Flow Analysis & Inflow and Infiltration Evaluation

City of West Plains, MO

Flow Analysis & Inflow and Infiltration Evaluation

Project No. 126220

8/6/2021

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prepared for

City of West Plains, MO
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West Plains, Missouri

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prepared by

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INDEX AND CERTIFICATION

City of West Plains, MO
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Certification

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David Ecklund

David Ecklund, P.E., MO 2019017809

Date: 8/6/2021

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LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
ADDF	Average daily dry-weather flow
BMcD	Burns & McDonnell Engineering Company, Inc.
Gal	Gallons
I/I	Inflow and Infiltration
MIT	Minimum Inter-event Time
MGD	Million gallons per day
NASSCO	National Association of Sewer Services Companies
NOAA	National Oceanic and Atmospheric Administration
PDDF	Peak daily dry-weather flow
SSES	Sanitary Sewer Evaluation Surveys
WWTP	Wastewater Treatment Plant

1.0 EXECUTIVE SUMMARY

The City of West Plains, Missouri (City) administered a flow and rainfall monitoring program that was completed in Fall of 2020. This monitoring program was completed to prioritize improvements within the sanitary sewer system. This information can also be used in the future to develop an Inflow and Infiltration (I/I) Strategic Plan which would include components such as sewer rehabilitation recommendations, I/I reduction strategies, and development of a hydraulic model.

This Flow Analysis and I/I Evaluation is the first step for the City to develop an I/I Reduction Program and I/I Strategic Plan. Flow monitoring and public source I/I reduction would all be utilized together to provide the City with additional tools to implement a comprehensive, cost-effective I/I reduction plan for its wastewater collection system.

1.1 Flow and Rainfall Monitoring

Flow and rainfall monitoring were performed in Fall 2020 to establish a relationship between precipitation (rainfall intensity and rainfall volume) and wastewater system flow rates. The wastewater collection system was divided into six (6) independent meter catchments covering the extents of the wastewater collection system. A total of six (6) ISCO area-velocity meters were initially installed for a period of 60-days between October 2020 and December 2020.

Rainfall data was collected during this period to allow for the correlation between the rainfall data and the flow monitoring data. A rain gauge network consisting of three (3) rain gauges was installed at different spatial locations throughout the City to obtain temporal and spatial variations in rainfall. Fifteen (15) rainfall events totaling over nine (9) inches of rain were recorded during the monitoring period.

1.2 Flow and Rainfall Analysis

Flow analysis is completed to deconstruct flow meter hydrographs into the various components of sanitary sewer system flow. Flow analysis consists of two analysis: dry weather and wet weather. Dry weather flow analysis provides an analysis of the average daily dry weather flow (ADDF). A typical dry weather flow pattern consists of an average daily diurnal pattern where peak flows occur during the morning and late evening; diurnal patterns were developed at each of the six (6) flow meter locations as part of the dry weather analysis. Wet weather analysis involves identification of flow volumes related to inflow and infiltration (separately) and total I/I in each meter basin. Wet weather analysis allows for projected wet weather volumes experienced in each of the six (6) meter basins.

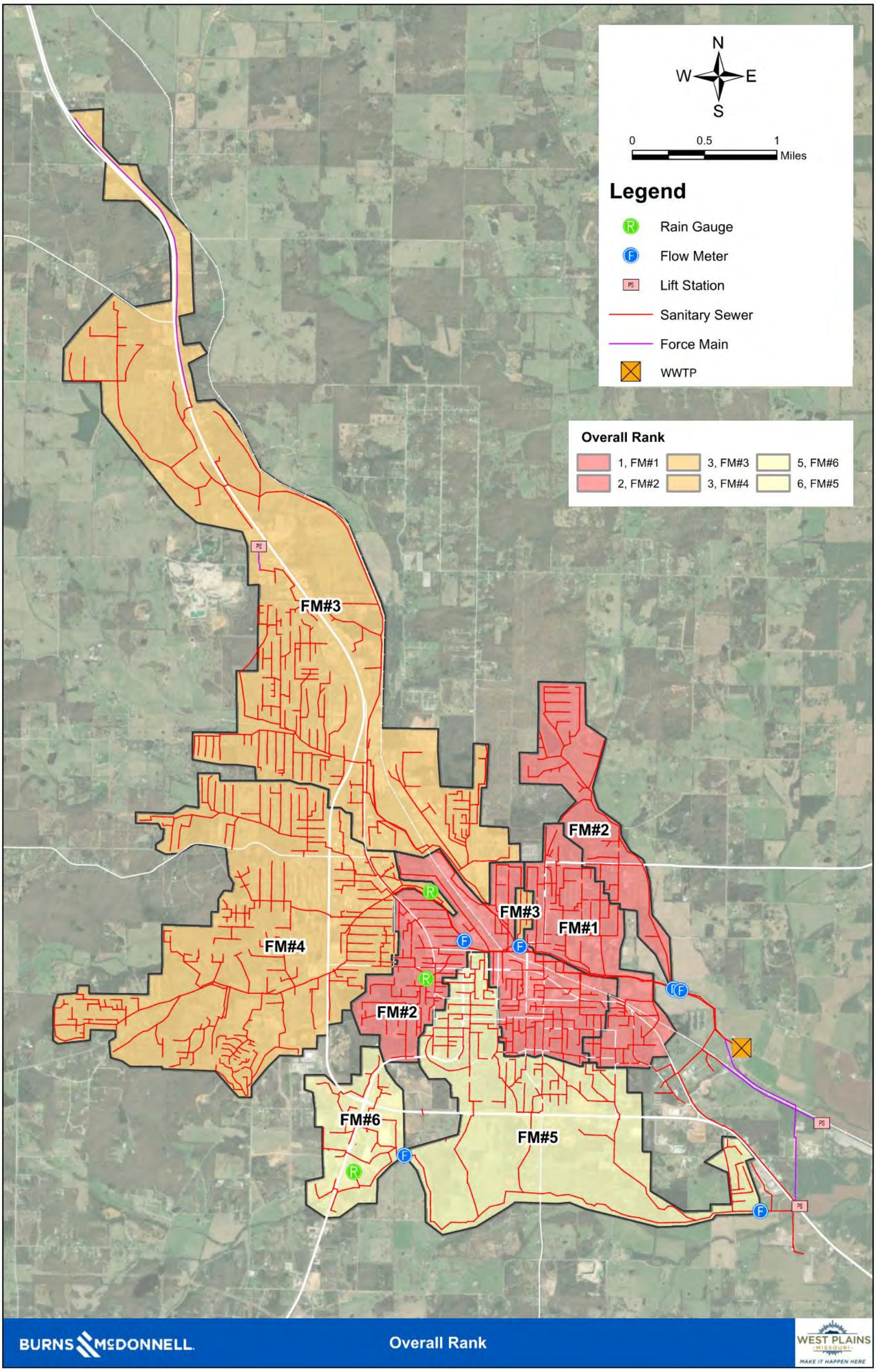
1.3 Summary of I/I Assessment

Figure 1-1 shows the routing of I/I through the system, identifying meter catchments with high levels of total I/I. Following the completion of the I/I evaluation, it was found that meter catchments FM#1 and FM#2 are contributing a substantial amount of I/I into the collection system. FM#1 is located at the downstream end of the southern 24-inch main interceptor, which conveys flow east to the Wastewater Treatment Plant (WWTP). FM#2 is located at the downstream end of the northern 24-inch main interceptor, which also conveys flow east to the WWTP.

Based on the indices of total I/I volume, inflow volume, and infiltration volume, the individual rankings were cumulated and ranked to produce an overall rank for each meter catchment. These index rankings can be used to aid in prioritizing an I/I Strategic Plan to focus Sanitary Sewer Evaluation Surveys (SSES) and public and private I/I reduction practices on the highest contributing areas.

Developing an I/I Strategic Plan is recommended following completion of a flow monitoring program. An I/I Strategic Plan utilizes the data analyzed in the flow monitoring program to lay out a definitive list of steps to address and reduce I/I observed within the collection system. Further consultation with the City would be required to identify specific action items and a path forward that is within the means of the City to complete based on available resources, budget, and needs of the collection system.

Figure 1-1: Total I/I Volume (Thousand Gallons) per Inch of Rainfall



2.0 INTRODUCTION

The City of West Plains, Missouri (City) administered a flow and rainfall monitoring program that was completed in Fall of 2020. A review of the collection system has been conducted in an effort to prioritize inflow and infiltration (I/I) reduction and increased pipe capacity within the sanitary sewer system and plan for future growth. This information can also be used in the future to prepare a hydraulic model.

This Flow Analysis and I/I Evaluation is the first step for the City to develop an I/I Reduction Program and I/I Strategic Plan. This flow metering data and I/I analysis would aid in the development of an I/I Strategic Plan. Flow monitoring and public source I/I reduction would all be utilized together to provide the City with additional tools to implement a comprehensive, cost-effective I/I reduction plan for its wastewater collection system.

The purpose of this report is to summarize the flow and rainfall data collection and analysis. Information developed during dry weather flow analysis includes diurnal patterns and average daily dry weather flow (ADDF) for both weekdays and weekends. Flow metering and rainfall data acquired was also used to isolate wet weather volume generation across the system for wet weather events of varying intensity and duration.

The flow analysis also allowed for the identification of the meter catchment areas that are contributing the highest I/I to the wastewater collection system. Each of the metering basins were ranked considering total I/I volume, total inflow volume, and total infiltration volume. The data was measured against multiple index rankings to eliminate any bias related to metering area. Using these metrics, an overall basin ranking was developed which would aid in the development of an I/I Strategic Plan. The I/I Strategic Plan would be developed to identify the scope and cost opinion of the sanitary sewer evaluation surveys (SSES) and public and private rehabilitation reduction within each basin.

The following sections of this Technical Memorandum provide a detailed analysis of the flow and rainfall metering data collected as part of the Fall 2020 flow and rainfall monitoring program.

Moving forward, developing an I/I Strategic Plan is recommended upon completion of a flow monitoring program. An I/I Strategic Plan utilizes the data analyzed in the flow monitoring program to lay out a definitive list of steps to address and reduce I/I observed within the collection system.

3.0 FLOW AND RAINFALL MONITORING

Flow and rainfall monitoring were performed to establish a relationship between precipitation (rainfall intensity and rainfall volume) and system flow rates.

3.1 Flow and Rainfall Monitoring Locations

Six (6) flow meter locations were originally selected to monitor flows throughout the system. Flow monitoring site information is summarized in **Table 3-1**. Flow meter site sheets are provided in **Appendix A**. It should be noted that flow meter FM #6 was installed fourteen (14) days after the rest of the flow meters.

Flow meters were installed in the incoming pipes of the manholes for best hydraulic conditions. Meter locations are shown in **Figure 3-1**, and a flow meter schematic showing the relationship between flow meters is presented in **Figure 3-2**.

Table 3-1: Flow Meter Locations

Flow Meter ID	Manhole ID	Pipe Diameter (in)	Install Date	Removal Date
FM#1	01786	24	10/1/2020	12/1/2020
FM#2	01785	24	10/1/2020	12/1/2020
FM#3	02662	24	10/1/2020	12/1/2020
FM#4	02088	18	10/1/2020	12/1/2020
FM#5	01568	24	10/1/2020	12/1/2020
FM#6	01454	18	10/15/2020	12/15/2020

3.2 Rain Gauges

Rain gauges were installed in three (3) locations to capture spatial variation of rainfall. One (1) rain gauge was installed at the Aquatic Center, one (1) rain gauge was installed at the Fire Station, and one (1) rain gauge was installed at the Water Treatment Plant. It should be noted that the rain gauge at the Water Treatment Plant was not used for analysis due to the rain gauge reading data incorrectly the first month of the monitoring period. The rain gauge locations are also shown in **Figure 3-1.**

Figure 3-1: Flow Meter and Rain Gauge Locations

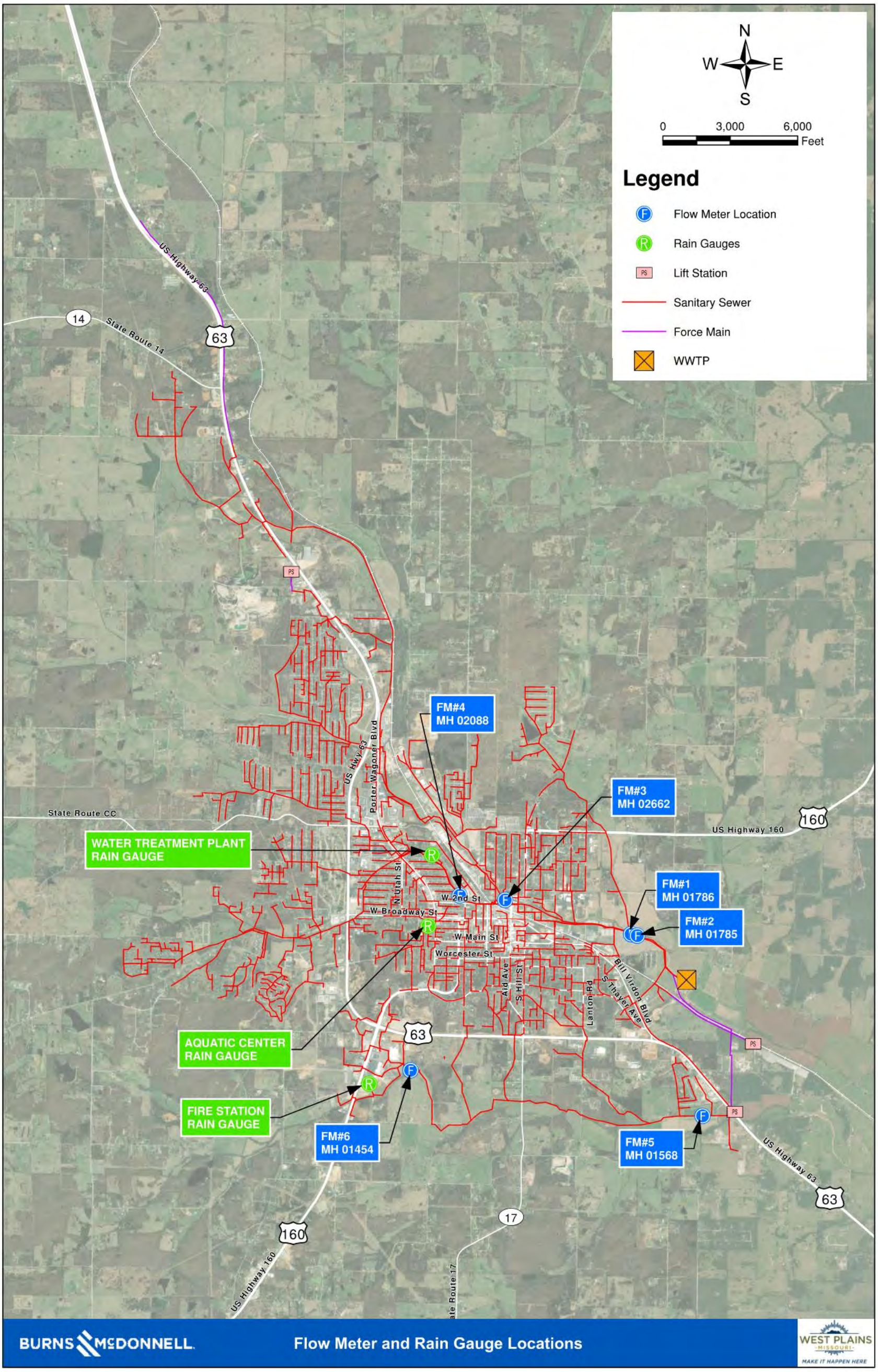
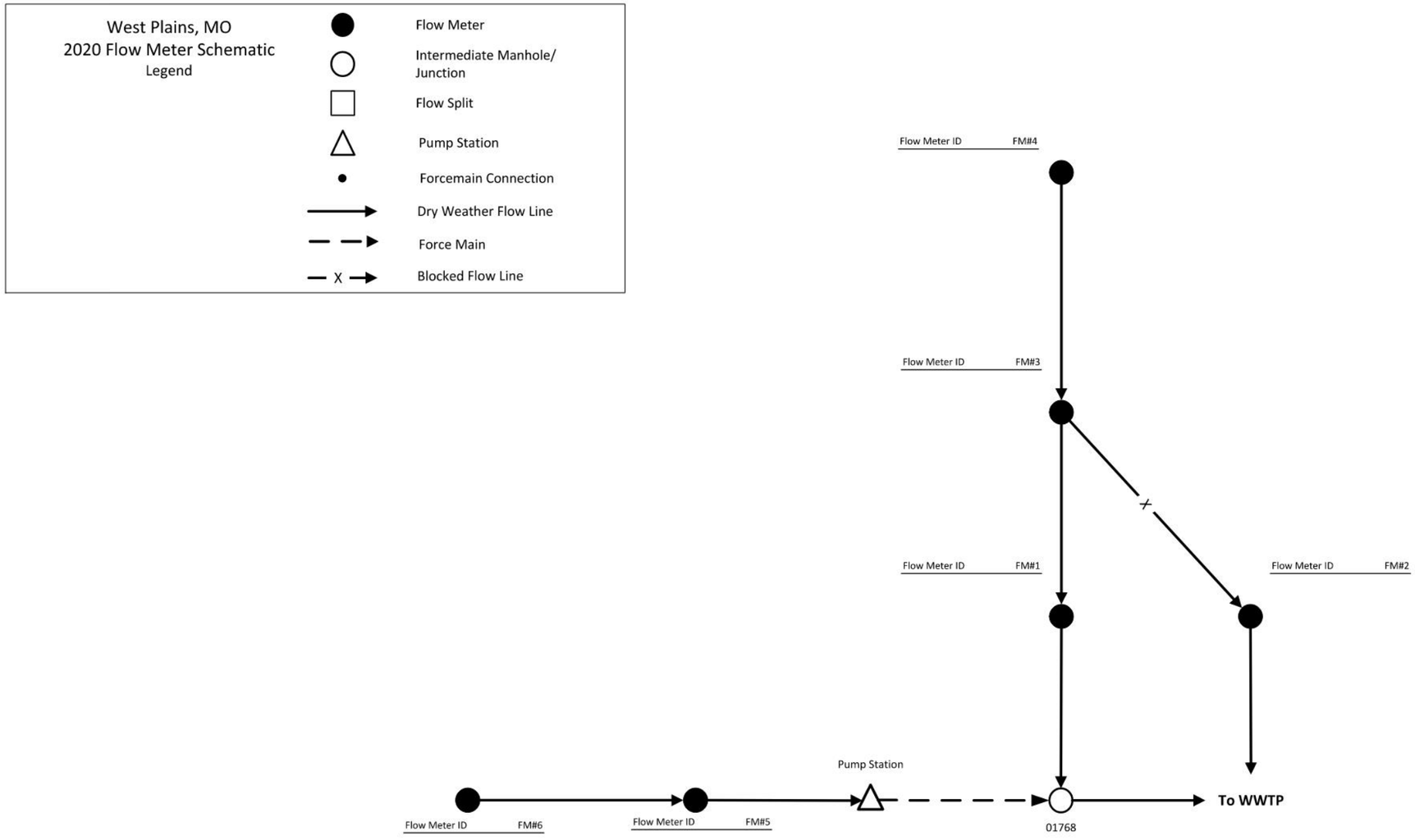


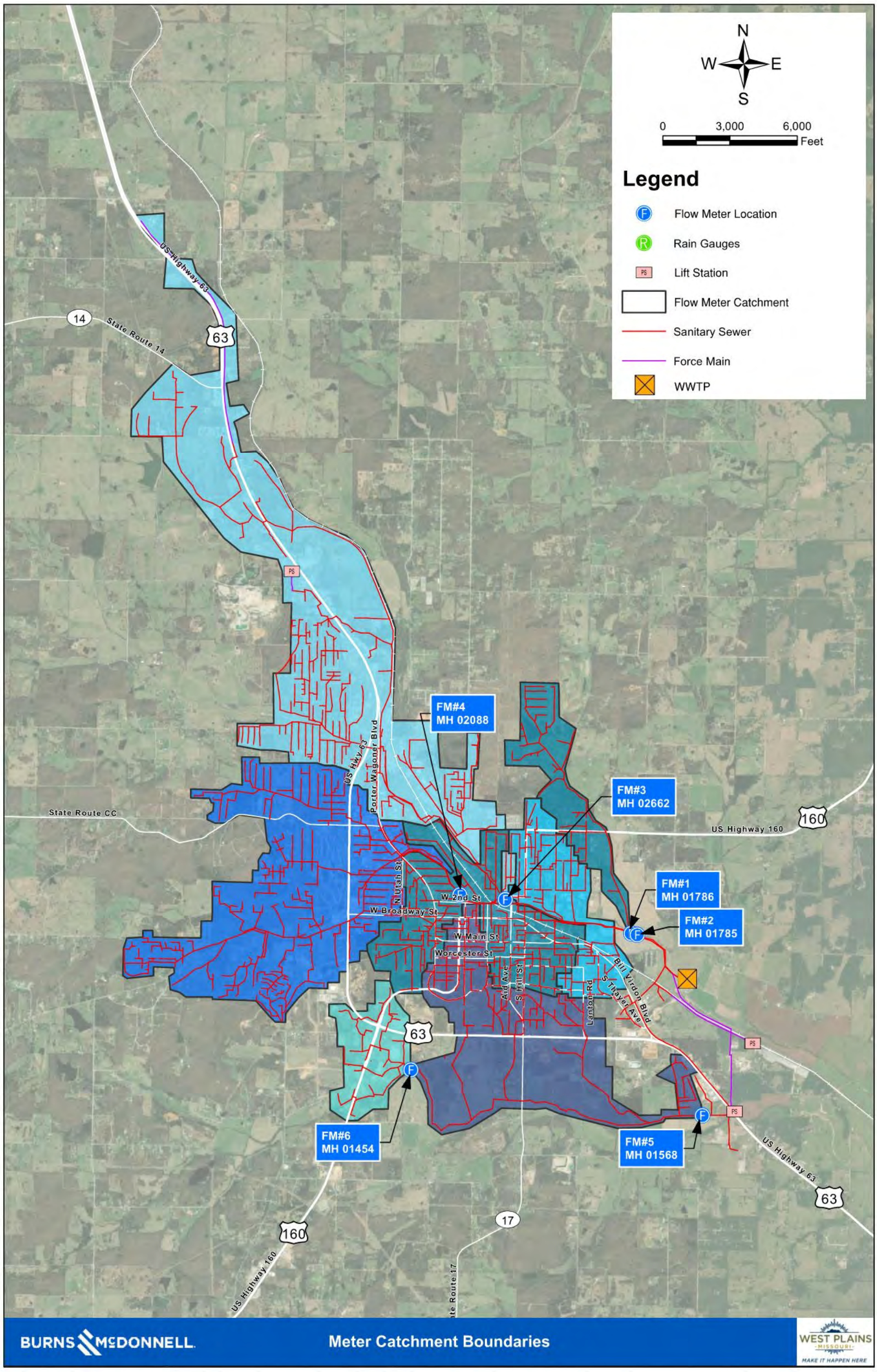
Figure 3-2: Flow Meter Schematic



3.3 Meter Catchments

Meter catchments represent the tributary area draining to each of the flow meters. Flow meter locations were established throughout the collection system to provide adequate and distributed flow data to support flow analysis. The delineated basins were used to rank the locations for I/I based on wet-weather volume. A total of six (6) flow metering basins delineated representing the monitored flow as installed at the beginning of the flow meter period. The meter catchments are illustrated on **Figure 3-3**.

Figure 3-3: Meter Catchments



4.0 FLOW AND RAINFALL ANALYSIS

Flow and rainfall analysis were completed using the collected flow and rainfall data from the monitoring period. The analyses were completed to identify dry weather and wet weather contributions from each meter catchment. The analyses are described in more detail in the subsequent sections.

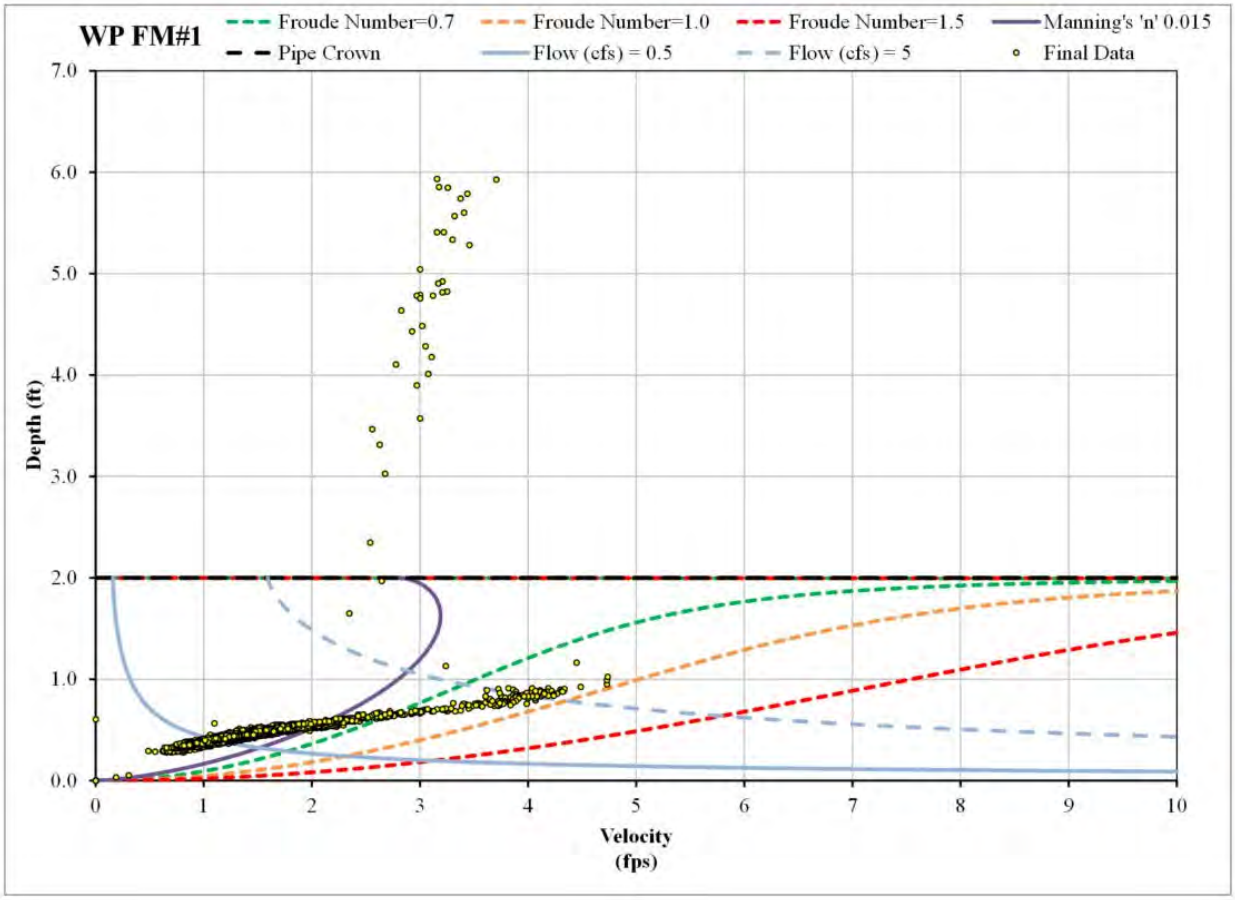
4.1 Recorded Depth vs Recorded Velocity

A scatter graph plots depth versus velocity from recorded data. Ideal flow data has a distinct depth versus velocity pattern: as velocity increases, depth increases according to the Manning's Equation.

Scatter graphs were used to evaluate the reliability of depth and velocity data because of the relationship between velocity and depth. Scatter graphs were developed for each flow meter and are provided in **Appendix B.** It is important to note that no vertical elevation data is available in the collection system, and as a result the pipe slopes were assumed based on the shape of the scatter graph data to best fit the Manning's equation curve. If vertical elevation data is collected or made available, the scatter graphs can be further refined.

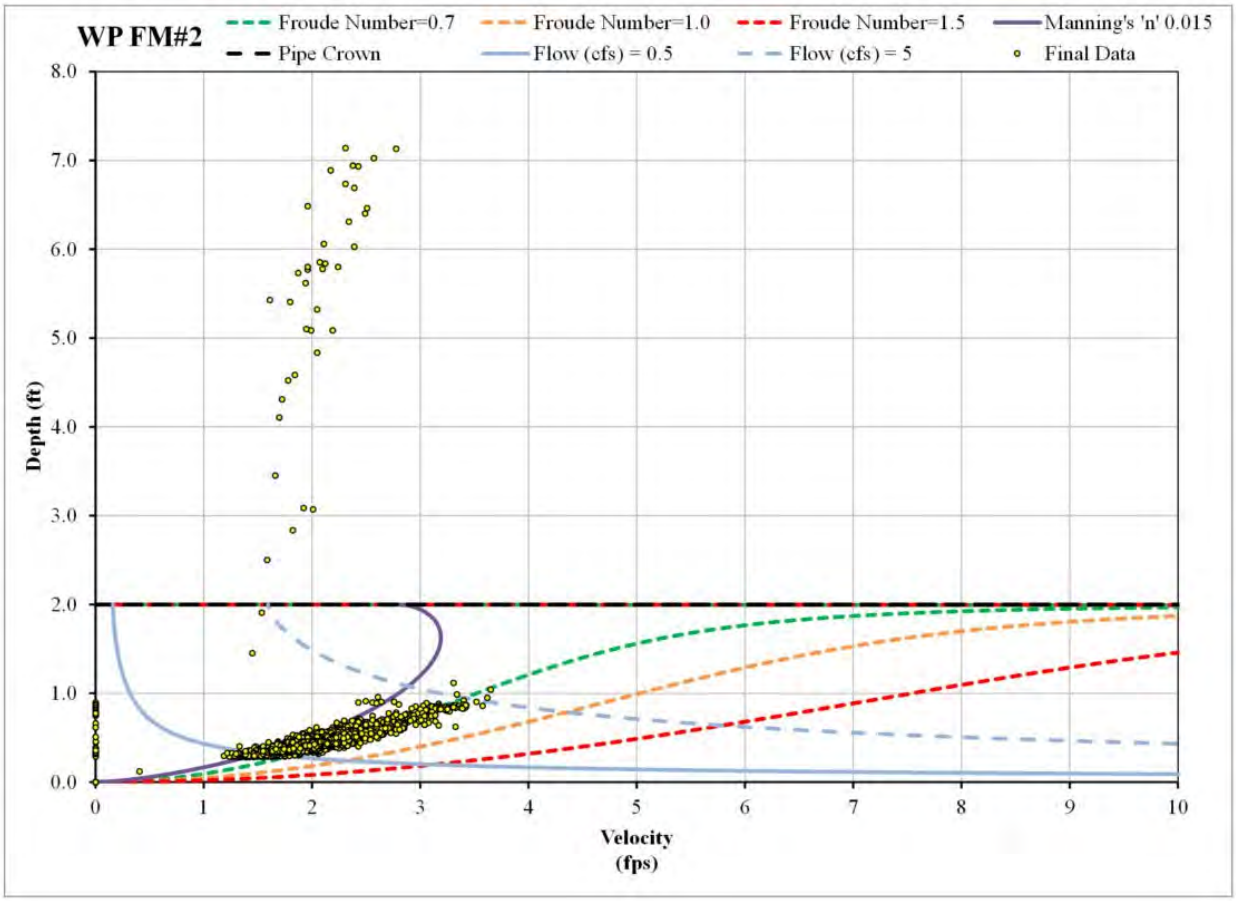
The scatter graph for site FM#1 shown on **Figure 4-1** was assumed at a slope of 0.2% and with a Manning's N value of 0.015. This flow meter was installed along the northern parallel 24-inch pipes that is tributary to the wastewater treatment plant (WWTP). At depths below 12-inches, the velocity and depth readings correlate as expected and roughly follow the expected Manning's n curve. At depths above 12-inches, the velocity versus depth pattern shows a rising depth with no change in velocity. This indicates the wastewater flow backs-up at a depth of approximately 12-inches, when the pipe continues to fill before surcharging. The cause of this backup could be related to downstream flow restrictions, a blocked or broken pipe, or insufficient capacity at the WWTP. Further analysis would be required to identify the location and type of flow blockage. This does not impact the overall quality of the flow data but identifies an occurrence that should be considered for future improvements. This backup indicates a pipe capacity of approximately 6 cubic feet per second (cfs) or 3.2 million gallons per day (MGD). If this pipe were flowing at its full flow capacity, this would correspond to a flow of approximately 6.1 MGD. The scatter graph also shows depths above 24-inches. These depths indicate an elevated water level above the crown of the pipe, but this does not necessarily indicate there is flow overtopping the manholes and being released into the environment.

Figure 4-1: FM#1 Scatter Graph



The scatter graph for site FM#2 shown on **Figure 4-2** was assumed at a slope of 0.2% and with a Manning's N value of 0.015. This flow meter was installed along the southern parallel 24-inch pipes that is tributary to the wastewater treatment plant (WWTP). At depths below 12-inches, the velocity and depth readings correlate as expected and roughly follow the expected Manning's n curve. At depths above 12-inches, the velocity versus depth pattern shows a rising depth with no change in velocity. This indicates the wastewater flow backs-up at a depth of approximately 12-inches, when the pipe continues to fill before surcharging. The cause of this backup could be related to downstream flow restrictions, a blocked or broken pipe, or insufficient capacity at the WWTP. Further analysis would be required to identify the location and type of flow blockage. This does not impact the overall quality of the flow data but identifies an occurrence that should be considered for future improvements. This backup indicates a pipe capacity of approximately 5 cubic feet per second (cfs) or 2.7 million gallons per day (MGD). If this pipe were flowing at its full flow capacity, this would correspond to a flow of approximately 6.1 MGD. The scatter graph also shows depths above 24-inches. These depths indicate an elevated water level above the crown of the pipe, but this does not necessarily indicate there is flow overtopping the manholes and being released into the environment.

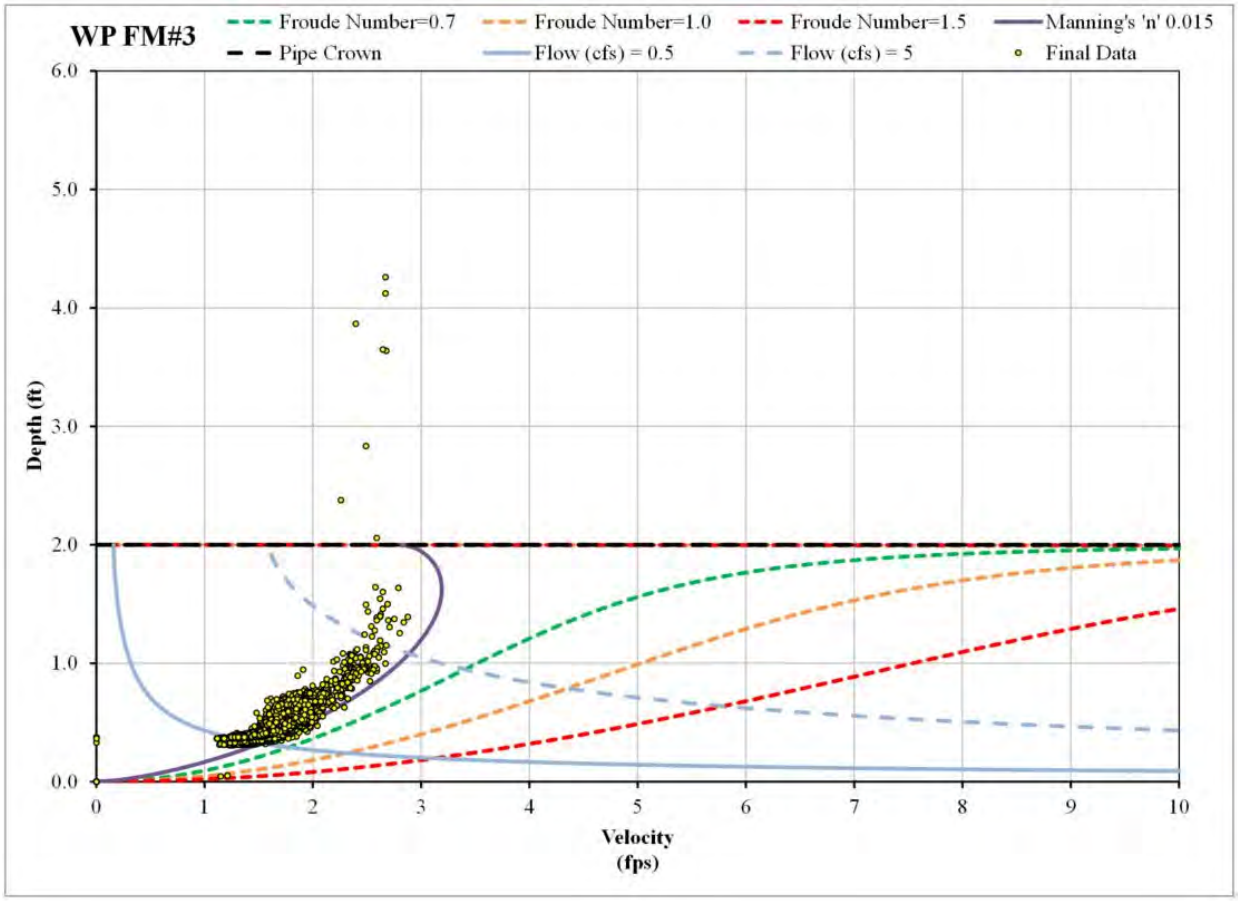
Figure 4-2: FM#2 Scatter Graph



FM#1 and FM#2 are tributary to the WWTP. Using the flow meter data during this observed period, the peak flow reaching the WWTP from these the two parallel 24-inch pipes where these meters are installed is 5.9 MGD. If the pipes are allowed to flow at full capacity, a total of 12.2 MGD would reach the WWTP from these parallel 24-inch pipes.

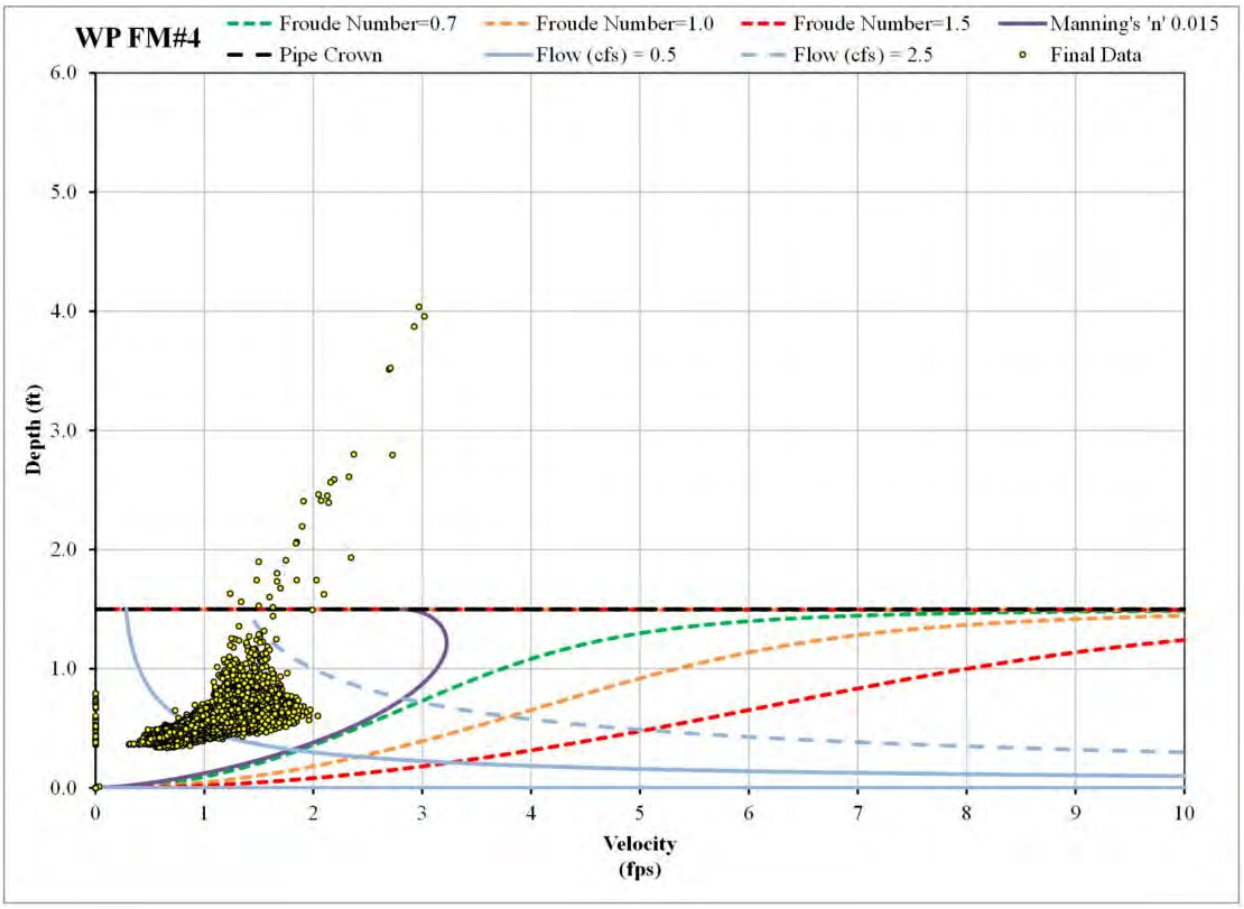
The scatter graph for site FM#3 shown on **Figure 4-3** was assumed at a slope of 0.2% and with a Manning's N value of 0.015 and represents an ideal depth versus velocity pattern. Each of the points follow closely to the Manning's equation line, representing the 'theoretical' path for a pipe of that size and slope. The reasonable depth-velocity relationships suggests that the flow metering data is of good quality and considered reliable for further evaluation.

Figure 4-3: FM#3 Scatter Graph



The scatter graph for site FM#4 shown on **Figure 4-4** was assumed at a slope of 0.3% and with a Manning's N value of 0.015 illustrates clumping of the data. This is a result of the Water Treatment Plant (WTP) backwashing water into the collection system, upstream of the meter, acting as an additional source of flow into the system. The discharge from the WTP was considered during further evaluations at this flow meter location; this does not affect the integrity of the data at this location.

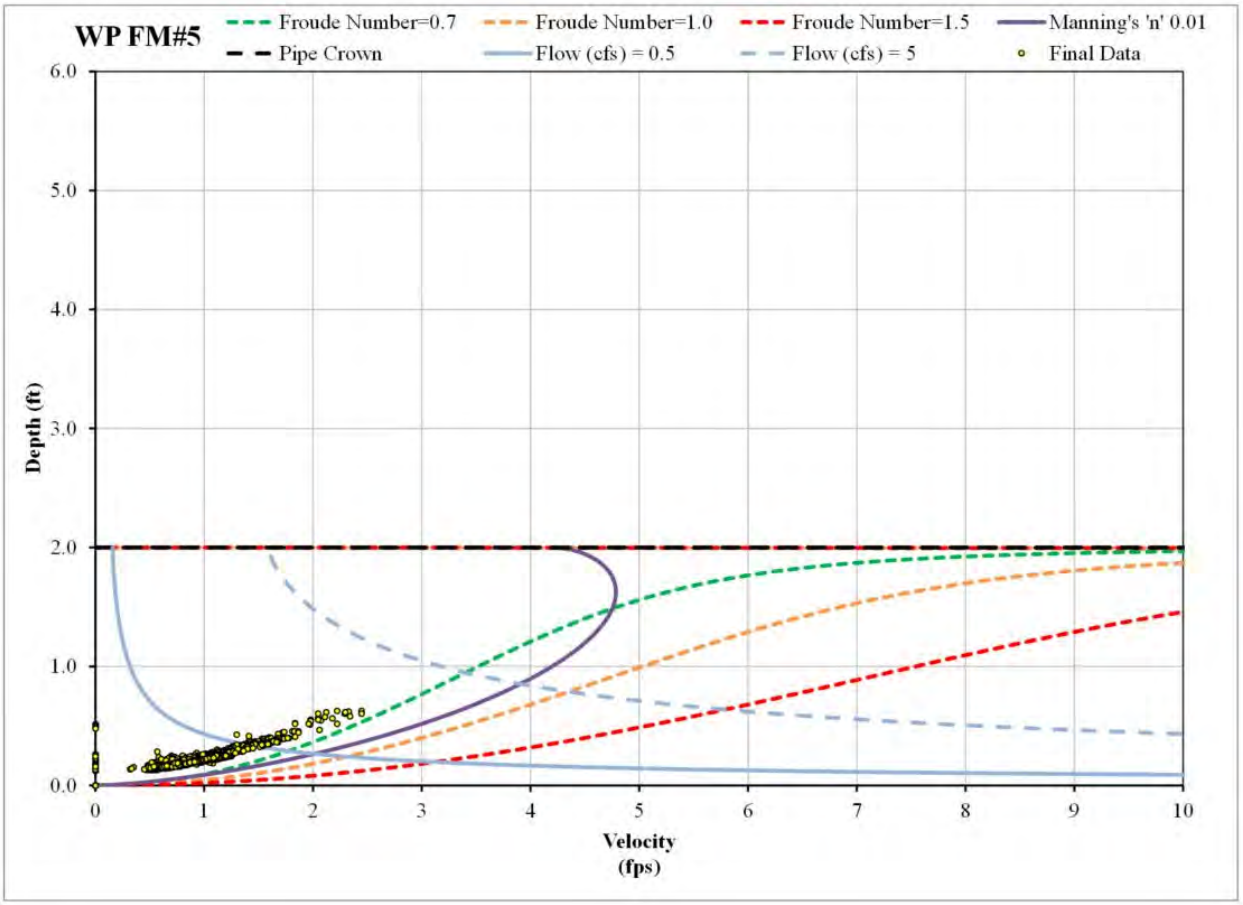
Figure 4-4: FM#4 Scatter Graph



The scatter graph for site FM#5 shown on **Figure 4-5** represents an ideal depth versus velocity pattern. This flow meter was assumed at a slope of 0.2% and with a Manning's N value of 0.01. Each of the points follow closely to the Manning's equation line, representing the 'theoretical' path for a pipe of that size and slope. The reasonable depth-velocity relationships suggests that the flow metering data is of good quality and considered reliable for further evaluation.

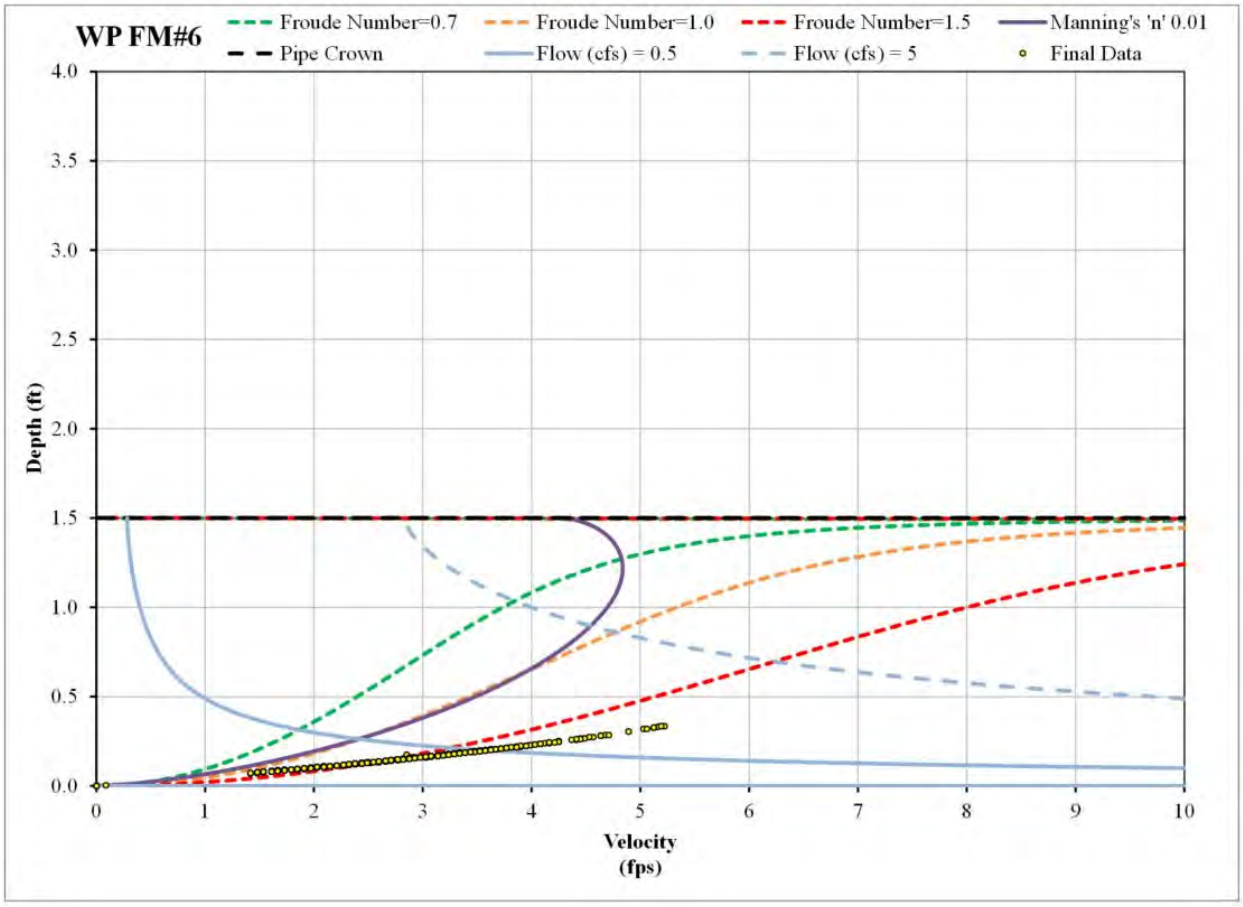
It should be noted that even under peak flow conditions, the maximum velocity observed in this meter only reaches 2.5 feet per second (fps). The recommended cleansing velocity during dry weather flow conditions is two (2) fps. In addition, the maximum depth observed at this flow meter is less than one (1) foot, indicating that even under observed peak flow conditions, the pipe flows less than 50% full. When cleansing velocities are not achieved, biological buildup may be seen in the collection system, causing further blockages in the system. The low cleansing velocity could be a result of flat or back-pitched pipes. Further investigations would need to be completed to confirm the cause of the low cleansing velocities. FM#5 is tributary to a lift station which discharges immediately upstream of the WWTP.

Figure 4-5: FM#5 Scatter Graph



The scatter graph for site FM#6 shown on **Figure 4-6** was assumed at a slope of 0.3% and with a Manning's N value of 0.01. The velocity of this meter reaches approximately 5.25 fps. This is much higher than the maximum observed velocity at FM#5, which is immediately downstream of this meter. The higher observed velocities could be a result of steeper pipes.

Figure 4-6: FM#6 Scatter Graph



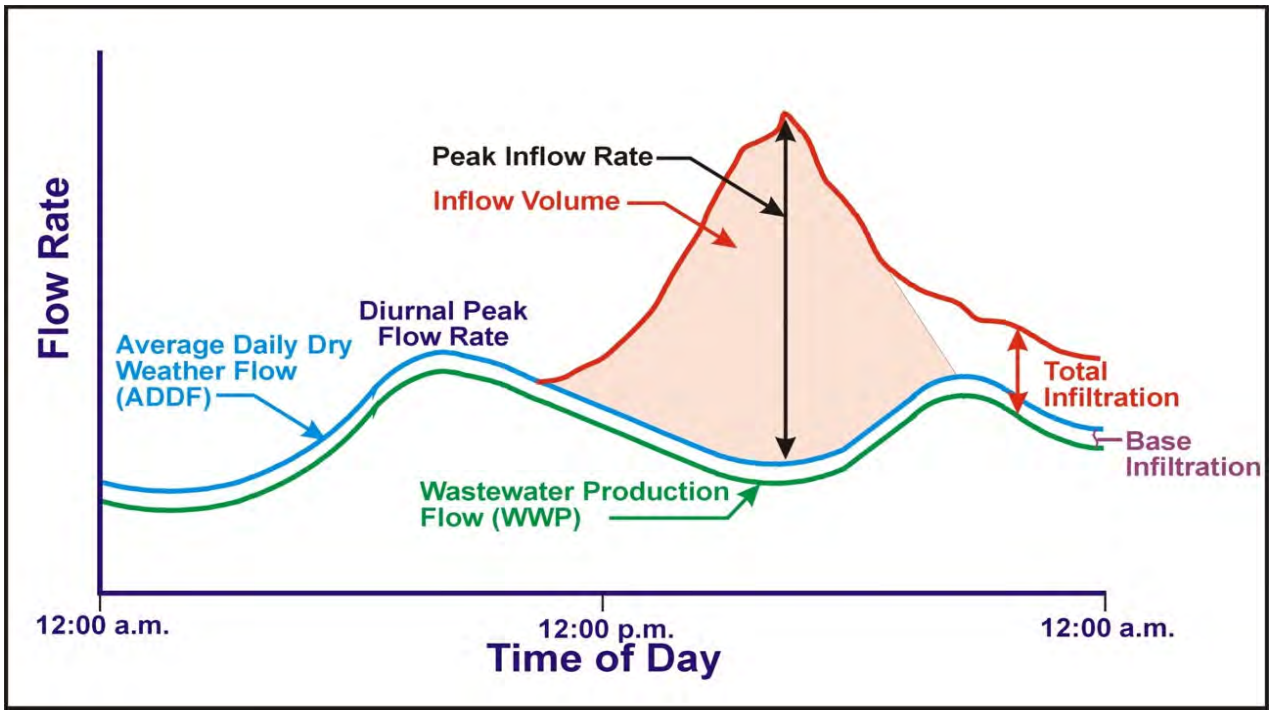
During these dry weather conditions, there is evidence of attenuation in the system at sites FM#5 and FM#6. Attenuation can occur when a higher velocity is rushing into a slower moving flow regime, which is observed to have occurred at these sites in the system.

The inflow reaction present in FM#6 translates to greater amounts of infiltration response at FM#5 as this flow takes time to route through the system and the peak flow is attenuated heading into the Lift Station. This corresponds to a lower peak flow observed at the downstream flow meter (FM#5), which is not typically observed in collection systems. Further explanation and graphical representation of this is provided in section 4.2.1.

4.2 Dry Weather Flow Analysis

Flow analyses were performed to deconstruct flow meter hydrographs into the various components of sanitary sewer system flows. ADDF, peak daily dry-weather flow (PDDF), and I/I were estimated through the analyses described in the following sections. **Figure 4-7** illustrates the flow components of a typical sanitary flow response hydrograph.

Figure 4-7: Typical Hydrograph Flow Components



4.2.1 Dry Weather Flow Parameters

Dry weather flow is the flow present in the sanitary sewer without the influence of rainfall. The ADDF includes wastewater production and infiltration present during dry, low groundwater conditions. Dry weather flow does not include inflow or groundwater infiltration due to rainfall. To eliminate the possibility of wet weather influences on a dry weather flow day, there should be no rainfall that day or the previous day. Additionally, the flow hydrograph must be reviewed to avoid the use of days with residual high groundwater entering the system from a previous rain event.

Several representative dry weather days were selected and averaged to determine ADDF. Weekday and weekend ADDF curves for each flow meter are provided in **Appendix C**.

PDDF is the maximum one-hour flow rate during a 24-hour period. The PDDF was determined by averaging the maximum one-hour flow rate for the selected dry weather days. The dry weather peaking factor was then calculated as the ratio of PDDF to ADDF.

Minimum night-time flow is the lowest 3-hour flow, typically between 2 AM and 5 AM. The average minimum night-time flow was determined by averaging the lowest 3-hour flow rate for the selected dry weather days.

A summary of the flow parameters (ADDF, PDDF, peaking factor, and average minimum night-time flow) for each flow meter is provided in **Table 4-1** for weekdays and **Table 4-2** for weekends. **Figure 4-11** and **Figure 4-12** illustrate the cumulative and incremental ADDF as the flow is routed through the system to the WWTP for weekday and weekend days, respectively.

Table 4-1: Dry Weather Flow Parameter Summary - Weekdays

Flow Meter ID	Incremental ADDF (MGD)	Cumulative ADDF (MGD)	Incremental PDDF (MGD)	Cumulative PDDF (MGD)	Dry Weather Peaking Factor	Average Minimum Night-Time Flow (MGD)
FM#1	-0.317	0.360	-0.516	0.584	1.625	0.153
FM#2	0.569	0.569	0.827	0.827	1.455	0.299
FM#3	0.248	0.677	0.242	1.100	1.628	0.323
FM#4	0.429	0.429	0.858	0.858	2.001	0.156
FM#5	-0.029	0.107	-0.074	0.163	1.552	0.053
FM#6	0.136	0.136	0.237	0.237	1.744	0.056

Table 4-2: Dry Weather Flow Parameter Summary - Weekends

Flow Meter ID	Incremental ADDF (MGD)	Cumulative ADDF (MGD)	Incremental PDDF (MGD)	Cumulative PDDF (MGD)	Dry Weather Peaking Factor	Average Minimum Night-Time Flow (MGD)
FM#1	-0.292	0.321	-0.497	0.572	1.787	0.153
FM#2	0.513	0.513	0.798	0.798	1.557	0.288
FM#3	0.222	0.613	0.227	1.069	1.750	0.314
FM#4	0.391	0.391	0.842	0.842	2.154	0.153
FM#5	-0.021	0.109	-0.064	0.172	1.577	0.050
FM#6	0.130	0.130	0.236	0.236	1.825	0.062

A negative incremental ADDF and PDDF is shown at FM#1 and FM#5 for both weekday and weekend dry weather flow.

At FM#1, there is an ADDF and PDDF volume imbalance. There is an existing flow diversion between FM#1 and FM#2 at the third structure upstream from the two meters. This diversion was plugged during this flow monitoring period, directing the flow to FM#1; however, there may be additional diversions upstream that contribute to this flow imbalance.

At FM#5, there is also a volume imbalance in ADDF and PDDF. The observed velocities at FM#5 are low, only reaching about 2.5 fps. The meter upstream of this is FM#6, which showed much higher observed velocities at about 5.25 fps. **Figure 4-8** shows the hydrographs and how flow routing occurs from FM#6 to FM#5. The difference in observed velocities is thought to be due to flat or back-sloped pipes between FM#5 and FM#6. When a higher velocity flow is rushing into a slower moving flow regime, flow attenuation can occur. This is caused when peak flow rates are decreased due to a reduction in velocity caused by flat sloped pipes. In some cases, this can cause a capacity restriction and surcharging upstream in the system. Neither a capacity restriction nor surcharging were observed at FM#5 or FM#6 during this metering period.

At FM#3, the diurnal pattern does not display a typical pattern.

Figure 4-8: FM#6 and FM#5 Flow Hydrographs for October 18, 2020 Storm

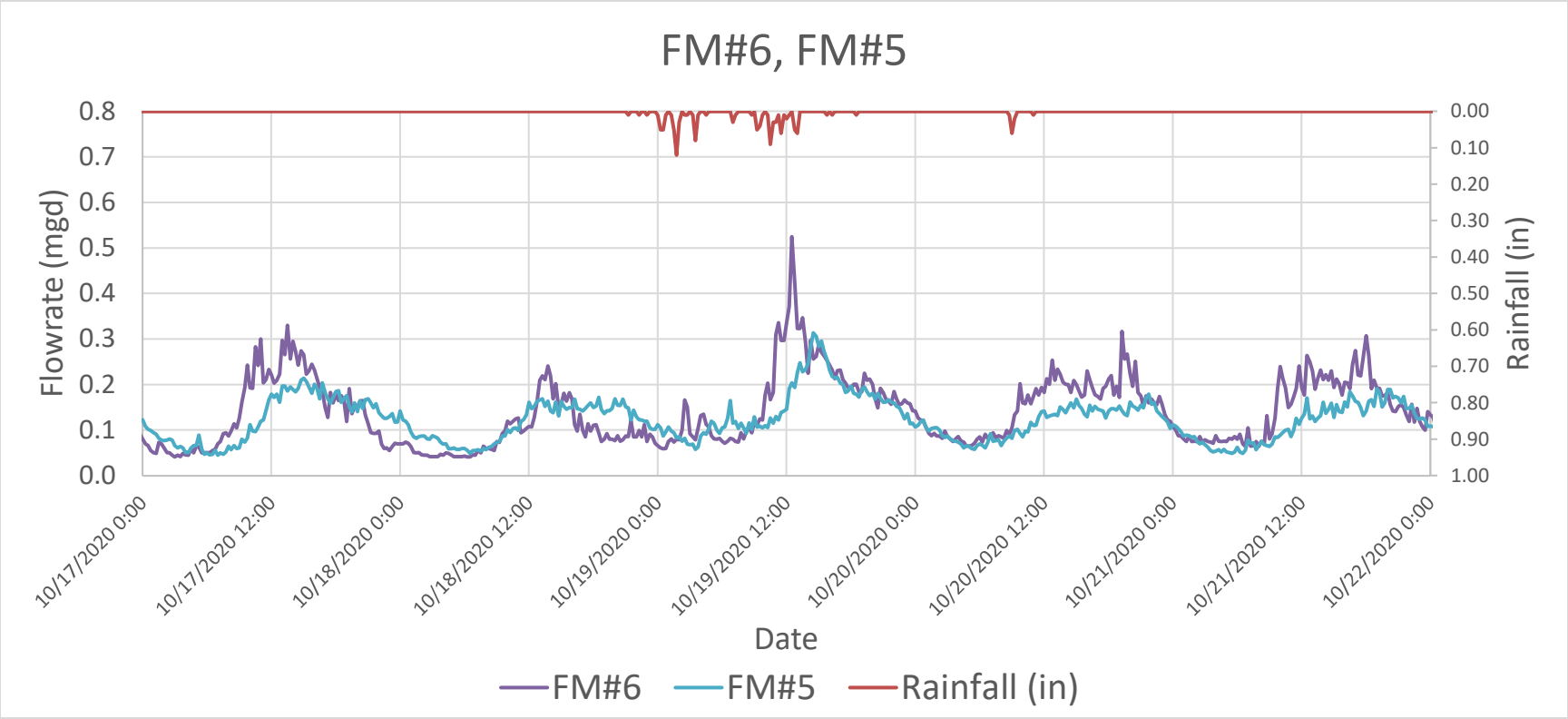


Figure 4-9 illustrates the diurnal with many peaks due to the impacts from the lift station upstream of the flow meter. This does not impact the overall quality of data.

At FM#4, the diurnal pattern does not display a typical pattern. **Figure 4-10** illustrates the diurnal with many peaks due to the impacts from the WTP backwashing water into the collection system upstream of the flow meter. This does not impact the overall quality of data.

Figure 4-8: FM#6 and FM#5 Flow Hydrographs for October 18, 2020 Storm

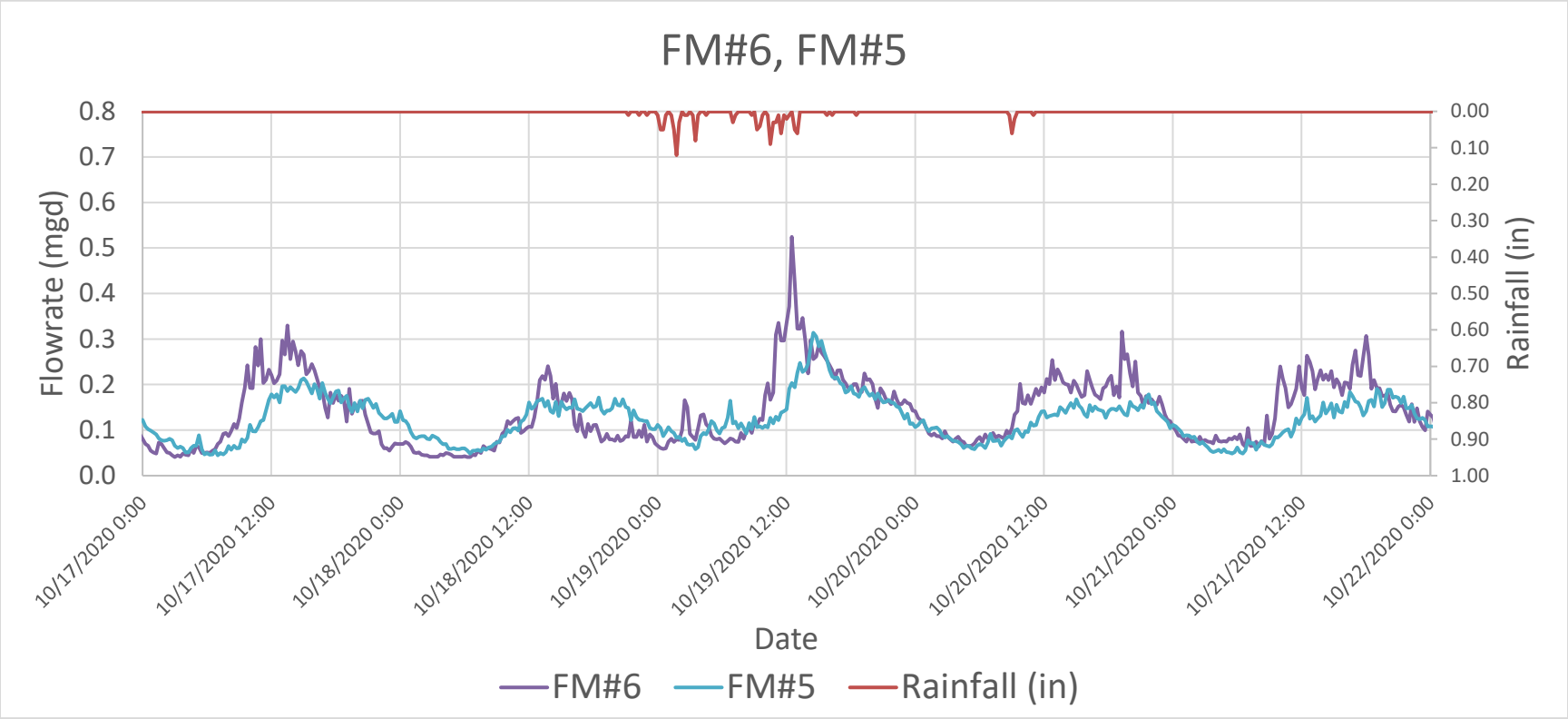


Figure 4-9: FM#3 ADDF Diurnal - Weekday

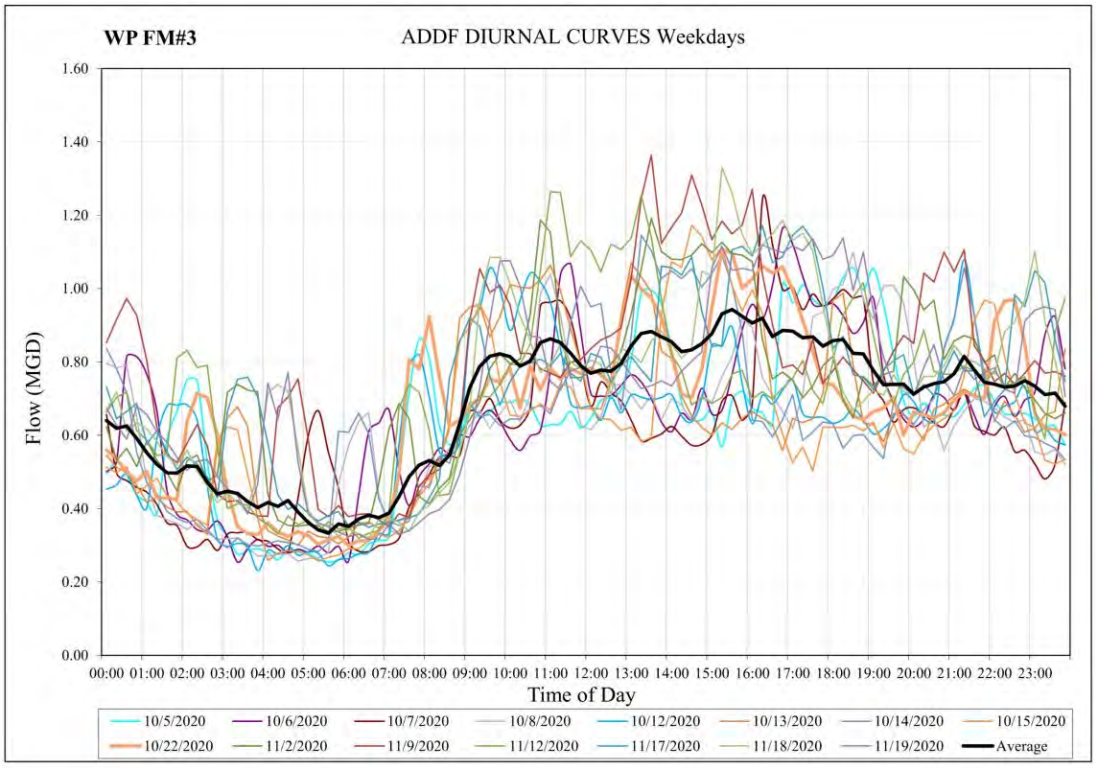


Figure 4-10: FM#4 ADDF Diurnal - Weekday

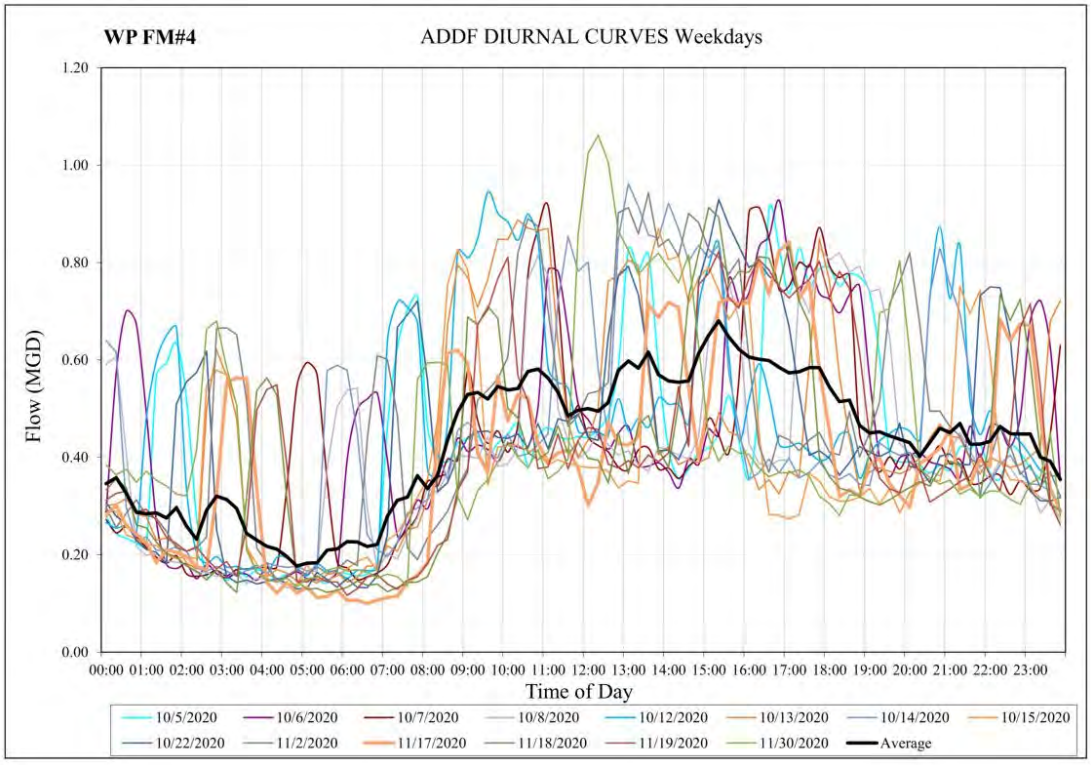


Figure 4-11: Weekday ADDF Schematic

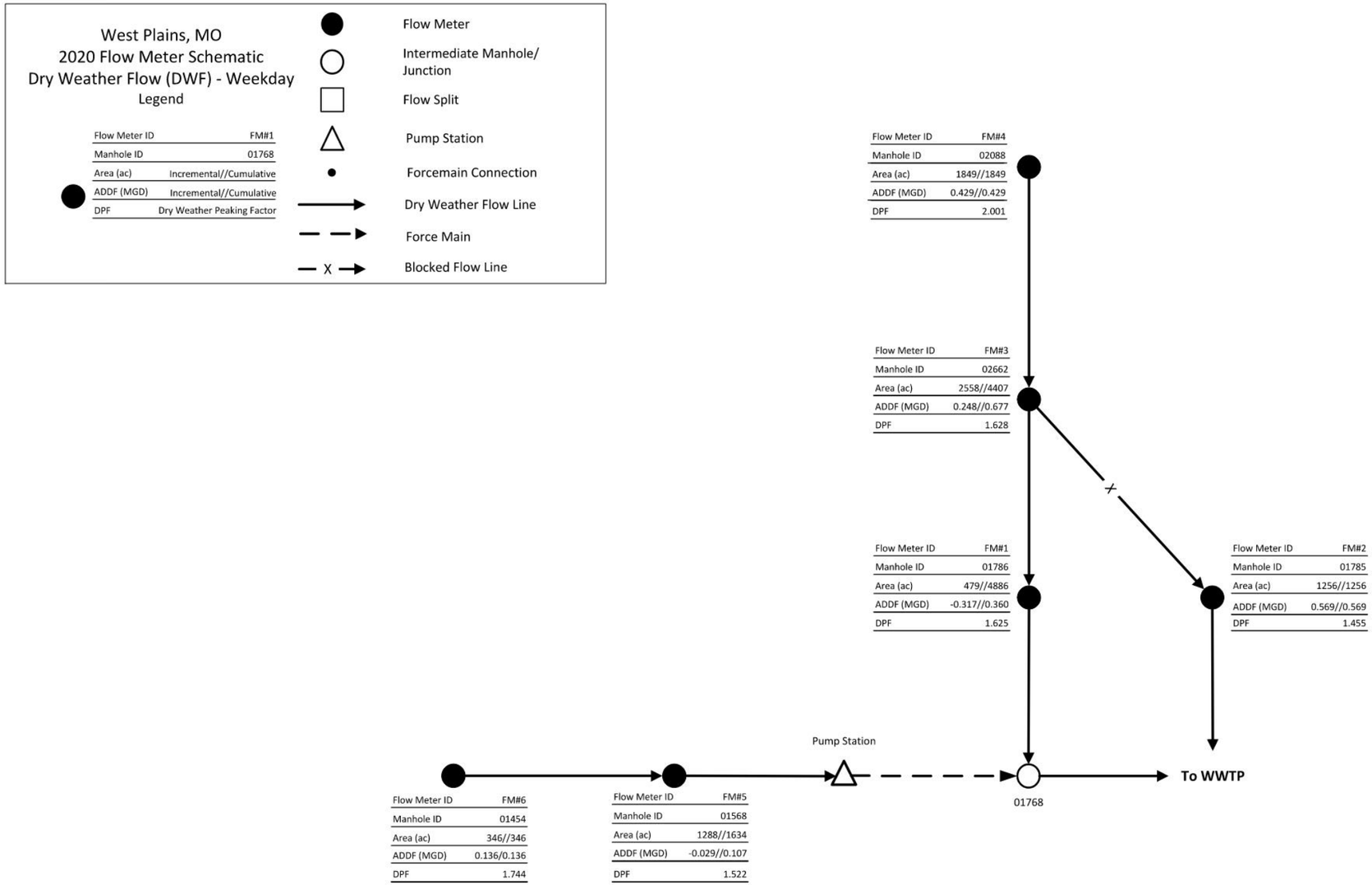
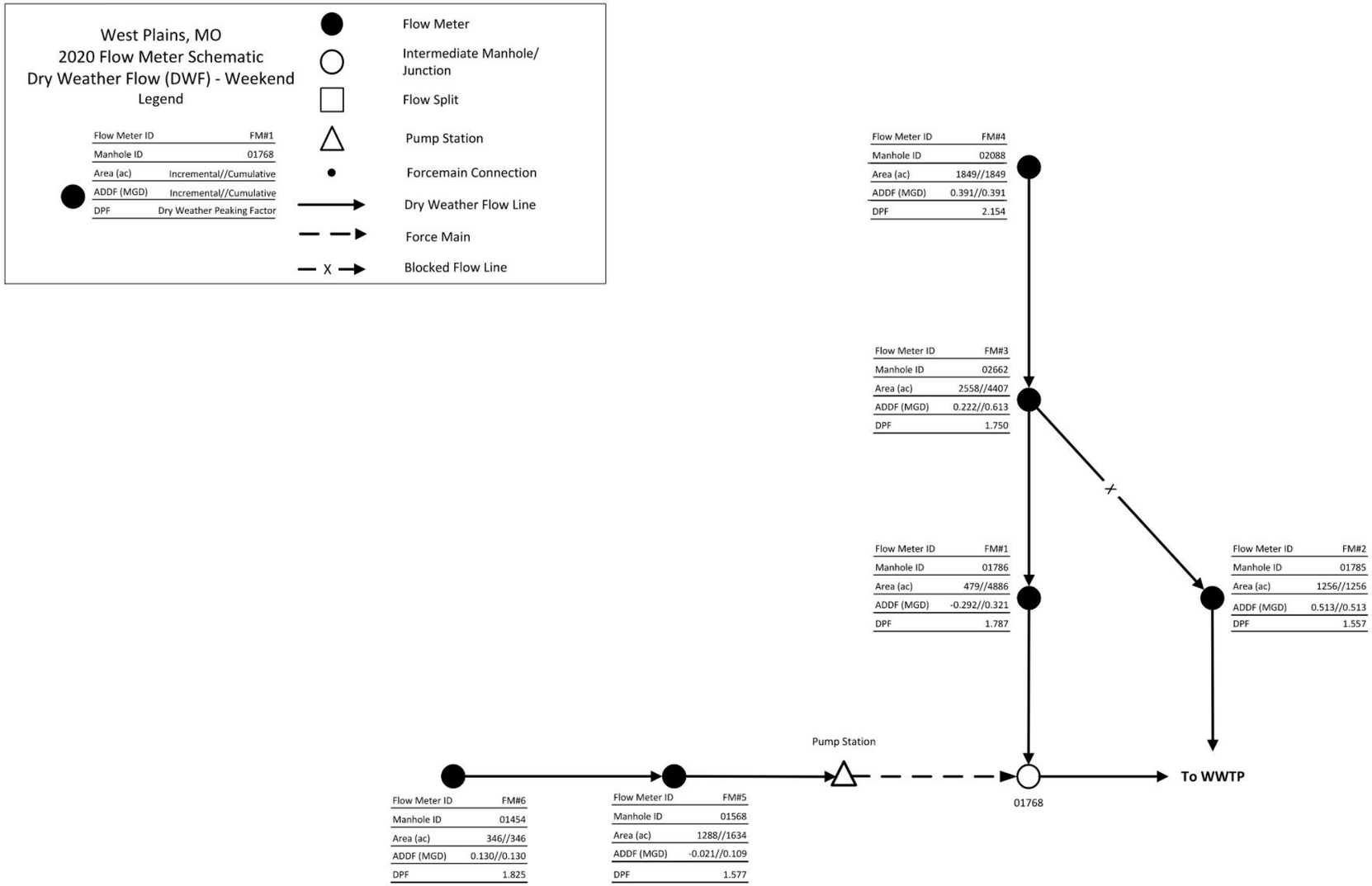


Figure 4-12: Weekend ADDF Schematic



4.3 Rainfall Events

The minimum inter-event time (MIT) is the minimum number of dry hours between rainfall events. MIT is defined such that system flows have returned (or substantially returned) to dry weather flow conditions. For this project, discrete rainfall events were defined based on an MIT of 12 hours. During several larger rainfall events, system flows did not substantially return to dry weather flow conditions during the 12-hour MIT. In these cases, rainfall events were utilized in combination for I/I analysis, described in the following sections.

Not all rainfall events are suitable for use in I/I analysis. The rainfall to be used must be large enough to produce a noticeable response in the sewer system (as measured by the flow meter), but small enough that the sewer system does not become surcharged. This is because peak wet weather flow response to rainfall is desired, and this cannot be ascertained during restricted, hydraulic surcharge conditions.

Rainfall events as measured at each rain gauge are summarized in **Table 4-3**. Throughout the monitoring period, fifteen (15) rainfall events were recorded, totaling over nine (9) inches of rain. The rainfall events selected for I/I analysis are identified in the table by shading. Rain gauges were assigned to meter catchments based on Theissen polygons, which relate the spatial location of each rain gauge to each flow meter. Blanks in the table indicate that the rain gauge did not record rainfall. This typically occurred during very small (< 0.01 inch) rainfall events.

Table 4-3: Rainfall Event Summary

Rainfall Event	Total Depth (inches)			Total Duration (hours)		
	Aquatic Center Rain Gauge	Fire Station Rain Gauge	*Water Treatment Plant Rain Gauge	Aquatic Center Rain Gauge	Fire Station Rain Gauge	*Water Treatment Plant Rain Gauge
10/1/2020	-	0.06	-	-	0.25	-
10/2/2020	-	0.02	-	-	0.25	-
10/3/2020	0.02	0.02	-	0.25	0.25	-
10/18/2020	1.16	1.05	-	36	21.5	-
10/20/2020	-	0.10	-	-	2.5	-
10/26/2020	2.61	2.59	-	26	25.75	-
10/28/2020	2.68	2.33	-	25.75	25.75	-
11/10/2020	0.01	-	0.02	0.25	-	5.75
11/14/2020	0.42	0.35	0.54	24.5	25.5	25.25
11/21/2020	0.37	0.35	0.42	24.5	18.75	22
11/23/2020	-	0.01	-	-	0.25	-
11/24/2020	-	0.24	0.73	-	15	15
12/3/2020	-	0.01	-	-	0.25	-
12/11/2020	-	0.54	-	-	10.5	-
12/13/2020	-	0.24	-	-	27.25	-

* The Water Treatment Plant Rain Gauge was replaced on 11/2/2020 due to an unresponsive initial rain gauge at this location.

4.4 Inflow and Infiltration Assessment

Sanitary sewer systems are impacted by I/I that enters the system through cracks in the pipes and manholes or unintended stormwater connections (e.g. downspouts, sump pumps, etc.). I/I into the sanitary sewer system is identified by an increase in sewer flow during and after a rainfall event.

Inflow is observed as a fast flow reaction, corresponding with or immediately following the peak of the rainfall event.

Infiltration is observed as a slower flow reaction. Infiltration is represented in the tail of the wet weather flow reaction and is higher than average dry weather flow. The inflow and infiltration flow components of a typical hydrograph are illustrated in **Figure 4-7**.

The I/I volumes identified from the flow monitoring data were evaluated and ranked. Two (2) I/I volume to rainfall indices were evaluated to eliminate biases in the data to specific meter catchment characteristics, such as large meter catchment area or high lineal feet of pipe. The two indices evaluated were:

- I/I volume (gal) / Rainfall (in)
- I/I volume (gal) / Meter Catchment Area (ac) / Rainfall (in)

These indices were evaluated for each of the selected flow meter location basins and ranked against each index.

Total wet-weather volume was determined by review of the wet weather hydrograph and taking total wet weather flow and subtracting the ADDF, integrated over time during wet weather. Inflow and infiltration were calculated using the same process.

A linear regression relationship between the volume of total I/I, inflow, and infiltration versus total rainfall depth was developed for the selected rainfall events. The linear regression curve obtained from observed data was extrapolated to the 5-year, 6-hour (3.00 inches) event rainfall depths as defined by the Point Precipitation Frequency Estimates reported in *National Oceanic and Atmosphere (NOAA) Atlas 14, Volume 8, Version 2*.

The 5-year, 6-hour event was selected as the event to project I/I volumes against as part of this analyses. Standardization of the I/I indices allow comparison of I/I rates across different meter catchments and across different flow monitoring periods. The projected volumes of total I/I, inflow, and infiltration versus rainfall depth are provided in **Appendix D**. The 5-year, 6-hour event is shown in these volume projections.

There is an existing flow diversion between FM#1 and FM#2. The flow diversion is the third structure upstream from the two meters. During the flow monitoring program, a balloon was inserted into this diversion to direct the flow to only one of the downstream meters. The flow was directed to FM#1.

4.4.1 I/I Volume per Inch of Rainfall Index

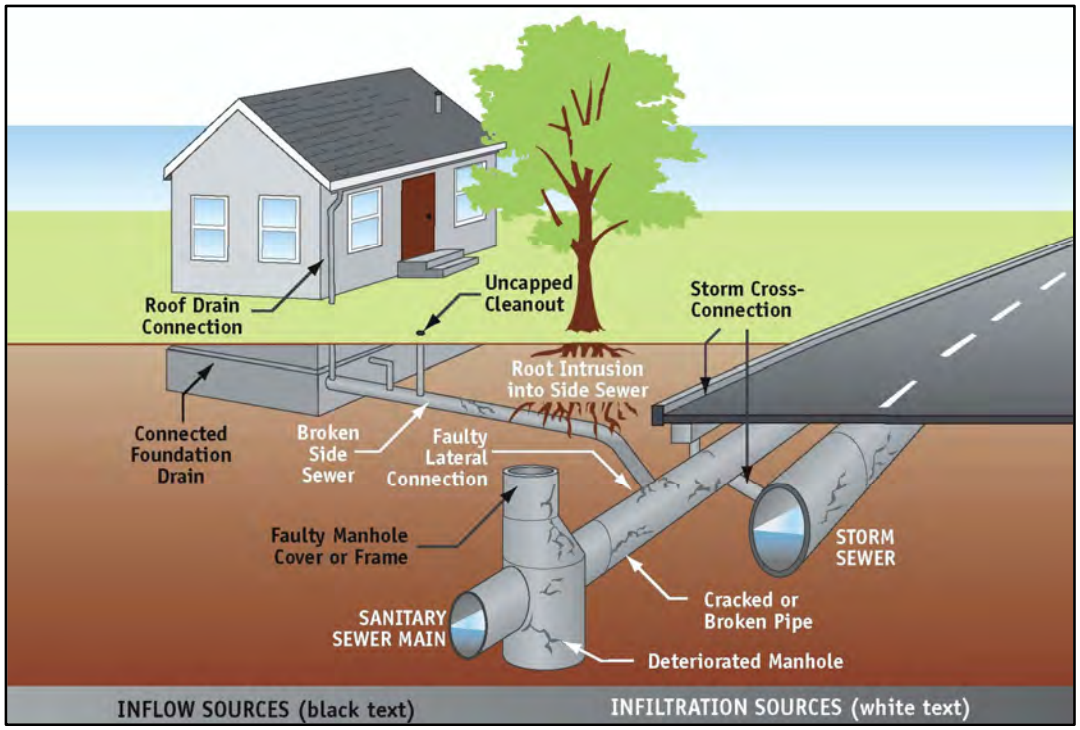
A relationship between I/I volume and rainfall was established for each meter. Total I/I, inflow, and infiltration volumes were calculated and ranked based on incremental volume.

The meter data reflects the cumulative flow observed at the meter location. The incremental volume per meter reflects I/I volume produced by the individual meter catchment. Ideally, flow monitoring would produce positive incremental flows at each subsequent meter location. It is not unusual, however, to have negative incremental flow volumes. This can be due to a variety of reasons such as inherent flow meter inaccuracies, regression curve error, flow attenuation, and limitations in flow measurement/resolution. Higher incremental volumes indicate meter catchments which experience higher I/I. Incremental volumes were also evaluated for inflow and infiltration separately. Meter catchments with high incremental volumes

for inflow indicate surface runoff entering the system through manhole covers, exposed broken pipe, defective pipe joints, cross connections between storm sewers and sanitary sewers, and/or illicit connections of downspouts, area drains, sanitary cleanouts, or storm inlets.

Meter catchments with high incremental infiltration volume indicate groundwater is entering a sewer system through broken pipes and sanitary service laterals, defective pipe joints, or illegal connections of foundation drains. **Figure 4-13** illustrates typical I/I sources for sanitary sewer systems.

Figure 4-13: Typical I/I Sources



Source: King County Department of Natural Resources and Parks

Figure 4-14 illustrates the cumulative and incremental volume of total I/I, inflow, and infiltration (thousand gallons) per inch of rainfall. The schematic represents the wet weather flow generated, defined in volume, that is generated for a 1-inch rainfall event.

Figure 4-14: I/I Volume per Inch of Rainfall – Flow Meter Schematic

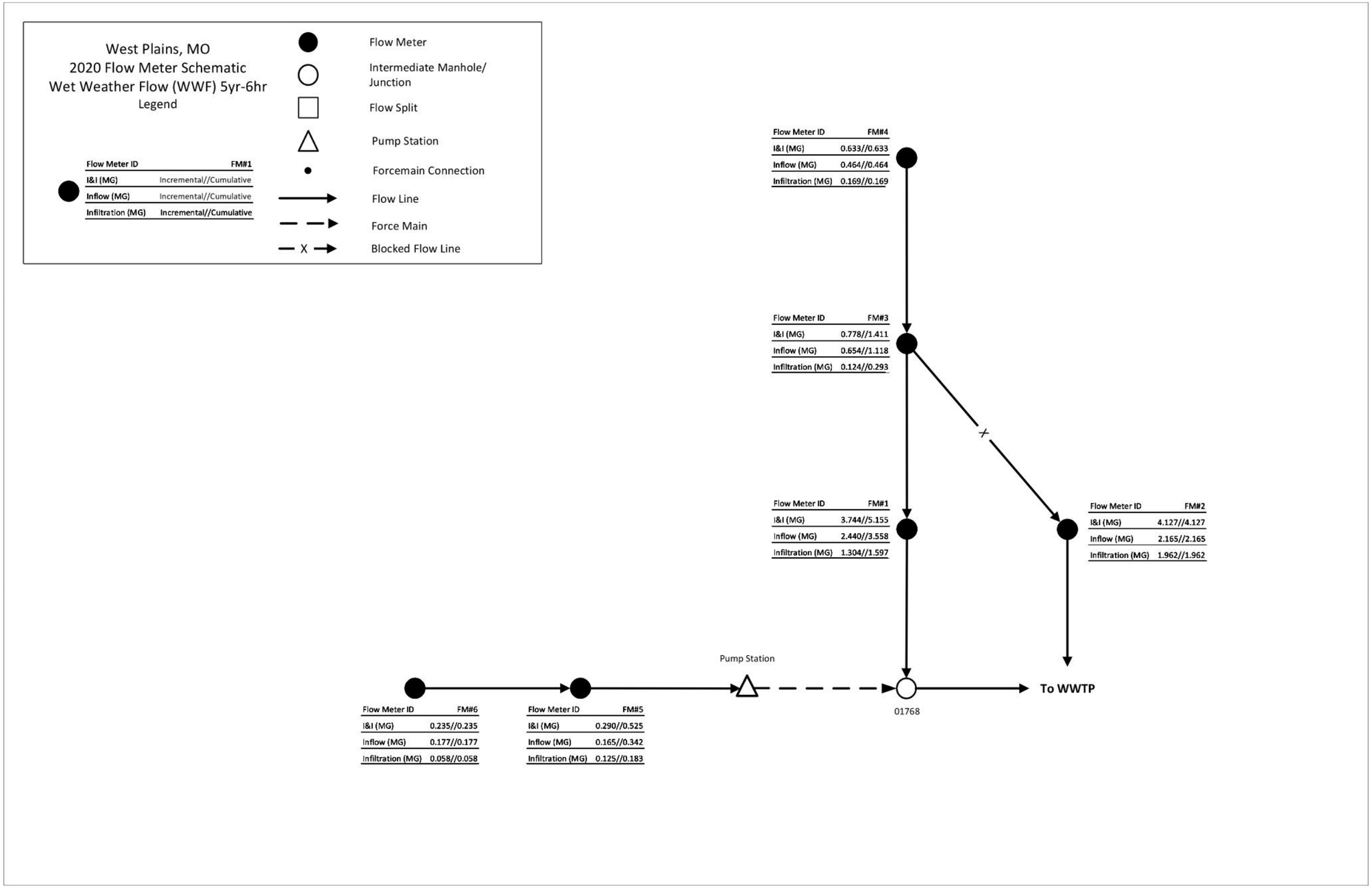


Figure 4-15 through **Figure 4-17** illustrate the meter catchment assessment and ranking. **Appendix E** provides tables detailing the evaluation and ranking.

Figure 4-15: Meter Catchment Rankings – Total I/I Volume per inch of Rainfall

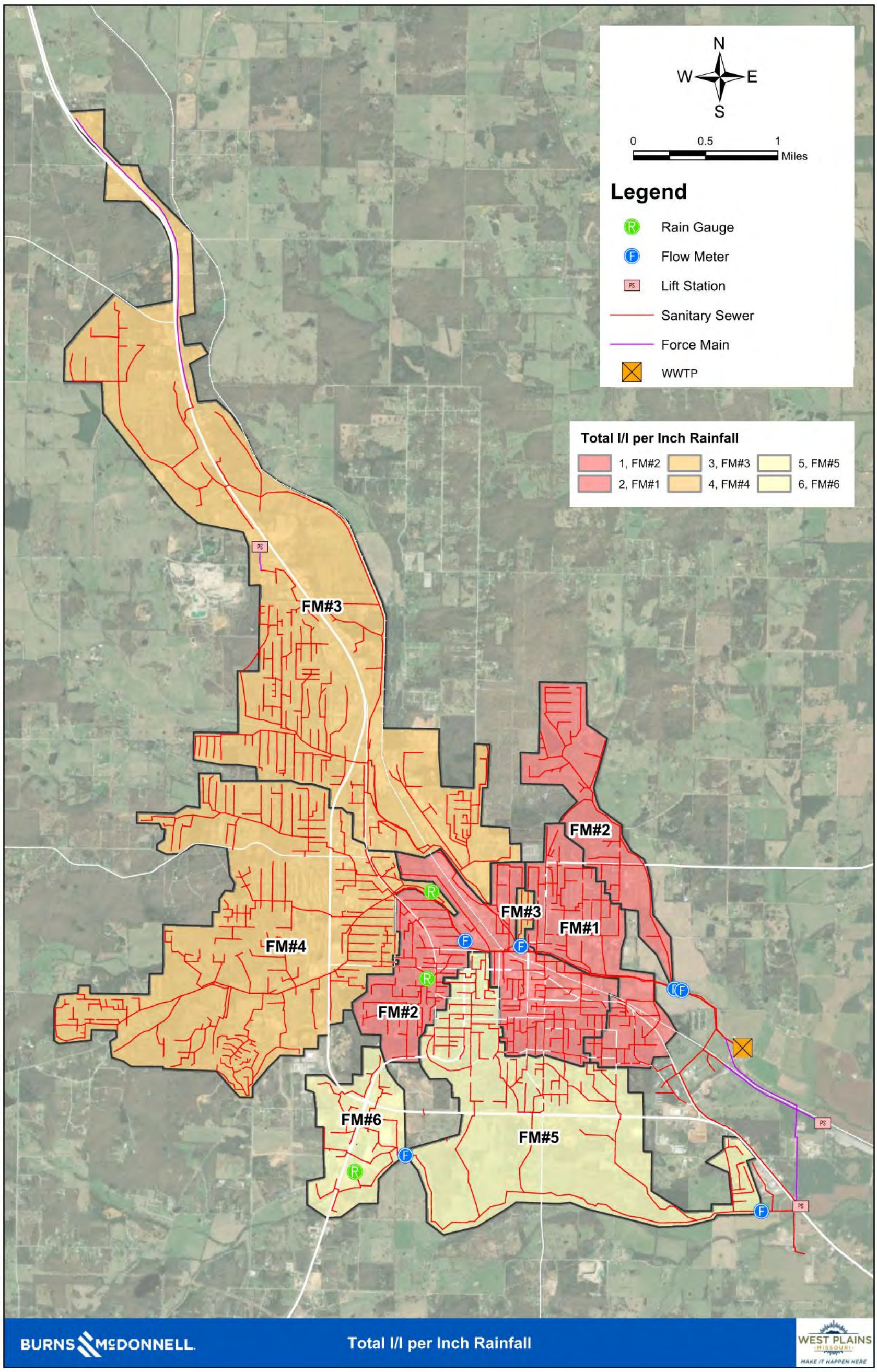


Figure 4-16: Meter Catchment Rankings - Total Inflow Volume per Inch of Rainfall

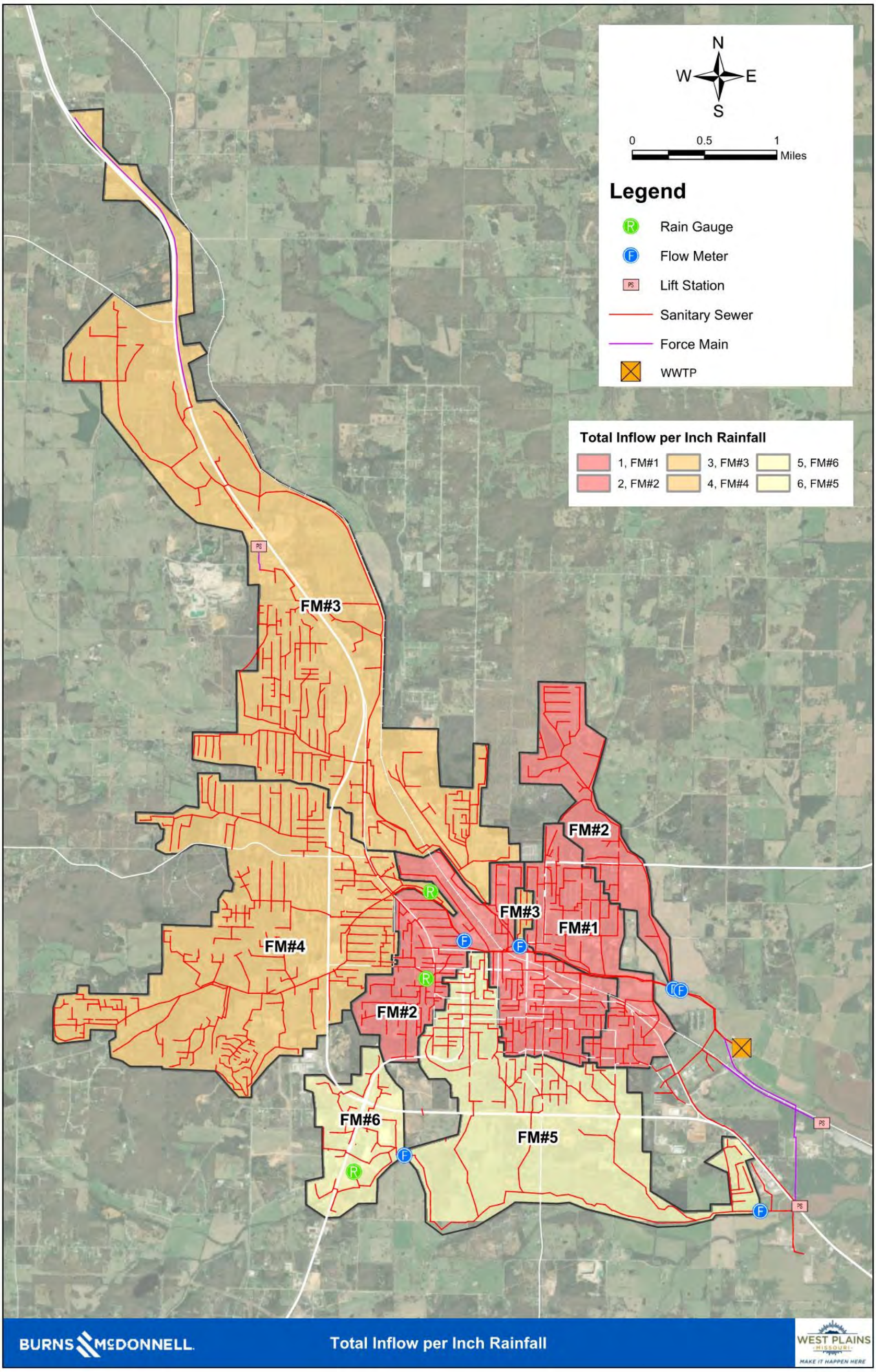
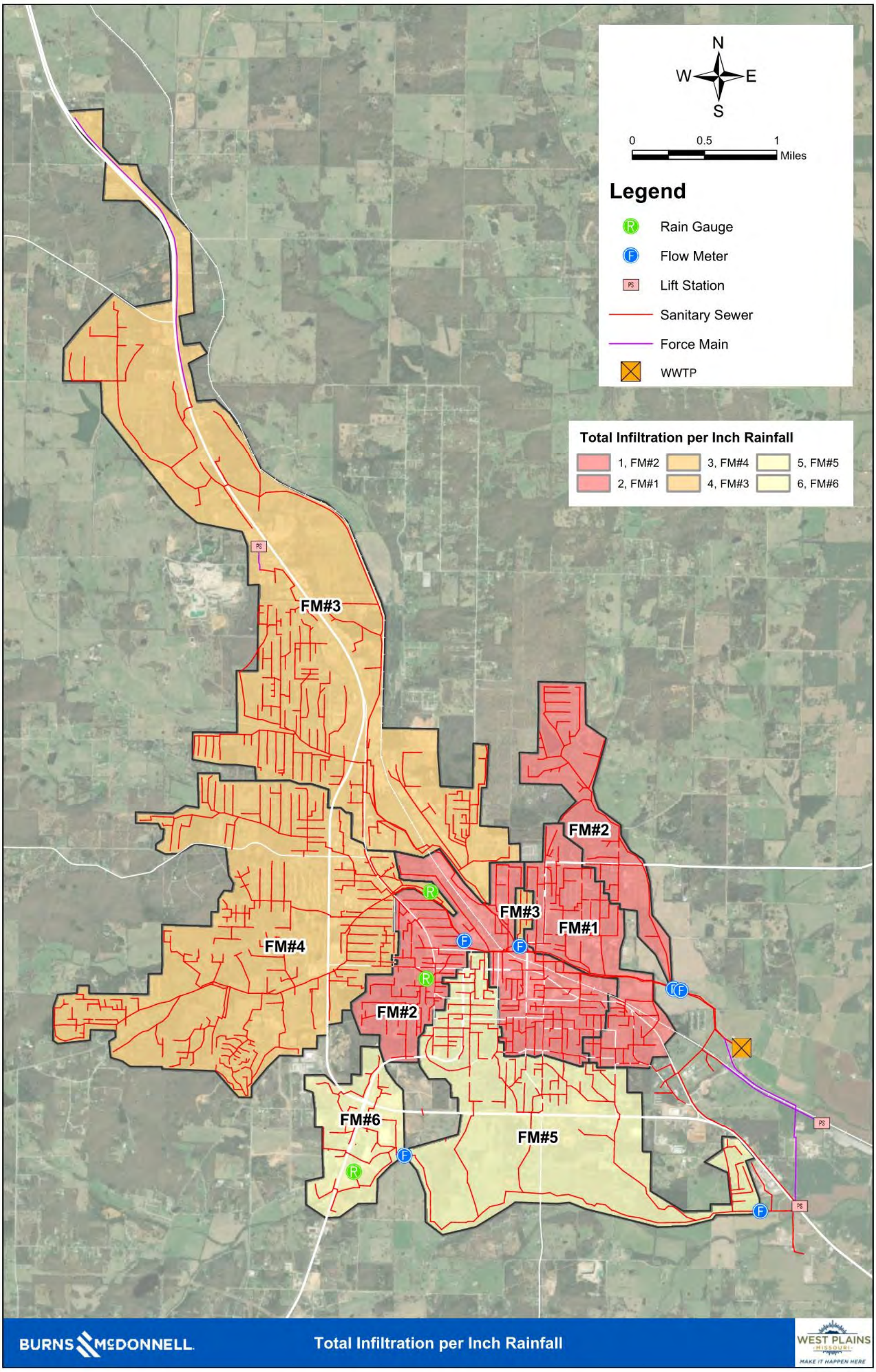


Figure 4-17: Meter Catchment Rankings – Total Infiltration Volume per Inch of Rainfall



4.4.2 Area Index

The volume of I/I is impacted by the surface area of each meter catchment. The surface area of the meter catchment is used to normalize the volume of I/I, inflow, and infiltration to eliminate any biases due to an abnormally large meter catchment. The amount of surface area of each meter catchment determines the volume of surface runoff available to enter the sewer system. I/I volume per acre per inch of rainfall was calculated and ranked for each selected rainfall event. **Figure 4-18** through **Figure 4-20** illustrate the area index rankings. **Appendix E** provides tables detailing the evaluation and ranking.

Figure 4-18: Assessment of I/I per Area per Inch of Rainfall

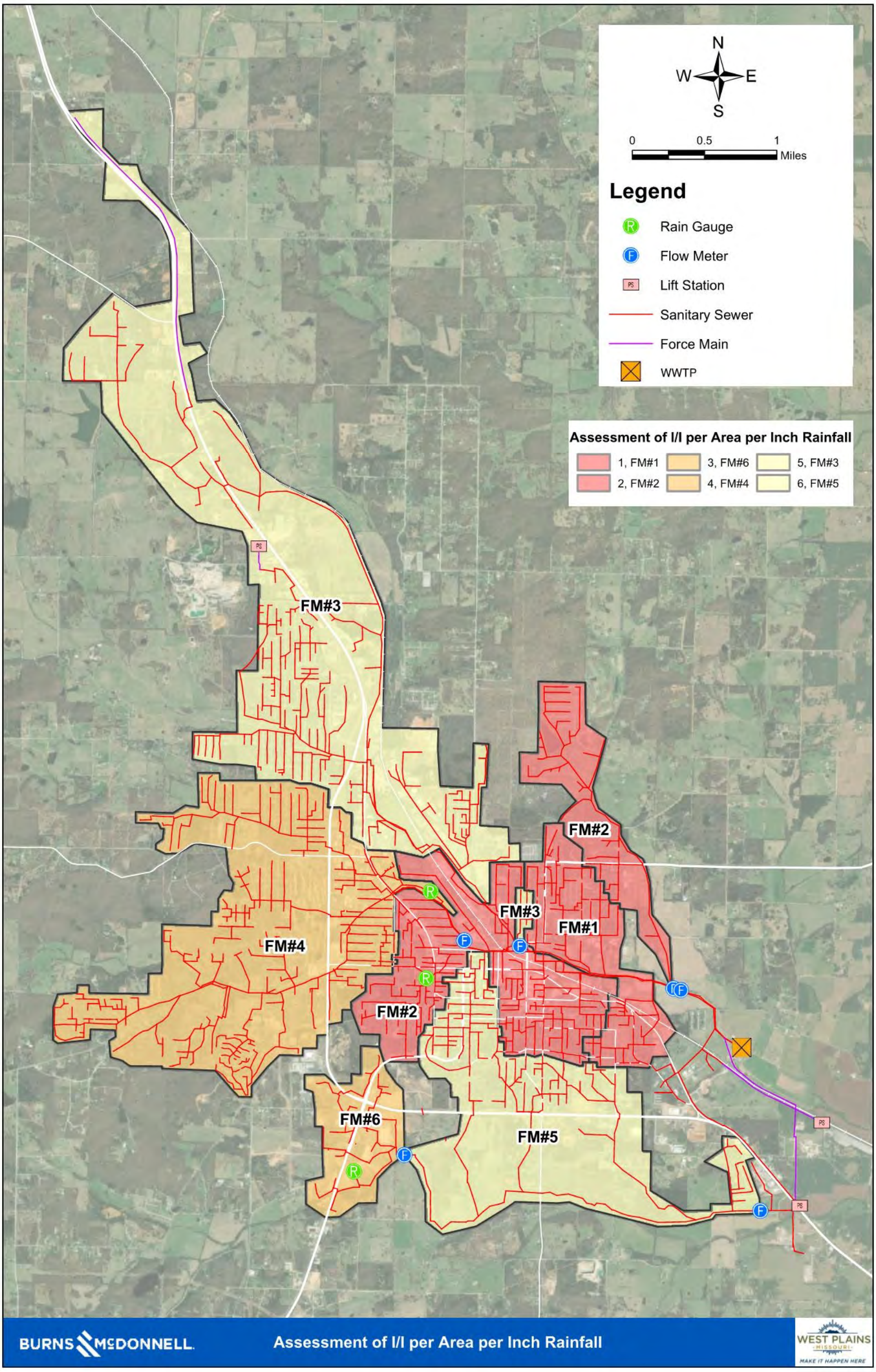


Figure 4-19: Assessment of Inflow per Area per Inch of Rainfall

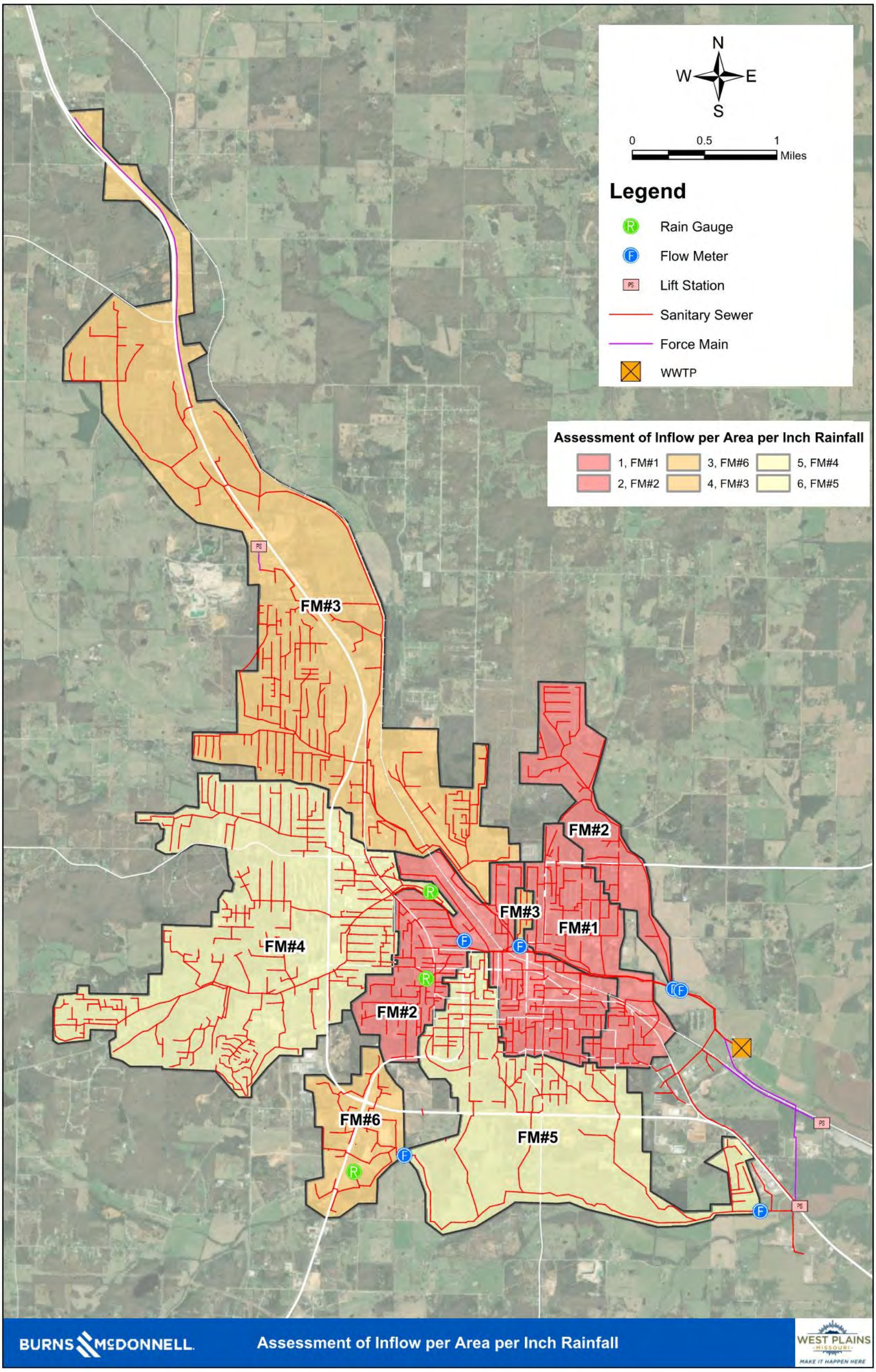
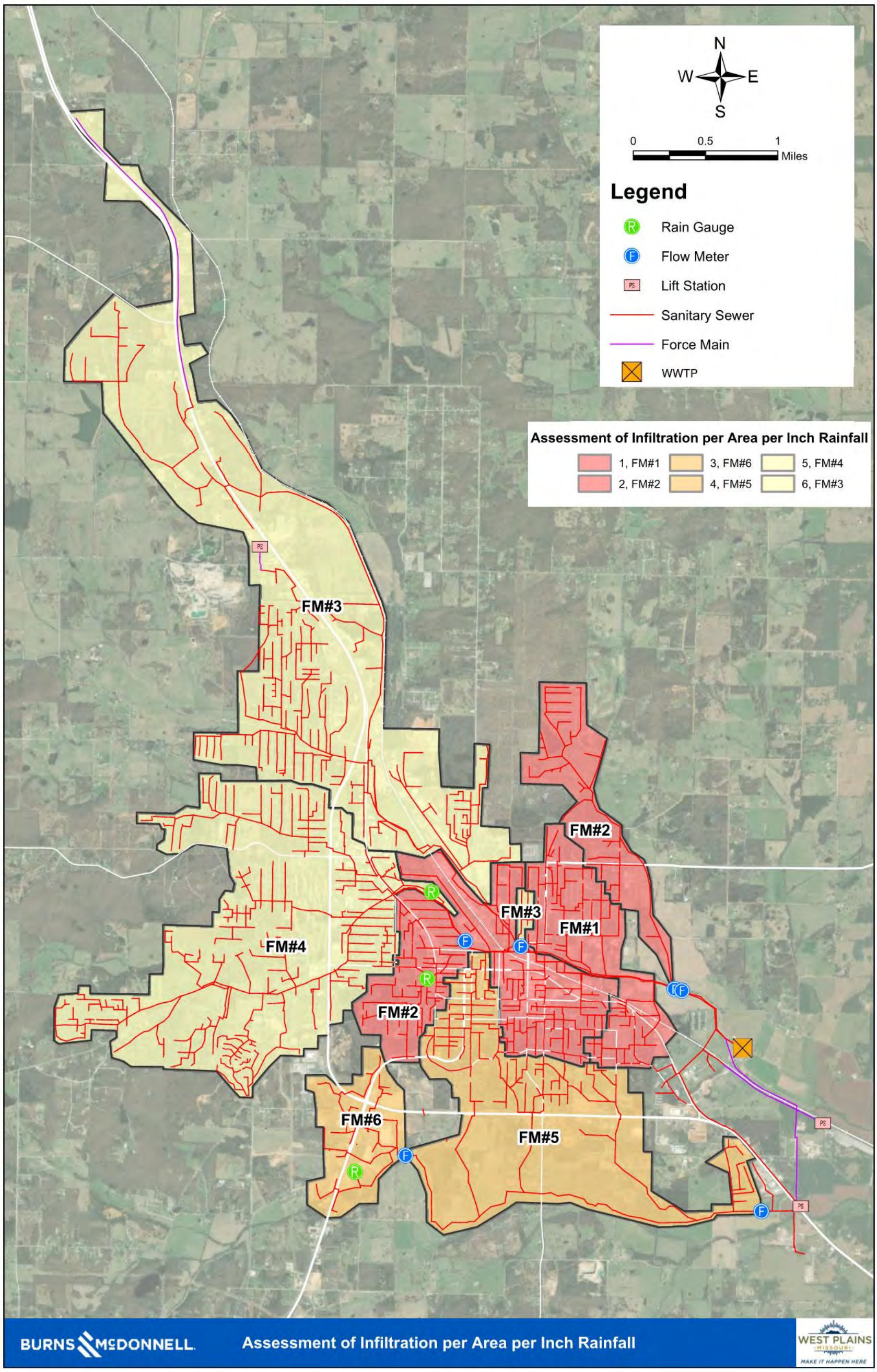


Figure 4-20: Assessment of Infiltration per Area per Inch of Rainfall



4.5 Summary of I/I Assessment

Based on the indices of total I/I volume, inflow volume, and infiltration volume, the individual rankings were cumulated and ranked in descending order to produce an overall rank for each meter catchment. These are outlined in **Table 4-4**. The columns "Total I/I", "Inflow", and "Infiltration" are the cumulated rankings of the two indices for evaluation. Multiple I/I analysis indices were evaluated to decrease the sensitivity of the meter catchment I/I rankings to specific meter catchment characteristics. For example, FM#6 has individual rankings of 6 and 3 for volume of I/I per inch of rainfall and volume of I/I per inch of rainfall per acre, respectively. The sum of these rankings is 9, or the value in column 3, Combined Rankings. The combined I/I rankings were re-ranked to create column 4, I/I Rank. A similar process was applied to the Inflow Rankings and the Infiltration Rankings in columns 5-8. Column 9, Overall Total Rank, is the sum of the Combined Rankings for I/I, Inflow, and Infiltration. The Overall Total Rank was re-ranked to develop column 10, the Overall Rank.

Figure 4-21 shows the overall ranking of I/I volume in the sewer system. Areas of higher I/I are located generally immediately upstream of the WWTP and along Howell Creek. These rankings can be used by the City to prioritize future investigations and development of projects for I/I reduction.

Figure 4-22 shows the overall ranking with total percentages of I/I volume per basin. **Table 4-5** illustrates these percentages of I/I volume per basin. The meter catchments with the highest percentage of total I/I are FM#1 and FM#2, which have significantly more I/I (38% and 42%, respectively) than the next highest meter catchment, FM#3, with just under 8% of the total I/I observed in the collection system.

Table 4-4: Overall Rankings

Flow Meter ID	Basin	Combined I/I Rankings	Rank	Combined Inflow Rankings	Rank	Combined Infiltration Rankings	Rank	Total Rank	Overall Rank
FM#1	FM#1	3	1	2	1	3	1	8	1
FM#2	FM#2	3	1	4	2	3	1	10	2
FM#3	FM#3	8	3	7	3	10	6	25	3
FM#4	FM#4	8	3	9	5	8	3	25	3
FM#6	FM#6	9	5	8	4	9	4	26	5
FM#5	FM#5	11	6	12	6	9	4	32	6

Table 4-5: Total I/I Volume Percentage per Basin

Flow Meter ID	Basin	% of Total I/I
FM#1	FM#1	38.18%
FM#2	FM#2	42.08%
FM#3	FM#3	7.93%
FM#4	FM#4	6.45%
FM#5	FM#5	2.96%
FM#6	FM#6	2.40%

Figure 4-21: Overall Rank

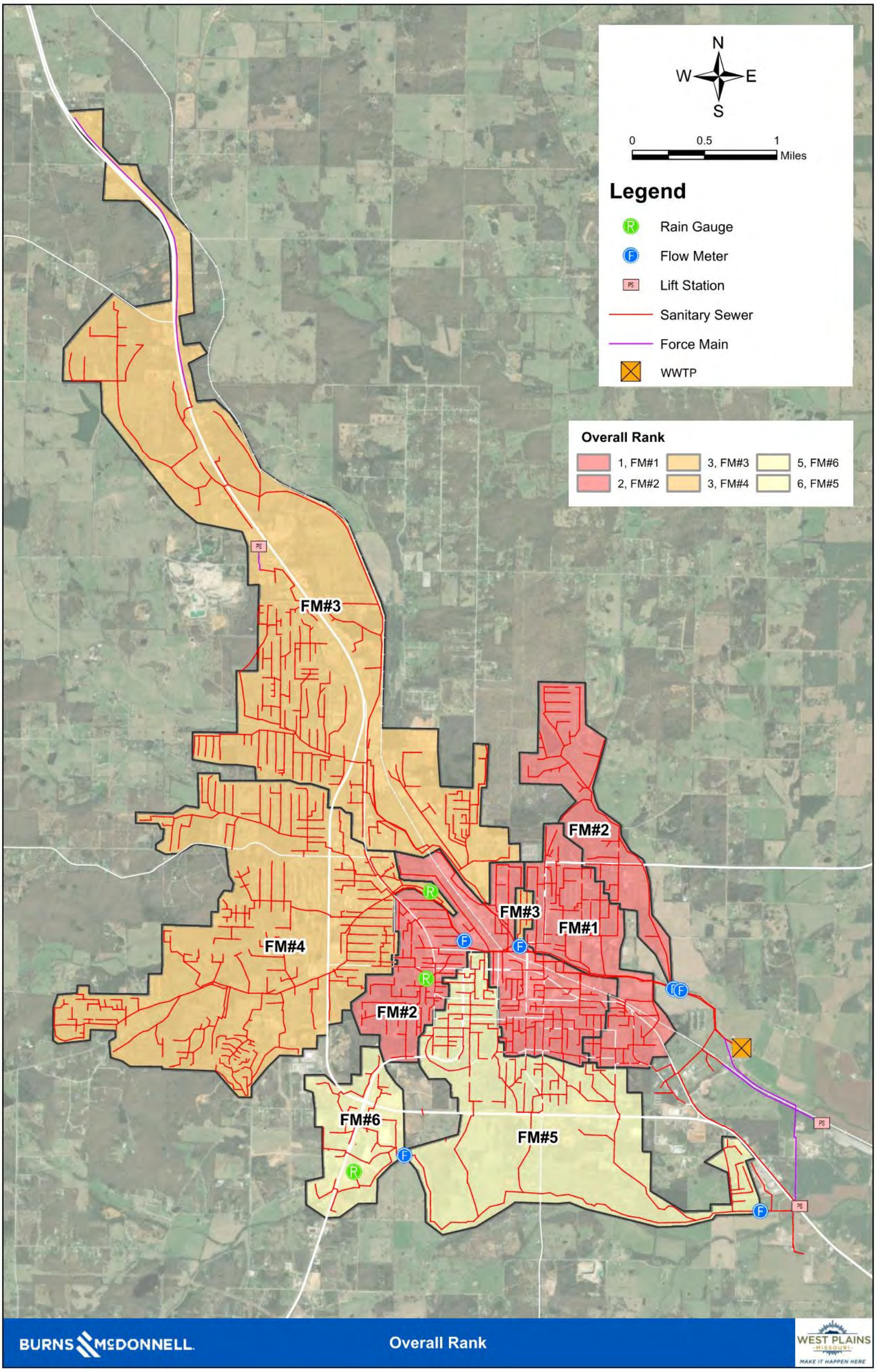
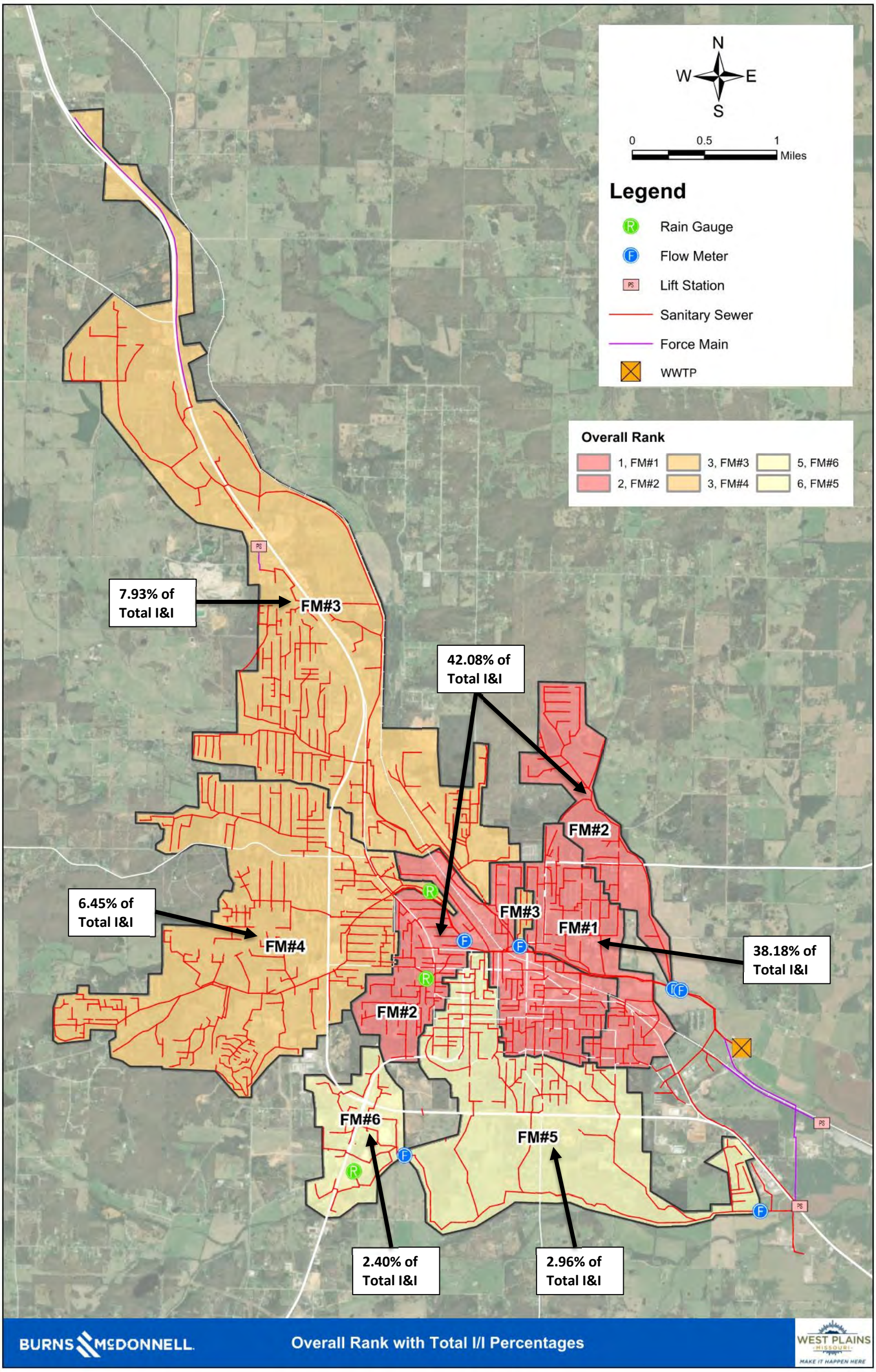


Figure 4-22: Overall Rank with Total I/I Percentages



4.6 Wet Weather Peaking Factors

The flow data was reviewed to evaluate wet weather peaking factors across the system. Volume comparisons as discussed identify the basins that contribute to the greatest amount of I/I that will be required to be treated at the WWTP. Peak flow rates have a greater impact on the ability for the collection system to convey wastewater flows due to capacity restrictions.

Wet weather peak flow was predicted based on the peak hourly flows observed at each meter location for each of the meter catchments. **Table 4-6** illustrates the observed wet weather peak flow and peaking factors for each metered catchment. The metered catchments have been ranked from highest to lowest by wet weather peaking factor, with rank 1 being the highest.

Table 4-6: 5-Year Wet Weather Peaking Factors

Flow Meter ID	Cumulative ADDF (MGD)	Peak Flow (MGD)	Dry Weather Peaking Factor	Wet Weather Peaking Factor	Peaking Factor Rank
FM#1	0.36	6.96	1.63	19.33	1
FM#5	0.11	1.26	1.55	11.74	2
FM#2	0.57	5.16	1.46	9.07	3
FM#3	0.68	5.29	1.63	7.81	4
FM#4	0.43	3.32	2.00	7.74	5
FM#6	0.14	0.97	1.74	7.13	6

Recommended Standards for Wastewater Facilities, 2014 Edition (Ten States Standards) indicates that for communities of the size of the West Plains, peaking factors should be about 2.87. **Table 4-6** indicates that all six (6) meter catchments that were analyzed have higher than recommended peaking factors. Peak flows of this rate can have an impact to the ability to effectively convey wastewater and provide an adequate level of service. Hydraulic grade lines (HGL) should also be evaluated to determine the impact of these peak flows on the collection system; however, a hydraulic model is required to complete this evaluation.

5.0 CONCLUSIONS

5.1 I/I Rankings

The meter catchments were ranked in order of severity of I/I for the purposes of identifying cost-effective locations for proposed sewer improvements and rehabilitation. For comparison, **Table 5-1** presents the top four (4) previously discussed I/I rankings.

Table 5-1: Top Four I/I Rankings

Rank	I/I	Inflow	Infiltration	Total
1	FM#1/FM#2	FM#1	FM#1/FM#2	FM#1
2		FM#2		FM#2
3	FM#3/FM#4	FM#3	FM#4	FM#3/FM#4
4		FM#6	FM#5/FM#6	

Table 5-1 indicates that FM#1 and FM#2 are consistently two of the highest I/I ranked areas. The remaining metered areas typically show either a low or medium level of inflow or infiltration. This results in a distinct gap between the levels of I/I from the meter basins for FM#1, FM#2, and the remaining meter basins.

6.0 NEXT STEPS MOVING FORWARD

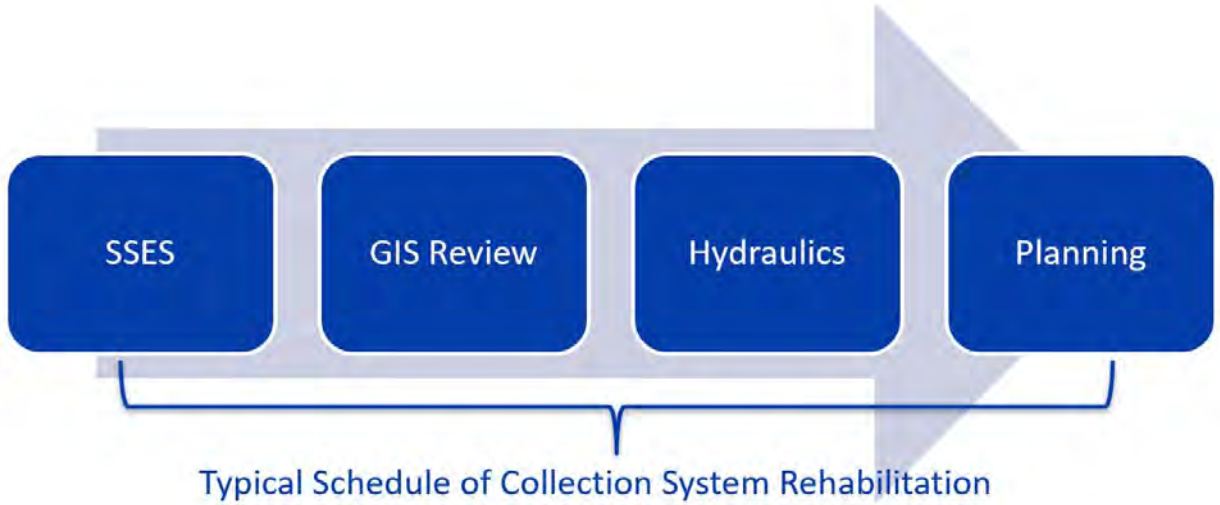
Following completion of a flow monitoring program, it is recommended that an I/I Strategic Plan is developed. An I/I Strategic Plan utilizes the data analyzed in the flow monitoring program to lay out a definitive list of steps to address and reduce I/I observed within the collection system. A brief summary of specific items that would be further detailed in an I/I Strategic Plan are discussed below. Further consultation with the City would be required to identify specific action items and a path forward that is within the means of the City to complete based on available resources, budget, and needs of the collection system.

6.1 Typical Schedule of Collection System Rehabilitation

The typical schedule for collection system rehabilitation is illustrated in **Figure 6-1**, which shows potential I/I reduction steps that would be identified in an I/I Strategic Plan. These include, but are not limited to:

- Sanitary Sewer Evaluation Surveys (SSES) which include smoke testing, National Association of Sewer Services Companies (NASSCO) manhole condition assessments, NASSCO Closed-Circuit Television (CCTV), and dye flood tracing.
- A review of the City's GIS database would take place to determine if any key pieces of data are missing and how this data could be used more effectively for city employees and the community.
- A hydraulic model would be developed to illustrate the current conditions of the wastewater collection system and to identify potential problematic sources in the system, such as bottlenecks.
- The planning component of this schedule would include consulting services to work with the City to develop a formal I/I Strategic Plan.

Figure 6-1: Typical Schedule of Collection System Rehabilitation



6.2 Cost for Collection System Investigation

The cost for further collection system investigation for the City has been approximated in **Table 6-1**. The cost for each individual flow meter basin has been broken down by categories. General assumptions for this preliminary cost estimate include:

- Three types of SSES are included in this cost estimate: manhole inspection, smoke testing, and CCTV/dye flooding.
- The costs for manhole inspections are system wide, encompassing every manhole in each basin. The smoke testing costs per basin are also system wide.
- The costs for CCTV and dye flooding covers 25% of the length of pipes in the system.
- The model development cost per basin includes a sewer interceptor model for pipes 12-inches and greater.
- The planning cost per basin includes system wide asset ranking and rehabilitation selection.

Table 6-1: Cost for Collection System Investigation

Flow Meter Basin	Overall I/I Rank	Manhole Inspection	Smoke Testing	CCTV & Dye Flooding	Model Development	Consulting Services (Planning)	Total Cost
FM#1	1	$29,875	$28,750	$39,540	$10,000	$20,000	$128,165
FM#2	2	$61,500	$78,970	$108,580	$10,000	$15,000	$274,050
FM#3	3	$86,375	$86,560	$119,020	$10,000	$15,000	$316,955
FM#4	4	$102,250	$78,720	$108,240	$10,000	$15,000	$314,210
FM#6	5	$49,875	$49,960	$68,700	$10,000	$15,000	$193,535
FM#5	6	$16,875	$12,000	$16,500	$10,000	$15,000	$70,375
Subtotals		$346,750	$334,960	$460,580	$60,000	$95,000	
						Grand Total	**$1,297,000**

By combining the components outlined above for a successful I/I reduction program and utilizing the City's budget of approximately $750,000 per year for I/I reduction activities, an I/I Strategic Plan can be developed to outline steps required to work towards reducing observed I/I within the existing collection system and provide tools for the City to make informed decisions in the future in regard to collection system rehabilitation.

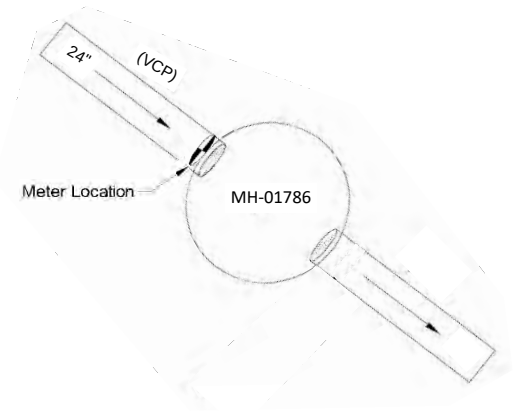
APPENDIX A - FLOW METER SITE SHEETS

Flow Meter Site Installation

Project #:	Location:	Date/Time:	Crew:
126220	West Plains, MO	10/1/2020	SDJ, SLJ
MH#:	**Pipe Shape:**	**Pipe Material:**	**Pipe Size (in):**
01786	Circular	VCP	24
Site ID:	**Address:**	**Site Quality:**	**Basin:**
FM#1	1002 Bratton Ave	Good	FM#1

Location Map

Planar Description



Describe MH Location

(Roadway, Easement, Field, Sidewalk)

Easement - North of fence along creek

Site Hazards		Measurements		Site Conditions	
Heavy Traffic?	No	**Manhole Depth (ft):**	10	**Surcharge Evidence?**	Yes
H2S: 12	O: 20.2	**Measured Flow Depth (in):**	5.1	**Depth of Surcharge (ft):**	3
LEL: 0	CO: 2	**Manhole Dia (in):**	48	**Depth of Debris (in):**	---
Describe potential hazards:		**Measured Velocity (fps):**	1.25	Meter: 2102	
Air blower used		**Comments:**			

Flow Meter Site Installation

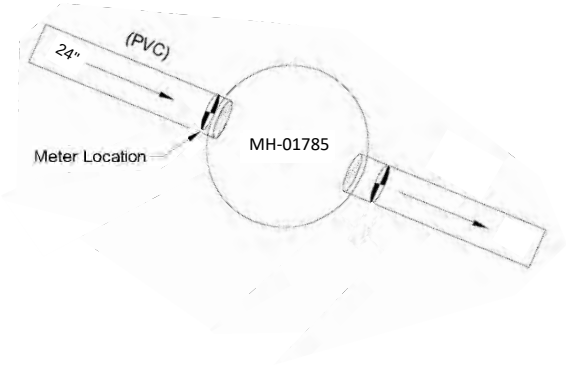
Area	Pipe Size
Measured Flow Depth	**Installation**

Flow Meter Site Installation

Project #:	Location:	Date/Time:	Crew:
126220	West Plains, MO	10/1/2020	SDJ, SLJ
MH#:	**Pipe Shape:**	**Pipe Material:**	**Pipe Size (in):**
01785	Circular	PVC	24
Site ID:	**Address:**	**Site Quality:**	**Basin:**
FM#2	1002 Bratton Ave	Good	FM#2

Location Map

Planar Description



Describe MH Location

(Roadway, Easement, Field, Sidewalk)

Easement - south of fence along creek

Site Hazards		Measurements		Site Conditions	
Heavy Traffic?	No	**Manhole Depth (ft):**	11	**Surcharge Evidence?**	Yes
H2S: 6	O: 20.6	**Measured Flow Depth (in):**	6.5	**Depth of Surcharge (ft):**	8
LEL: 0	CO: 0	**Manhole Dia (in):**	48	**Depth of Debris (in):**	---
Describe potential hazards:		**Measured Velocity (fps):**	2	Meter: 2624	
		Comments:			

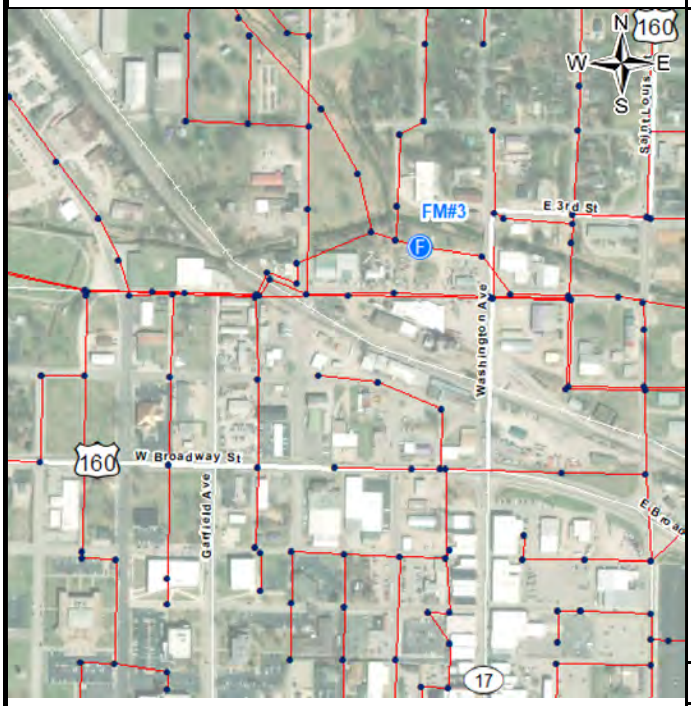
Flow Meter Site Installation

Area	Pipe Size
Measured Flow Depth	**Installation**

Flow Meter Site Installation

Project #:	Location:	Date/Time:	Crew:
126220	West Plains, MO	10/1/2020	SDJ, SLJ
MH#:	**Pipe Shape:**	**Pipe Material:**	**Pipe Size (in):**
02662	Circular	PVC	24
Site ID:	**Address:**	**Site Quality:**	**Basin:**
FM#3	701 Washington Ave	Good	FM#3

Location Map



Planar Description

Describe MH Location

(Roadway, Easement, Field, Sidewalk)

Easement - graveled parking lot

Site Hazards		Measurements		Site Conditions	
Heavy Traffic?	No	**Manhole Depth (ft):**	14.2	**Surcharge Evidence?**	No
H2S: 0	O: 20.8	**Measured Flow Depth (in):**	8.25	**Depth of Surcharge (ft):**	0
LEL: 0	CO: 4	**Manhole Dia (in):**	48	**Depth of Debris (in):**	---
Describe potential hazards:		**Measured Velocity (fps):**	1.75	Meter: 0870	
		Comments:			

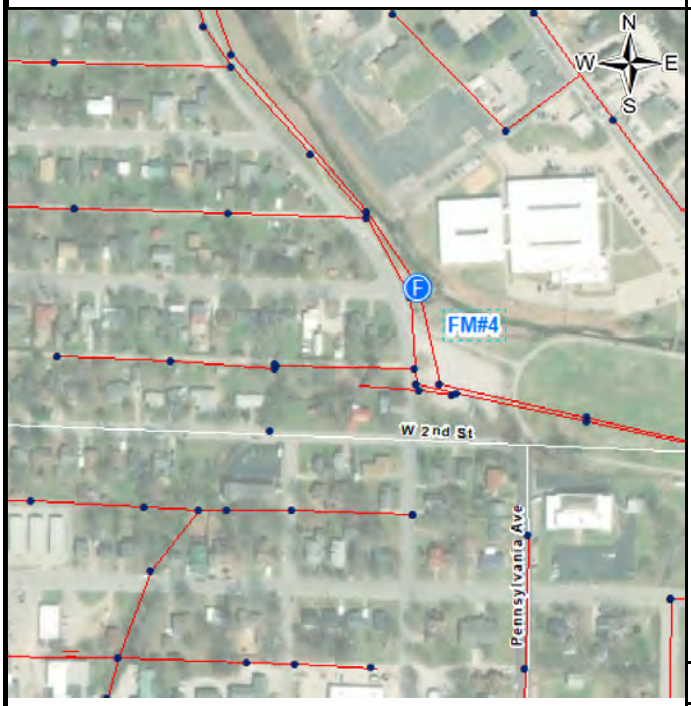
Flow Meter Site Installation

Area	Pipe Size
Measured Flow Depth	**Installation**

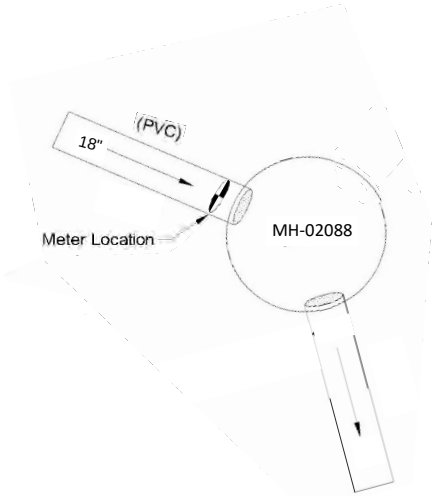
Flow Meter Site Installation

Project #:	Location:	Date/Time:	Crew:
126220	West Plains, MO	10/1/2020	SDJ, SLJ
MH#:	**Pipe Shape:**	**Pipe Material:**	**Pipe Size (in):**
02088	Circular	PVC	18
Site ID:	**Address:**	**Site Quality:**	**Basin:**
FM#4	1004 W 3rd St	Good	FM#4

Location Map



Planar Description



Describe MH Location

(Roadway, Easement, Field, Sidewalk)

Easement - grass

Site Hazards		Measurements		Site Conditions	
Heavy Traffic?	No	**Manhole Depth (ft):**	12	**Surcharge Evidence?**	Yes
H2S: 0	O: 20.4	**Measured Flow Depth (in):**	10.2	**Depth of Surcharge (ft):**	4.5
LEL: 0	CO: 3	**Manhole Dia (in):**	48	**Depth of Debris (in):**	---
Describe potential hazards:		**Measured Velocity (fps):**	1.2	Meter: 0867	
		Comments:			

Flow Meter Site Installation

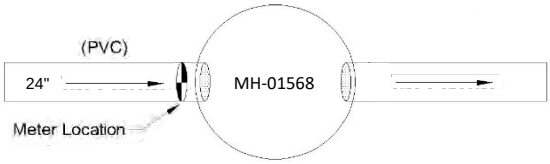
Area	Pipe Size
Measured Flow Depth	**Installation**

Flow Meter Site Installation

Project #:	Location:	Date/Time:	Crew:
126220	West Plains, MO	10/1/2020	SDJ, SLJ
MH#:	**Pipe Shape:**	**Pipe Material:**	**Pipe Size (in):**
01568	Circular	PVC	24
Site ID:	**Address:**	**Site Quality:**	**Basin:**
FM#5	1809 US Hwy 63	Good	FM#5

Location Map

Planar Description



Describe MH Location

(Roadway, Easement, Field, Sidewalk)

Easement - field

Site Hazards		Measurements		Site Conditions	
Heavy Traffic?	No	**Manhole Depth (ft):**	8	**Surcharge Evidence?**	Yes
H2S: 0	O: 20.8	**Measured Flow Depth (in):**	3	**Depth of Surcharge (ft):**	4
LEL: 0	CO: 1	**Manhole Dia (in):**	48	**Depth of Debris (in):**	---
Describe potential hazards:		**Measured Velocity (fps):**	1	Meter: 0870	
		Comments:			

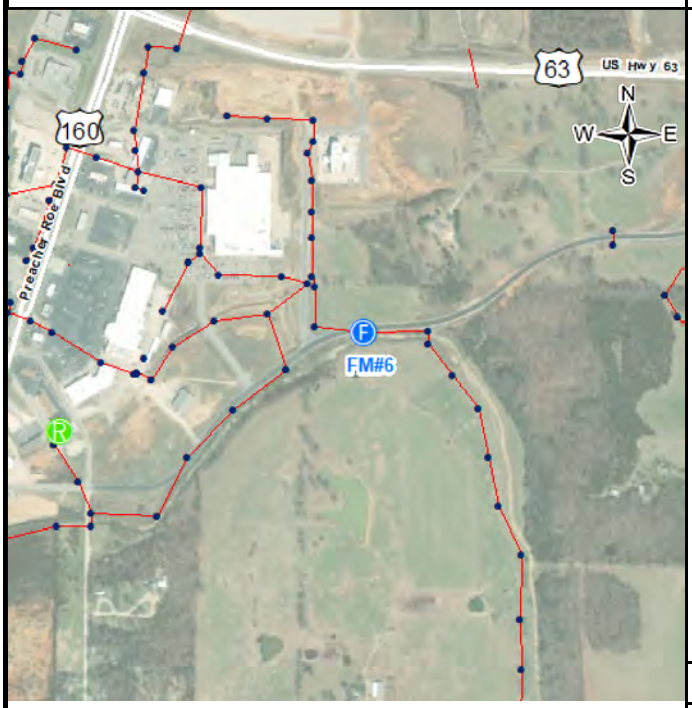
Flow Meter Site Installation

Area	Pipe Size
Measured Flow Depth	**Installation**

Flow Meter Site Installation

Project #:	Location:	Date/Time:	Crew:
126220	West Plains, MO	10/15/2020	SDJ, SLJ
MH#:	**Pipe Shape:**	**Pipe Material:**	**Pipe Size (in):**
01454	Circular	PVC	18
Site ID:	**Address:**	**Site Quality:**	**Basin:**
FM#6	1365 Ramseur Rd	Good	FM#6

Location Map



Planar Description

Describe MH Location

(Roadway, Easement, Field, Sidewalk)

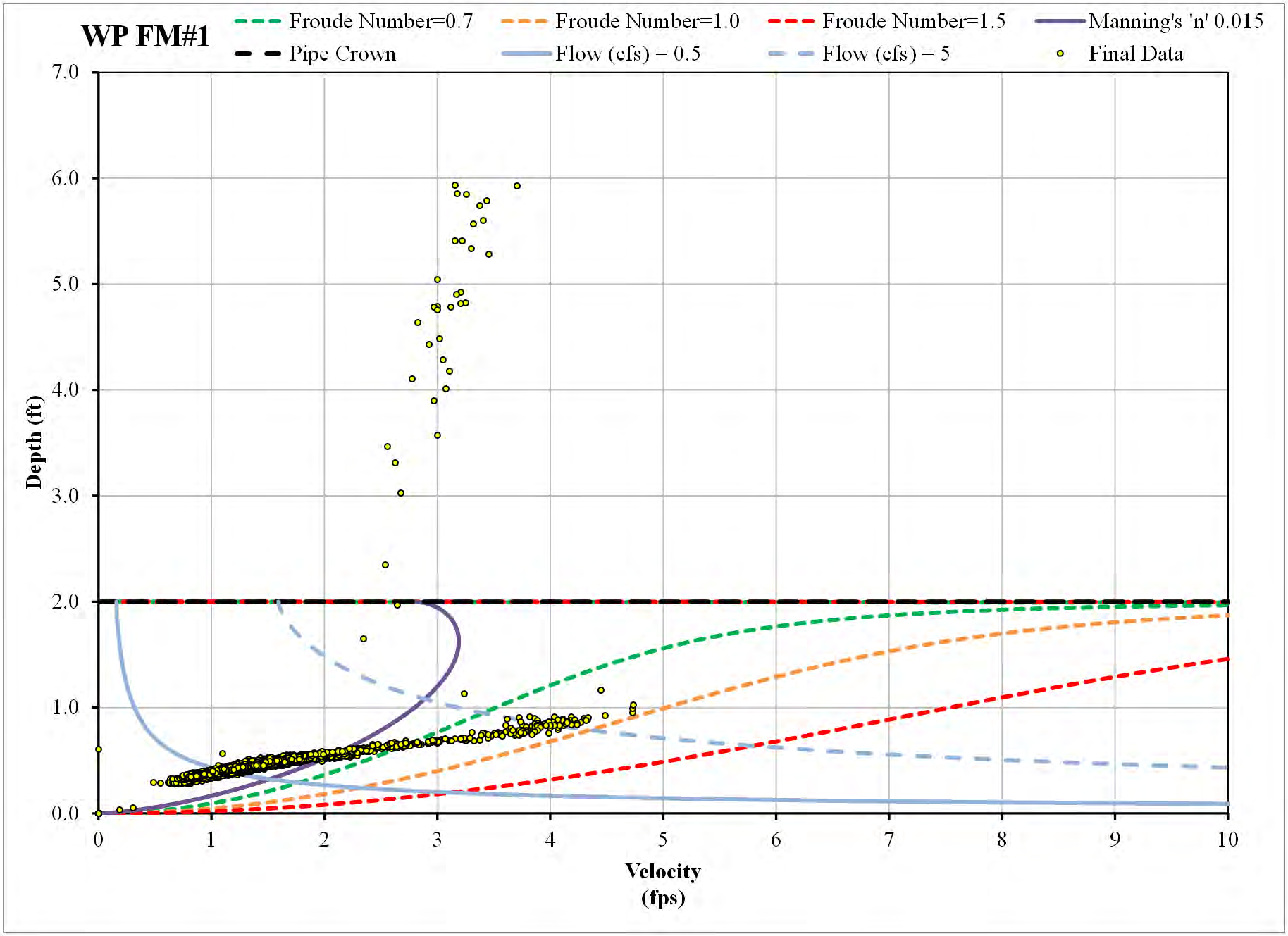
Roadway - Asphalt cover

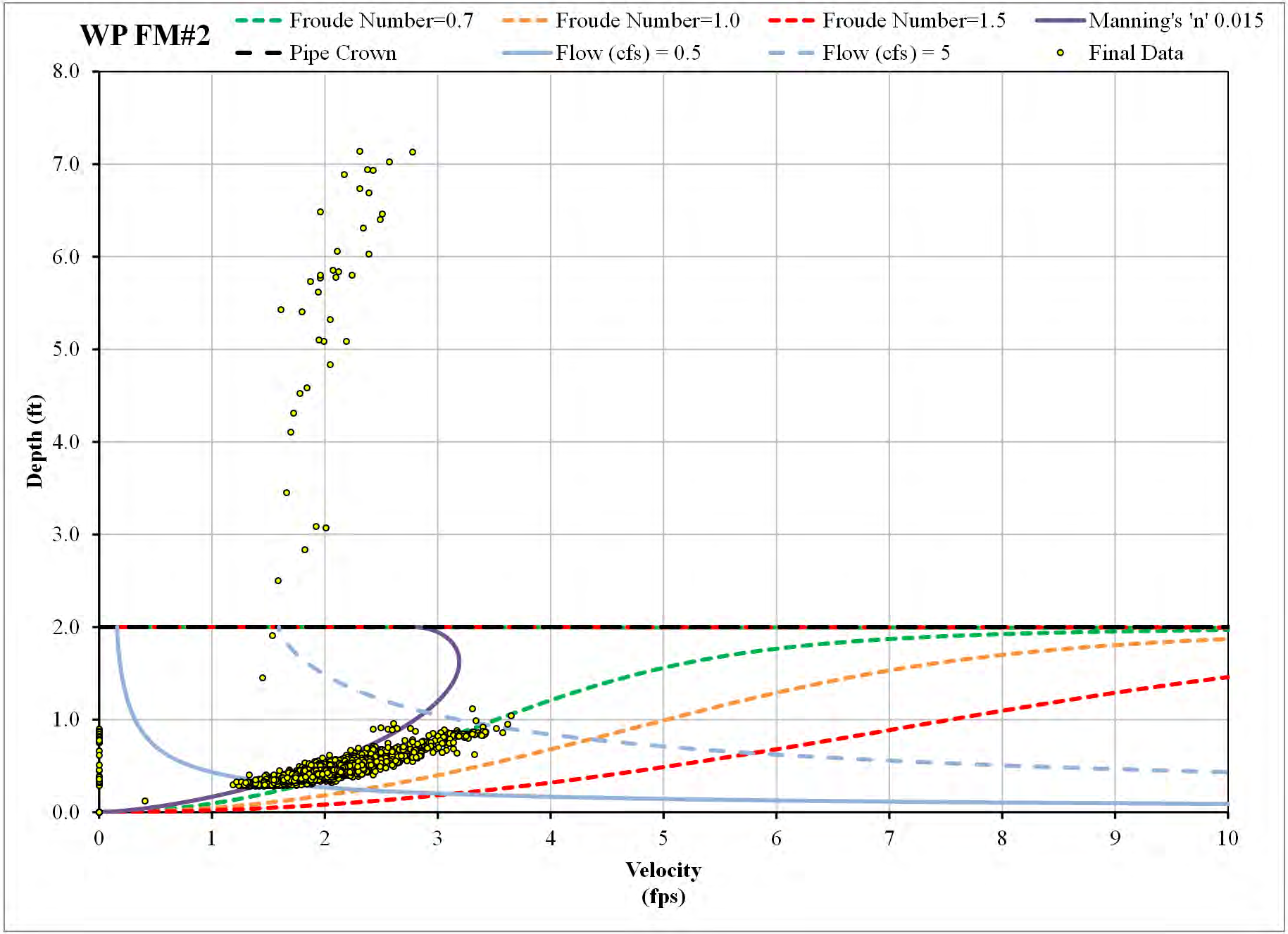
Site Hazards		Measurements		Site Conditions	
Heavy Traffic?	Yes	**Manhole Depth (ft):**	9	**Surcharge Evidence?**	No
H2S: 0	O: 20.6	**Measured Flow Depth (in):**	2.25	**Depth of Surcharge (ft):**	0
LEL: 2	CO: 4	**Manhole Dia (in):**	48	**Depth of Debris (in):**	---
Describe potential hazards:		**Measured Velocity (fps):**	3.4	Meter: 0875	
		Comments:			

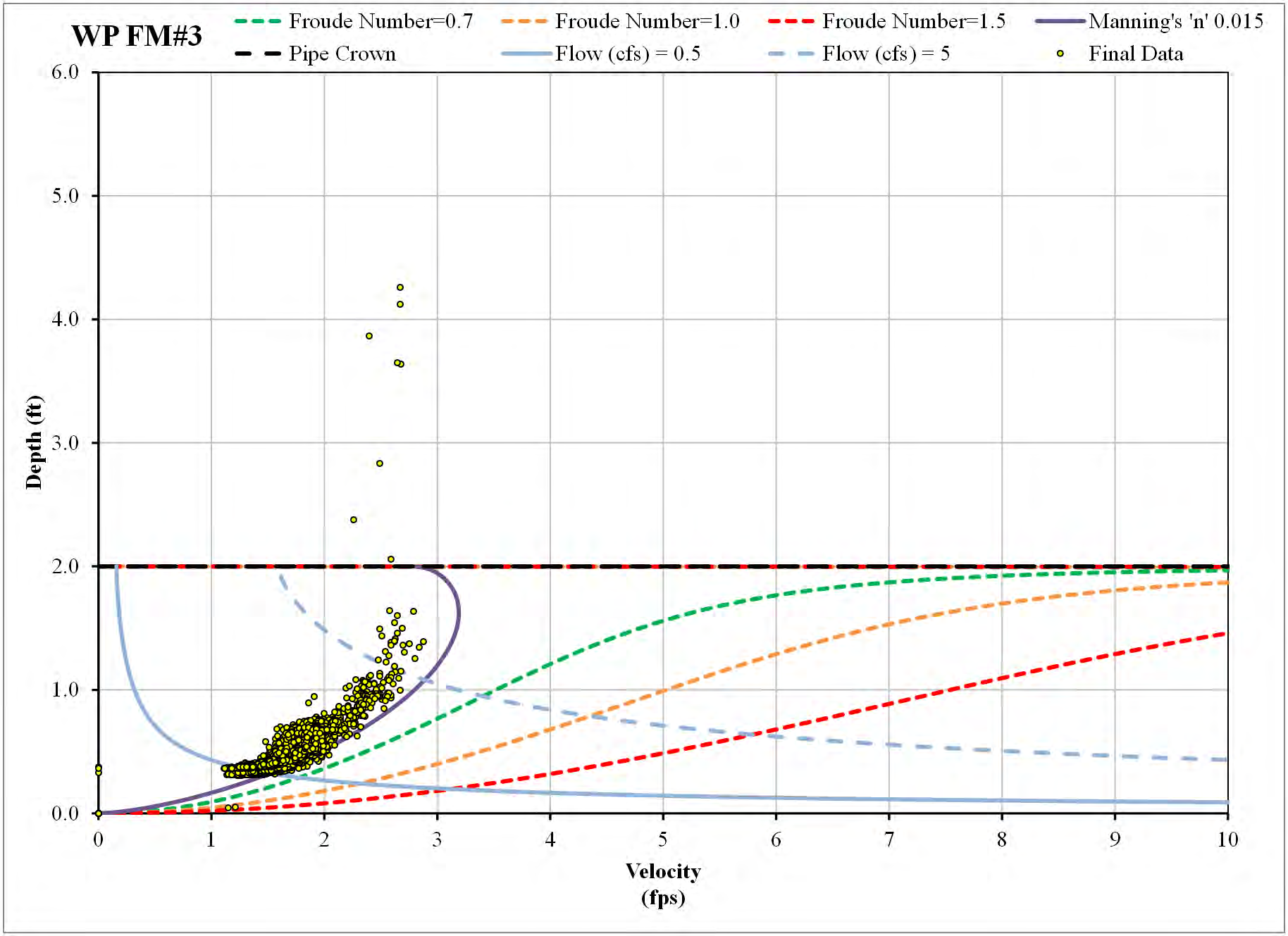
Flow Meter Site Installation

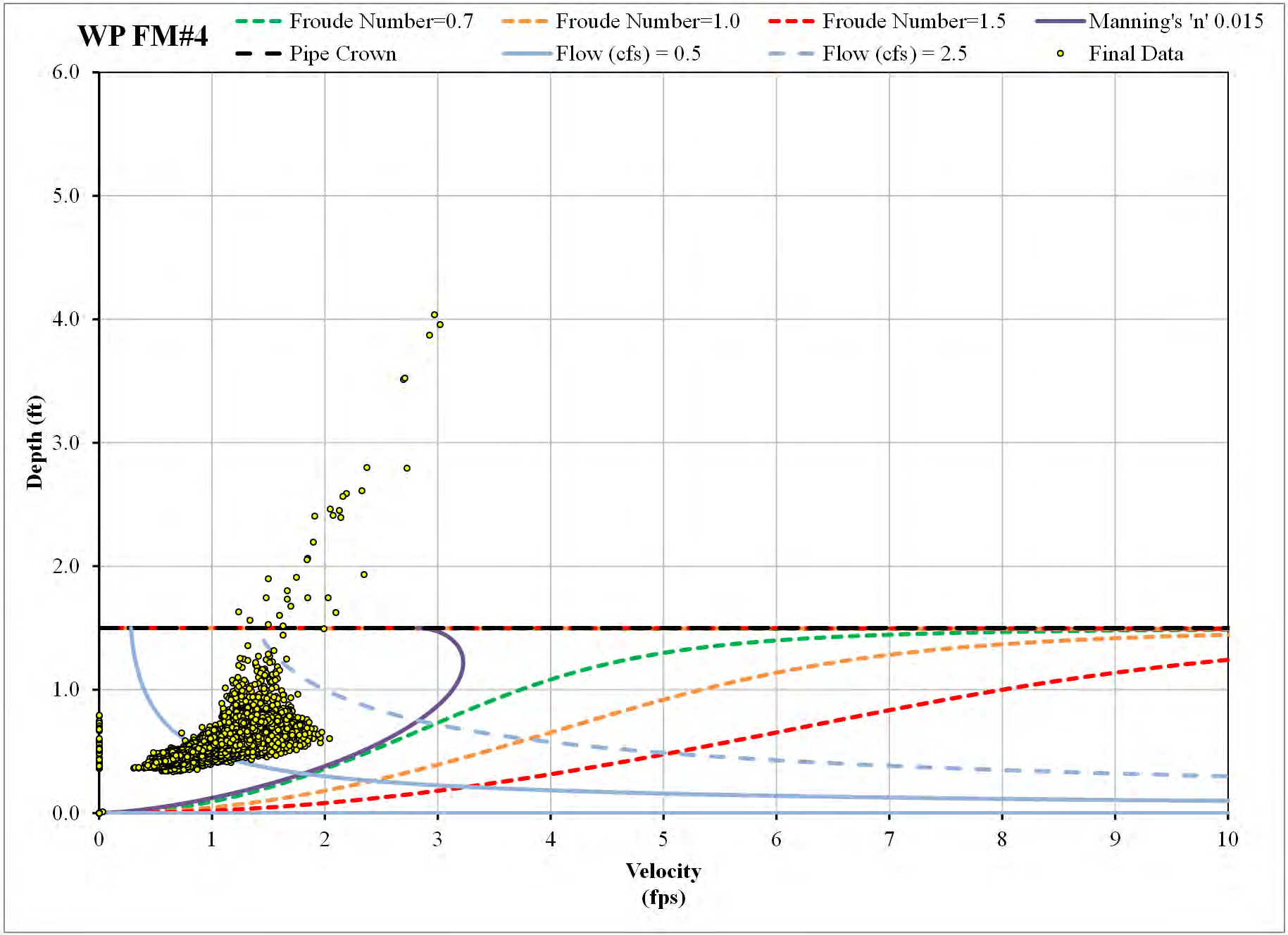
Area	Pipe Size
Measured Flow Depth	**Installation**

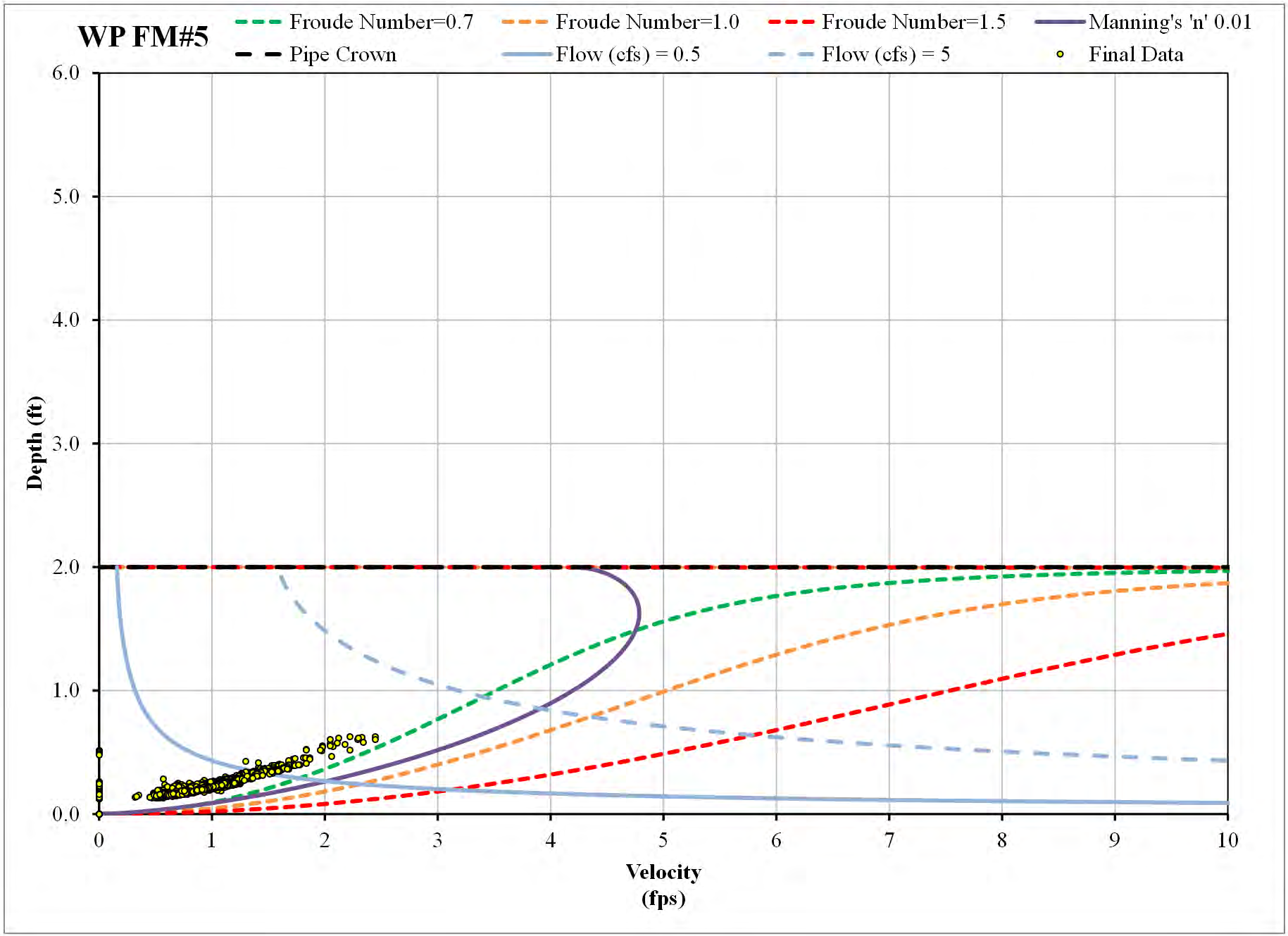
APPENDIX B – SCATTER GRAPH


WP FM#1
Froude Number=0.7
Froude Number=1.0
Froude Number=1.5
Manning's 'n' 0.015
Pipe Crown
Flow (cfs) = 0.5
Flow (cfs) = 5
Final Data
Depth (ft)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
Velocity
(fps)


WP FM#2
Froude Number=0.7
Froude Number=1.0
Froude Number=1.5
Manning's 'n' 0.015
Pipe Crown
Flow (cfs) = 0.5
Flow (cfs) = 5
Final Data
Depth (ft)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
Velocity
(fps)


WP FM#3
Froude Number=0.7
Froude Number=1.0
Froude Number=1.5
Manning's 'n' 0.015
Pipe Crown
Flow (cfs) = 0.5
Flow (cfs) = 5
Final Data
Depth (ft)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
Velocity
(fps)


WP FM#4
Froude Number=0.7
Froude Number=1.0
Froude Number=1.5
Manning's 'n' 0.015
Pipe Crown
Flow (cfs) = 0.5
Flow (cfs) = 2.5
Final Data
Depth (ft)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
Velocity
(fps)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Froude Number=0.7
Froude Number=1.0
Froude Number=1.5
Manning's 'n' 0.01
Pipe Crown
Flow (cfs) = 0.5
Flow (cfs) = 5
Final Data
Depth (ft)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
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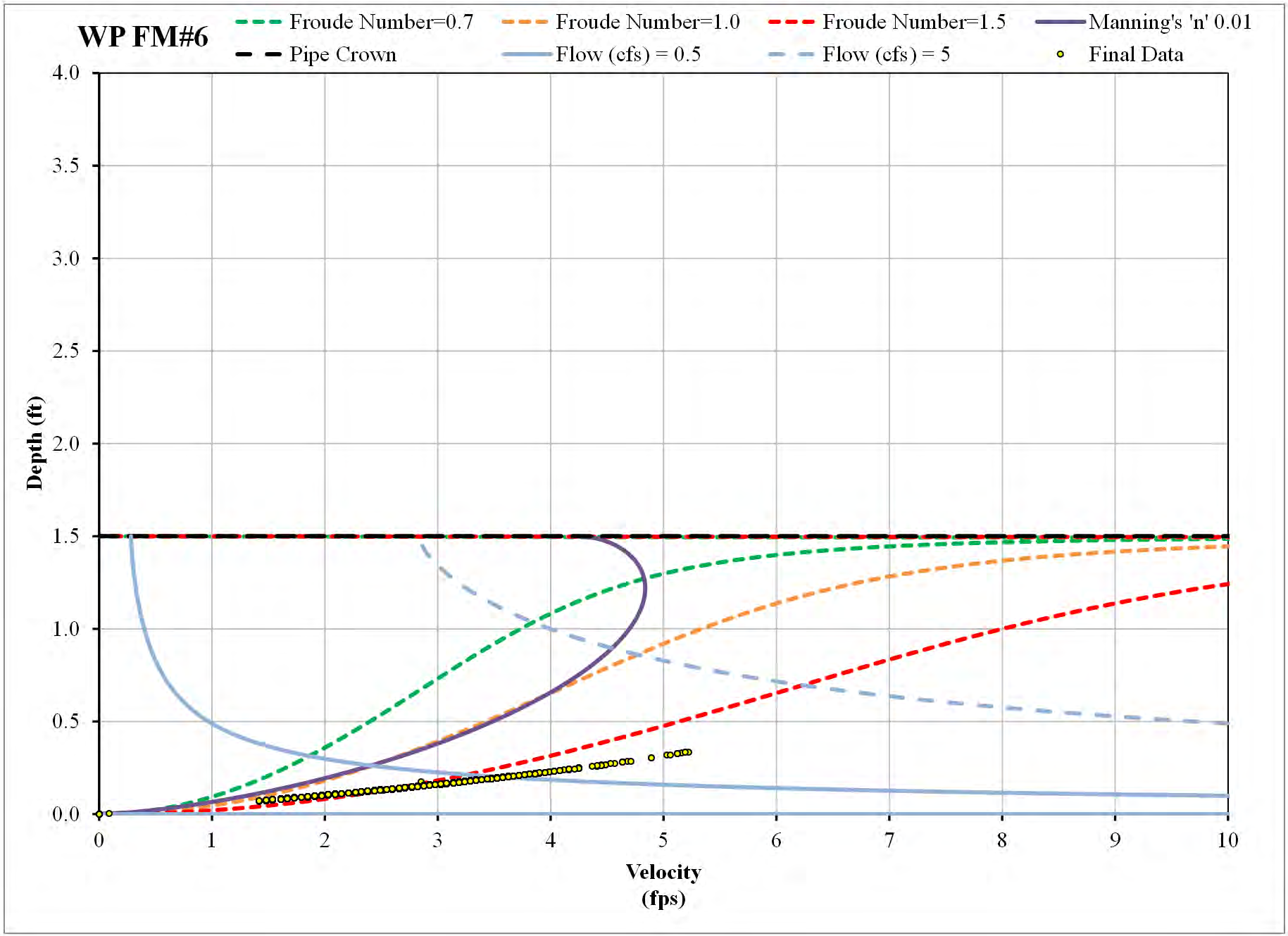
9
10
Velocity
(fps)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Froude Number=0.7
Froude Number=1.0
Froude Number=1.5
Manning's 'n' 0.01
Pipe Crown
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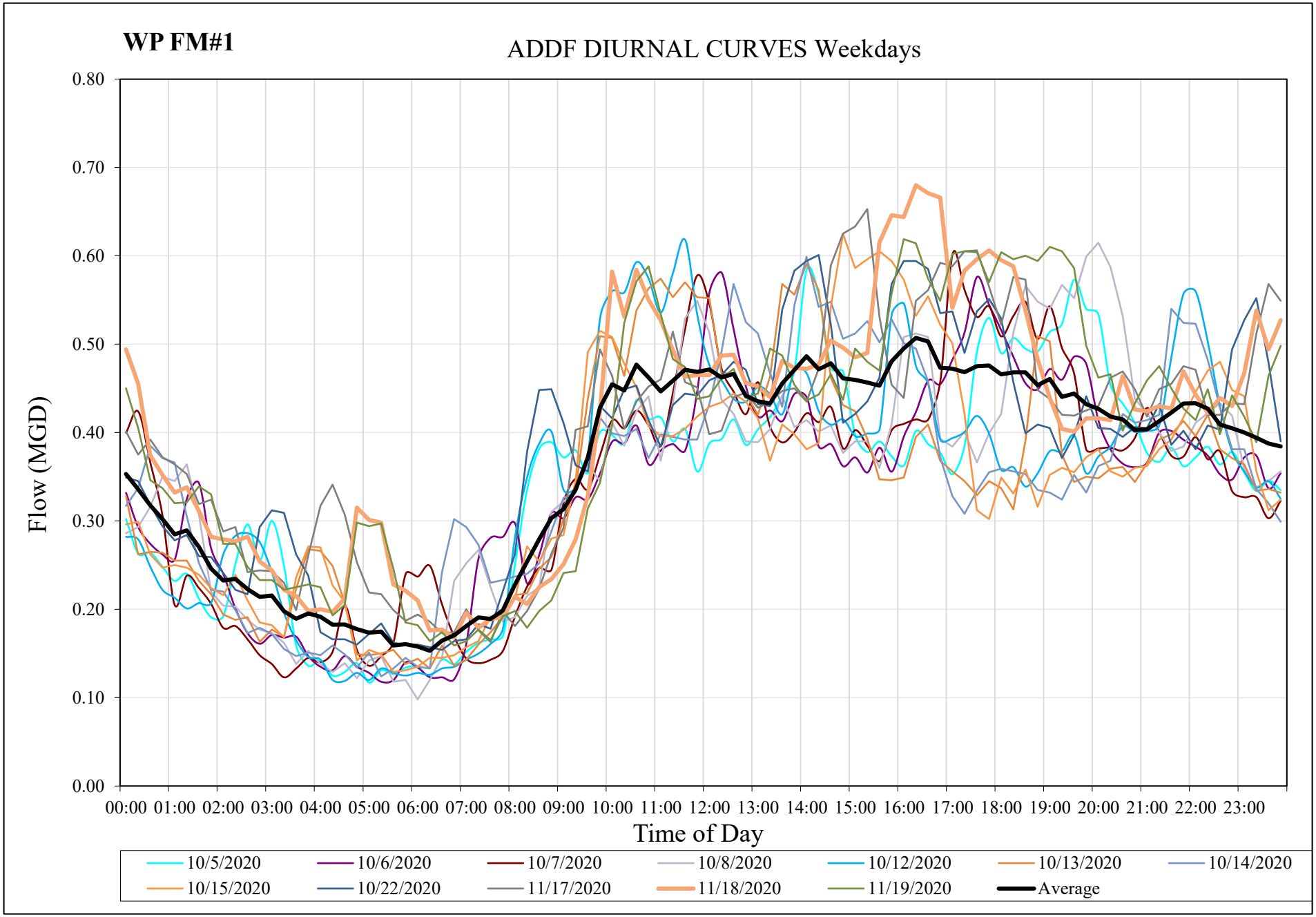
Flow (cfs) = 5
Final Data
Depth (ft)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
Velocity
(fps)

APPENDIX C – DIURNAL PATTERN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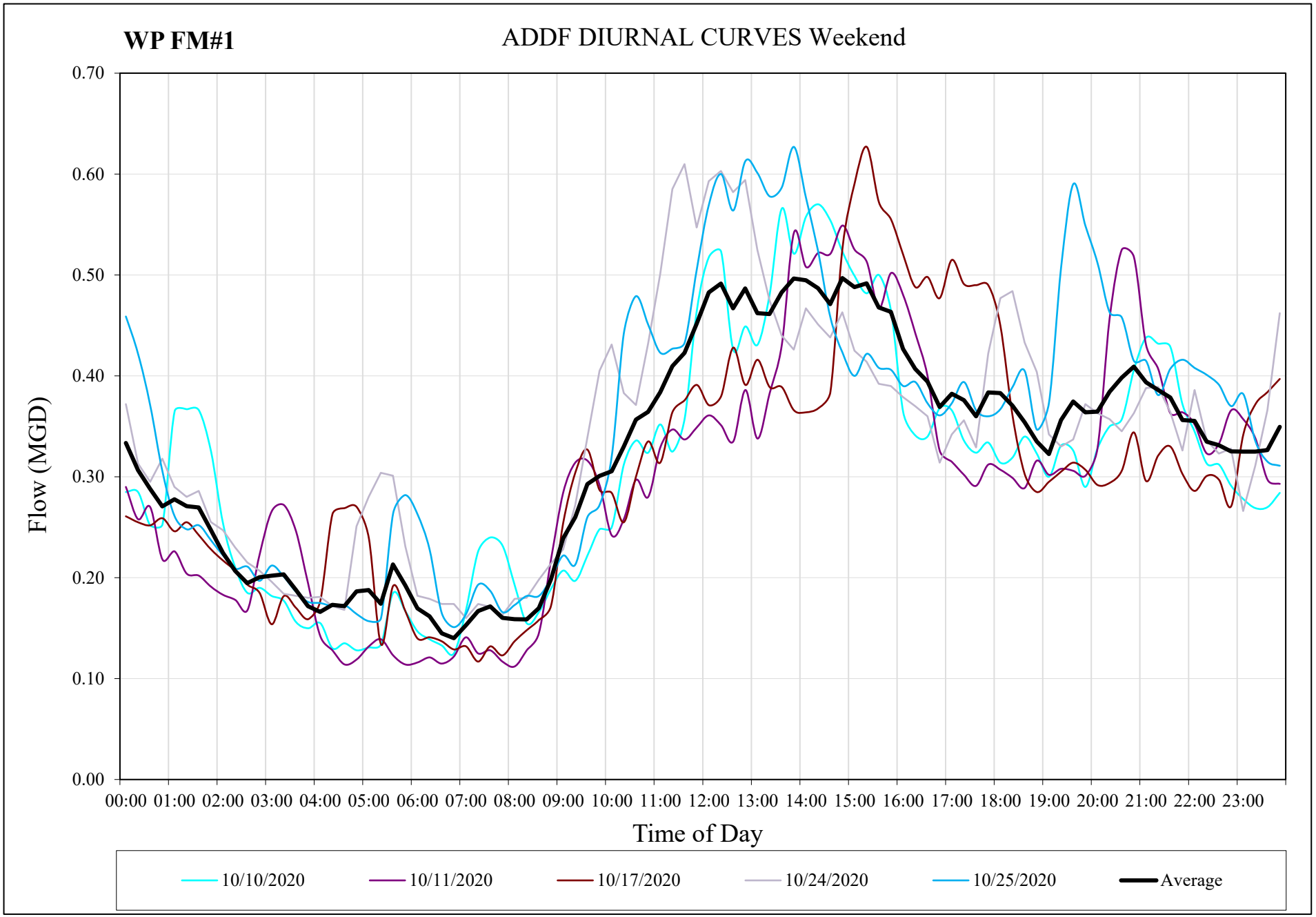
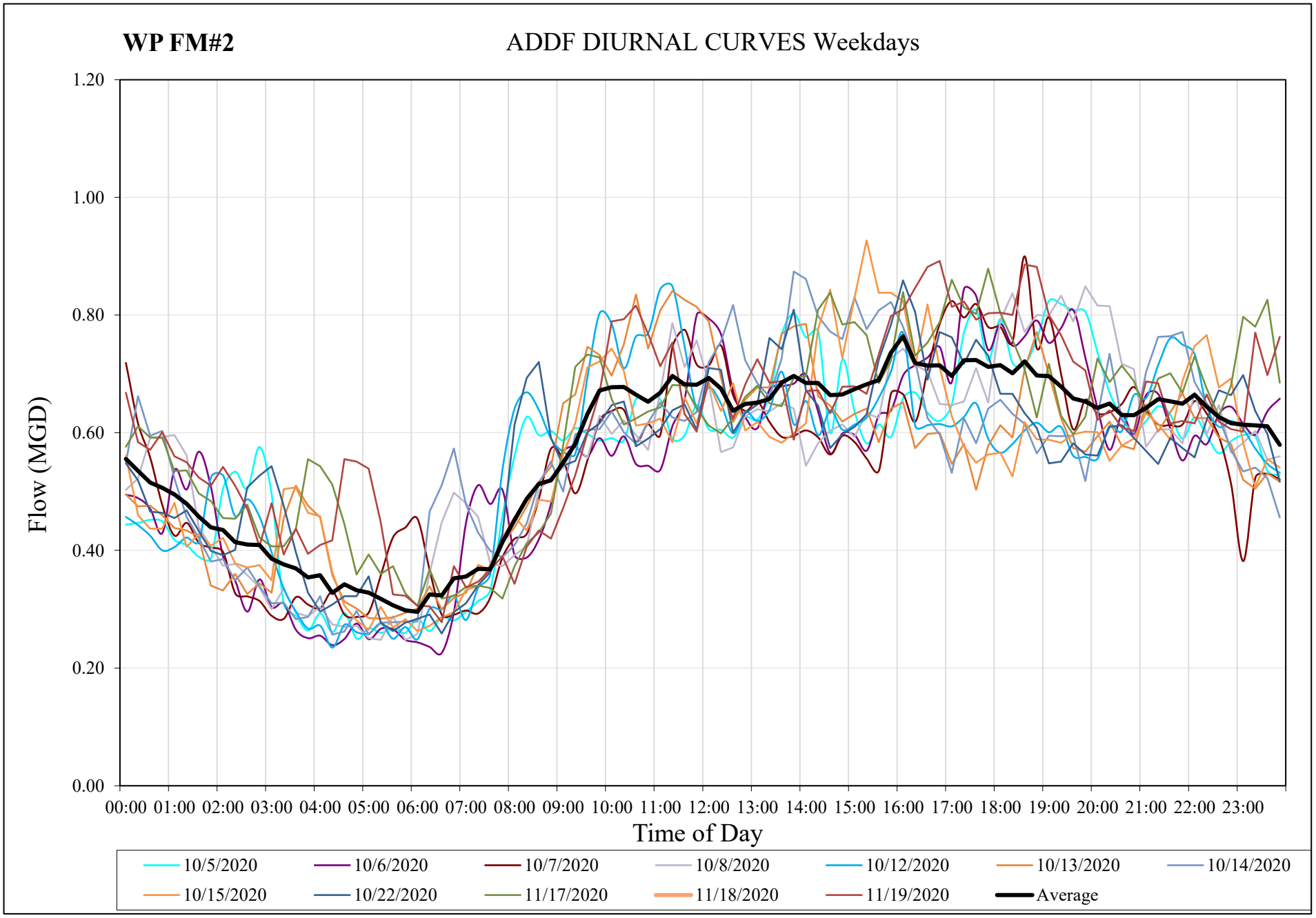
ADDF DIURNAL CURVES Weekdays
Flow (MGD)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/5/2020
10/6/2020
10/7/2020
10/8/2020
10/12/2020
10/13/2020
10/14/2020
10/15/2020
10/22/2020
11/17/2020
11/18/2020
11/19/2020
Average


WP FM#1
ADDF DIURNAL CURVES Weekend
Flow (MGD)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/10/2020
10/11/2020
10/17/2020
10/24/2020
10/25/2020
Average


WP FM#2
ADDF DIURNAL CURVES Weekdays
Flow (MGD)
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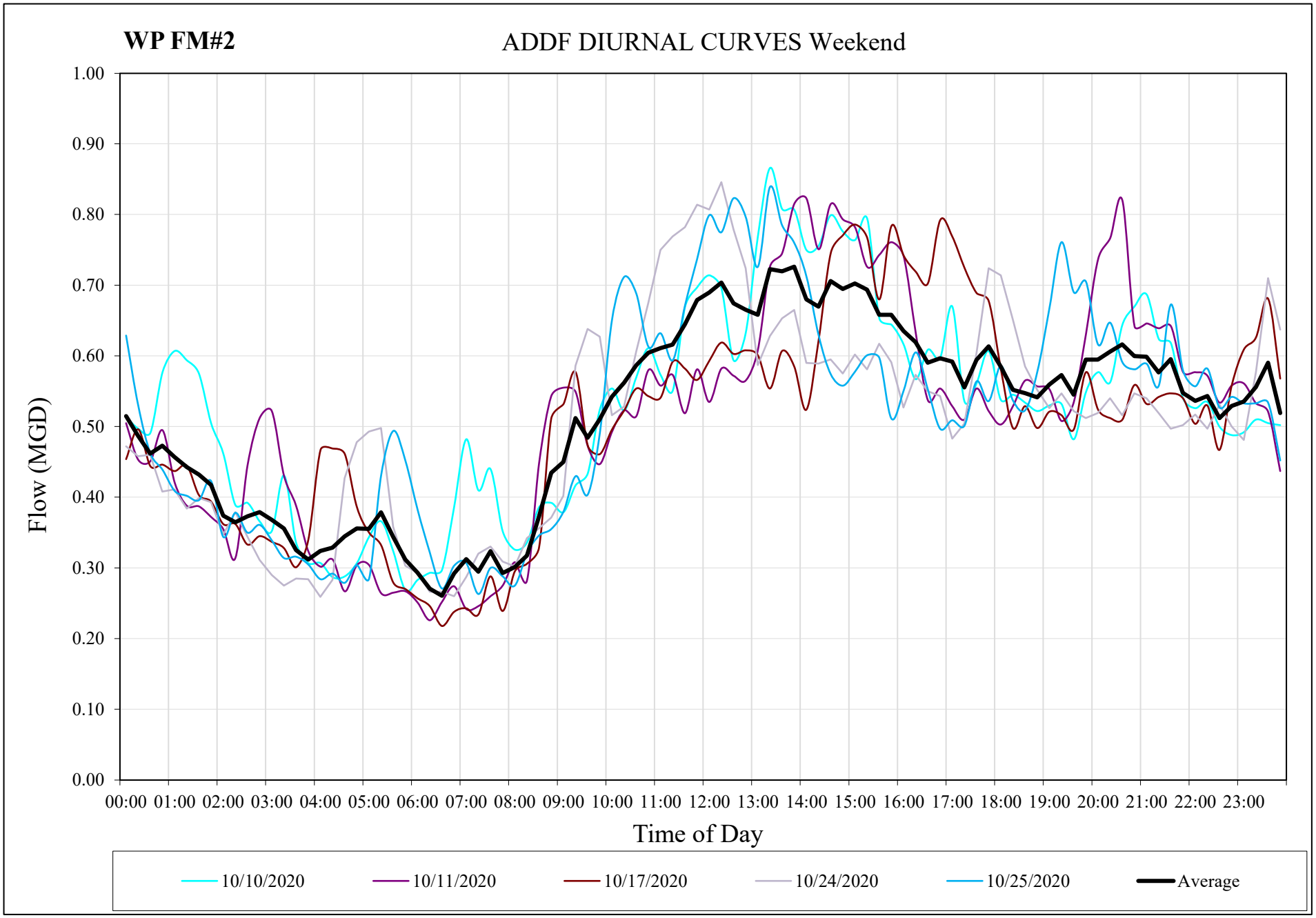
1.00
0.80
0.60
0.40
0.20
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/5/2020
10/6/2020
10/7/2020
10/8/2020
10/12/2020
10/13/2020
10/14/2020
10/15/2020
10/22/2020
11/17/2020
11/18/2020
11/19/2020
Average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ADDF DIURNAL CURVES Weekend
Flow (MGD)
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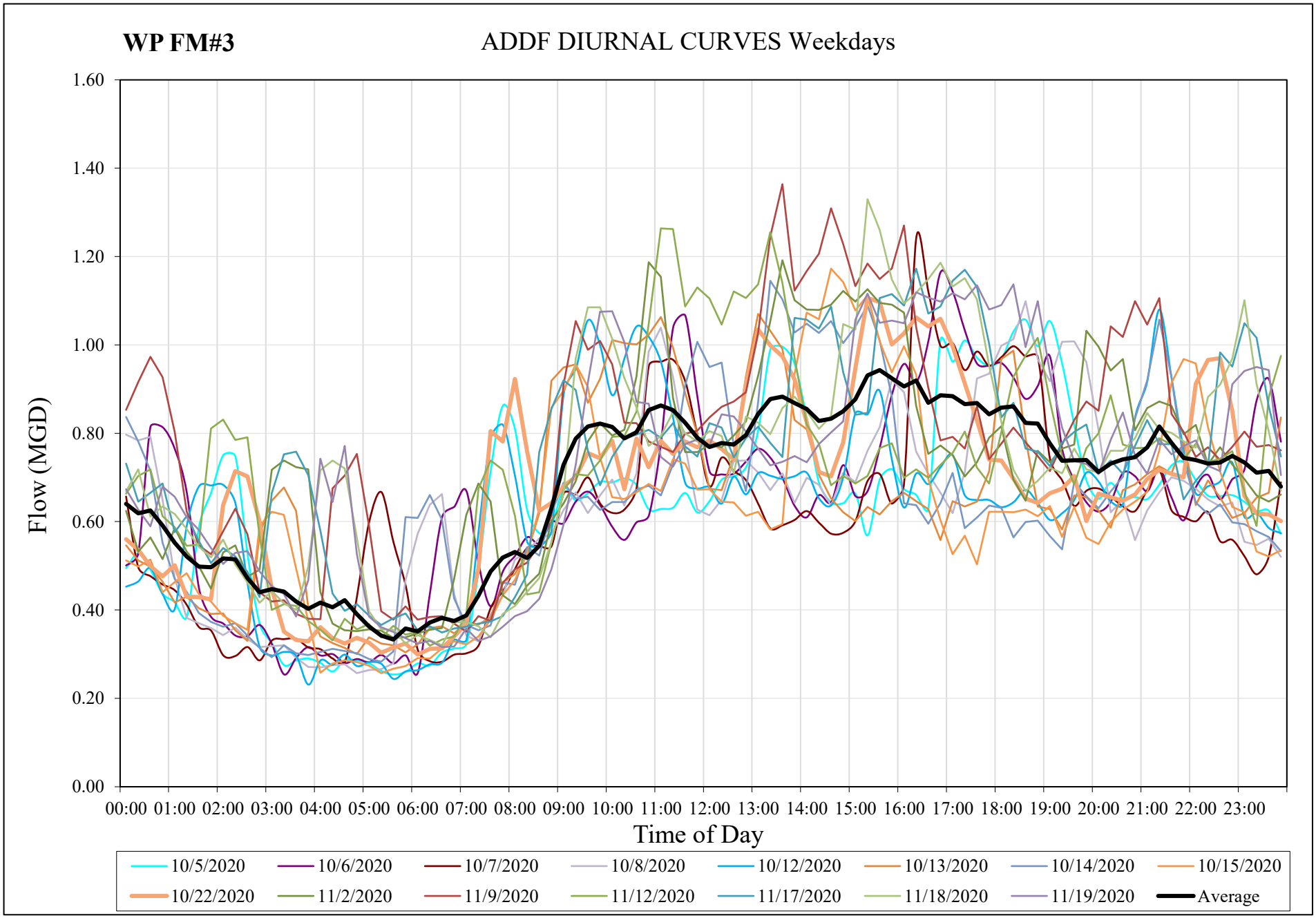
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/10/2020
10/11/2020
10/17/2020
10/24/2020
10/25/2020
Average


WP FM#3
ADDF DIURNAL CURVES Weekdays
Flow (MGD)
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1.20
1.00
0.80
0.60
0.40
0.20
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
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10/6/2020
10/7/2020
10/8/2020
10/12/2020
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10/14/2020
10/15/2020
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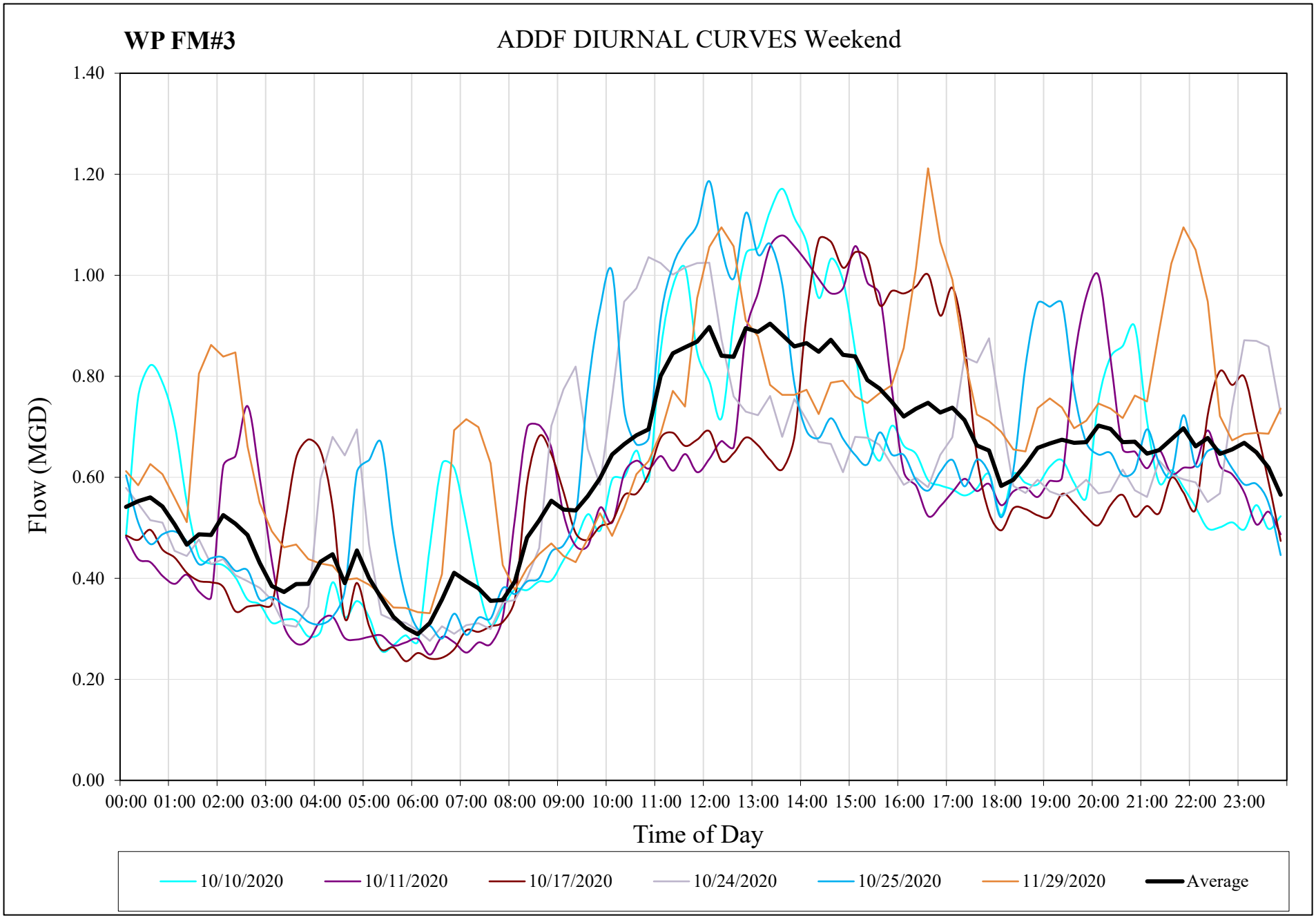
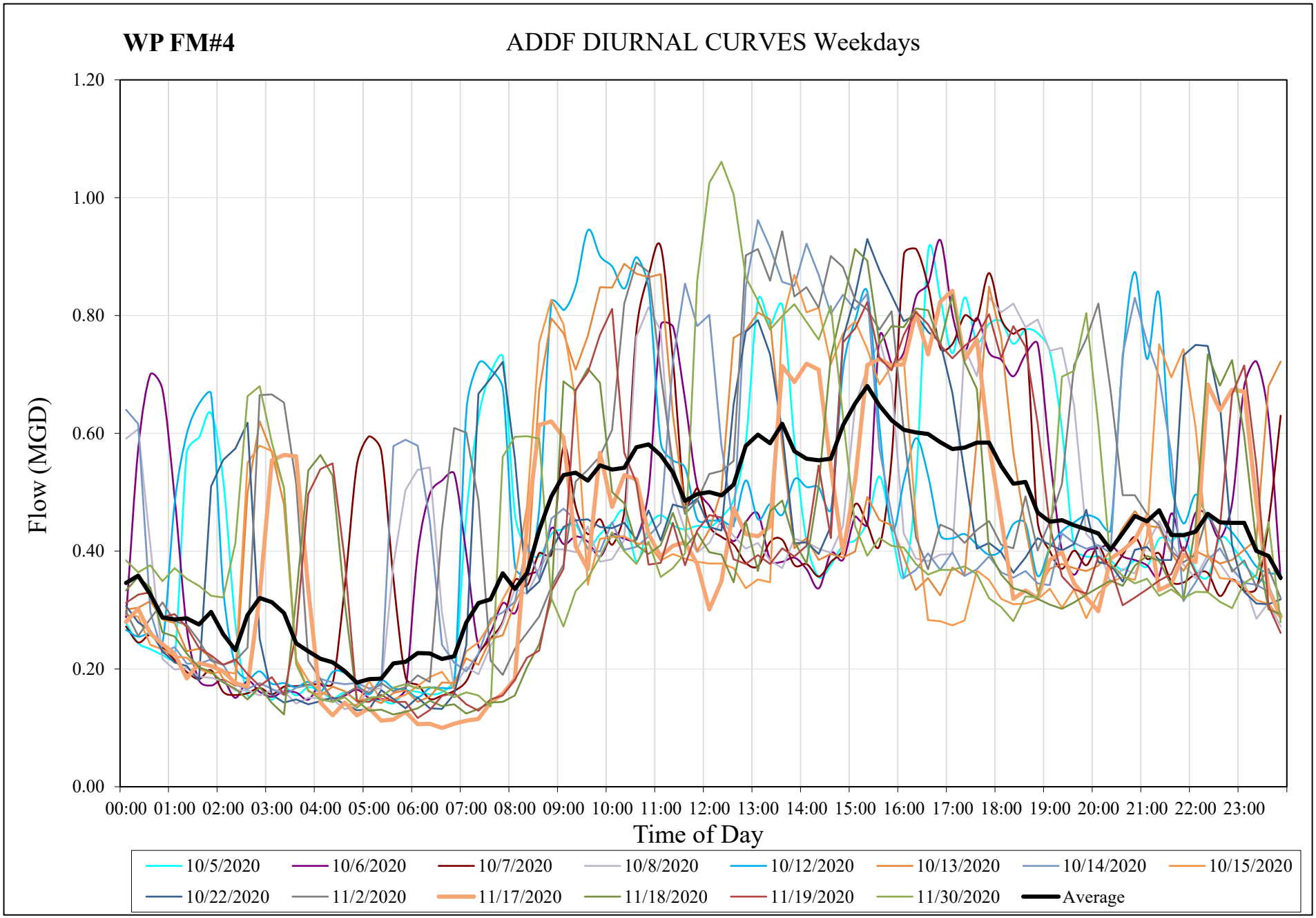
11/2/2020
11/9/2020
11/12/2020
11/17/2020
11/18/2020
11/19/2020
Average


WP FM#3
ADDF DIURNAL CURVES Weekend
Flow (MGD)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/10/2020
10/11/2020
10/17/2020
10/24/2020
10/25/2020
11/29/2020
Average


WP FM#4
ADDF DIURNAL CURVES Weekdays
Flow (MGD)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/5/2020
10/6/2020
10/7/2020
10/8/2020
10/12/2020
10/13/2020
10/14/2020
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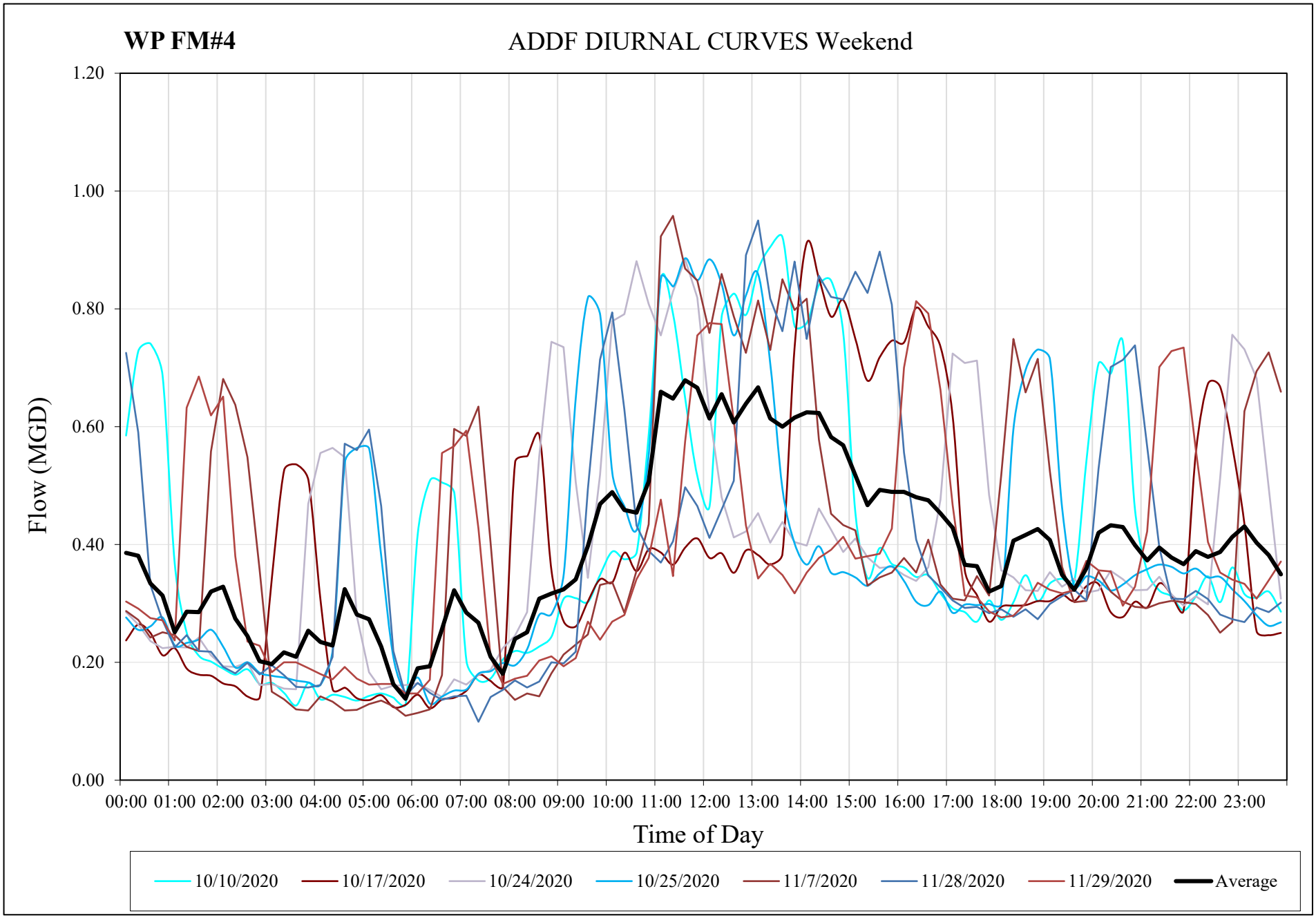
10/22/2020
11/2/2020
11/17/2020
11/18/2020
11/19/2020
11/30/2020
Average


WP FM#4
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Flow (MGD)
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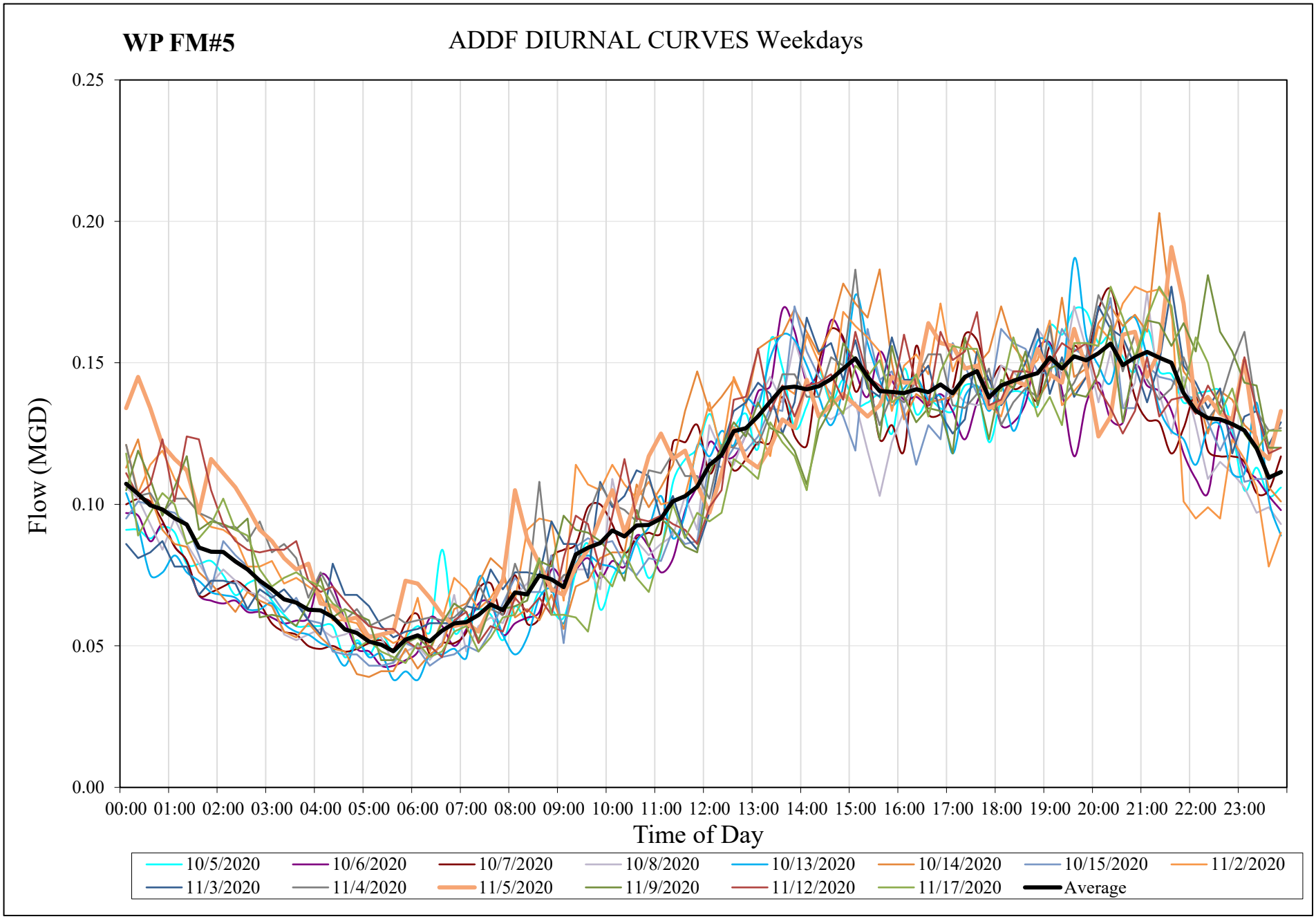
1.00
0.80
0.60
0.40
0.20
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/10/2020
10/17/2020
10/24/2020
10/25/2020
11/7/2020
11/28/2020
11/29/2020
Average


WP FM#5
ADDF DIURNAL CURVES Weekdays
Flow (MGD)
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0.15
0.10
0.05
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
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10/6/2020
10/7/2020
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10/14/2020
10/15/2020
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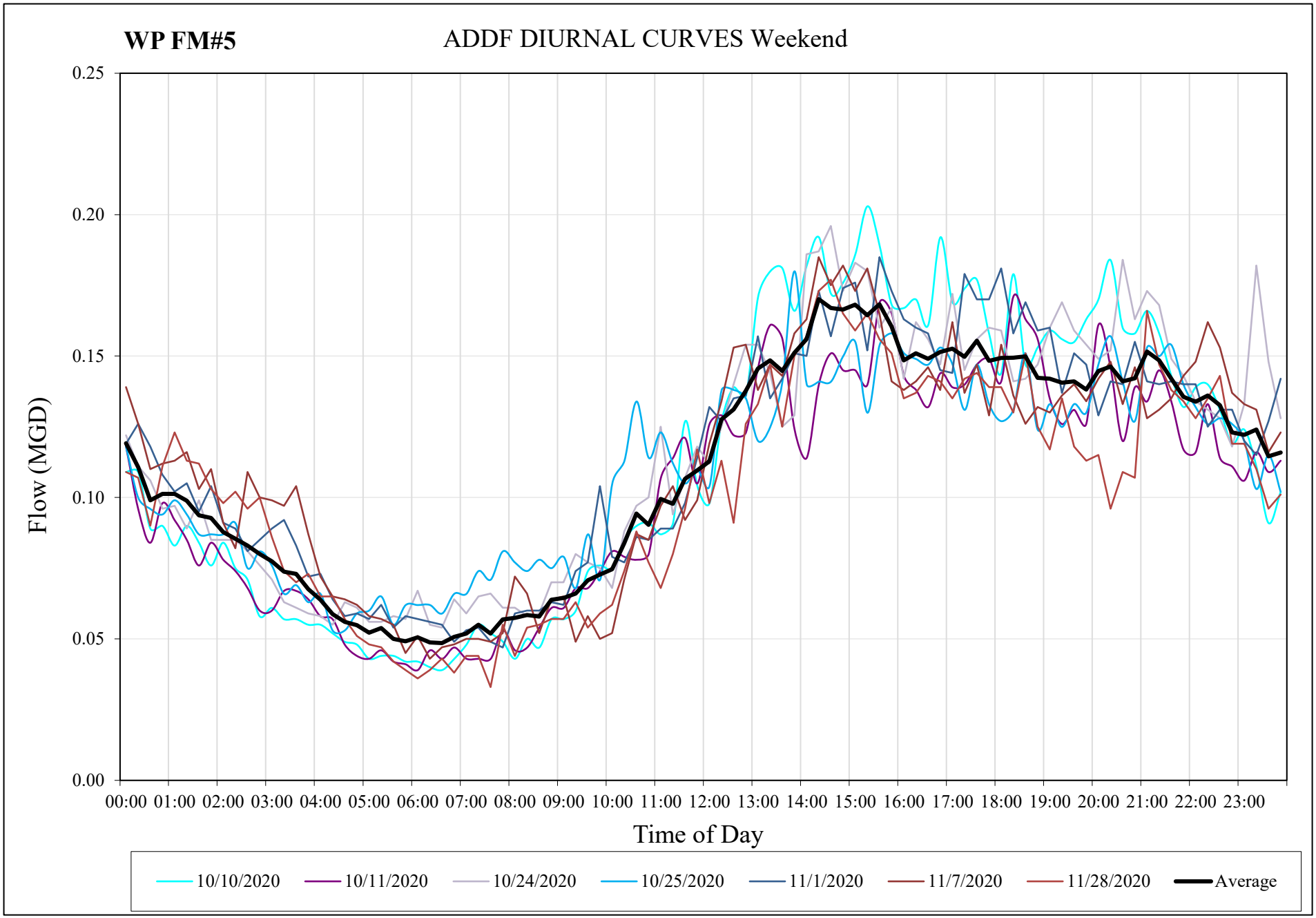
11/3/2020
11/4/2020
11/5/2020
11/9/2020
11/12/2020
11/17/2020
Average


WP FM#5
ADDF DIURNAL CURVES Weekend
Flow (MGD)
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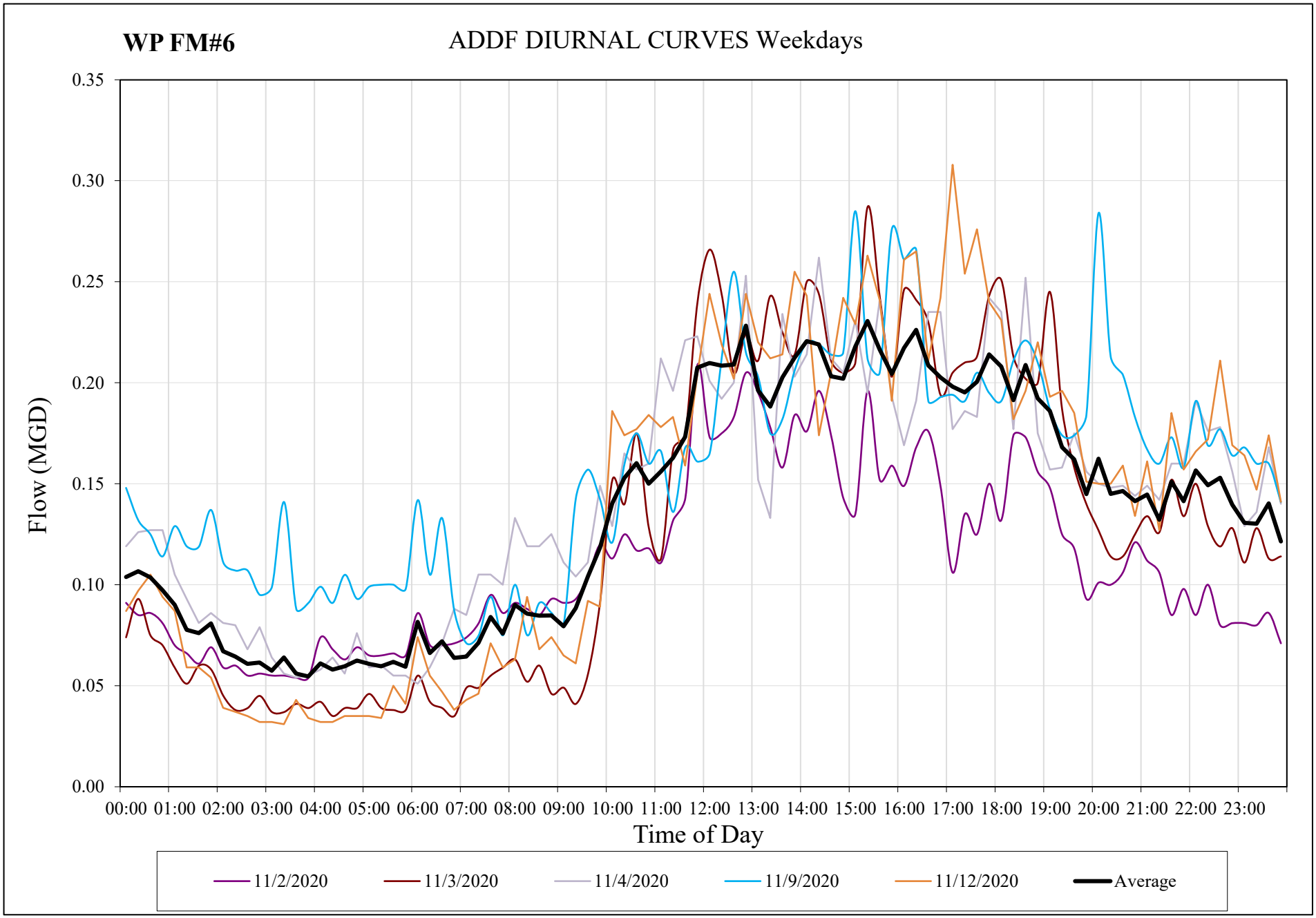
0.20
0.15
0.10
0.05
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
10/10/2020
10/11/2020
10/24/2020
10/25/2020
11/1/2020
11/7/2020
11/28/2020
Average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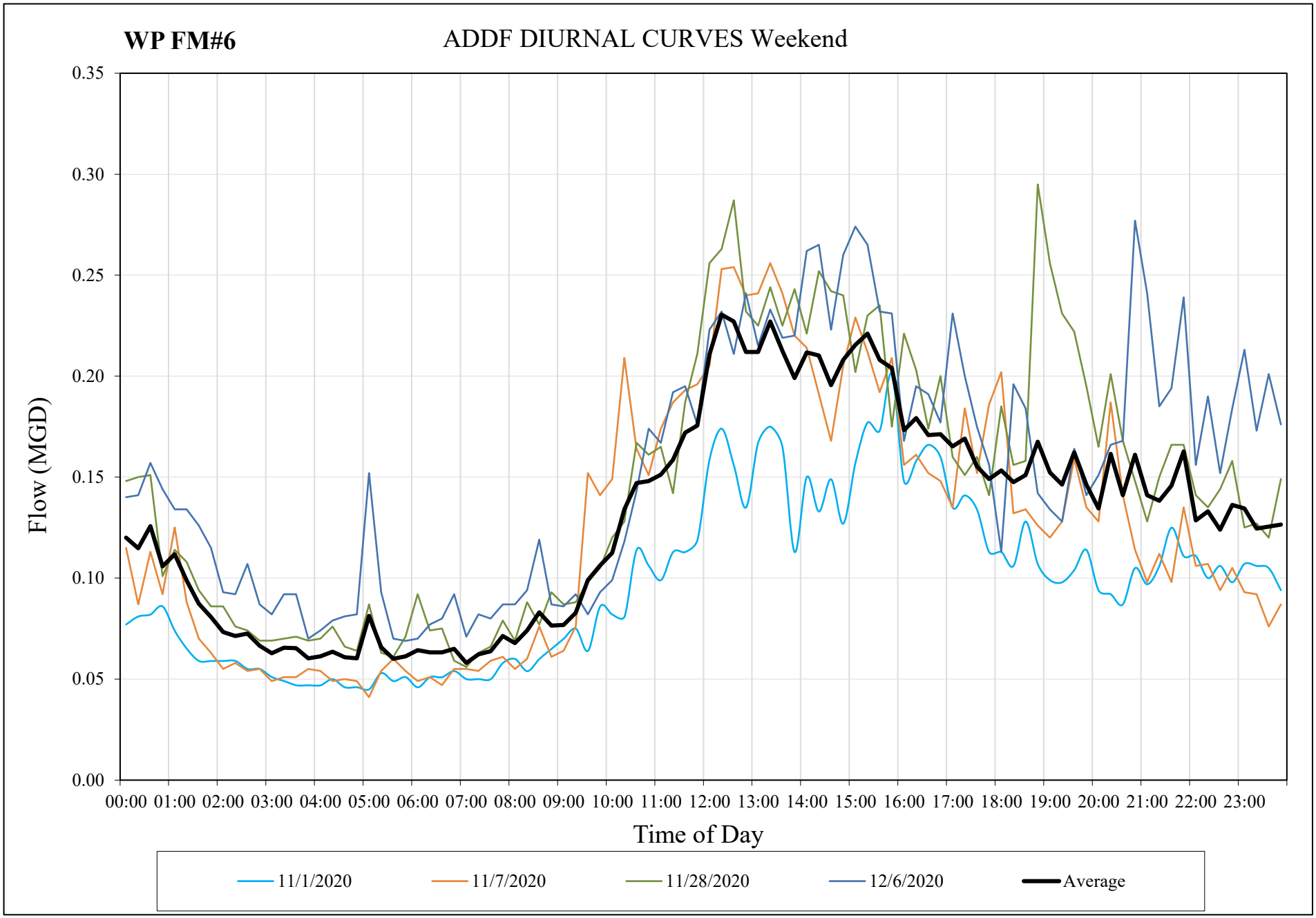
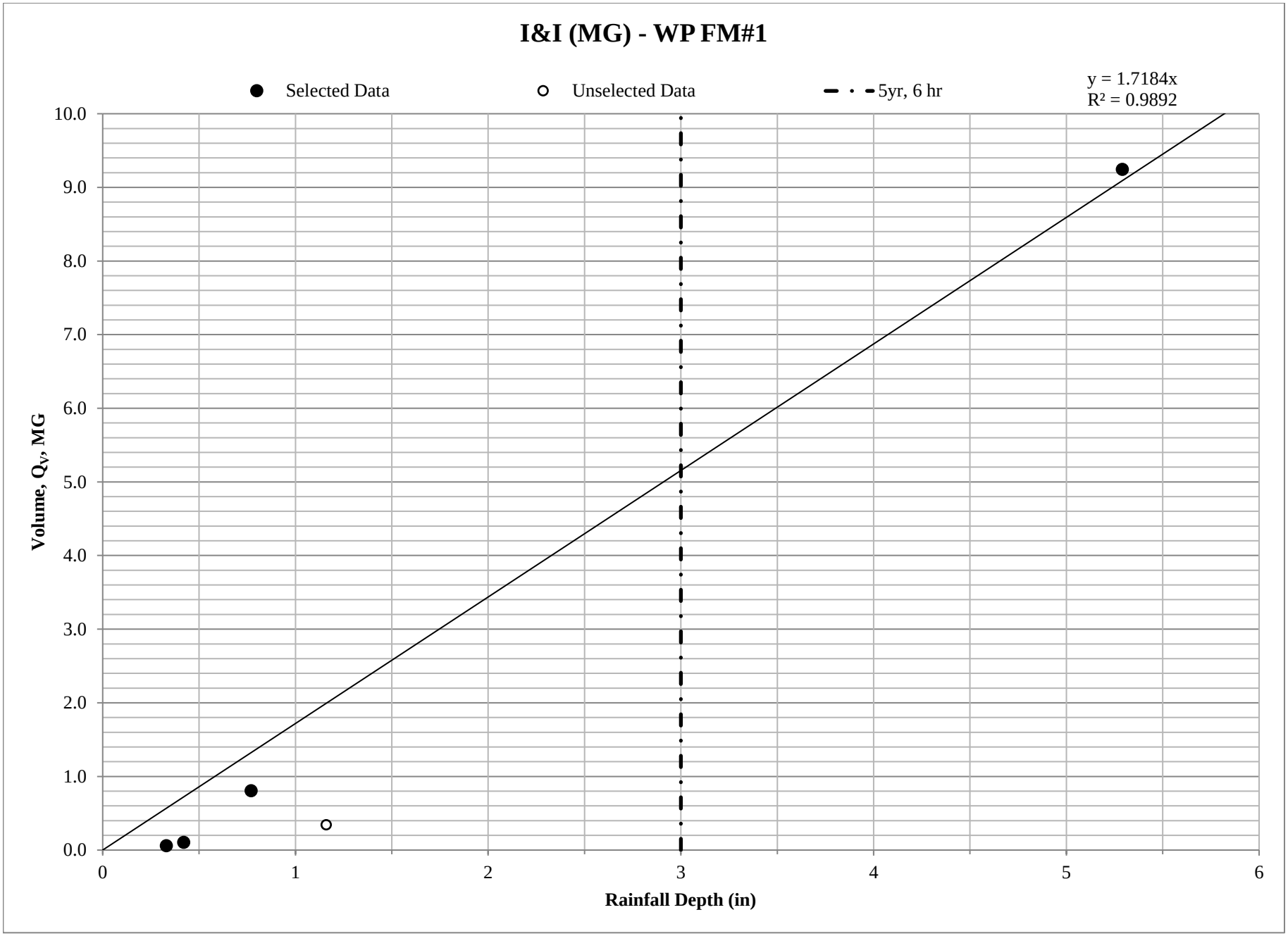
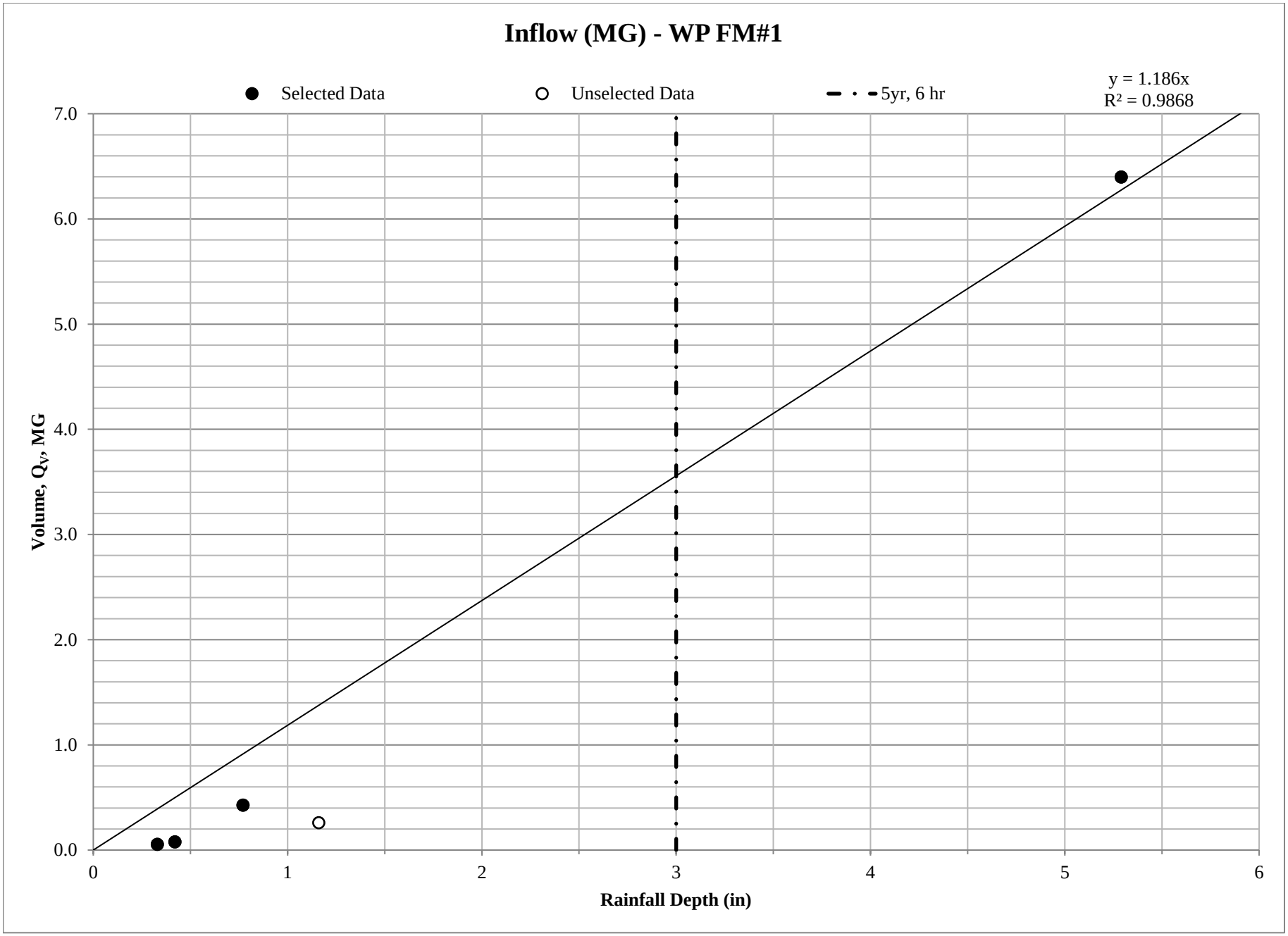
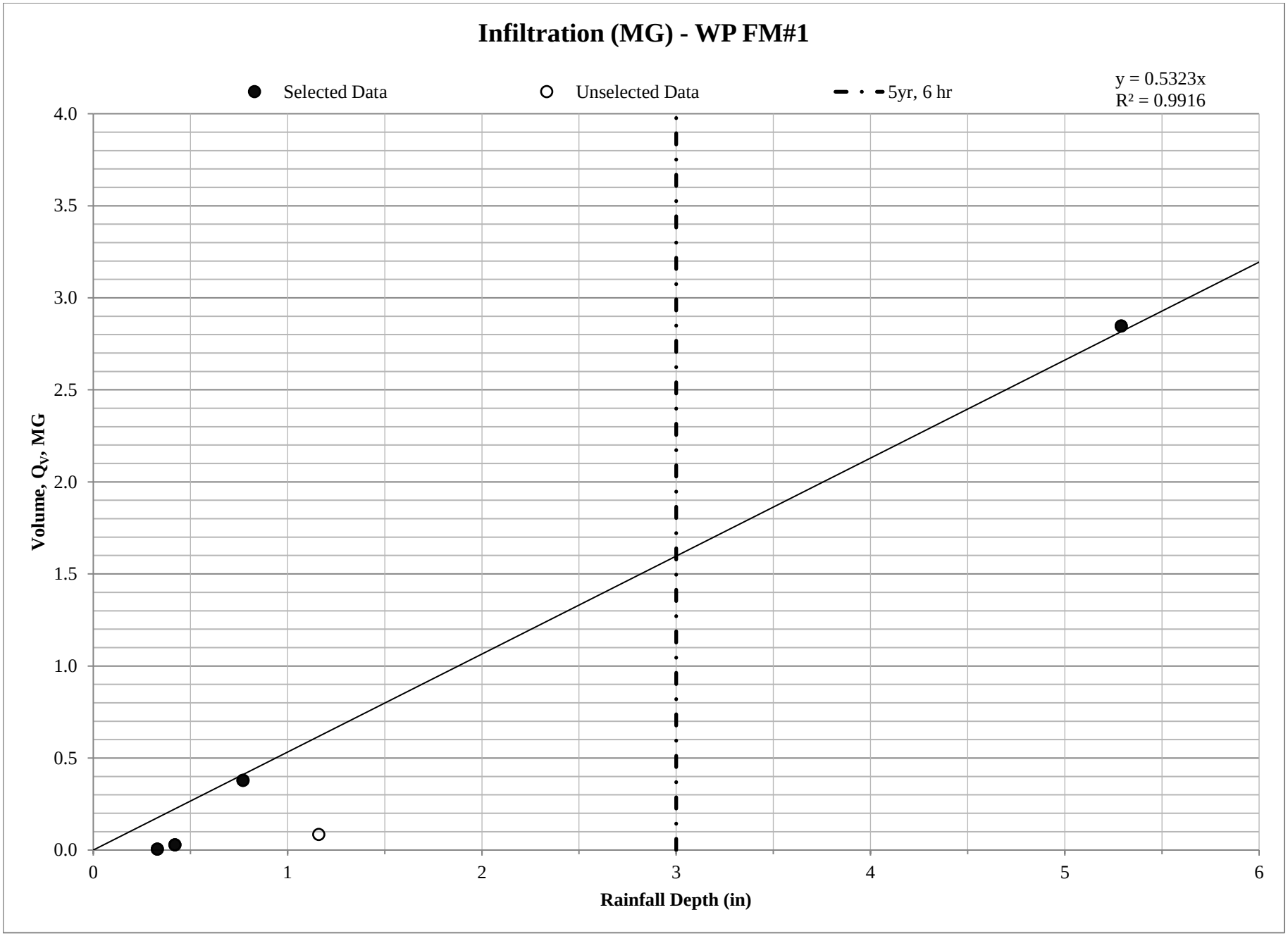
0.25
0.20
0.15
0.10
0.05
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
11/2/2020
11/3/2020
11/4/2020
11/9/2020
11/12/2020
Average

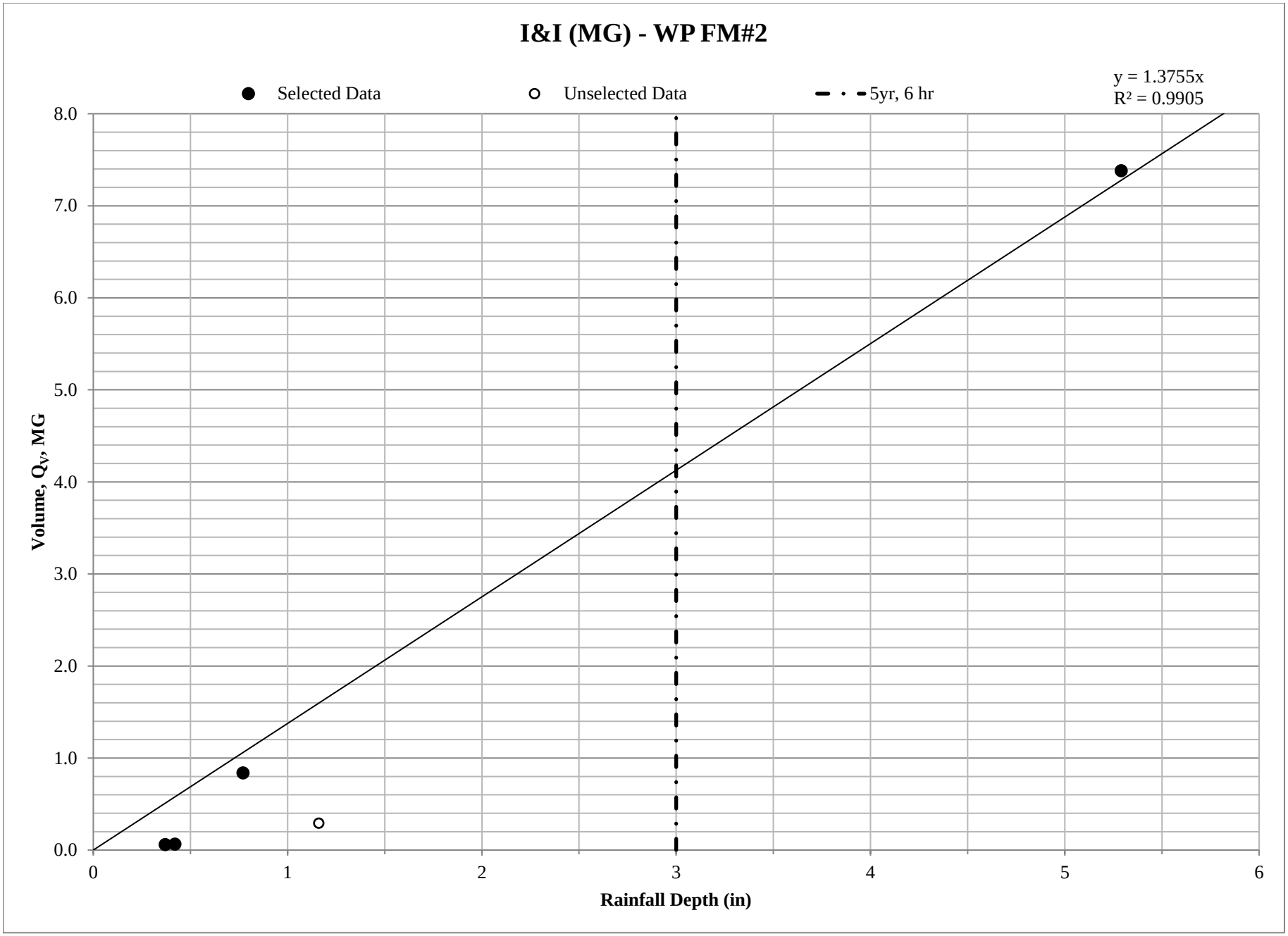

WP FM#6
ADDF DIURNAL CURVES Weekend
Flow (MGD)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
11/1/2020
11/7/2020
11/28/2020
12/6/2020
Average

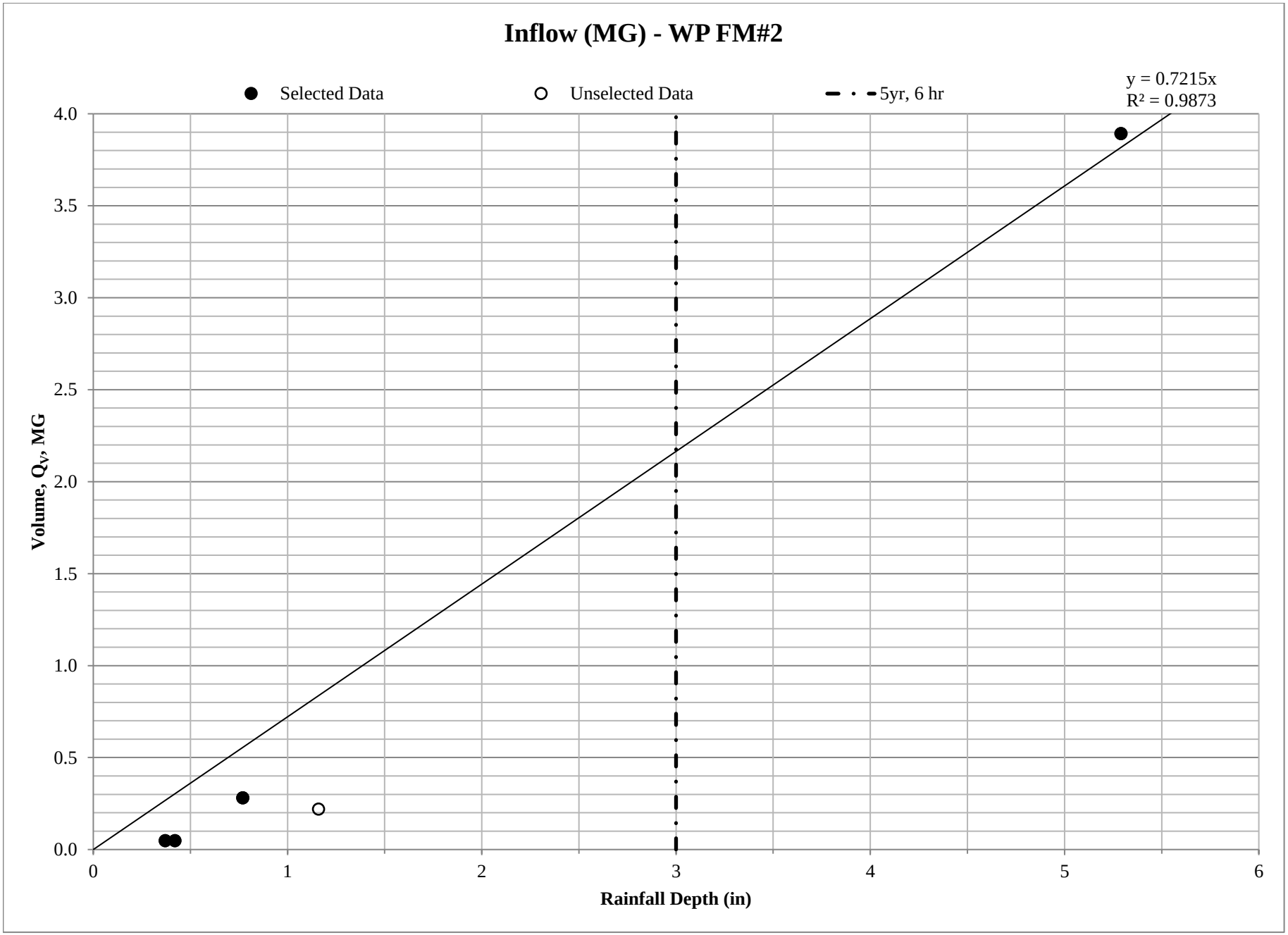
APPENDIX D - VOLUME VERSUS RAINFALL DEPTH

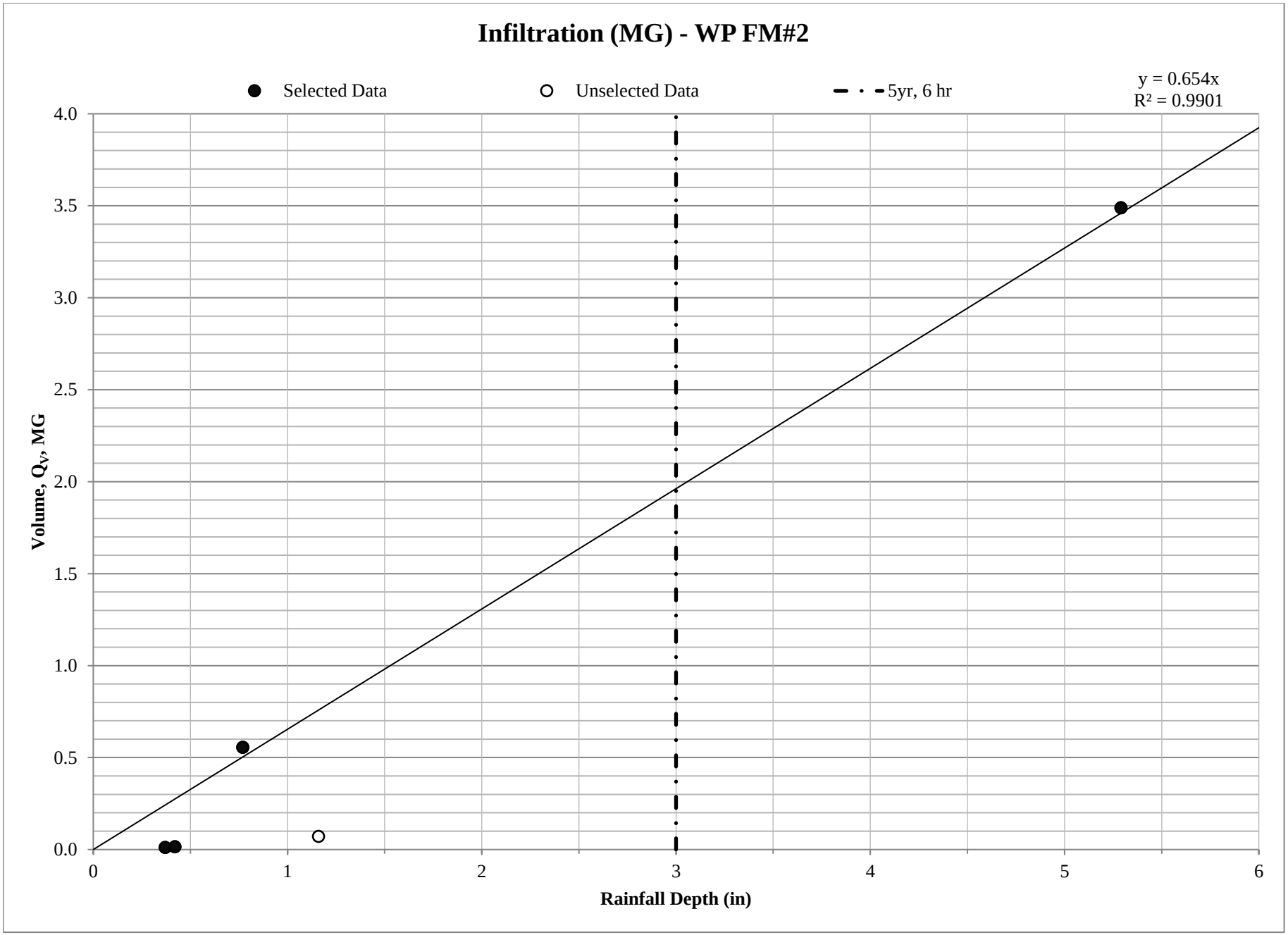

I&I (MG) - WP FM#1
Selected Data
Unselected Data
5yr, 6 hr
y = 1.7184x
R² = 0.9892
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Volume, Qv, MG
0
1
2
3
4
5
6
Rainfall Depth (in)

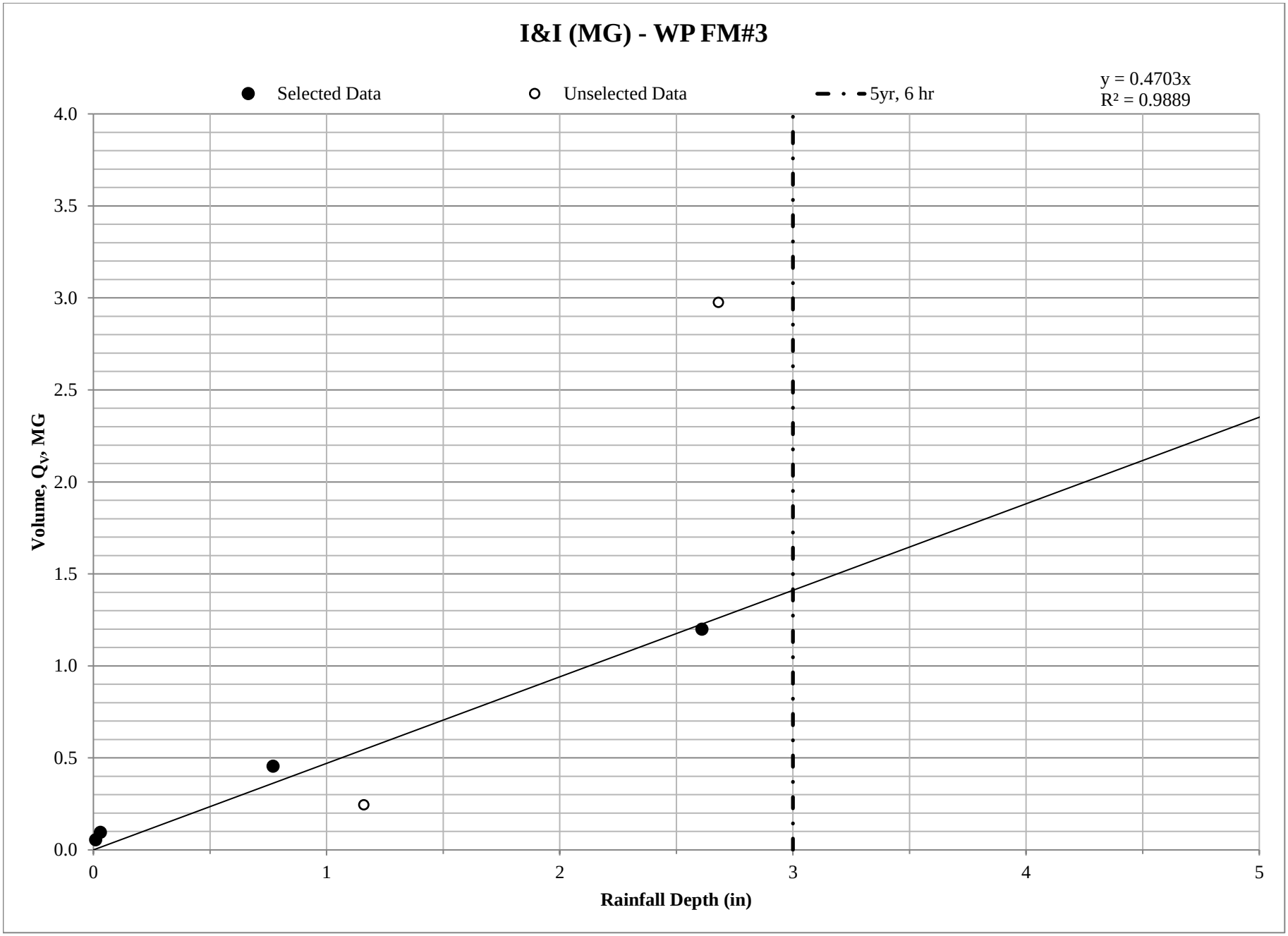

Inflow (MG) - WP FM#1
Selected Data
Unselected Data
5yr, 6 hr
y = 1.186x
R² = 0.9868
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Volume, Qv, MG
0
1
2
3
4
5
6
Rainfall Depth (in)

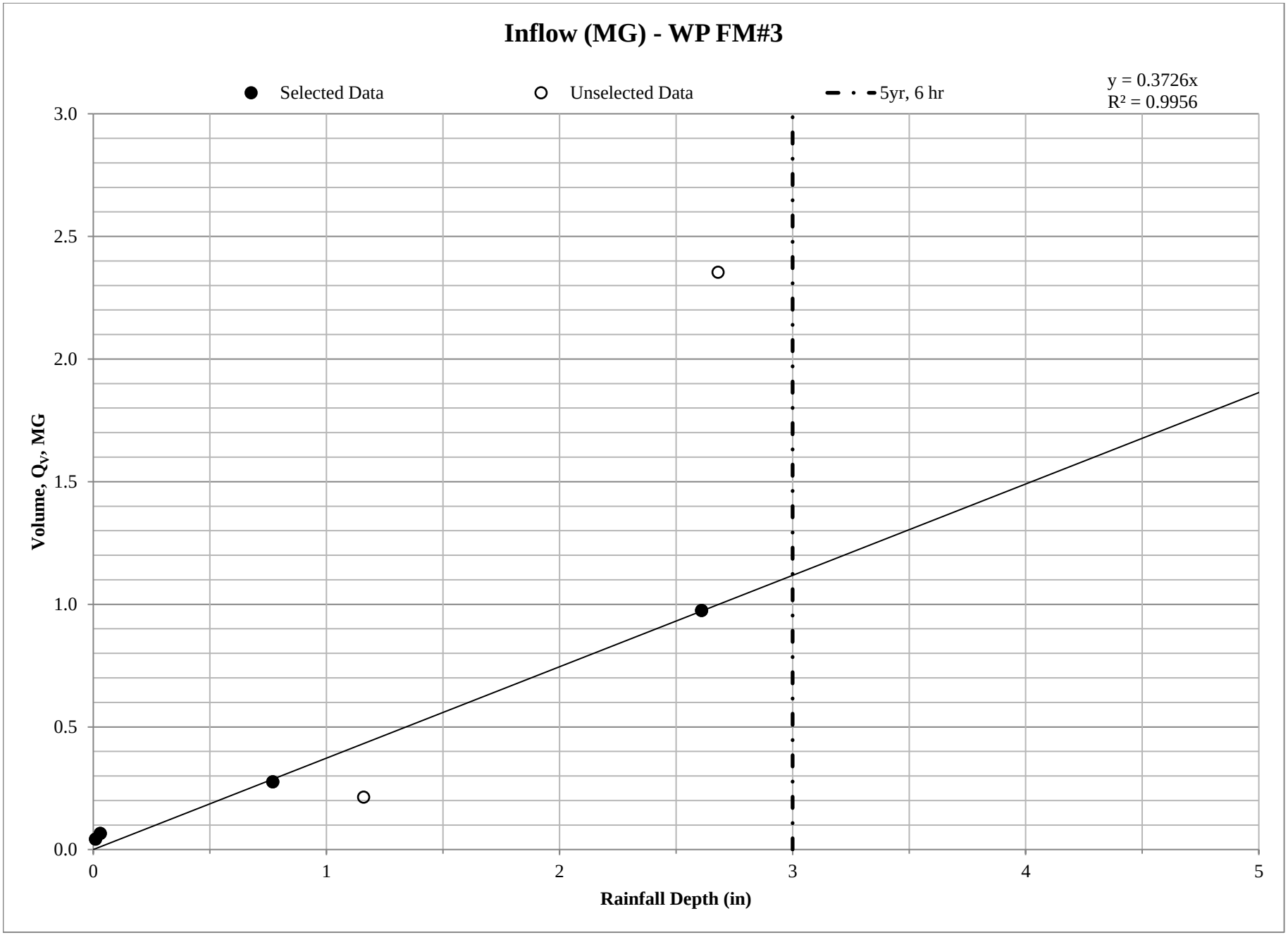

Infiltration (MG) - WP FM#1
Selected Data
Unselected Data
5yr, 6 hr
y = 0.5323x
R² = 0.9916
Volume, Qv, MG
Rainfall Depth (in)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6

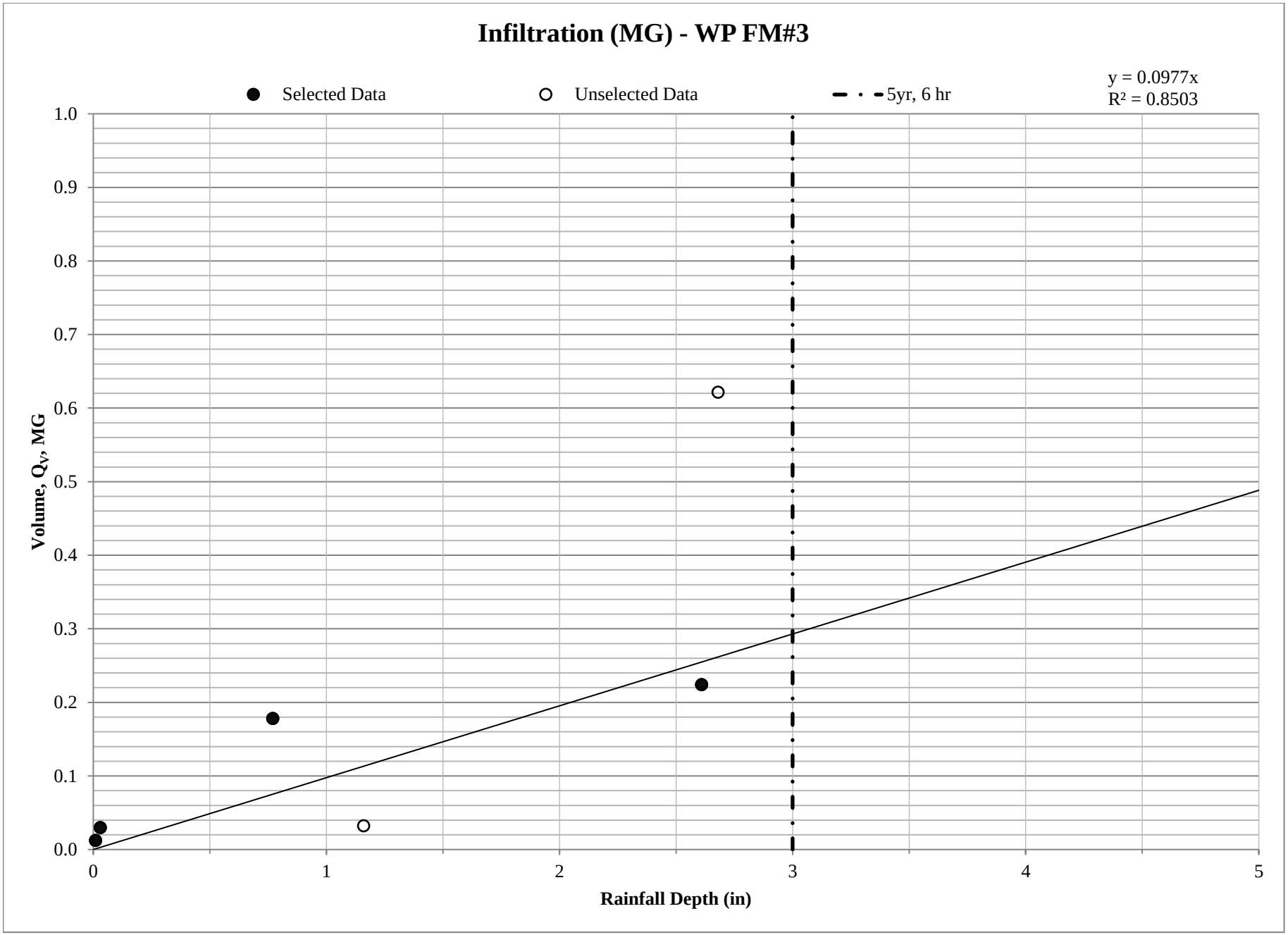

I&I (MG) - WP FM#2
Selected Data
Unselected Data
5yr, 6 hr
y = 1.3755x
R² = 0.9905
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Volume, Qv, MG
0
1
2
3
4
5
6
Rainfall Depth (in)

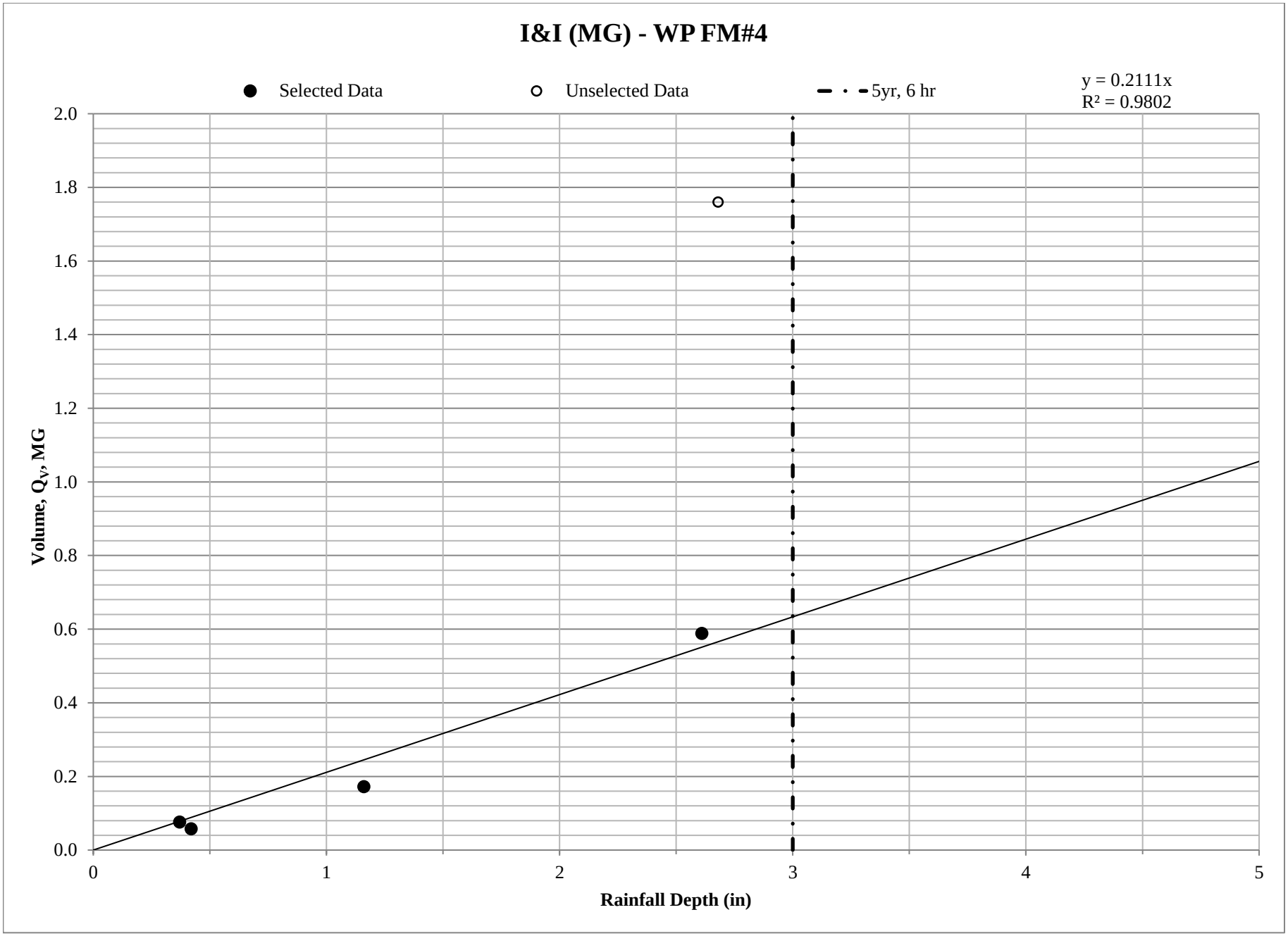

Inflow (MG) - WP FM#2
Selected Data
Unselected Data
5yr, 6 hr
y = 0.7215x
R² = 0.9873
Volume, Qv, MG
Rainfall Depth (in)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6

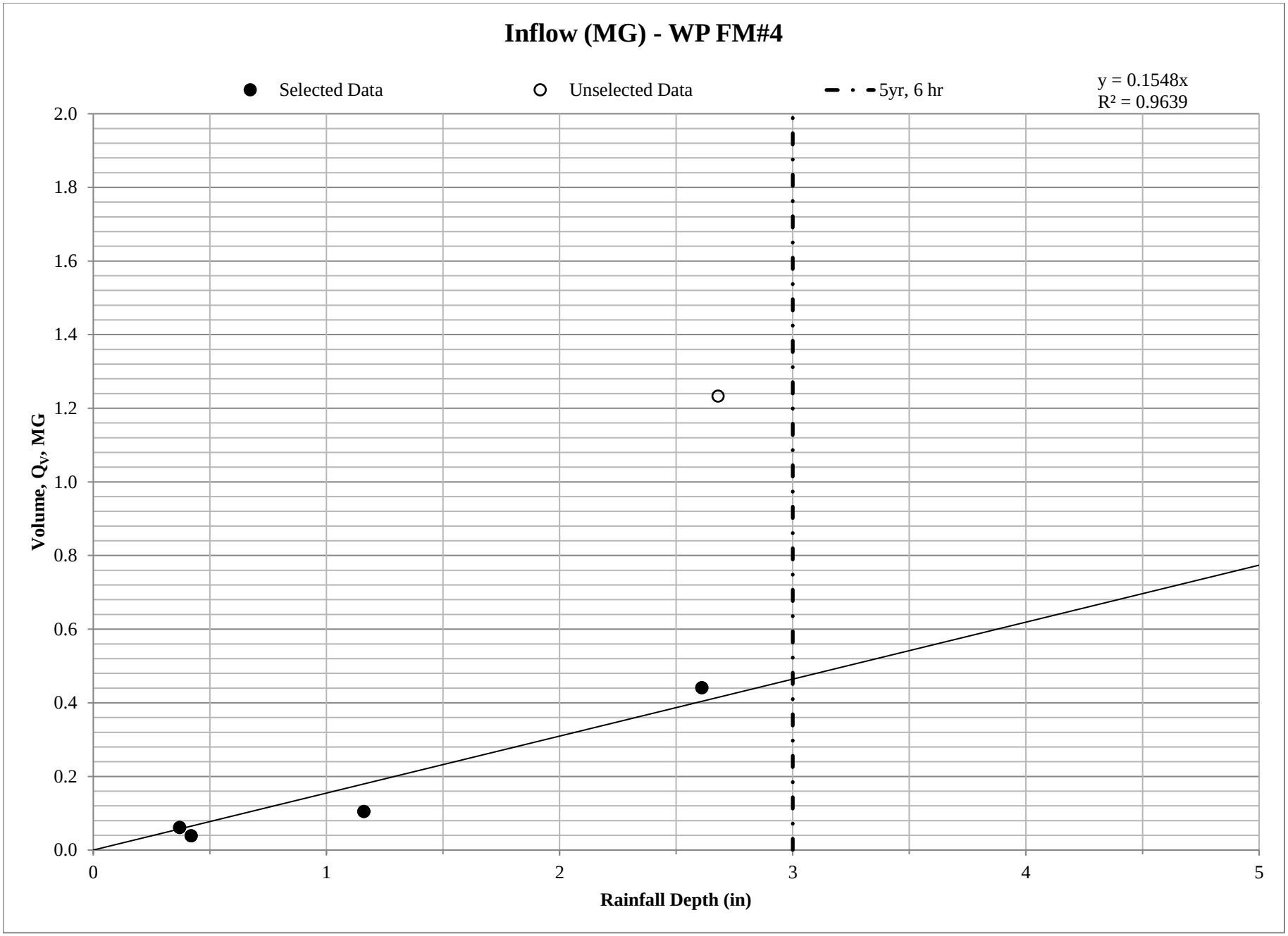

Infiltration (MG) - WP FM#2
Selected Data
Unselected Data
5yr, 6 hr
y = 0.654x
R² = 0.9901
Volume, Qv, MG
Rainfall Depth (in)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
1
2
3
4
5
6

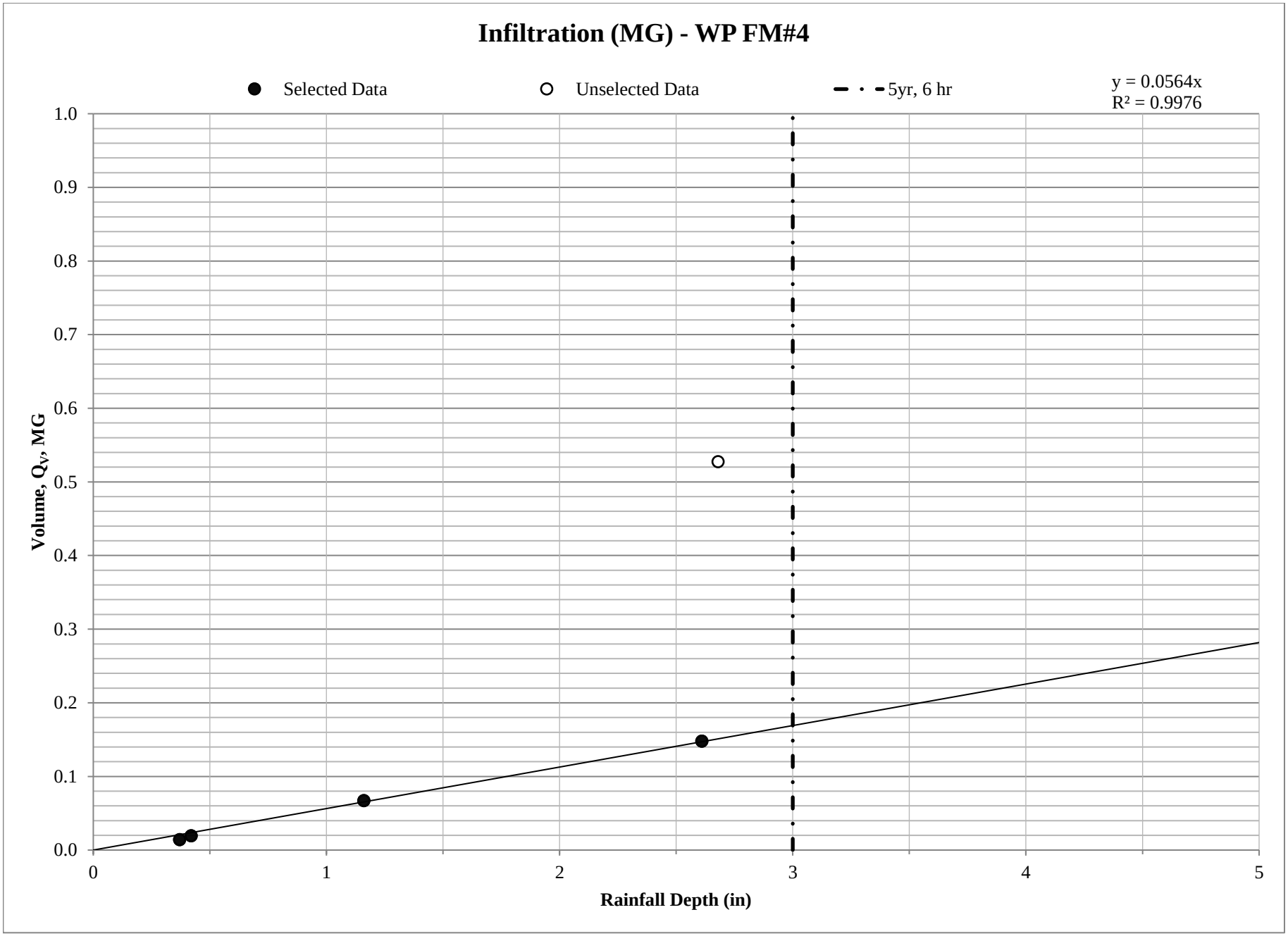

I&I (MG) - WP FM#3
Selected Data
Unselected Data
5yr, 6 hr
y = 0.4703x
R² = 0.9889
Volume, Qv, MG
Rainfall Depth (in)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
1
2
3
4
5

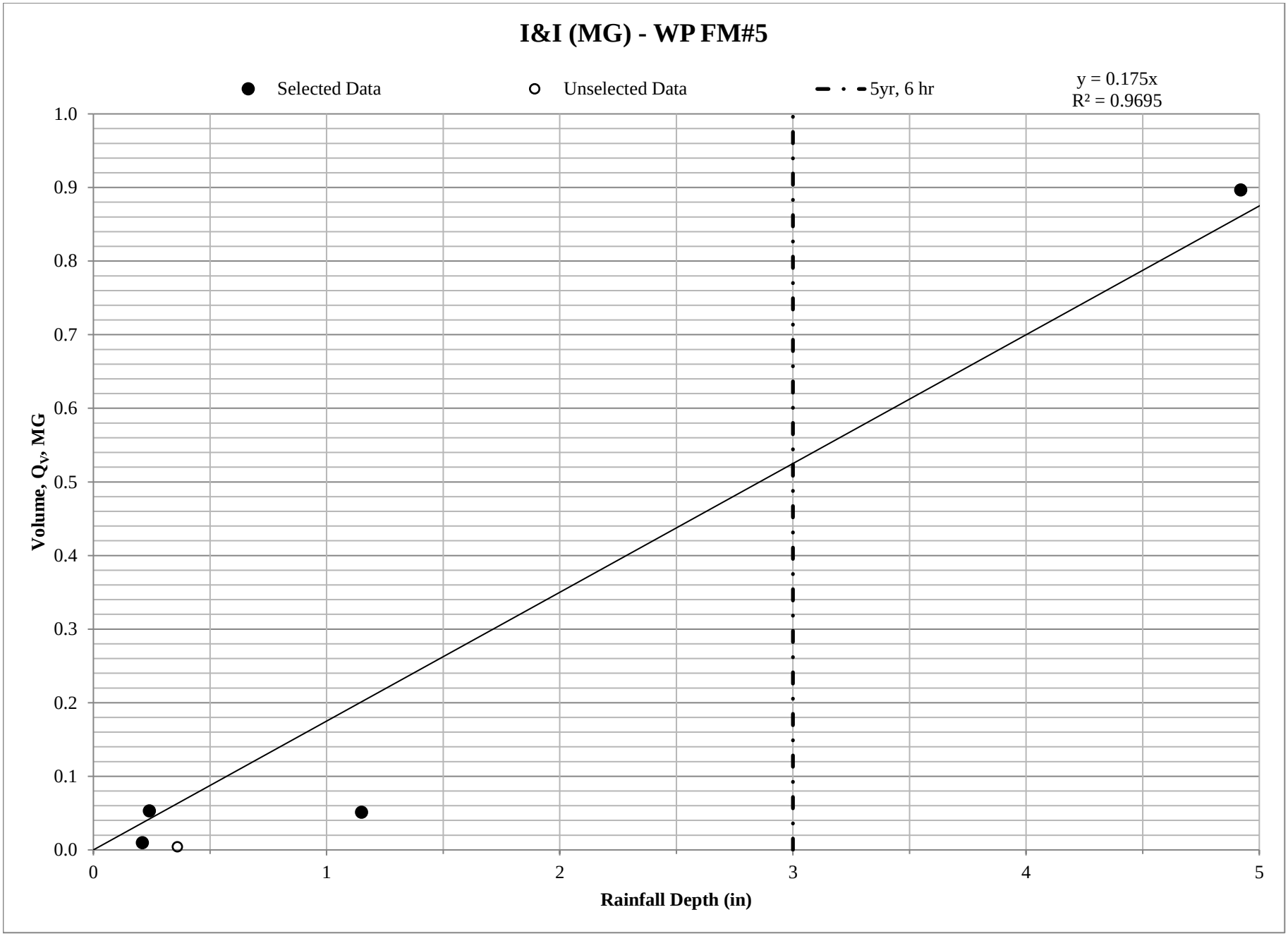

Inflow (MG) - WP FM#3
Selected Data
Unselected Data
5yr, 6 hr
y = 0.3726x
R² = 0.9956
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)

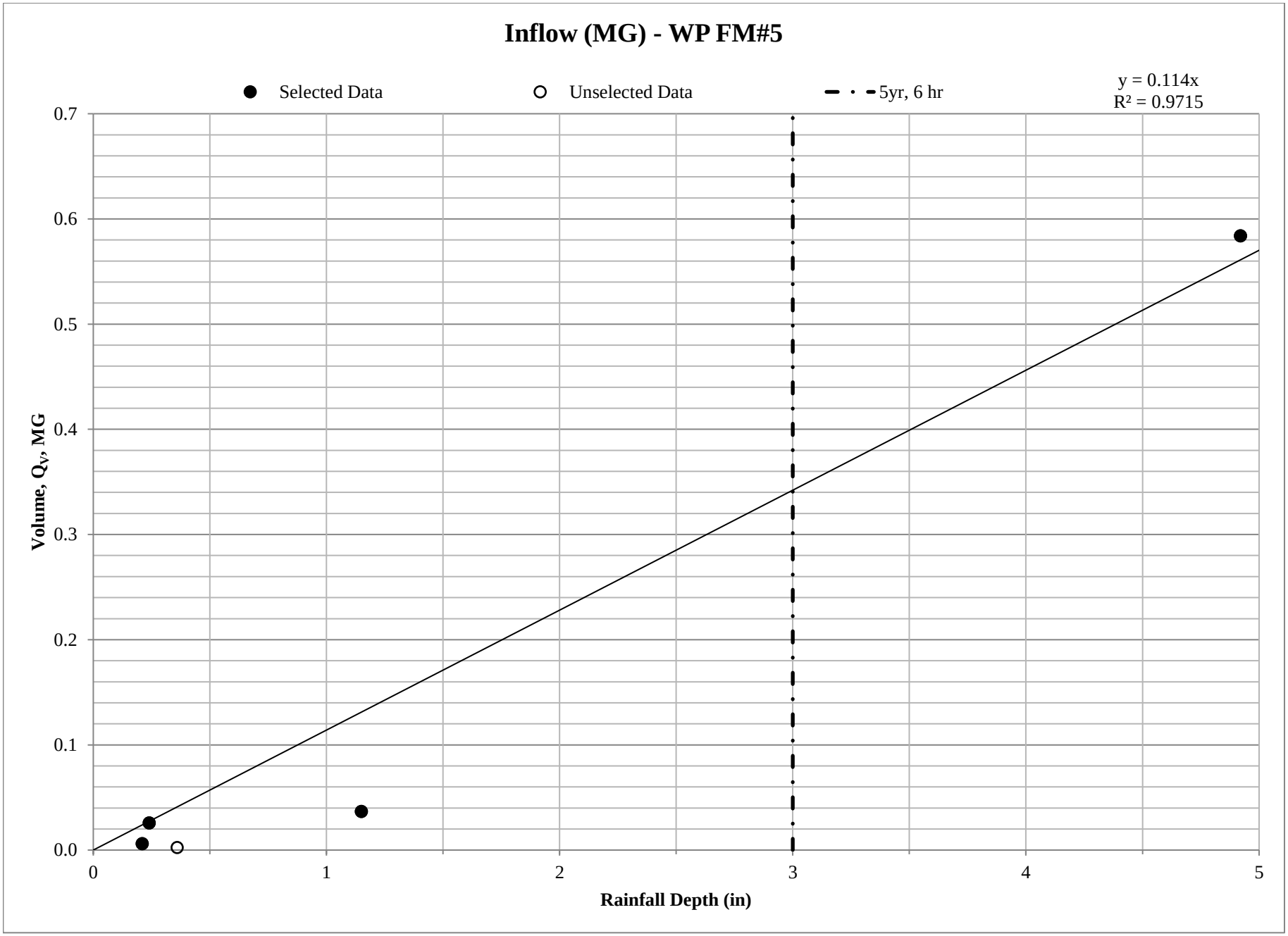

Infiltration (MG) - WP FM#3
Selected Data
Unselected Data
5yr, 6 hr
y = 0.0977x
R² = 0.8503
Volume, Qv, MG
Rainfall Depth (in)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5

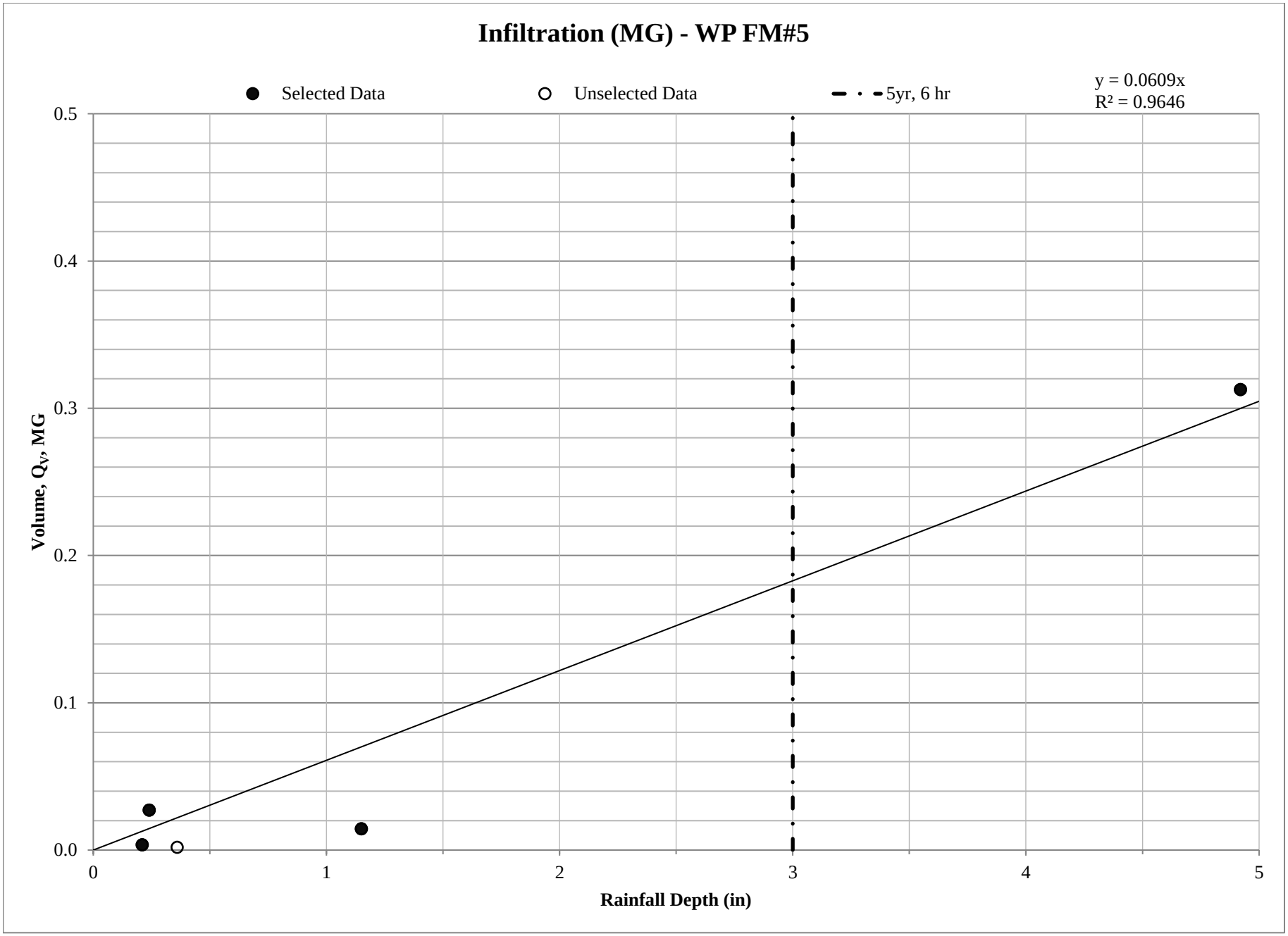

I&I (MG) - WP FM#4
Selected Data
Unselected Data
5yr, 6 hr
y = 0.2111x
R² = 0.9802
Volume, Qv, MG
Rainfall Depth (in)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
1
2
3
4
5

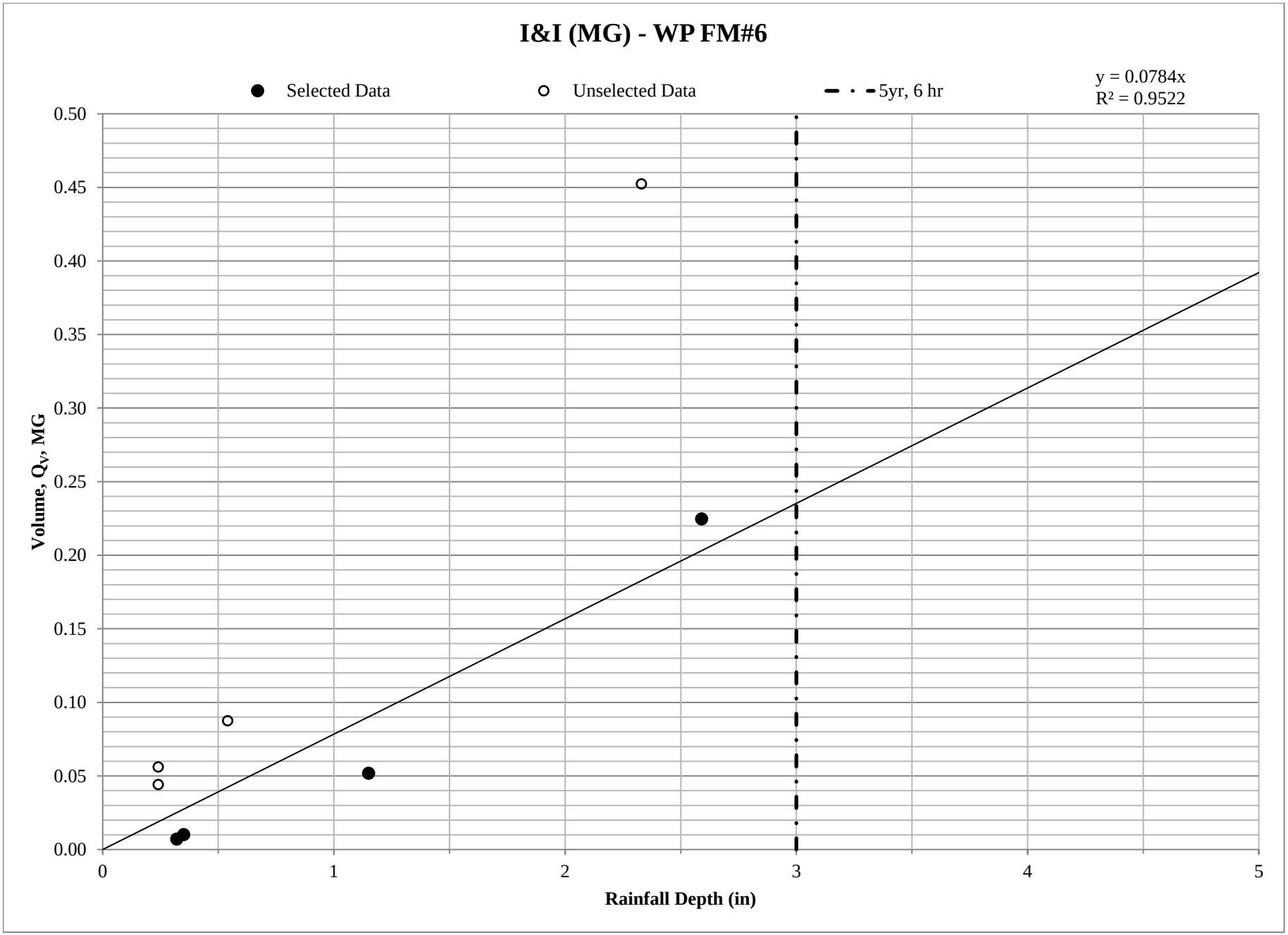

Inflow (MG) - WP FM#4
Selected Data
Unselected Data
5yr, 6 hr
y = 0.1548x
R² = 0.9639
Volume, Qv, MG
Rainfall Depth (in)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
1
2
3
4
5

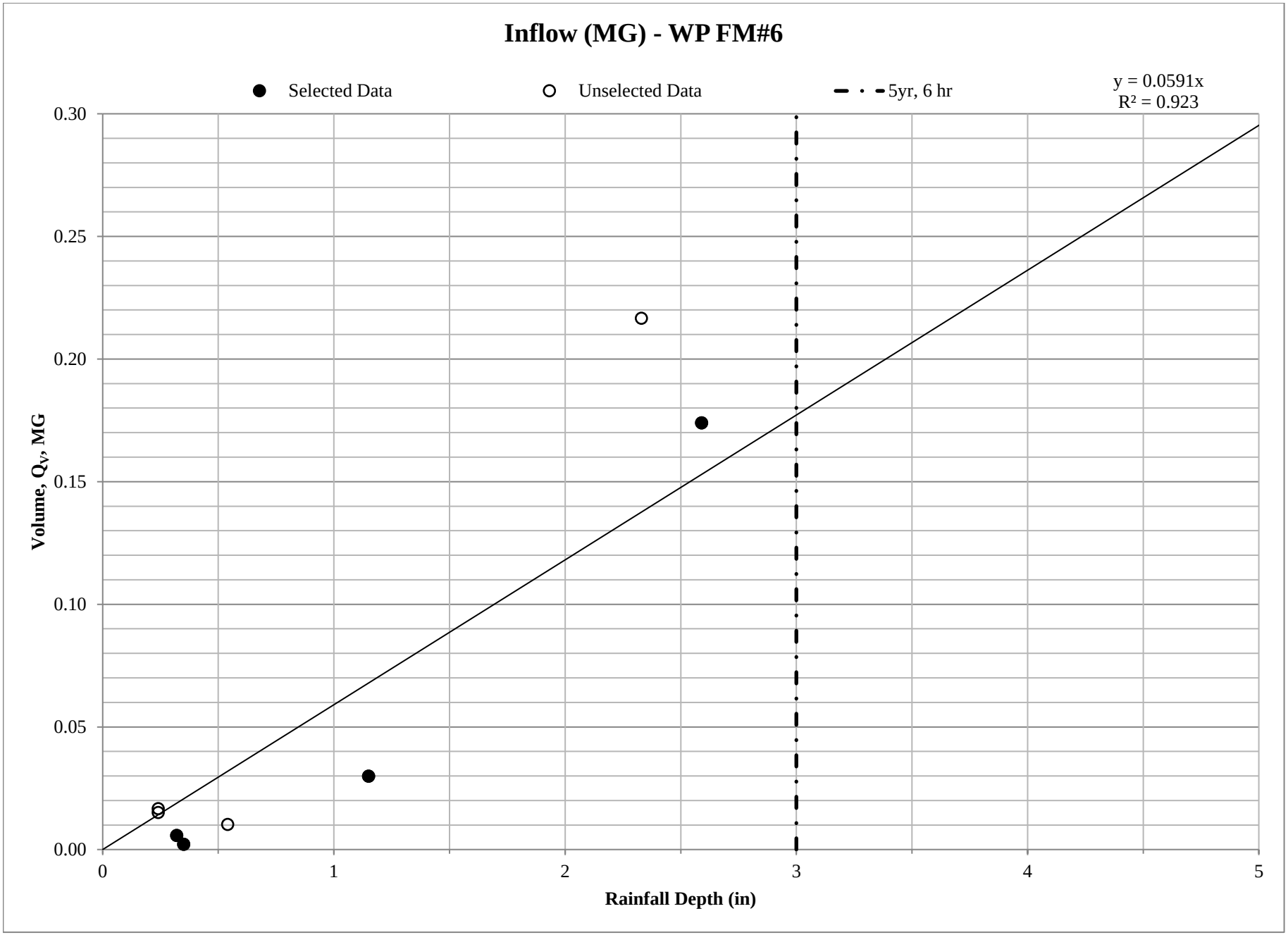

Infiltration (MG) - WP FM#4
Selected Data
Unselected Data
5yr, 6 hr
y = 0.0564x
R² = 0.9976
Volume, Qv, MG
Rainfall Depth (in)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5

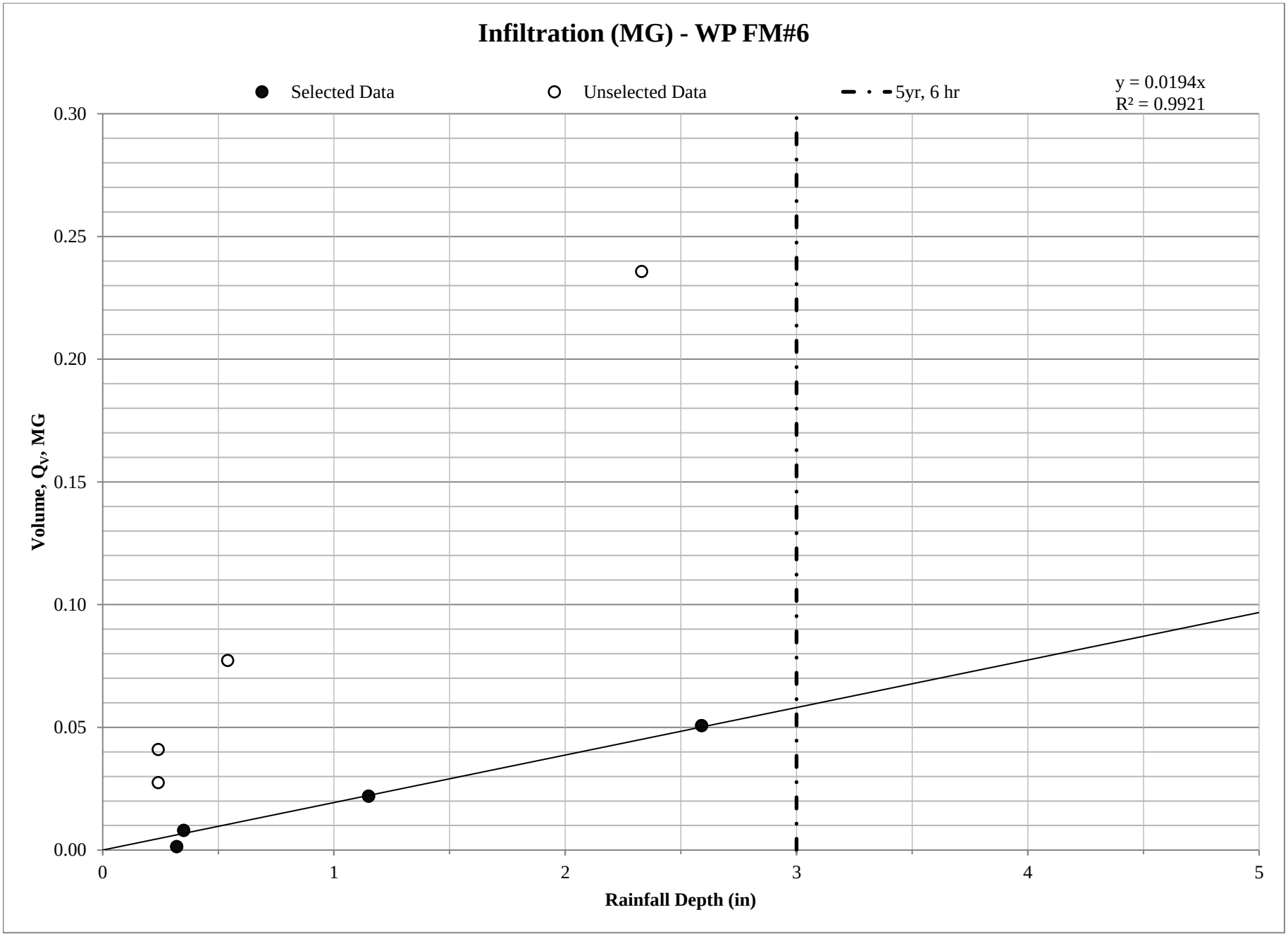

I&I (MG) - WP FM#5
Selected Data
Unselected Data
5yr, 6 hr
y = 0.175x
R² = 0.9695
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)


Inflow (MG) - WP FM#5
Selected Data
Unselected Data
5yr, 6 hr
y = 0.114x
R² = 0.9715
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)


Infiltration (MG) - WP FM#5
Selected Data
Unselected Data
5yr, 6 hr
y = 0.0609x
R² = 0.9646
0.5
0.4
0.3
0.2
0.1
0.0
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)


I&I (MG) - WP FM#6
Selected Data
Unselected Data
5yr, 6 hr
y = 0.0784x
R² = 0.9522
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)


Inflow (MG) - WP FM#6
Selected Data
Unselected Data
5yr, 6 hr
y = 0.0591x
R² = 0.923
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)


Infiltration (MG) - WP FM#6
Selected Data
Unselected Data
5yr, 6 hr
y = 0.0194x
R² = 0.9921
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Volume, Qv, MG
0
1
2
3
4
5
Rainfall Depth (in)

APPENDIX E - I/I ASSESSMENT TABLES

Table E-1: Volume of I/I, Inflow, and Infiltration per Rainfall

Flow Meter ID	Volume I/I (Thousand Gal)[1]		Volume I/I per Rainfall[2]		Rank[3]	Volume Inflow (Thousand Gal)[1]		Volume I/I per Rainfall[2]		Rank[3]	Volume Infiltration (Thousand Gal)[1]		Volume I/I per Rainfall[2]		Rank[3]
	Cum.	Inc.	Cum.	Inc.		Cum.	Inc.	Cum.	Inc.		Cum.	Inc.	Cum.	Inc.	
FM #1	5,155	3,744	1,718	1,248	2	3,558	2,440	1,186	813	1	1,597	1,304	532	435	2
FM #2	4,127	4,127	1,376	1,376	1	2,165	2,165	722	722	2	1,962	1,962	654	654	1
FM #3	1,411	778	470	259	3	1,118	654	373	218	3	293	124	98	41	4
FM #4	633	633	211	211	4	464	464	155	155	4	169	169	56	56	3
FM #5	525	290	175	97	5	342	165	114	55	6	179	120	60	40	5
FM #6	235	235	78	78	6	177	177	59	59	5	59	59	20	20	6

Note 1: Rainfall Depth based on the SCS 5-year, 6-hour event of 3.00 inches.

Note 2: Rainfall Depth based on 1 inch of rainfall.

Note 3: Basin ranking based on volume generated from 1 inch of rainfall.

Table E-2: Volume of I/I, Inflow, and Infiltration per Area per Rainfall

Flow Meter ID	Area	Incremental Volume I/I (Thousand Gal)[1]	Volume I/I per Area[2]	Rank[3]	Incremental Volume Inflow (Thousand Gal)[1]	Volume Inflow per Area[2]	Rank[3]	Incremental Volume Infiltration (Thousand Gal)[1]	Volume Infiltration per Area[2]	Rank[3]
FM #1	479	3,744	2.605	1	2,440	1.698	1	1,304	0.907	1
FM #2	1,256	4,127	1.095	2	2,165	0.575	2	1,962	0.521	2
FM #3	2,558	778	0.101	5	654	0.085	4	124	0.016	6
FM #4	1,849	633	0.114	4	464	0.084	5	169	0.030	5
FM #5	1,288	290	0.075	6	165	0.043	6	120	0.031	4
FM #6	346	235	0.226	3	177	0.171	3	59	0.057	3

Note 1: Rainfall Depth based on the SCS 5-year, 6-hour event of 3.00 inches.

Note 2: Rainfall Depth based on 1 inch of rainfall.

Note 3: Basin ranking based on volume generated from 1 inch of rainfall.

Table E-3: Overall Basin Rankings for Total I/I, Inflow, and Infiltration

Flow Meter ID	Sum of I/I Index Rankings	Overall I/I Rank	Sum of Inflow Index Rankings	Overall Inflow Rank	Sum of Infiltration Index Rankings	Overall Infiltration Rank	Total	Overall Rank
FM #1	3	1	2	1	3	1	8	1
FM #2	3	1	4	2	3	1	10	2
FM #3	8	3	7	3	10	6	25	3
FM #4	8	3	9	5	8	3	25	3
FM #5	11	6	12	6	9	4	32	6
FM #6	9	5	8	4	9	4	26	5

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