Flow Monitoring Report

City of Warren Comprehensive SSO Study

August 11, 2017

AECOM Project No. 60526190

Prepared for

the city of WARREN Ohio

AECOM

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Figures

Tables

Appendix

Acronyms and Abbreviations

A	Area
CSO	Combined Sewer Overflow
City	City of Warren
I/I	Inflow and Infiltration
LF	Lineal Feet
MGD or mgd	Million Gallons per Day
OEPA	Ohio Environmental Protection Agency
Q	Flow
SSO	Sanitary Sewer Overflow
V	Volume
WWTP	Wastewater Treatment Plant

1.0 EXECUTIVE SUMMARY

This report documents and summarizes the sanitary sewer flow monitoring conducted in the City of Warren, Ohio during the period of November 14, 2016 to June 20, 2017 as part of the ongoing comprehensive sewer study of the Warren system. Thirty-six flow meters and five rain gauges were deployed during this period.

The purpose of the flow monitoring was to document flows in the sanitary sewer system during dry and wet weather periods. The flow and rainfall data will be used in calibrating the city wide model AECOM is building as part of this study. Once calibrated, the sewer model will be used to analyze alternatives for improving the sewer system's performance under wet weather conditions.

Section 2 of this report gives a brief history of Warren and its sewer system and discusses the current issues in the system, including the High Street Sanitary Sewer Overflow (SSO).

Section 3 of this report discusses the placement of rain gauges and flow meters throughout the system.

Section 4 then provides analysis of the collected data. Individual flow meter catchment areas of note are discussed. An inflow and infiltration (I/I) analysis of each catchment area was performed. The dry weather and wet weather calculations are explained and example calculations for one flow meter are shown in the body of the report. The rest of the analyses are included in the appendix.

Section 5 gives a brief conclusion to the flow metering analysis.

The next step on this project will be the sewer characterization report. This report will describe the building and calibration of the sewer model based on the flow monitoring program discussed in this report.

2.0 INTRODUCTION

The sewer system that serves the City of Warren, Ohio (City) was once a combined sewer system. Over the course of many years, the City completed numerous construction projects to separate its sewer system. One of the commonly employed separation methods was building a new storm sewer parallel to the existing combined sewer and connecting public storm water sources to the new storm sewer. The existing combined sewer then became the sanitary sewer. While these improvements did a lot to address wet weather flows entering the now separate sanitary sewer system, they did not explicitly address storm water connections from private property. The City formally required private properties to disconnect their storm water connections from the sanitary sewer but many did not and still have not complied, even under the punishment of doubled or tripled sewer bills.

When the City's sewer system was operating as a combined storm and sanitary sewer system, there were numerous combined sewer overflows (CSOs) to prevent basement backups and other flooding from occurring during rain events. As the City attempted to separate its sewer system, these CSOs were closed. However, even with the sewer separation projects, the City has continued to see high peak flows in its sewer system during wet weather periods. Without these CSOs to relieve the high waters, basement and manhole flooding have become common in several locations throughout the City. Recognizing the problem, the Ohio Environmental Protection Agency (OEPA) allowed the City to reopen one former CSO, what is now called the High Street SSO. This SSO is only allowed to remain open for a limited period of time.

To address eliminating the SSO, the City hired AECOM to perform a sewer study of the areas in the vicinity of the SSO. The final report from this study was submitted in September 2015 and is attached to this report as Appendix G. The conclusion from this study was that the wet weather problems of the Warren sewer system are not restricted to just the downtown area, but are system wide. OEPA accepted the recommendation from this report that a comprehensive sewer study be performed for the entire system before eliminating the SSO. A deadline of May 1, 2018 has been set for submittal of this comprehensive sewer study and the City selected AECOM to perform this work.

As the City has never modeled their sewer system, one of the key tasks of the comprehensive sewer study was to build a computer model of the current sewer system from scratch. A working sewer model is needed in order to properly evaluate improvements to the sewer system that would allow eliminating the High Street SSO without causing additional flooding issues. It would also allow assessment of wet weather flows in various catchment areas, and development of recommendations for flow reduction or other improvements. Existing City record drawings were the basis of this model. All sewers 12" in diameter and larger were added to the model, as well as the eight City pump stations, and select sewers smaller than 12" that were found to be important for an accurate depiction on the City's flow regime. Concurrent to building this model, thirty-six flow meters were installed city wide and remained installed for approximately six months. The model is continuing to be calibrated based on the flow meter data gathered.

2.1 PURPOSE

The purpose of this report is to summarize the findings of the field investigations done as part of the comprehensive sewer study and to discuss some of the analysis done of this flow data. This report documents the flow monitoring program methodology and results. This report also discusses the performance of the sanitary sewer system from a city wide perspective during both wet and dry weather, and the methods and results for prioritizing areas with the most inflow and infiltration (I&I) problems. The data analysis in this report was used to rank the flow meter catchment areas in terms of the response observed during wet weather.

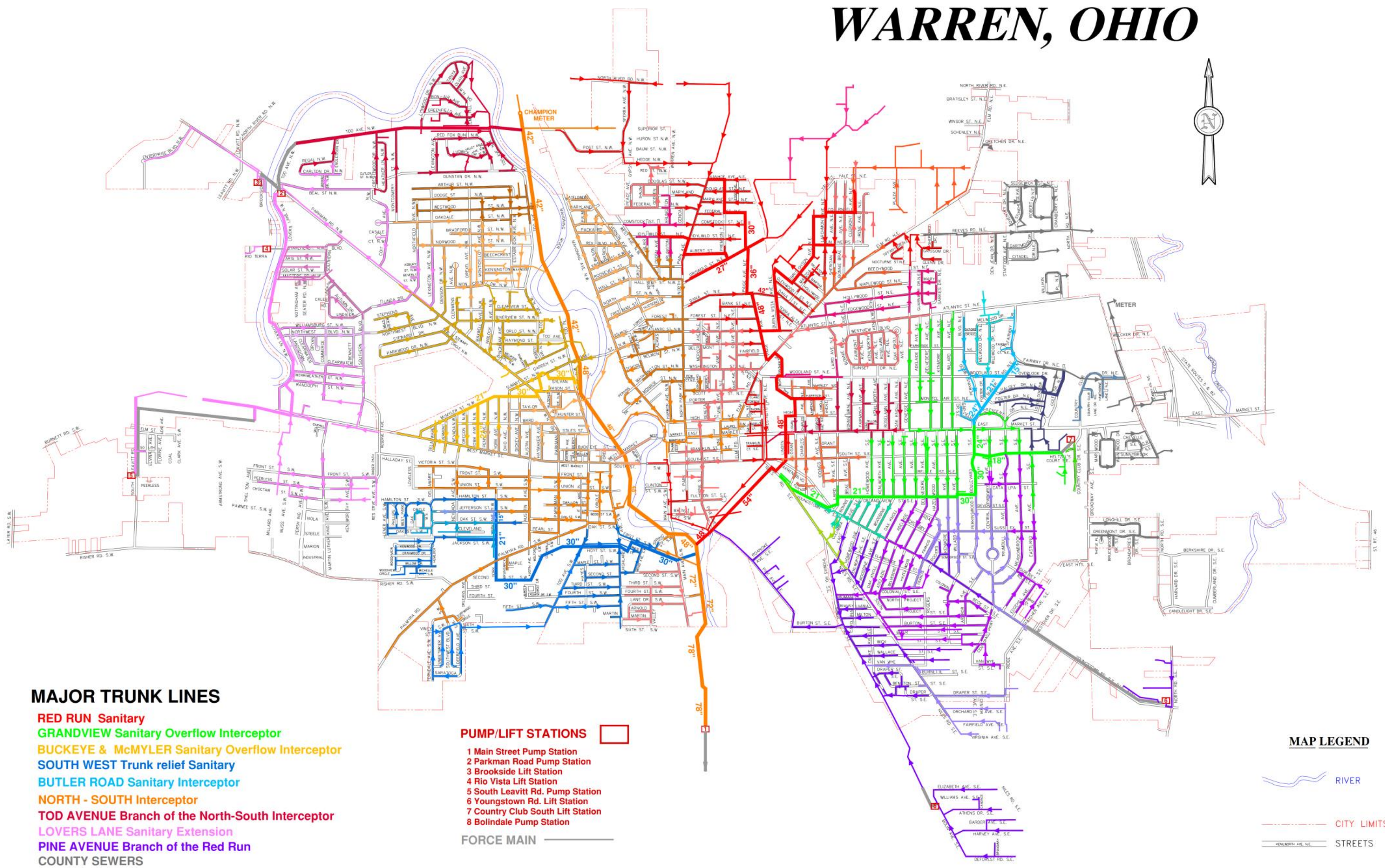
2.2 EXISTING SYSTEM

The City of Warren owns and maintains its own storm and sanitary sewer collection system located within the City. An overview map of the system can be seen on Figure 2-1 on the next page. The sanitary sewer system flows generally from north to south into the City's main pump station, which is located just north of the City's wastewater treatment plant (WWTP). Some pipes in the sanitary sewer system date back to the 19^{th} century. The City's storm sewer system is newer. Many storm sewers were constructed in the 1990s or early 2000s as part of the City's sewer system separation projects.

The WWTP is currently designed based on an average daily flow of 16 million gallons per day (mgd) with a peak flow of approximately 40 mgd. The WWTP is in the process of being upgraded to 20 mgd average daily flow and 60 mgd peak flow. Concurrent to the work at the WWTP, the main pump station is also being upgraded to a peak flow capacity of 60 mgd.

Two communities outside of the City, Champion and Lordstown, are also tributary to the Warren sewer system. The flow from Champion enters the sewer system at the northernmost part of the City. The City records flow from Champion with a Parshall flume. The flow from Lordstown enters the City's WWTP via force main and does not contribute to any of the flow monitored during this study.

Figure 2-1: Overview of Existing Sewer System



3.0 DATA COLLECTION AND FIELD INVESTIGATION

After studying the city wide existing sewer system and performing field reconnaissance, AECOM discussed locations for flow meters and rain gauges with the City. These locations focused on major interceptors, river crossings, outside tributary areas, and pump stations. Deployment of flow meters and rain gauges began in the middle of November 2016. Initially 29 flow meters and 4 rain gauges were installed throughout the City. The locations of these initial metering instruments along with the initial meter catchments are depicted on Figure 3-1.

After four months of monitoring, it was determined to add seven more meters and one additional rain gauge, to better understand and characterize the system. In total, there were 36 flow monitors and 5 rain gauges utilized during the monitoring period. See Appendix A for the flow meter and rain gauge site installation forms.

3.1 RAINFALL GAUGES

Initially four rain gauges were installed at different directional locations in Warren. The north rain gauge was located at 2660 Mahoning Avenue; the south rain gauge at the Main Pump Station; the west rain gauge at the Warren Township Fire Station #1; and the east rain gauge at Lane Funeral Home. Later, a fifth rain gauge was installed to document the precipitation in the Champion area, the major tributary to the Warren sewer system outside of the City. It was placed at St. William's Parish. The locations of the five rain gauges are shown on Figure 3-2.

Multiple rain gauges were installed to monitor the wet weather effects on the system. Because rain events produce more rainfall in certain areas over others, these rain gauges helped explain the different responses in the system from each individual storm.

The tipping bucket rain gauges used on this project recorded every 0.01 inch of rain and reported data in 5-minute intervals using a Telog data collector. Not all storms created a reaction in the system. Some small storms produced so little precipitation that no sewer response was apparent. Other storms were so large that the system did not return to dry-weather flow conditions before the next rain event. In these cases, storms occurring within 12 hours of each other were considered a single event. Events ranged from 0.01" to 2.03" of rain. In all, there were sixty-six storm events recorded during the flow monitoring period.

The south rain gauge was located nearby the City's permanent rain gauge at its WWTP and showed comparable results, which verified the accuracy of the rain gauges used on this project.

Because some rain gauges were added later than others, recorded data from the ones installed were averaged to produce an estimated rainfall for areas without a rain gauge during certain events.

Figure 3-1: Initial Flow Monitoring and Rain Gauge Site Locations, November 2016

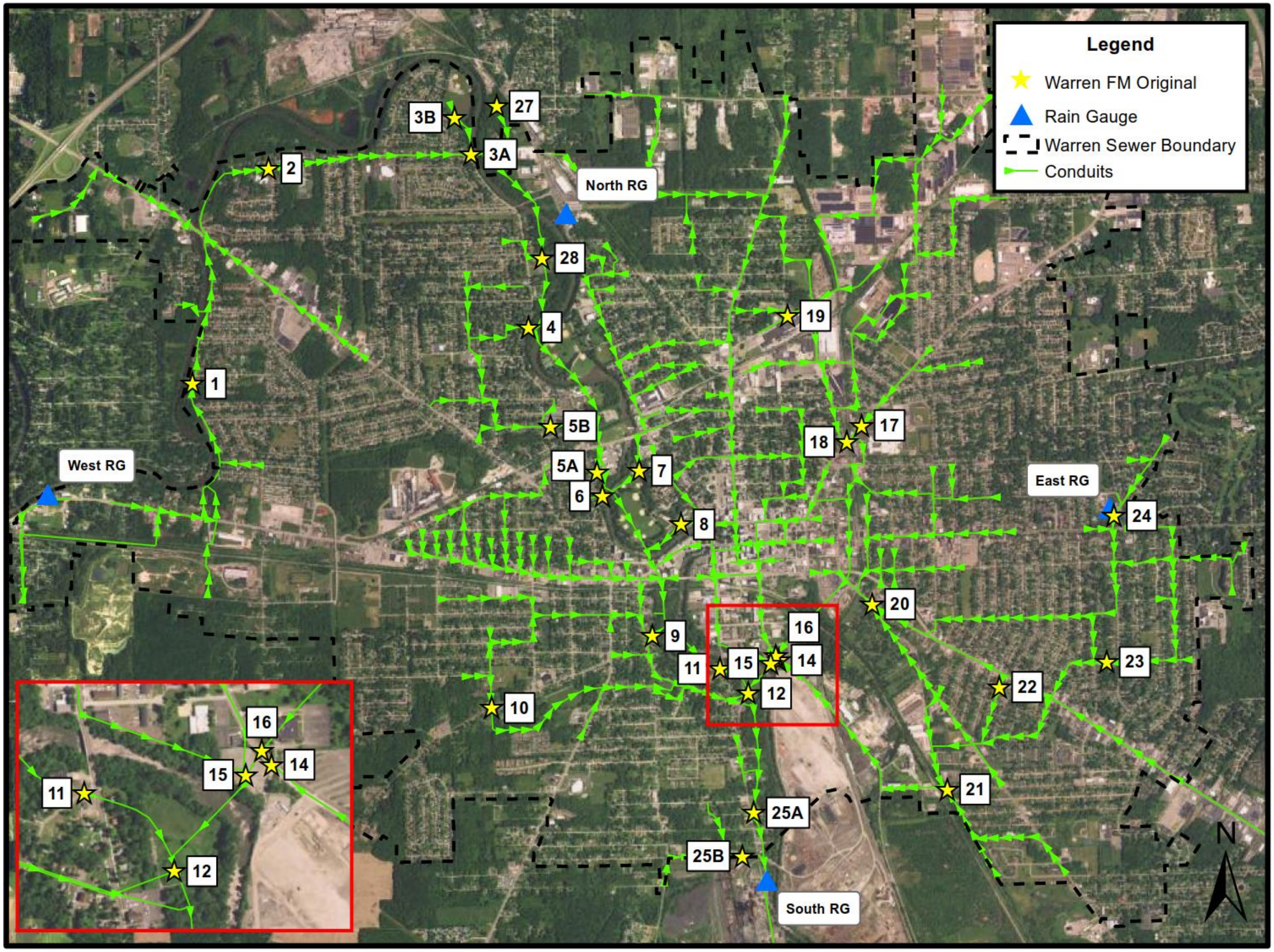
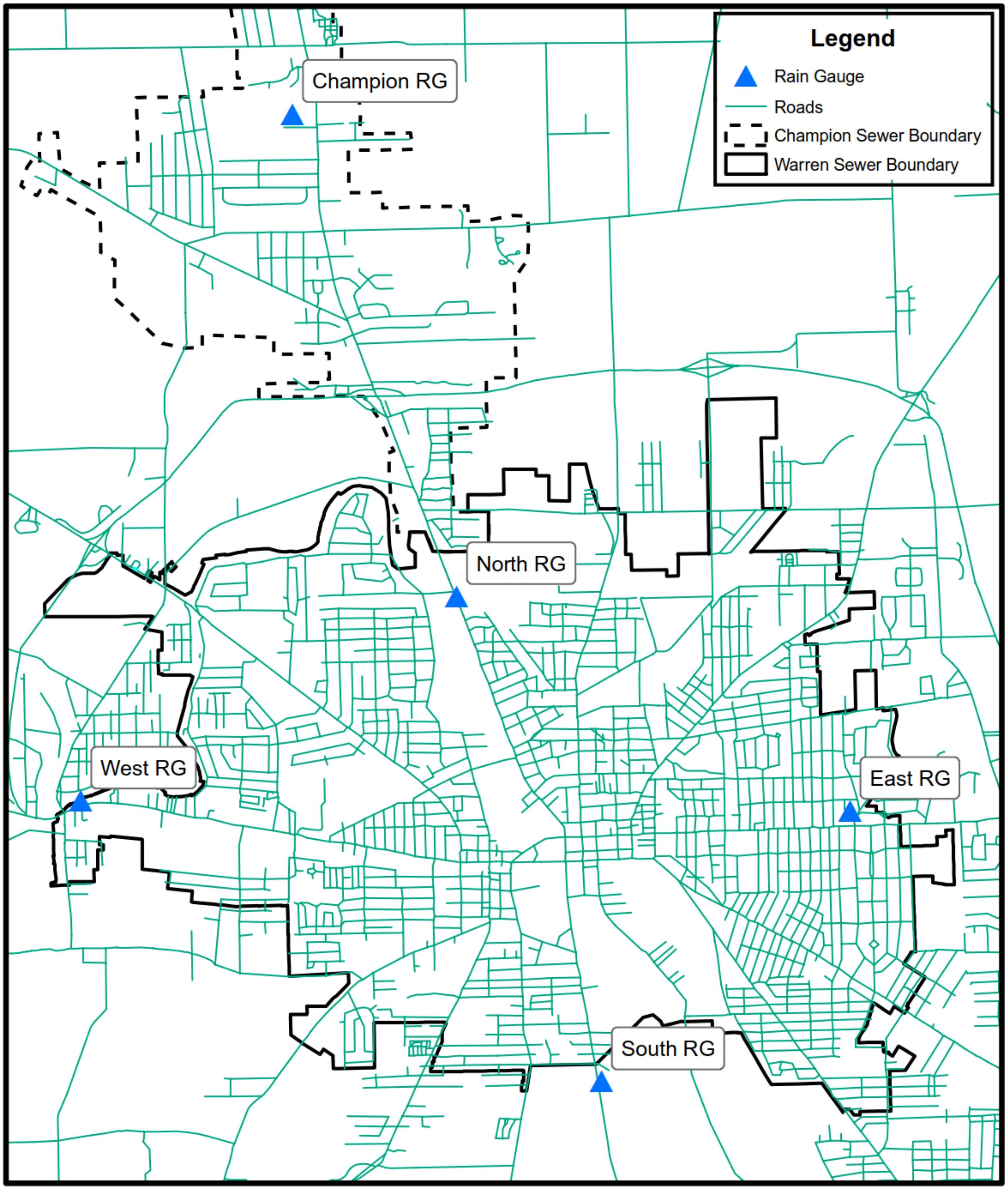


Figure 3-2: Rain Gauge Site Locations



3.2 PAST FLOW MONITORING

As part of the downtown flooding study, completed by AECOM in 2015 and attached as Appendix G, a flow monitoring program utilizing eleven flow meters and two rain gauges was conducted for approximately six weeks. Data from this project will be used as necessary to fill in gaps in the flow monitoring done for the comprehensive sewer study.

3.3 FLOW MONITORING

Initially twenty-nine flow meters were installed at different locations throughout the Warren sewer system. Existing sewer system maps were used to select the installation locations of the flow meters. The locations of meter from the past sewer study were noted in selecting sites for the current flow monitoring. The objectives in selecting meter locations included isolation of the study area from upstream flows, general system flow characterization and understanding and detection of flow anomalies in the collection system. The overall tributary area was divided into relatively equal sub-catchments. Field reconnaissance was conducted to determine the suitability of the selected manholes for the installations based on manhole accessibility, pipe conditions and hydraulic conditions, such as slopes, bends, and proximity to lift stations. Flow monitors were calibrated at each location, both during installation and periodically during the flow monitoring period, to facilitate the collection of accurate data. The final flow monitoring locations selected met the goals of the project and the practical limitations of the flow monitoring equipment. Damage to the equipment caused by debris or vandalism can compromise flow data. Therefore, the monitor installations were inspected periodically.

As flow meter data was being collected and more was learned about the sewer system, seven additional flow meters were installed; five in downtown Warren in the vicinity of the Trumbull County courthouse, one near the main pump station, and one near the Champion meter. The locations of the additional downtown meters are shown on Figure 3-3. The locations of all 36 flow meters installed on this project are shown on Figure 3-4. A schematic of the flow monitoring network is shown in Figure 3-5. The physical locations of each flow meter as well as some brief comments on each site are shown in Table 3-1. Sewer maps for each meter catchment area are shown in Appendix B.

The installed flow meters recorded depth and velocity information in 5-minute intervals. This data was used to assess the sewer characteristics under both dry and wet weather conditions. Dry weather flows are defined by the base sanitary flow, infiltration and a diurnal pattern, which is a time-based fluctuation in flow based on customer water usage. Recorded wet weather flows indicate the presence of wet weather derived infiltration and inflow (I/I) due to storm water in the system.

Figure 3-3: Additional Downtown Flow Meters, Installed March 2017

Figure 3-4: Flow Meter Locations for SSO Comprehensive Study

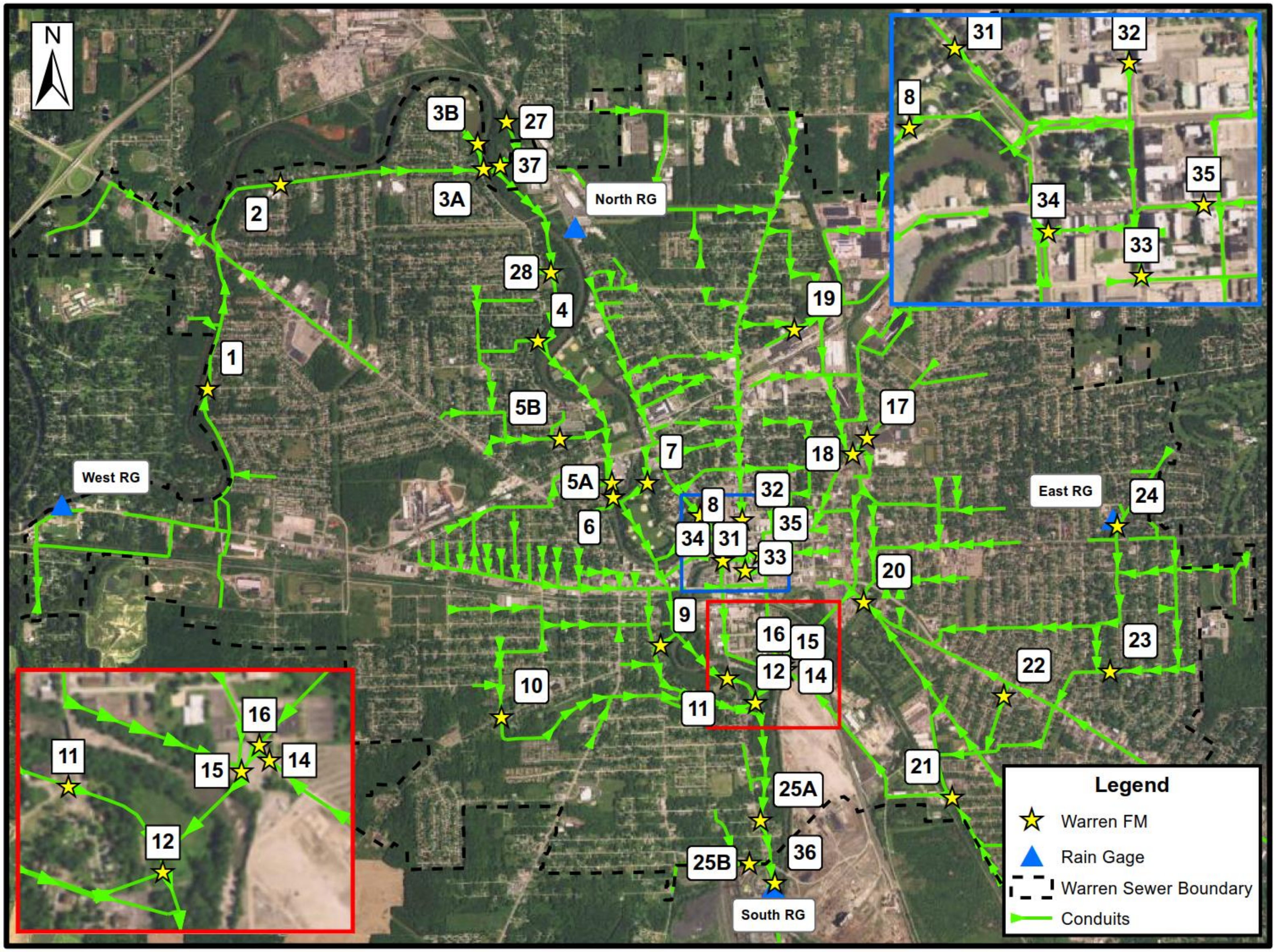


Figure 3-5: Flow Meter Schematic for SSO Comprehensive Study

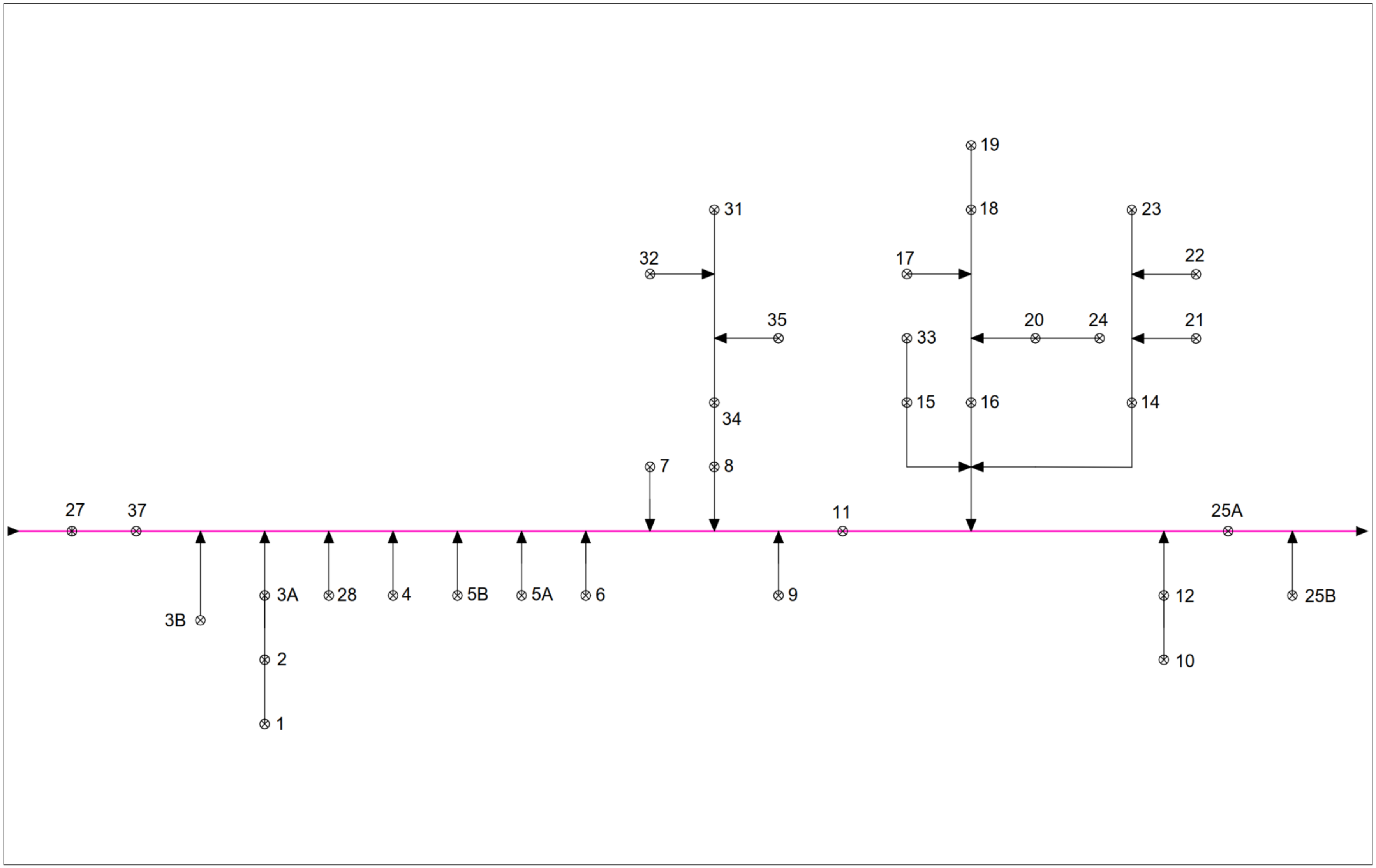


Table 3-1: Flow Meter Installation Locations

SITE #	SITE NAME	PIPE DIA. (IN)	SITE/FLOW COMMENTS
1	1429 Lovers Lane	24	Flow pattern from pump station can be noticed. Had to move up-stream one manhole due to pipe maintenance while monitoring.
2	4121 Tod Ave	24	Some velocity drop outs. Manual velocity was a higher value than recorded, could effect flow calculations.
3a	3033 Tod Ave	18	Good, located in woods near river.
3b	Burbank Park	10	Occasional velocity drop outs. Back flow is observed. Next to a pond.
4	1108 Maywood St	18	Good site, straight through manhole.
5a	856 Tod Ave	330	Good site, straight through manhole. Few velocity drop outs.
5b	1280 Robert	20	Junction manhole. Frequent velocity drop outs near the end of the monitoring period.
6	610 Tod Ave	12	Back flow observed. Sporadic velocities throughout monitoring period.
7	Perkins Park - North	18	Junction manhole. A few velocity drops. Evidence of back flow. Located near the river.
8	Perkins Park - Amphitheatre	15	Junction manhole. Located in a low laying area by the river. Sporadic velocities during rain events.
9	505 Highland Ave	24	Junction manhole. Sensor located in downstream pipe.
10	1609 Palmyra Rd	21	Occasional varying velocities. Some velocity drop outs. Straight through manhole.
11	916 Main St	30	Straight through manhole. Main Interceptor. Back flow observed during high levels.
12	1018 Main Ave	30	Large range of velocities. Evidence of back flow. Sharp bend in manhole. Installed in the upstream pipe.
14	999 Pine Ave	36	Disordered velocities during some periods. Evidence of back flow. Straight through manhole
15	999 Pine Ave	54	Industrial Site. High silt levels. Battery failure.
16	999 Pine Ave	48	Unresponsive velocity for the first 2 months. Frequent velocity drop outs. High silt levels.
17	785 Elm Rd	24	Straight through manhole. Problematic velocity sensor. Disordered velocity readings with frequent velocity dropouts.
18	663 Elm Rd	48	Good site and data. Straight through manhole.
19	404 Griswold St	27	Junction manhole. Industrial site. Disordered velocity readings.
20	823 Niles Rd	21	High velocity area. Short junction manhole. Velocity drop outs. Original sensor was lost after a storm event. A new one was installed upstream 2 manholes.
21	1619 Burton	15	Flow pattern influenced by US Pump Station. Disordered velocity. Data is unreliable for most of the monitoring period.
22	1159 Oak Knoll	12	Good site. Straight through manhole.
23	2659 Sussex St	21	Good site. Straight through manhole. Flow, level and velocity patterns are influenced by US pump station.
24	180 Garfield Dr	24	Straight through manhole. Durations of disordered velocity readings through out monitoring period. Some velocity drop outs.
25a	148 Township Hwy	78	Straight through manhole. Sensor installed in DS pipe. Deep manhole (31 ft), used extension cable to connect to meter. Peak level readings flatline after 14 ft. Occasional velocity drop outs.
25b	Dover Ave SW	24	Good site data. Evidence of backflow during larger storm events.
27	US Champion Meter Pit	36	Occasional velocity drop outs. High velocity readings produced inaccurate flow values.
28	2348 Tod Ave	10	Good site. Straight through manhole. Located on a 10" pipe.
31	Mahoning Ct. and Mahoning Ave	15	Good site. Straight through manhole. Clean data.
32	271 N. Park	28x24	Good site. Junction manhole. Clean data.
33	Franklin and Park	12	Located on a sewer relief pipe. Junction manhole. Occasional velocity drop outs.
34	David Grohl Alley	45x38	Junction manhole. Sensor placed in DS pipe. High silt area. Large brick and egg shaped sewer pipe. Produced high flow readings compared to DS meter.
35	W. Market and Pine Ave	27x30	Junction manhole. Brick and egg shaped sewer pipe. High amount of silt. Commercial area with evidence of oil/grease.
36	Main Ave PF OF	-	Good data. Produced results usable for quantitative analysis.
37	DS Champion Meter Pit	36	Good site. Location was difficult to access. Telemetry was used to retrieve data. Straight through manhole. Occasional velocity drop outs or error.

4.0 FLOW MONITORING ANALYSIS

The purpose of this section of the report is to analyze the flow meter data that was collected during the Warren comprehensive sewer study flow monitoring program.

4.1 FIELD RESULTS

The flow meters used depth and velocity data to calculate flow. Flow depth is converted to a cross sectional area (A) based on the size and geometry of the pipe. The velocity sensor of the meter measures the velocity (V) of the flow which is used to calculate the total flow (Q) from the equation $Q = A \times V$. Hydrographs were developed from the meter data and flow characteristics were analyzed.

4.2 AVERAGE DRY WEATHER FLOW

Flow monitoring data was used to calculate average dry weather flow, infiltration and the diurnal curve pattern for each flow meter. To perform these calculations, dry weather flow days were identified for each metering basin. Dry weather flow days were defined as days during which the flows in the system were not influenced by storm water runoff. The dry weather flow days for each flow meter are identified in Tables 4-1 and 4-2.

Dry weather flow was calculated individually for most of thirty six flow meters that were installed on this project with the following exceptions:

- **FM 2** – The data from FM 2 was very similar to the data FM 1, and thus in modeling, the catchment data from FM 2 was included with the catchment for the next flow meter downstream, which was FM 3A.

- **FM 27** – FM 27 was installed just upstream of the Champion flow meter and FM 37 was installed just downstream of the Champion flow meter. Both meters show similar flows, and thus only FM 37 was included in the dry weather flow calculations.

- **FM 34** – FM 34 is tributary to and just upstream of FM 8. The catchment data from FM 34 was combined FM 8.

- **FM 35** – The flow data from FM 35, one of the flow meters added midway through the flow monitoring program, was inferior to the flow data from a flow meter installed in a similar location as part of the downtown flooding study (FM 9 from that past study). Data based on this meter will be used for model calibration.

- **FM 36** – FM 36 was installed at the main pump station and dry weather flow calculations are not applicable.

- **FM 8 & 33 and FM 14 & 20** – In addition to being calculated individually, these two pairs of catchments also had their dry weather flow calculations done together because of the interconnections between the tributary basins. FM 33 measured a relief sewer for the FM 8 catchment. There are multiple interconnections between the FM 14 and 20 basins.

Table 4-1: Dry Weather Flow Dates

	11/14	11/15	11/16	11/17	11/18	11/26	11/27	12/3	12/4	12/9	12/10	12/11	12/14	12/15	12/16	12/21	12/22	12/23	2/4	2/5	2/20	2/21	3/13	3/14	3/15	3/20	3/21	3/22
FM 1						x	x				x	x		x	x	x	x											
FM 3a				x	x	x	x				x	x		x	x													
FM 3b	x	x	x	x				x	x	x	x	x																
FM 4	x	x	x	x	x	x	x				x	x																
FM 5a	x	x	x	x	x	x	x	x						x	x													
FM 5b	x	x	x	x	x	x	x				x	x		x	x													
FM 6	x	x	x	x	x						x	x		x	x													
FM 7	x	x	x	x	x	x	x				x	x				x	x											
FM 8														x	x						x	x						
FM 9	x	x	x	x	x						x	x		x	x													
FM 10	x	x	x	x	x						x	x		x	x	x	x											
FM 11	x	x	x	x	x																							
FM 12	x	x	x	x	x																							
FM 14	x	x	x	x	x																							
FM 15																												
FM 16																												
FM 17																												
FM 18																												
FM 19				x	x						x	x				x	x	x	x	x								
FM 20						x	x				x	x		x	x	x	x											
FM 21											x	x		x	x													
FM 22								x	x		x	x	x	x												x	x	x
FM 23	x	x	x	x	x	x	x				x	x		x	x													
FM 24	x	x	x	x	x																							
FM 25a																												
FM 25b											x	x		x	x				x	x			x	x	x			
FM 28	x	x	x	x	x			x			x	x							x	x								
FM 31																												
FM 32																												
FM 37																												
FM 14 &20						x	x																					
FM 8 & 33																												

Table 4-2: Dry Weather Flow Dates, Continued

	3/23	3/25	3/26	4/15	4/16	4/22	4/23	4/24	4/25	4/26	4/27	4/28	5/13	5/14	5/16	5/17	5/18	6/6	6/7	6/8	6/10	6/11	6/12	6/13	6/14	6/15	6/16	6/17
FM 1																												
FM 3a																												
FM 3b																												
FM 4																												
FM 5a																												
FM 5b																												
FM 6																												
FM 7																												
FM 8								x	x	x																		
FM 9																												
FM 10																												
FM 11																					x	x	x	x	x	x	x	x
FM 12																					x	x	x	x	x	x	x	x
FM 14																					x	x	x	x	x	x	x	x
FM 15															x	x	x											
FM 16																					x	x	x	x	x	x	x	x
FM 17																					x	x	x	x	x	x	x	x
FM 18																					x	x	x	x	x	x	x	x
FM 19																												
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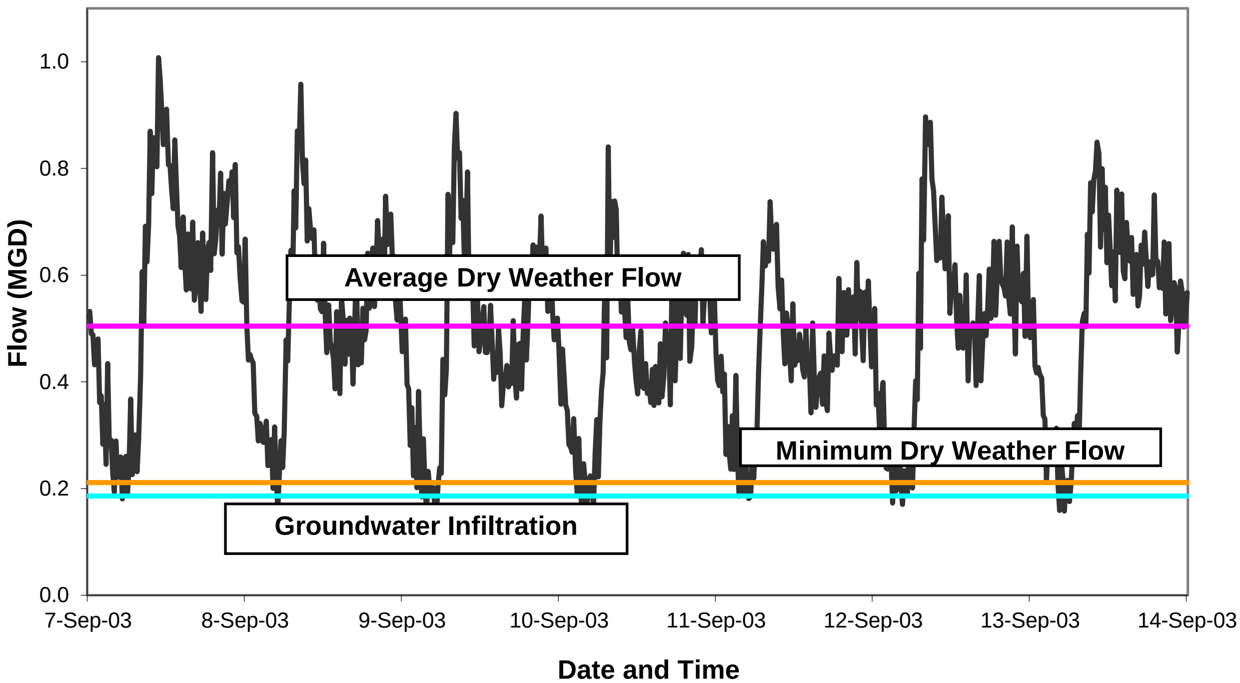
FM 21																												
FM 22	x																											
FM 23								x	x	x																		
FM 24		x		x			x	x	x	x	x	x																
FM 25a																		x	x	x								x
FM 25b				x	x																							
FM 28																												
FM 31		x				x	x	x	x	x																		
FM 32		x						x	x	x																		
FM 37																												
FM 14 &20								x	x	x	x		x	x		x	x											
FM 8 & 33	x	x					x	x		x	x																	

Dry weather flows were analyzed to determine average dry weather flow, minimum dry weather flow and groundwater infiltration rates, as defined in Figure 4-1. Average dry weather flow has two components, the base sanitary flow and groundwater infiltration. The base sanitary flow varies as described by a diurnal curve. The term groundwater infiltration is used to differentiate between flows infiltrating into the sanitary system during dry weather and those entering during wet weather. While groundwater infiltration is predominantly groundwater, it can also include industrial and commercial discharges, water softening discharges and other flow sources that are not sanitary in nature.

Figure 4-1: Typical Diurnal Sewer Patterns and Groundwater Infiltration



Average dry weather flows were calculated by averaging the flows recorded during the dry weather period. Minimum dry weather flow is the lowest daily average dry weather flow. The lowest sanitary flows of the day generally occur between the hours of 2 am and 5 am. A review of the flow monitoring data indicated this generally applied to the study area.

Groundwater infiltration was estimated as 88% of the minimum dry weather flow. The use of 88% is a generally accepted practice, though values can range from 85% to 92%. The groundwater infiltration that was observed for each metered area is shown in Table 4-3.

Table 4-3: Dry Weather Infiltration by Catchment Area

FM	Average Dry Weather Flow Weekday (MGD)	Average Dry Weather Flow Weekend (MGD)	Dry weather I/I Weekday (MGD)	Dry weather I/I Weekend (MGD)	Average I/I (%)
1	0.357	0.378	0.091	0.107	26.90%
3a	0.345	0.799	0.125	0.307	37.78%
3b	0.015	0.017	0.006	0.009	47.43%
4	0.066	0.098	0.032	0.050	50.50%
5a	0.058	0.076	0.029	0.044	54.48%
5b	0.147	0.183	0.076	0.101	53.60%
6	0.100	0.136	0.050	0.054	43.78%
7	0.160	0.182	0.108	0.096	59.61%
8	0.237	0.149	0.169	0.099	69.31%
9	0.078	0.098	0.034	0.034	38.46%
10	0.137	0.135	0.082	0.061	52.55%
11	3.346	3.339	2.265	2.211	66.96%
12	0.157	0.150	0.054	0.047	32.84%
14	0.885	0.892	0.678	0.683	76.60%
15	0.324	-	0.207	-	63.76%
16	2.443	2.276	1.494	1.270	58.57%
17	0.203	0.208	0.118	0.116	57.01%
18	0.595	0.508	0.371	0.309	61.70%
19	0.040	0.048	0.021	0.030	57.75%
20	1.333	0.858	0.919	0.491	64.36%
21	0.116	0.117	0.072	0.067	59.90%
22	0.079	0.074	0.054	0.050	68.09%
23	0.346	0.380	0.174	0.246	57.89%
24	0.192	0.209	0.131	0.148	69.68%
25a	5.948	6.832	3.767	4.494	64.64%
25b	0.389	0.404	0.311	0.327	80.48%
28	0.058	0.053	0.030	0.035	59.14%
31	0.039	0.039	0.027	0.022	62.80%
32	0.260	0.237	0.189	0.157	69.53%
33	0.203	0.203	0.125	0.133	63.55%
37	0.757	0.787	0.507	0.508	65.72%
14+20	2.218	1.750	1.598	1.173	69.84%
8+33	0.440	0.352	0.294	0.232	66.35%

The diurnal variations of the dry weather flows were analyzed. The diurnal pattern describes the short-term variation in flows throughout an average dry weather day. As expected, minimum flows occurred during the early morning hours and peak flows occurred during the mid-morning and early evening hours. The size, duration and time of occurrence of crests and troughs varied with each individual sanitary basin. The diurnal curves for each flow meter that was analyzed are located in Appendix C. The curves also show the average dry weather flow, which was generated by averaging the flows for the multiple dry weather days. In general, there was consistent performance throughout the dry weather flow in the basins with no unusual peaks. An example of this process of developing diurnal flow patterns for each flow meter catchment is shown below for FM 1 in Figures 4-2, 4-3 and 4-4.

Figure 4-2: FM 1 Dry Weather Weekdays

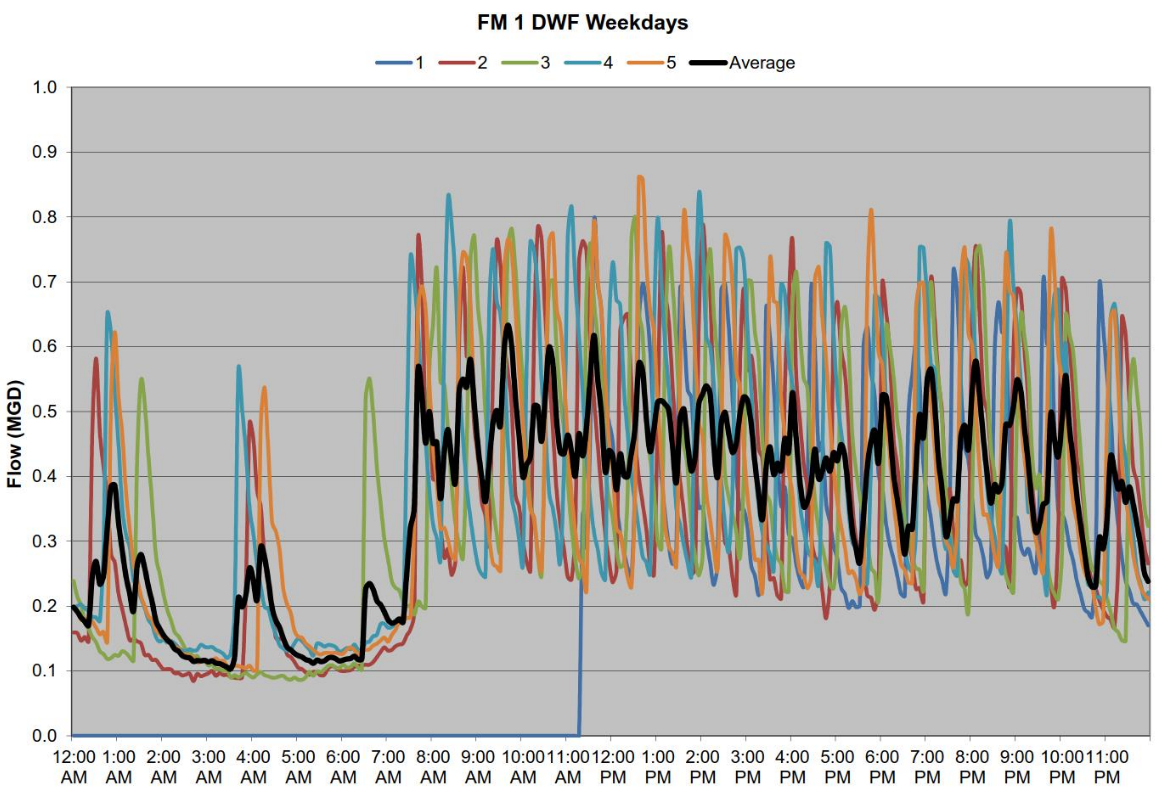


Figure 4-3: FM 1 Dry Weather Weekend Days

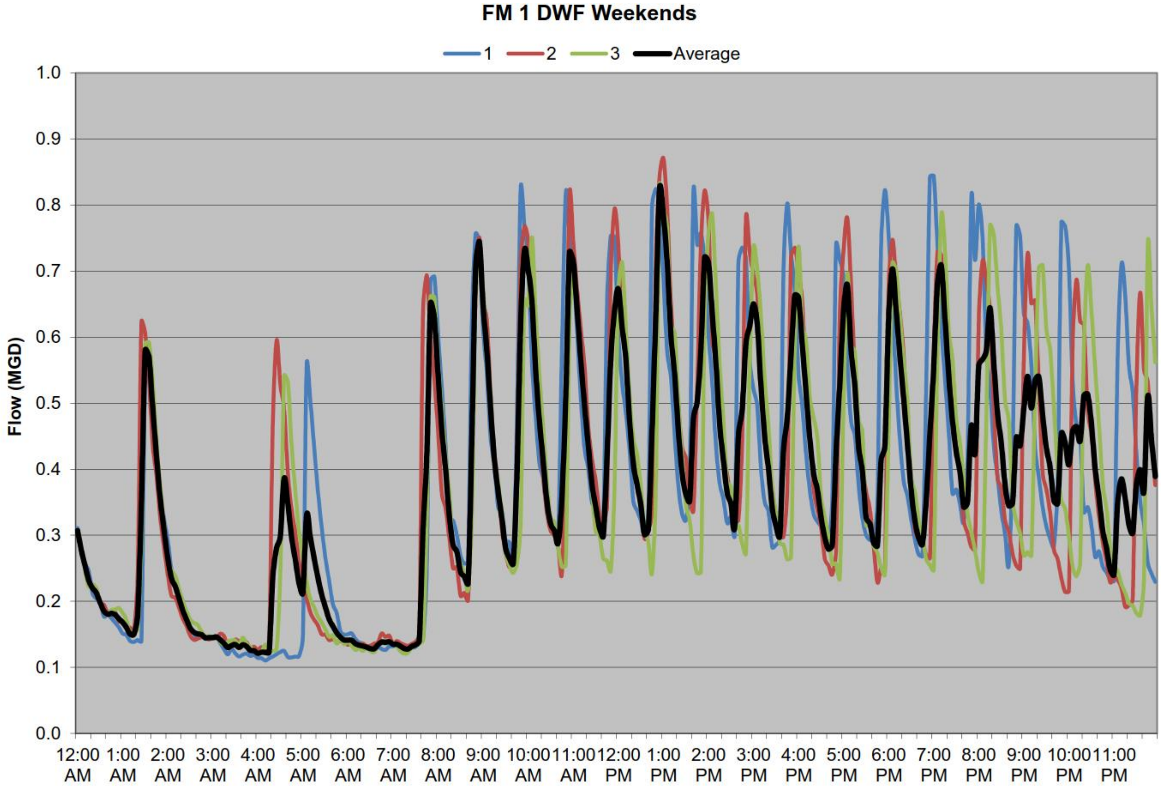
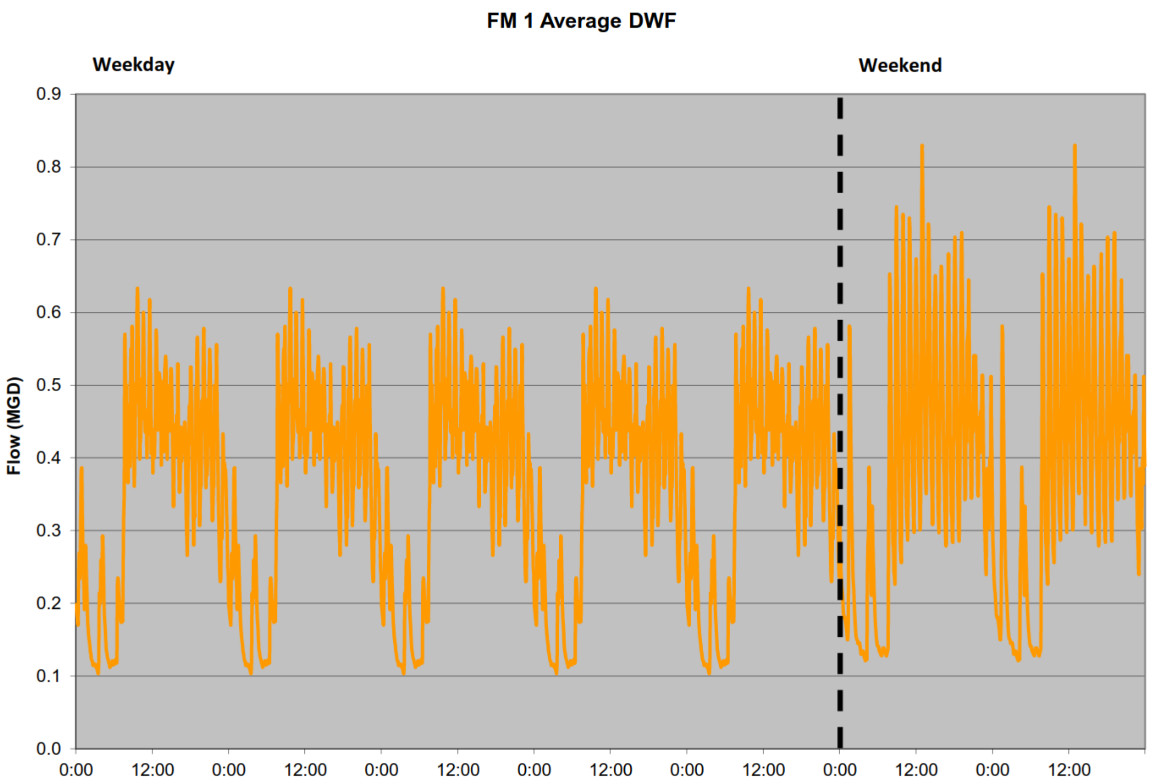


Figure 4-4: FM 1 Combined Diurnal Pattern



4.3 RAINFALL DATA

The flow meters and rain gauges were installed for an extended period of time and numerous wet weather events were observed. The return periods for the storms that were recorded at each rain gauge are shown in Figures 4-5, 4-6, 4-7, 4-8 and 4-9. Similar to the dry weather data, storm events that had good meter responses were identified for each meter for which diurnal patterns were created. These dates are listed in full in Appendix D. An example of this data for FM-1 is shown in Table 4-4.

Figure 4-5: West Rain Gauge Storms

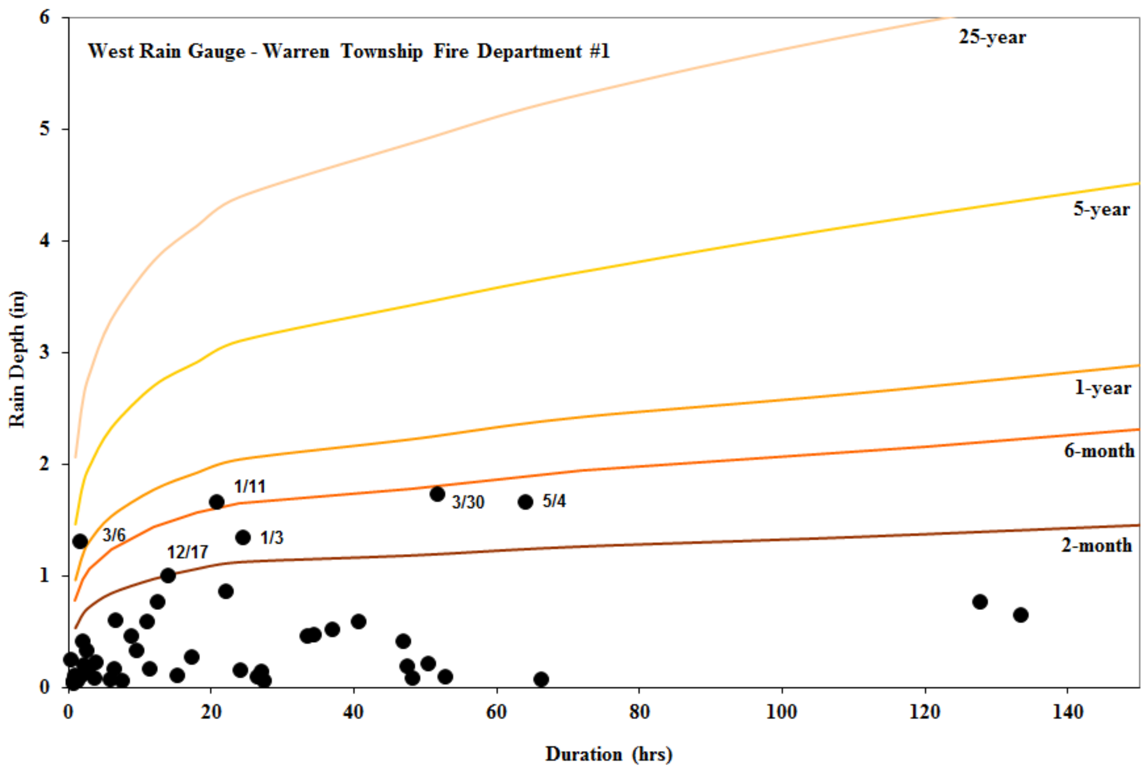


Figure 4-6: North Rain Gauge Storms

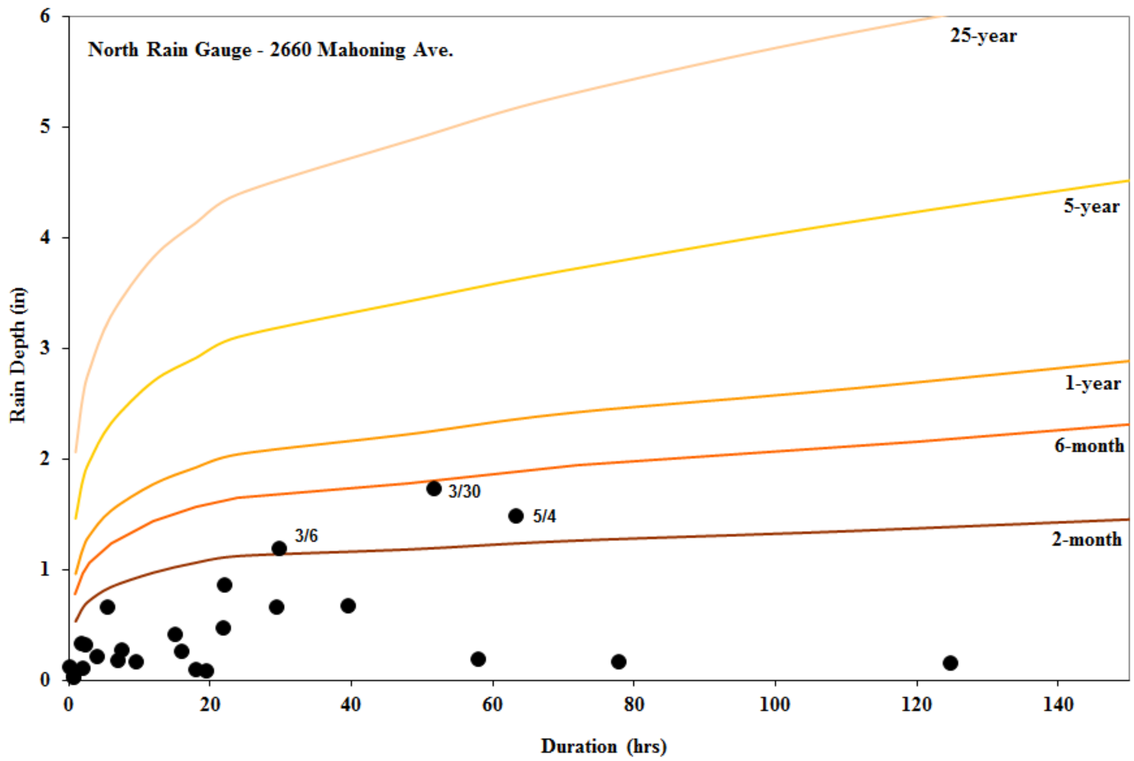


Figure 4-7: East Rain Gauge Storms

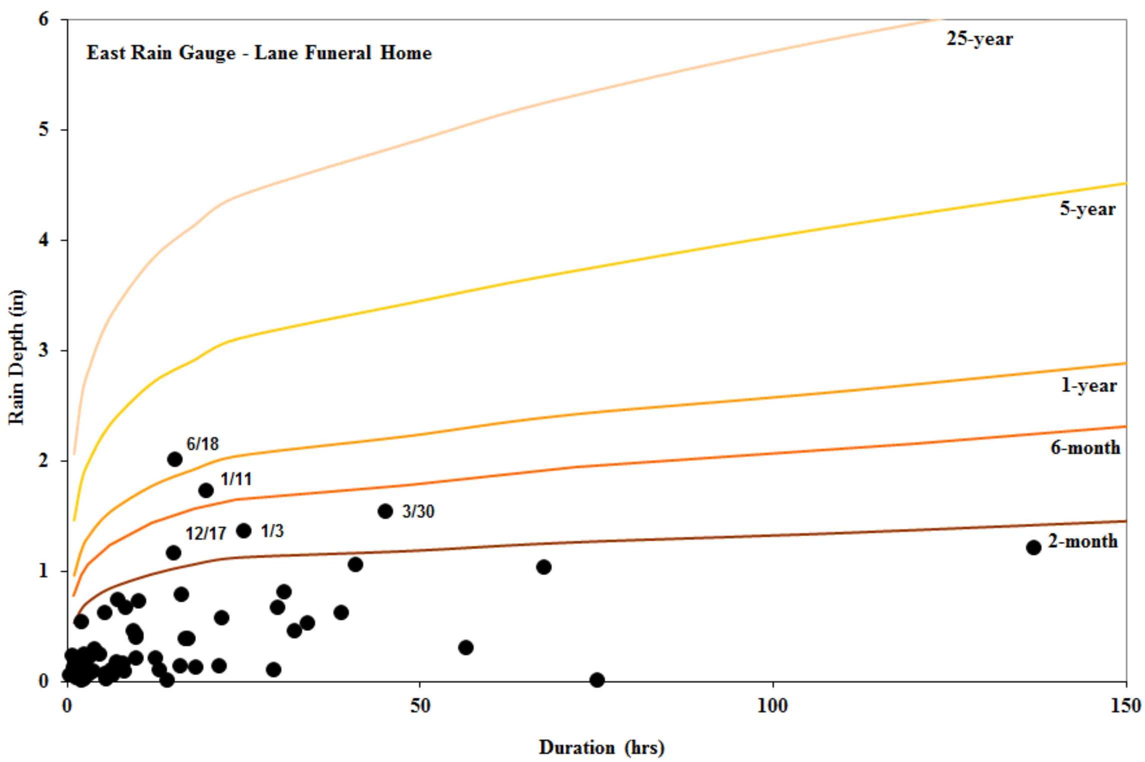


Figure 4-8: South Rain Gauge Storms

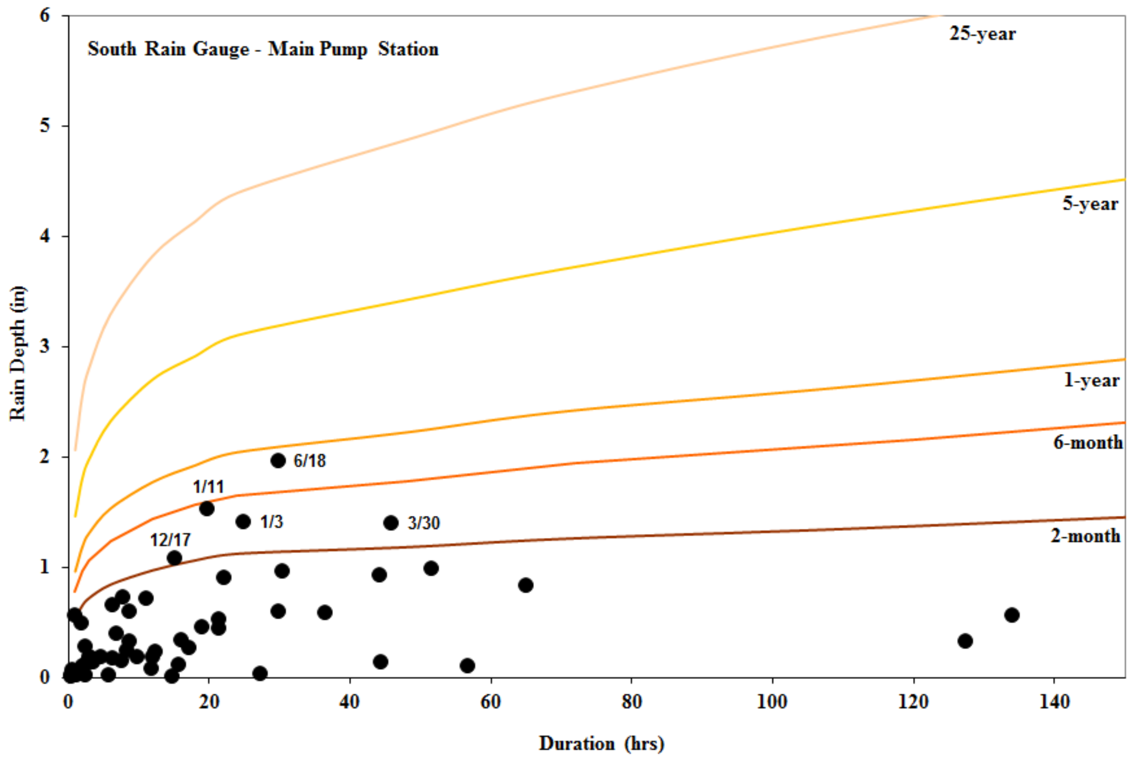


Figure 4-9: Champion Rain Gauge Storms

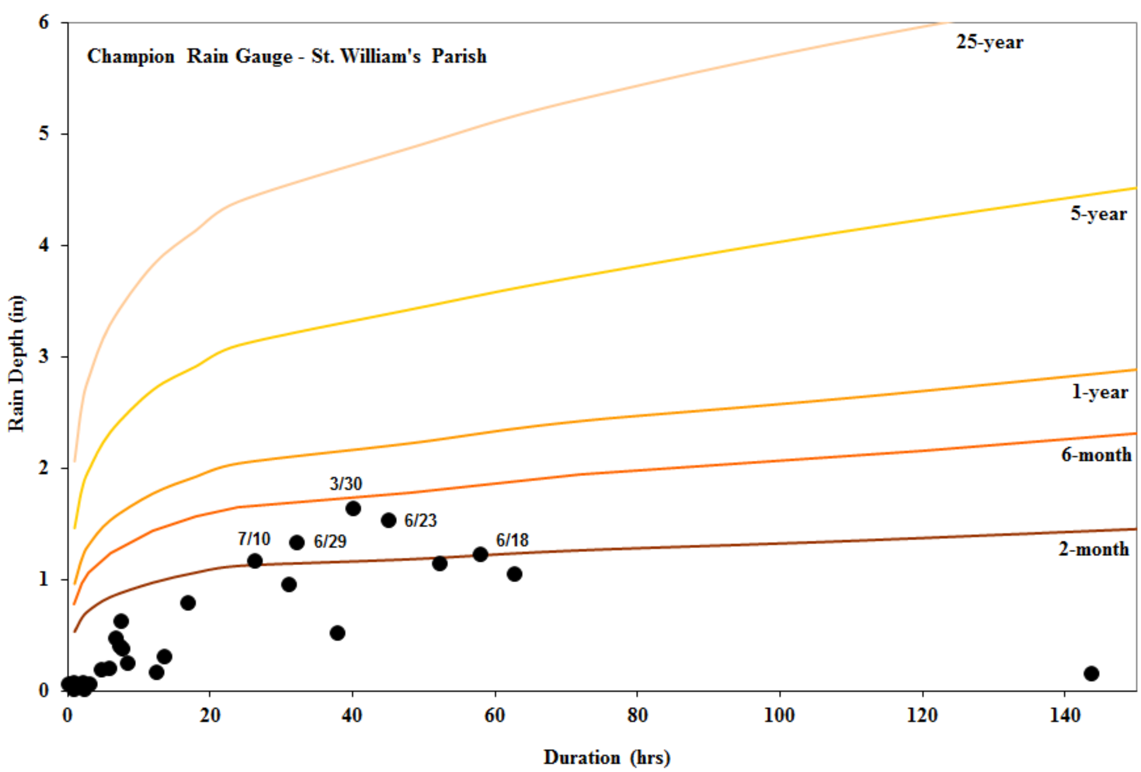


Table 4-4: FM 1 Storm Events

Storm Date	Rain Duration (hr)	Rainfall (in.)	Peak Intensity (in/hr)	Return Frequency	Rain Gauge
FM 1					
12/6/2016	8:50:00	0.46	0.12	<2-month	West RG
12/17/2016	13:55:00	1.01	0.15	<6-month	West RG
1/3/2017	24:25:00	1.35	0.26	<6-month	West RG
1/11/2017	20:40:00	1.66	0.42	<1-year	West RG
2/25/17	6:30:00	0.61	0.21	<2-month	West RG
3/6/17	1:30:00	1.31	0.08	<2-year	West RG
3/30/17	51:35:00	1.73	0.19	<6-month	West RG
4/28/17	24:00:00	0.16	0.04	<2-month	West RG
5/1/17	26:55:00	0.15	0.04	<2-month	West RG
5/4/17	63:55:00	1.67	0.13	<6-month	West RG

4.4 WET WEATHER FLOW

The wet weather analysis began with balancing inflows to identify flow losses or flow monitoring problems. Wet weather flows are considered to be balanced if the inflow volumes increase as tributary acreage increases.

Wet weather flow was isolated from normal dry weather flow using the average dry weather flow hydrographs. Two examples of the isolation of I/I for FM 1 during rain events are shown in Figures 4-10 and 4-11. Dry weather flows are subtracted from the wet weather flows and summed over the duration of the I/I period, which was generally much longer than the duration of the rain event. Rainfall depths and inflow volumes were compiled from each of the rain events. I/I isolation graphs for every storm for every flow meter catchment area are included in Appendix E. A linear regression model that provided a prediction of inflow volume generated by a given rain was developed. The general form of the model is:

Inflow Volume (ac-in.) = (I/I Ratio * Basin Area (ac.)) * Rainfall (in.) + Depression Storage (ac-in.)

Figure 4-12 shows a sample of a linear regression results developed for FM 1. Inflow volumes, in terms of acre-inches, were plotted on the y-axis. Rainfall depths were plotted on the x-axis. The slope of the line was the product of the basin area and the I/I ratio. This I/I ratio represented the portion of the storm water runoff that entered the sanitary system. The I/I ratio has a maximum value of 1 (or 100%), which means that all rainfall landing in the basin enters the sewer system. A combined sewer system may have I/I ratios of 50%, while a new sanitary sewer system may have I/I ratios under 10%. Ranges of acceptable I/I ratios vary with the age and condition of a system. The I/I ratio is calculated by dividing the slope of the line by the size of the catchment area. Linear regressions were done for all flow meter catchment areas that were analyzed and are included in Appendix F.

Figure 4-10: FM 1 I/I Isolation, Rain Event of December 17, 2016

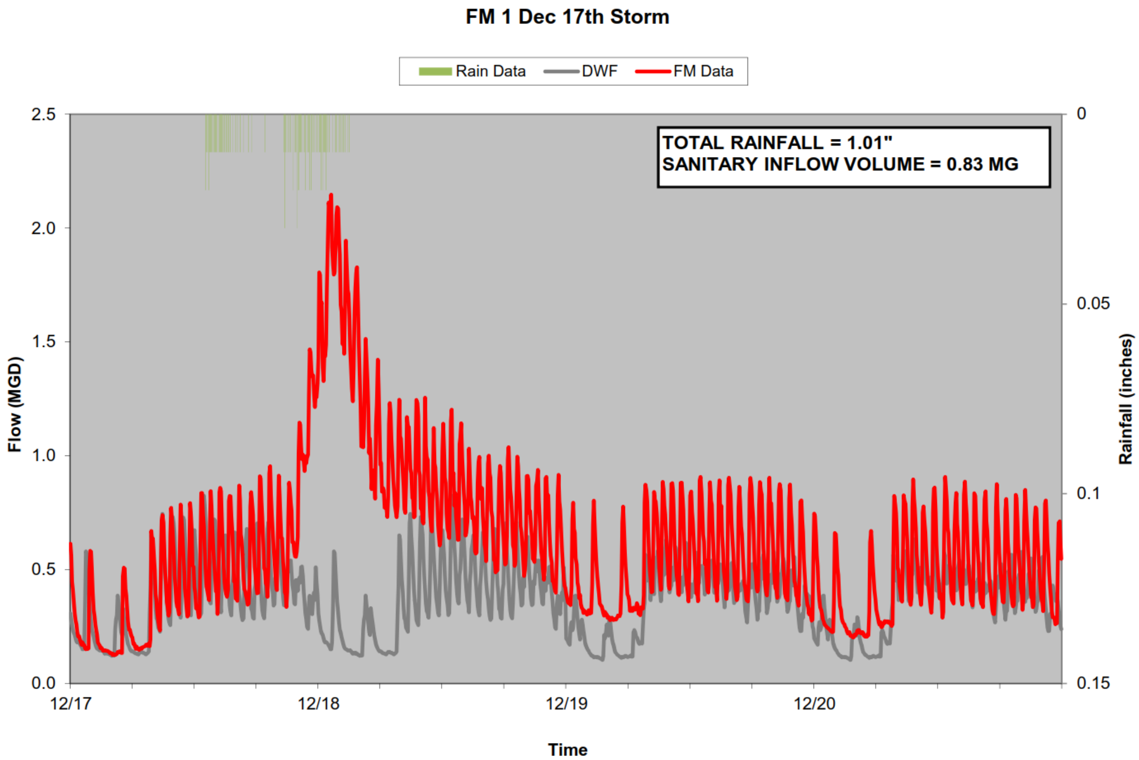


Figure 4-11: FM 1 I/I Isolation, Rain Event of January 3, 2017

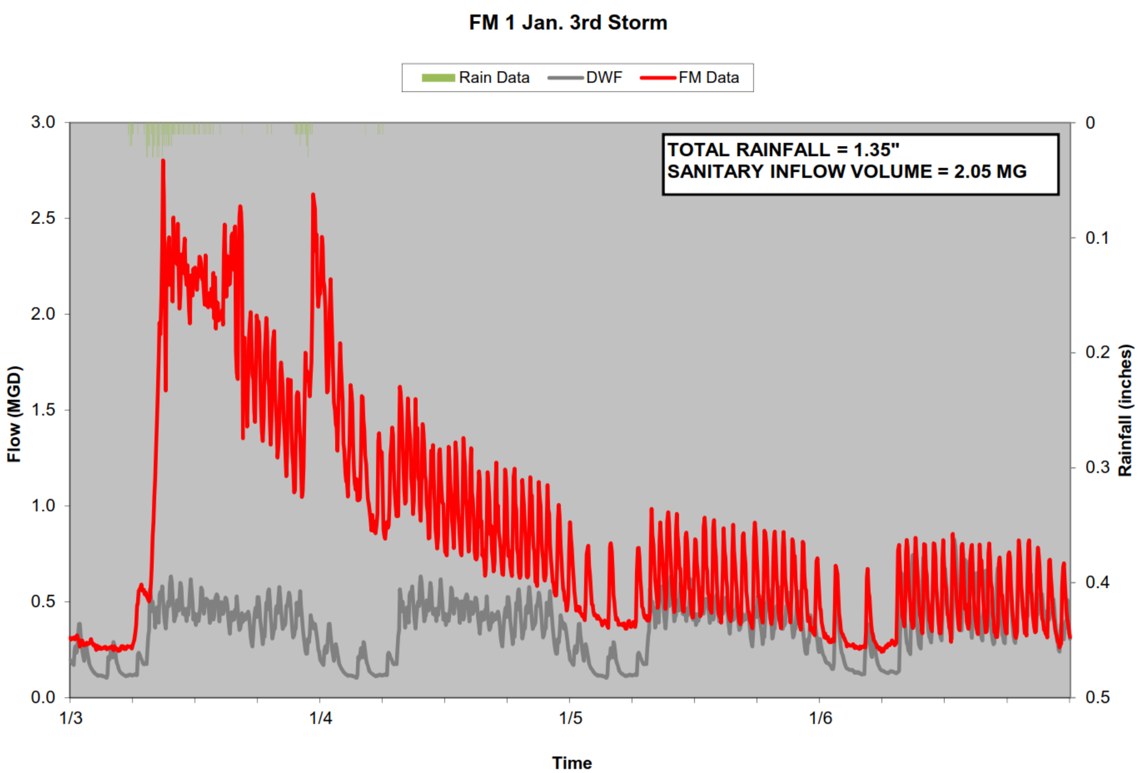
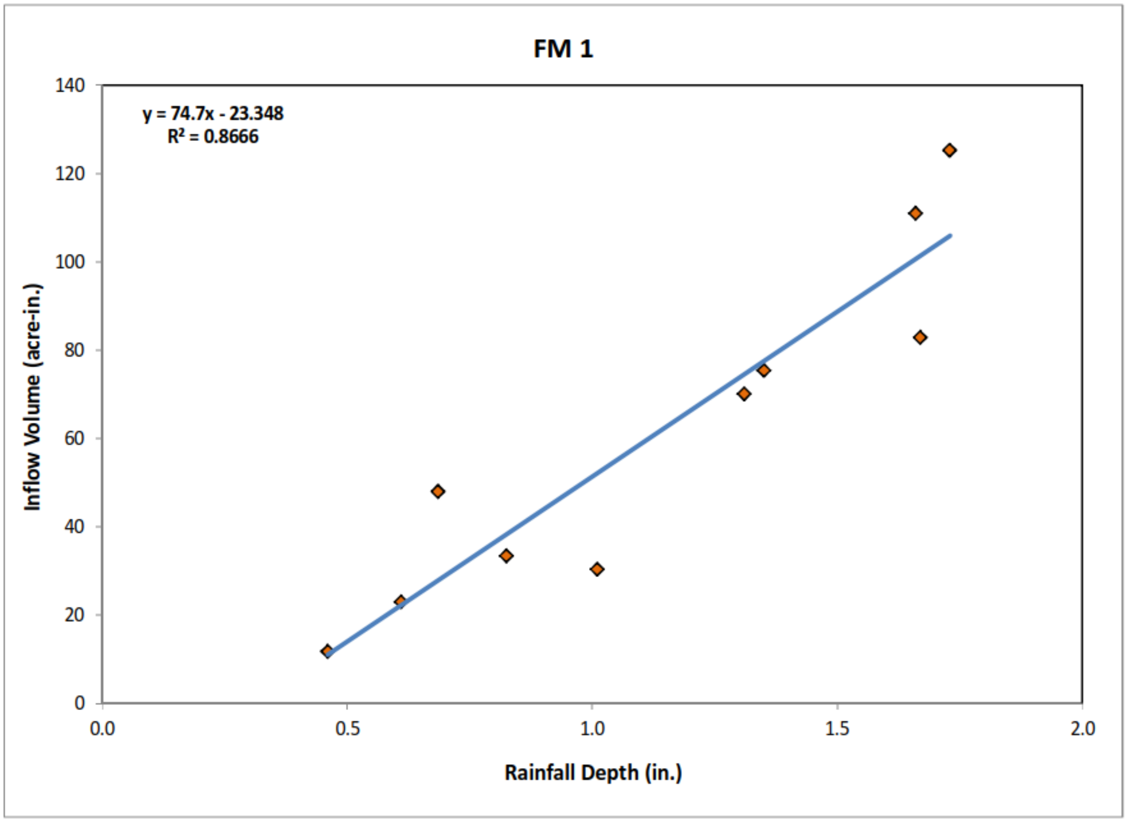


Figure 4-12: Inflow Volume Linear Regression for FM 1



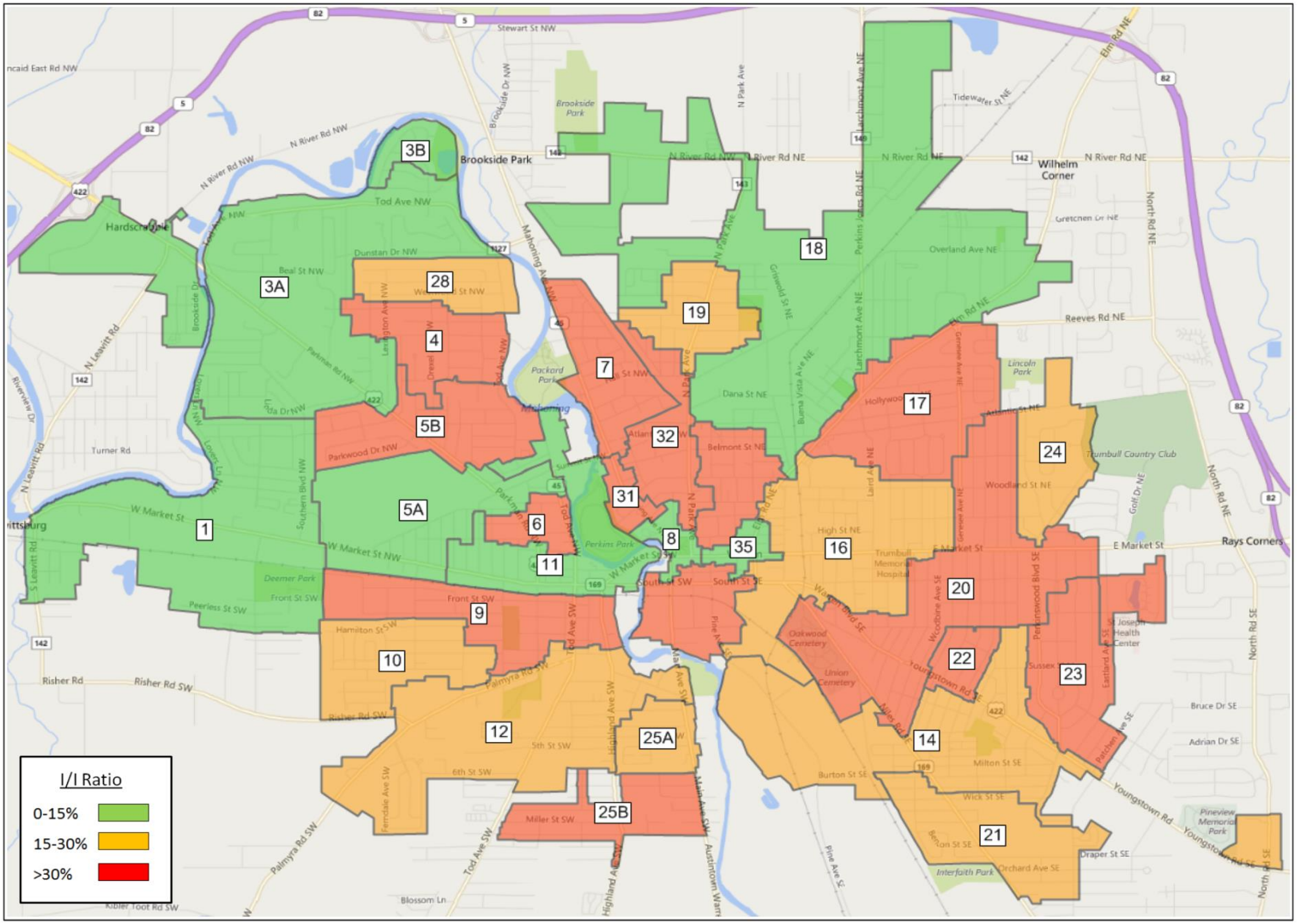
The y-intercept value indicates the amount of depression storage, in acre-inches, available in the system. Depression storage is the amount of available volume within a given basin for storing storm water without affecting the sanitary sewer system. It would include ponds, ditches, and other depressions that are normally empty but could hold wet weather volume. For Figure 4-12, that value was 23.348 acre-inches. Setting the inflow volume at zero and solving for the minimum rainfall event can assess the sensitivity of the system to a rainfall event. This is the approximate size of a rainfall event that fills the entire depression storage but does not affect the sanitary sewer system. For this example, the minimum rainfall is 0.31 inches.

Upstream areas need to be removed to complete the wet weather analysis. The upstream effects, when applicable, were removed by subtracting the upstream equations from the downstream equation. Table 4-5 contains the I/I ratios and minimum rainfall results for each basin. The system generally has high I/I ratios reflecting a sewer system that is receiving a lot of storm flows. Figure 4-13 shows a map of the City with the catchments color-coded by I/I ratio. This map provides a priority of areas where removal of wet weather flows may be effective.

Table 4-5: I/I Ratios by Catchment Area

Flow Meter	Area (acres)	Adjusted Slope	Adjusted Y-Intercept	I/I Ratio (%)	Minimum Rainfall (in)
FM 6	60	36.742	2.8097	**61.2**	0.00
FM 25b	159	94.456	-11.791	**59.4**	0.12
FM 32	146	82.745	-14.35	**56.7**	0.17
FM 15	249	109.07	-13.386	**43.7**	0.12
FM 5b	236	96.491	-19.846	**40.9**	0.21
FM 17	320	127.82	10.372	**39.9**	0.00
FM 7	172	67.83	-11.938	**39.4**	0.18
FM 22	60	22.192	0.5388	**37.0**	0.00
FM 8+33	264	96.432	-21.782	**36.6**	0.23
FM 23	202	72.159	-1.9286	**35.7**	0.03
FM 4	168	57.032	-4.5161	**34.0**	0.08
FM 9	251	78.732	7.5387	**31.4**	0.00
FM 31	40	12.145	-2.1851	**30.4**	0.18
FM 19	141	42.069	-10.1	**29.8**	0.24
FM 24	158	37.673	-4.5887	**23.8**	0.12
FM 14+20	1864	438.79	-43.96	**23.5**	0.10
FM 21	241	43.422	-2.2933	**18.0**	0.05
FM 33	249	44.586	-5.9302	**17.9**	0.13
FM 10	208	36.546	-4.8173	**17.6**	0.13
FM 28	127	21.414	-2.6679	**16.9**	0.12
FM 12	549	89.44	43.084	**16.3**	0.00
FM 25a	12010	1925.4	-185.81	**16.0**	0.10
FM 14	1083	172.00	-0.5799	**15.9**	0.00
FM 16	3096	466.32	-63.142	**15.1**	0.14
FM 8	264	38.571	3.3436	**14.6**	0.00
FM 5a	325	46.165	-10.165	**14.2**	0.22
FM 3a	1578	187.6	-5.7801	**11.9**	0.03
FM 11	6827	767.39	-91.811	**11.2**	0.12
FM 1	669	74.7	-23.348	**11.2**	0.31
FM 18	1356	144.18	-48.662	**10.6**	0.34
FM 3b	64	2.3513	-0.6749	**3.7**	0.29
FM 37	3329	103.46	25.344	**3.1**	0.00

Figure 4-13: Catchment Map by I/I Ratio



4.5 I/I ANALYSIS SUMMARY

Any catchment areas colored orange or red on Figure 4-13 have high I/I ratios. In a separate sewer system, percentages greater than 15% are considered needing further evaluation. On a more extreme note, the areas with I/I ratios approaching or exceeding 50% are operating like combined sewers.

Some of the catchment areas had additional catchments upstream. These were analyzed with both the upstream areas included and separated. After comparing results from the linear regressions, the most qualified analysis was selected for use. Meters that required this type of analysis were FMs 3A, 8, 11, 12, 14, 16, 18, 20, and 25A.

For FMs 3A, 8, 11 and 25A, it was difficult to obtain a set of storms where all meters tributary to this area produced quality flow data usable for regression analysis. It was decided to include the upstream tributary areas for these meters.

For some of the catchment areas, there was difficulty in calculating I/I values. Additional investigation into the sanitary system layout was done to try to explain unusual data from some of the meters. Through these investigations, relief connections at multiple locations between different interceptors were found. These relief connections bypassed flow from one meter area and to another. The most prominent use of diversions is in the southeastern sections of the city. Five relief connections were discovered in the area between the Grandview Interceptor and the Pine Avenue interceptor. These relief connections made it difficult to perform accurate flow balances between the FM 14 and 20 catchments. In response, flow data from these two meters was combined and analyzed as a double barrel system. This method ensured that no flow was lost during I/I calculation. Analytical differences can be seen between the FM 14 & 20 combined analysis and the analysis where tributary areas were subtracted. Combining these two catchments in the calculations produced better results.

Relief connections also affected FM 16 because FM 20 is tributary to FM 16 but FM 14 is not. Since flow is split between these two meters for various storm intensities, and the relationship is not readily quantifiable, FM 16 was analyzed with its entire tributary area included.

Other problematic areas include a relief connection in the downtown area, which was recorded by FM 33, and FM 8, which receives the remaining flow not diverted. Again, this area was analyzed as a double barrel system. When these two meters were combined and the tributary areas were subtracted, the accuracy of the I/I calculations severely decreased. The I/I analysis used in this report included all tributary areas upstream of these two meters. Individual analysis of these meters was also included for comparison. Adjacent to this system, FM 35 also produced poor individual results, so its tributary area was included with the analysis of FM 8.

In addition to the I/I that can be predicted by rain events, several meter catchments showed high levels of infiltration that were not directly correlated with individual rain events. Most notable among these areas is FM 37, which recorded the flow coming in from the Champion area.

5.0 CONCLUSIONS

As part of this flow monitoring report, groundwater infiltration and I/I ratios for the various meter catchments were calculated. Some of the areas with the highest I/I exhibited responses to rain events that are more consistent with combined sewers than a separate sewer system. These are locations where programs to rehabilitate existing sewers or investigate improper sanitary connections are likely to yield the greatest benefit. These areas are colored red on the Figure 4-13 on page 4-15.

In additional to areas with high I/I ratios, areas that have significant dry weather infiltration and large acreages, are also areas for further investigation. The most notable of these is the FM 37 area, which recorded flows coming in from Champion.