Section 5 - Inflow and Infiltration Analysis

5.1 Introduction

The section presents a comprehensive review of the historical flow metering data collected for the sewer collection system in the Towns of Cary and Morrisville. Those data are assembled as a result of the permanent flow metering program established by the Town of Cary dating back to 2006. Our analysis of the historical flow metering data focuses on determining the adequacy of the existing system conveyance capacity as it delivers both dry and wet weather wastewater flows to water reclamation facilities (WRFs) for treatment and discharge. This assessment was carried out in conjunction with an examination of corresponding rainfall data and water consumption data to identify the existing and potential bottlenecks in the system and to optimize system operational efficiency, thereby enabling the Town of Cary to develop a sound capital investment program and minimize O&M costs in the future.

The existing permanent flow metering flow program was developed from the recommendations made by Hazen and Sawyer, P.C. in the previous wastewater master plan project completed in June of 2003.

There are two primary objectives of the permanent flow metering program:

- To monitor collection system performance and identify sewer basins with excessive inflow and infiltration (I/I) problems for further field investigation
- To help calibrate/verify the hydraulic model of the sewer collection system using actual field data

5.2 Background

As described in Section 2, the Town of Cary's wastewater collection system lies within the Neuse River Basin and the Cape Fear River Basin. The system map is included in Figure 2-1. A total of 23 flow meters have been in place since 2006 (Figure 2-14) and are maintained throughout the service area. The flow metering services for the Town of Cary have been provided by Frazier Engineers, Inc. of Charlotte, N.C. The data set for this master plan covers the period from January of 2006 to December of 2010.

A sewer catchment basin delineates the existing sewer service area from which the sanitary sewer system conveys flow to each interceptor in the sanitary sewer collection system. The boundaries of the sewer basin in this master plan are largely based upon the 2003 sewer basin boundaries in the wastewater master plan with minor modifications, reflecting the service area and flow direction changes that have taken place since the last master plan. Each of the sewer basins is denoted by a letter, such as "N", "S" or "W", plus a two-digit number. Each of the letters defines an individual service area in the Cary system, with "N" representing the North Cary service area, "S" representing the South Cary service area, "W" representing the West Cary service area and "M" representing the previous Morrisville area.. The wastewater flow generated from each separate service area is discharged into its corresponding water reclamation facility (WRF). For instance, all sewer basins with the "N" notation discharge their generated flows to the North Cary

Water Reclamation Facility (WRF), all sewer basins with "S" to the South Cary WRF and all sewer basins with "W" to Durham County's Triangle WWTP. There are 99 individual basins in this version of sewer basin files, 43 of which ultimately drain to the North Cary WRF ("N"), 28 to the South Cary WRF ("S") and 28 to Durham County's Triangle WWTP ("W").

A meter basin was defined for this analysis as the total area draining to a specific flow meter minus the area draining to any other upstream flow meters. These meter basins are not the same as the sewer basins. There are 23 permanent flow meters in the Town of Cary. Consequently, there are 26 meter basins in this wastewater master plan, of which three account for the service area downstream of all flow meters prior to discharging into the respective wastewater reclamation facilities.

As part of this project, we have reviewed and modified the meter basin and sewer basin boundaries for the Town of Cary. This was done to ensure consistency between the existing system operation conditions and the basin boundaries as of late 2010. More changes in the future are expected to occur in the sewer collection system for the Towns of Cary and Morrisville, such as the further consolidation of previously Morrisville-owned service area with Cary's own system, and continuous efforts of shifting additional flows from the Neuse River Basin to the Cape Fear River Basin, thus satisfying the State of North Carolina's requirement for Interbasin Transfer (IBT) regulation. We recommend that the Town of Cary continuously modify and maintain an up-to-date version of meter basin and sewer basin data to reflect ongoing system operating conditions, thus facilitating future system monitoring and management.

As discussed in Section 4, significant population growth and accompanying wastewater flow increases have occurred in the Town of Cary's service area since the last master plan project was finished. For the purposes of our analysis, a period with relatively stable system operating conditions in terms of system configuration and flow direction is needed as a baseline scenario for further assessment. In 2009, no major changes were implemented except for the flow transfer via the Fieldstone Pump Station from the North Cary service area to the West Cary service area. In close consultation with the Town's staff, the system condition as of late 2009 was selected as the baseline scenario for further analysis. A new Infoworks CS network, which includes all manholes, gravity sewers and force main lines, was derived from the existing GIS to reflect the system condition as of late 2009. It is deemed as the base model and utilized as a robust tool to assist further analysis.

Table 5-1 presents an inventory of the existing sewer service areas, sewer lengths, inch-miles (IM) of gravity sewer pipe for each meter basin, and their cumulative meter basins upstream under the baseline condition. Data were determined based on the tally of the baseline InfoWorks model. The unit "inch-miles" represents the pipe length in miles times the pipe diameter in inches, and is used to rate the relative quantity of groundwater infiltration entering the system. All areal and take-off statistics are furnished here on an individual and accumulative basis (reflecting all systems upstream). Figures 5-1, 5-2 and 5-3 show diagrams of connectivity and system take-off for all meter basins in the Town of Cary. The data cited in those figures are based upon individual meter basins.

Table 5-1: Service Area Inventory Data for Flow Meters

Flow meters	Service Area		Sewer Length		Inch-Miles (IM) of Sewer	
	Including Meter Basins upstream (ac)	Meter Basin only (ac)	Including Meter Basins upstream (ft)	Meter Basin only (ft)	Including Meter Basins upstream (im)	Meter Basin only (im)
M1	993	993	25	25	216	216
M2	3155	357	84	9	763	94
M3	10208	1345	257	28	2556	276
M4	1480	1480	40	40	373	373
M5	2798	1318	75	35	669	296
M6	4701	2609	117	64	1048	592
M7	1473	1473	39	39	336	336
M8	1344	1344	38	38	367	367
M9	619	619	14	14	120	120
M10	690	690	17	17	145	145
M11	1953	1953	58	58	517	517
M12	2267	1274	58	33	528	312
M13	754	754	21	21	183	183
M14	2450	478	76	15	727	155
M15	10861	1373	280	38	2591	404

Table 5-1: Service Area Inventory Data for Flow Meters (Continued)

Flow meters	Service Area		Sewer Length		Inch-Miles (IM) of Sewer	
	All Upstream Meter Basin included (ac)	Meter Basin (ac)	All Upstream Meter Basin included (ft)	Meter Basin (ft)	All Upstream Meter Basin included (im)	Meter Basin (im)
M16	5678	1627	161	45	1536	469
M17	942	942	24	24	231	231
M18	1265	1265	30	30	354	354
M22	345	345	9	9	106	106
M23	1520	1175	43	33	397	291
M24	308	308	4	4	43	43
M25	1357	1357	22	22	303	303
M26	1972	1972	61	61	572	572

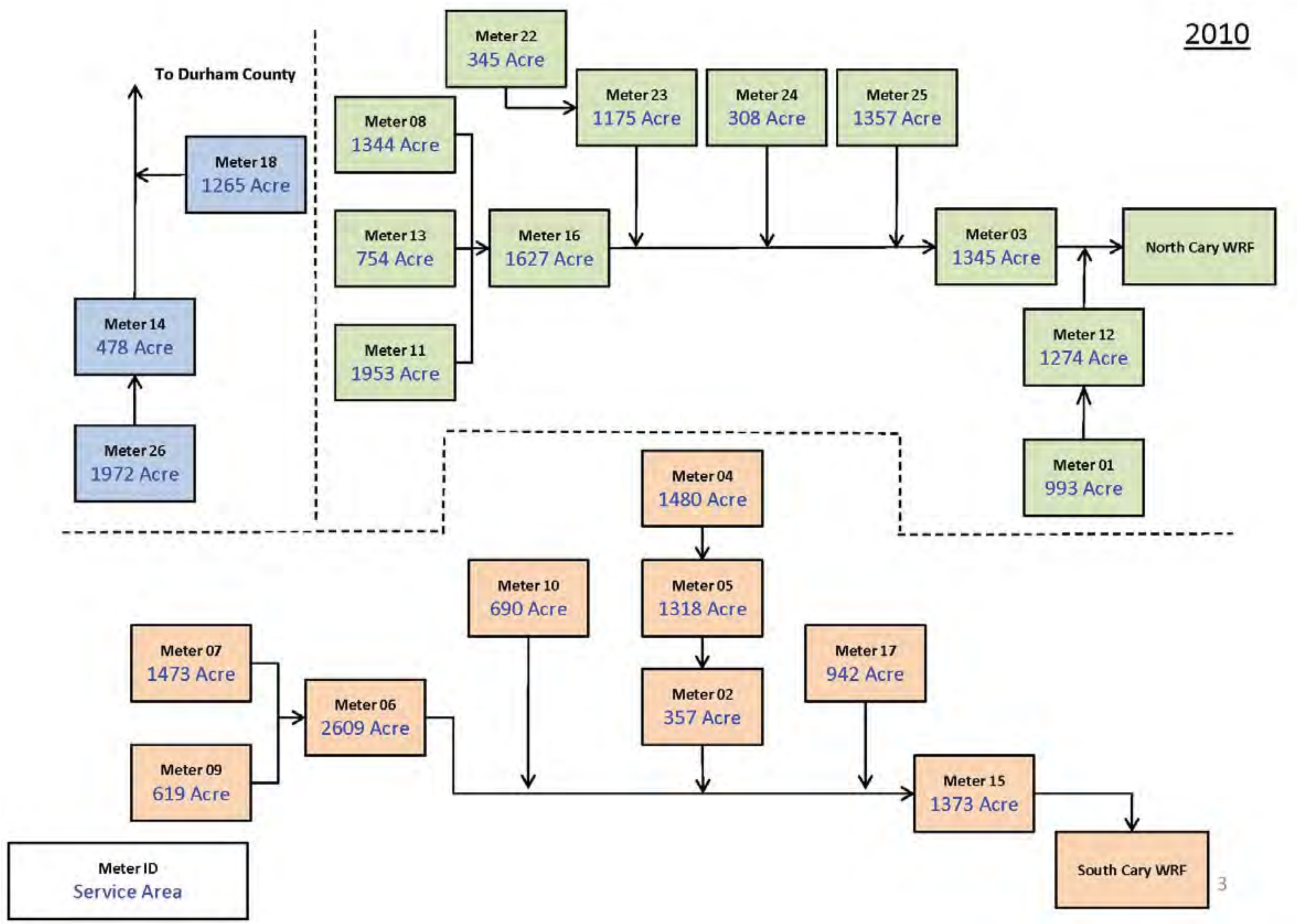

Figure 5-1: Service Area Diagram of Town of Cary's Sewer Collection System (on Individual Meter Basins)

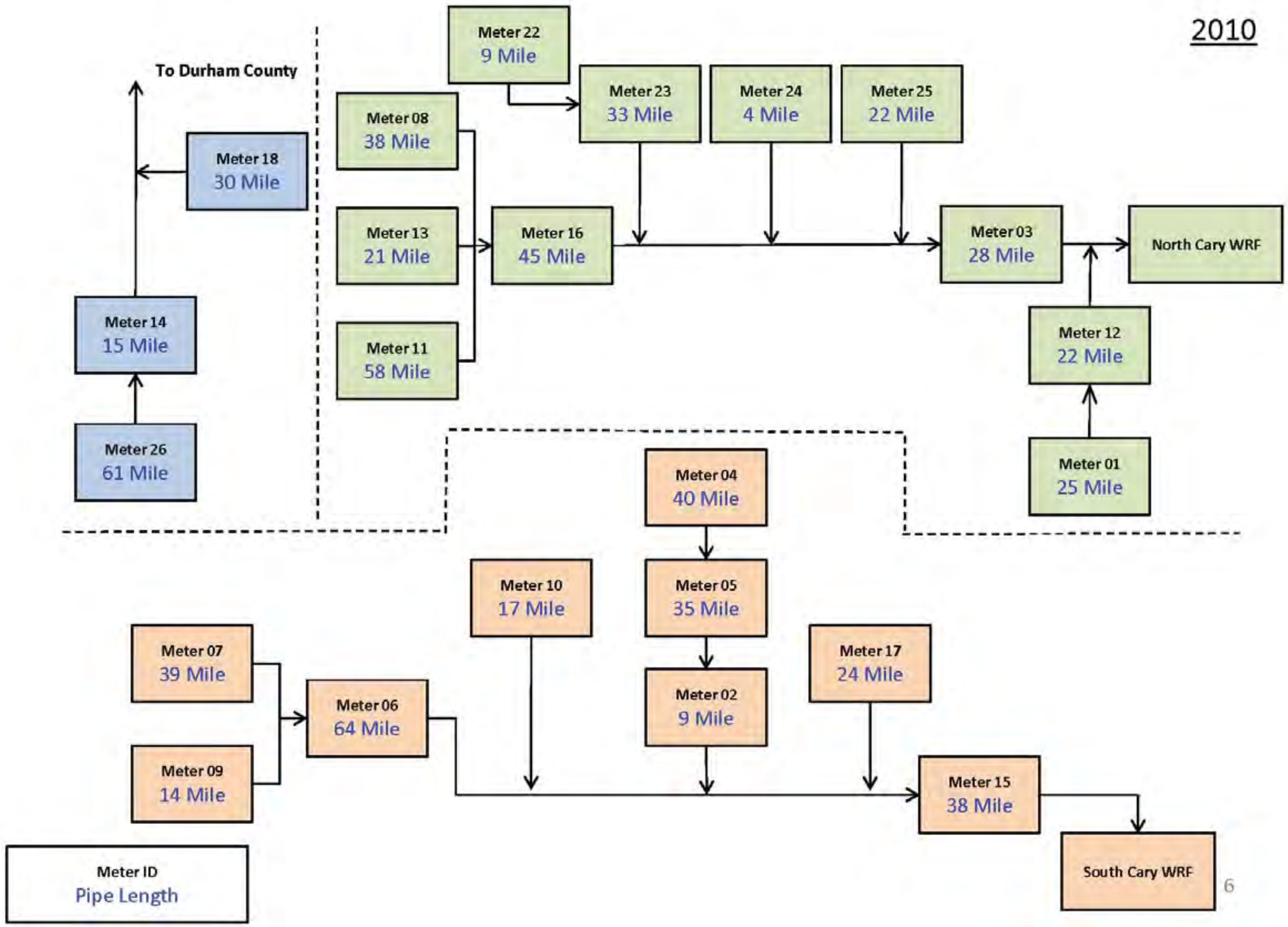

Figure 5-2: Sewer Length Diagram of Town of Cary's Sewer Collection System (on Individual Meter Basins)

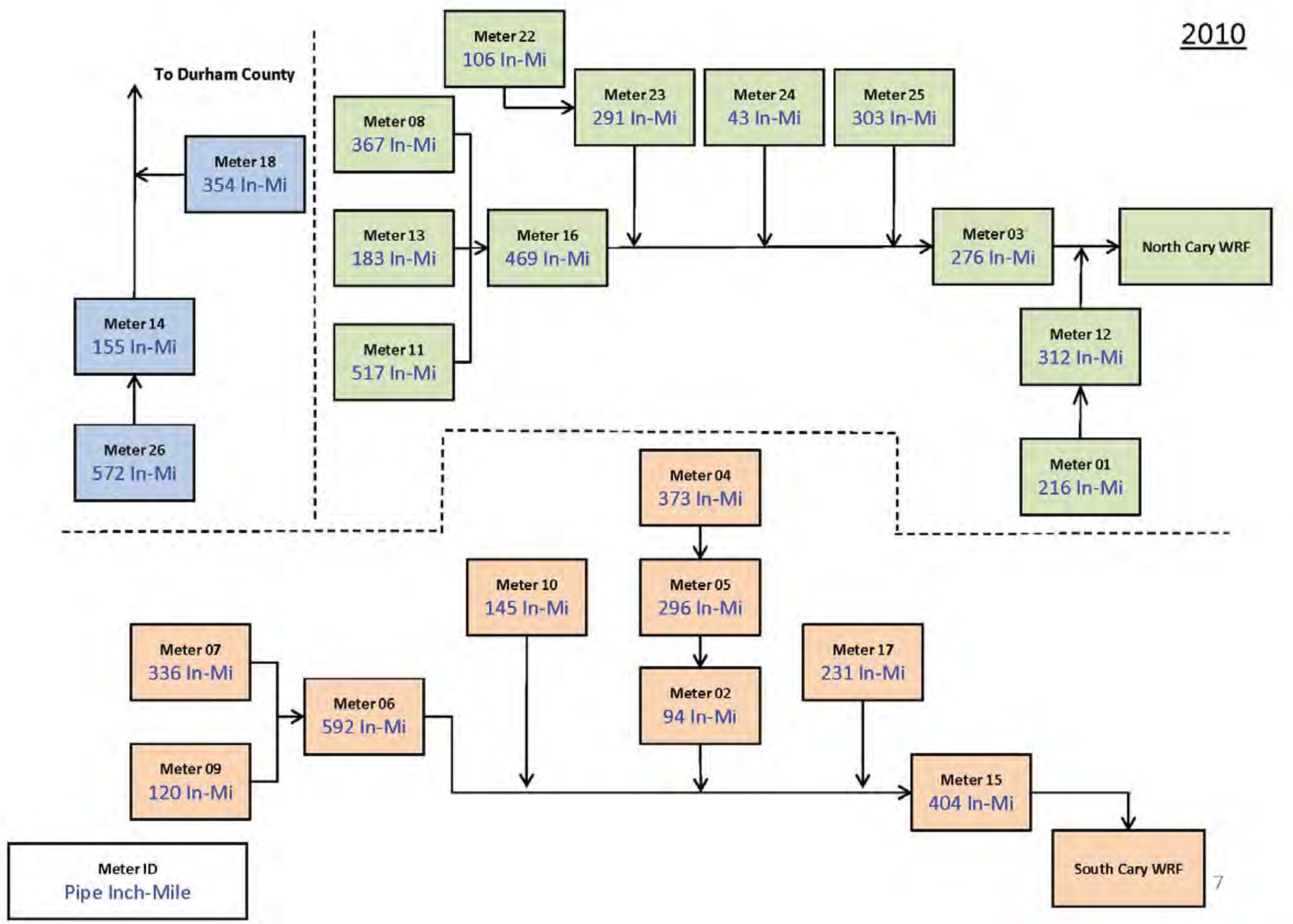

Figure 5-3: Inch-Mile Diagram of Town of Cary's Sewer Collection System (on Individual Meter Basins)

5.2.1 Average Base Flow (ABF)

Average base flow is the flow normally recorded at each of the flow metering sites without any influences of precipitation. It has two primary components: Average Daily Sewer Flow (ADSF) and Groundwater Infiltration (GWI). ADSF is the normal flow in a sewer system during non-rainfall periods, excluding any extraneous flow from other sources. ADSF includes the residential, commercial, institutional, and industrial flow discharged to a sanitary sewer system for collection and treatment. As shown in Figure 5-4, ADSF normally varies with daily water use patterns within a service area throughout a 24-hour period, with higher flows during the morning period and lower flows during the night. In most cases, the ADSF is more or less constant during a short duration of time, but varies more widely in quantity on a monthly and seasonal basis. ADSF generally represents a significant portion of the flows treated at wastewater treatment facilities.

As shown in Figure 5-4, groundwater infiltration (GWI) represents the infiltration of groundwater that enters the collection system through leaking pipes, pipe joints and manhole walls. GWI varies throughout the year, often entering at a higher rate in late winter and early spring as groundwater levels and soil moisture levels rise, and subsiding in late summer or after an extended dry period. As sewer pipes age and deteriorate, GWI is expected to increase in intensity, frequency and coverage. GWI problems can be particularly severe in areas where sewer systems are installed below the groundwater table, such as pipes installed near large water bodies like lakes or creeks. In central North Carolina, GWI can be closely correlated with the seasonal variations in groundwater tables that typically peak in early spring and early winter. GWI would result in the need for larger sewerage facility capital investments and elevated operational and maintenance (O&M) costs for pumping and treatment. Therefore, it merits more detailed analysis in this project.

GWI and ADSF together comprise the ABF that occurs in a sanitary sewer system. Because the proportion of the GWI and ADSF components of the ABF is variable in nature, various assumptions related to the water consumption return rates and wastewater composition during early morning hours are typically used to help estimate these flow components.

The average base flow (ABF) can be expressed for the following equation,

$$ABF = ADSF + GWI \qquad (5\text{-}1)$$

Where,

ABF = average base flow

ADSF = average daily sewer flow

GWI = groundwater infiltration

The determination of GWI in each day at each flow metering location is performed by measuring the minimum daily flow, typically occurring during the early hours, as demonstrated in the following equations:

MBF = MDSF + GWI (5-2)

where,

MBF = Minimum base flow

MDSF = Minimum daily sewer flow = ADSF x 0.12

Where 0.12 is a commonly observed value between MDSF and ADSF (WEF Manual of Practice FD-6).

As illustrated in Section 4, the flow from the Cary service area is largely residential. There are no notable industrial or commercial customers who operate their businesses on a continuous 24-hour shift. In the early hours of every day, the MDSF for the Cary service area is almost negligible. As such, we can preliminarily assume that:

GWI = (ABF – (ABF – MBF)/.88) (5-3)

The monthly average GWI for all flow meters is tabulated in Table 5-2. For the sake of clarity and simplicity, the meters with a similar range of GWI rate were clustered into four separate figures, Figures 5-5 to 5-8, which plot the varying trends of monthly GWI for all flow meters in 2010. For the majority of flow meters, the data shows a seasonal peak in the months of March and December when soil moisture level is high, and a parallel valley in the summer months of July and August when the soil is the driest. Those patterns are consistent with seasonal groundwater level variations and the trends demonstrated from other flow metering data collected for adjoining municipalities.

On an incremental basis, the service area, inch-miles, ABF, and GWI were calculated for each individual meter basin, as listed in Table 5-3. Since the computed ABF values for Meter 3 and Meter 15 are lower than the sum of the ABF values from their respective upstream meters, zero ABF and GWI values were assigned to Meter 3 and Meter 15. Similarly, the GWI value for Meter 2 was also negligible and therefore assigned a value of zero.

Meters 2, 3, 5, 6, 12, 14, 15 and 16 were all found to report a comparatively high degree of GWI.

GWI/ABF ratio is also an important parameter for observing the degree to which the ABF of a meter is dominated by the contribution of its GWI component. Previously mentioned Meters 2, 3, 5, 6, 12, 14, 15 and 16 have a GWI/ABF ratio greater than 50 percent. This is a good indication of high groundwater table and the possible proximity of an aquatic environment such as major creeks and lakes. Both the North and South Cary service areas have an equal number of meters with high GWI/ABF, GWI/area and GWI/inch-mile ratios, which merit further attention in subsequent analyses. All of the meters in the West Cary service area have relatively low GWI/ABF, GWI/area, and GWI/inch-mile ratios, likely due to the fact that the sewer system is relatively new in this area.

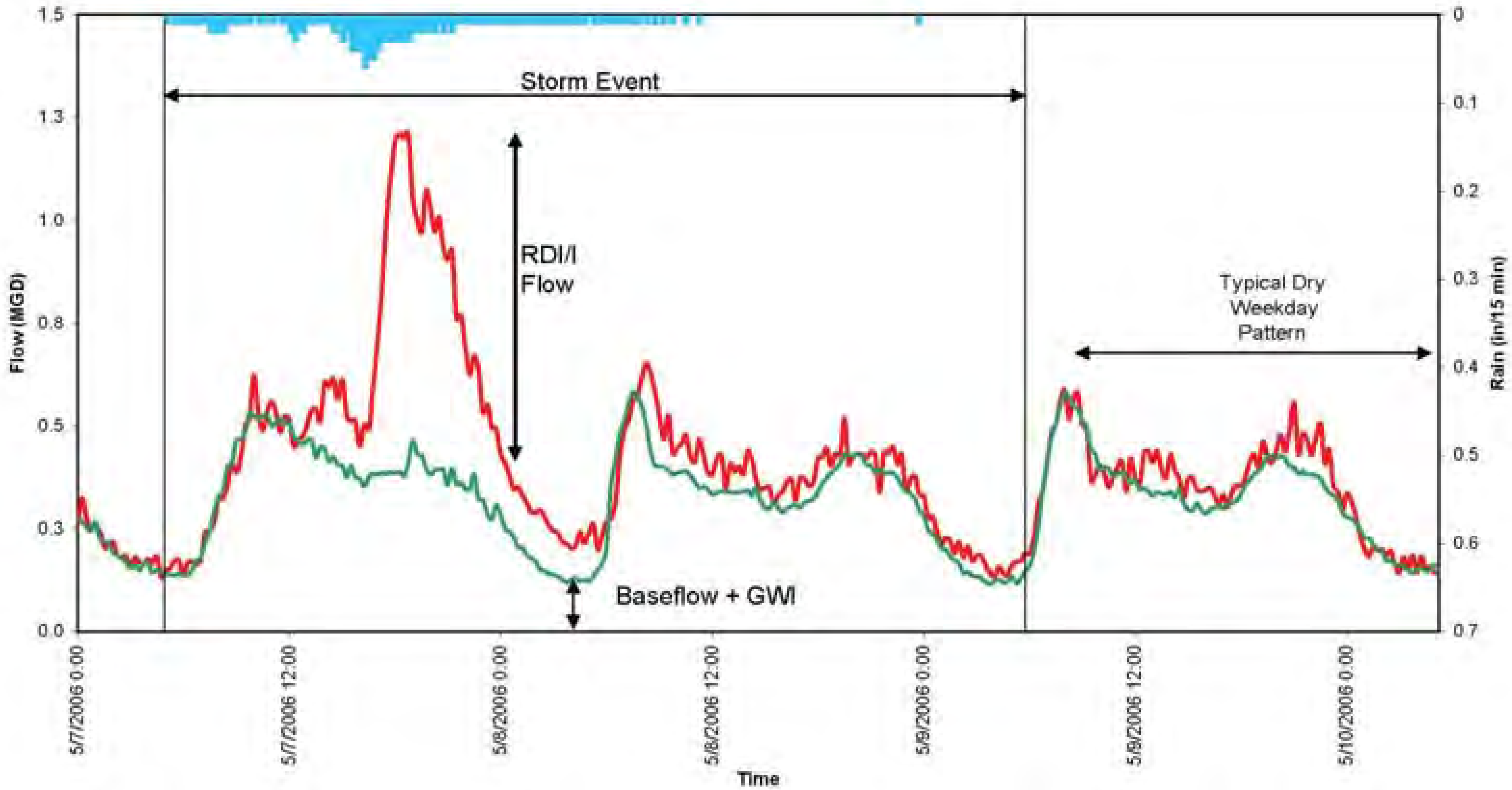

Figure 5-4: Components of Average Base Flow

Table 5-2: Average Monthly GWI for all Meters in 2010

Meter	January	February	March	April	May	June	July	August	September	October	November	December	Average
M1	0.12	0.12	0.16	0.15	0.12	0.11	0.12	0.14	0.13	0.11	0.09	0.10	0.12
M2	0.68	0.72	0.63	0.60	0.62	0.56	0.50	0.53	0.51	0.53	0.52	0.54	0.58
M3	2.27	1.80	2.08	1.75	1.76	2.06	2.04	2.02	1.59	1.84	1.74	1.86	1.87
M4	0.32	0.40	0.30	0.25	0.27	0.23	0.20	0.21	0.20	0.20	0.18	0.19	0.25
M5	0.615	0.799	0.618	0.499	0.535	0.482	0.467	0.482	0.493	0.572	0.611	0.565	0.56
M6	1.36	1.65	1.45	1.33	1.31	1.09	1.00	1.03	0.92	0.96	0.87	0.92	1.15
M7	0.41	0.60	0.50	0.41	0.40	0.30	0.26	0.28	0.25	0.25	0.26	0.26	0.35
M8	0.19	0.23	0.25	0.14	0.19	0.17	0.14	0.15	0.16	0.22	0.15	0.13	0.18
M9	0.06	0.06	0.07	0.06	0.05	0.05	0.04	0.05	0.037	0.06	0.04	0.04	0.05
M10	0.19	0.20	0.18	0.20	0.22	0.13	0.11	0.09	0.09	0.11	0.10	0.10	0.14
M11	0.68	0.78	0.71	0.62	0.56	0.53	0.55	0.59	0.49	0.48	0.41	0.46	0.57
M12	0.68	0.73	0.73	0.63	0.62	0.59	0.62	0.70	0.59	0.56	0.66	0.72	0.65

Table 5-2: Average Monthly GWI for all Meters in 2010 (Continued)

Meter	January	February	March	April	May	June	July	August	September	October	November	December	Average
M13	0.14	0.13	0.12	0.09	0.09	0.09	0.08	0.09	0.07	0.06	0.06	0.07	0.09
M14	1.00	1.09	0.94	0.88	0.56	0.55	0.57	0.57	0.53	0.50	0.43	0.37	0.67
M15	2.54	2.77	2.59	2.47	2.40	2.28	2.19	2.22	2.07	1.87	1.87	1.99	2.27
M16	1.13	1.15	1.18	1.06	1.13	1.04	0.99	0.99	0.89	0.89	0.83	0.90	1.01
M17	0.20	0.23	0.19	0.20	0.16	0.17	0.13	0.15	0.14	0.14	0.12	0.14	0.16
M18	0.30	0.33	0.31	0.29	0.33	0.31	0.32	0.31	0.30	0.29	0.30	0.32	0.31
M22	0.08	0.06	0.06	0.05	0.04	0.05	0.07	0.05	0.05	0.05	0.04	0.05	0.05
M23	0.43	0.45	0.42	0.29	0.27	0.24	0.19	0.23	0.19	0.17	0.14	0.16	0.26
M24	0.012	0.009	0.007	0.006	0.009	0.007	0.007	0.005	0.006	0.005	0.008	0.006	0.01
M25	0.71	0.67	0.67	0.68	0.68	0.66	0.66	0.65	0.66	0.68	0.68	0.68	0.67
M26	0.48	0.56	0.51	0.47	0.46	0.45	0.41	0.45	0.36	0.37	0.36	0.38	0.44

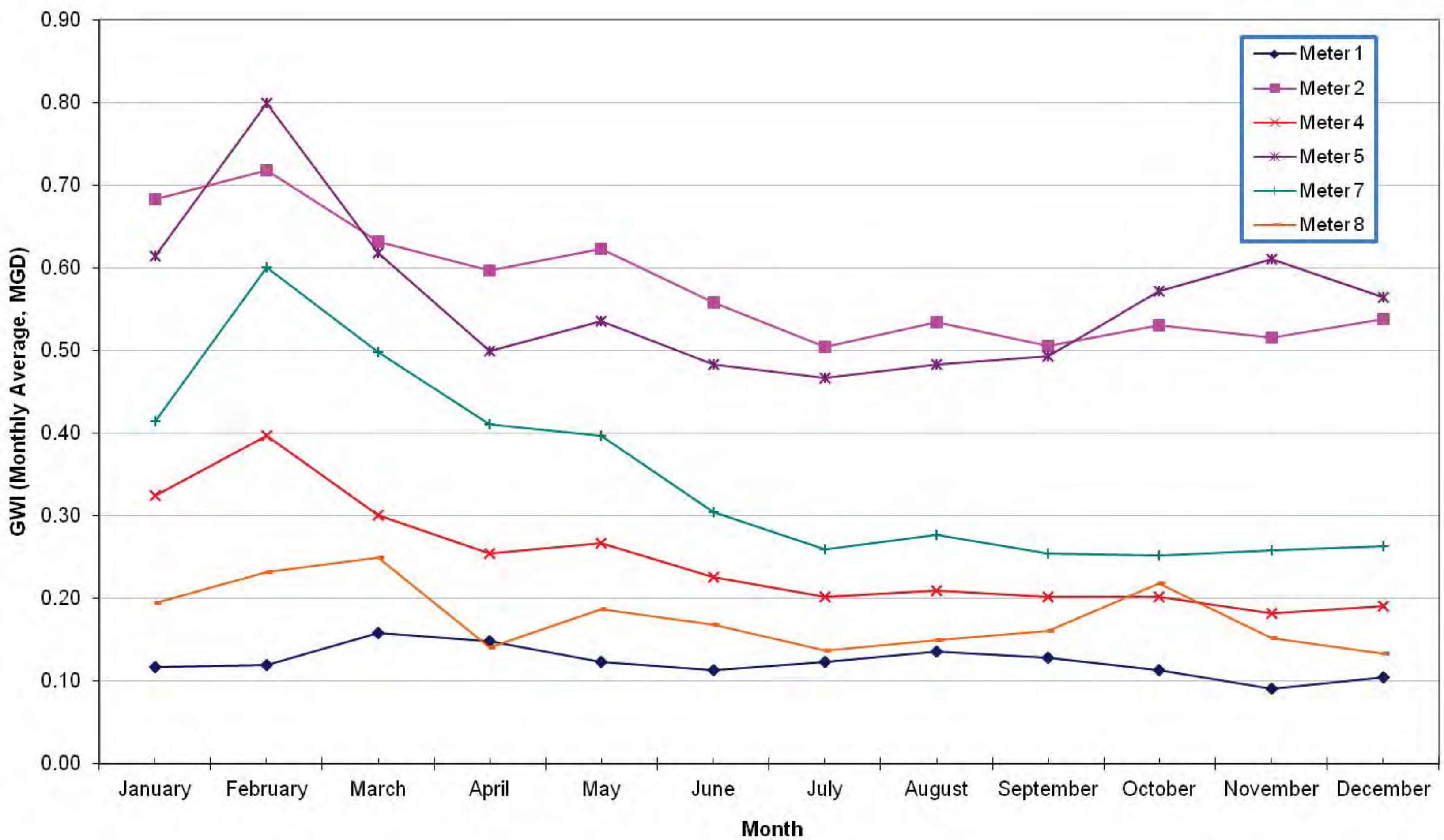

Figure 5-5: Average Monthly GWI in 2010 (Meters 1, 2, 4, 5, 7 and 8)

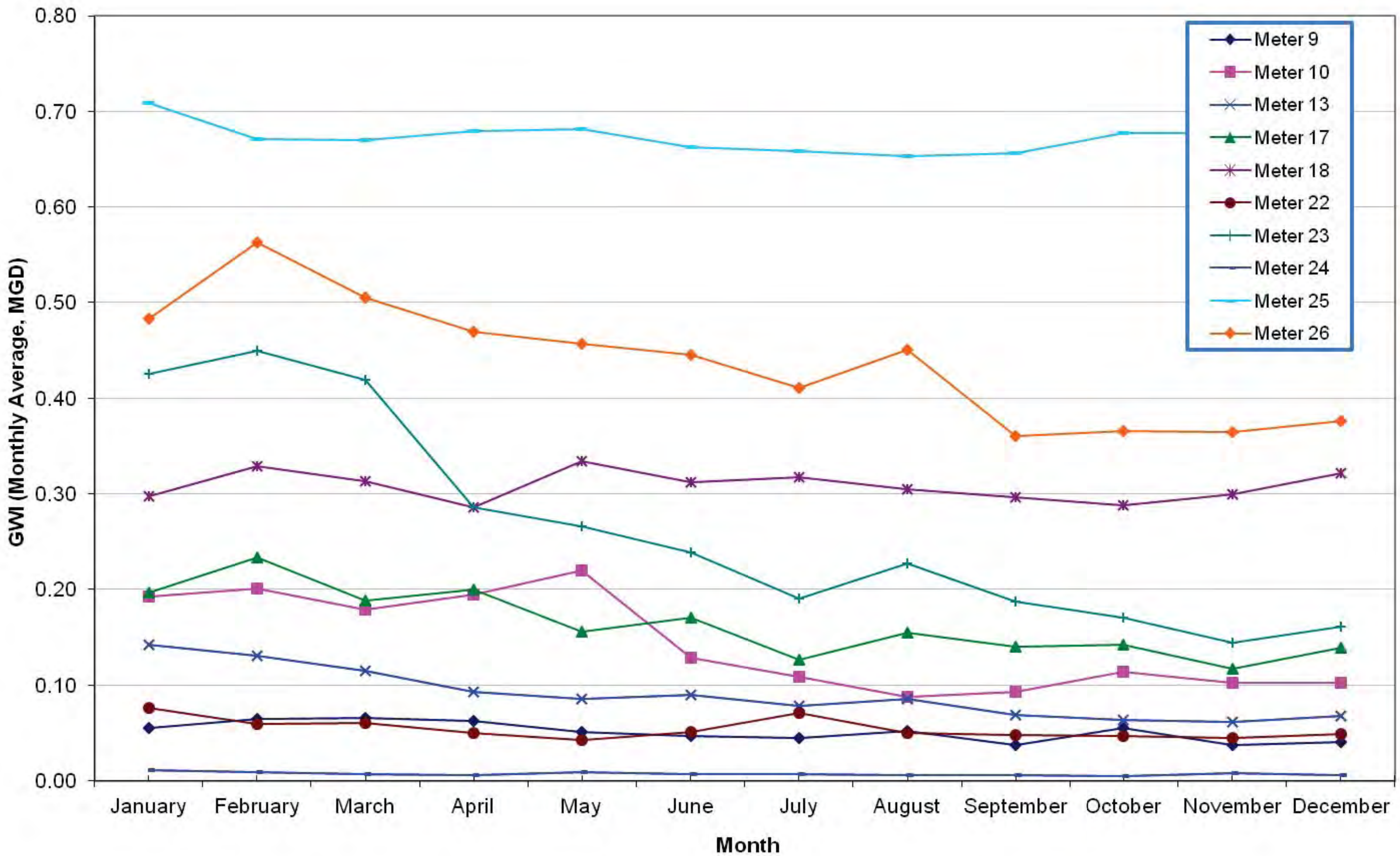

Figure 5-6: Average Monthly GWI in 2010 (Meters 9, 10, 13, 17, 18, 22, 23, 24, 25 and 26)

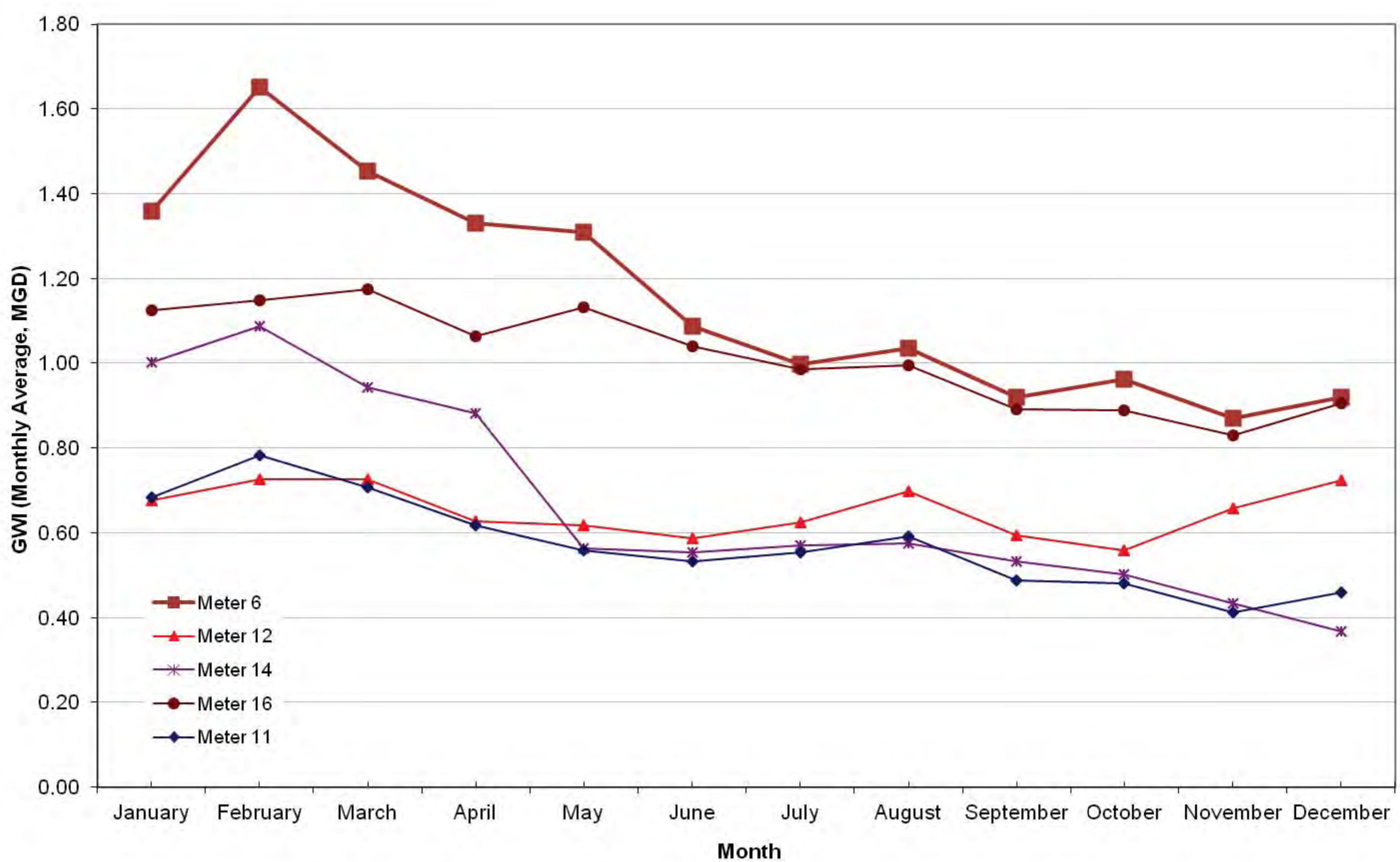

Figure 5-7: Average Monthly GWI in 2010 (Meters 11, 12, 14, and 16)

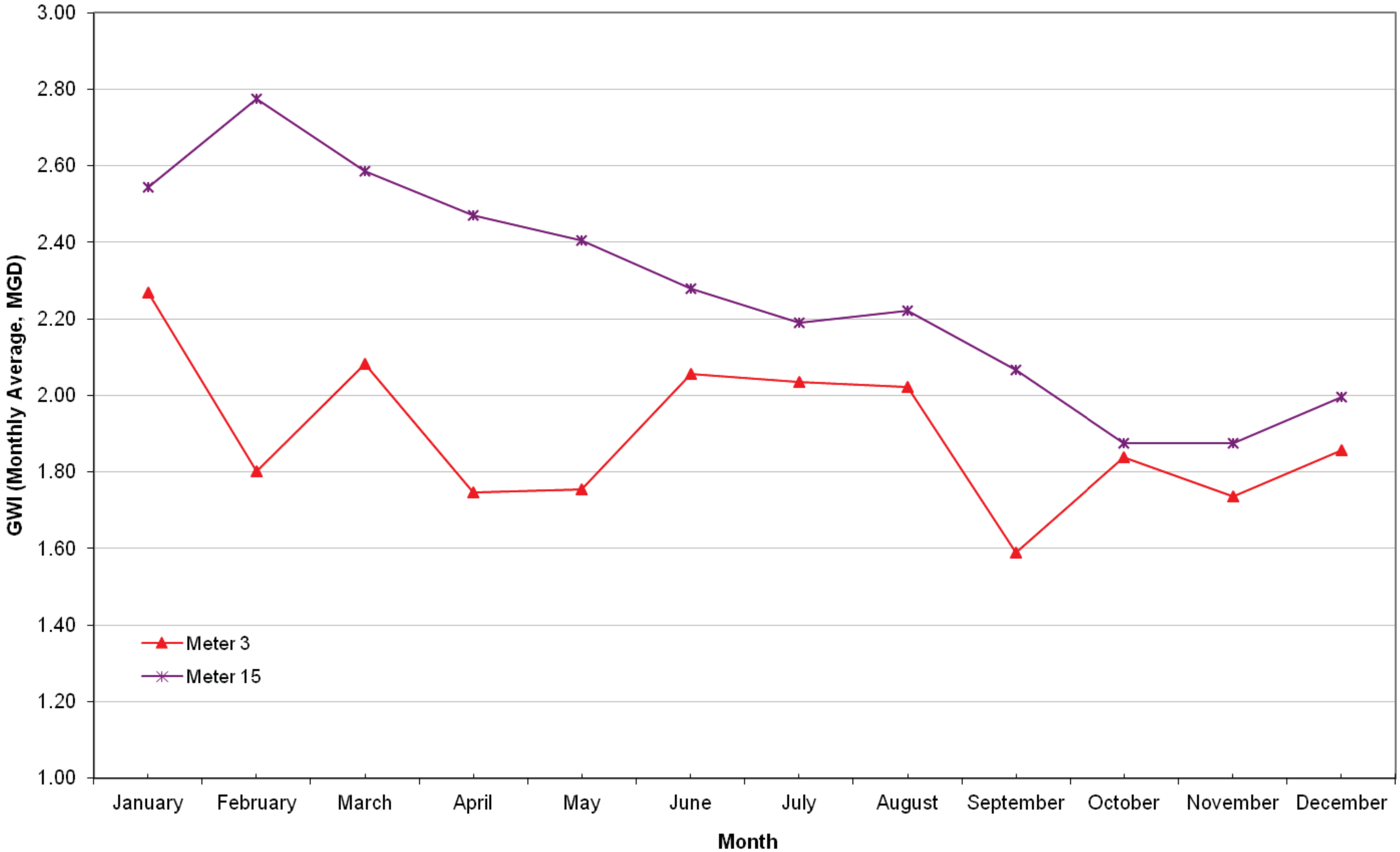

Figure 5-8: Average Monthly GWI in 2010 (Meters 3 and 15)

Table 5-3: GWI Among All Meter Basins

Meter	Meter-basin Service Area (Acres)	Inch-Mile (in-mi)	Service Region	ABF (MGD)	GWI (MGD)	GWI/ABF	GWI/Area (GPD/Acre)	GWI/Inch-Mile (GPD/in-mile)
M1	993	216	North	0.4	0.28	0.70	282	1296
M2	357	94	South	1.33	0.75	0.56	2101	7979
M3	1345	276	North	4	2.19	0.55	1628	7935
M4	1480	373	South	0.68	0.43	0.63	291	1153
M5	1318	296	South	1.38	0.82	0.59	622	2770
M6	2609	592	South	2.55	1.4	0.55	537	2365
M7	1473	336	South	1.02	0.67	0.66	455	1994
M8	1344	367	North	0.64	0.46	0.72	342	1253
M9	619	120	South	0.16	0.11	0.69	178	917
M10	690	145	South	0.41	0.27	0.66	391	1862
M11	1953	517	North	1.28	0.71	0.55	364	1373
M12	1274	312	North	1.33	0.68	0.51	534	2179
M13	754	183	North	0.27	0.18	0.67	239	984
M14	478	155	West	1.73	1.06	0.61	2218	6839
M15	1373	404	South	4.98	2.71	0.54	1974	6708
M16	1627	469	North	3.05	2.04	0.67	1254	4350
M17	942	231	South	0.59	0.43	0.73	456	1861

Table 5-3: GWI Among All Meter Basins (Continued)

Meter	Meter-basin Service Area (Acres)	Inch-Mile (in-mi)	Service Region	ABF (MGD)	GWI (MGD)	GWI/ABF	GWI/Area (GPD/Acre)	GWI/Inch-Mile (GPD/in-mile)
M18	1265	354	West	0.68	0.41	0.60	324	1158
M22	345	106	North	0.16	0.11	0.69	319	1038
M23	1175	291	North	0.63	0.37	0.59	315	1271
M24	308	43	North	0.05	0.04	0.80	130	930
M25	1357	303	North	1.24	0.57	0.46	420	1881
M26	1972	572	West	1.4	0.96	0.69	487	1678

Another important factor to consider is the local capacity to convey the high GWI component to the water reclamation facility for treatment. For instance, Meter 25 serves a large portion of the service area (1357 acres). It is installed on a 42-inch pipe discharging directly into the Crabtree Creek Interceptor (48-inch). The service area itself is relatively undeveloped. The pipe currently has adequate capacity to handle this excess GWI flow. It is also worth noting that eliminating GWI in a large service area is a difficult and expensive task. Therefore, it is not of immediate concern for the Town of Cary to address the GWI issue in Meter 25.

In contrast, Meter 23 is installed on a 17-inch portion of the York Interceptor, which used to be part of the Morrisville system. As discussed in a later part of this section, the York Interceptor does not have adequate capacity to handle the existing wet weather flow. More efforts should be directed to divert or eliminate the GWI contribution for Meter 23. Meters 6, 7, 10, 11, 12 are cases somewhere in between the more extreme cases shown in Meters 23 and 25. Their GWI contribution should be examined in light of the available local capacity with which to handle the extraneous GWI flow.

5.2.2 Comparing Water Consumption Data

Identifying the utilization pattern of sewerage service is critical to sound capacity management practice and economical capital planning by the Town. Unlike water meters in the water distribution system, it is impossible to have flow meters installed at each household and on an individual user level. One alternative for estimating the magnitude of ABF and GWI is to compare the ABF at each flow meter to its total upstream water demand on a yearly average basis.

The year 2010 water billing data for the entire service area were made available by the Town of Cary. Table 5-4 lists the total water demand from the Town of Cary's service area in the year 2010 categorized based on its service type. IR stands for "Irrigation"; MS and SM represent accounts with only sewer service. "WA" denotes accounts receiving both water and sewer service from the Town. "RW" includes all reclaimed water accounts. Through discussion with the Town's staff, the non-irrigation water demand of 11.35 MGD for 2010 was chosen as the base water billing data to be used in this analysis.

Table 5-4: Classification of Water Demand by Service Type

Service Type	Daily Average Water Demand (MGD)
IR	2.06
MS	0
RW	0.26
SM	0.31
WA	10.78
Total Water Demand	13.41
Non-Irrigation Water Demand	11.35

As discussed in more detail in Section 6, the individual water billing data from each water meter location were directly linked to the adjoining manhole based on proximity. It was intended to capture the general sewer service usage pattern on a broad scale. On an individual basis, this proximity matching may not be 100% correlated to the condition in the field. The errors introduced as a result of the proximity assumption are deemed as a comparatively minor factor based on our past experience, and ones that will not alter the analysis of the broad utilization pattern for the purpose of this study.

Additional calculations were performed to identify the total water demand upstream of each flow meter, which was subsequently compared with the average day flow measured at the corresponding water reclamation facilities. The data for each meter is tabulated in Table 5-5. The sewer return ratio, as defined by the ratio of the sewer ABF and the total water demand upstream of each flow meter, is shown in the table. Figures 5-9, 5-10 and 5-11 show the data for all flow meters for the year 2010.

Table 5-5: Sewer Return Ratio of Flow Meters

Meter	ABF (MGD)	GWI (MGD)	ADSF (MGD)	Upstream Water Demand (MGD)	Sewer Return Ratio
M1	0.40	0.12	0.28	0.37	75%
M2	1.33	0.58	0.75	1.17	64%
M3	4.00	1.81	2.19	3.39	65%
M4	0.68	0.25	0.43	0.68	64%
M5	1.38	0.56	0.82	1.07	77%
M6	2.55	1.15	1.40	1.59	88%
M7	1.02	0.35	0.67	0.63	106%
M8	0.64	0.18	0.46	0.52	89%
M9	0.16	0.05	0.11	0.16	68%
M10	0.41	0.14	0.27	0.26	103%
M11	1.28	0.57	0.71	0.79	90%
M12	1.33	0.65	0.68	0.93	73%
M13	0.27	0.09	0.18	0.3	60%
M14	1.73	0.67	1.06	0.95	112%

Table 5-5: Sewer Return Ratio of Flow Meters (Continued)

Meter	ABF (MGD)	GWI (MGD)	ADSF (MGD)	Upstream Water Demand (MGD)	Sewer Return Ratio
M15	4.98	2.27	2.71	4.01	68%
M16	3.05	1.01	2.04	2.2	93%
M17	0.59	0.16	0.43	0.46	93%
M18	0.68	0.27	0.41	0.74	55%
M22	0.16	0.05	0.11	0.1	106%
M23	0.63	0.26	0.37	0.36	102%
M24	0.05	0.01	0.04	0.04	107%
M25	1.24	0.67	0.57	0.46	123%
M26	1.40	0.44	0.96	0.81	119%

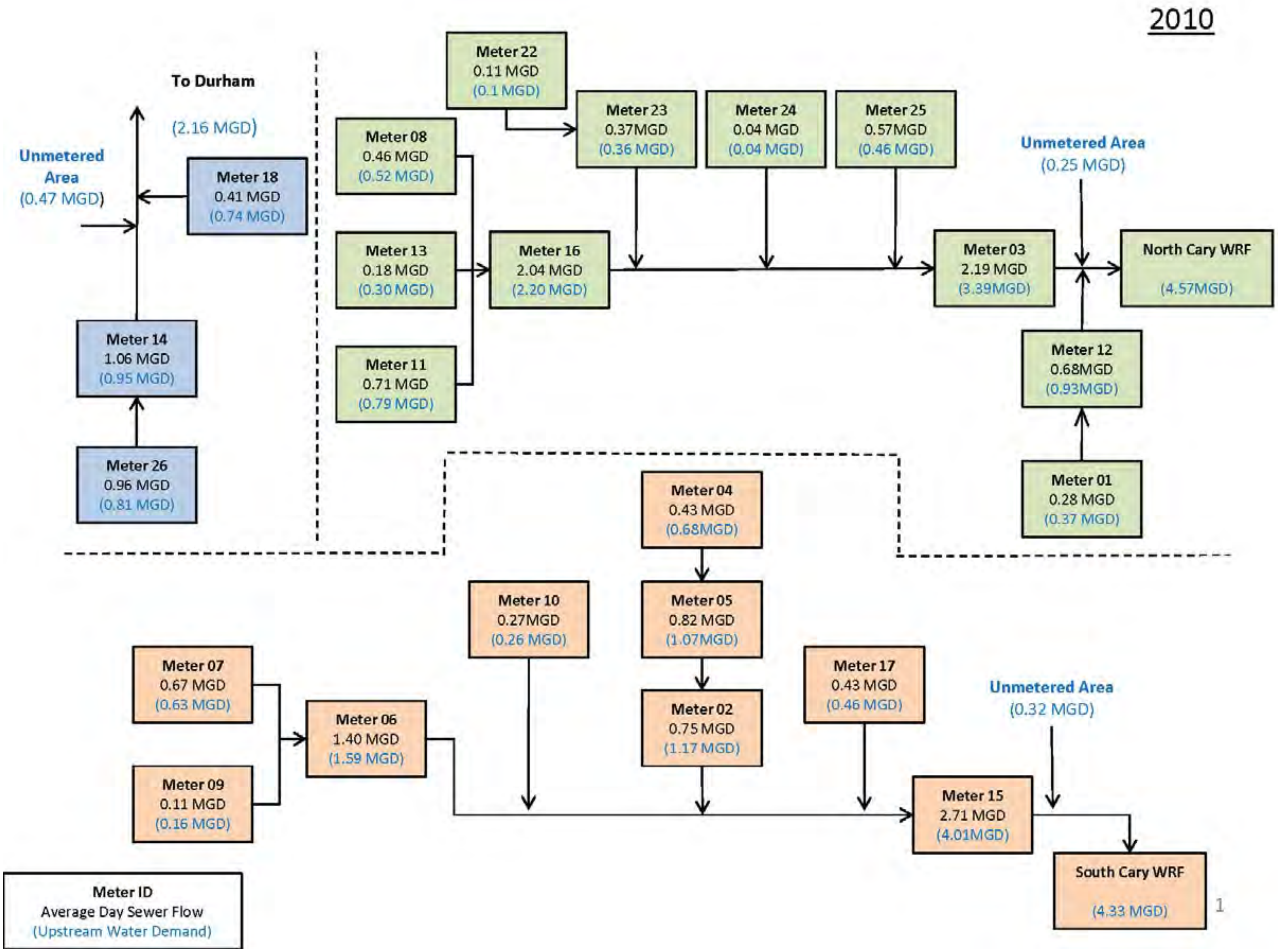

Figure 5-9: Flow Diagram of Upstream Water Demand vs. ADSF

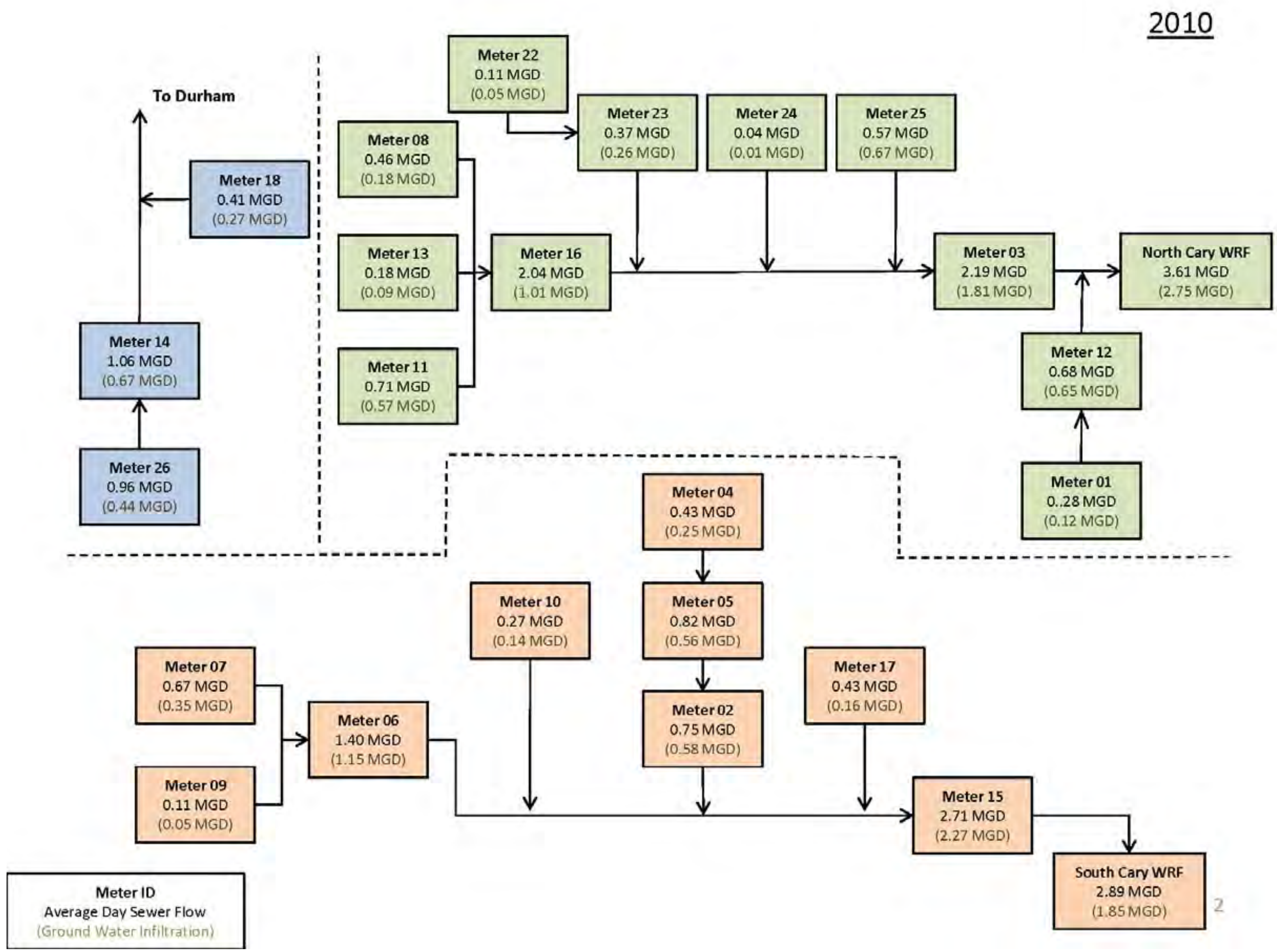

Figure 5-10: Flow Diagram of ADSF vs. GWI

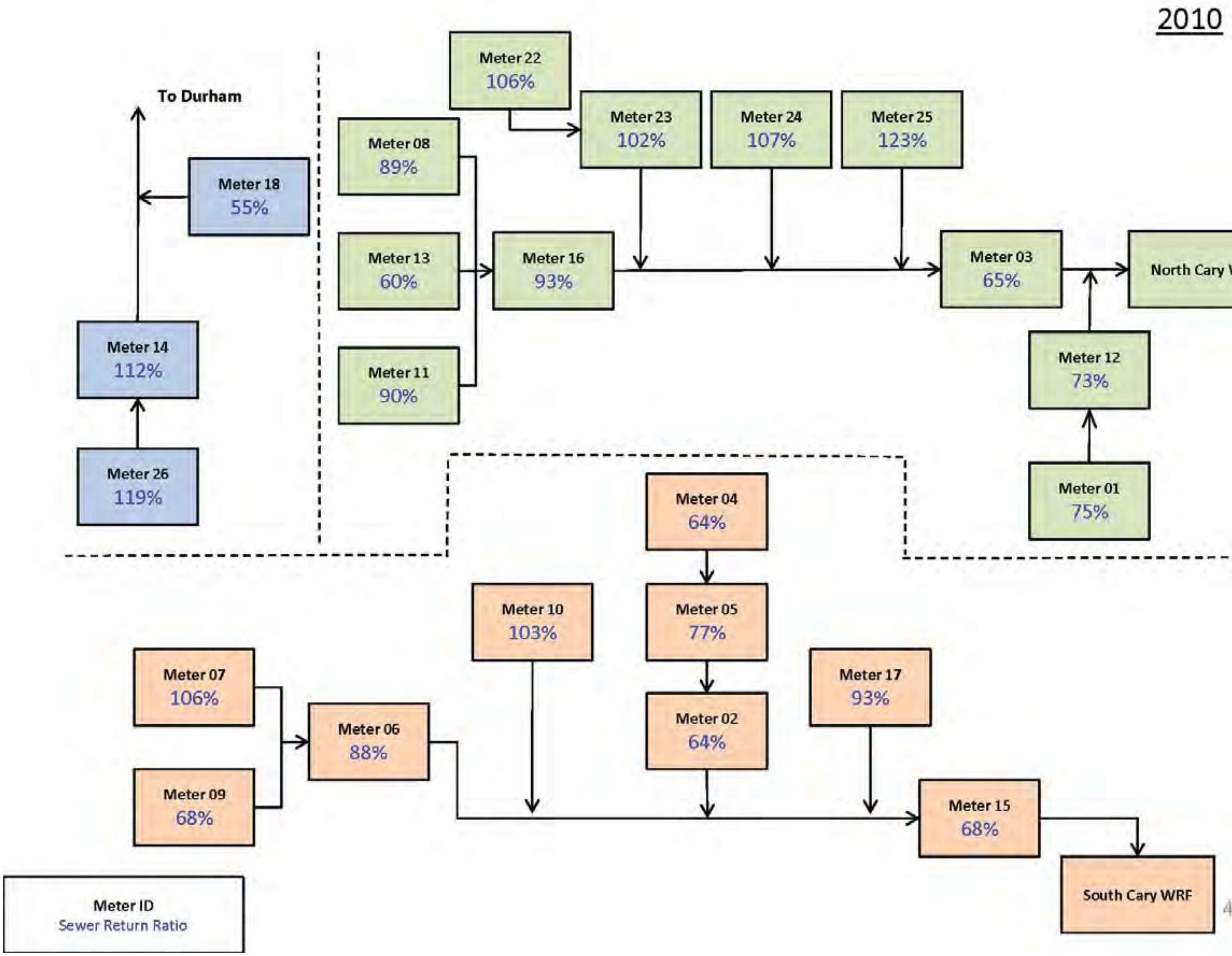

Figure 5-11: Flow Diagram for Sewer Return Ratio

5.2.3 Rainfall-Dependent Inflow and Infiltration (RDI/I)

Rainfall dependent inflow and infiltration is the extraneous water that enters the sewer system in direct response to intensive rainfall events. A simple illustration of RDI/I is presented in Figure 5-12. The analysis of RDI/I involves correlating sewer system flow to rainfall measurements, from which the hydrology for each flow meter's service area is derived and the hydraulics in the proximity of each flow meter can be studied. Our objective is to identify the basins with the highest potential for RDI/I by compiling flow/volume statistics for all flow meters during specific events during which the sewer system configurations are close to the existing system conditions as of late 2009 and early 2010.

Changes were made from 2006 to 2010 to shift flows from the North Cary Service Area to the West Cary Service Area. Recent flow metering data were collected in system configurations largely similar to the existing conditions. Therefore, more focus was expended on storm events in 2009 and 2010. The storm event of 6/16 in 2009 was identified as the biggest storm during this period, in which many meters displayed surcharging conditions. Therefore, it was selected for detailed analysis as shown below.

The number of times that each flow meter is subject to surcharge conditions for the period from January 2008 to April 2010 is presented in Table 5-6 and as a bar chart in Figure 5-13. Since there have been many changes in the collection system since 2008, the number of times of surcharge may not be a perfect indicator for examination of piping capacity adequacy. However, it is a good surrogate to gauge system hydraulics. The system connectivity for all meters is changed only at a very slow pace.

Meters 22 and 23 show six and four months of surcharge, respectively. Both meters are located near the downtown Morrisville area on the Indian Creek Interceptor and the York Interceptor, respectively, where many segments of the system were laid prior to the 1980s (shown in Figure 5-14 and Appendix B). Both meters are discharging into the York Interceptor and then pumped through the Aviation Parkway Pump Station into the Crabtree Creek Interceptor. Inadequate capacity in the York Interceptor or in the Aviation Parkway Pump Station may render both meters more susceptible to surcharge conditions.

As illustrated in Figure 5-15, both Meter 22 and 23 experienced significant surcharge during the 6/16/2009 storm event. The level reading at both meters increased from less than 10 inches to more than 6 ft. (the diameters for Meter 22 and 23 are 20-inch and 17-inch, respectively). Meter 22's surcharge lasted for more than 8 hours while the surcharge for Meter 23 persisted for more than 4 hours. Further examination of the data reveals that surcharge at the two flow meters was caused by different hydraulic conditions. Figure 5-16 shows the velocity readings for both Meters 22 and 23 during the event. As the flow increases at Meter 23, the level reading and velocity for Meter 23 increases as well. The subsequent surcharge at Meter 23 is caused by the insufficient capacity at the branch interceptor on which Meter 23 is installed. On the contrary, as flow and level readings increase at Meter 22, the velocity reading is depressed during a large portion of the surcharge period. This indicates that the actual bottleneck is not the branch pipe on which Meter 22 is installed. Instead, the downstream small 12-inch pipe on the York Interceptor is the bottleneck.

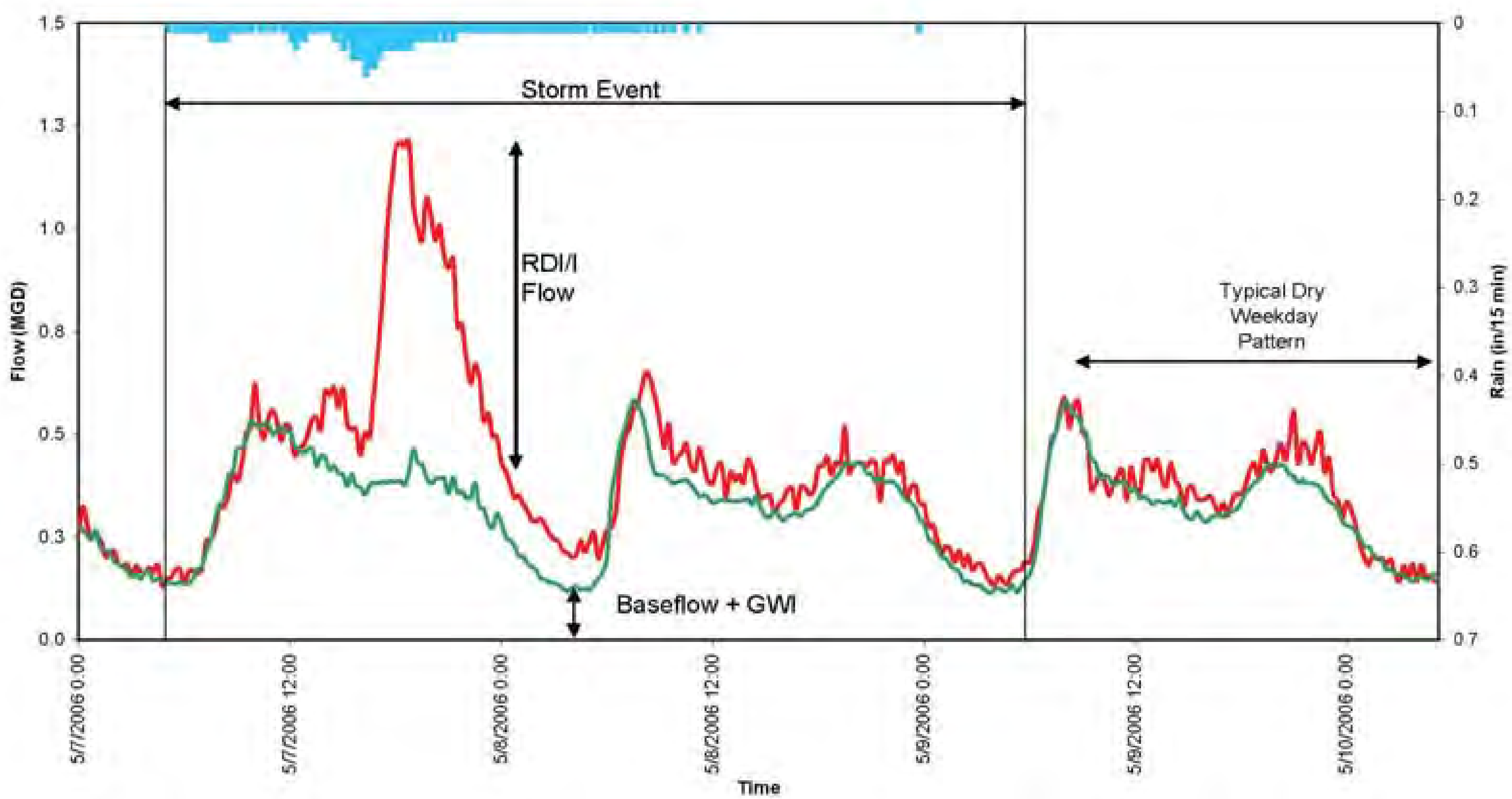

Figure 5-12: Illustration of RDI/I

Table 5-6: Monthly Maximum Depth Reading and Surcharge for All Flow Meters from Jan 2008 to April 2010

Meter No	Diameter (in)	Jan-08 (in)	Feb-08 (in)	Mar-08 (in)	Apr-08 (in)	May-08 (in)	Jun-08 (in)	Jul-08 (in)	Aug-08 (in)	Sep-08 (in)	Oct-08 (in)	Nov-08 (in)	Dec-08 (in)	Jan-09 (in)	Feb-09 (in)	Mar-09 (in)	Apr-09 (in)	May-09 (in)	Jun-09 (in)	Jul-09 (in)	Aug-09 (in)	Sep-09 (in)	Oct-09 (in)	Nov-09 (in)	Dec-09 (in)	Jan-10 (in)	Feb-10 (in)	Mar-10 (in)	Apr-10 (in)
M1	29	7.2	8.7	7.3	7.1	6.7	7.0	7.4	7.2	8.2	7.9	7.5	7.4	8.0	7.5	8.4	7.1	6.3	8.0	5.3	8.3	6.1	6.1	7.1	9.3	6.7	6.6	5.9	6.0
M2	24	15.2	16.0	18.6	19.7	17.4	19.4	19.7	19.7	24.0	14.5	17.7	19.5	17.8	15.0	19.7	15.1	19.9	24.1	14.7	17.7	14.4		19.0	31.2	17.9	23.4	15.8	16.2
M3	48	23.9	23.2	25.0	26.1	25.1	28.5	27.2	29.0	34.5	24.0	24.9	30.6	25.3	23.6	25.9	21.9	24.6	53.7	23.0	23.6	29.3	23.4	33.8	38.5	24.2	29.5	24.9	23.3
M4	24	8.3	7.8	9.6	9.9	7.4	11.0	11.4	10.9	11.1	6.0	7.0	11.0	7.8	6.8	9.3	6.4	14.5	33.5	6.7	8.0	8.0	6.6	9.5	24.3	9.2	9.9	7.5	6.4
M5	21	11.9	5.2	11.0	11.7	9.1	12.4	11.8	11.0	55.3	7.3	9.6	11.8	10.3	8.4	11.3	7.9	11.7	70.7	8.0	8.2	9.2	7.5	12.0	66.6	10.5	13.7	8.3	7.4
M6	30	10.9	11.0	10.7	11.8	11.0	11.3	11.1	14.5	31.9	9.1	11.2	16.5	11.4	10.0	14.7	9.7	11.5	17.6	10.1	12.3	10.4	9.6		38.4	12.5	15.6	12.3	11.3
M7	21	7.9	8.0	11.3	11.4	8.3	12.8	11.8	16.9	16.5	7.9	9.0	17.4	10.6	8.6	13.7	7.8	13.0	31.6	9.2	14.5	10.8	7.7	11.5	28.4	9.6	13.5	8.9	7.4
M8	30	6.0	6.4	8.0	5.7	5.0	5.9	8.0	8.5	8.2	5.6	5.9	5.6	6.2	5.9	7.0	6.3	9.1	10.8	6.0	5.6	6.6	6.1	7.0	6.9	6.9	8.9	7.3	7.3
M9	18	5.3	4.6	4.5	5.2	5.6	4.5	5.1	5.0	5.8	4.6	5.1	4.9	4.9	4.8	6.0	5.0	4.9	4.7	5.5	5.1	5.7	4.8	5.5	6.4	5.0	4.9	5.0	4.8
M10	12	7.4	7.2	8.0	7.0	7.0	7.2	7.3	8.5	8.2	6.5	6.4	8.5	7.0	7.1	7.8	6.5	6.9	22.1	7.7	5.9	7.7	6.2	8.5	9.3	6.5	7.0	6.4	6.6
M11	30	6.6	6.8	7.0	7.6	7.1	7.3	9.2	6.4	8.4	6.7	7.3	7.6	7.2	7.0	7.7	7.2	8.2	8.8	6.6	7.7	7.5	7.1	7.5	7.9	6.8	7.5	7.2	7.1
M12	29	8.2	8.1	9.0	9.0	8.5	9.4	9.8	9.5	9.7	8.8	9.4	10.5	9.0	8.5	9.4	8.4	11.8	10.6	8.1	9.9	7.6	7.5	8.8	9.8	8.6	9.8	8.2	7.9
M13	25	7.1	5.9	6.3	7.0	7.2	6.6	7.2	6.3	8.3	7.2	7.3	6.8	6.8	7.5	8.2	7.4	9.8	9.6	7.1	7.3	7.4	7.3	8.4	7.5	5.7	6.3	5.0	5.0
M14	30	6.6	6.4	6.7	6.2	6.6	8.7	6.8	6.9	8.5	6.9	7.4	7.2	7.1	7.3	8.1	7.1	8.8	7.3	7.4	7.5	9.2	7.4	9.9	9.7	7.9	7.4	7.2	6.8
M15	42	14.4	14.2	16.0	19.3	17.8	17.7	17.4	19.5	25.3	13.7	17.4	19.9	18.0	16.8	19.9	16.7	18.4	25.7	16.0	18.2	21.2	14.8	22.4		15.9	19.5	16.2	18.3
M16	36	12.2	13.1	15.4	14.3	13.3	15.7	21.1	18.2	25.1	12.4	15.3	17.2	16.1	13.3	18.2	13.7	26.1	72.8	13.7	15.0	17.1	15.5	17.5	22.2	16.1	19.1	15.9	14.1
M17	23	6.1	5.6	5.7	5.9	6.1	5.9	6.5	6.3	6.7	5.7	5.9	5.9	6.1	6.2	6.7	5.9	6.3	6.4	5.2	5.2	5.4	5.5	6.6	6.0	6.6	6.1	5.7	5.8

Table 5-6: Monthly Maximum Depth Reading and Surcharge for All Flow Meters from Jan 2008 to April 2010 (Continued)

Meter No	Diameter (in)	Jan-08 (in)	Feb-08 (in)	Mar-08 (in)	Apr-08 (in)	May-08 (in)	Jun-08 (in)	Jul-08 (in)	Aug-08 (in)	Sep-08 (in)	Oct-08 (in)	Nov-08 (in)	Dec-08 (in)	Jan-09 (in)	Feb-09 (in)	Mar-09 (in)	Apr-09 (in)	May-09 (in)	Jun-09 (in)	Jul-09 (in)	Aug-09 (in)	Sep-09 (in)	Oct-09 (in)	Nov-09 (in)	Dec-09 (in)	Jan-10 (in)	Feb-10 (in)	Mar-10 (in)	Apr-10 (in)
M18	42	16.0	8.7	7.1	7.1	8.3	7.6	8.5	8.1	9.5	8.0	7.4	7.8	7.2	9.1	14.9	10.5	7.7	9.6	8.0	8.0	7.8	7.7	9.6	9.3	8.6	10.0	8.7	9.7
M22	20	6.8	5.6	29.6	6.1	5.3	17.1	37.8	49.8	65.5	5.8	5.9	5.9	5.6	5.3	5.9	4.8	24.4	70.9	5.0	7.2	5.4	4.4	5.7		5.3	5.5	5.5	5.5
M23	17	7.8	8.8	22.4	10.7	8.5	12.5	15.6	24.9	59.4	7.9	11.0	8.6	11.0	8.9	12.8	9.5	14.3	75.2	10.9	11.9	11.0	8.3	13.4	11.9	10.9	11.9	12.6	8.2
M24	16	2.8	2.9	5.4	3.1	3.1	4.4	5.0	5.4	6.3	3.6	3.4	3.1	3.2	3.1	3.1	2.9	2.8	47.7	4.9	2.8	3.1	3.2	3.9	4.5	3.5	3.3	3.0	3.4
M25	42		18.0	25.6	19.7	18.3	21.6	24.9	29.8	34.6	17.0	22.3	24.0	22.2	18.1	25.3	18.0	28.9	46.0	16.7	17.4	21.8	19.4	28.0	31.4	22.1	26.1	20.8	18.1
M26	36												6.6	6.9	7.6	7.5	7.4	7.4	8.3	6.2	6.4	6.6	6.5	7.1	8.1	7.5	7.9	8.5	8.0

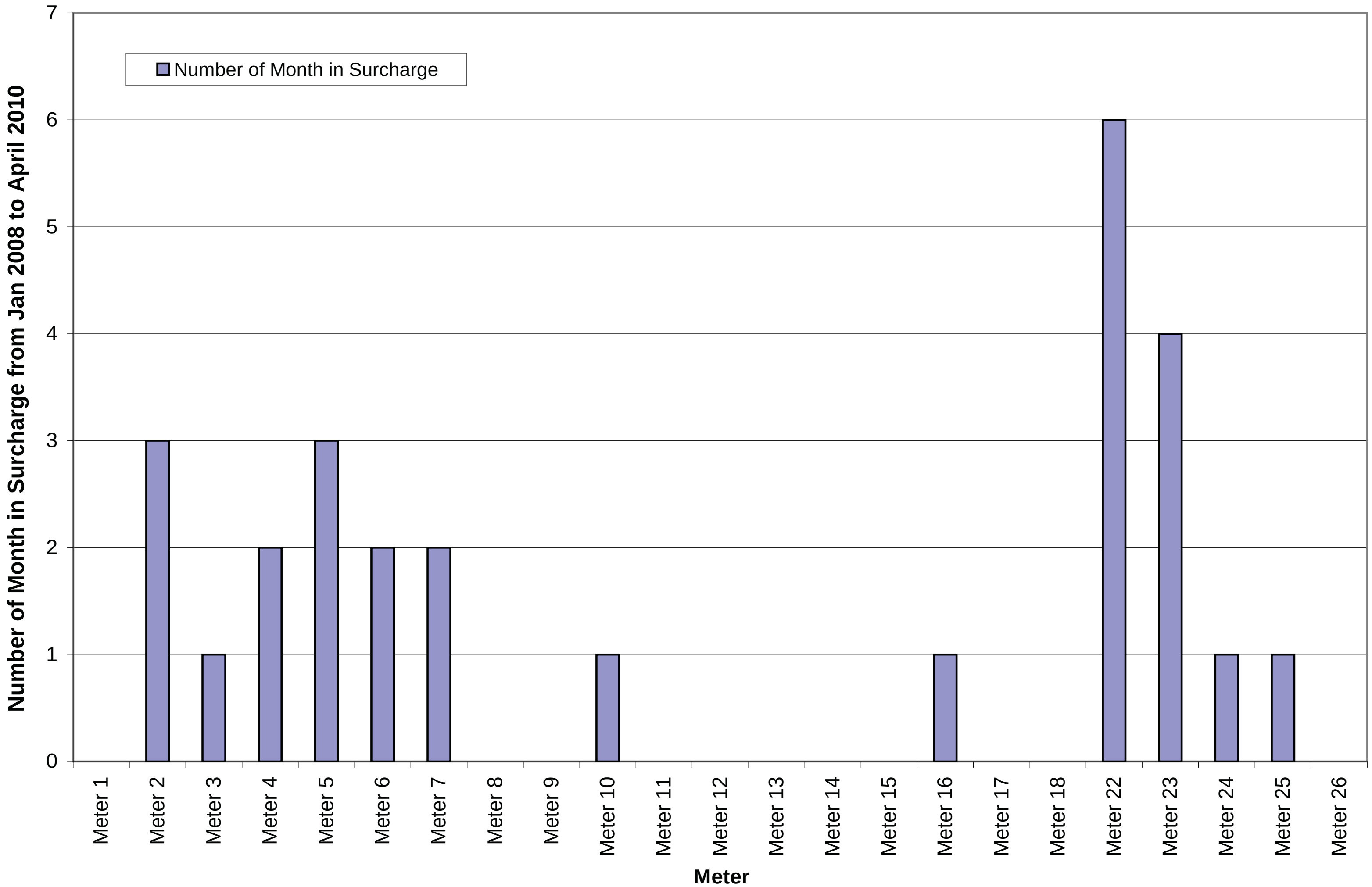

Figure 5-13: Numbers of Months from January 2008 to April 2010 Showing Surcharge for Each Meter

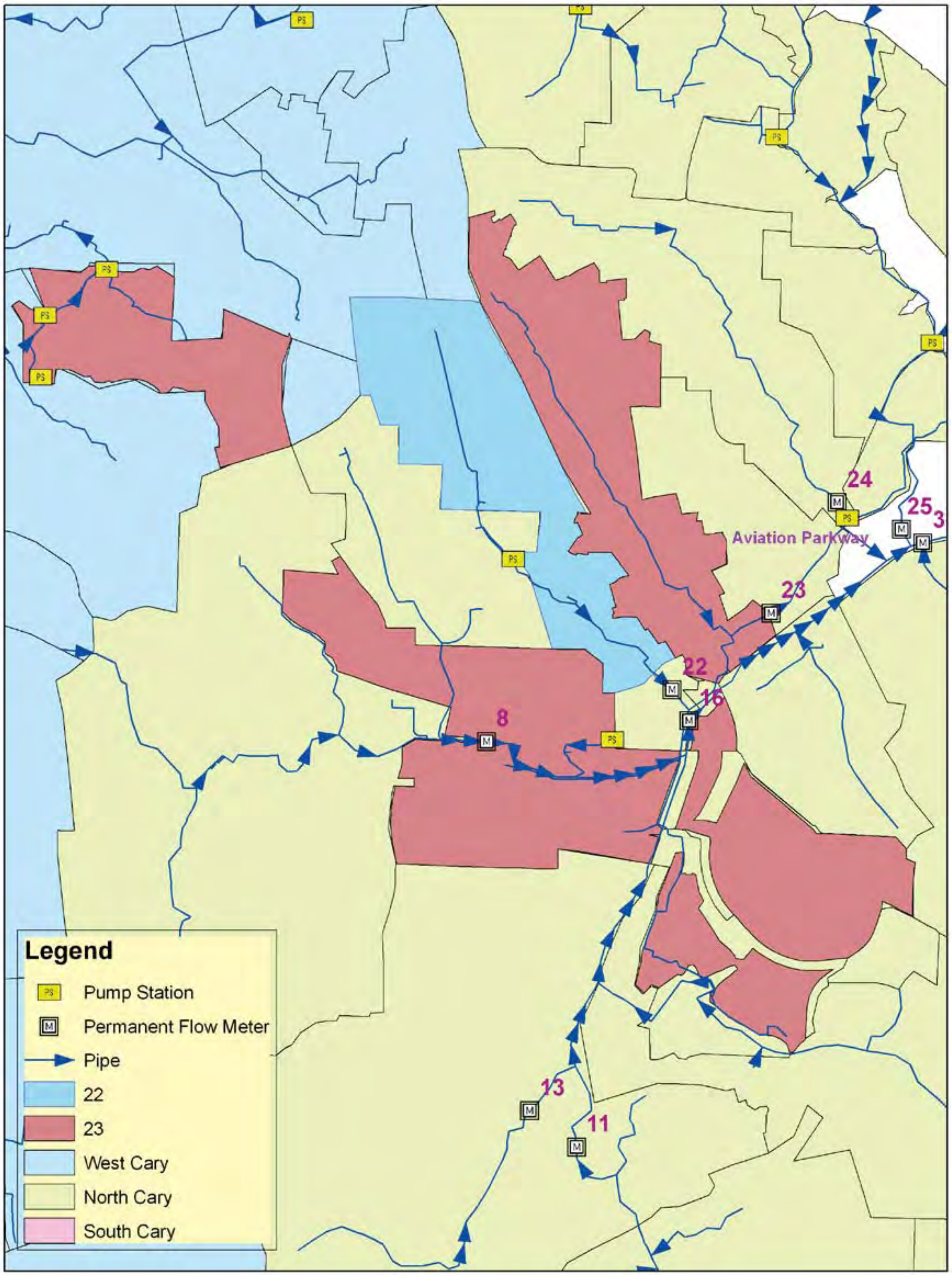

Figure 5-14: Plan View of Meter 22/23 In Reference to Aviation Parkway Pump Station

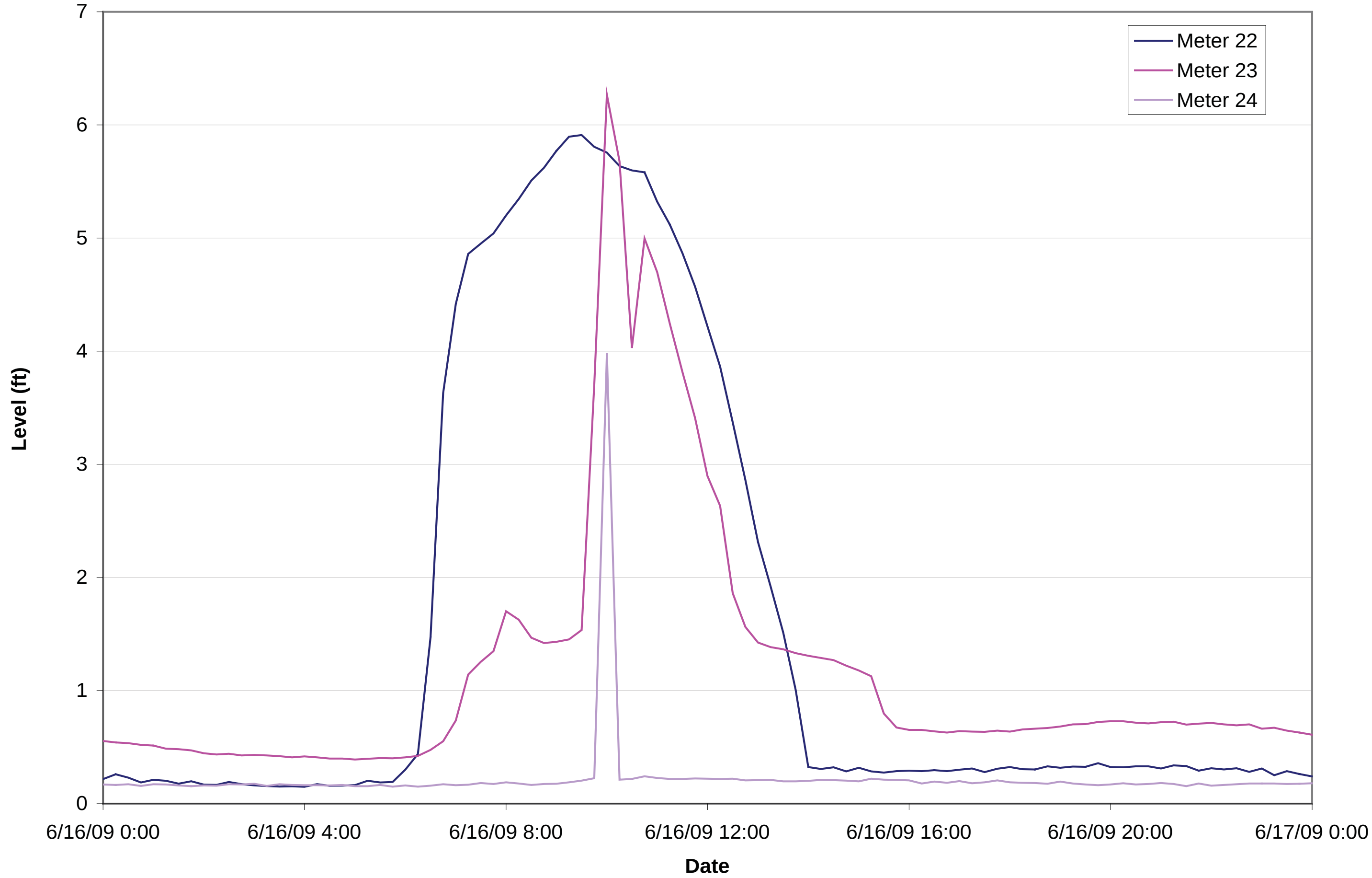

Figure 5-15: Level Readings for Meters 22, 23 and 24 During 6/16/2009 Wet Weather Event

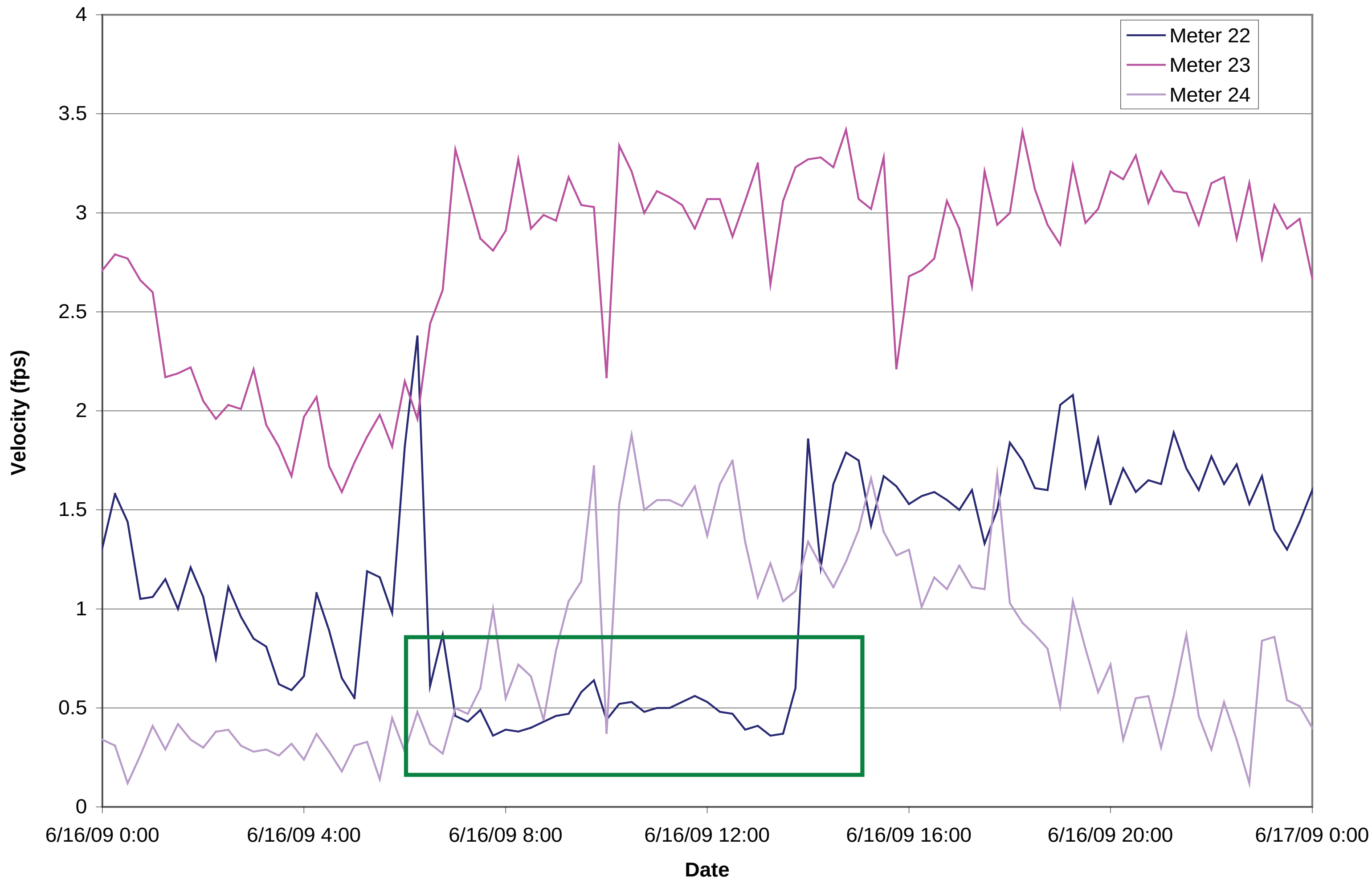

Figure 5-16: Velocity Readings for Meters 22, 23 and 24 During 6/16/2009 Wet Weather Event

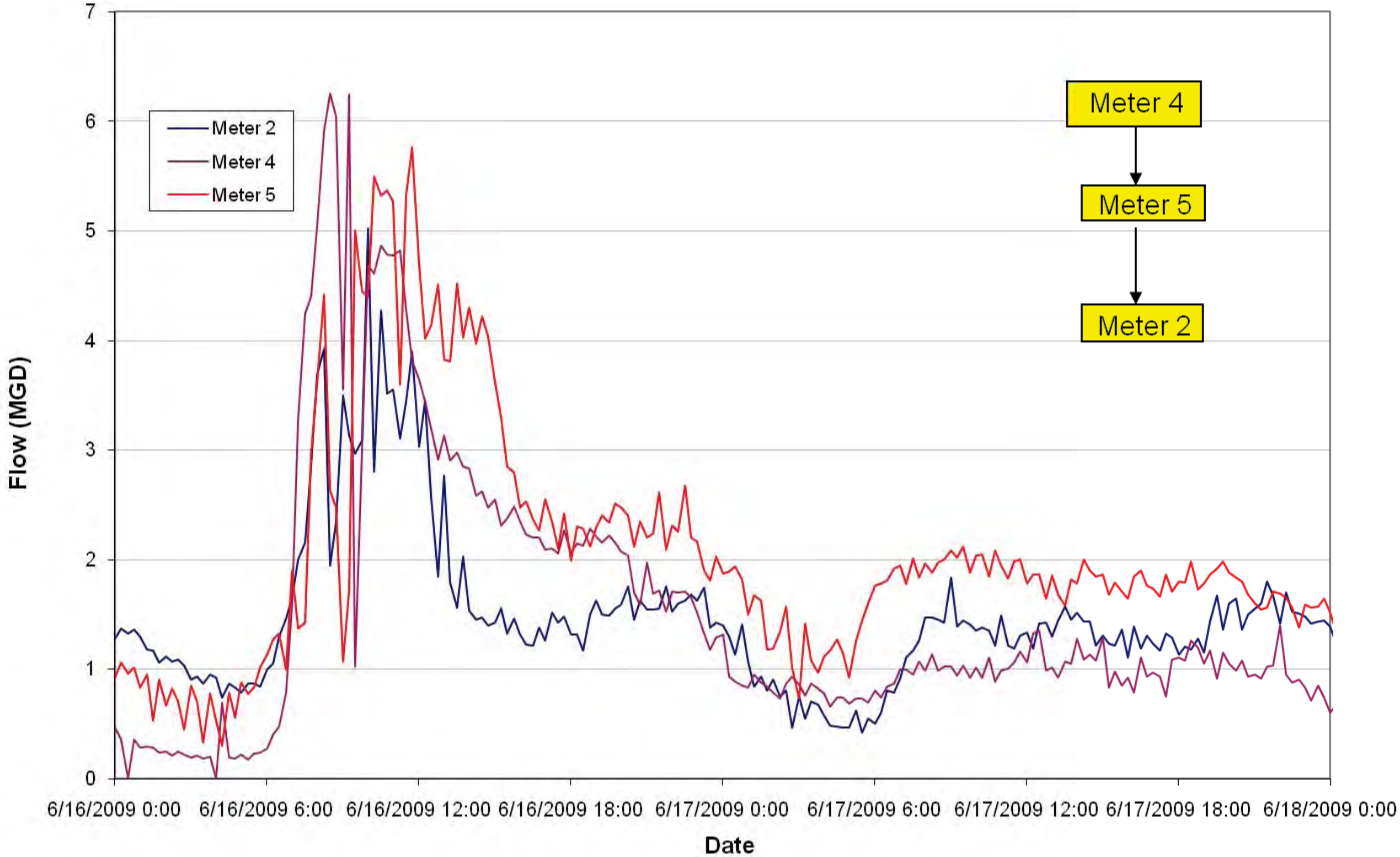

Figure 5-17: Flow Data for Meters 2, 4, and 5 During 6/16/2009 Event

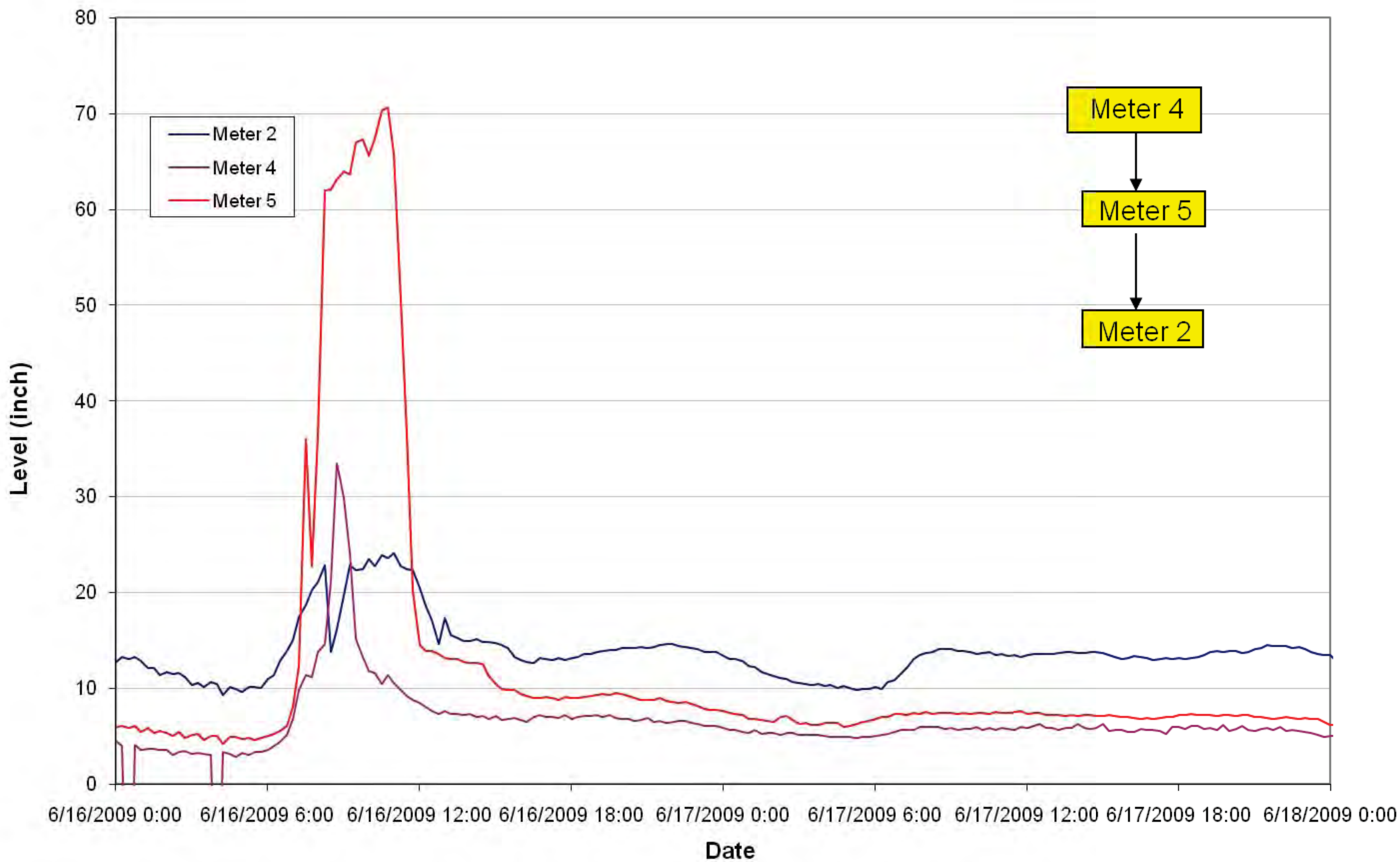

Figure 5-18: Depth Readings for Meters 2, 4 and 5 During 6/16/2009 Event

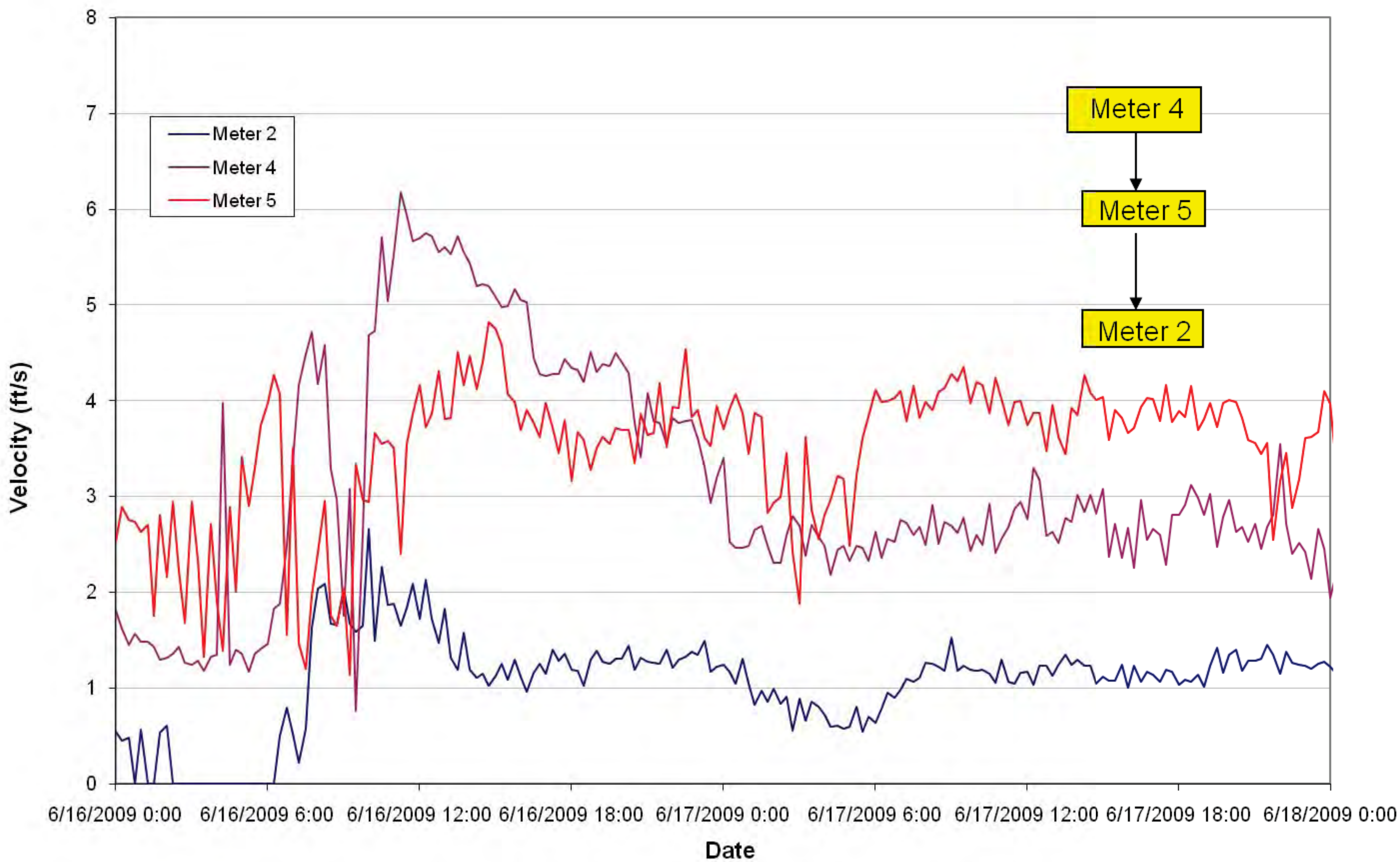

Figure 5-19: Velocity Readings for Meters 2, 4 and 5 During 6/16/2009 Event

In Figures 5-17, 5-18, and 5-19, Meters 2, 4 and 5 show data for the second block of meters that draw our attention. As shown in Figure 5-17 and Appendix B, the Walnut Creek Pump Station (immediately downstream of Meter 4), has a switching pumping capability to allow it to pump into either the Speight Branch Interceptor in the South Cary service area or into the Black Creek Interceptor in the North Cary service area. In the baseline operating condition as of late 2009, the Walnut Creek Pump Station was pumping south into the South Cary service area. Therefore, the flow collected at the Walnut Creek Pump Station (immediately downstream of Meter 4) was pumped into Meter 5 and subsequently to Meter 2. In Figure 5-17, the flow rates for Meters 2, 4 and 5 are plotted for the storm event in 6/16/2009. The volume of RDI/I can be determined by calculating the area below each curve by simple integration. The volumes of RDI/I for all meters were calculated and are tabulated in Table 5-7.

The volume of RDI/I is almost identical between Meter 4 (1.78 MG) and its immediate downstream meter, Meter 5 (1.94 MG). The RDI/I volume contribution from the incremental service area of Meter 5 itself is very minor. As such, the majority of RDI/I observed at Meter 5 and Meter 2 is the direct result of RDI/I at Meter 4 upstream of Walnut Creek Pump Station. A lower RDI/I volume and flow rate were recorded at Meter 2 than at Meter 5, the difference of which cannot be explained readily.

It is also worth noting that the peak flow to the Walnut Creek Pump Station during the 6/16/2009 storm reached as high as 7.5 MGD. As shown in Section 3, the firm capacity of the Walnut Creek Pump Station was found to be 3.85 MGD. The total capacity of the Walnut Creek Pump Station may be around 6 MGD. Therefore, it is the wet well in the Walnut Creek Pump Station that helped store the volume of RDI/I during this event. The firm capacity and total capacity of the Walnut Creek Pump Station is below the peak flow recorded at Meter 4. Therefore, we believe that the Walnut Creek Pump Station may need upsizing in the future to accommodate the high RDI/I flow generated from the Meter 4 basin.

Based on the data in Table 5-7, Meter 22 has an RDI/I volume of 0.12 MG vs. an RDI/I volume of 0.973 MG for Meter 23. Therefore, the large RDI/I volume from Meter 23 is the cause for the surcharge, while the small RDI/I volume originating from Meter 22 is just the symptom of the surcharge experienced at Meter 22. Therefore, further improvement projects should be directed at increasing the flowing capacity of the York Interceptor instead of paralleling the branch pipe on which Meter 22 is installed.

Table 5-7: RDI/I Volume for All Flow Meters During the 6/16/2009 Event

Flow Meter	Sewer Length (mi)	6/16/2009 Storm	
		RDI/I Volume (MG)	Average RDI/I (gal/LF)
1	24.8	0.042	0.32
2	83.94	0.542	1.22
3	257.31	4.23	3.11
4	39.83	1.78	8.46
5	74.61	1.94	4.92
6	117.14	1.97	3.19
7	39.25	1.06	5.11
8	37	0.129	0.66
9	14.21	0.024	0.32
10	17.3	0.287	3.14
11	58.26	0.067	0.22
12	58.17	0.392	1.28
13	20.5	0.509	4.70
14	75.58	0.402	1.01
15	280	2.62	1.77
16	160.98	3.97	4.67
17	23.7	0.31	2.48

Table 5-7: RDI/I Volume for All Flow Meters During the 6/16/2009 Event (Continued)

Flow Meter	Sewer Length (mi)	6/16/2009 Storm	
		RDI/I Volume (MG)	Average RDI/I (gal/LF)
18	29.84	0.102	0.65
22	9.41	0.12	2.42
23	42.64	0.973	4.32
24	3.96	0.018	0.86
25	22.18	1.11	9.48
26	61.01	0.714	2.22

Both Meter 3 and Meter 16 (see Appendix B) are showing substantial flow increases and surcharge, as illustrated in Figures 5-20, 5-21 and 5-22. During the event of 6/16/2009, the RDI/I volume identified at Meter 16 (3.97 MGD) dominated the RDI/I volume recorded at Meter 3 (4.07 MG). It also showed a higher and earlier peak than Meter 3, a typical characteristic of damping in the collection system. In Figure 5-20, the flow reading for Meter 16 was reduced to almost zero for four hours during the 6/16/2009 event. The flow reading for Meter 3 was also decreased to zero briefly during the 6/16/2009 event. Further evidence that supports the previous observation of damping can be found in Figure 5-22, which plots the velocity readings for Meters 3 and 16 during the same event. As shown in Figure 5-22, Meter 22 shows sustained stall of flows in the adjoining area of Meter 16. Meter 23 also has a brief period in which the velocity of pipe was reduced to almost zero. This is an indication of downstream blockage.

Based on the information collected by Frazier Engineering, the logical sequence of events seems to be that the flow from upstream of Meter 16 surges first, which in turn causes the blockage of Meter 3 or the area downstream of Meter 3. The area downstream of Meter 3 is rather complicated in that it receives the flow from Meter 12 (Black Creek Interceptor) and Meter 1. Its hydraulic condition is also controlled by the downstream influent pump station for the North Cary WRF.

From a capital investment perspective, we would argue for extending the economic life of the Crabtree Creek Interceptor and postponing immediate investment in the short term, while the Town devotes more resources to completing the Western Wake WRF and its associated collection/pump station system. We recommend more detailed study to further ascertain the cause of surcharge. The study should be directed to isolating the causes of the surcharge that can be attributed to local blockages, elevated levels of GWI resulting from spiral wound pipe employed at the downstream segment of the Crabtree Creek Interceptor, or influent pump station operation at the North Cary WRF.

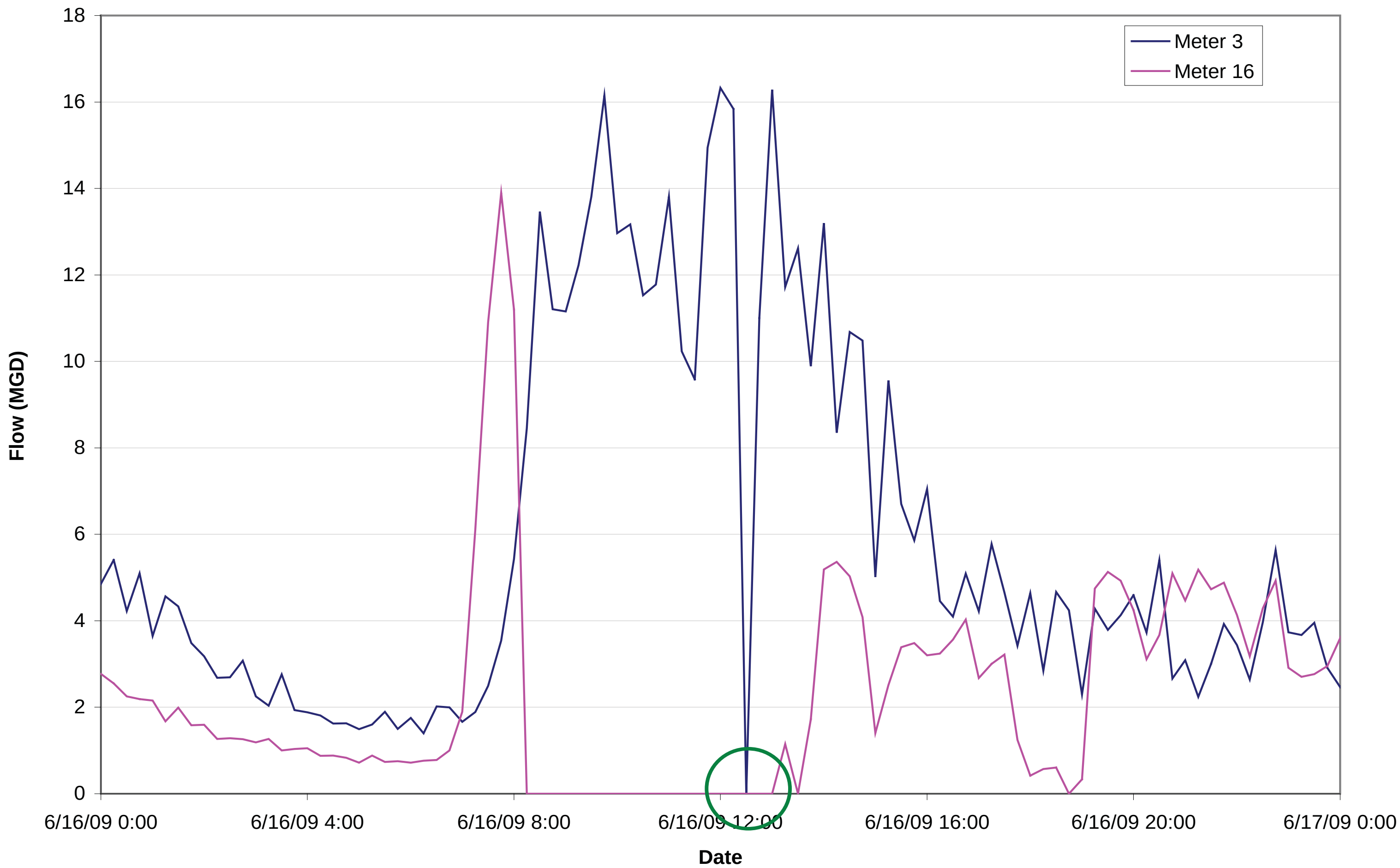

Figure 5-20: Flow Readings for Meters 3 and 16 During 6/16/2009 Event

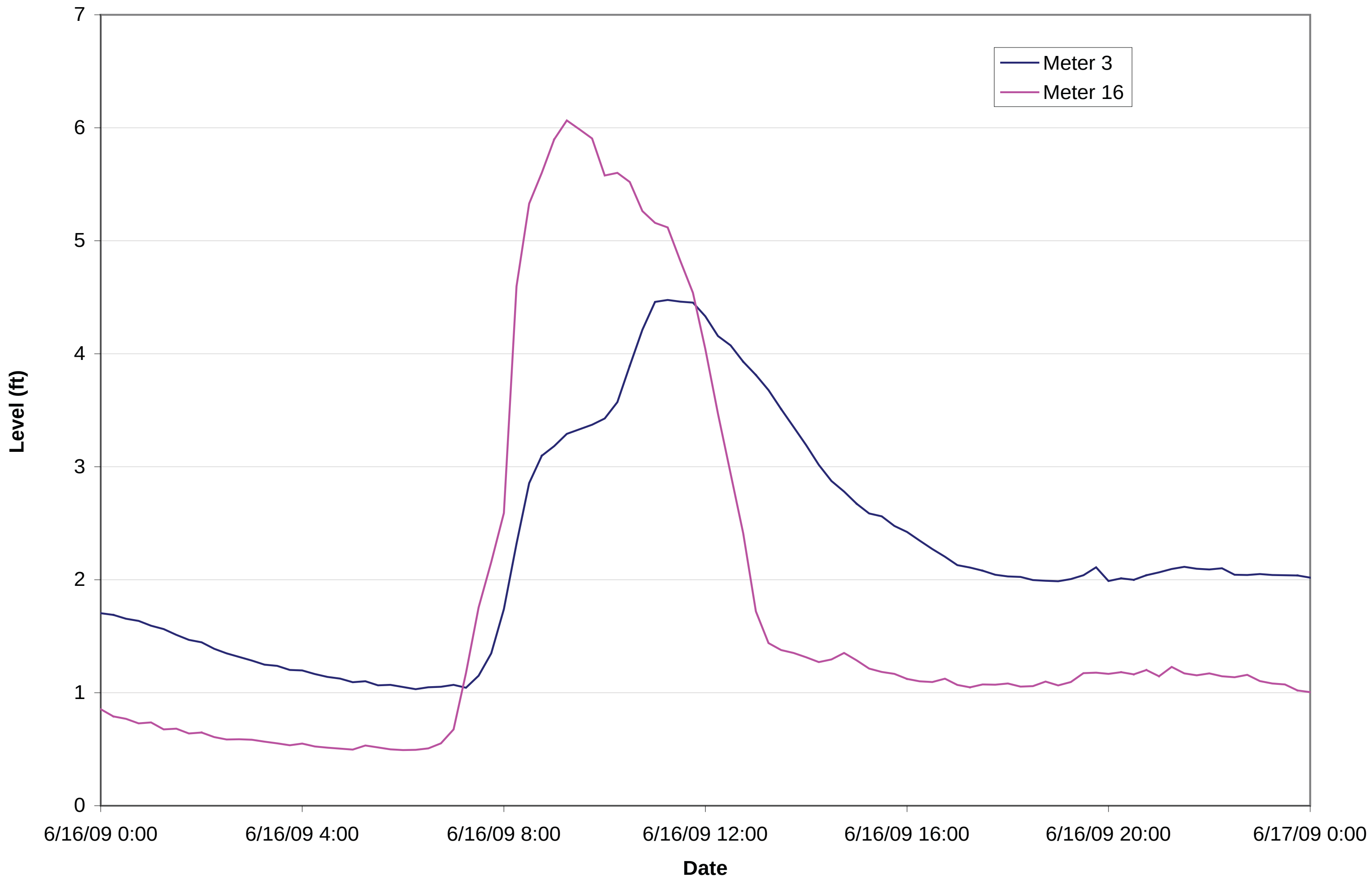

Figure 5-21: Level Readings for Meters 3 and 16 During 6/16/2009 Event

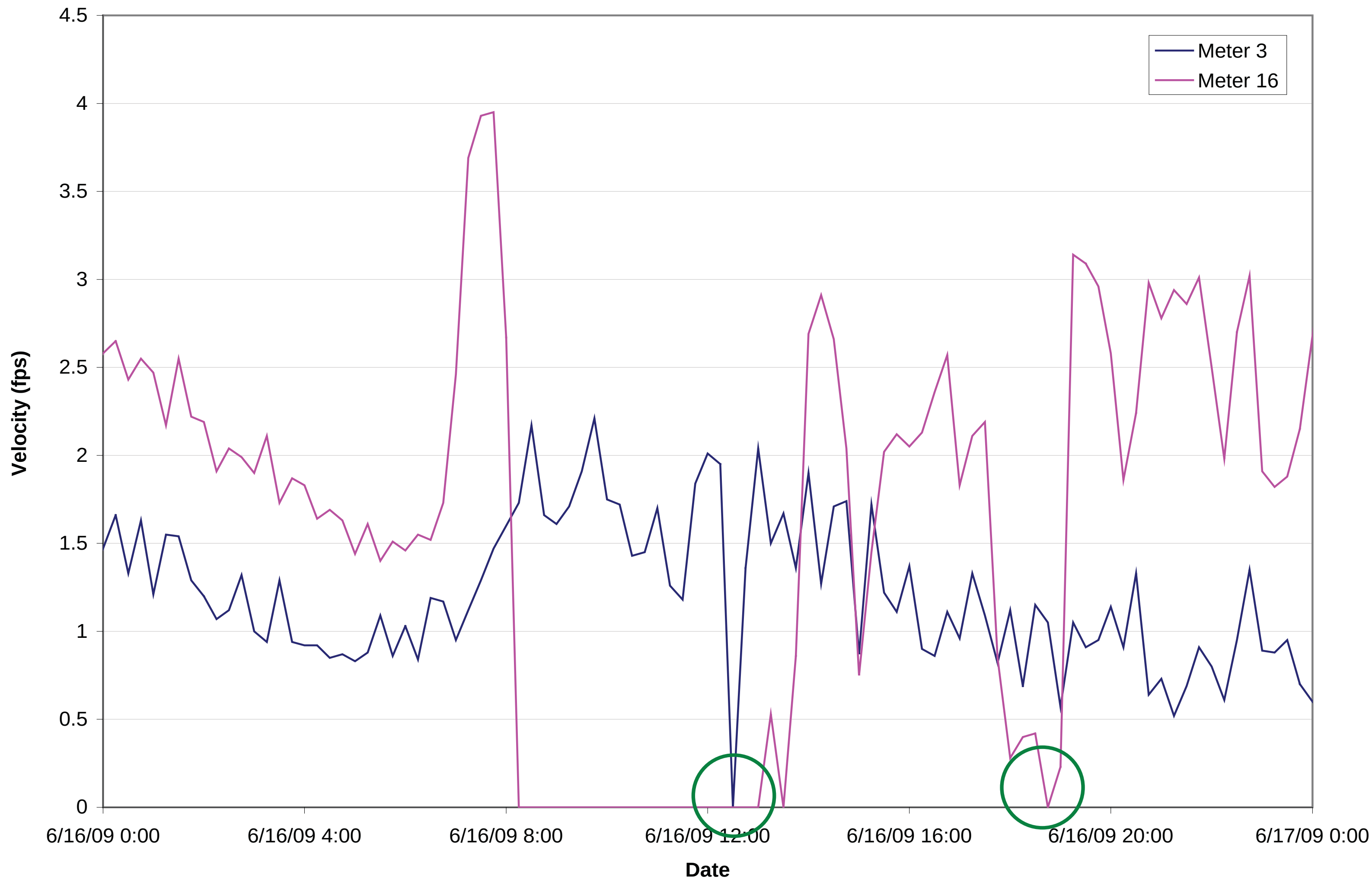

Figure 5-22: Velocity Readings for Meters 3 and 16 During the 6/16/2009 Event

Both Meter 6 and Meter 7 (see Appendix B) were surcharged twice from 2008 to 2010. Flow readings and depth readings for Meters 6 and 7 can be found in Figures 5-23 and 5-24, respectively. During the 6/16/2009 event, the flow at Meter 7 increase from 1 MGD to 5 MGD. The level reading increased to 2 ft. As highlighted in Figure 5-23, the flow reading for Meter 7 twice dropped close to 0 MGD. Figure 5-25 plots the velocity readings for Meters 6 and 7 during the 6/16/2009 event. It also shows a corresponding drop in velocity in two instances. It is a clear indication of a downstream surcharge condition due to a blockage. Compared to other meters, both Meter 6 and Meter 7 showed only mild surcharge. Therefore, we would recommend that future improvements be made in the vicinity of Meters 6 and 7 to address those capacity issues based on the model simulation results as discussed in Section 6.

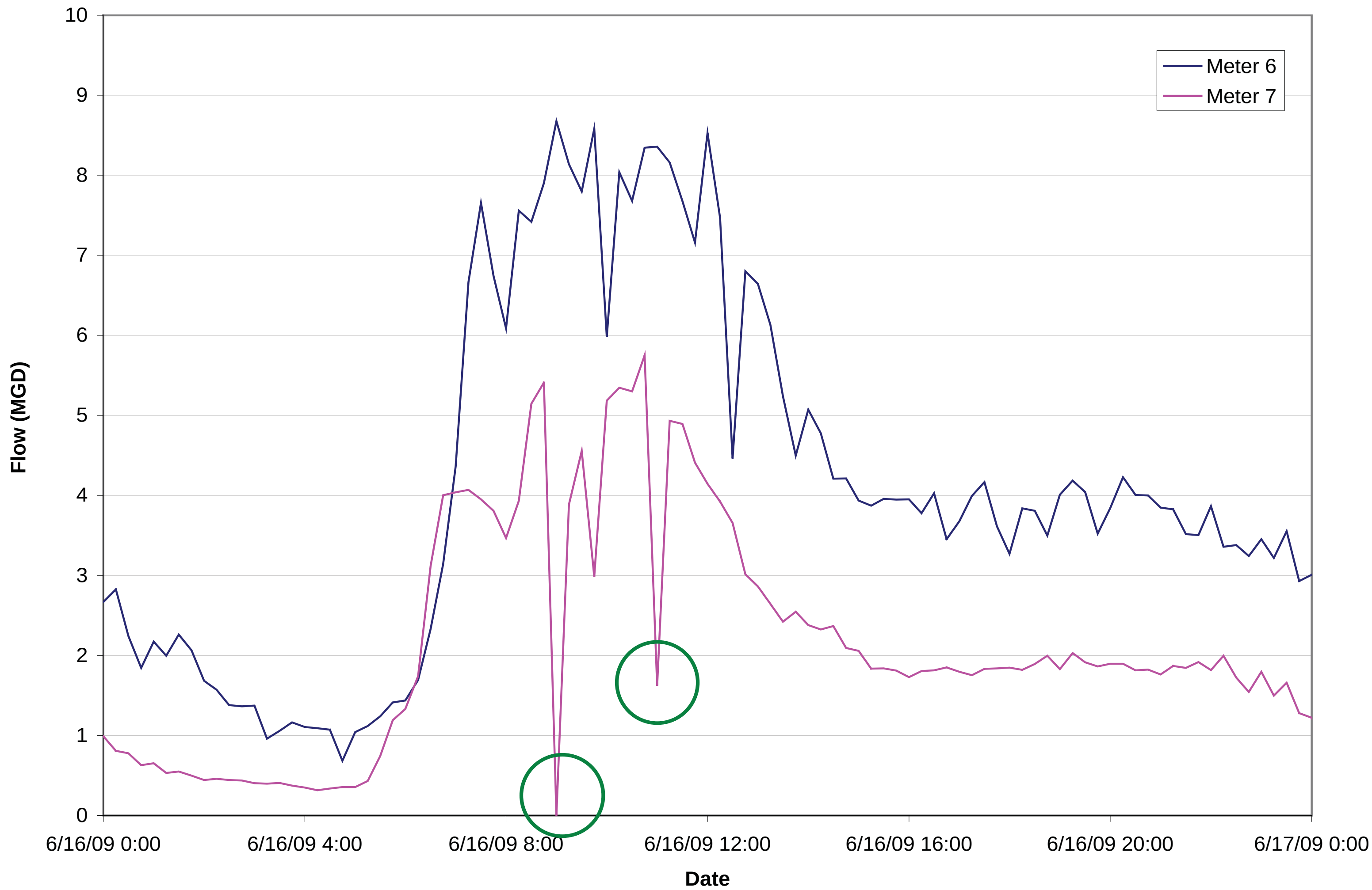

Figure 5-23: Flow Readings for Meters 6 and 7 During the 6/16/2009 Event

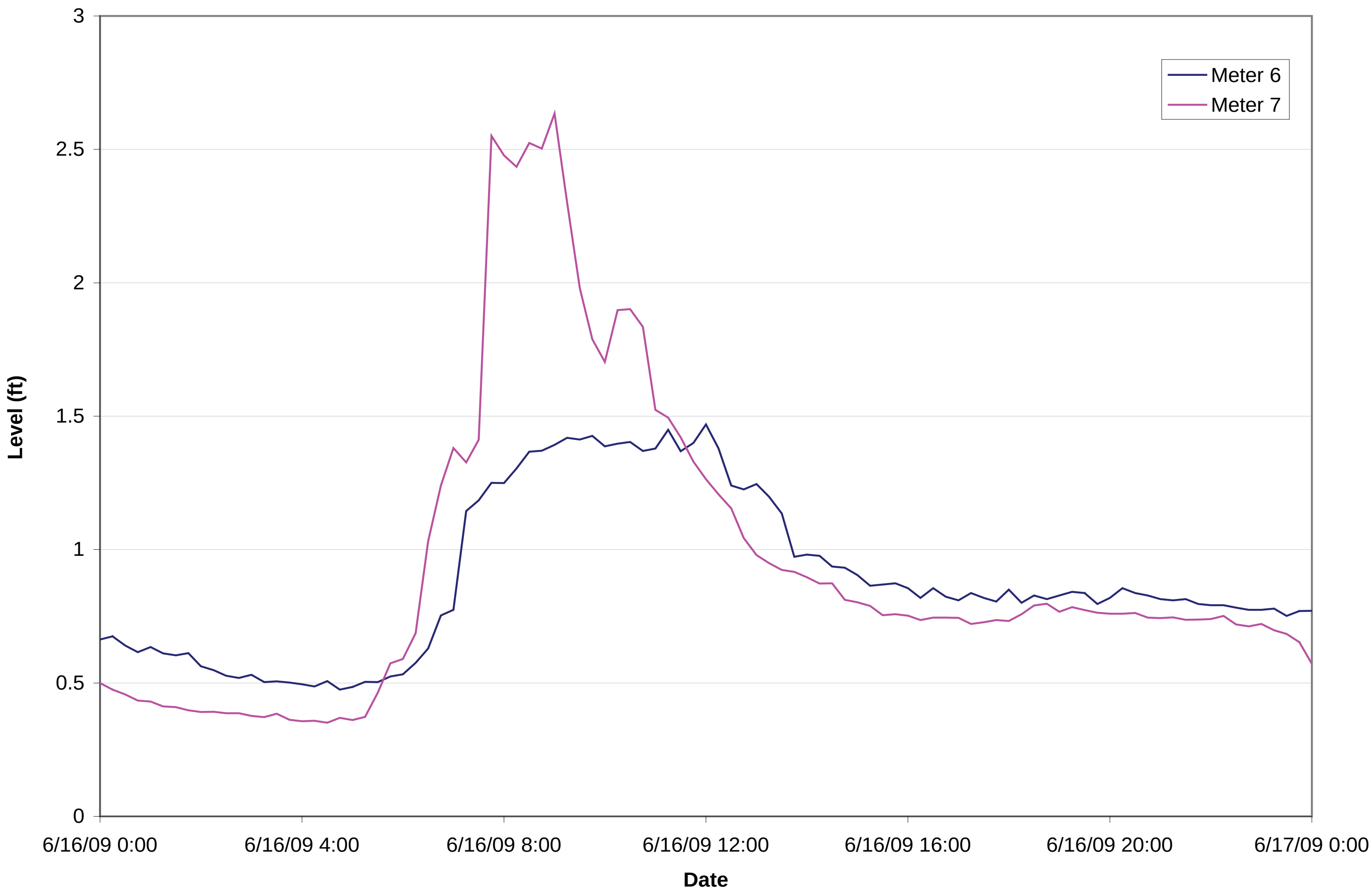

Figure 5-24: Level Readings for Meters 6 and 7 During the 6/16/2009 Event

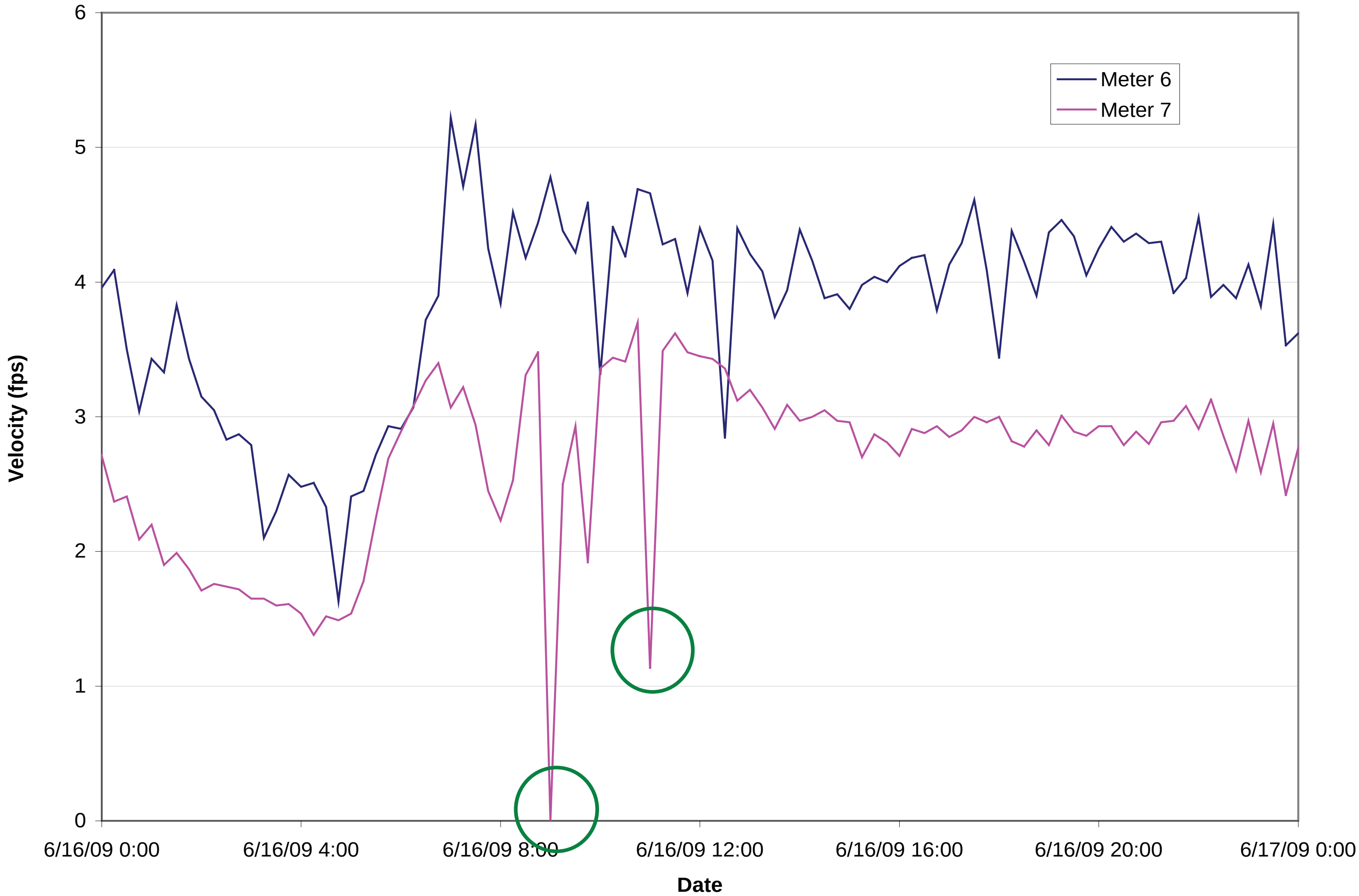

Figure 5-25: Velocity Readings for Meters 6 and 7 During the 6/16/2009 Event

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