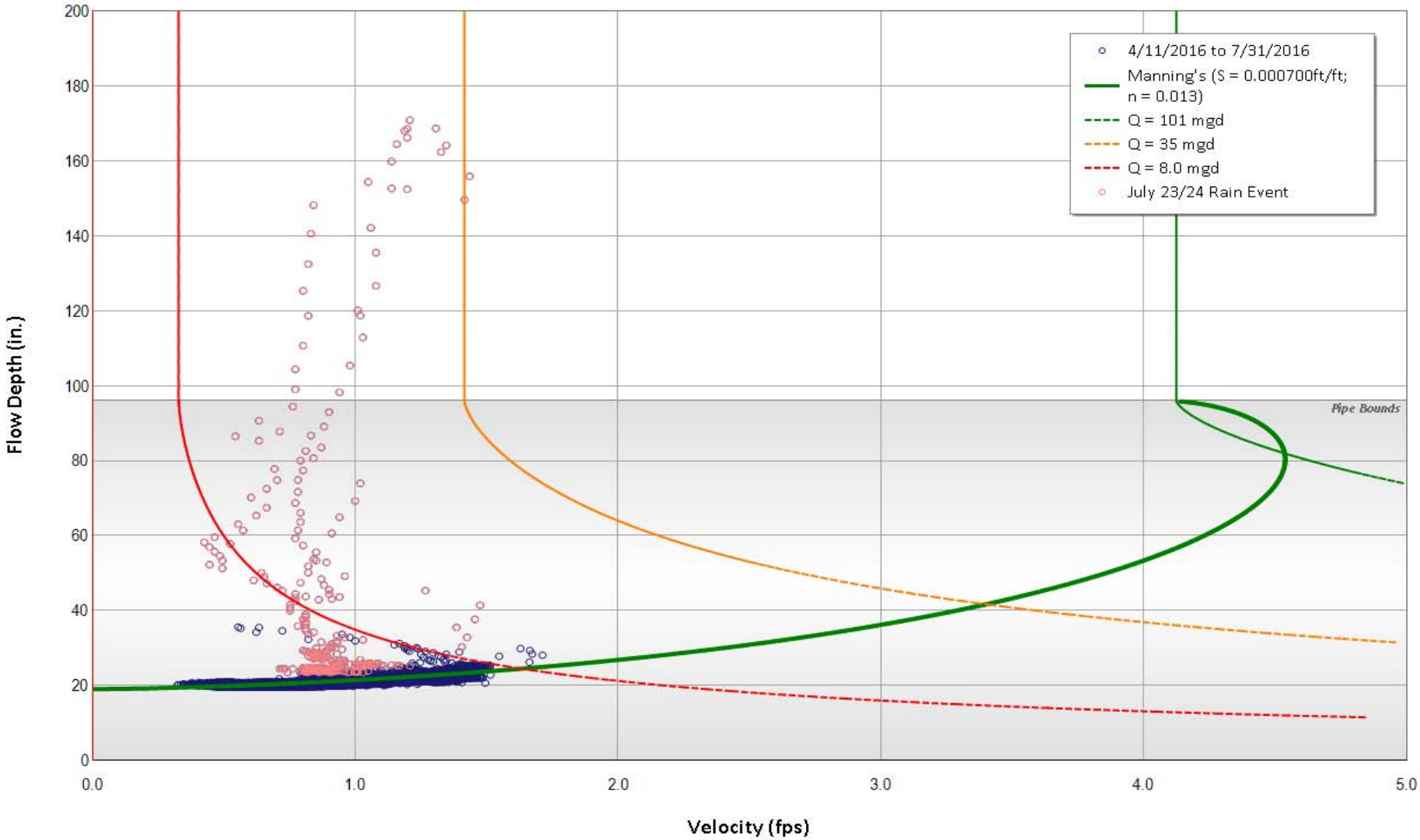
Scattergraph

Meter Site: NSISS-32



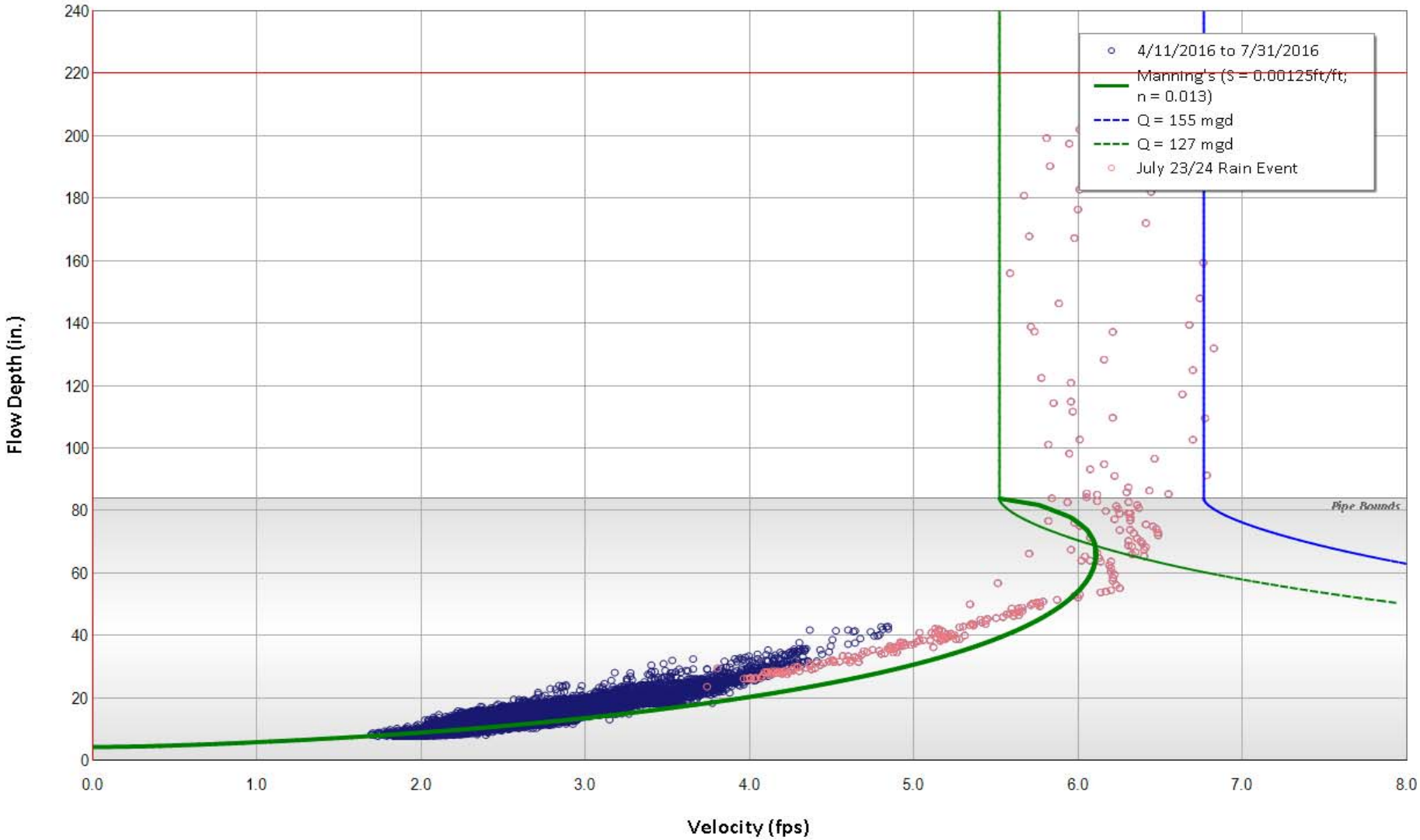
Scattergraph

Meter Site: NSISS-35



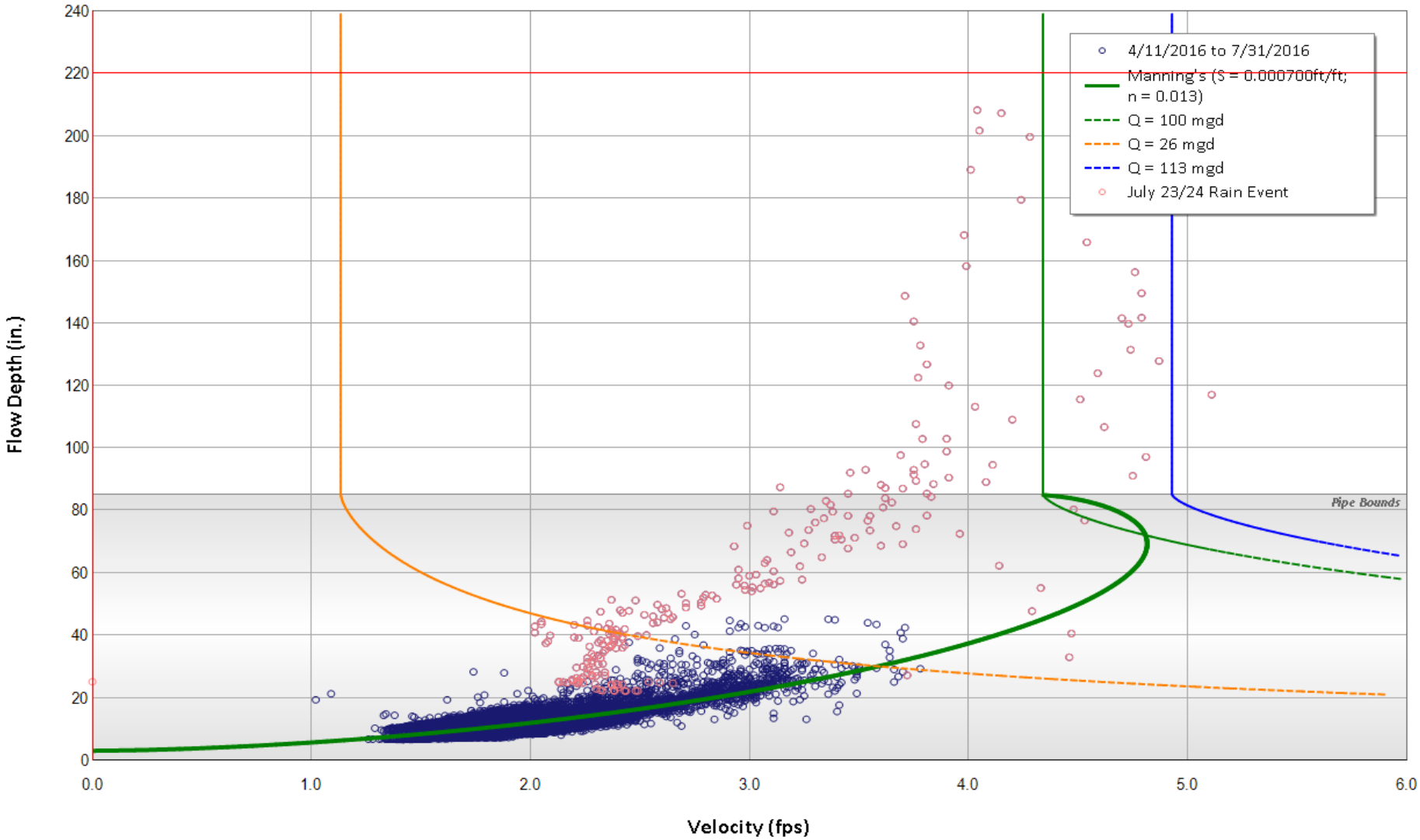
Scattergraph

Meter Site: NSISS-36



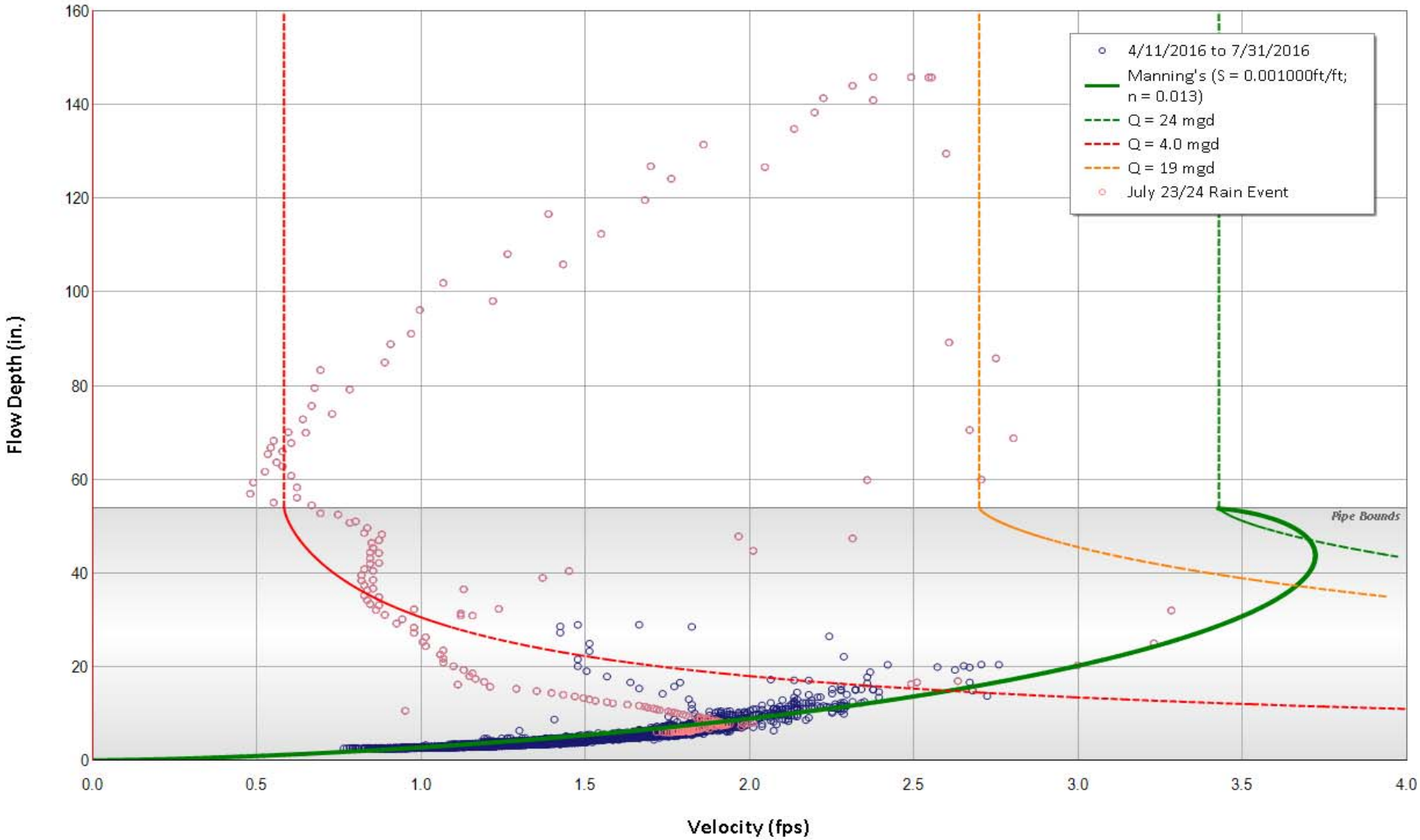
Scattergraph

Meter Site: NSISS-37



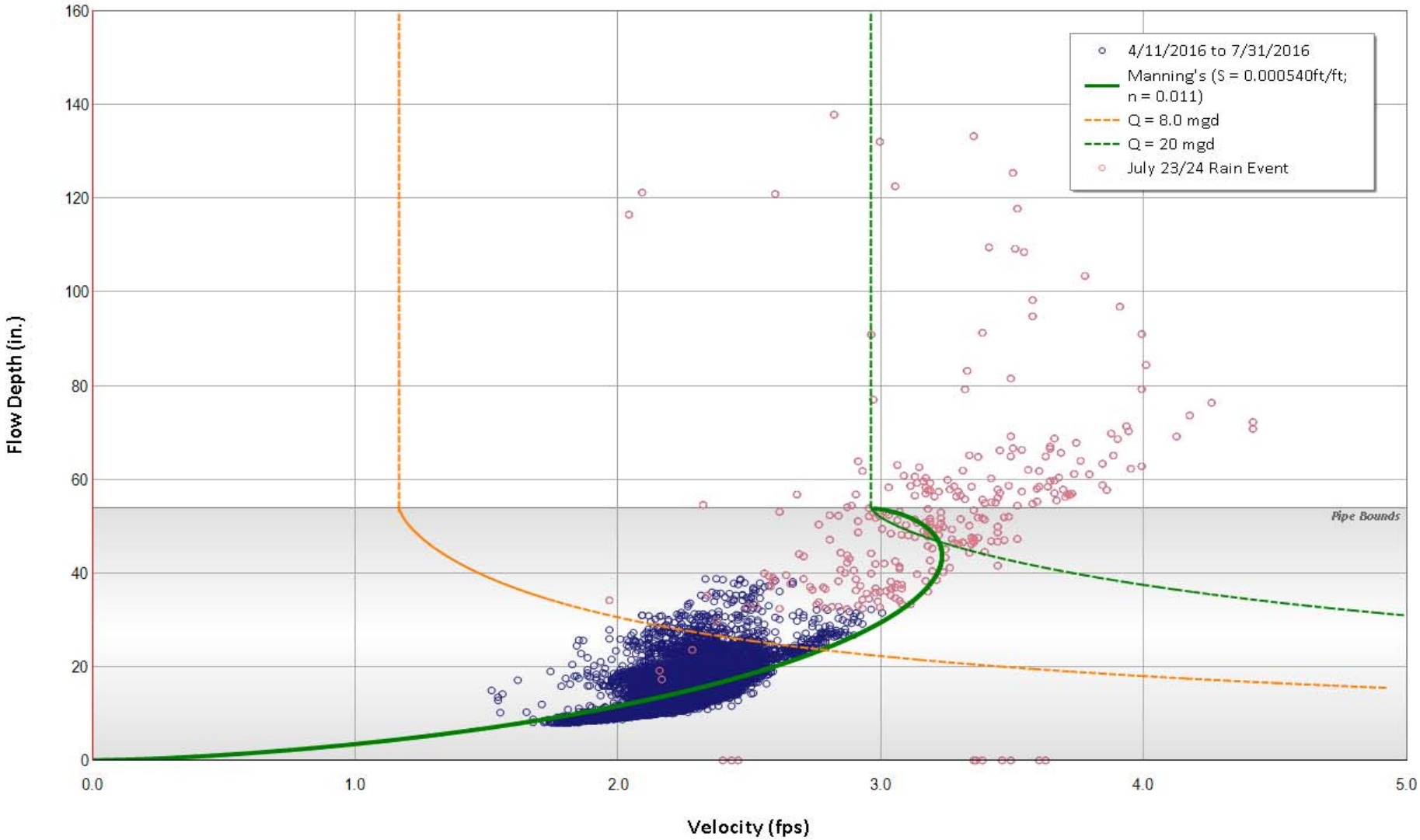
Scattergraph

Meter Site: NSISS-38



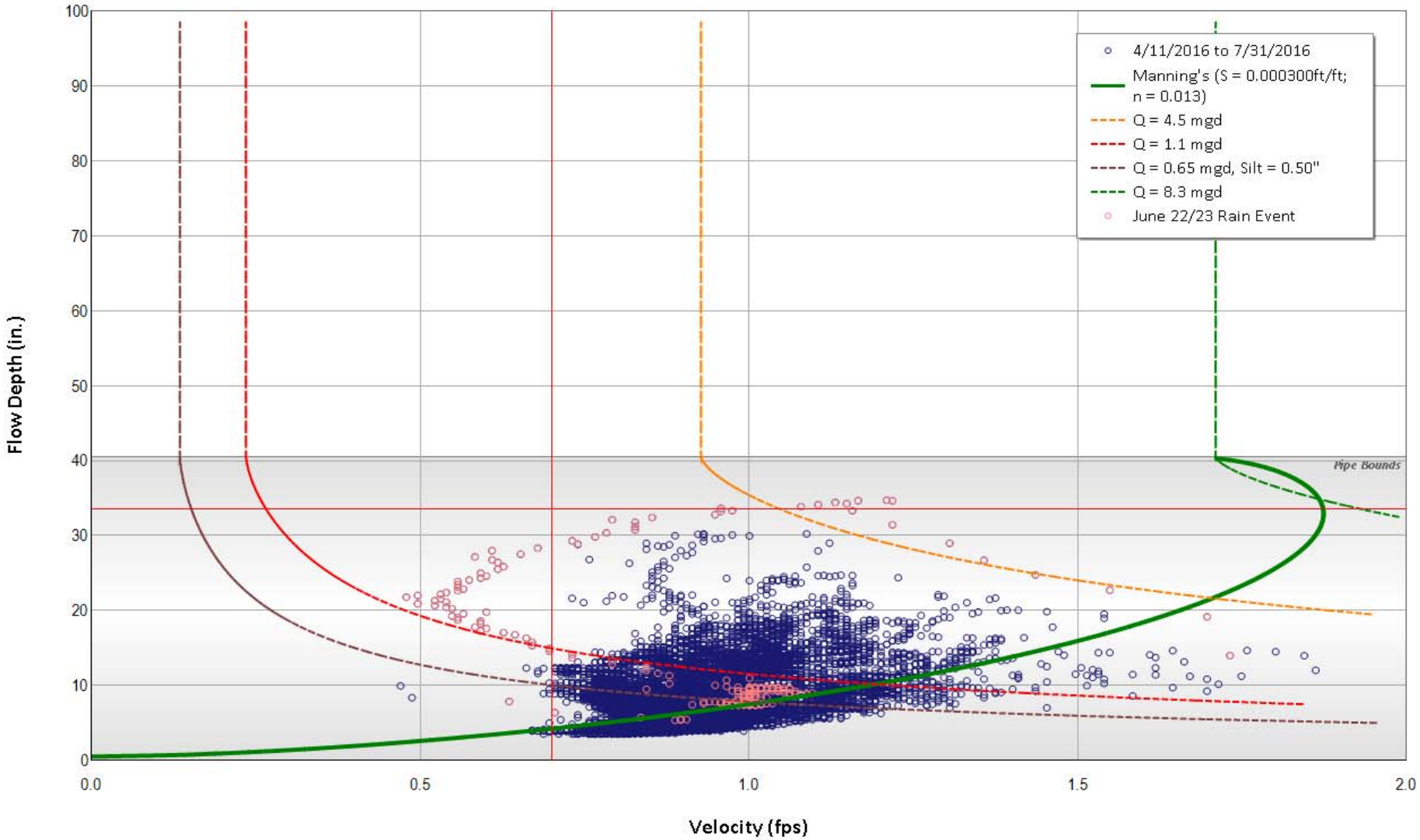
Scattergraph

Meter Site: NSISS-39



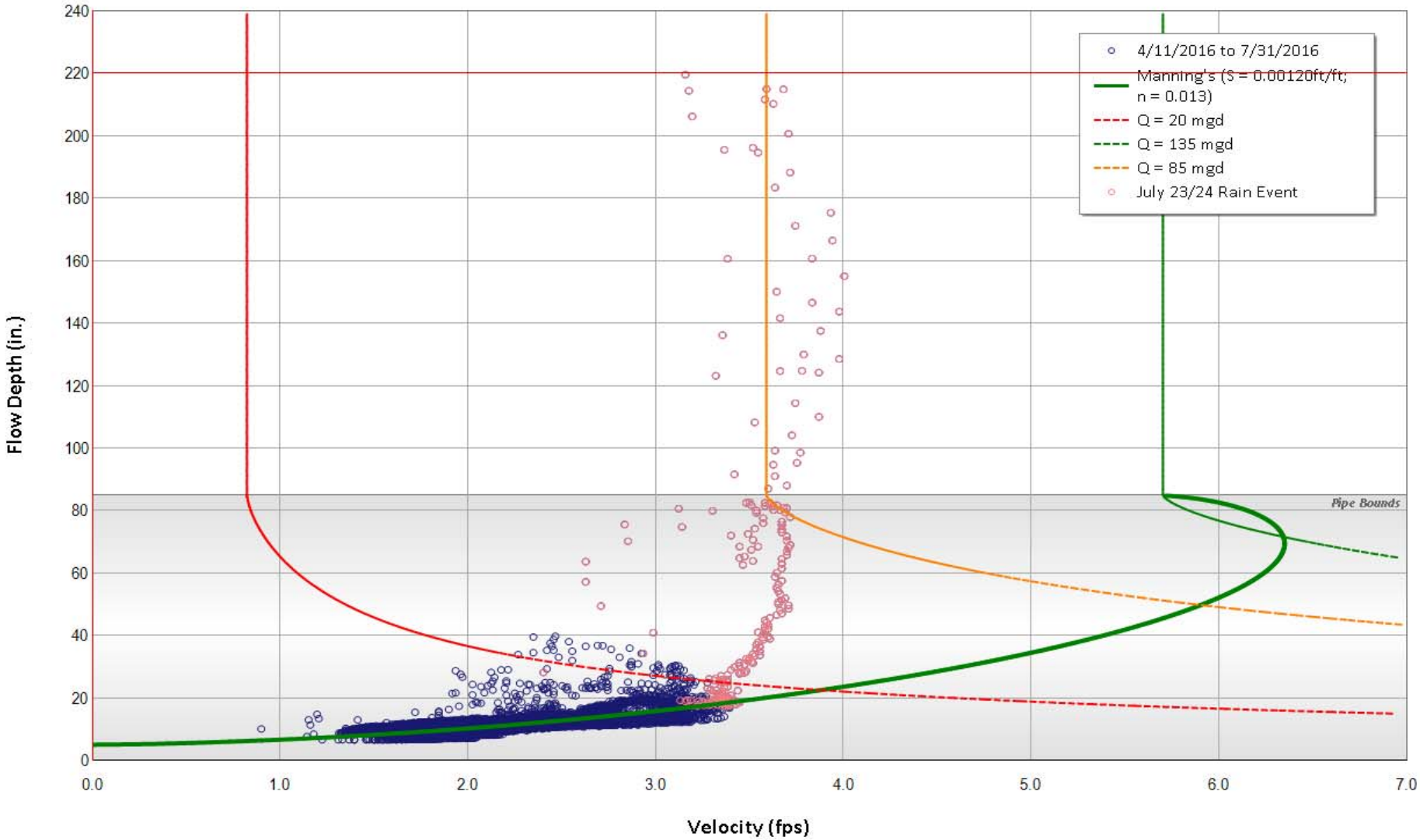
Scattergraph

Meter Site: NSISS-40



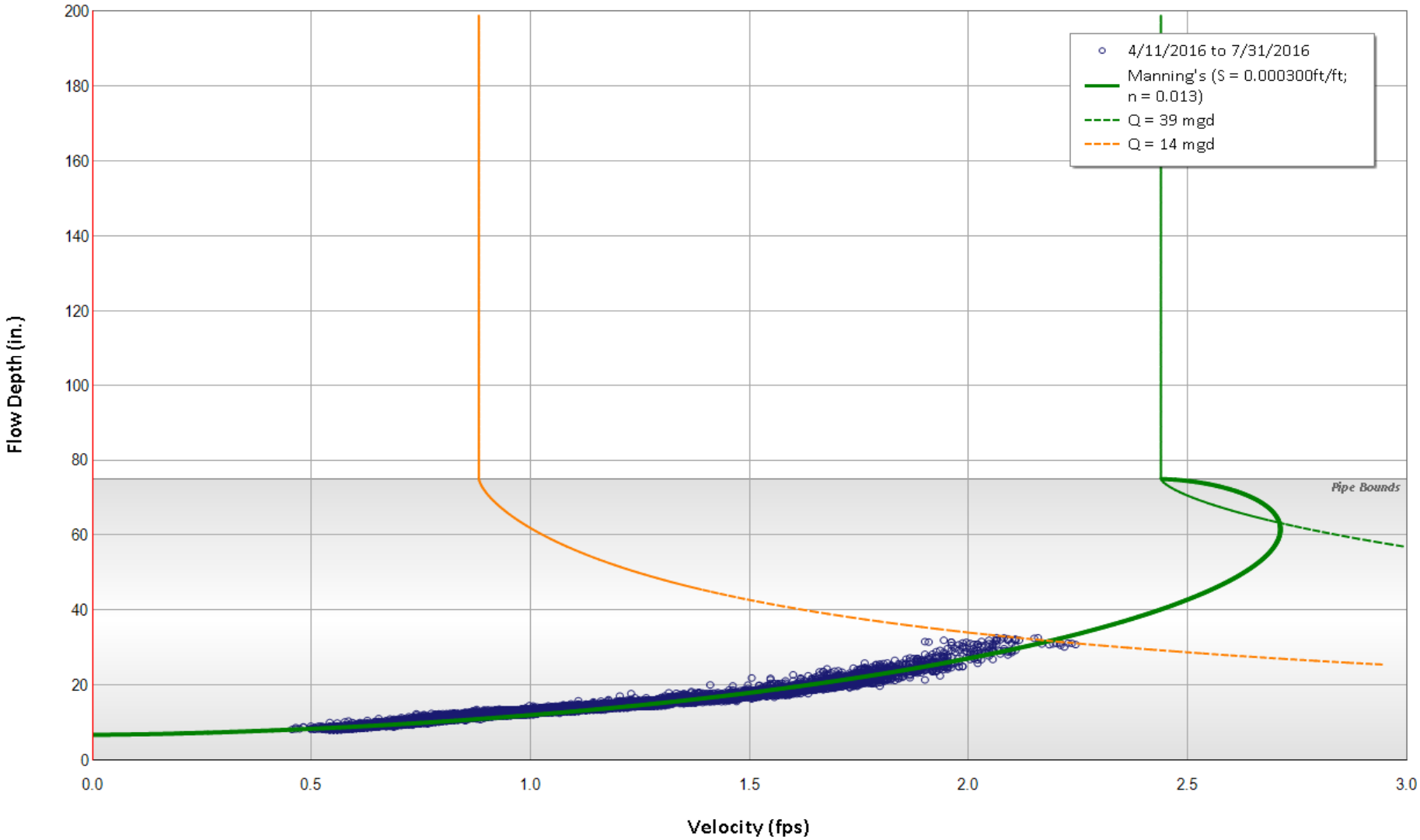
Scattergraph

Meter Site: NSISS-41A



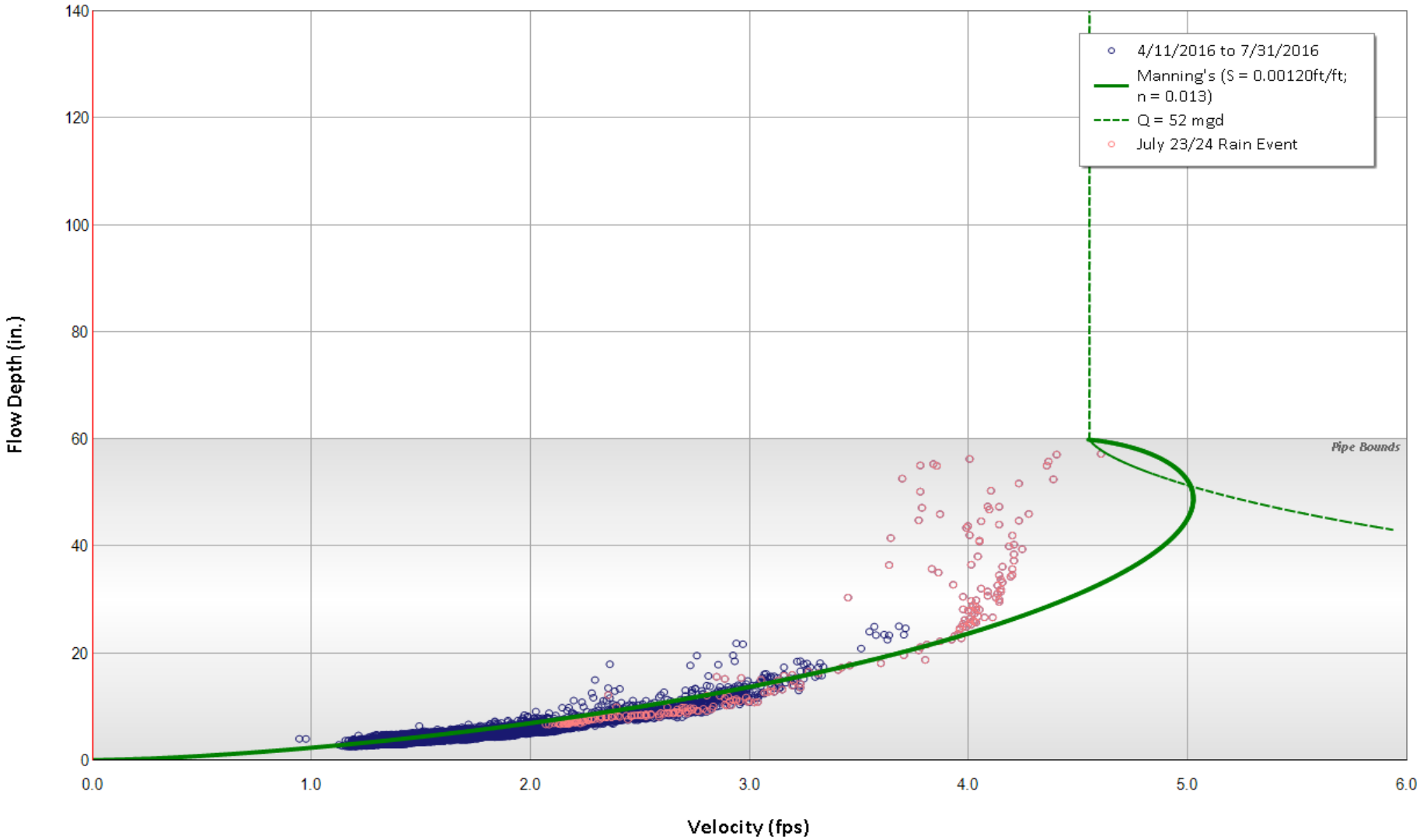
Scattergraph

Meter Site: NSISS-42



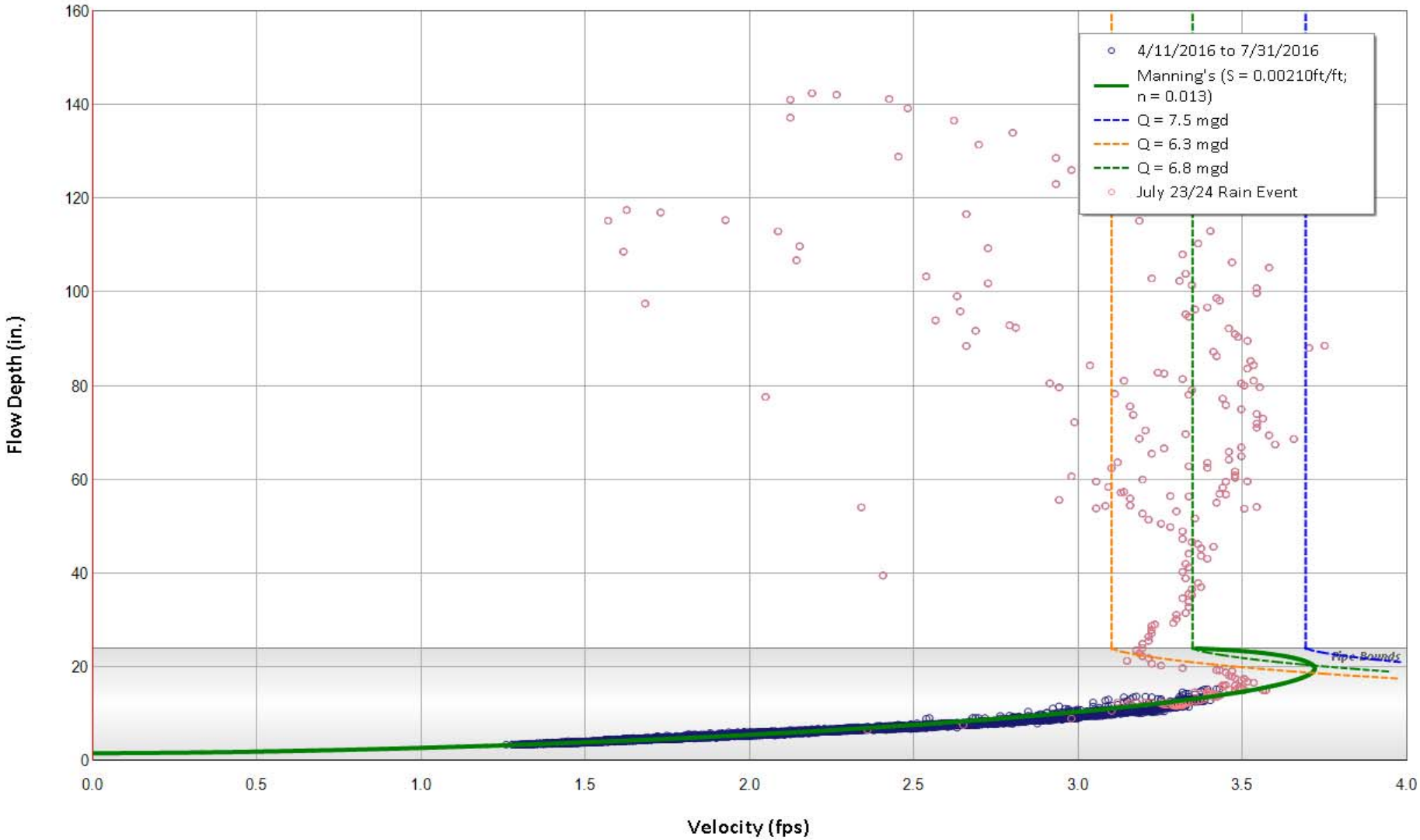
Scattergraph

Meter Site: NSISS-43



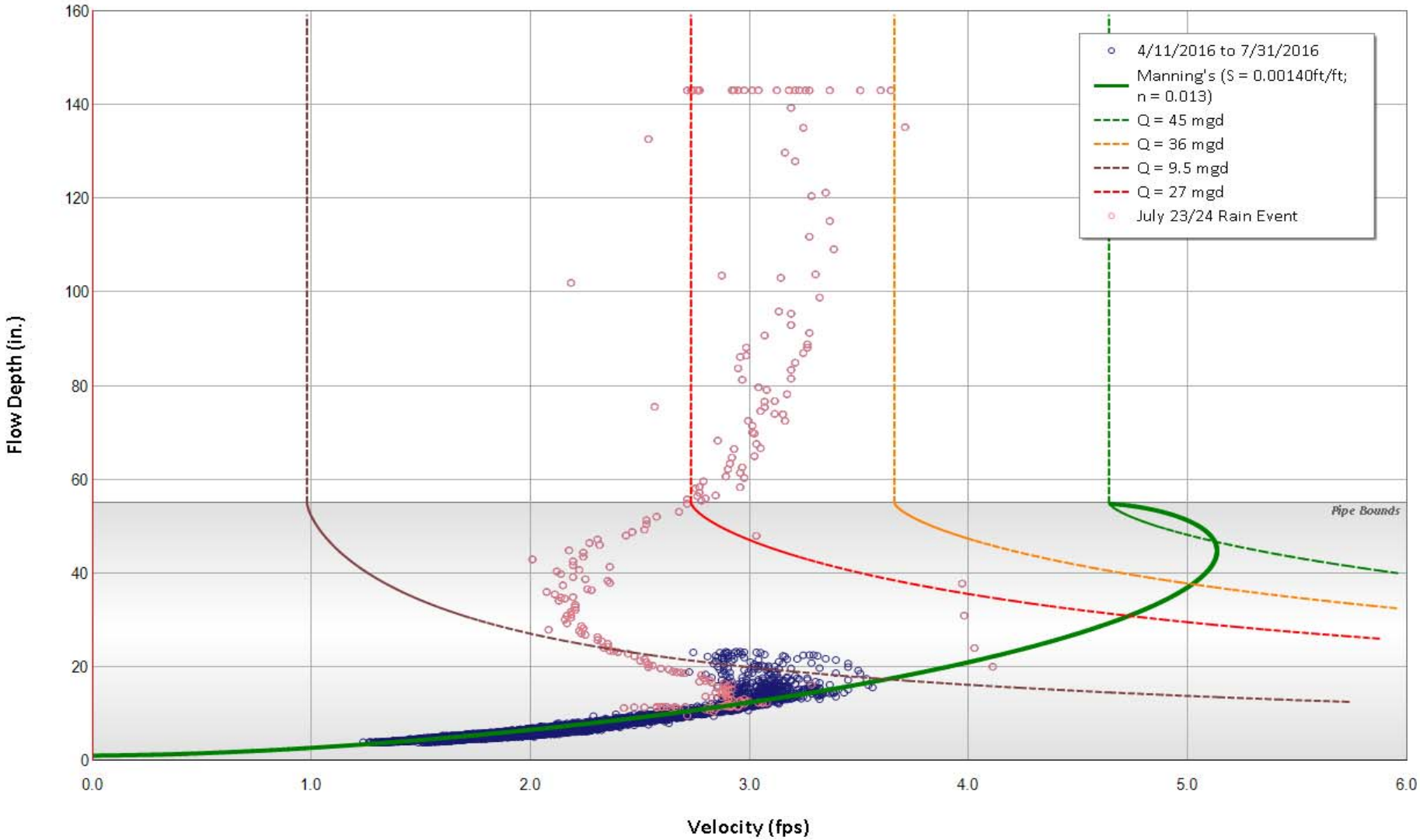
Scattergraph

Meter Site: NSISS-44



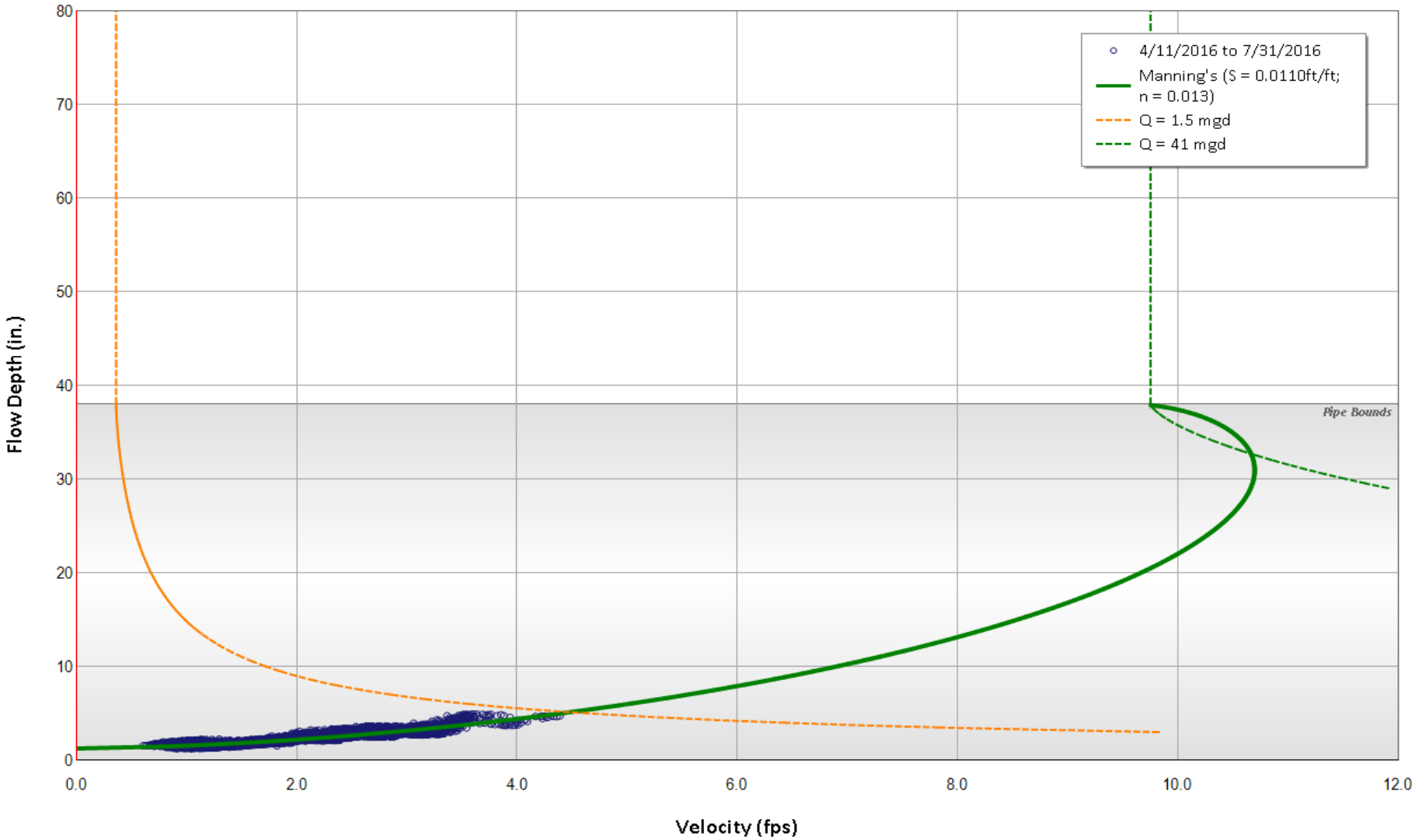
Scattergraph

Meter Site: NSISS-45



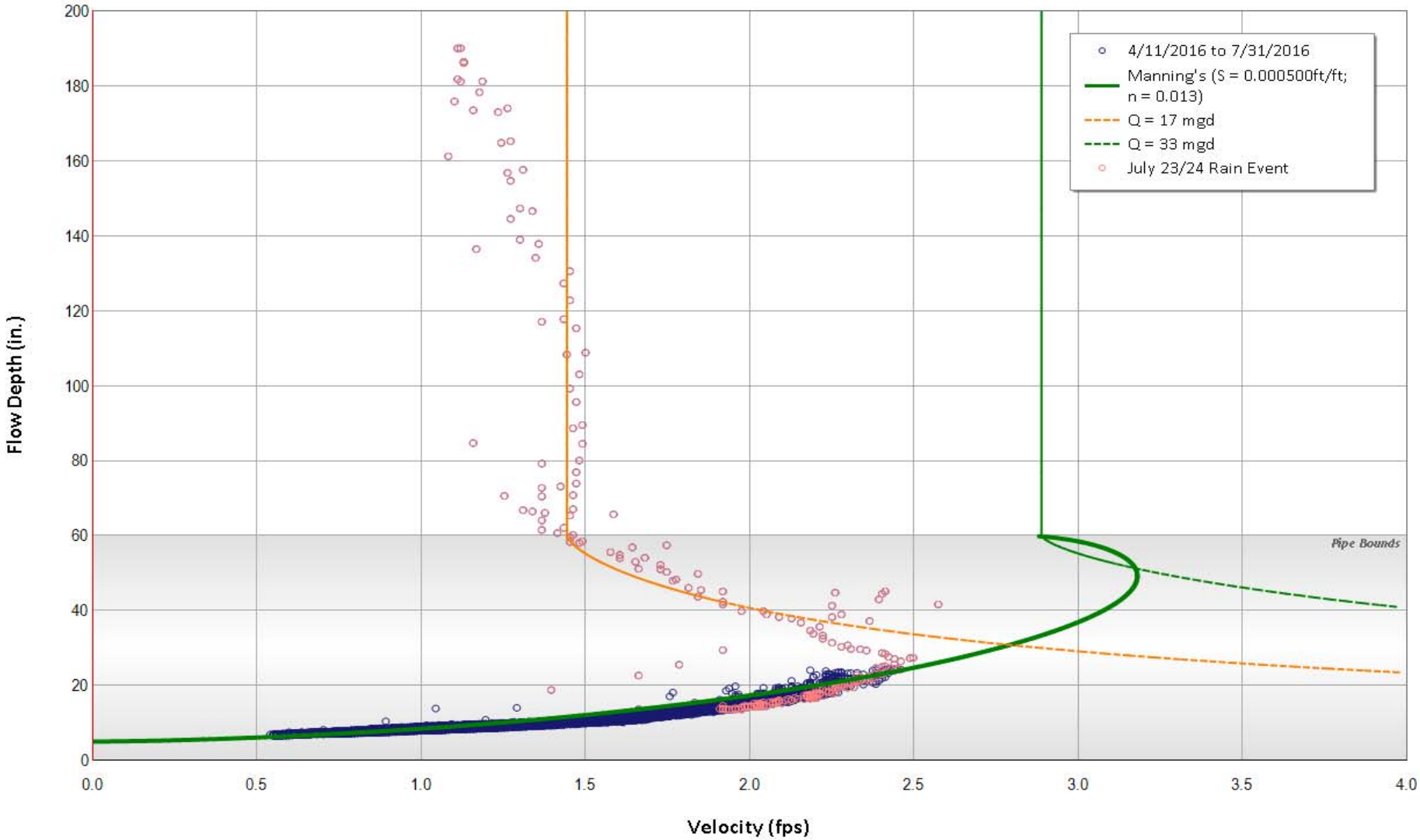
Scattergraph

Meter Site: NSISS-46



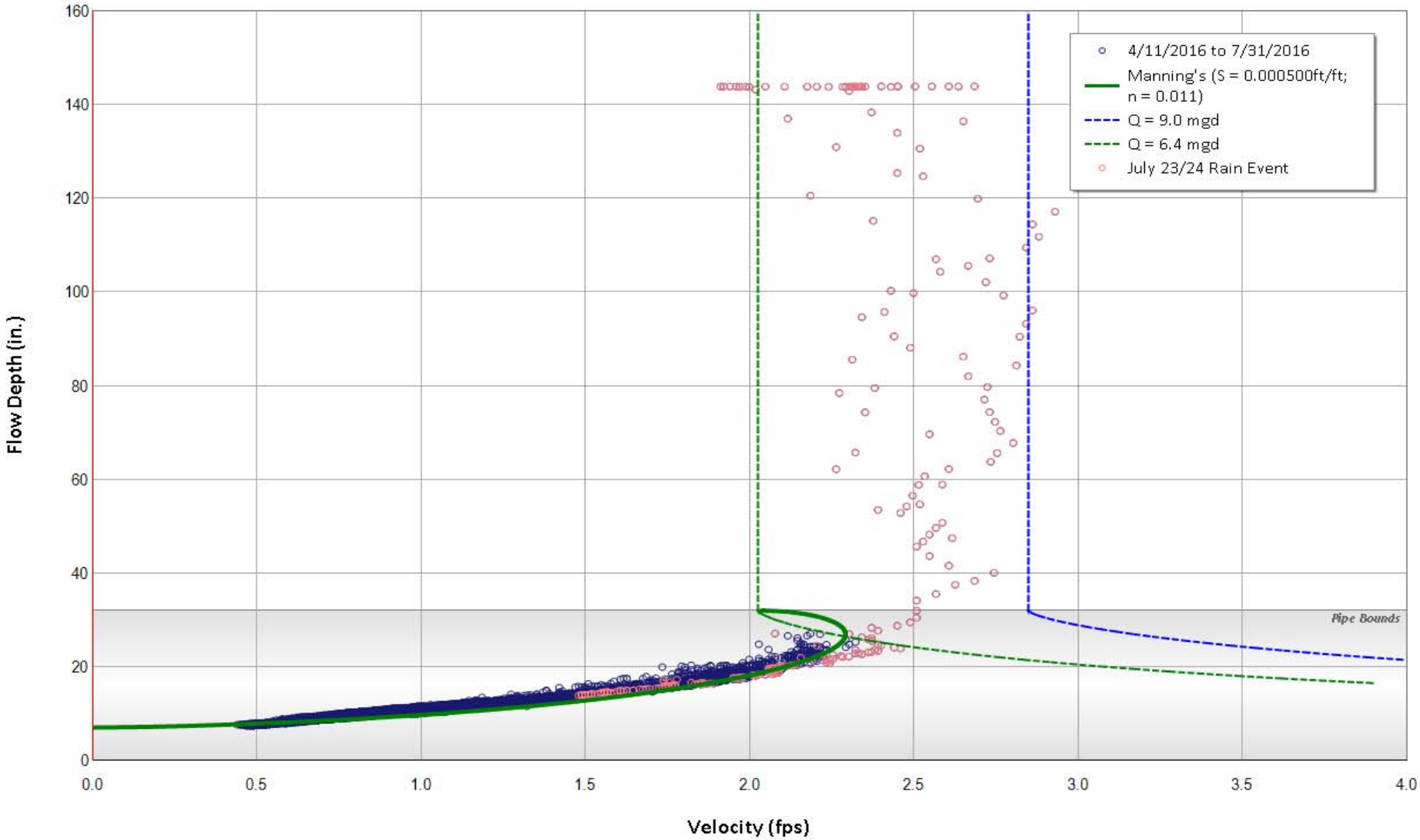
Scattergraph

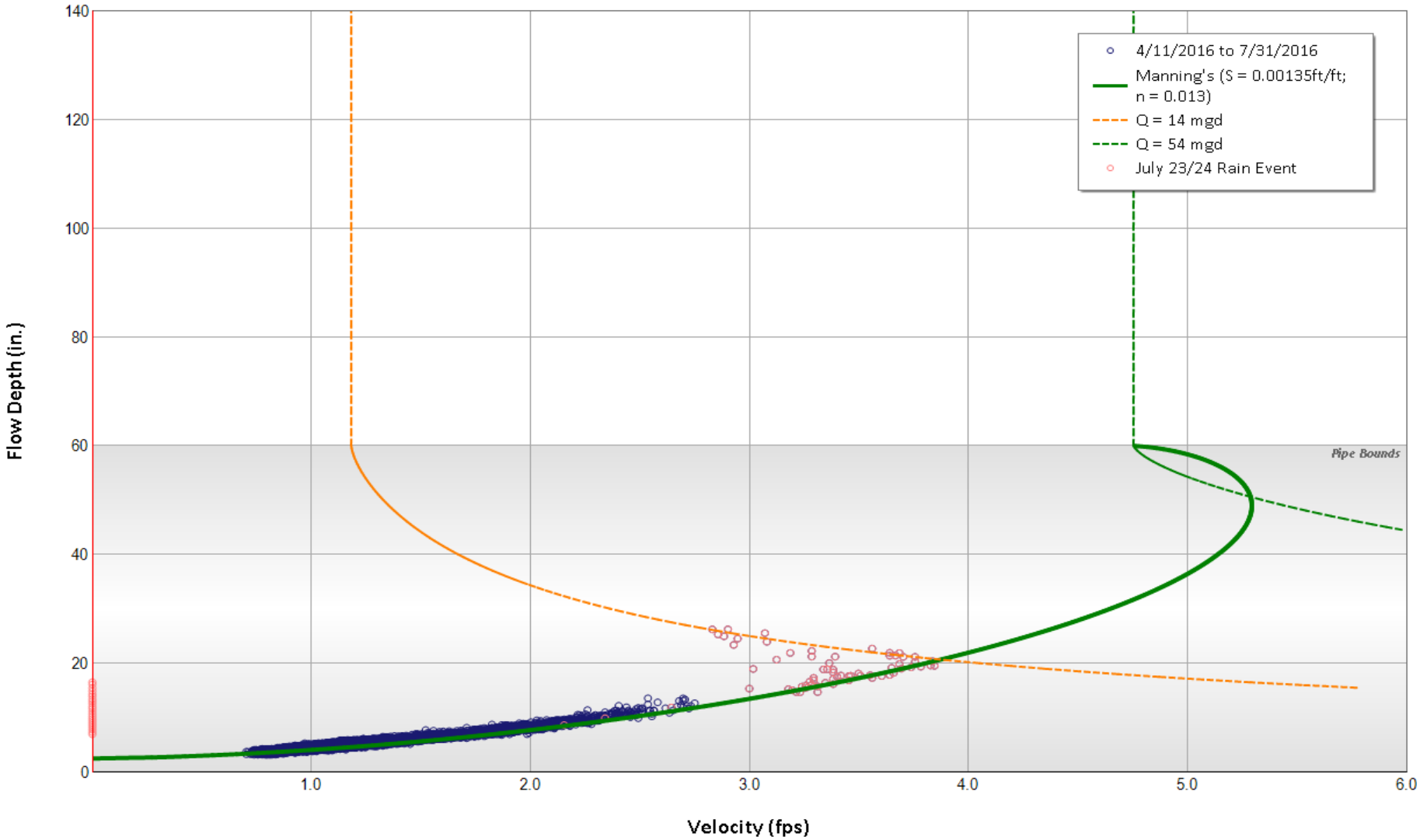
Meter Site: NSISS-47



Scattergraph

Meter Site: NSISS-48



Scattergraph

Meter Site: NSISS-49