City of Lincoln

2017 Flow Monitoring and Inflow/Infiltration Study

Prepared for:

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Date:

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<V&A Project No. 15-0319 Task Order 2>

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Abbreviations and Acronyms

Abbreviations/Acronyms	Definition
ADWF	Average Dry Weather Flow
AVG	Average
CCTV	Closed-Circuit Television
CDEC	California Data Exchange Center
CIP	Capital Improvement Plan
CO	Carbon Monoxide
CWOP	Citizen Weather Observing Program
DIA.	Diameter
d/D	Depth/Diameter Ratio
FT.	Feet
FM	Flow Monitor
GPD	Gallons per Day
GPM	Gallons per Minute
GWI	Groundwater Infiltration
H2S	Hydrogen Sulfide
IN.	Inch
I/I	Inflow and Infiltration
IDM	Inch-Diameter Mile
IDW	Inverse Distance Weighting
LEL	Lower Explosive Limit
MAX.	Maximum
MGD	Million Gallons per Day
MIN.	Minimum
NOAA	National Oceanic and Atmospheric Administration
N/A	Not applicable
PF	Peaking Factor
PS	Pump Station
Q	Flow Rate
RDI/I	Rainfall-Dependent Infiltration and Inflow
RG	Rain Gauge
SSO	Sanitary Sewer Overflow
V&A	V&A Consulting Engineers, Inc.
WEF	Water Environment Federation
WRCC	Western Regional Climate Center

Terms and Definitions

Term	Definition
Average dry weather flow (ADWF)	Average flow rate or pattern from days without noticeable inflow or infiltration response. ADWF usage patterns for weekdays and weekends differ and must be computed separately. ADWF is expressed as a numeric average and may include the influence of normal groundwater infiltration (not related to a rain event).
Basin	Sanitary sewer collection system upstream of a given location (often a flow meter), including all pipelines, inlets, and appurtenances. Also refers to the ground surface area near and enclosed by pipelines. A basin may refer to the entire collection system upstream from a flow meter or exclude separately monitored basins upstream.
Depth/diameter (*d/D*) ratio	Depth of water in a pipe as a fraction of the pipe's diameter. A measure of fullness of the pipe used in capacity analysis.
Design storm	A theoretical storm event of a given duration and intensity that aligns with historical frequency records of rainfall events. For example, a 10-year, 24-hour design storm is a storm event wherein the volume of rain that falls in a 24-hour period would historically occur once every 10 years. Design storm events are used to predict I/I response and are useful for modeling how a collection system will react to a given set of storm event scenarios.
Infiltration and inflow	Infiltration and inflow (I/I) rates are calculated by subtracting the ADWF flow curve from the instantaneous flow measurements taken during and after a storm event. Flow in excess of the baseline consists of inflow, rainfall-responsive infiltration, and rainfall-dependent infiltration. **Total I/I** is the total sum in gallons of additional flow attributable to a storm event.
Infiltration, *groundwater*	Groundwater infiltration (**GWI**) is groundwater that enters the collection system through pipe defects. GWI depends on the depth of the groundwater table above the pipelines as well as the percentage of the system that is submerged. The variation of groundwater levels and subsequent groundwater infiltration rates is seasonal by nature. On a day-to-day basis, groundwater infiltration rates are relatively steady and will not fluctuate greatly.
Infiltration, *rainfall-dependent*	Rainfall-dependent infiltration (**RDI**) is similar to groundwater infiltration but occurs as a result of storm water. The storm water percolates into the soil, submerges more of the pipe system, and enters through pipe defects. RDI is the slowest component of storm-related infiltration and inflow, beginning gradually and often lasting 24 hours or longer. The response time depends on the soil permeability and saturation levels.
Inflow	**Inflow** is defined as water discharged into the sewer system, including private sewer laterals, from **direct** connections such as downspouts, yard and area drains, holes in manhole covers, cross-connections from storm drains, or catch basins. Inflow creates a peak flow problem in the sewer system and often dictates the required capacity of downstream pipes and transport facilities to carry these peak instantaneous flows. Overflows are often attributable to high inflow rates.
Peaking factor (PF)	PF is the ratio of peak measured flow to average dry weather flow. This ratio expresses the degree of fluctuation in flow rate over the monitoring period and is used in capacity analysis.
Surcharge	When the flow level is higher than the crown of the pipe, then the pipeline is said to be in a **surcharged** condition. The pipeline is surcharged when the *d/D* ratio is greater than 1.0.
Synthetic hydrograph	A set of algorithms has been developed to approximate the actual I/I hydrograph. The synthetic hydrograph is developed strictly using rainfall data and response parameters representing response time, recession coefficient and soil saturation.

Executive Summary

Scope and Purpose

V&A Consulting Engineers (V&A) has completed sanitary sewer flow monitoring and rainfall monitoring with I/I analysis in the City of Lincoln (City). Flow and rainfall monitoring was performed over a period of over 2 months from January 4, 2017 to March 7, 2017. Open-channel flow monitoring was performed at 9 sites with submerged area-velocity sensors and volumetric-time flow monitoring was performed at 2 pump stations with state loggers. There were three general purposes of this study.

1. Establish the baseline sanitary sewer flows at the flow monitoring sites.
2. Estimate available sewer capacity.
3. Isolate I/I response and perform I/I analysis.

Monitoring Sites

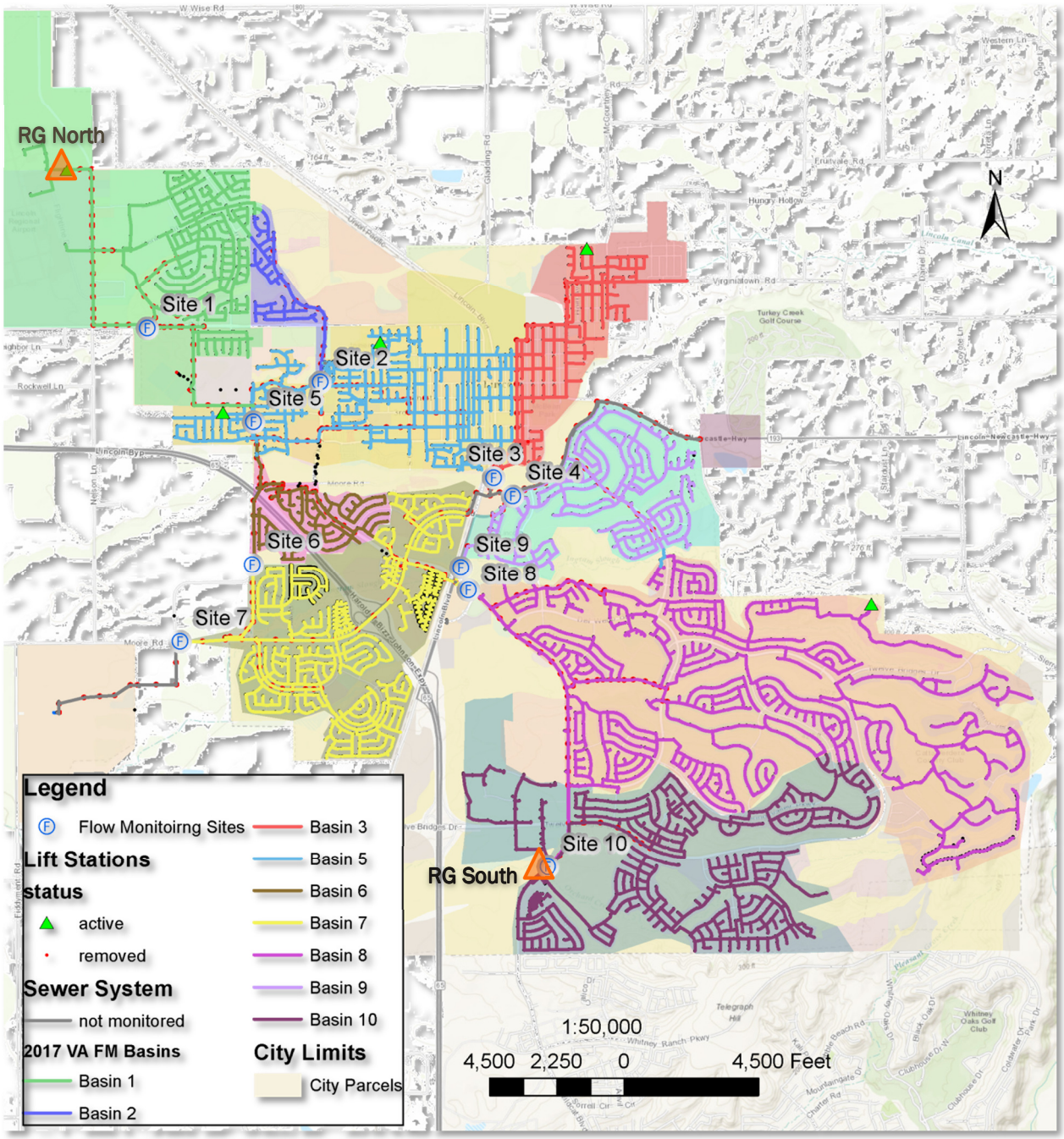
The flow monitoring site locations were selected and approved by Stantec and are listed in Table ES-1. The monitoring site locations and associated sewerage basins are illustrated in Figure ES-1.

Table ES-1. List of Monitoring Sites

Monitoring Site	City Manhole ID	Pipe Diameter (in)
Site 1*	NW355SS24	30
Site 2	NW386SS31	18
Site 3	NE492SS15	30
Site 4	SE493SS03	48
Site 5	NW355SS27	30
Site 6	SW359SS001	36.75
Site 7	SW361SS02	66
Site 8	SE461SS09	24
Site 9	SE461SS05	30
Site 10 PS**	N/A	N/A

* Nicholas PS was monitored via PS state loggers in support of the Site 1 flowmeter. The data from the Site 1 flow meter will be reported for this study.

** East Joiner PS was monitored via PS state loggers.



Note: colors shown in this figure are intended to differentiate sewerage basins only. The colors do not represent any additional basin information. Basin 4 contains flows from Auburn. The basin pipes, pipe lengths and boundary conditions for Basin 4 were not available for this report and are not illustrated above.

Figure ES-1. Map of Flow Monitoring Sites and Rain Gauges

Rainfall Monitoring

There were four main rainfall events that occurred over the course of the flow monitoring period and rainfall totals were more than double historical normal levels during this time period. The following storm event classification items are noted:

- Event 1 (January 7–13, 2017) was the largest classified rainfall event over the monitoring period.
  - **Short Term (< 24 hours):** There was a very strong hour of rainfall in the northern region of Lincoln that registered as a 50-Year event, dropping 0.9 inches on January 10 from 7:30pm to 8:30pm. This magnitude of cloudburst did not occur over the southern regions of Lincoln.
  - **Long-Term (1 – 10 days):** Event 1 was classified as a 5-year, 4-day rainfall event at RG North and as a 2-year, 4-day storm event at RG South.
- **Season:** For longer durations (>10 days), combined Events 3 and 4 (February 2 to 21) was classified as a 2-Year, 20-Day event. The full 60-day flow monitoring period was classified as a 7-year, 60-day event at RG North and a 3.5-year, 60-day event at RG South.

Flow Monitoring and Capacity Results

Peak measured flows and the consequent hydraulic grade line data are important to understand the capacity limitations of a collection system. The following capacity analysis terms are defined as follows:

- **Peaking Factor:** Peaking factor is defined as the peak measured flow divided by the average dry weather flow (ADWF). Peaking factors are influenced by many factors including size and topography of tributary area, flow attenuation, flow restrictions, characteristics of I/I entering the collection system, and hydraulic features such as pump stations.
- **d/D Ratio:** The d/D ratio is the peak measured depth of flow (d) divided by the pipe diameter (D). The d/D ratio for each site was computed based on the maximum depth of flow for the study. Standards for d/D ratio vary from agency to agency, but typically range between d/D ≤ 0.5 and d/D ≤ 0.75.

Table ES-2 summarizes the peak recorded flows, levels, d/D ratios, and peaking factors per site during the flow monitoring period. Results of note have been shaded in RED. Capacity analysis data is presented on a site-by-site basis and represents the hydraulic conditions only at the site locations; hydraulic conditions in other areas of the collection system will differ.

Table ES-2. Capacity Analysis Summary

Metering Site	ADWF (MGD)	Peak Measured Flow (MGD)	Peaking Factor	Pipe Diameter, *D* (IN)	Max Depth, *d* (IN)	*Max d/D* Ratio	Surcharge above Pipe Crown (FT)
Site 1	0.56	2.75	4.9	30	29.1	0.97	-
Site 2	0.10	0.62	6.1	18	22.1	1.23	0.3
Site 3	0.41	3.16	7.7	30	14.6	0.49	-
Site 4	1.65	11.47	6.9	48	14.1	0.29	-
Site 5	1.12	8.17	7.3	30	26.0	0.87	-
Site 6	1.30	8.78	6.8	36.75	13.9	0.38	-
Site 7	5.68	39.76	7.0	66	102.8	1.56	3.1
Site 8	0.98	5.21	5.3	24	8.7	0.36	-
Site 9	0.78	2.18	2.8	30	5.6	0.19	-
Site 10	0.50	2.08	4.1	N/A	N/A	N/A	N/A

Figure ES-2 illustrates a flow schematic of the peak flow condition at the flow monitoring sites. The following capacity analysis results are noted:

- Peaking Factor
  - Sites 3, 5 and 7 had peaking factors greater than 7. Peak flows for all sites occurred during Event 1.
- d/D Ratio:
  - Sites 2 and 7 reached a surcharged condition, surcharging 0.3 and 3.1 feet, respectively. Site 7 is located near the treatment facility; the surcharge event for Site 7 may have been due to treatment plant operations.
  - Sites 1 and 5 had a maximum *d/D* ratio that just exceeded a typical threshold of 0.75.

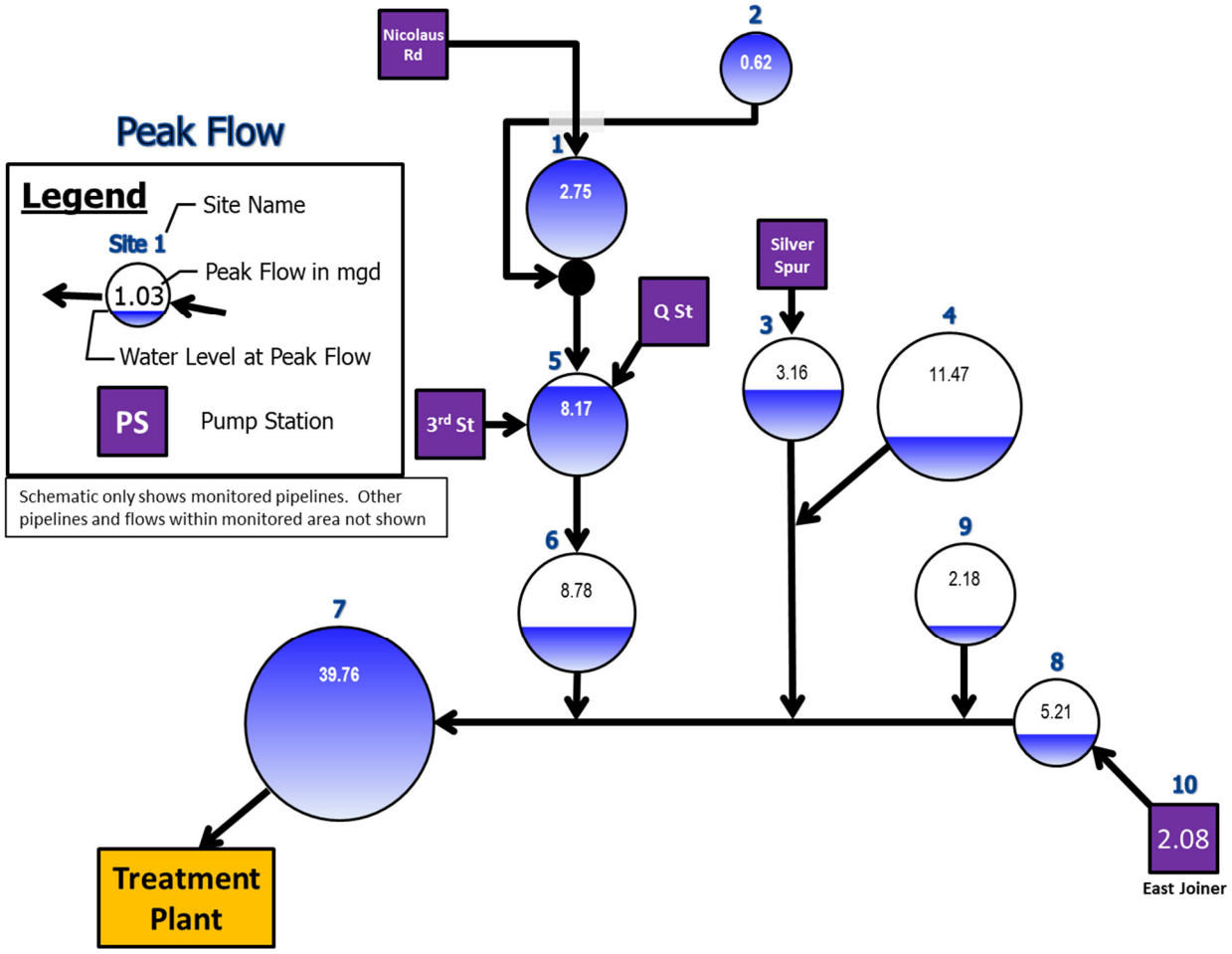


Figure ES-2. Wet Weather Flow Schematic

Infiltration and Inflow Analysis

Table ES-3 summarizes the flow monitoring and I/I results for the flow monitoring sites that were monitored during this study. A ranking of "1" represents the most I/I after normalization per both "per-ADWF" and "per-IDM" methods. Please refer to the *I/I Methods* section for more information on inflow and infiltration analysis methods and ranking methods.

Peak I/I rates (used for inflow analysis) were taken from Event 1 (January 7–13, 2017). The period from February 2 to 21, 2017 (Events 3 and 4 combined) was utilized for RDI and combined I/I analyses. Results of note have been shaded in RED.

Table ES-3. I/I Analysis Summary

Metering Basin	ADWF (mgd)	Peak I/I Rate (mgd)	Combined I/I (gallons)	Inflow Ranking	RDI Ranking	Possible High GWI?	Combined I/I Rank
Basin 1	0.56	1.99	9,267,000	6	2	-	5
Basin 2	0.10	0.44	967,000	4	9	-	9
Basin 3	0.41	2.61	8,588,000	2	5	Yes	2
Basin 4	1.65	8.94	31,262,000	5	3	-	3
Basin 5	0.46	4.12	9,400,000	3	8	Yes	4
Basin 6	0.18	0.57	7,256,000	9	1	Yes	1
Basin 7	0.56	9.58	7,987,000	1	10	-	8
Basin 8	0.48	2.86	6,978,000	7	4	-	6
Basin 9	0.78	1.39	5,022,000	8	7	Yes	7
Basin 10	0.50	1.28	4,418,000	10	6	Yes	10

The following inflow/infiltration analysis results are noted:

- Inflow: Basins 3, 5 and 7 had high normalized inflow.
- RDI: Basins 1, 4 and 6 had high normalized RDI contribution.
- GWI: Sites 3, 5, 6, 9 and 10 had high rates of GWI. Site 9 had very high levels of GWI.
- Combined I/I: Basins 3, 4, and 6 had the highest normalized total I/I contribution.
- Basins 3 and 4 ranked high on all the I/I rankings.

Estimated Peak Design Storm Event Flows

Synthetic I/I hydrograph algorithms were developed and applied to a 10-year, 24-hour design storm event. The resulting estimated peak flows hydrographs can be applied to sanitary sewer modeling efforts to determine if the collection system has adequate capacity to handle very large storm events. These results assume full ground saturation, and the peak I/I flows from the design storm coincide with peak baseline sanitary flows to get a "worst-case" scenario of peak wet weather flows. Table ES-4 summarizes the final results for the design storm on a site-by-site basis.

Table ES-4. Design Storm I/I Analysis Summary

Monitoring Site	Peak Dry Weather Flow (mgd)	Peak I/I Rate (mgd)	Peak Flow (mgd)
Site 1	1.32	1.82	3.14
Site 2	0.18	0.41	0.60
Site 3	0.66	3.17	3.83
Site 4	3.60	10.11	13.71
Site 5	1.81	6.88	8.70
Site 6	1.99	7.18	9.17
Site 7	8.31	33.05	41.37
Site 8	1.88	3.91	5.78
Site 9	0.97	1.51	2.47
Site 10	0.84	1.75	2.58

Note: It is possible that the peak flow rates predicted for a design storm event cannot be conveyed due to conveyance capacity limitations of the local collection system. A comprehensive dynamic model is required to determine the locations of the capacity issues and methods for relieving capacity.

Recommendations

V&A advises that future I/I reduction plans consider the following recommendations:

1. **Determine I/I Reduction Program:** The City should examine its I/I reduction needs to determine a future I/I reduction program.
    a. If peak flows, sanitary sewer overflows, and pipeline capacity issues are of greater concern, then priority can be given to investigate and reduce sources of inflow within the basins with the greatest inflow problems. Basins 3, 5 and 7 had the highest normalized inflow.
    b. If infiltration and general pipeline deterioration are of greater concern, then the program can be weighted to investigate and reduce sources of infiltration within the basins with the greatest infiltration problems. Basins 1, 4 and 6 had the highest normalized infiltration.
2. **I/I Investigation Methods:** Potential I/I investigation methods include the following:
    a. Smoke testing: This method is typically used to locate inflow sources.
    b. CCTV inspection: This method is typically used to locate condition assessment defects linked to infiltration sources. This would need to take place immediately after a strong rainfall event when groundwater levels are high so as to try and capture the infiltration “in the act”.
    c. Mini-basin flow monitoring: This method can be used to isolate smaller catchment areas in which to locate infiltration and inflow sources. Isolating the areas where the I/I is originating may be the most prudent course of action.
    d. Nighttime reconnaissance work to (1) investigate and determine direct point sources of inflow and (2) determine the areas and pipe reaches responsible for high levels of infiltration contribution.
3. **I/I Reduction Cost-Effectiveness Analysis:** The City may wish to conduct a study to determine which is more cost-effective: (1) locating the sources of inflow and infiltration and systematically rehabilitating or replacing the faulty pipelines or (2) continued treatment of the additional rainfall-dependent I/I flow.

1 Introduction

1.1 Scope and Purpose

V&A Consulting Engineers (V&A) has completed sanitary sewer flow monitoring and rainfall monitoring with I/I analysis in the City of Lincoln (City). Flow and rainfall monitoring was performed over a period of over 2 months from January 4, 2017 to March 7, 2017. Open-channel flow monitoring was performed at 9 sites with submerged area-velocity sensors and volumetric-time flow monitoring was performed at 2 pump stations with state loggers. There were three general purposes of this study.

1. Establish the baseline sanitary sewer flows at the flow monitoring sites.
2. Estimate available sewer capacity.
3. Isolate I/I response and perform I/I analysis.

1.2 Flow Monitoring Sites, Sewerage Basins and Rain Gauges

Flow monitoring sites are identified as the manholes where the flow monitors were secured and the pipelines wherein the flow sensors were placed. Capacity analysis and flow rate information is presented on a site-by-site basis.

Flow monitoring site data may include the flows of one or many drainage basins. Flow monitoring basins are localized areas of a sanitary sewer collection system upstream of a given location (often a flow meter), including all pipelines, inlets, and appurtenances. The basin refers to the ground surface area near and enclosed by the pipelines[1]. A basin may refer to the entire collection system upstream from a flow meter or may exclude separately monitored basins upstream. I/I analysis in this report will be conducted on a basin-by-basin basis. For this study, subtraction of flows was required to isolate the drainage areas of some flow monitoring basins[2].

V&A installed two rain gauges intending to capture rainfall in the northern and southern regions of the collection system.

The flow monitoring sites were selected and approved by Stantec. Information regarding the flow monitoring and rain gauge locations and associated sewerage basins are listed in Table 1-1 and shown in Figure 1-1 and Figure 1-2. Detailed descriptions of the individual flow monitoring sites, including photographs, are included in Appendix A.

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[1] Basin boundaries and IDM were determined using GIS sanitary sewer maps provided by Stantec. If not indicated, pipe lengths and diameters were estimated. Calculated IDMs for this project are considered estimates.

[2] There is error inherent in flow monitoring. Adding and subtracting flows increases error on an additive basis. For example, if Site A has an error of ±10% and Site B has an error of ±10%, then the resulting flow when subtracting Site A from Site B would have an error of up to ±20%.

Table 1-1. List of Flow Monitoring and Rain Gauge Locations

FM Site/ Basin	City MH ID	Dia. (in)	Location	Basin Size[3] (IDM)	Basin Isolation Equation
1*	NW355SS24 (1 MH downstream of FM discharge)	30	313 Chambers Drive	170.0	= Q_1
2	NW386SS31	18	Joiner Parkway north of 5th Street	35.8	= Q_2
3	NE492SS15	30	In field southeast of Lincoln Boulevard and Gateway Drive	117.3	= Q_3
4	SE493SS03	48	In field north of Ferrari Ranch Road	N/A	= Q_4
5	NW355SS27 (2 MHs upstream of orig. site NW390SS03)	30	2161 Boyden Drive	220.1	= $Q_5 - Q_1 - Q_2$
6	SW359SS001 (5 MHs upstream of orig. site SW360SS002)	36.75	Moore Road north of Sorrento Parkway	85.8	= $Q_6 - Q_5$
7	SW361SS02 (1 MH downstream of orig. site SW361SS03)	66	In field near 2675 Moore Road	338.2	= $Q_7 - Q_6 - Q_3 - Q_4 - Q_9 - Q_8$
8	SE461SS09	24	Parking lot behind Raley's Supermarket at Sterling Parkway and Joiner Parkway	366.3	= $Q_8 - Q_{10}$
9	SE461SS05	30	Lincoln Boulevard sidewalk next to Arco gas station	148.3	= Q_9
10 **	N/A	N/A	East Joiner Parkway west of Fieldstone Drive	262.2	= Q_{10}

Rain Gauge	Location
North	Nicolaus Rd PS
South	East Joiner PS

* Nicholas PS was monitored via PS state loggers in support of Site 1 flowmeter. The data from the Site 1 flow meter will be reported for this study.

** East Joiner PS was monitored via PS state loggers.

[3] Basin 4 contains flows from Auburn. The basin pipes, pipe lengths and boundary conditions were not available for this report.

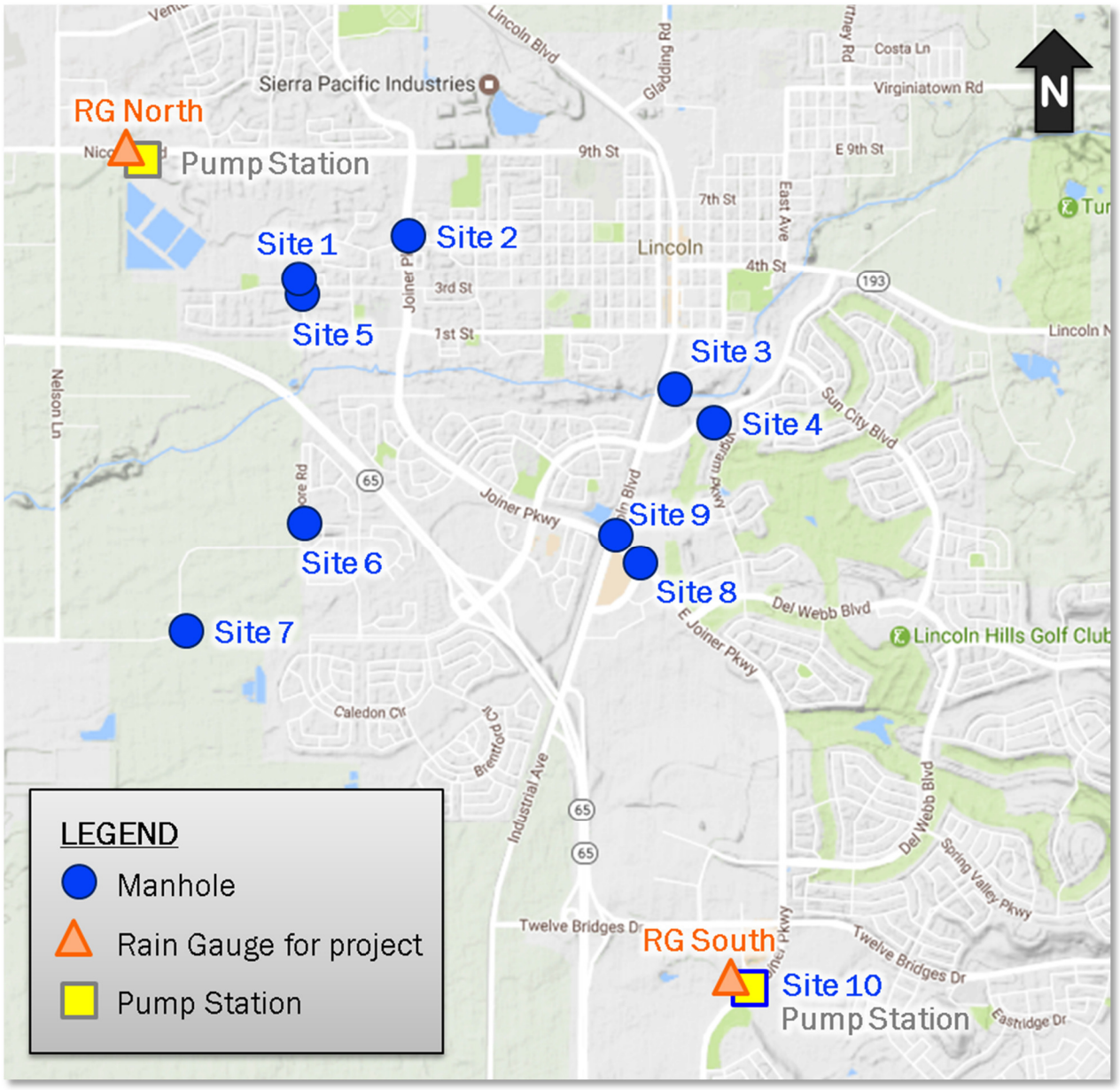
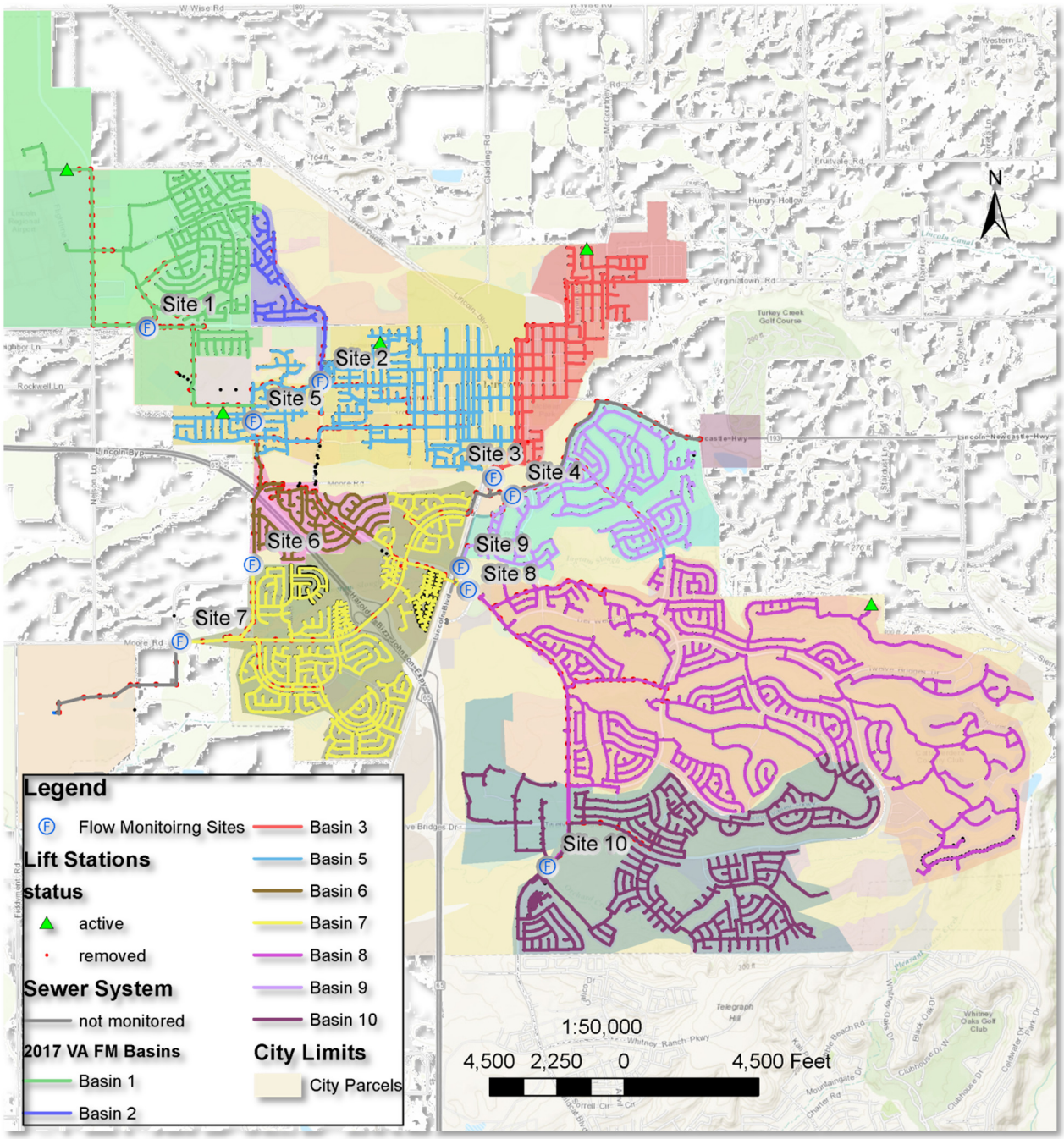


Figure 1-1. Map of Flow Monitoring Sites and Rain Gauges



Note: colors shown in this figure are intended to differentiate sewerage basins only. The colors do not represent any additional basin information. Basin 4 contains flows from Auburn. The basin pipes, pipe lengths and boundary conditions for Basin 4 were not available for this report and are not illustrated above.

Figure 1-2. Map of Flow Monitoring Basins

2 Methods and Procedures

2.1 Confined Space Entry

A confined space (Photo 2-1) is defined as any space that is large enough and so configured that a person can bodily enter and perform assigned work, has limited or restricted means for entry or exit and is not designed for continuous employee occupancy. In general, the atmosphere must be constantly monitored for sufficient levels of oxygen (19.5% to 23.5%), and the presence of hydrogen sulfide (H_2S) gas, carbon monoxide (CO) gas, and lower explosive limit (LEL) levels. A typical confined space entry crew has members with OSHA-defined responsibilities of Entrant, Attendant and Supervisor. The Entrant is the individual performing the work. He or she is equipped with the necessary personal protective equipment needed to perform the job safely, including a personal four-gas monitor (Photo 2-2). If it is not possible to maintain line-of-sight with the Entrant, then more Entrants are required until line-of-sight can be maintained. The Attendant is responsible for maintaining contact with the Entrants to monitor the atmosphere using another four-gas monitor and maintaining records of all Entrants, if there is more than one. The Supervisor is responsible for developing the safe work plan for the job at hand prior to entering.

Photo 2-1. Confined Space Entry

Photo 2-2. Typical Personal Four-Gas Monitor

2.2 Flow Meter Installation

V&A installed Isco 2150 area-velocity flow meters for temporary metering within the collection system. Isco 2150 meters use submerged sensors with a pressure transducer to collect depth readings and an ultrasonic Doppler sensor to determine the average fluid velocity. The ultrasonic sensor emits high-frequency (500 kHz) sound waves, which are reflected by air bubbles and suspended particles in the flow. The sensor receives the reflected signal and determines the Doppler frequency shift, which indicates the estimated average flow velocity. The sensor is typically mounted at a manhole inlet to take advantage of smoother upstream flow conditions. The sensor may be offset to one side to lessen the chances of fouling and sedimentation where these problems are expected to occur. Manual level and velocity measurements were taken during installation of the flow meters and again when they were removed and compared to simultaneous level and velocity readings from the flow meters to ensure proper calibration and accuracy. Figure 2-1 shows a typical installation for a flow meter with a submerged sensor.

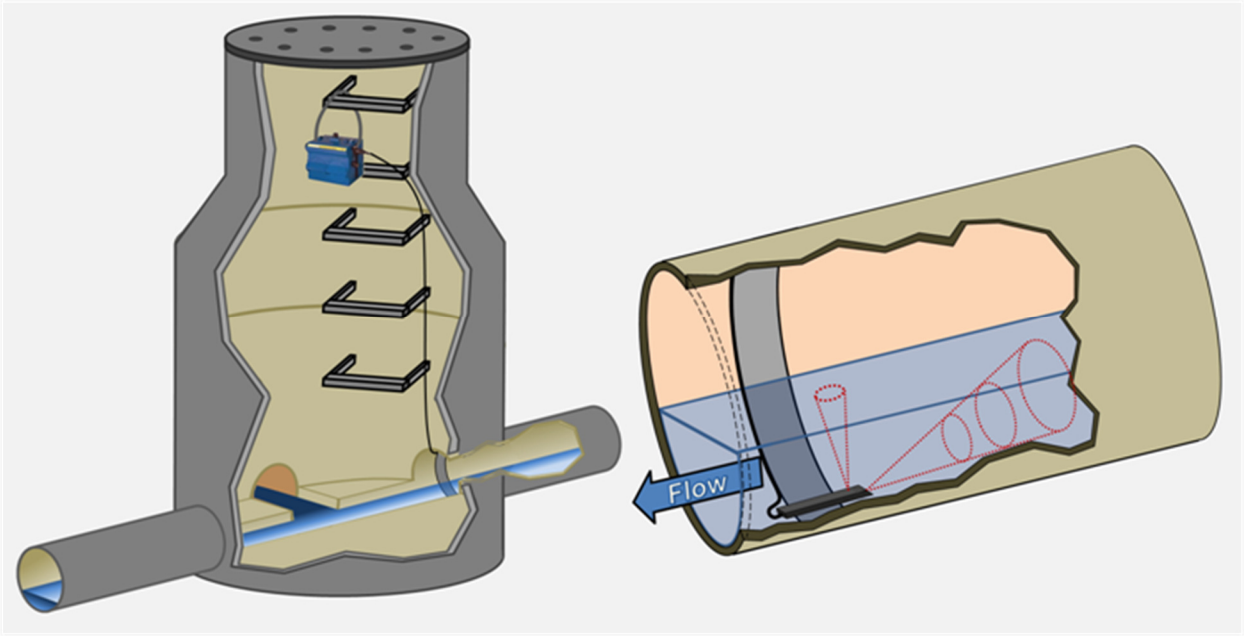


Figure 2-1. Typical Installation for Flow Meter with Submerged Sensor

2.3 State Logger Installation for Volumetric Flow Monitoring

V&A installed state loggers at the Nicolaus Rd Pump Station and the East Joiner Pump Station. The Nicolaus Rd Pump Station logger data acted as a secondary check for Site 1 open-channel flow monitoring data. The East Joiner Pump Station logger data was the individual source of flow monitoring data for Site 10.

Hobo "On/Off" state data loggers were installed on the electrical cables at the control panel for each pump. The state data loggers time stamp when the pumps turn on and off. Using the time elapsed during the wet well fill cycle when both pumps were off (not the pumping cycle), and knowing the volume of the wet well being filled, the influent flow rate is calculated. This flow rate is assigned a date/time at the midpoint of the fill cycle interval. The flow rate with date/time stamp is calculated for every fill cycle and plotted.

Figure 2-2. Hobo Motor On/Off State Logger

2.4 Flow Calculation

Data retrieved from the flow meter was placed into a spreadsheet program for analysis. Data analysis includes data comparison to field calibration measurements, as well as necessary geometric adjustments as required for sediment (sediment reduces the pipe's wetted cross-sectional area available to carry flow). Area-velocity flow metering uses the continuity equation,

$$Q = v \cdot A = v \cdot (A_T - A_S)$$

where Q : volume flow rate
v: average velocity as determined by the ultrasonic sensor
A: cross-sectional area available to carry flow
A_T: total cross-sectional area with both wastewater and sediment
A_S: cross-sectional area of sediment.

For circular pipe,

$$A_T = \left[\frac{D^2}{4}\cos^{-1}\left(1-\frac{2d_W}{D}\right)\right] - \left[\left(\frac{D}{2}-d_W\right)\left(\frac{D}{2}\right)\sin\left(\cos^{-1}\left(1-\frac{2d_W}{D}\right)\right)\right]$$

$$A_S = \left[\frac{D^2}{4}\cos^{-1}\left(1-\frac{2d_S}{D}\right)\right] - \left[\left(\frac{D}{2}-d_S\right)\left(\frac{D}{2}\right)\sin\left(\cos^{-1}\left(1-\frac{2d_S}{D}\right)\right)\right]$$

where d_W: distance between wastewater level and pipe invert
d_S: depth of sediment
D: pipe diameter

2.5 Average Dry Weather Flow Determination

For this study, four distinct average dry weather flow curves were established for each site location:

- Mondays – Thursdays
- Fridays
- Saturdays
- Sundays

Flows for many sites differ on Friday evenings compared to Mondays through Thursdays. Starting around 7 pm, the flows are often decreased (compared to Monday through Thursday). Similarly, flow patterns for Saturday and Sunday were also separated due to their unique evening flow pattern. This type of differentiation can be important when determining I/I response, especially if a rain event occurs on a Friday, Saturday or Sunday evening.

Figure 2-3 illustrates a sample of varying flow patterns within a typical week dry week.

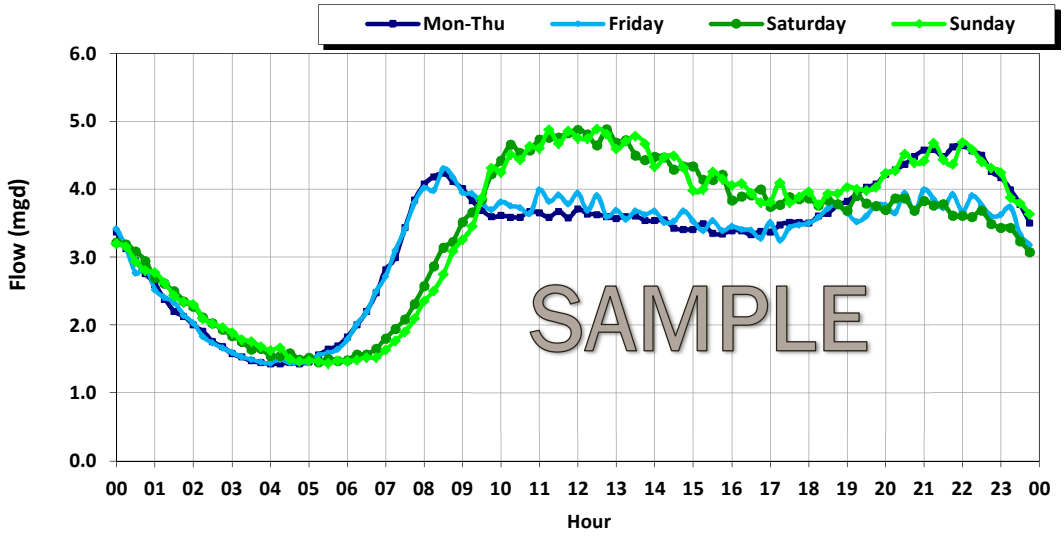


Figure 2-3. Sample ADWF Diurnal Flow Patterns

ADWF curves are taken from "Dry Days", when RDI had the least impact on the baseline flow. The overall average dry weather flow (ADWF) was calculated per the following equation:

$$ADWF = \left(ADWF_{Mon-Thu} \times \frac{4}{7} \right) + \left(ADWF_{Fri} \times \frac{1}{7} \right) + \left(ADWF_{Sat} \times \frac{1}{7} \right) + \left(ADWF_{Sun} \times \frac{1}{7} \right),$$

2.6 Flow Attenuation

Flow attenuation in a sewer collection system is the natural process of the reduction of the peak flow rate through redistribution of the same volume of flow over a longer period of time. This occurs as a result of friction (resistance), internal storage and diffusion along the sewer pipes. Fluids are constantly working towards equilibrium. For example, a volume of fluid poured into a static vessel with no outside turbulence will eventually stabilize to a static state, with a smooth fluid surface without peaks and valleys. Attenuation within a sanitary sewer collection system is based upon this concept. A flow profile with a strong peak will tend to stabilize towards equilibrium, as shown in Figure 2-4.

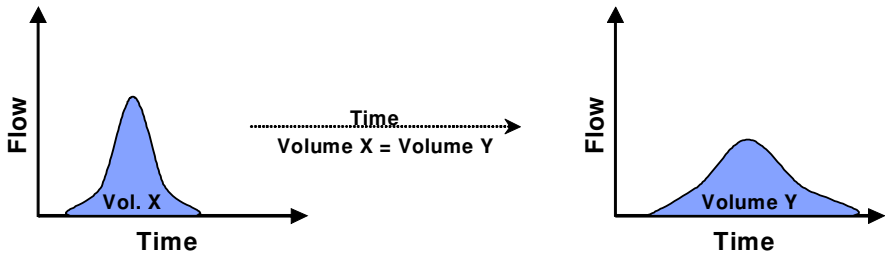


Figure 2-4. Attenuation Illustration

Within a sanitary sewer collection system, each individual basin will have a specific flow profile. As the flows from the basins combine within the trunk sewer lines, the peaks from each basin will (a) not necessarily coincide at the same time, and (b) due to the length and time of travel through the trunk sewers, peak flows will attenuate prior to reaching the treatment facility. The sum of the peak flows of the individual basins within a collection system will usually be greater than the peak flows observed at the treatment facility.

2.7 Inflow / Infiltration Analysis: Definitions and Identification

Inflow and infiltration (I/I) consists of storm water and groundwater that enter the sewer system through pipe defects and improper storm drainage connections and is defined as follows:

2.7.1 Definition and Typical Sources

- **Inflow:** Storm water inflow is defined as water discharged into the sewer system, including private sewer laterals, from direct connections such as downspouts, yard and area drains, holes in manhole covers, cross-connections from storm drains, or catch basins.
- **Infiltration:** Infiltration is defined as water entering the sanitary sewer system through defects in pipes, pipe joints, and manhole walls, which may include cracks, offset joints, root intrusion points, and broken pipes.

Figure 2-5 illustrates the possible sources and components of I/I.

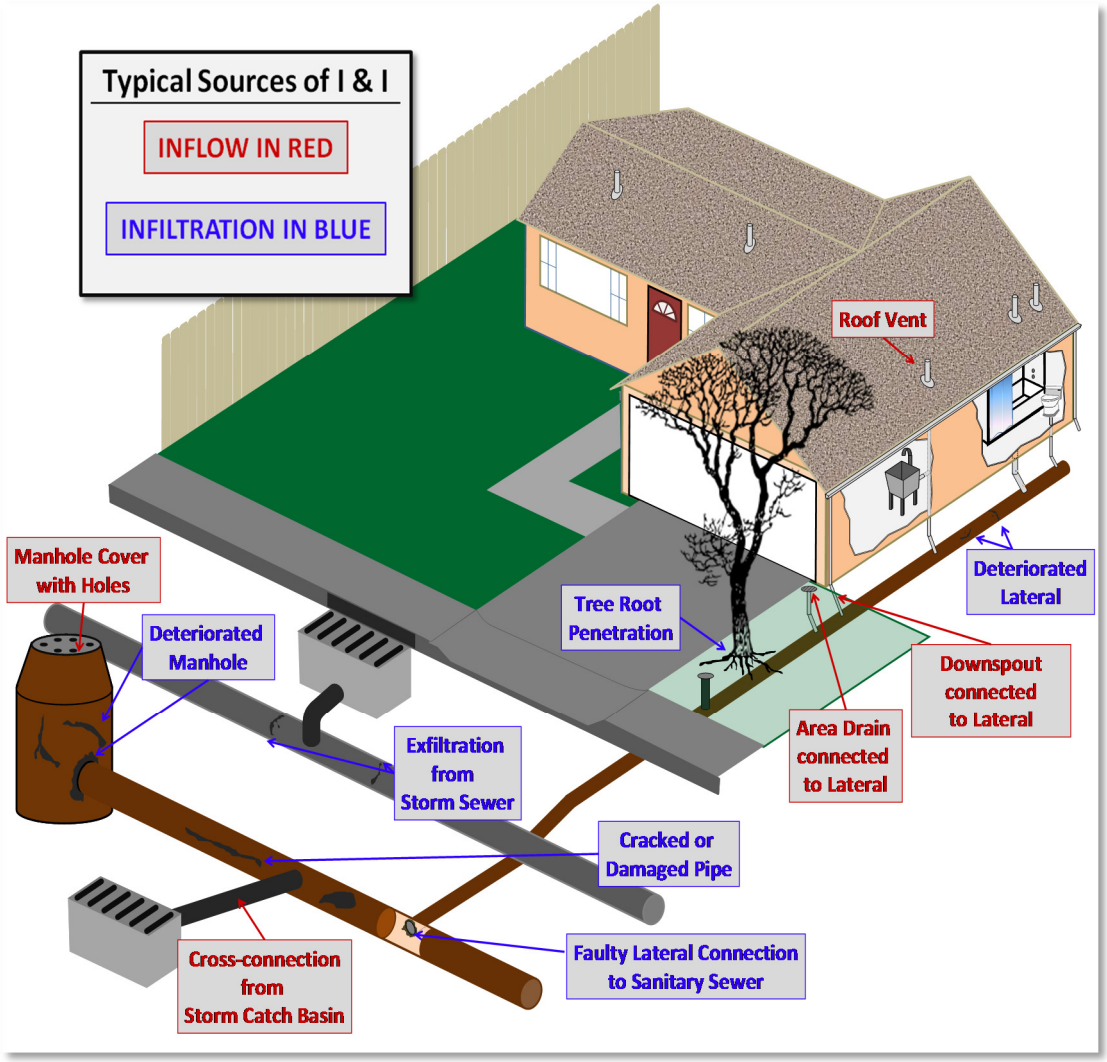


Figure 2-5. Typical Sources of Infiltration and Inflow

2.7.2 Infiltration Components

Infiltration can be further subdivided into components as follows:

- **Groundwater Infiltration:** Groundwater infiltration (GWI) depends on the depth of the groundwater table above the pipelines as well as the percentage of the system submerged. The variation of groundwater levels and subsequent groundwater infiltration rates is seasonal by nature. On a day-to-day basis, groundwater infiltration rates are relatively steady and will not fluctuate greatly.
- **Rainfall-Dependent Infiltration:** Rainfall-Dependent Infiltration (RDI) occurs as a result of storm water and enters the sewer system through pipe defects, as with groundwater infiltration. The storm water first percolates directly into the soil and then migrates to an infiltration point. Typically, the time of concentration for rainfall-related infiltration may be 24 hours or longer, but this depends on the soil permeability and saturation levels.
- **Rainfall-Responsive Infiltration** is storm water which enters the collection system indirectly through pipe defects, but normally in sewers constructed close to the ground surface such as private laterals. Rainfall-responsive infiltration is independent of the groundwater table and reaches defective sewers via the pipe trench in which the sewer is constructed, particularly if the pipe is placed in impermeable soil and bedded and backfilled with a granular material. In this case, the pipe trench serves as a conduit similar to a French drain, conveying storm drainage to defective joints and other openings in the system. This type of infiltration can have a quick response and graphically can look very similar to inflow.

2.7.3 Impact and Cost of Source Detection and Removal

- **Inflow:**
  - Impact: This component of I/I creates a peak flow problem in the sewer system and often dictates the required capacity of downstream pipes and transport facilities to carry these peak instantaneous flows. Because the response and magnitude of inflow is tied closely to the intensity of the storm event, the short-term peak instantaneous flows may result in surcharging and overflows within a collection system. Severe inflow may result in sewage dilution, resulting in upsetting the biological treatment (secondary treatment) at the treatment facility.
  - Cost of Source Identification and Removal: Inflow locations are usually less difficult to find and less expensive to correct. These sources include direct and indirect cross-connections with storm drainage systems, roof downspouts, and various types of surface drains. Generally, the costs to identify and remove sources of inflow are low compared to potential benefits to public health and safety or the costs of building new facilities to convey and treat the resulting peak flows.
- **Infiltration:**
  - Impact: Infiltration typically creates long-term annual volumetric problems. The major impact is the cost of pumping and treating the additional volume of water, and of paying for treatment (for municipalities that are billed strictly on flow volume).
  - Cost of Source Detection and Removal: Infiltration sources are usually harder to find and more expensive to correct than inflow sources. Infiltration sources include defects in deteriorated sewer pipes or manholes that may be widespread throughout a sanitary sewer system.

2.7.4 Graphical Identification of I/I

Inflow is usually recognized graphically by large-magnitude, short-duration spikes immediately following a rain event. Infiltration is often recognized graphically by a gradual increase in flow after a wet-weather event. The increased flow typically sustains for a period after rainfall has stopped and then gradually drops off as soils become less saturated and as groundwater levels recede to normal levels. Real time flows were plotted against ADWF to analyze the I/I response to rainfall events. Figure 2-6 illustrates a sample of how this analysis is conducted and some of the measurements that are used to distinguish infiltration and inflow. Similar graphs were generated for the individual flow monitoring sites and can be found in *Appendix A*.

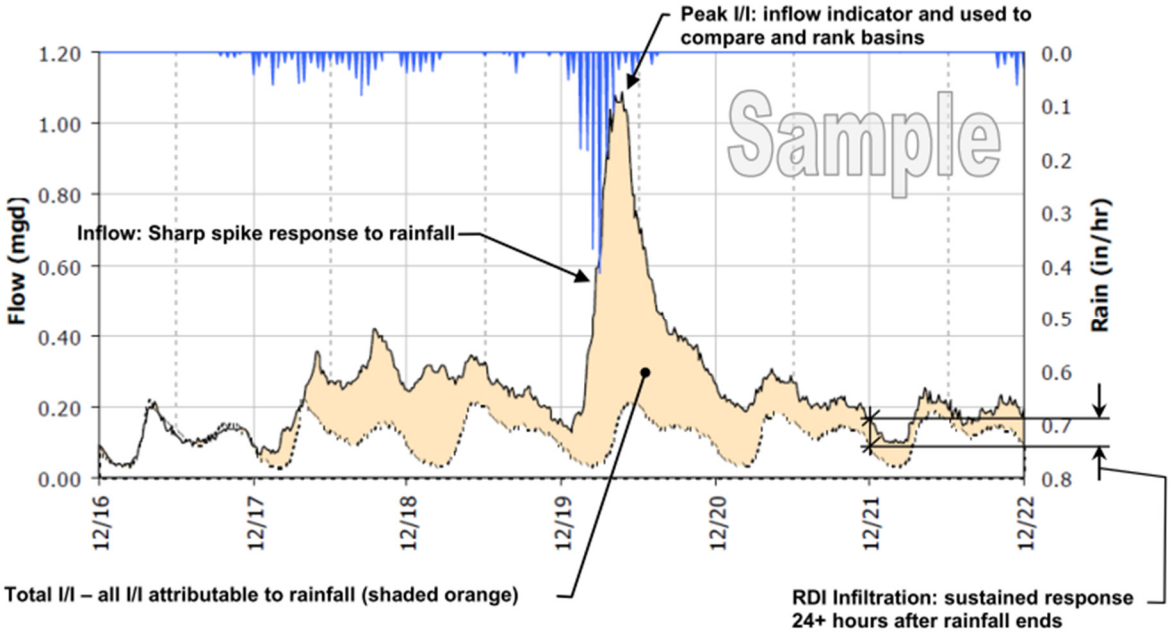


Figure 2-6. Sample Infiltration and Inflow Isolation Graph

2.7.5 Analysis Metrics

After differentiating I/I flows from ADWF flows, various calculations can be made to determine which I/I component (inflow or infiltration) is more prevalent at a particular site and to compare the relative magnitudes of the I/I components between drainage basins and between storm events:

- **Inflow – Peak I/I Flow Rate:** Inflow is characterized by sharp, direct spikes occurring during a rainfall event. Peak I/I rates are used for inflow analysis[4].
- **Groundwater Infiltration:** GWI analysis is conducted by looking at minimum dry weather flow to average dry weather flow ratios and comparing them to established standards to quantify the rate of excess groundwater infiltration.
- **Rainfall-Dependent Infiltration:** RDI Analysis is conducted by looking at the infiltration rates at set periods after the conclusion of a storm event. Depending on the particular collection system

[4] I/I flow rate is the real time flow less the estimated average dry weather flow rate. It is an estimate of flows attributable to rainfall. By using peak measured flow rates (inclusive of ADWF), the I/I flow rate would be skewed higher or lower depending on whether the storm event I/I response occurs during low-flow or high-flow hours.

and the time required for flows to return to ADWF levels, different periods may be examined to determine the basins with the greatest or most sustained rainfall-dependent infiltration rates.

- **Total Infiltration:** The total inflow and infiltration is measured in gallons per site and per storm event. Because it is based on total I/I volume, it is an indicator of combined inflow and infiltration and is used to identify the overall volumetric influence of I/I within the monitoring basin.

2.7.6 Normalization Methods

There are three ways to *normalize* the I/I analysis metrics for an "apples-to-apples" comparison amongst the different drainage basins:

- **per-ADWF:** The metric is divided by the established average dry weather flow rate and typically expressed as a ratio. *Peaking Factors* are examples of using ADWF to normalize data from different sites.
- **per-IDM:** The metric is divided by length of pipe (IDM [inch-diameter mile]) contained within the upstream basin. Final units typically are gallons per day (gpd) per IDM.
- **per-ACRE:** The metric is divided by the acreage of the upstream basin. Final units typically are gallons per day (gpd) per ACRE.

The infiltration and inflow indicators were normalized by the per-IDM and per-ADWF methods in this report, with per-IDM weighted 60% for rankings[5]. The per-IDM method was given a stronger percentage as I/I rehabilitation and/or reduction efforts are typically budgeted per unit length of pipe.

[5] Basin 4 is not included in the per-IDM rankings as Basin 4 contains flows from Auburn and the IDM lengths were not available.

3 Rainfall Results

3.1 Rainfall Monitoring

There were four main rainfall events that occurred over the course of the flow monitoring period, as summarized in Table 3-1. Events 3 and 4 occurred close to each other and were combined for I/I analyses conducted later in this report.

Figure 3-1 shows the rainfall average of the two rain gauges over the flow monitoring period, as the flow monitored basins were distributed between the two rain gauges. Additionally, the meters were installed during a rain event and rainfall data for January 1 to 4, prior to the rain gauge installation, were obtained from a Citizen Weather Observation Program (CWOP) for a full understanding of the rain event.

Table 3-1. Rainfall Events Used for I/I Analysis

Rainfall Event	RG North (in)	RG South (in)	RG Average (in)
Event 1: Jan 7 – Jan 13, 2017	5.45	4.24	4.75
Event 2: Jan 18 – Jan 24, 2017	1.83	2.07	1.93
Event 3: Feb 2 – Feb 12, 2017	4.34	4.44	4.39
Event 4: Feb 16 – Feb 21, 2017	2.90	3.02	2.96
Total over Monitoring Period (incl. Jan 2 – Jan 4)	*16.75*	*15.18*	*15.97*

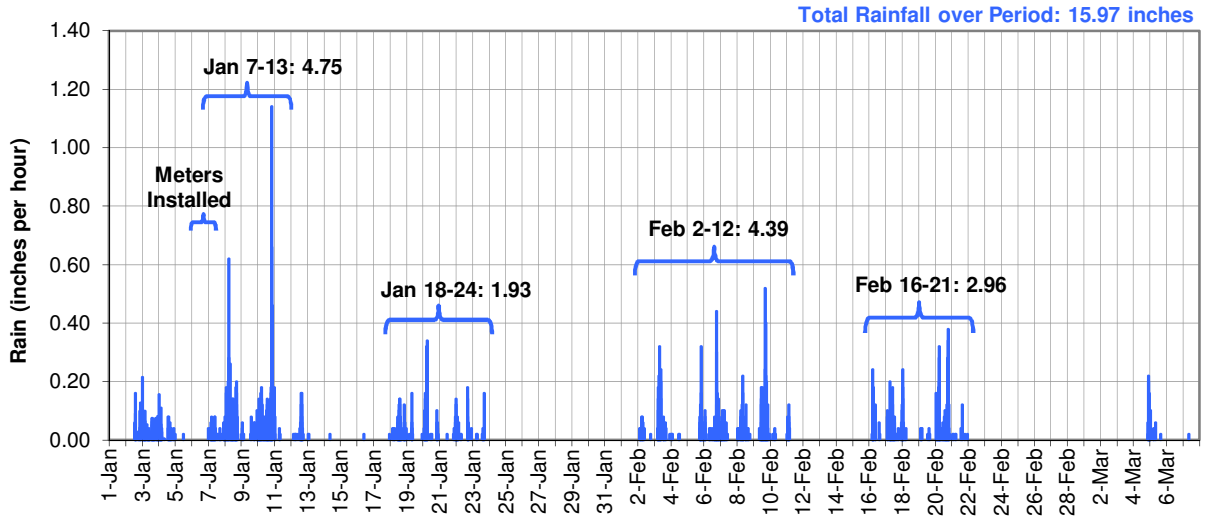


Figure 3-1. Rainfall Activity over Monitoring Period (Average of RG North and RG South)

Figure 3-2 shows the rain accumulation plot of the period rainfall, as well as the historical average rainfall[6] in Lincoln during this project duration. The historical average rainfall was obtained using the inverse distance weighting method (Section 3.1.1 on Page 25) from stations in Rocklin and Marysville. Rainfall totals for Lincoln were more than double historical normal levels during this time period.

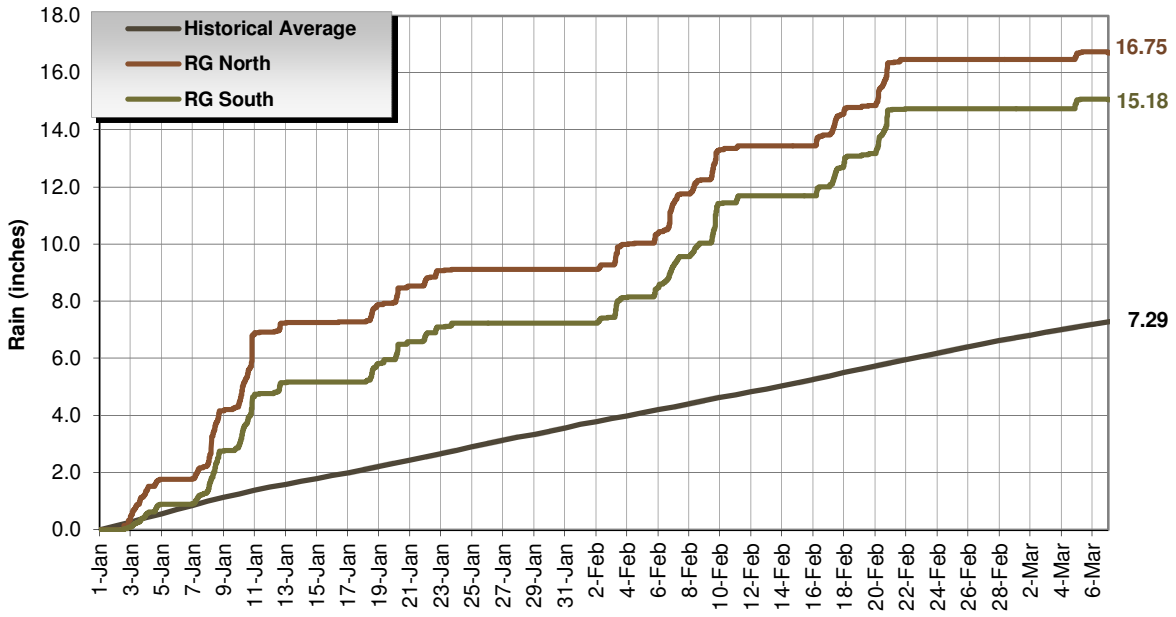


Figure 3-2. Accumulated Precipitation Monitored from Different Locations

[6] Historical data taken from the WRCC (Station 47516 in Rocklin and Station 45385 in Marysville): http://www.wrcc.dri.edu/summary/climsmnca.html

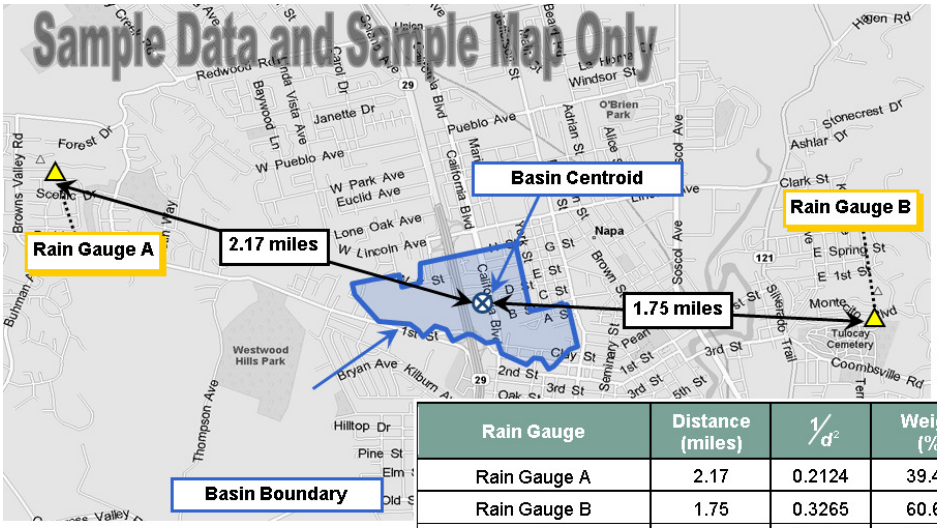
3.1.1 Rain Gauge Triangulation Distribution

Since historic rainfall data was not available for the City of Lincoln, it was calculated based on the proximity to other nearby historic rain gauge stations. The inverse distance weighting (IDW) method is an interpolation method that assumes the influence of each rain gauge location diminishes with distance.

IDW is performed using the equation:

$$w = \frac{1/d^p}{\sum 1/d^p}$$

where the weight, *w*, depends on the distance, *d*, from the available rain gauge to the desired location and *p*, a user-selected power ($p > 0$). The most common choice of *p* in hydrological studies of watershed areas is 2. Figure 3-3 illustrates the IDW method with sample data. The rain gauge distribution as calculated for each basin for this study is shown in Table 3-2.



Rain Gauge	Distance (miles)	$1/d^2$	Weight (%)
Rain Gauge A	2.17	0.2124	39.4%
Rain Gauge B	1.75	0.3265	60.6%
Totals		**0.5389**	**100%**

Figure 3-3. Rainfall Inverse Distance Weighting Method

Table 3-2. Rain Gauge Distribution by Basin

Basin	RG North (Nicolaus Rd PS)	RG South (East Joiner PS)
Basin 01	98%	2%
Basin 02	95%	5%
Basin 03	59%	41%
Basin 04	38%	62%
Basin 05	81%	19%
Basin 06	75%	25%
Basin 07	43%	57%
Basin 08	14%	86%
Basin 09	39%	61%
Basin 10	3%	97%

3.2 Rainfall: Storm Event Classification

It is important to classify the relative size of a major storm event that occurs over the course of a flow monitoring period in order to compare the observed flow response to that occurring during a design storm event (sanitary sewers are often designed to withstand I/I contribution to sanitary flows for specific-sized "design" storm events). Rainfall events are classified by intensity and duration. For example, the National Oceanic and Atmospheric Administration (NOAA) Rainfall Frequency Atlas shown in Figure 3-4 (NOAA Western U.S. Precipitation Frequency Maps Atlas 14, Volume 6, Version 2: http://www.wrcc.dri.edu/pcpnfreq.html) classifies a 10-year, 24-hour storm event at RG North as 3.38 inches. This means that in any given year, at this specific location, there is a 10% chance that 3.38 inches of rain will fall in any 24-hour period.

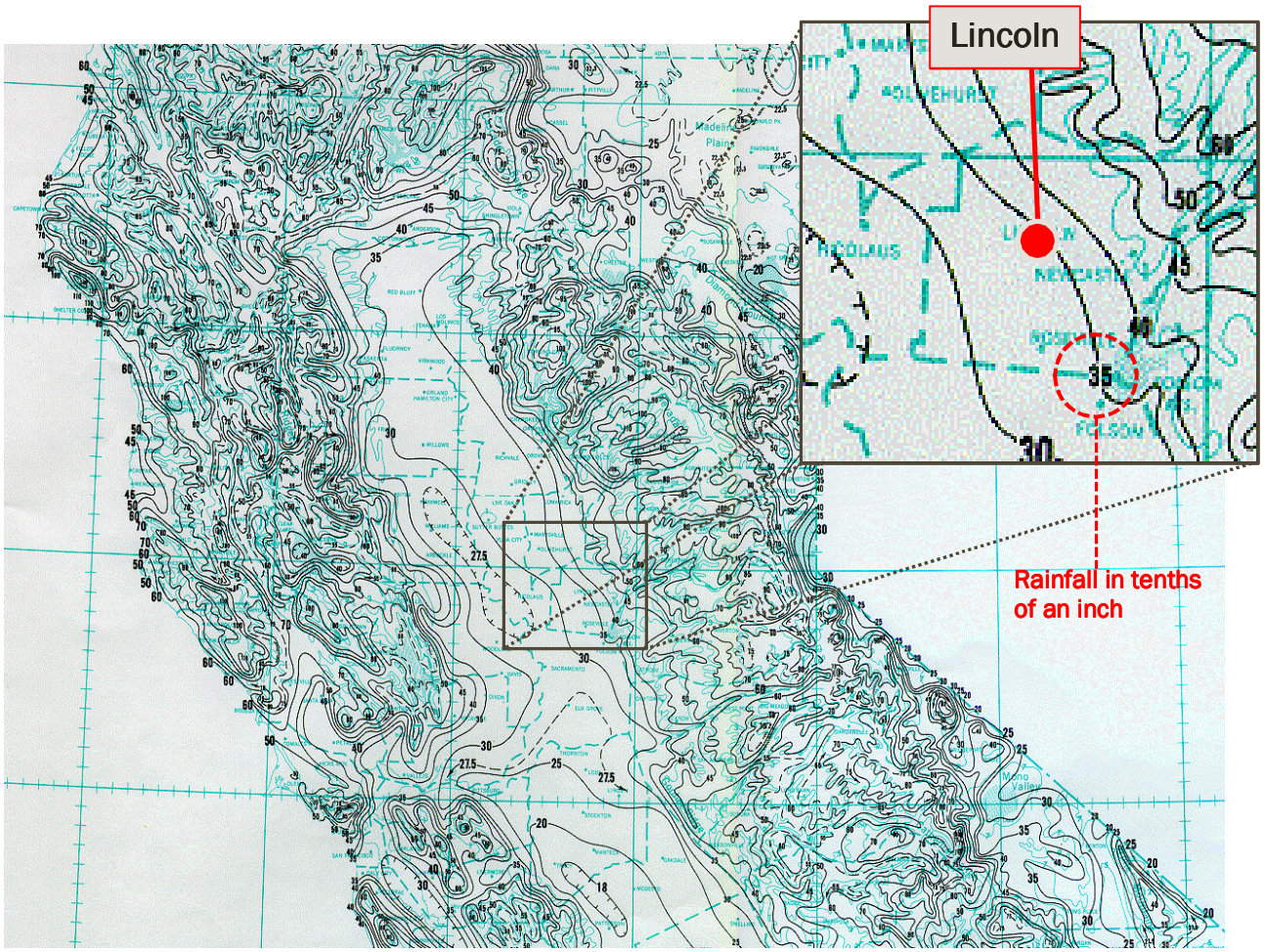


Figure 3-4. NOAA Northern California Rainfall Frequency Map (10-Year, 24-Hour IDF)

From the NOAA frequency maps, for a specific latitude and longitude, the rainfall densities for period durations ranging from 15 minutes to 60 days are known for rain events ranging from 1-year to 100-year intensities. These are plotted to develop a rain event frequency map specific to each rainfall monitoring site. Superimposing the peak measured densities for all the rainfall events on the rain event frequency plot determines the classification of the storm event, shown in Figure 3-5 for RG North. Table 3-3 summarizes the classification of the rainfall events that occurred during the flow monitoring period.

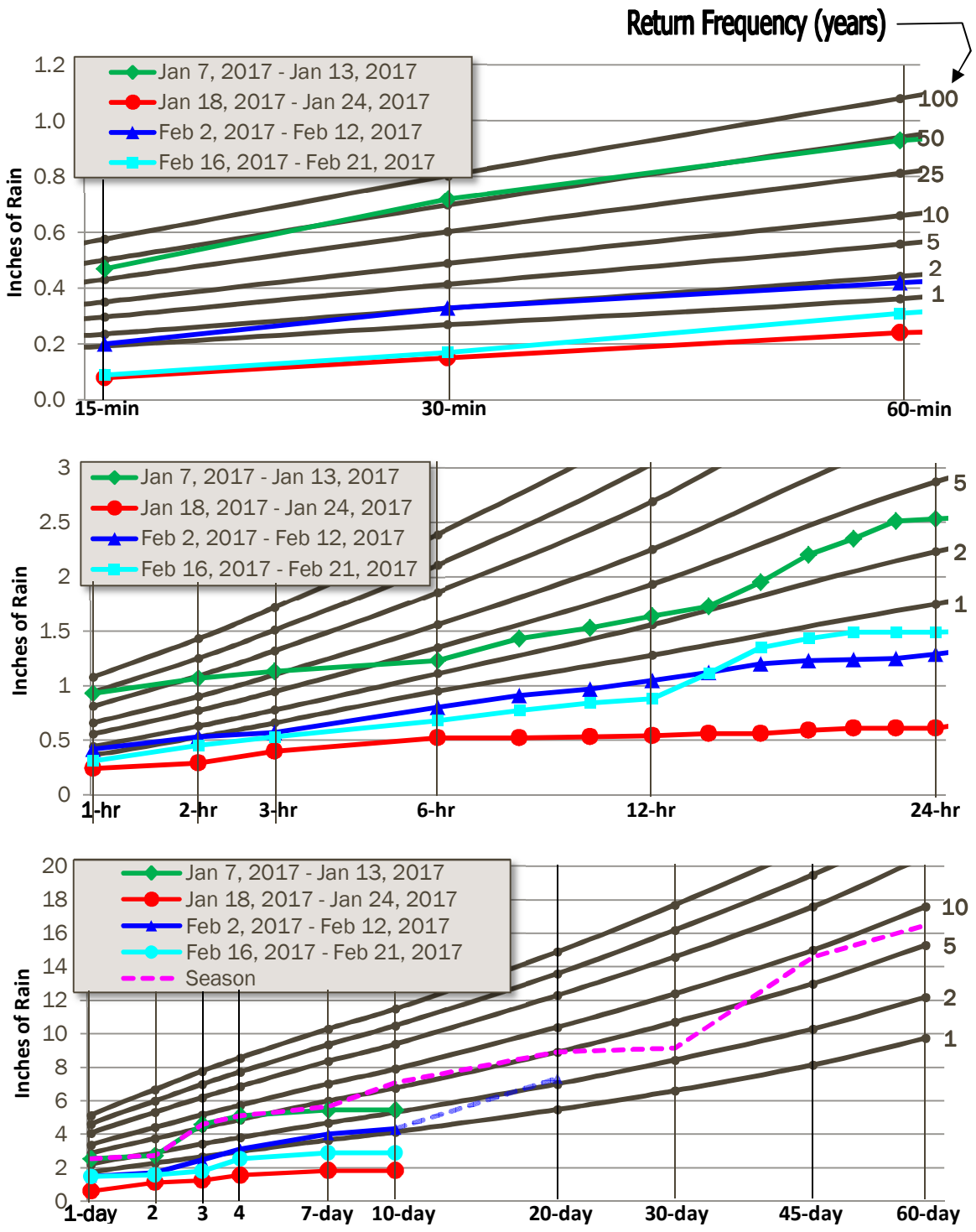


Figure 3-5. Rainfall Event Classification (RG North)

Table 3-3. Classification of Rainfall Events

Rainfall Event	RG North	RG South
Event 1: Jan 7 – Jan 13, 2017	50-Year, 1-Hour 25-Year, 2-Hour 10-Year, 3-Hour 5-Year, 4-Day 4-Year, 7-Day	1.5-Year, 30-min 2-Year, 4-Day 1.5-Year, 7-Day
Event 2: Jan 18 – Jan 24, 2017	<1-Year Event	<1-Year Event
Event 3: Feb 2 – Feb 12, 2017	2-Year, 30-min 1.2-Year, 10-Day	2-Year, 3-Hour 1.6-Year, 10-Hour 1-Year, 10-Day
Event 4: Feb 16 – Feb 21, 2017	<1-Year Event	1-Year, 3-Hour 1-Year, 4-Day <1-Year, 7-Day
Event 3 & 4: Feb 2 – Feb 21, 2017	2-Year, 20-Day	2-Year, 20-Day
Monitoring Period (incl. Jan 2 – Jan 4)	5-Year, 4-Day 6-Year, 10-Day 9-Year, 45-Day 7-Year, 60-Day	2-Year, 4-Day 2-Year, 20-Day 5-Year, 45-Day 3.5 Year, 60-Day

The following storm event classification items are noted:

- Event 1 (January 7 – 13, 2017) was the largest classified rainfall event over the monitoring period.
  - **Short Term (< 24 hours):** There was a very strong hour of rainfall in the northern region of Lincoln that registered as a 50-Year event, dropping 0.9 inches on January 10 from 7:30pm to 8:30pm[7]. This magnitude of cloudburst did not occur over the southern regions of Lincoln.
  - **Long-Term (1 – 10 days):** Event 1 was classified as a 5-year, 4-day rainfall event at RG North and as a 2-year, 4-day storm event at RG South.
- **Season:** For longer durations (>10 days), combined Events 3 and 4 (February 2 to 21) was classified as a 2-Year, 20-Day event. The full 60-day flow monitoring period was classified as a 7-year, 60-day event at RG North and a 3.5-year, 60-day event at RG South.

[7] A similar rainfall event happened in the northern region of Lincoln during last year's flow monitoring; on March 4, 2016 a 100-year 1-hour event occurred.

4 Flow Monitoring Results

4.1 Average Flow Analysis

ADWF curves were established when RDI had the least impact on the baseline flow. Table 4-1 summarizes the dry weather flow data measured for this study. ADWF curves for each site can be found in *Appendix A*. Figure 4-1 shows a schematic diagram of the average dry weather flows and flow levels.

Table 4-1. Dry Weather Flow

Monitoring Site	Sediment (IN)	Mon-Thu ADWF (MGD)	Friday ADWF (MGD)	Saturday ADWF (MGD)	Sunday ADWF (MGD)	Overall ADWF (MGD)
Site 1	0	0.558	0.551	0.530	0.603	0.550
Site 2	0.25	0.102	0.098	0.098	0.110	0.101
Site 3	0.75	0.405	0.393	0.420	0.445	0.411
Site 4	0	1.669	1.653	1.659	1.590	1.628
Site 5	2.00	1.092	1.116	1.126	1.193	1.108
Site 6	0	1.296	1.251	1.293	1.355	1.292
Site 7	0	5.791	5.549	5.601	5.489	5.645
Site 8	0	0.984	0.942	0.988	1.009	0.973
Site 9	0	0.776	0.778	0.771	0.791	0.776
Site 10	0	0.502	0.485	0.503	0.519	0.499

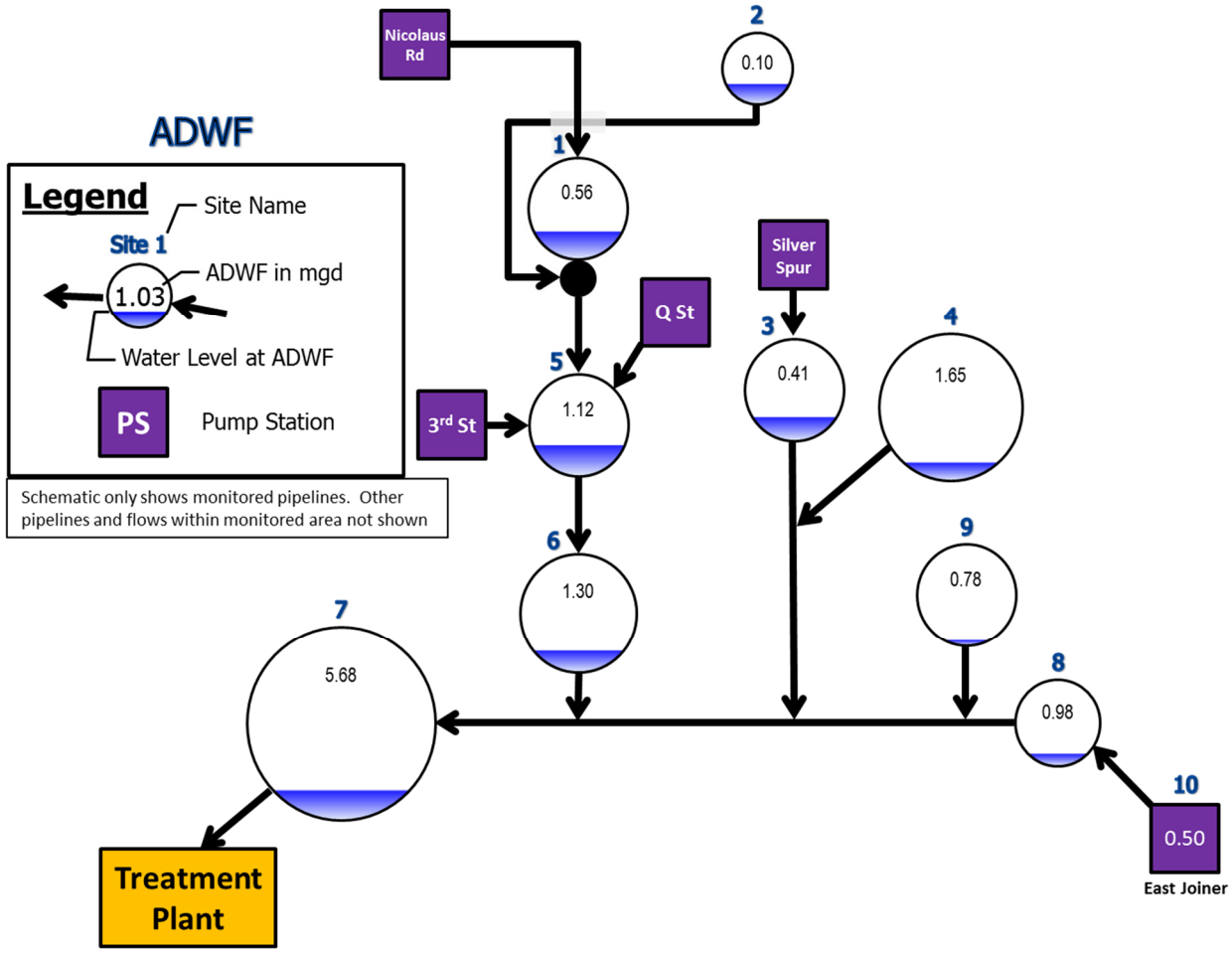


Figure 4-1. Dry Weather Flow Schematic

4.2 Capacity Analysis: Peaking Factor and d/D Ratio

Peak measured flows and the corresponding flow levels (depths) are important to understand the capacity limitations of a collection system. The peak flows and flow levels reported are from the peak measurements as taken across the entirety of the flow monitoring period. Peak flows and levels may not correspond to a rainfall event.

The following capacity analysis terms are defined as follows:

- **Peaking Factor:** Peaking factor is defined as the peak measured flow divided by the ADWF. Peaking factors are influenced by many factors including size and topography of tributary area, proximity to pump stations, and the amount and characteristics of I/I entering the collection system. Flow attenuation and flow restrictions will also affect the peaking factor. A peaking factor threshold value of 3.0 is commonly used for sanitary sewer design of new pipe; however, it is noted that this value is variable and subject to attenuation and the size of the upstream collector area. The City should follow its own standards and criteria when examining peaking factors.
- **d/D Ratio:** The d/D ratio is the peak measured depth of flow (d) divided by the pipe diameter (D). Standards for d/D ratio vary from agency to agency, but typically range between $d/D \leq 0.5$ and $d/D \leq 0.75$. The d/D ratio for each site was computed based on the maximum depth of flow for the flow monitoring study.

Table 4-2 summarizes the peak recorded flows, levels, *d/D* ratios, and peaking factors per site during the flow monitoring period. Results of note have been shaded in RED. Capacity analysis data are presented on a site-by-site basis and represents the hydraulic conditions only at the site locations; hydraulic conditions in other areas of the collection system will differ.

Table 4-2. Capacity Analysis Summary

Metering Site	ADWF (MGD)	Peak Measured Flow (MGD)	Peaking Factor	Pipe Diameter, *D* (IN)	Max Depth, *d* (IN)	*Max d/D* Ratio	Surcharge above Pipe Crown (FT)
Site 1	0.56	2.75	4.9	30	29.1	0.97	-
Site 2	0.10	0.62	6.1	18	22.1	1.23	0.3
Site 3	0.41	3.16	7.7	30	14.6	0.49	-
Site 4	1.65	11.47	6.9	48	14.1	0.29	-
Site 5	1.12	8.17	7.3	30	26.0	0.87	-
Site 6	1.30	8.78	6.8	36.75	13.9	0.38	-
Site 7	5.68	39.76	7.0	66	102.8	1.56	3.1
Site 8	0.98	5.21	5.3	24	8.7	0.36	-
Site 9	0.78	2.18	2.8	30	5.6	0.19	-
Site 10	0.50	2.08	4.1	N/A	N/A	N/A	N/A

The following capacity analysis results are noted:

- Peaking Factor
  - Peak flows for all sites occurred during Event 1.

- Site 2 had a dumping event on March 3, 2017.
- Sites 3, 5 and 7 had the higher peaking factors.

- d/D Ratio:
  - Sites 3 and 7 peak levels occurred during Event 2 and did not coincide with peak flow. Site 7 peak level and surcharge occurred due to a downstream restriction in flow for approximately 2 hours on 2/7/2017 5:00-7:00am, whereby velocity dropped from approximately 6 to 0.96 feet per second. Site 7 is located near the treatment facility – this may have been due to treatment plant operations.
  - Site 2 and 7 surcharged 0.3 and 3.1 feet respectively.
  - Site 2 peak level occurred during peak flow in Event 1. The dumping event on March 3, 2017 did not cause much of an increase in flow level (approximately 3 inches) as the velocity was able to increase to the monitoring period's peak velocity of 1.29 feet per second.
  - Sites 1 and 5 had a maximum *d/D* ratio that just exceeded the typical threshold of 0.75.

Figure 4-2 shows a schematic diagram of the peak measured flows with peak flow levels. Figure 4-3 and Figure 4-4 show bar graphs of the capacity results.

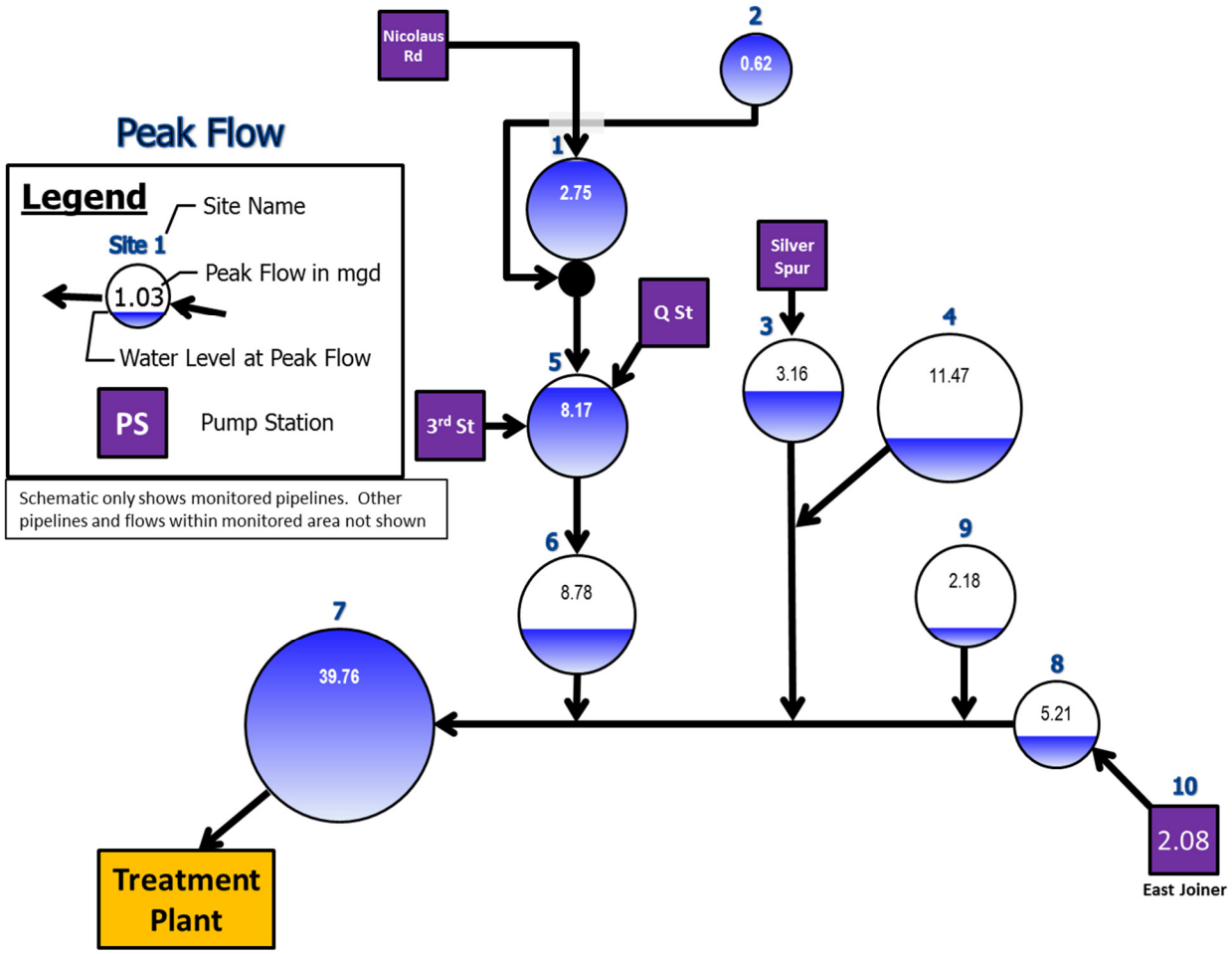


Figure 4-2. Wet Weather Flow Schematic

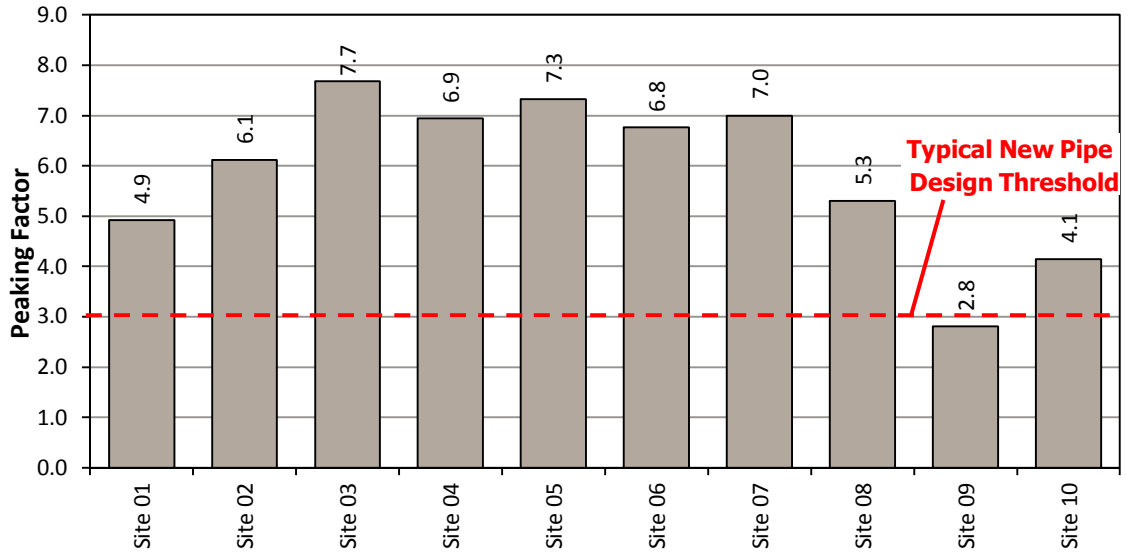


Figure 4-3. Capacity Summary: Peaking Factors

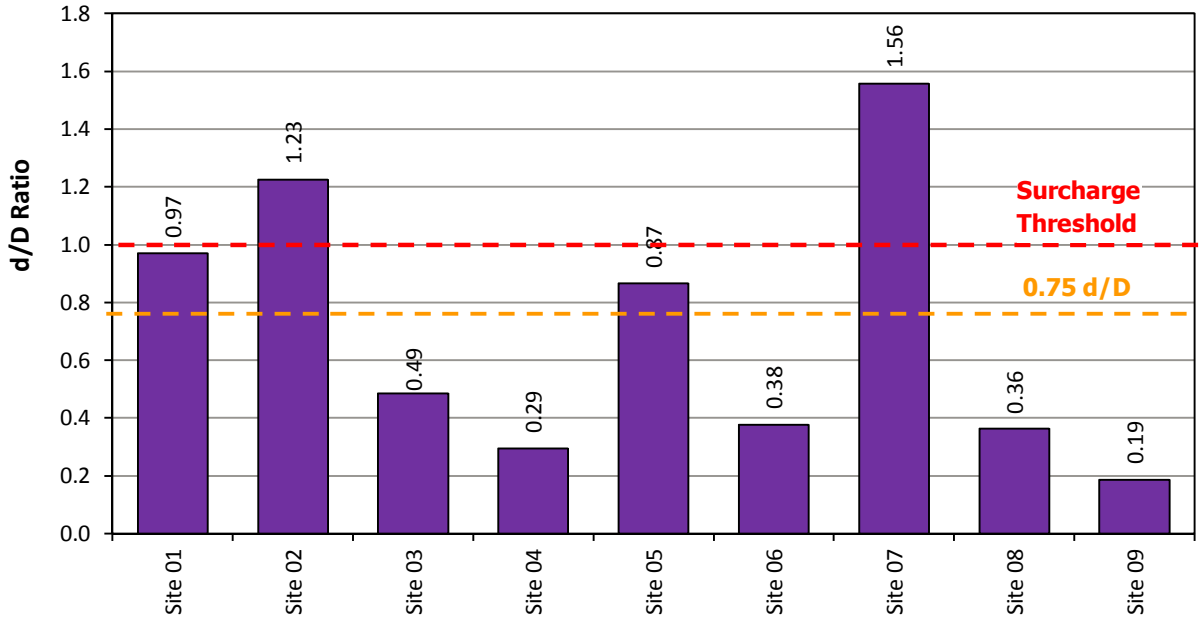


Figure 4-4. Capacity Summary: Max d/D Ratios

5 Inflow and Infiltration Results

5.1 Inflow Results Summary

Inflow is storm water discharged into the sewer system through direct connections such as downspouts, area drains, cross-connections to catch basins, etc. These sources transport rain water directly into the sewer system and the corresponding flow rates are tied closely to the intensity of the storm. This component of I/I often causes a peak flow problem in the sewer system and often dictates the required capacity of downstream pipes and transport facilities to carry these peak instantaneous flows.

Table 5-1 summarizes the peak measured I/I flows and inflow analysis results. Peak I/I rates for all sites were measured during Event 1. The top ranked basins with the highest normalized inflow have been shaded in RED.

Table 5-1. Inflow Analysis Summary

Monitoring Basin	ADWF (mgd)	Basin Size (IDM)	Peak I/I Rate (mgd)	Peak I/I per IDM (gpd/IDM)	Peak I/I per ADWF	Inflow Ranking
Basin 1	0.56	170.0	1.99	11,731	3.6	6
Basin 2	0.10	35.8	0.44	12,151	4.3	4
Basin 3	0.41	117.3	2.61	22,260	6.3	2
Basin 4*	1.65	N/A	8.94	N/A	5.4	5
Basin 5	0.46	220.1	4.12	18,730	9.1	3
Basin 6	0.18	85.8	0.57	6,635	3.1	9
Basin 7	0.56	338.2	9.58	28,334	17.2	1
Basin 8	0.48	366.3	2.86	7,807	6.0	7
Basin 9	0.78	148.3	1.39	9,390	1.8	8
Basin 10	0.50	262.2	1.28	4,889	2.6	10

* The Basin 4 ranking was based solely on the per-ADWF normalization metric.

The following inflow analysis results are noted:

- Basins 3, 5 and 7 had high normalized inflow contribution for both normalization methods.

Figure 5-1 shows bar graph summaries of the inflow analyses.

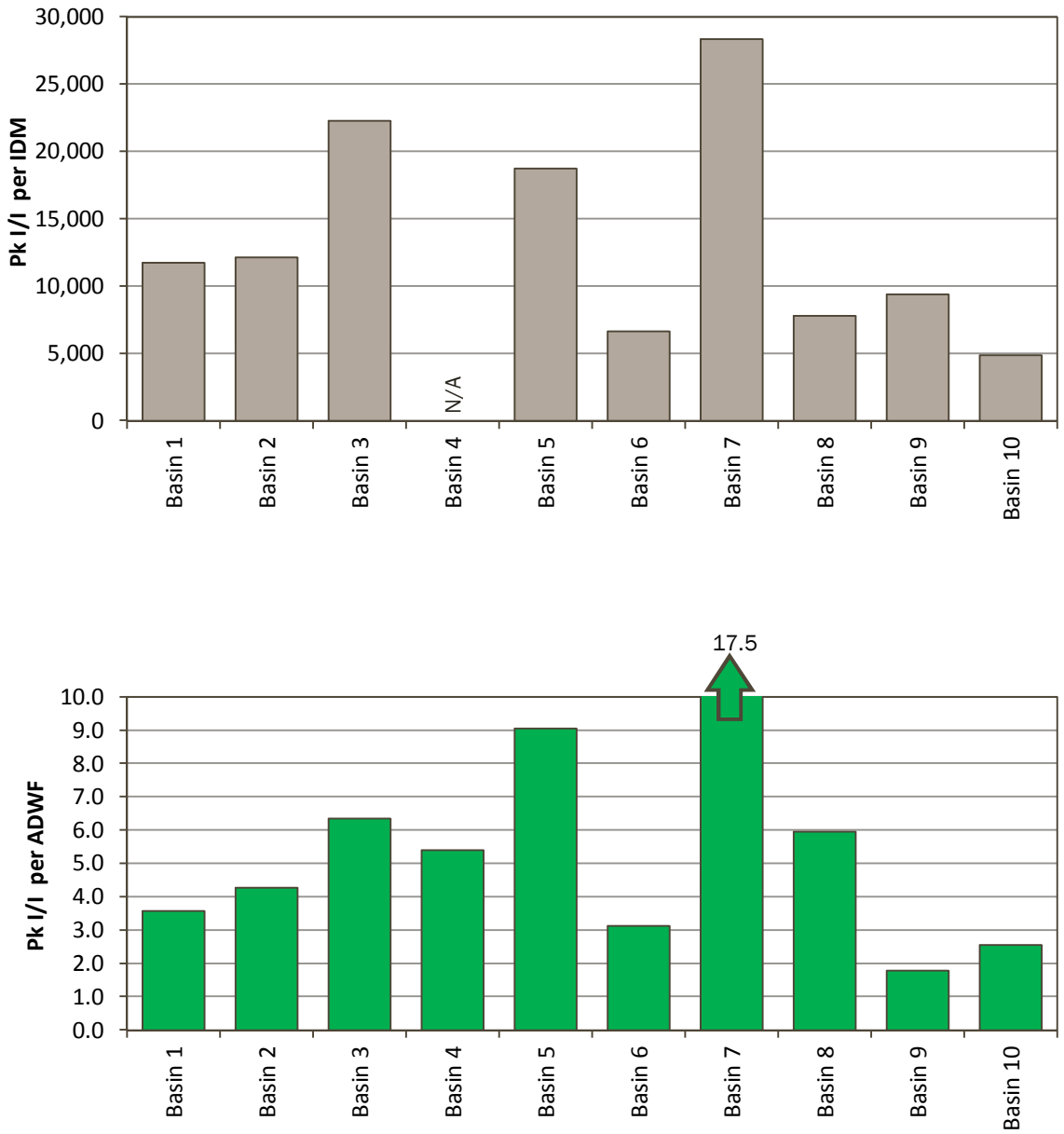


Figure 5-1. Bar Graphs: Inflow Analysis Summary

5.2 RDI Results Summary

Infiltration is defined as water entering the sanitary sewer system through defects in pipes, pipe joints, and manhole walls, which may include cracks, offset joints, root intrusion points, and broken pipes. Increased flows into the sanitary sewer system are usually tied to groundwater levels and soil saturation levels. Infiltration sources transport rain water into the system *indirectly*; flow levels in the sanitary system increase gradually, are typically sustained for a period after rainfall has stopped, and then gradually drop off as soils become less saturated and as groundwater levels recede to normal. Infiltration typically creates long-term annual volumetric problems. The major impact is the cost of pumping and treating the additional volume of water, and of paying for treatment (for municipalities that are billed strictly on flow volume).

For this study, the RDI rate used for comparative analysis was measured as the average I/I rate from February 21 at 19:00 to February 22 at 19:00 (approximately 24 hours after the conclusion of the February 20 rain event) (illustrated in Figure 5-2 for Site 6). Table 5-2 summarizes the calculated RDI flow rates. The top ranked basins with the highest normalized RDI rates have been shaded in RED.

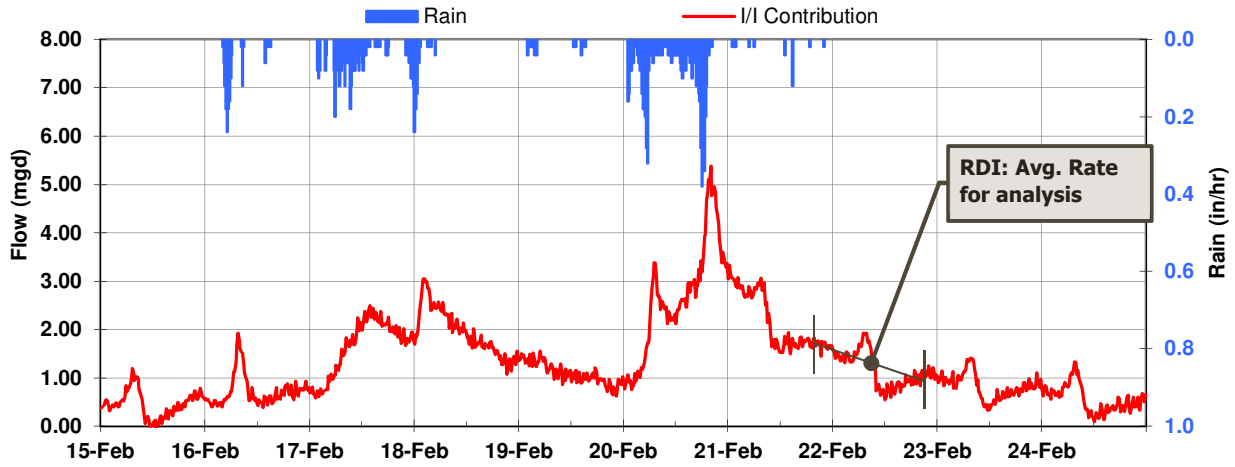


Figure 5-2. I/I Isolation Curve, Site 6

Table 5-2. Basins RDI Analysis Summary

Metering Basin	ADWF (mgd)	Basin Size (IDM)	ADWF (mgd)	RDI Rate (mgd)	RDI per IDM (gpd/IDM)	RDI per ADWF	RDI Ranking
Basin 1	0.56	170.0	0.56	0.17	1,012	0.31	2
Basin 2	0.10	35.8	0.10	0.003	90	0.03	9
Basin 3	0.41	117.3	0.41	0.09	740	0.21	5
Basin 4*	1.65	N/A	1.65	0.64	N/A	0.38	3
Basin 5	0.46	220.1	0.46	0.03	130	0.06	8
Basin 6	0.18	85.8	0.18	0.27	3,172	1.49	1
Basin 7	0.56	338.2	0.56	0.01	30	0.02	10
Basin 8	0.48	366.3	0.48	0.25	673	0.51	4
Basin 9	0.78	148.3	0.78	0.03	182	0.03	7
Basin 10	0.50	262.2	0.50	0.05	174	0.09	6

* The Basin 4 ranking was based solely on the per-ADWF normalization metric.

Figure 5-3 shows bar graph summaries of the RDI analyses. The following RDI analysis results are noted:

- Basins 1, 4, and 6 had high normalized RDI contribution for both normalization methods.

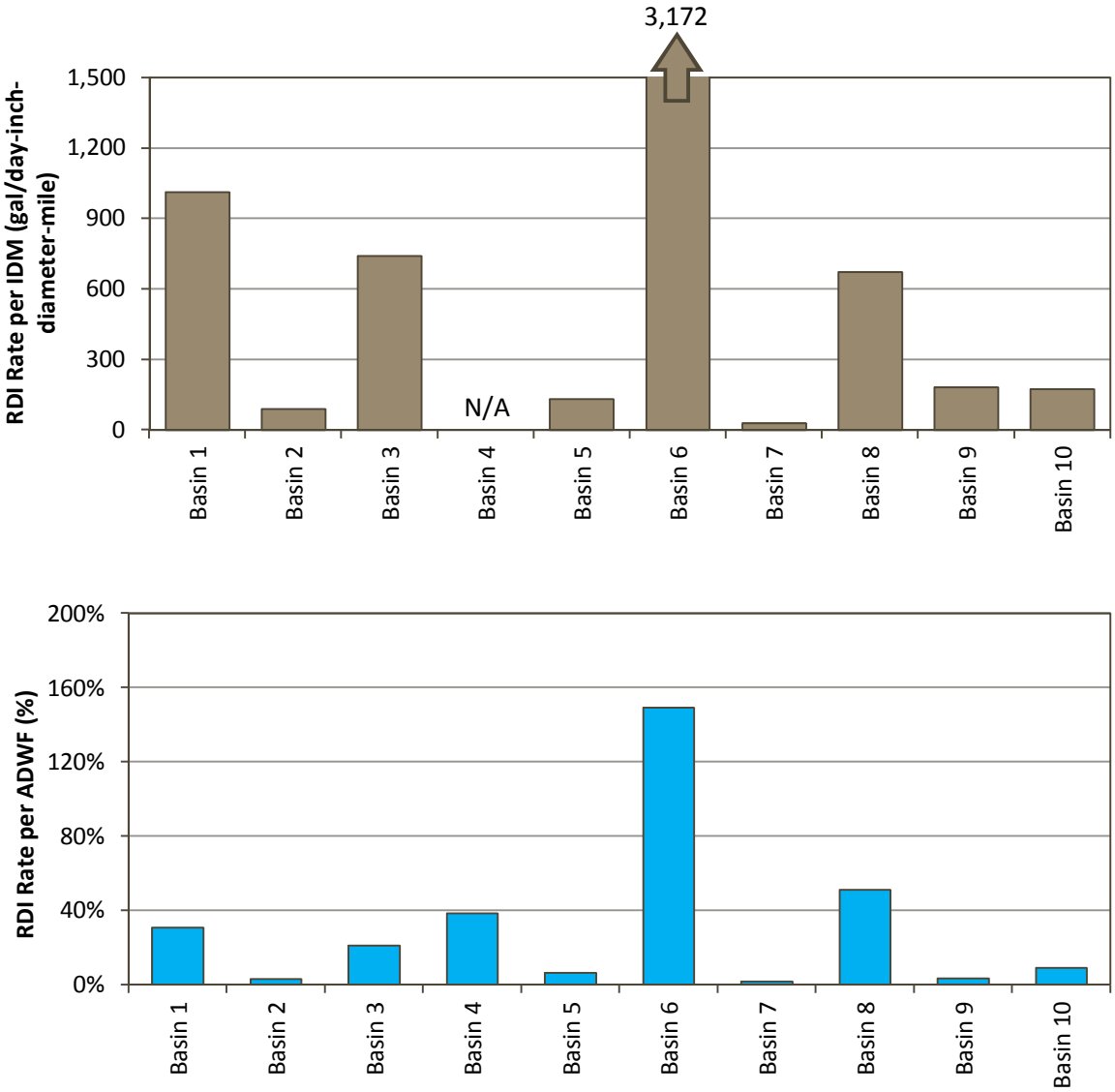


Figure 5-3. Bar Graphs: RDI Analysis Summary

5.3 Groundwater Infiltration Results Summary

Dry weather (ADWF) flow can be expected to have a predictable diurnal flow pattern. While each site is unique, experience has shown that, given a reasonable volume of flow and typical loading conditions, the daily flows fall into a predictable range when compared to the daily average flow. If a site has a large percentage of groundwater infiltration occurring during the periods of dry weather flow measurement, the amplitudes of the peak and low flows will be dampened[8]. Figure 5-4 shows a sample of two flow monitoring sites, both with nearly the same average daily flow, but with considerably different peak and low flows. In this *sample* case, Site B1 may have a considerable volume of groundwater infiltration.

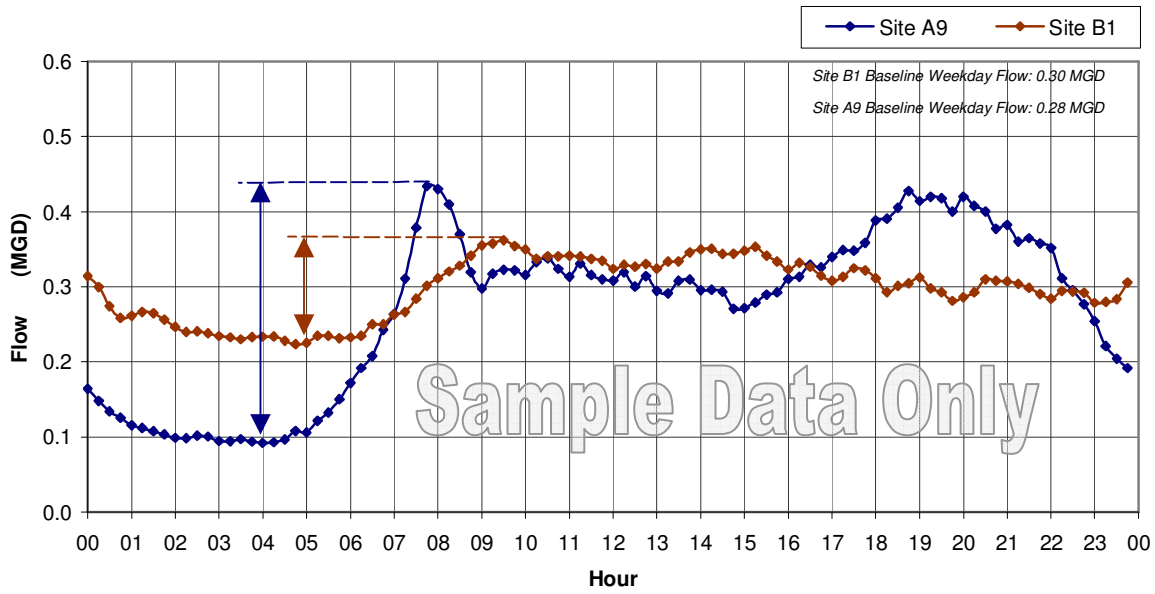


Figure 5-4. Sample Groundwater Infiltration Sample Graph

It can be useful to compare the low-to-ADWF flow ratios for the flow metering sites. A site with abnormal ratios, and with no other reasons to suspect abnormal flow patterns (such as proximity to a pump station, treatment facilities, etc.), has a possibility of higher levels of groundwater infiltration in comparison to the rest of the collection system.

Figure 5-5 plots the low-to-ADWF flow ratios against the ADWF flows for the basins monitored during this study. The brown dashed line shows “typical” low-to-ADWF ratios per the Water Environment Federation (WEF)[9].

[8] In an extreme case, perhaps 0.2 mgd of ADWF flow and 2.0 mgd of groundwater infiltration, the peaks and lows would be barely recognizable; the ADWF flow would be nearly a straight line.

[9] WEF Manual of Practice No. 9, “Design and Construction of Sanitary and Storm Sewers.”

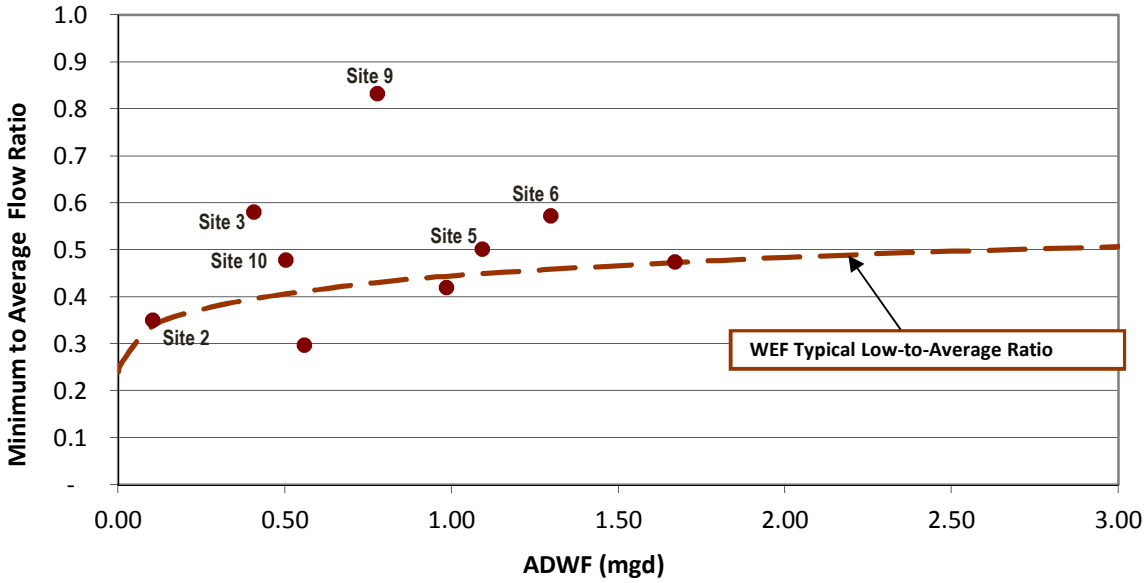


Figure 5-5. Minimum Flow Ratios vs. ADWF[10]

The graph suggests that GWI in the basins upstream from Sites 3, 5, 6, 9, and 10 above typical groundwater infiltration standards (as set forth by WEF). Sites 3, 6 and 9 have GWI rates that are substantially higher. Table 5-3 summarizes excess GWI that, if removed, would bring the above sites to within typical WEF Low-to-Average ratios.

Table 5-3. Excess GWI per WEF

Metering Site	Excess GWI (mgd)	Excess GWI (gpm)
Site 3	0.133	92
Site 5	0.117	81
Site 6	0.301	209
Site 9	0.572	397
Site 10	0.069	48

It is strongly noted that the GWI analysis took place during a wet weather period with greater than average rainfall. Though the ADWF curves were established during dry periods between rain events, it is likely that the ADWF curves are higher than would be established during the summer months. The GWI analysis results may be interpreted as a combination of both GWI and residual RDI, which may suggest high GWI. A true GWI analysis would have to occur using data measured during the dry season.

[10] Due to attenuation, it should be expected that sites with larger flow volumes should not have quite the peak-to-average and low-to-average flow ratios as sites with lesser flow volumes, which is why the WEF typical trend lines slope closer to 1.0 as the ADWF increases, as shown in the figure.

5.4 Combined I/I Results Summary

Combined I/I analysis considers the totalized volume (in gallons) of both inflow and rainfall-dependent infiltration over the course of a storm event. Table 5-4 summarizes the combined I/I flow results for the entire storm period of February 2 to 21, 2017 (Events 3 and 4 combined). The top ranked basins with the highest normalized combined I/I have been shaded in RED.

Table 5-4. Basins Combined I/I Analysis Summary

Metering Basin	ADWF (mgd)	Basin Size (IDM)	Combined I/I (gallons)	Combined I/I per IDM (per Inch Rain)	Combined I/I per ADWF (per Inch Rain)	Combined I/I Rank
Basin 1	0.56	170.0	9,267,000	9,989	3.04	5
Basin 2	0.10	35.8	967,000	4,989	1.76	9
Basin 3	0.41	117.3	8,588,000	14,672	4.18	2
Basin 4*	1.65	N/A	31,262,000	N/A	4.00	3
Basin 5	0.46	220.1	9,400,000	8,127	3.93	4
Basin 6	0.18	85.8	7,256,000	16,334	7.69	1
Basin 7	0.56	338.2	7,987,000	4,930	2.99	8
Basin 8	0.48	366.3	6,978,000	4,297	3.28	6
Basin 9	0.78	148.3	5,022,000	7,143	1.36	7
Basin 10	0.50	262.2	4,418,000	3,911	2.04	10

* The Basin 4 ranking was based solely on the per-ADWF normalization metric.

The following combined I/I analysis are noted:

- Basins 3, 4, and 6 had the highest normalized total I/I contribution for both normalization methods.

Figure 5-6 shows bar graph summaries of the combined I/I analysis.

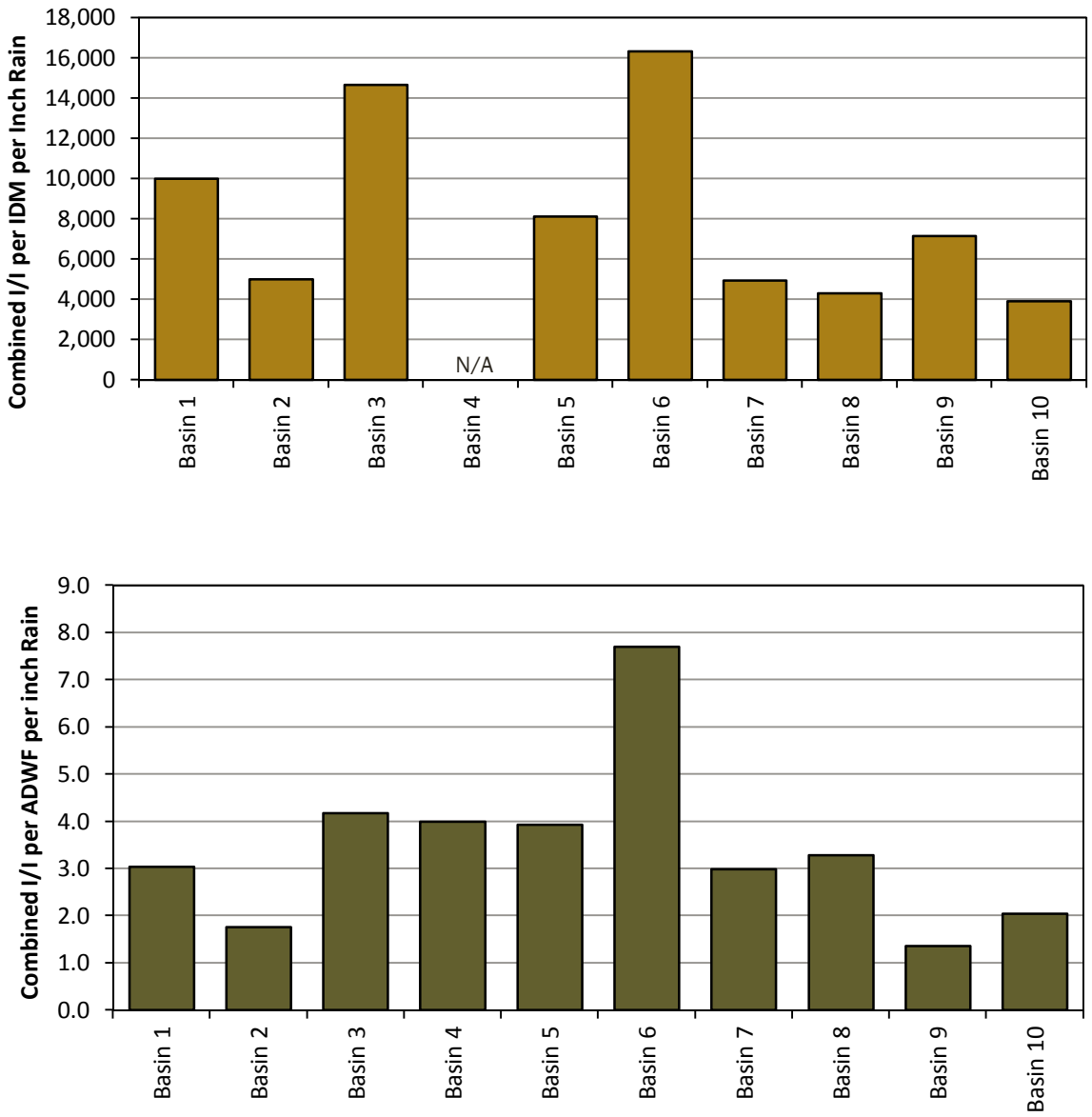


Figure 5-6. Bar Graphs: Combined I/I Analysis Summary

5.5 I/I Results Summary

Table 5-5 summarizes the flow monitoring and I/I results for the flow monitoring sites that were monitored during this study. A ranking of "1" represents the most I/I after normalization per both "per-ADWF" and "per-IDM" methods. Please refer to the *I/I Methods* section for more information on inflow and infiltration analysis methods and ranking methods.

Table 5-5. I/I Analyses Results Summary

Metering Basin	ADWF (mgd)	Peak I/I Rate (mgd)	Combined I/I (gallons)	Peak I/I Ranking	RDI Ranking	Possible High GWI?	Combined I/I Rank
Basin 1	0.56	1.99	9,267,000	6	2	-	5
Basin 2	0.10	0.44	967,000	4	9	-	9
Basin 3	0.41	2.61	8,588,000	2	5	Yes	2
Basin 4	1.65	8.94	31,262,000	5	3	-	3
Basin 5	0.46	4.12	9,400,000	3	8	Yes	4
Basin 6	0.18	0.57	7,256,000	9	1	Yes	1
Basin 7	0.56	9.58	7,987,000	1	10	-	8
Basin 8	0.48	2.86	6,978,000	7	4	-	6
Basin 9	0.78	1.39	5,022,000	8	7	Yes	7
Basin 10	0.50	1.28	4,418,000	10	6	Yes	10

The following inflow/infiltration analysis results are noted:

- Inflow: Basins 3, 5 and 7 had high normalized inflow.
- RDI: Basins 1, 4 and 6 had high normalized RDI contribution.
- GWI: Sites 3, 5, 6, 9 and 10 had high rates of GWI. Site 9 had very high levels of GWI.
- Combined I/I: Basins 3, 4, and 6 had the highest normalized total I/I contribution.
- Basins 3 and 4 ranked high on all the I/I rankings.

6 Model Design Storm Results

6.1 Synthetic I/I Hydrograph Development

V&A modeled I/I response as a function of rainfall using synthetic hydrographs analysis techniques. Synthetic hydrographs were developed to approximate the actual RDI hydrograph shape in terms of the time to the peak and the recession coefficient. The actual RDI hydrograph was best matched with a synthetic hydrograph by separating the synthetic hydrograph into seven volume components (R1 through R7). The seven components represent different response times to the rainfall event and, therefore, different infiltration or inflow paths into the sewer system. R1 is characterized by a short response time (inflow) and R7 represents slower response and longer recession times (RDI). Levels of soil saturation are also considered. Using synthetic hydrograph analysis, appropriate time and recession parameters were estimated by a trial-and-error procedure until a good match was obtained. For example, the hydrograph and its component hydrographs for Site 5 are shown in Figure 6-1.

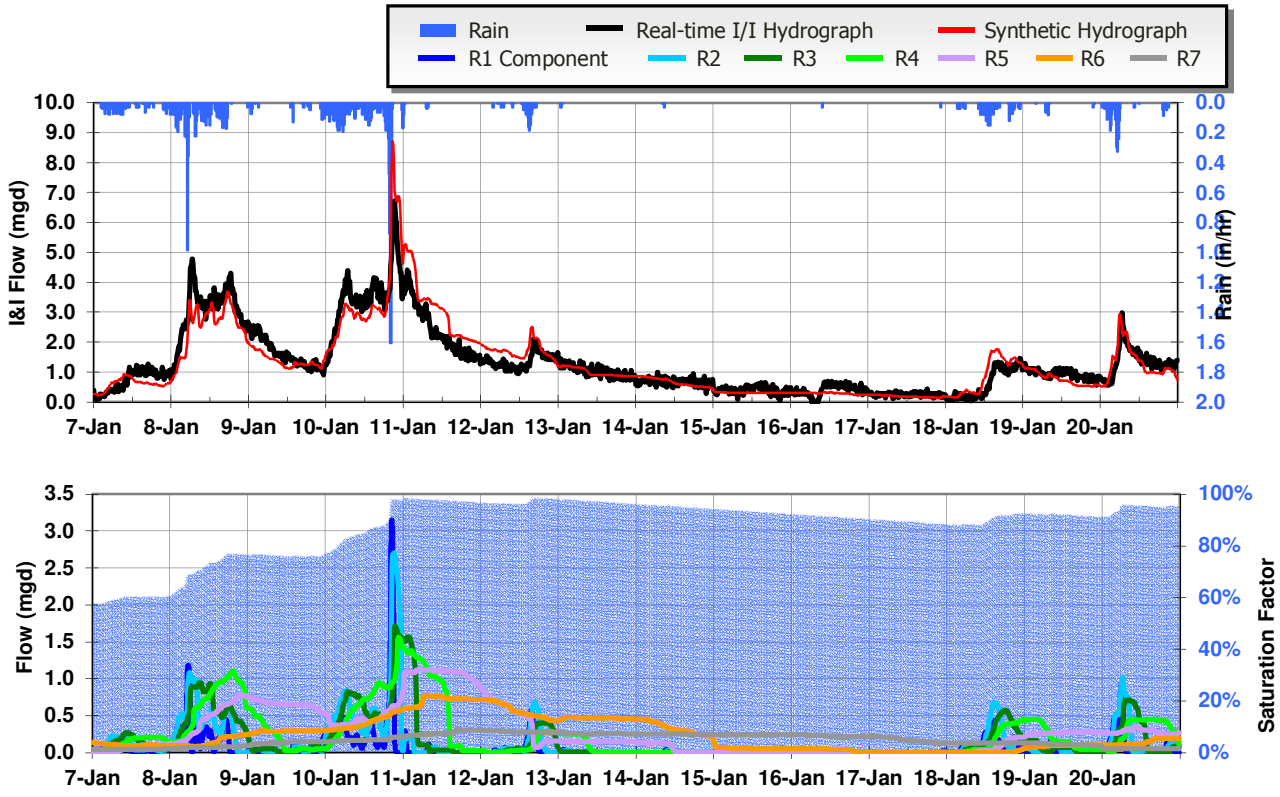


Figure 6-1. Synthetic Hydrograph Development (Site 5)

6.2 Design Storm Development

V&A used a 10-year, 24-hour design storm for this analysis. Storm events were taken from the NOAA Precipitation-Frequency Atlas of the Western United States. For example,

Figure 6-2 summarizes the design storm magnitude and profile at Rain Gauge North. The 10-year, 24-hour design storm was developed for each flow monitoring site by taking data from the two rain gauges and using the IDW method. This particular profile distribution also fits the NOAA criterion for 2-hour and 6-hour durations, in addition to the 24-hour duration.

10-Year, 24-hour Design Storm	
Hour	**Inches of Rain**
1	0.009
2	0.023
3	0.234
4	0.140
5	0.047
6	0.014
7	0.201
8	0.115
9	0.161
10	0.057
11	0.029
12	0.011
13	0.118
14	0.331
15	0.039
16	0.125
17	0.125
18	0.327
19	0.607
20	0.250
21	0.125
22	0.095
23	0.158
24	0.047
Total:	**3.39**

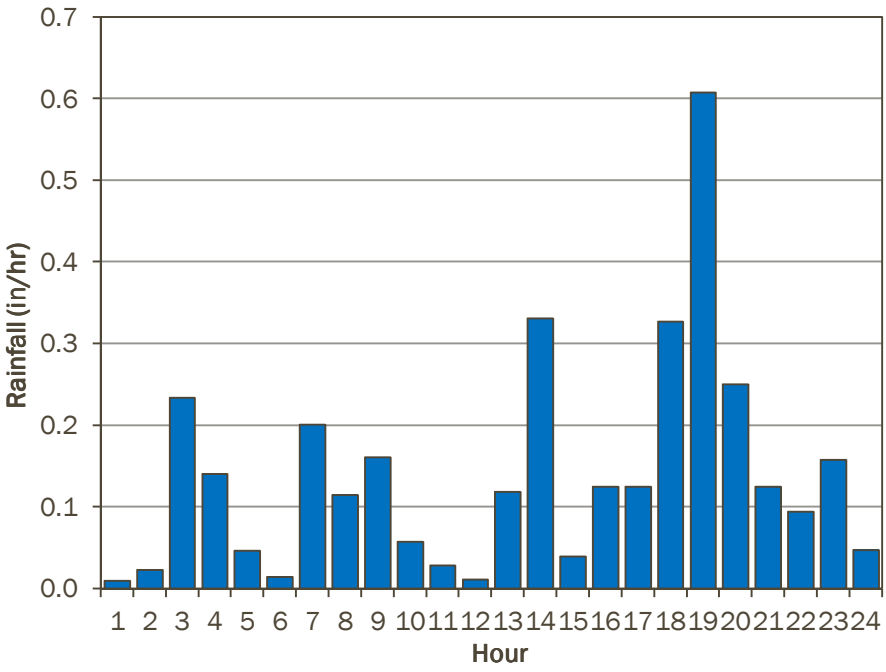


Figure 6-2. 10-Year, 24-Hour Design Storm Values and Profile

6.3 Design Storm Response Summary

The synthetic I/I hydrograph algorithms were applied to the 10-year, 24-hour design storm event. The resulting estimated peak flows hydrographs can be applied to sanitary sewer modeling efforts to determine if the collection system has adequate capacity to handle very large storm events. These results assume full ground saturation, and the peak I/I flows from the design storm coincide with peak baseline sanitary flows to get a "worst-case" scenario of peak wet weather flows. Table 6-1 summarizes the final results for the design storm on a site-by-site basis.

Table 6-1. Design Storm I/I Analysis Summary

Monitoring Site	Peak Dry Weather Flow (mgd)	Peak I/I Rate (mgd)	Peak Flow (mgd)
Site 1	1.32	1.82	3.14
Site 2	0.18	0.41	0.60
Site 3	0.66	3.17	3.83
Site 4	3.60	10.11	13.71
Site 5	1.81	6.88	8.70
Site 6	1.99	7.18	9.17
Site 7	8.31	33.05	41.37
Site 8	1.88	3.91	5.78
Site 9	0.97	1.51	2.47
Site 10	0.84	1.75	2.58

Note: It is possible that the peak flow rates predicted for a design storm event cannot be conveyed due to conveyance capacity limitations of the local collection system. A comprehensive dynamic model is required to determine the locations of the capacity issues and methods for relieving capacity. Figure 6-3 shows the synthetic hydrograph response for the design storm event at Site 5.

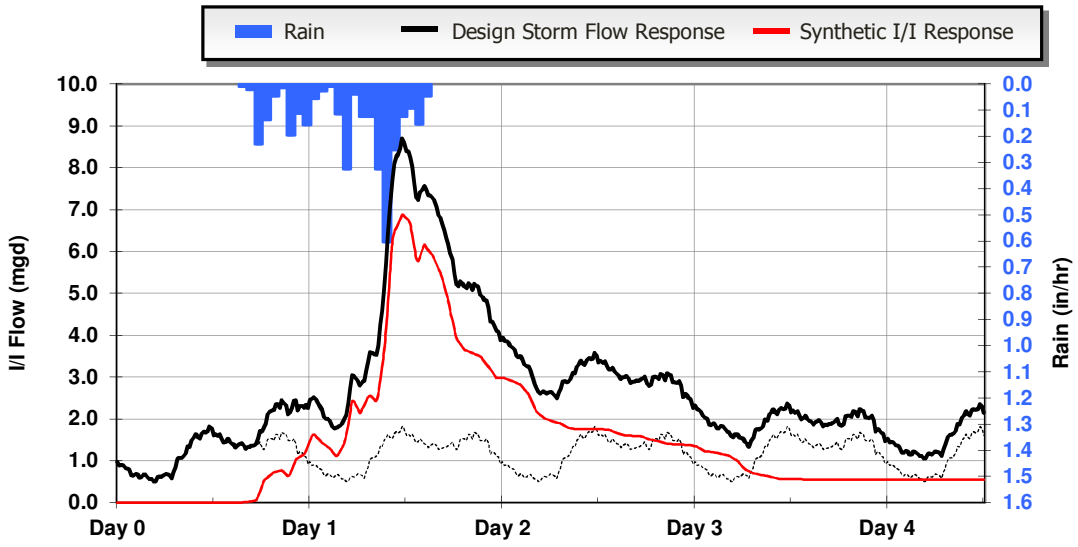


Figure 6-3. 10-Year, 24-Hour Design Storm: Estimated I/I Response at Site 5

7 Recommendations

V&A advises that future I/I reduction plans consider the following recommendations:

1. **Determine I/I Reduction Program:** The City should examine its I/I reduction needs to determine a future I/I reduction program.
    a. If peak flows, sanitary sewer overflows, and pipeline capacity issues are of greater concern, then priority can be given to investigate and reduce sources of inflow within the basins with the greatest inflow problems. Basins 3, 5 and 7 had the highest normalized inflow.
    b. If infiltration and general pipeline deterioration are of greater concern, then the program can be weighted to investigate and reduce sources of infiltration within the basins with the greatest infiltration problems. Basins 1, 4 and 6 had the highest normalized infiltration.
2. **I/I Investigation Methods:** Potential I/I investigation methods include the following:
    a. Smoke testing: This method is typically used to locate inflow sources.
    b. CCTV inspection: This method is typically used to locate condition assessment defects linked to infiltration sources. This would need to take place immediately after a strong rainfall event when groundwater levels are high so as to try and capture the infiltration “in the act”.
    c. Mini-basin flow monitoring: This method can be used to isolate smaller catchment areas in which to locate infiltration and inflow sources. Isolating the areas where the I/I is originating may be the most prudent course of action.
    d. Nighttime reconnaissance work to (1) investigate and determine direct point sources of inflow and (2) determine the areas and pipe reaches responsible for high levels of infiltration contribution.
3. **I/I Reduction Cost-Effectiveness Analysis:** The City may wish to conduct a study to determine which is more cost-effective: (1) locating the sources of inflow and infiltration and systematically rehabilitating or replacing the faulty pipelines or (2) continued treatment of the additional rainfall-dependent I/I flow.

Appendix A
Flow Monitoring Site Reports: Data, Graphs, Information

City of Lincoln

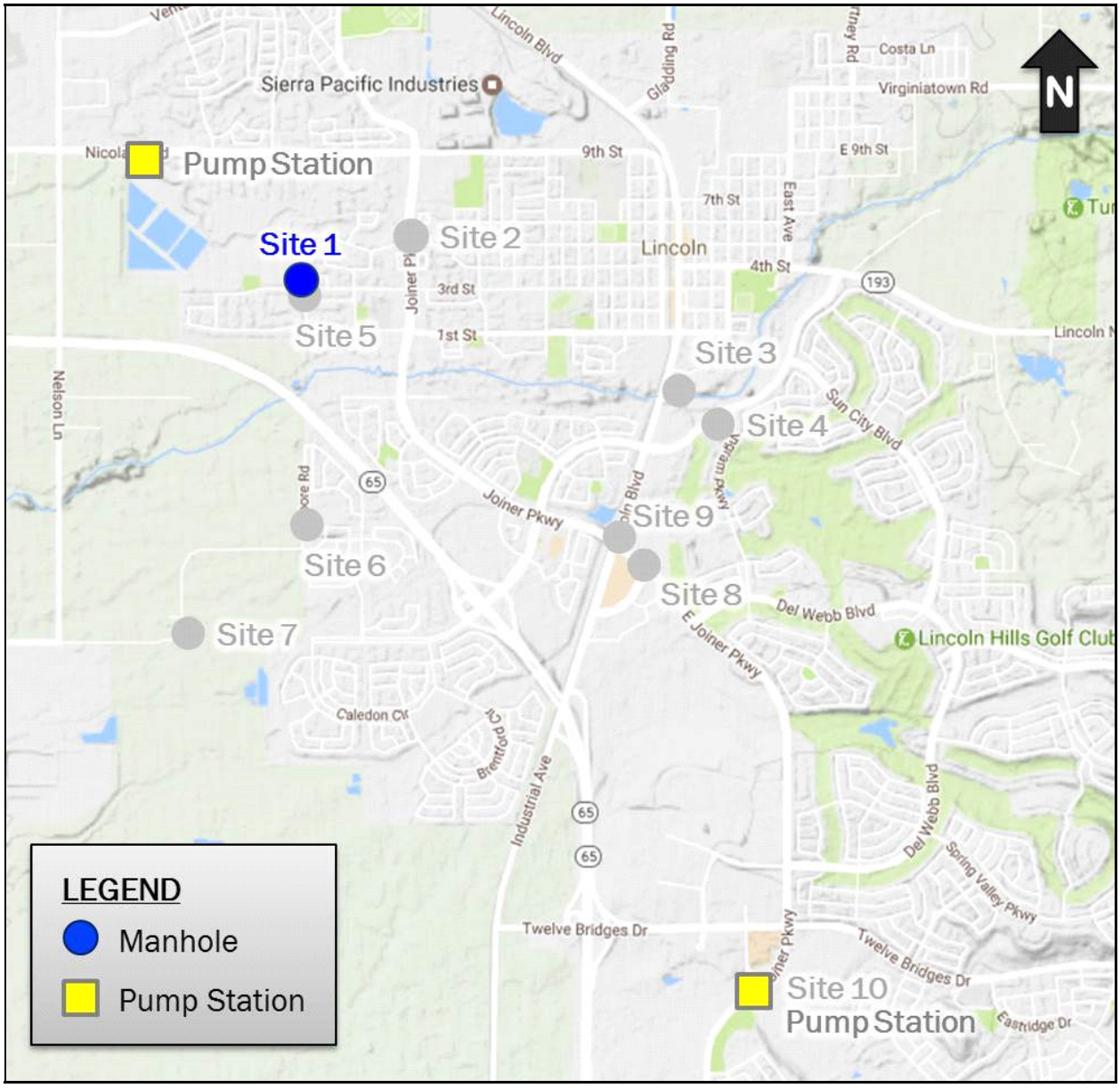
Sanitary Sewer Flow Monitoring

Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 01

Location: 313 Chambers Drive

Data Summary Report



Vicinity Map: Site 01

SITE 01

Site Information

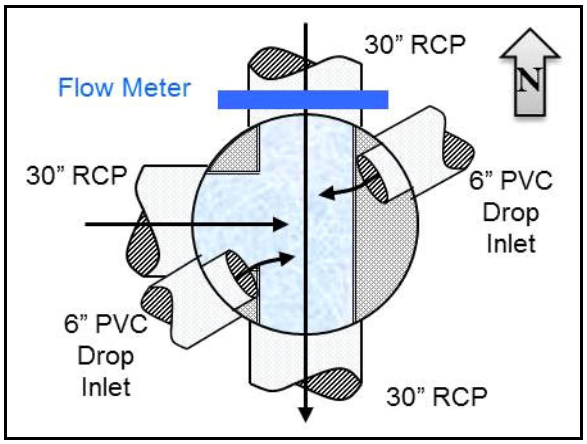
Location: 313 Chambers Drive

District ID: NW355SS24

Coordinates:	121.3213° W, 38.8899° N
Expected Pipe Diameter (Orig. if Relocated):	18 inches
Measured Pipe Diameter:	30 inches
ADWF:	0.558 mgd
Peak Measured Flow:	2.746 mgd
Rim Elevation (GEarth):	134 feet

Satellite Map

Sewer Map



Flow Sketch

Street View

Plan View

SITE 01

Additional Site Photos

Effluent Pipe

North Influent Pipe

SITE 01

Additional Site Photos

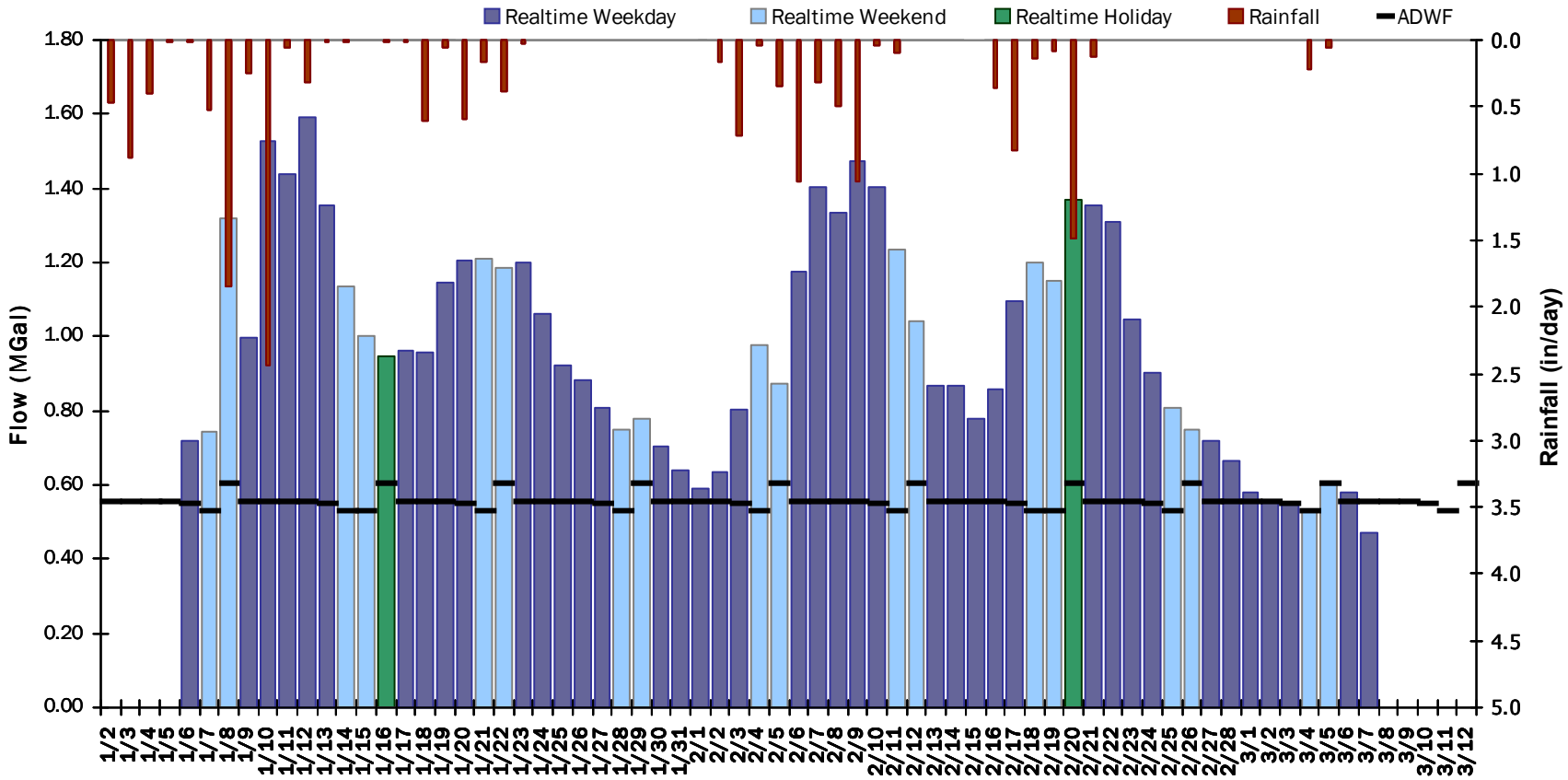
West Influent Pipe

SITE 01

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 0.979 MGal Peak Daily Flow: 1.592 MGal Min Daily Flow: 0.470 MGal

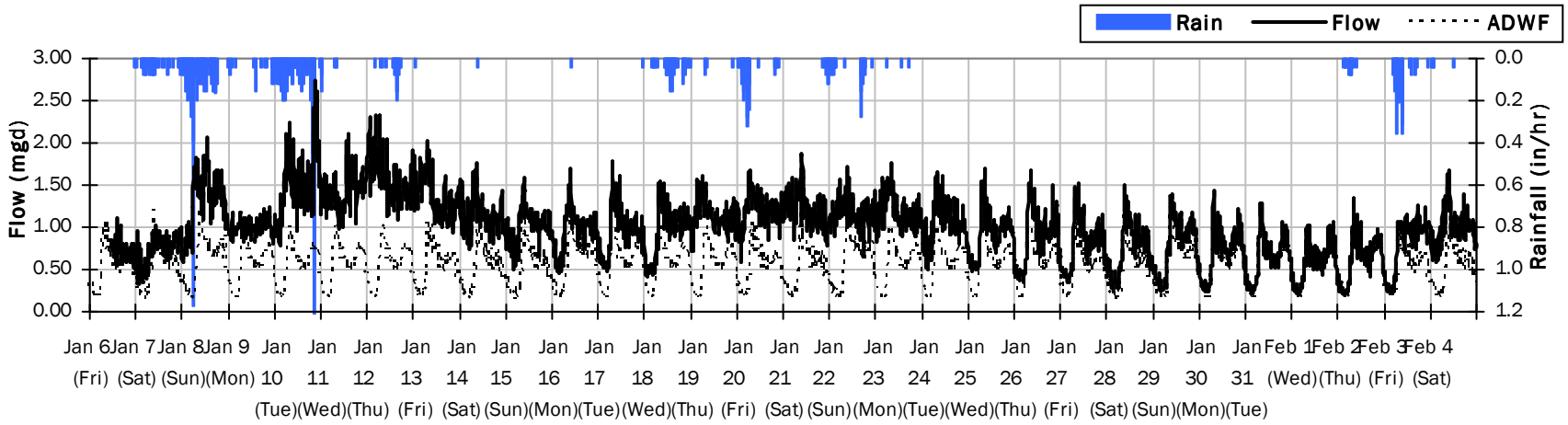
Total Period Rainfall: 16.71 inches

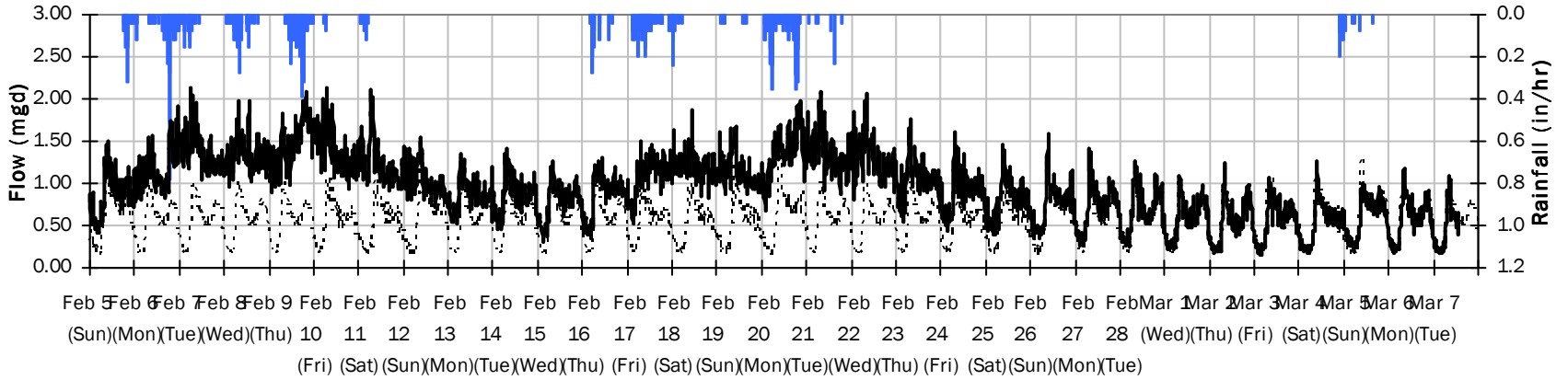


SITE 01

Flow Summary: 1/6/2017 to 3/7/2017

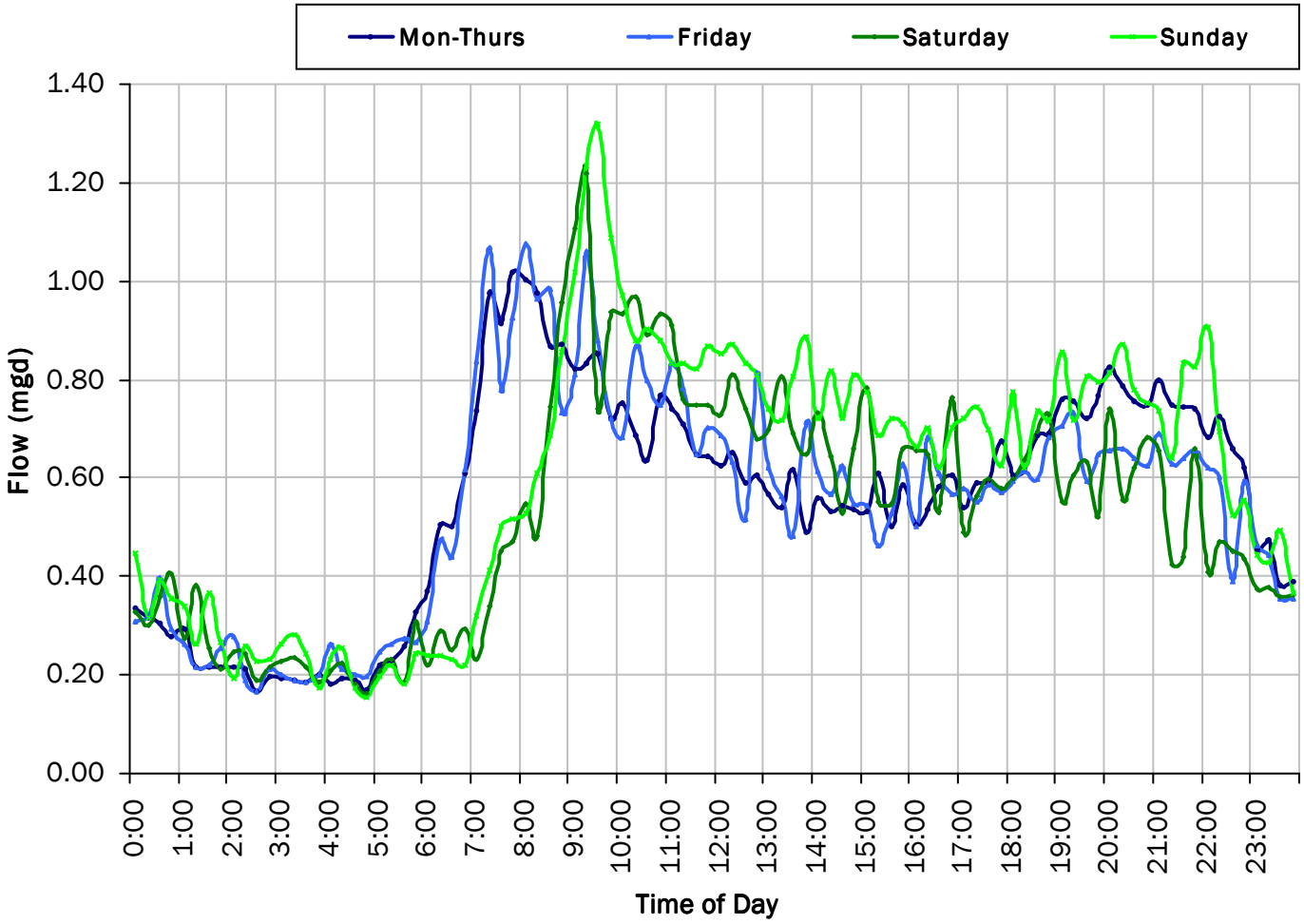
Total Period Rainfall: 14.96 inches **Avg Flow: 0.985 mgd** **Peak Flow: 2.746 mgd** **Min Flow: 0.153 mgd**





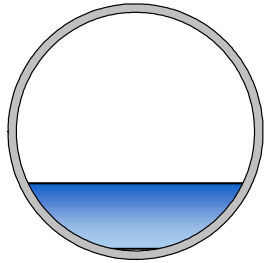
SITE 01

Average Dry Weather Flow Hydrographs



ADWF:

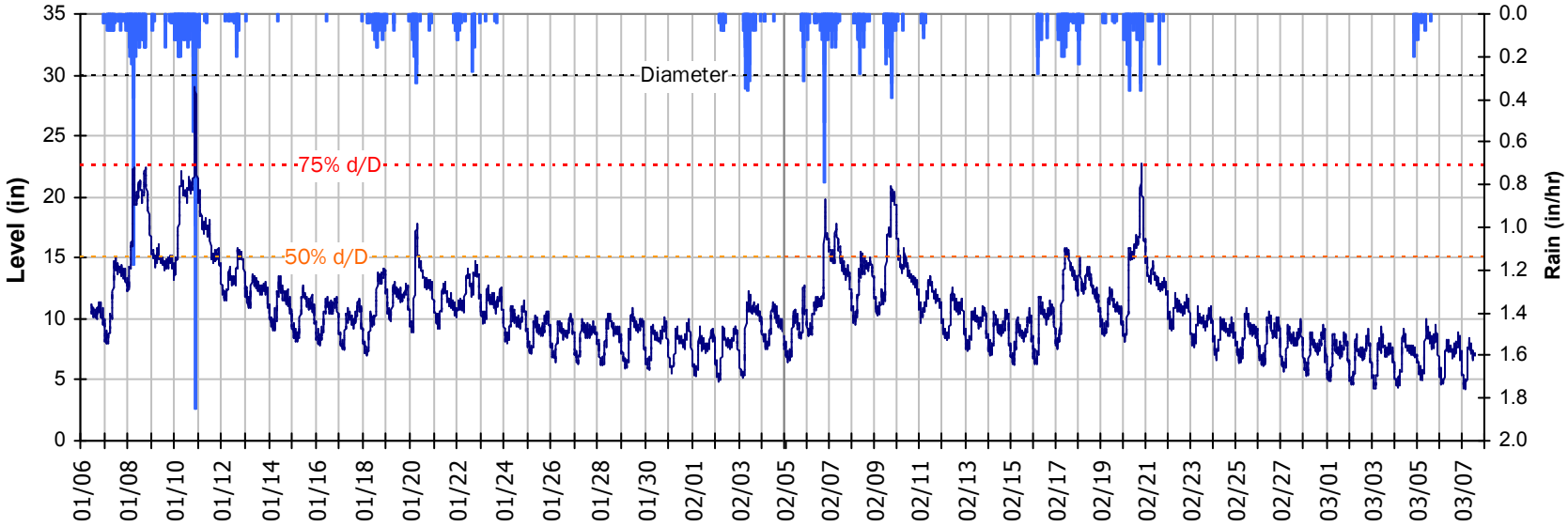
0.558 *mgd*

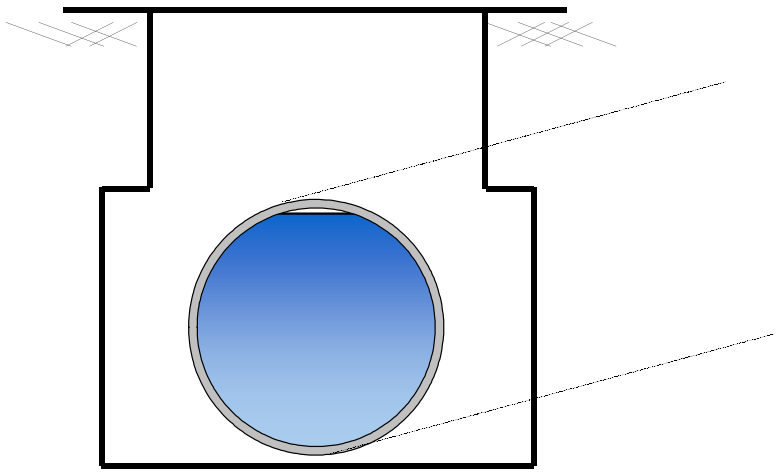


SITE 01

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period



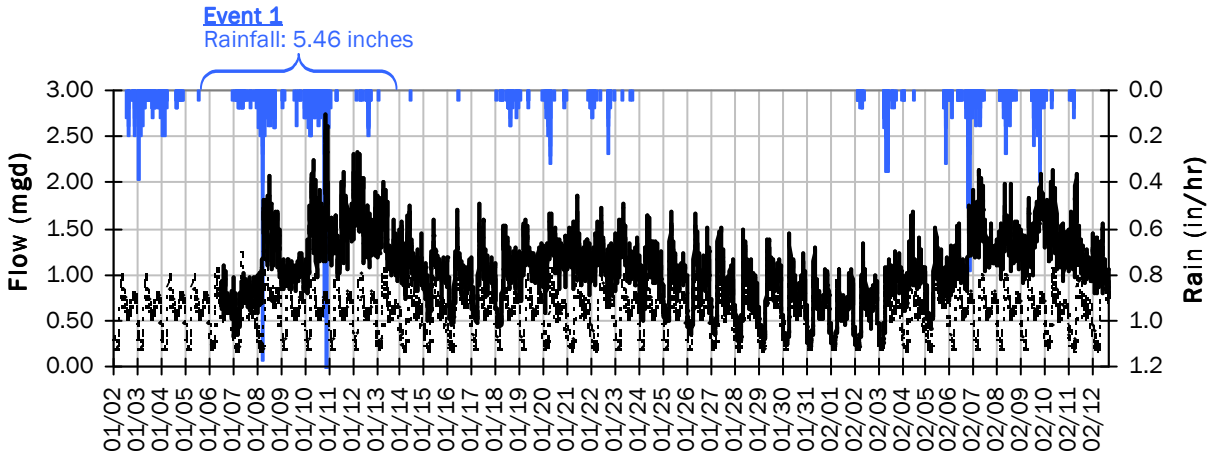


Pipe Diameter:	30	*inches*
Peak Measured Level:	29.1	*inches*
Peak d/D Ratio:	0.97	

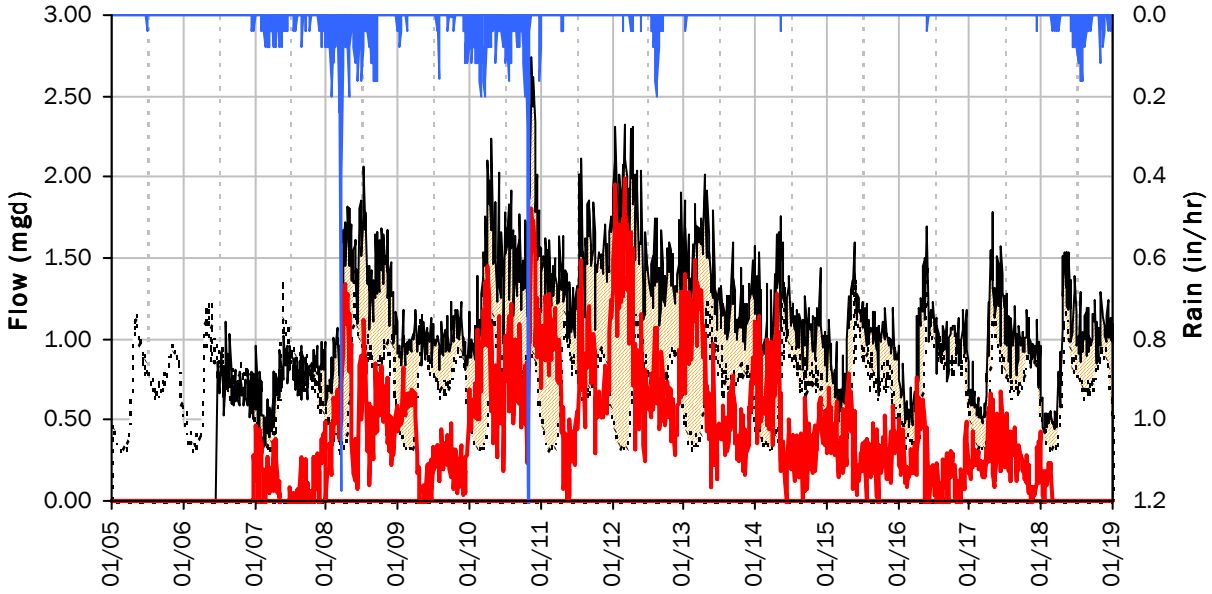
SITE 01

I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

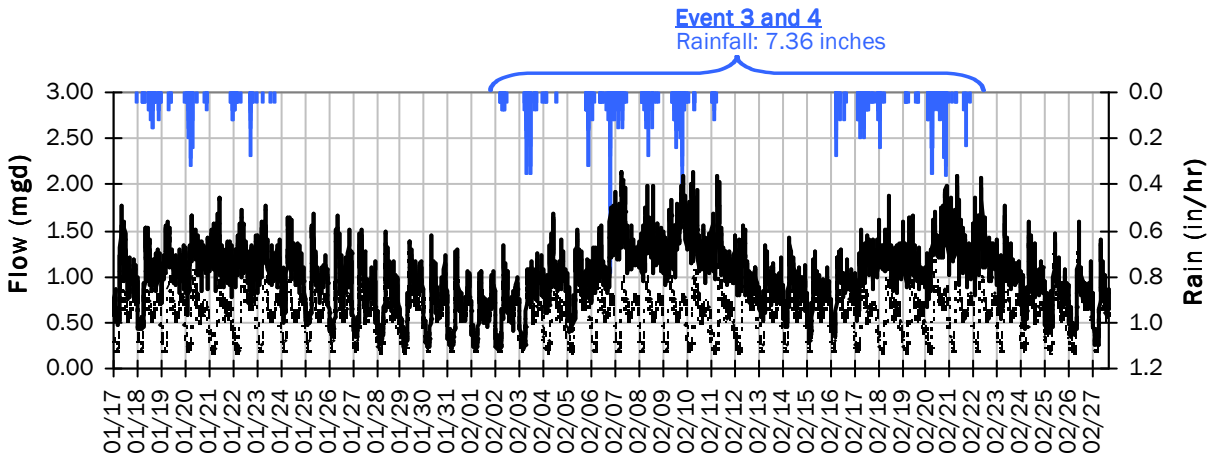


Storm Event I/I Analysis (Rain = 5.46 inches)

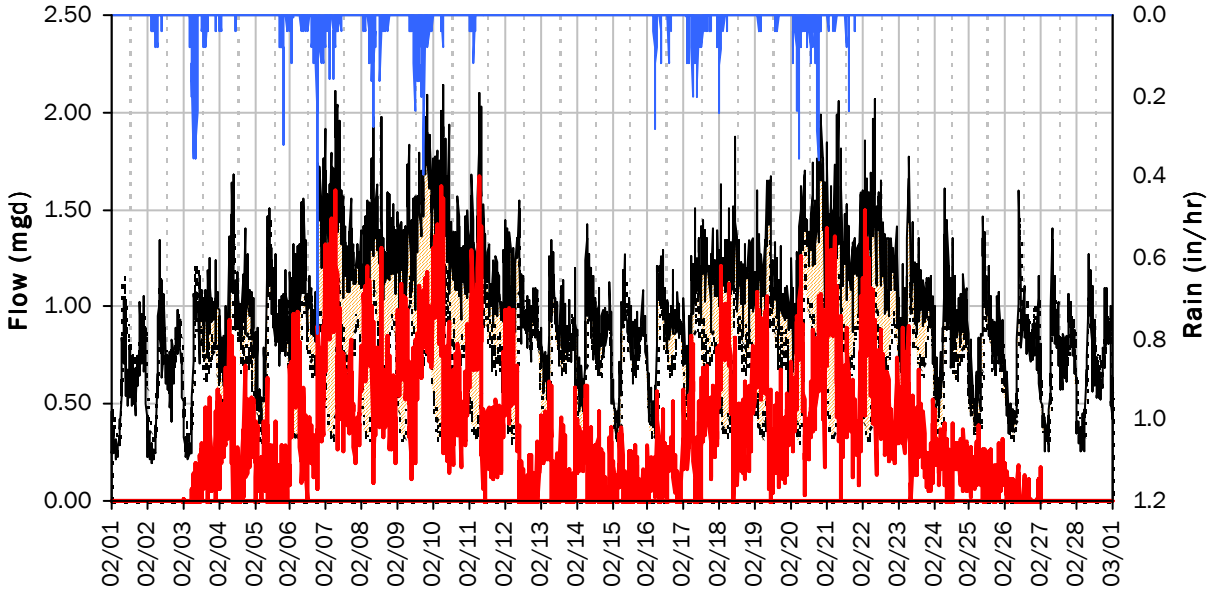
Capacity		Inflow / Infiltration	
Peak Flow:	2.75 *mgd*	**Peak I/I Rate:**	1.99 *mgd*
PF:	4.92	**Total I/I:**	5,381,000 *gallons*
Peak Level:	29.08 *in*		
d/D Ratio:	0.97		

SITE 01
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



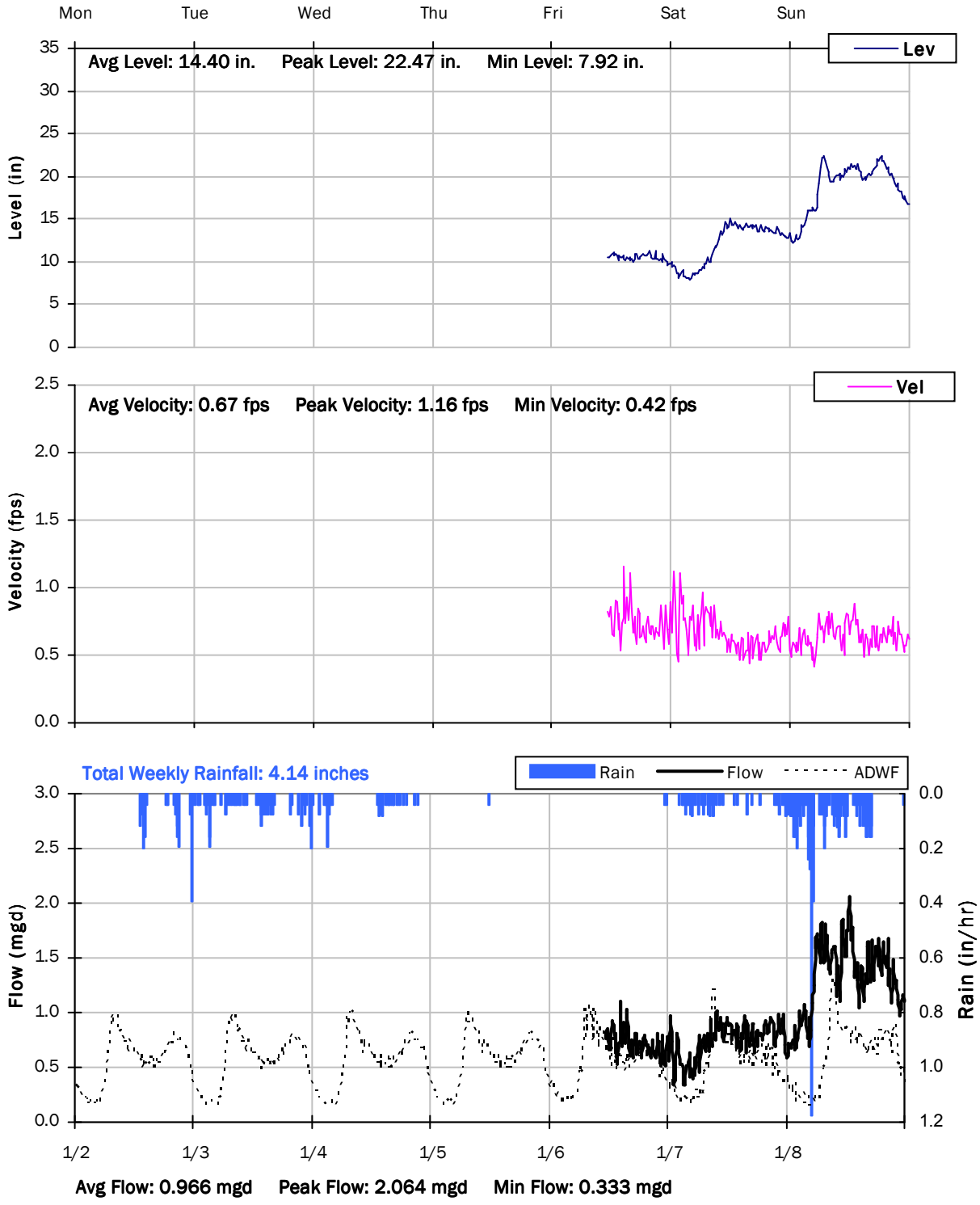
Storm Event I/I Analysis (Rain = 7.36 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	2.14 *mgd*	**Peak I/I Rate:**	1.67 *mgd*
PF:	3.83	**Total I/I:**	9,267,000 *gallons*
Peak Level:	22.71 *in*		
d/D Ratio:	0.76		

SITE 01

Weekly Level, Velocity and Flow Hydrographs

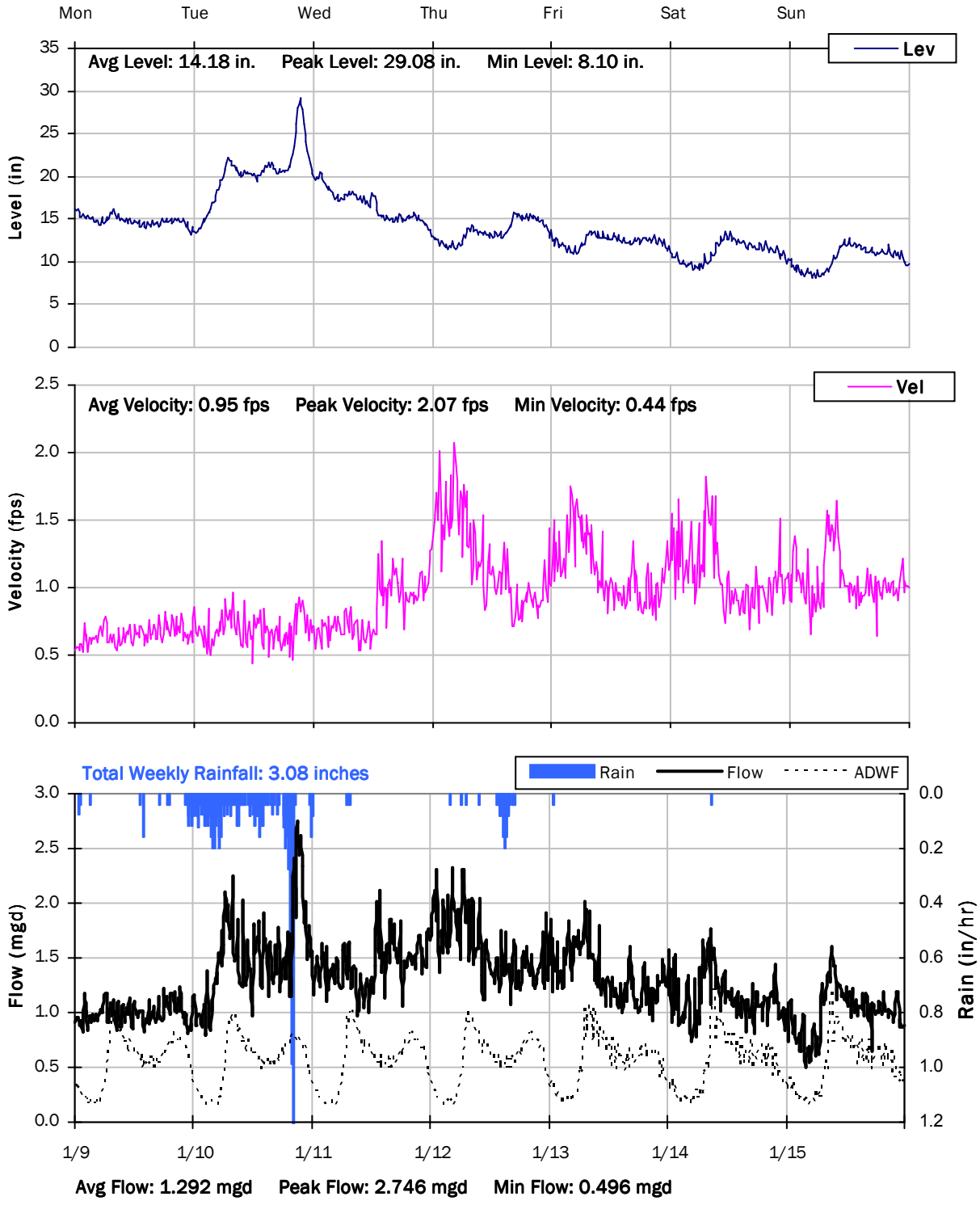
1/2/2017 to 1/9/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

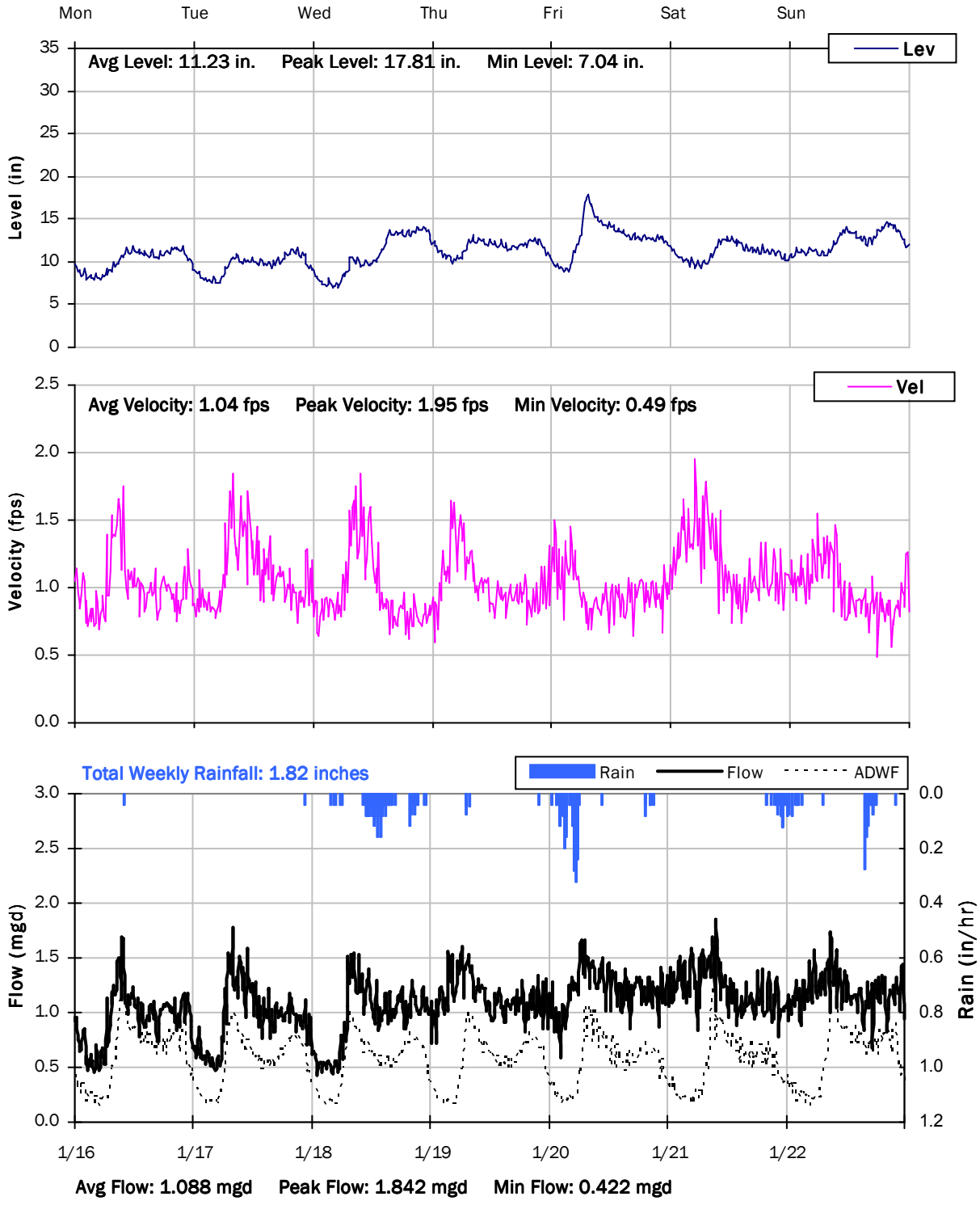
1/9/2017 to 1/16/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

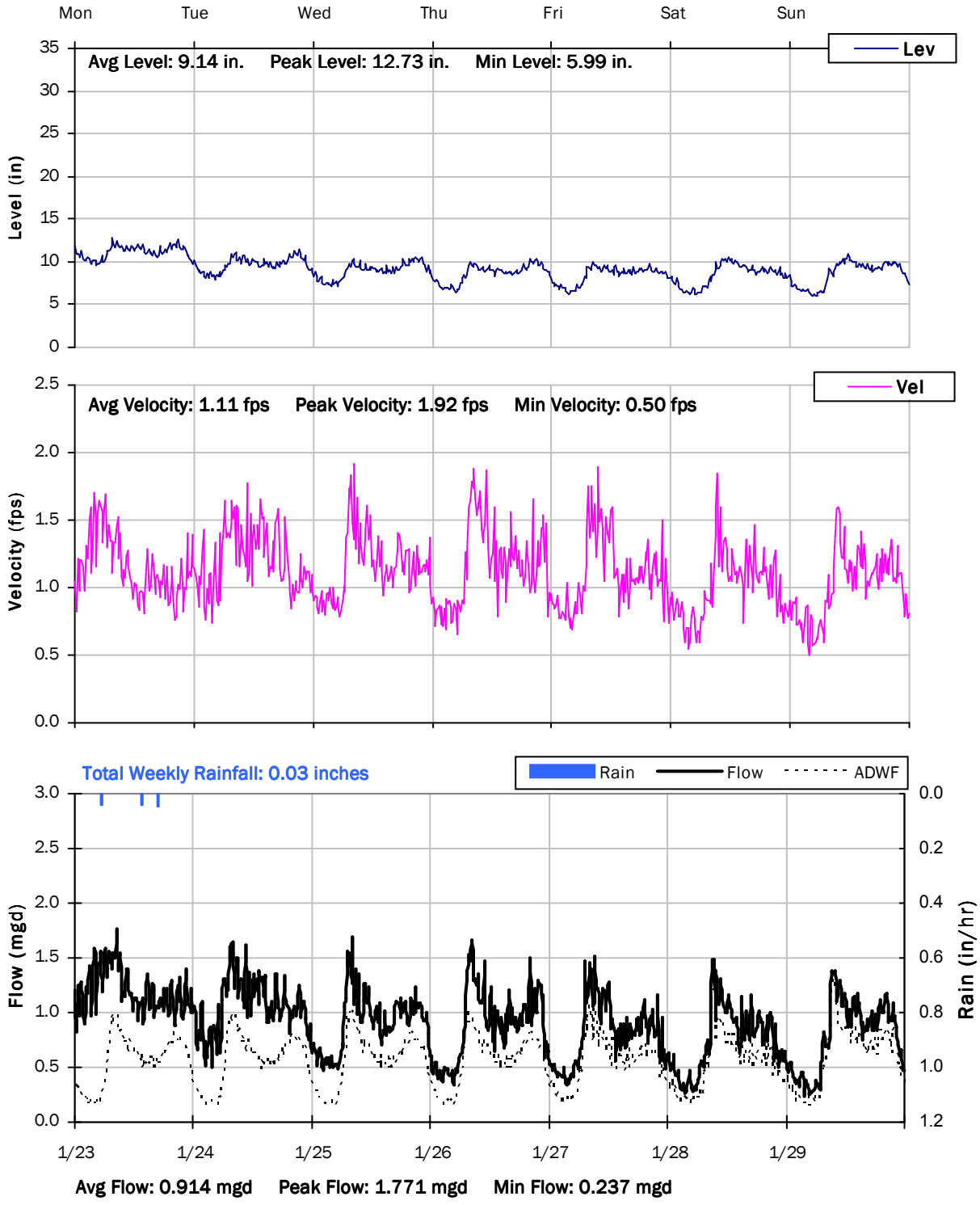
1/16/2017 to 1/23/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

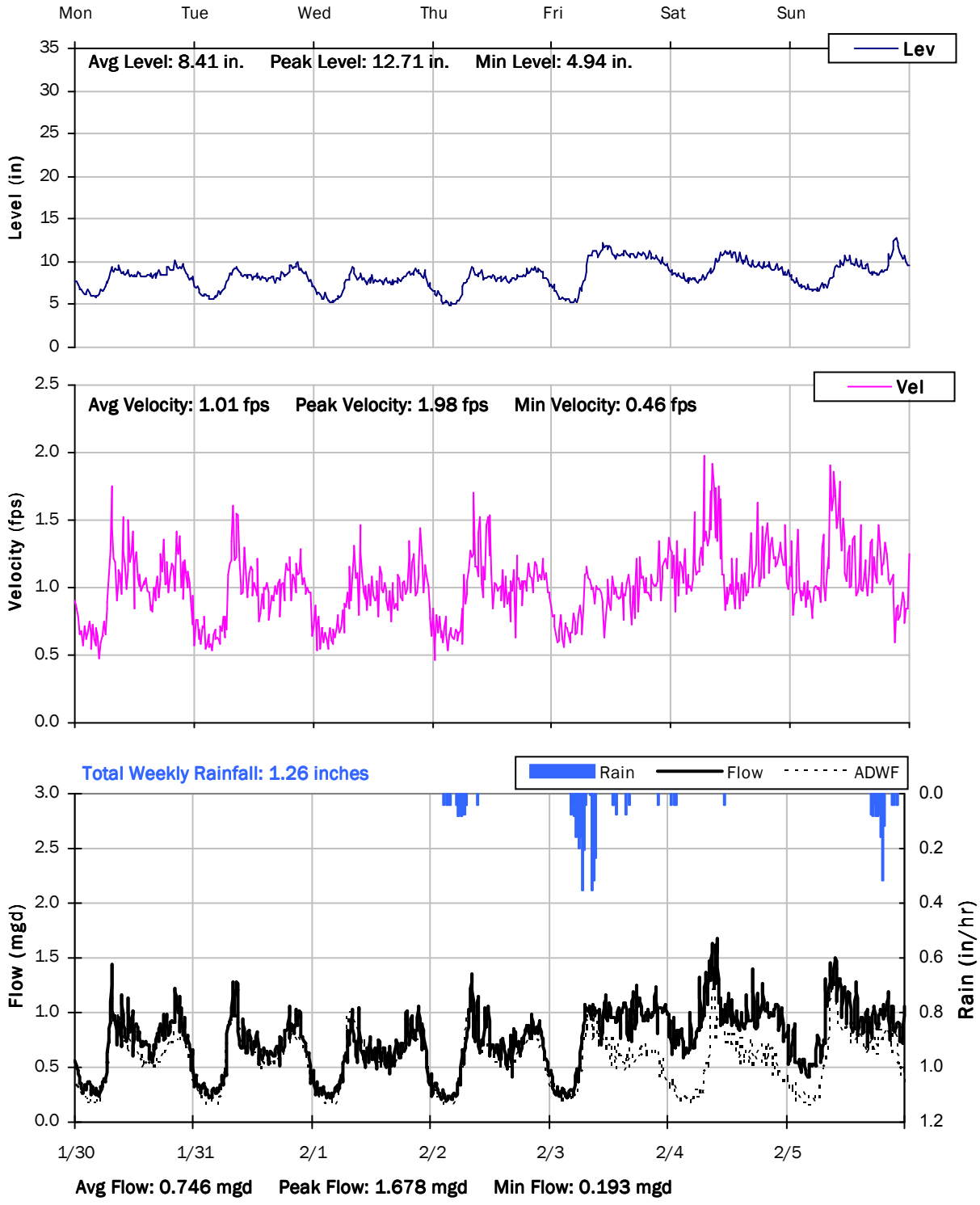
1/23/2017 to 1/30/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

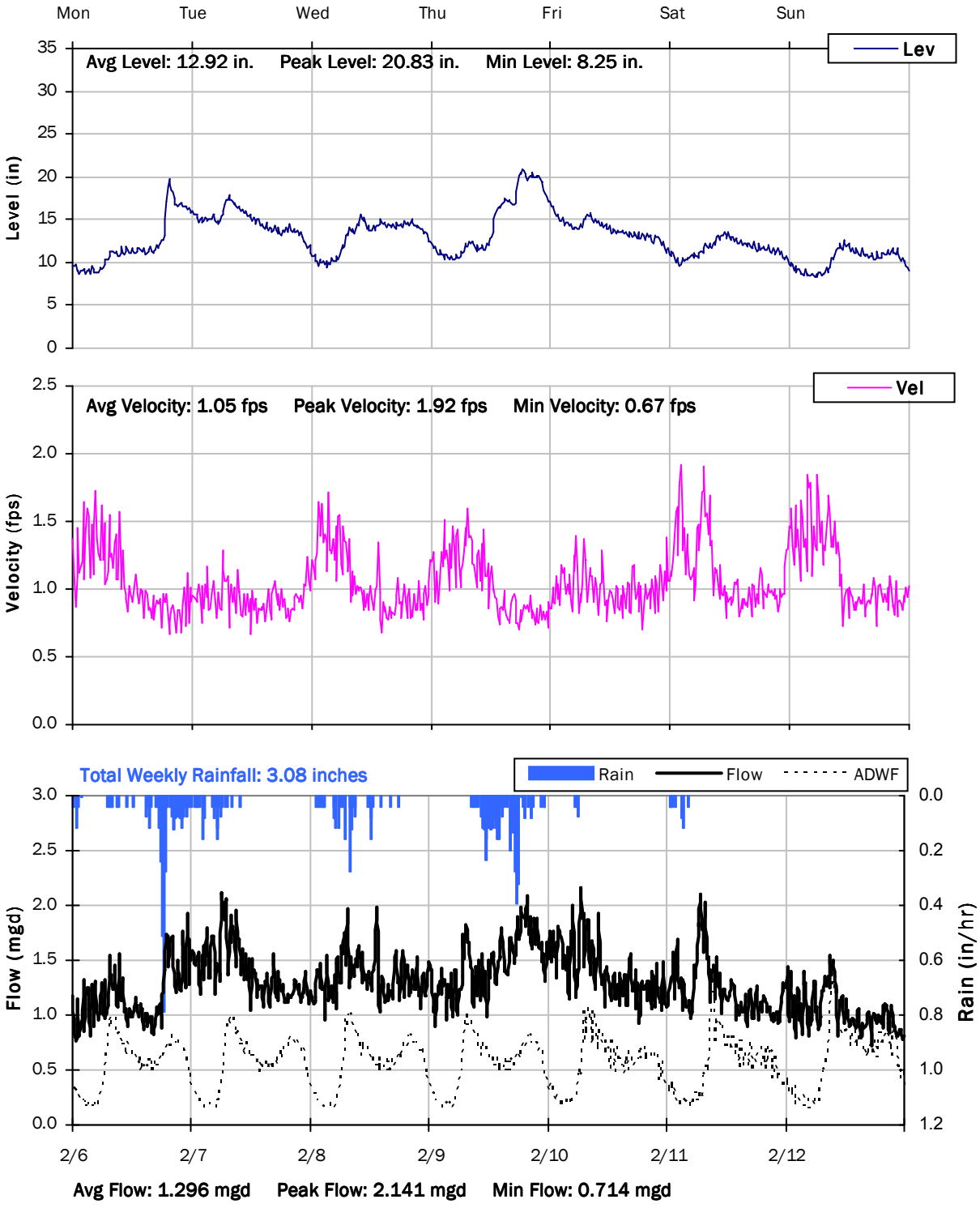
1/30/2017 to 2/6/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

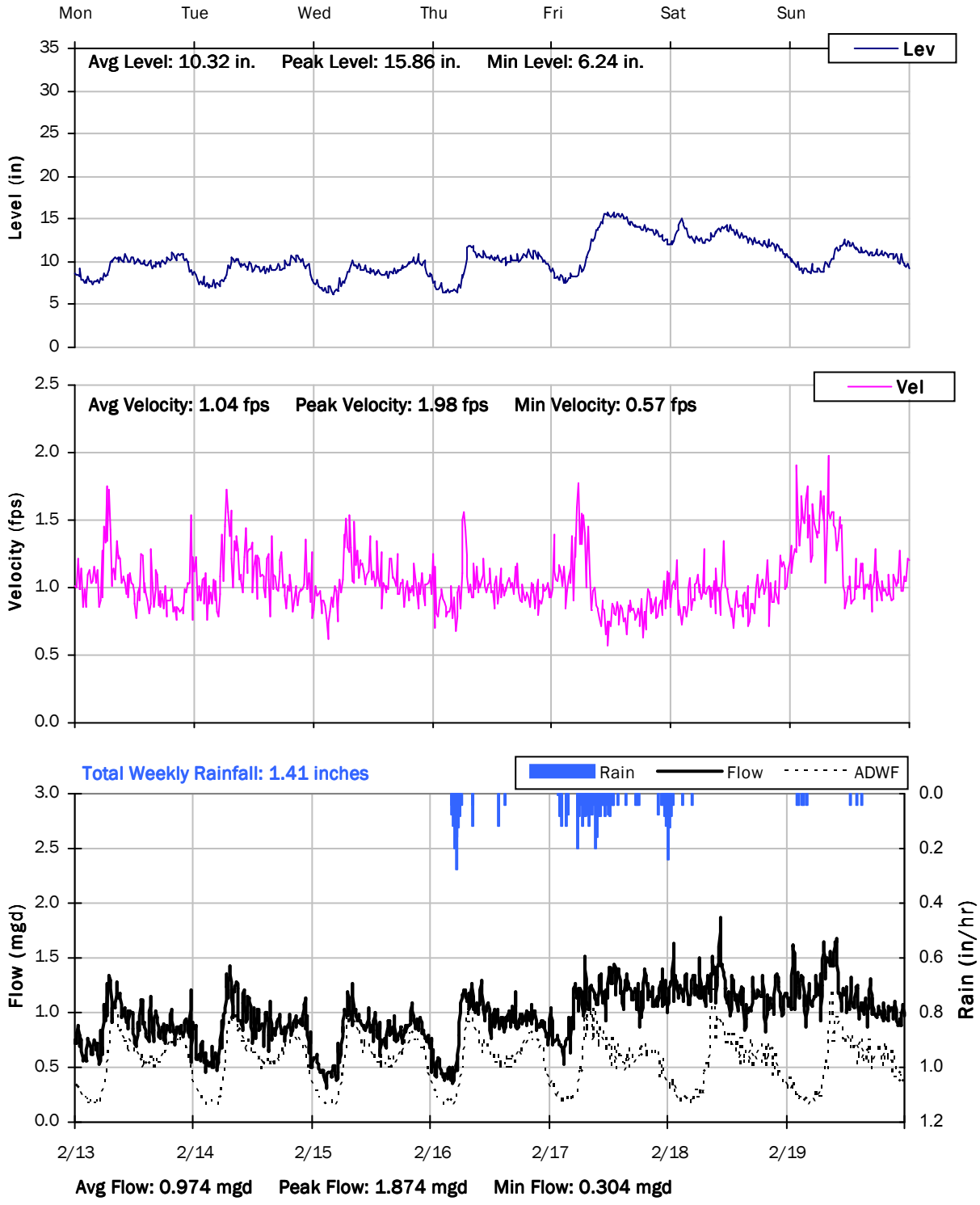
2/6/2017 to 2/13/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

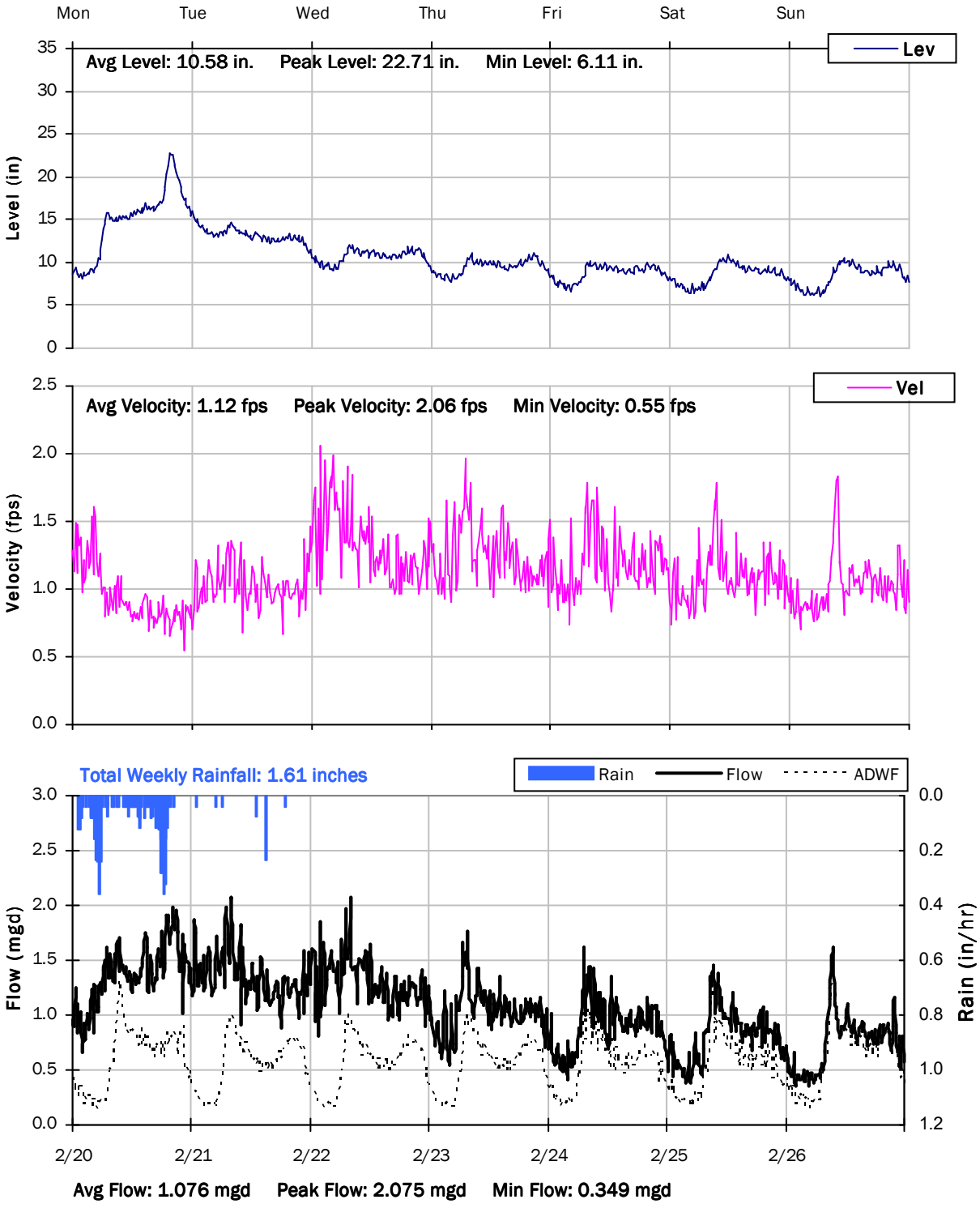
2/13/2017 to 2/20/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

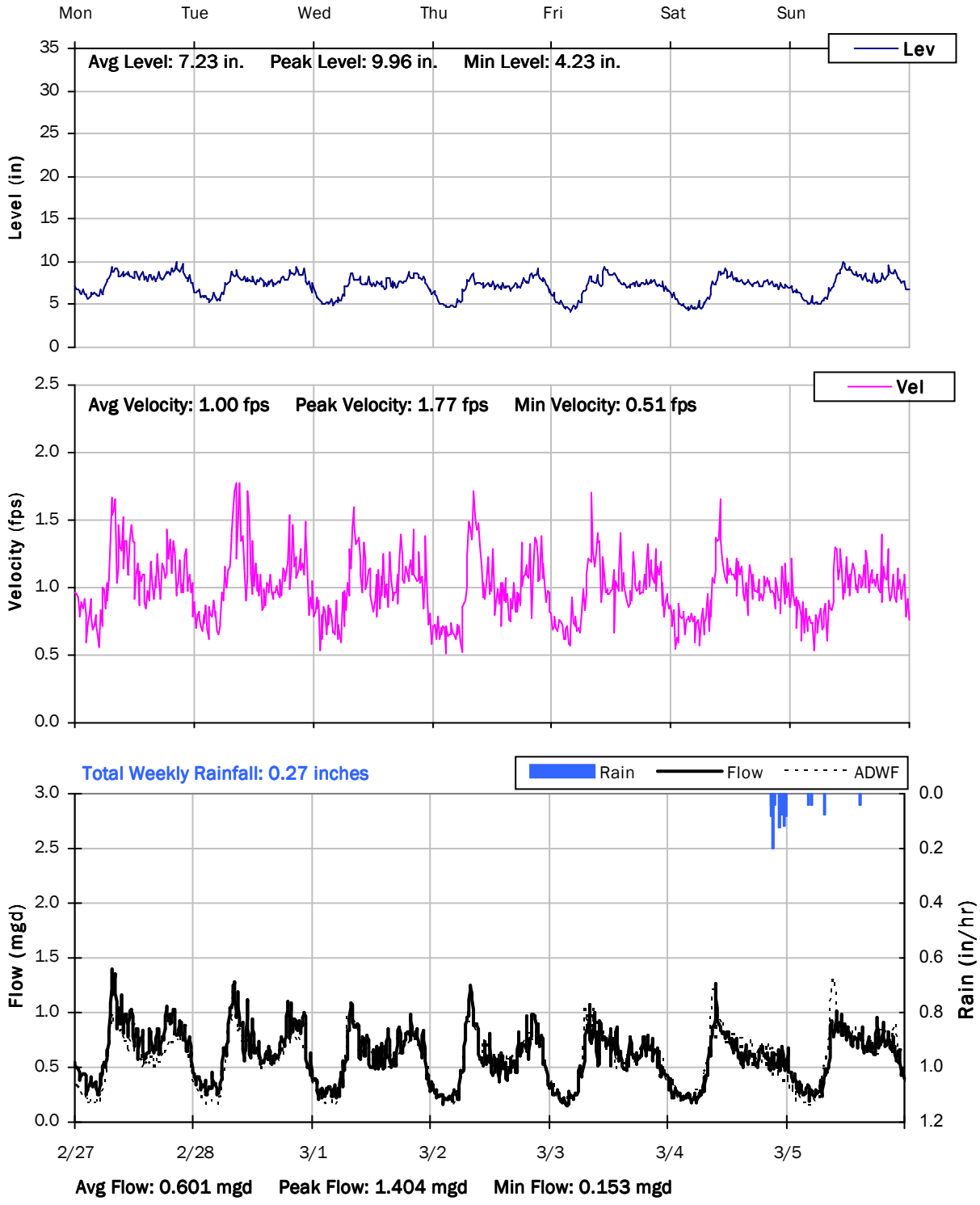
2/20/2017 to 2/27/2017



SITE 01

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



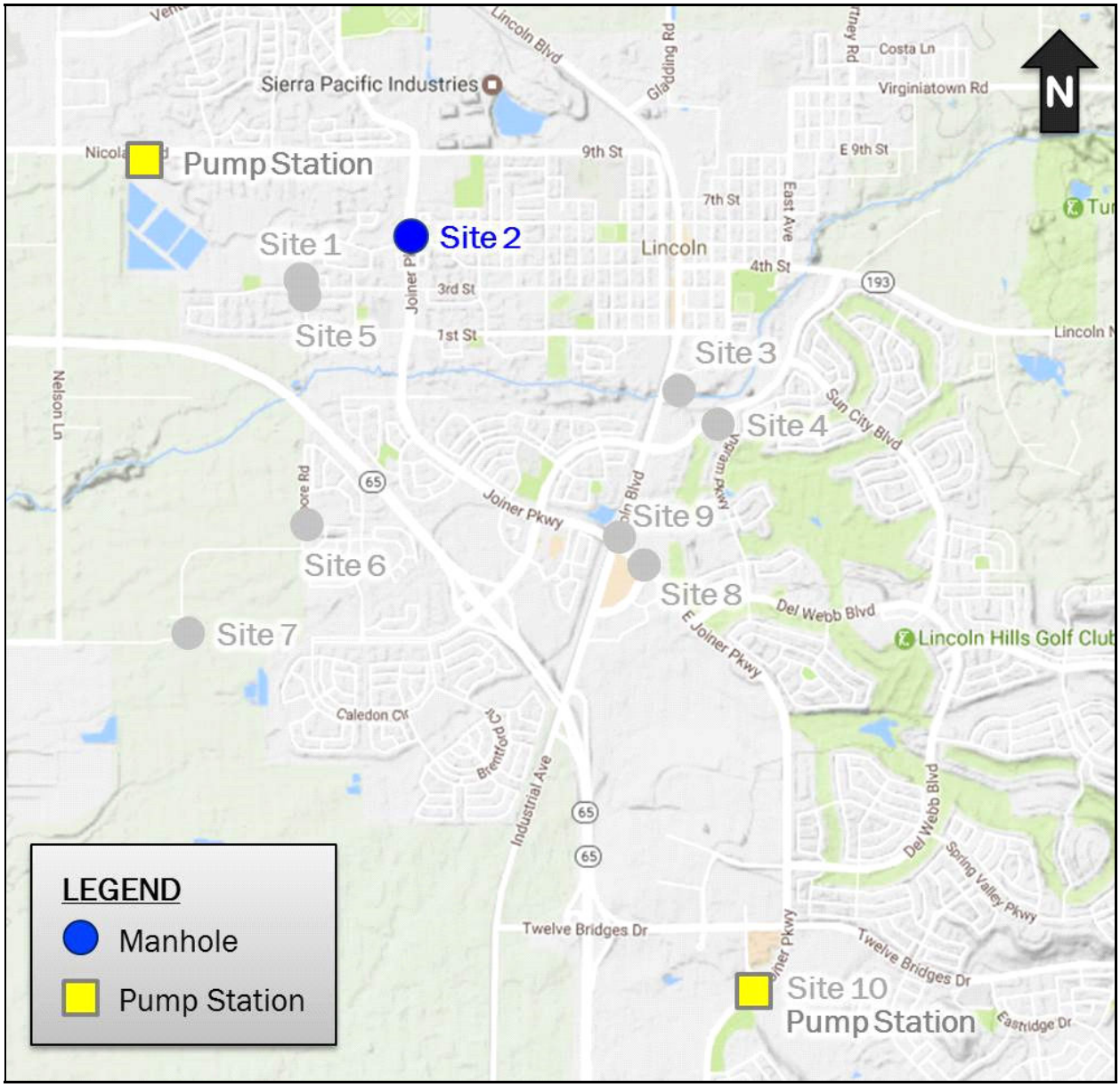
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 02

Location: Joiner Parkway north of 5th Street

Data Summary Report



Vicinity Map: Site 02

SITE 02

Site Information

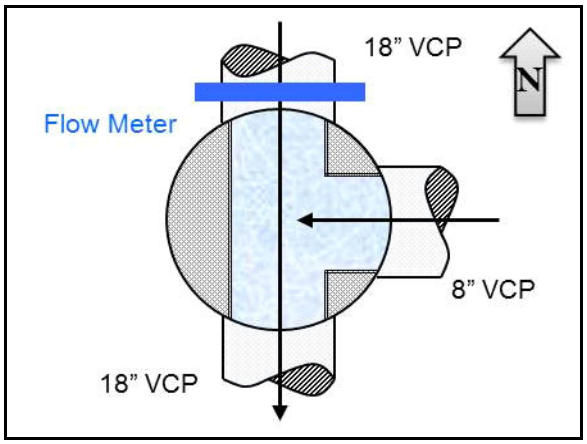
Location: Joiner Parkway north of 5th Street

District ID: NW386SS31

Coordinates:	121.3134° W, 38.8921° N
Expected Pipe Diameter (Orig. if Relocated):	18 inches
Measured Pipe Diameter:	18 inches
ADWF:	0.102 mgd
Peak Measured Flow:	0.630 mgd
Rim Elevation (GEarth):	143 feet

Satellite Map

Sewer Map



Flow Sketch

Street View

Plan View

SITE 02

Additional Site Photos

Effluent Pipe

North Influent Pipe

SITE 02

Additional Site Photos

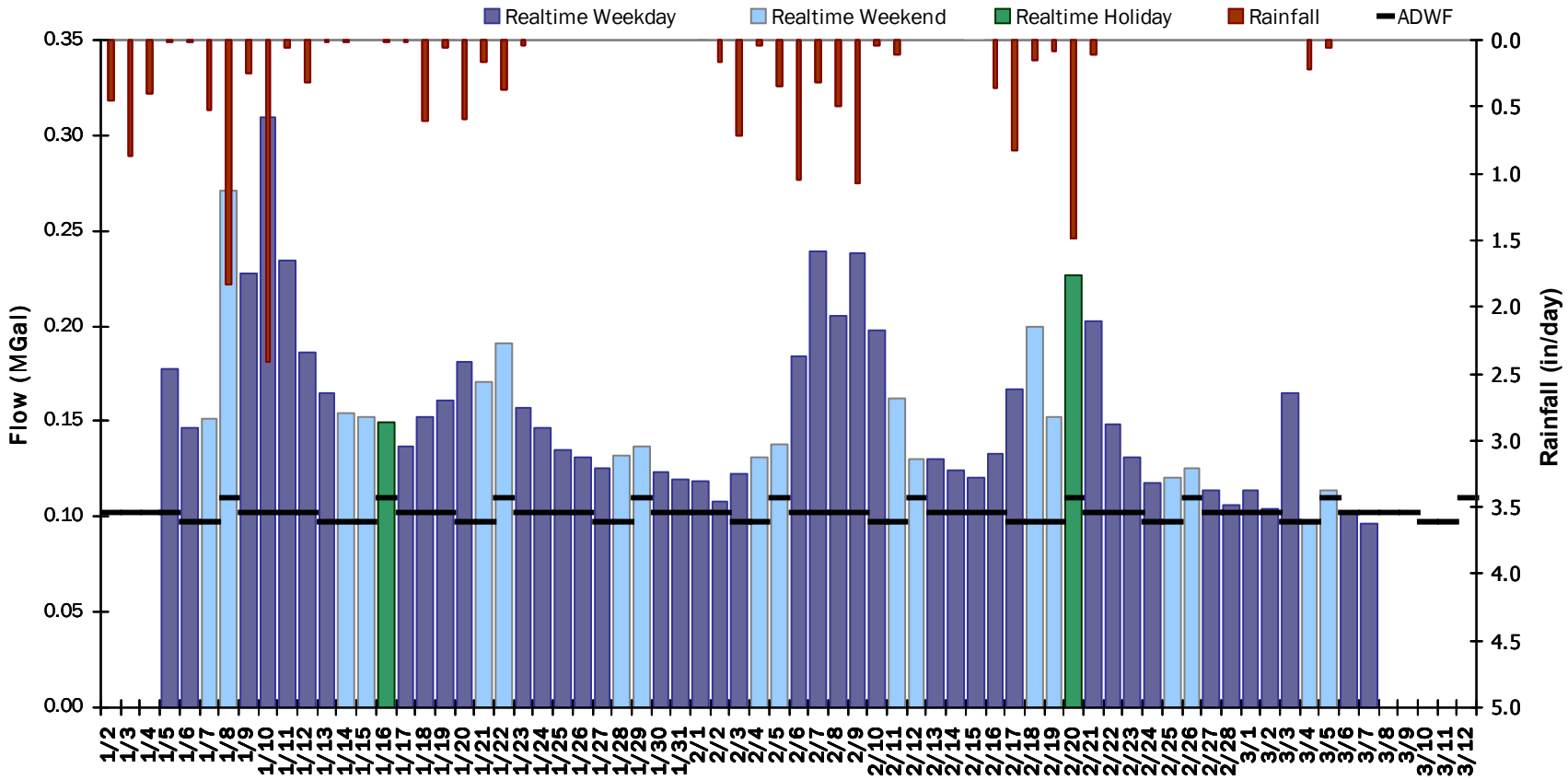
East Influent Pipe

SITE 02

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 0.155 MGal Peak Daily Flow: 0.309 MGal Min Daily Flow: 0.096 MGal

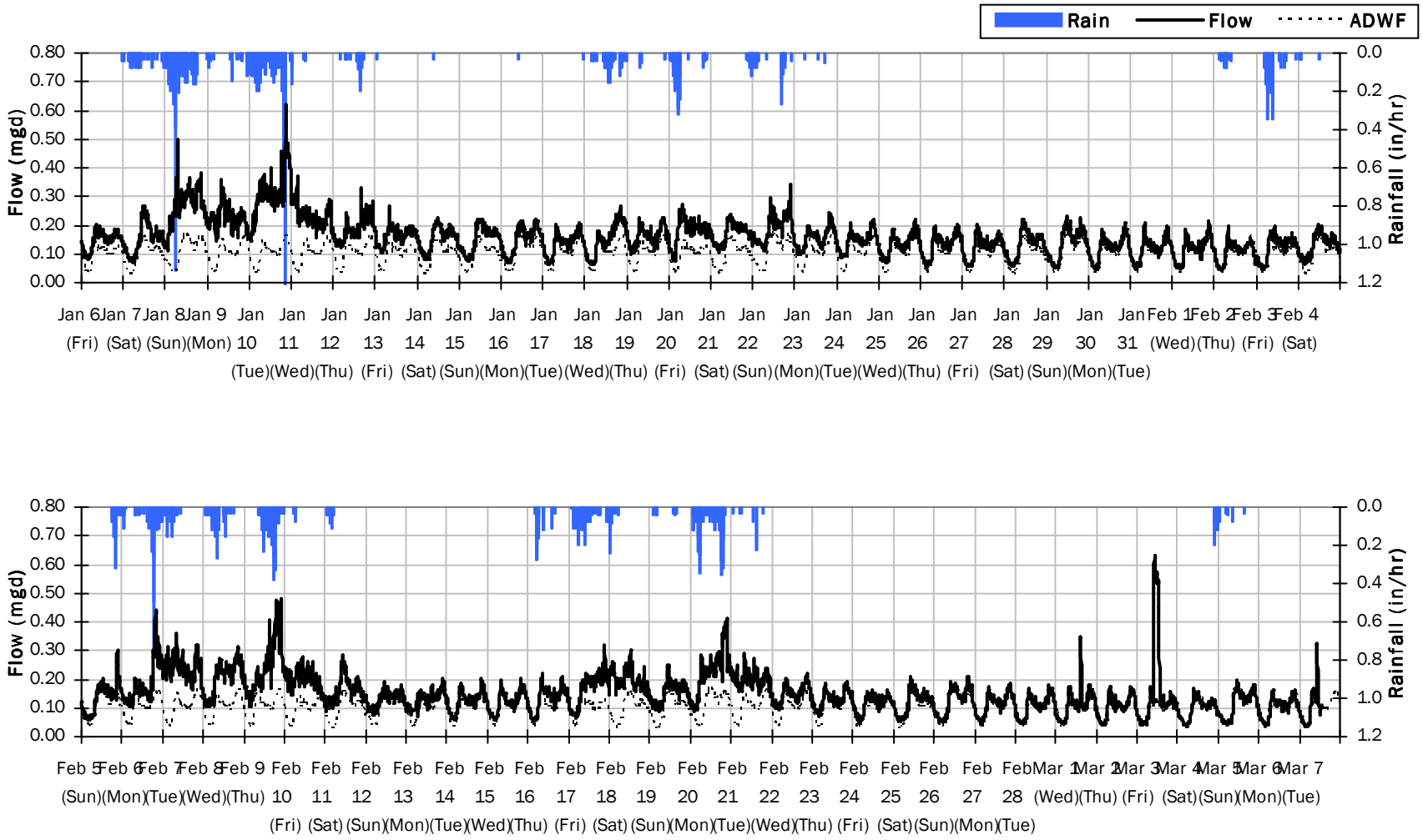
Total Period Rainfall: 16.65 inches



SITE 02

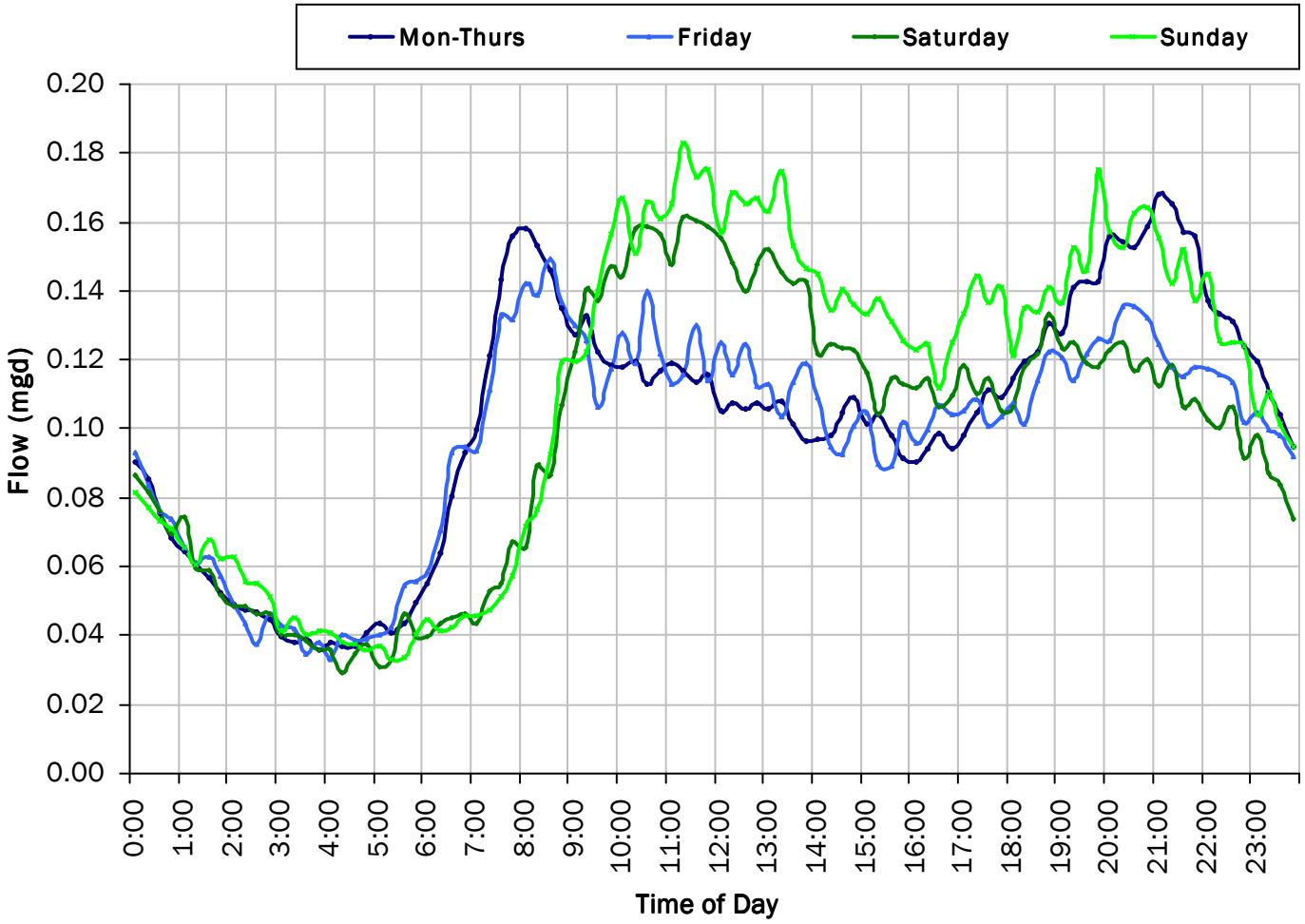
Flow Summary: 1/6/2017 to 3/7/2017

Total Period Rainfall: 14.93 inches **Avg Flow: 0.155 mgd** **Peak Flow: 0.630 mgd** **Min Flow: 0.034 mgd**



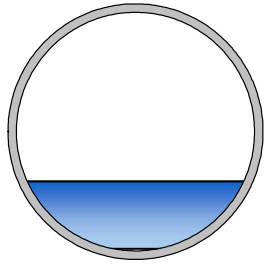
SITE 02

Average Dry Weather Flow Hydrographs



ADWF:

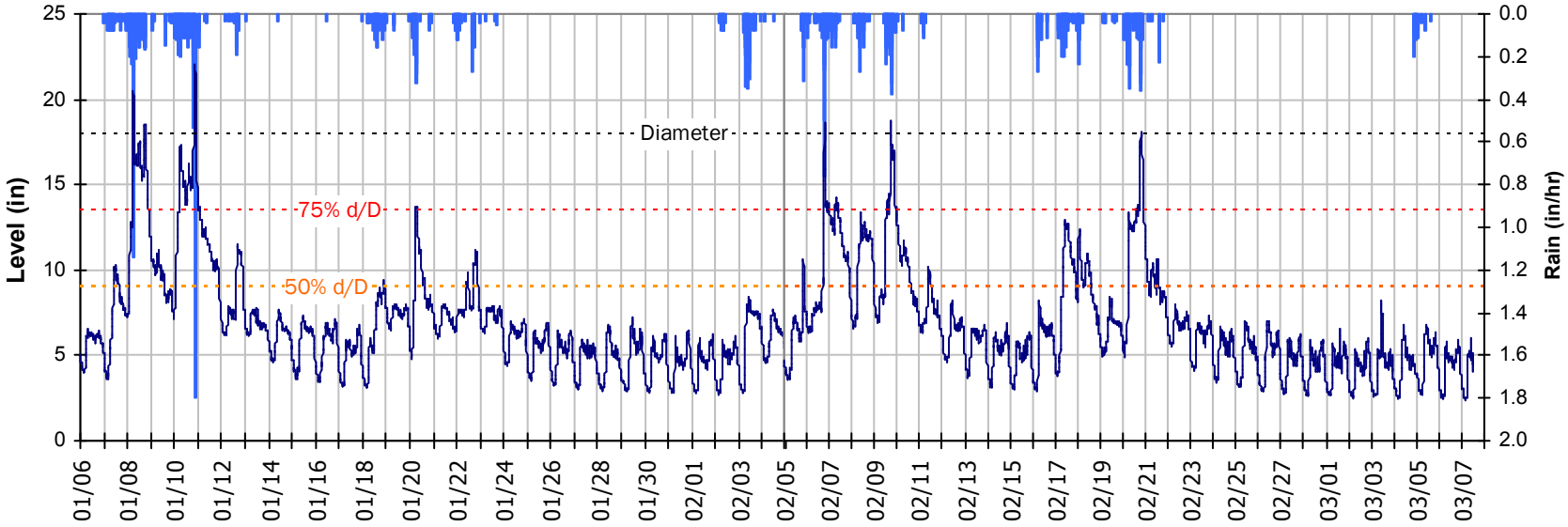
0.102 *mgd*

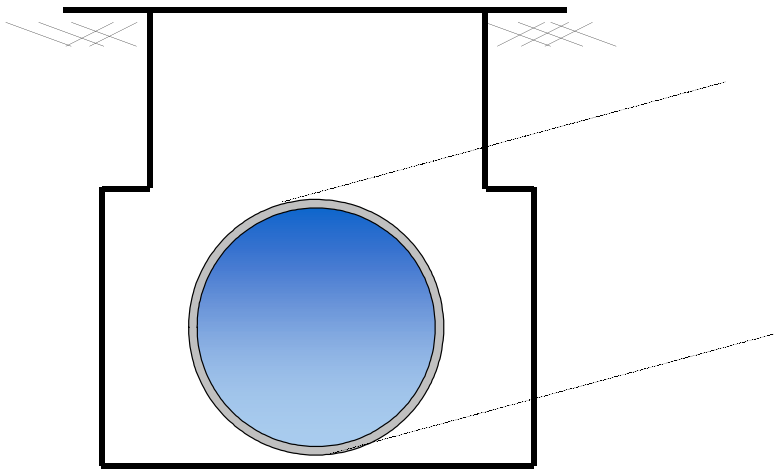


SITE 02

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period



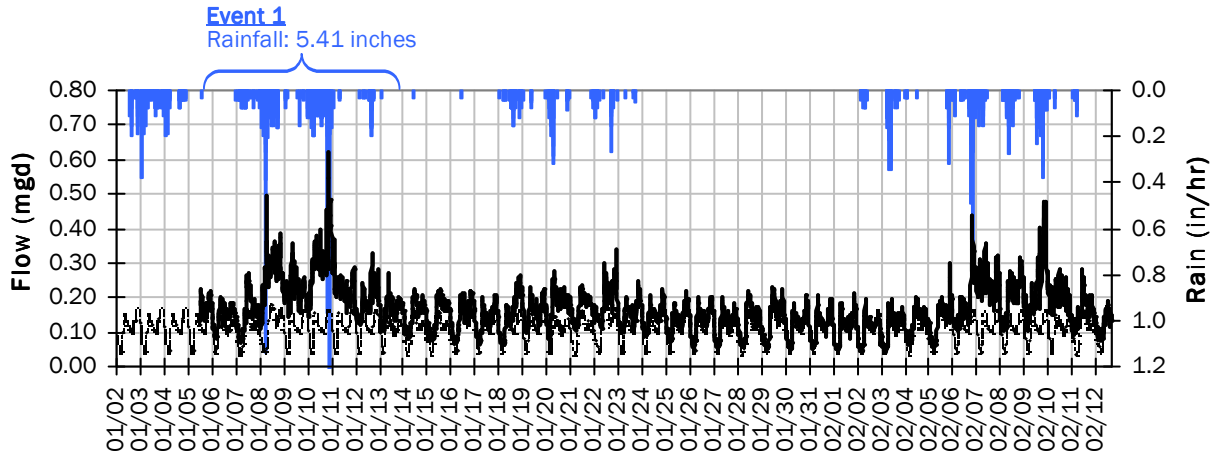


Pipe Diameter:	18	*inches*
Peak Measured Level:	22.1	*inches*
Peak d/D Ratio:	1.23	

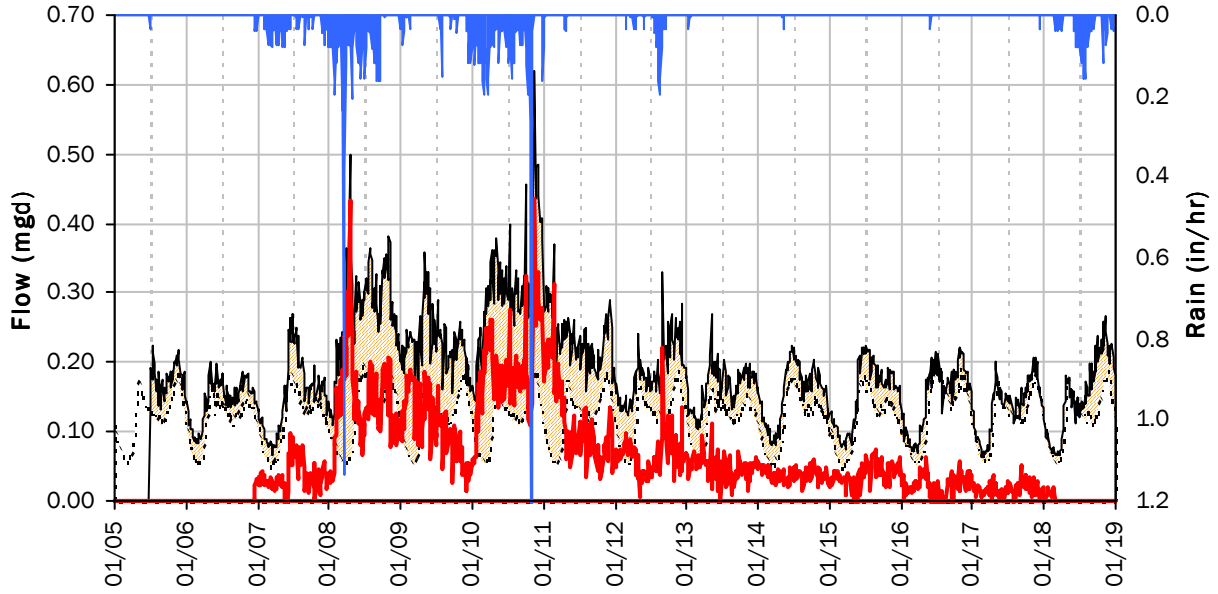
Surcharged 4.1 inches over crown

SITE 02
I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

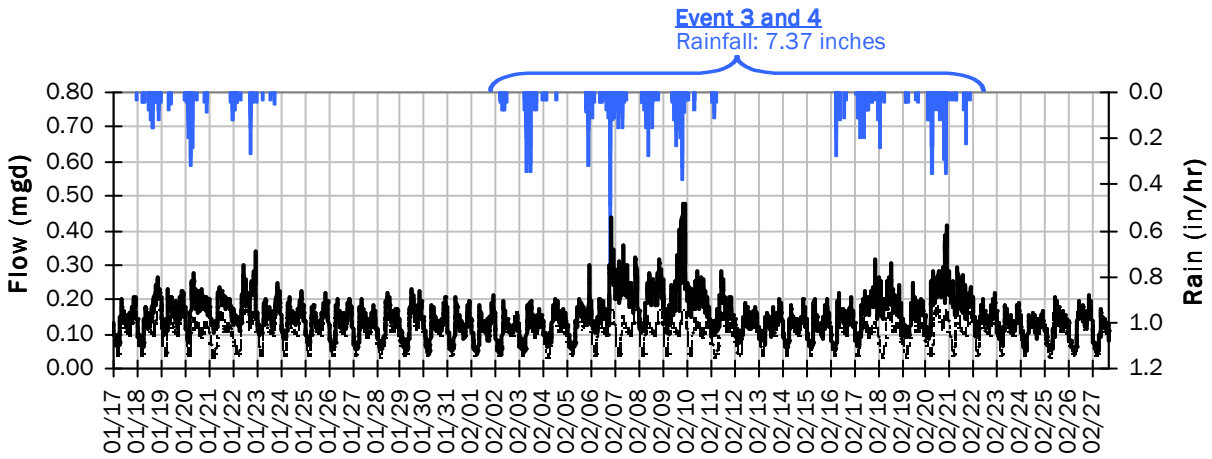


Storm Event I/I Analysis (Rain = 5.41 inches)

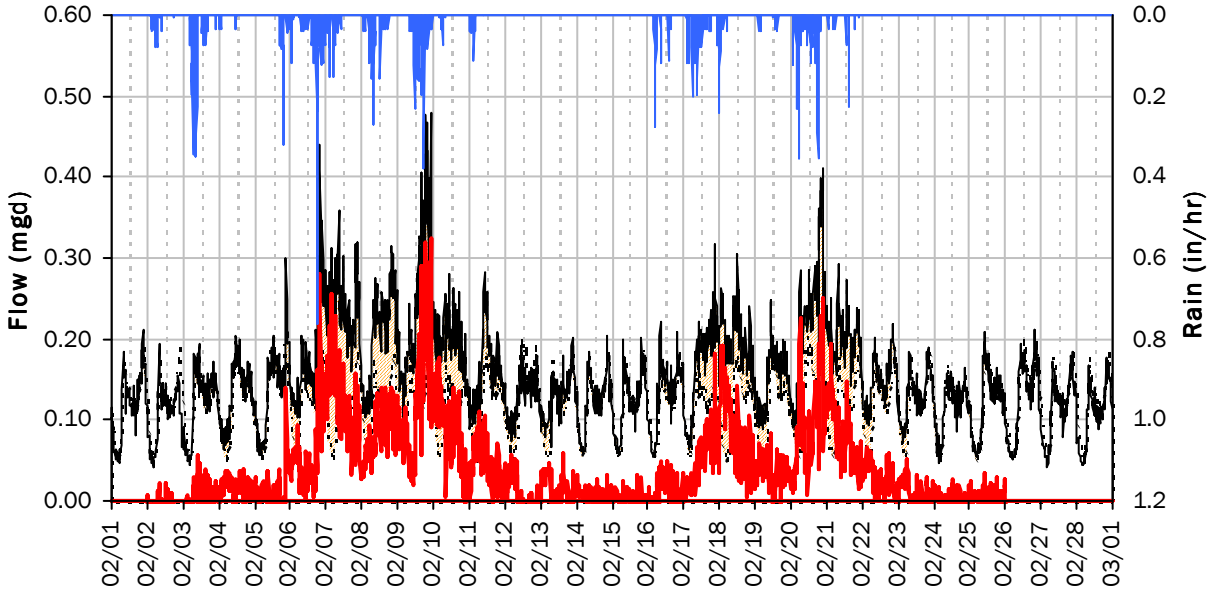
Capacity		Inflow / Infiltration	
Peak Flow:	0.62 *mgd*	**Peak I/I Rate:**	0.44 *mgd*
PF:	6.11	**Total I/I:**	822,000 *gallons*
Peak Level:	22.05 *in*		
d/D Ratio:	1.23		

SITE 02
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



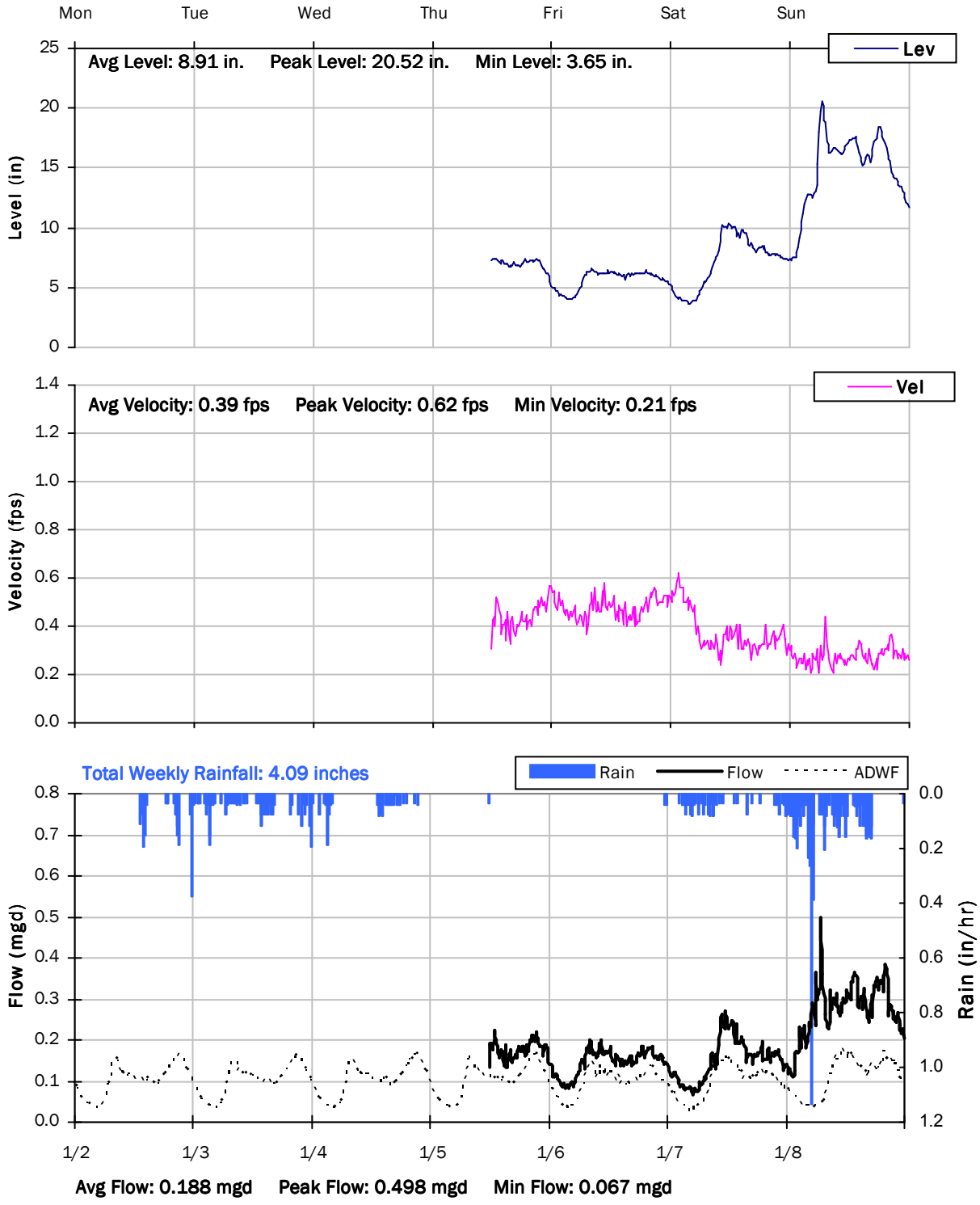
Storm Event I/I Analysis (Rain = 7.37 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	0.48 *mgd*	**Peak I/I Rate:**	0.32 *mgd*
PF:	4.72	**Total I/I:**	967,000 *gallons*
Peak Level:	18.79 *in*		
d/D Ratio:	1.04		

SITE 02

Weekly Level, Velocity and Flow Hydrographs

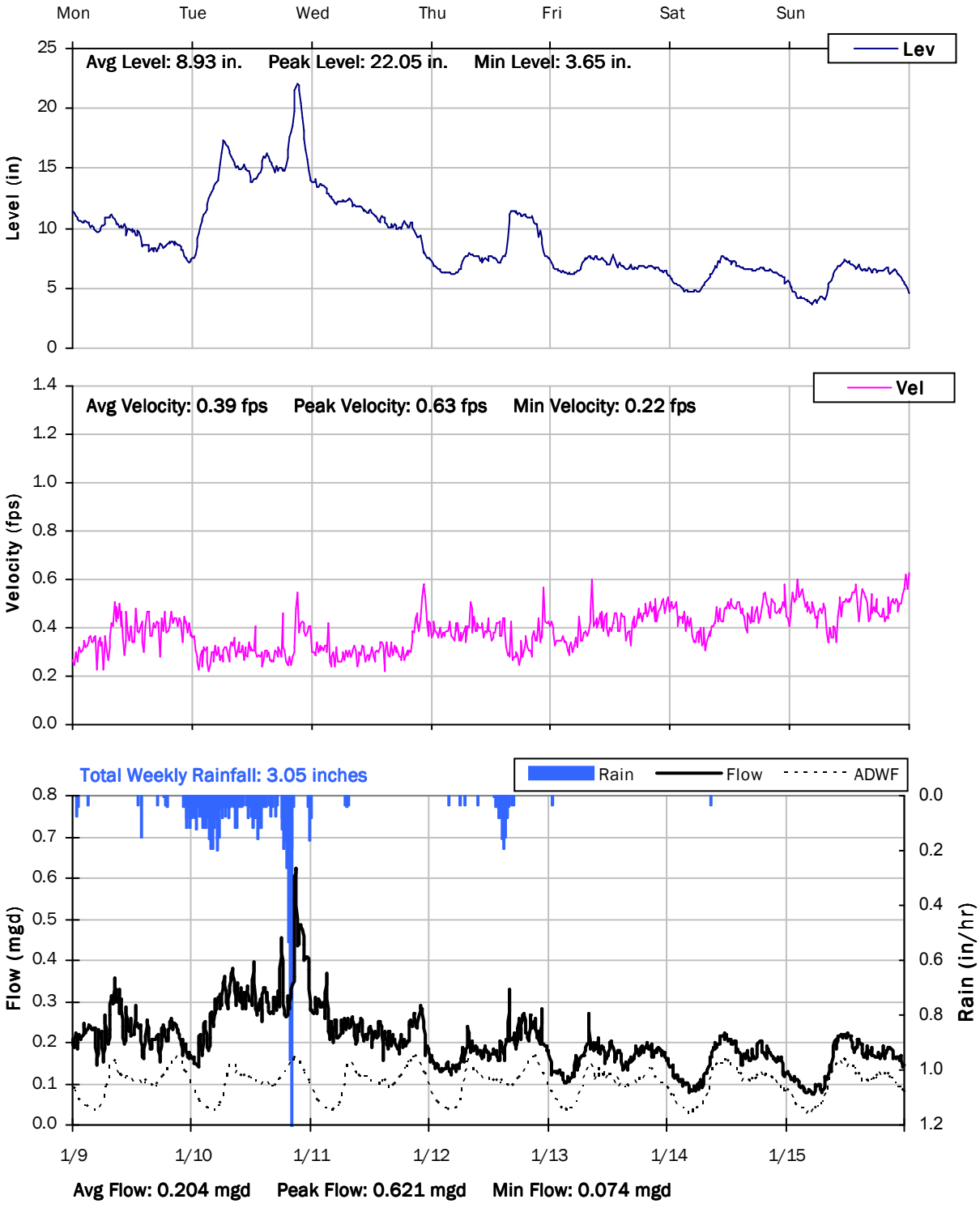
1/2/2017 to 1/9/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

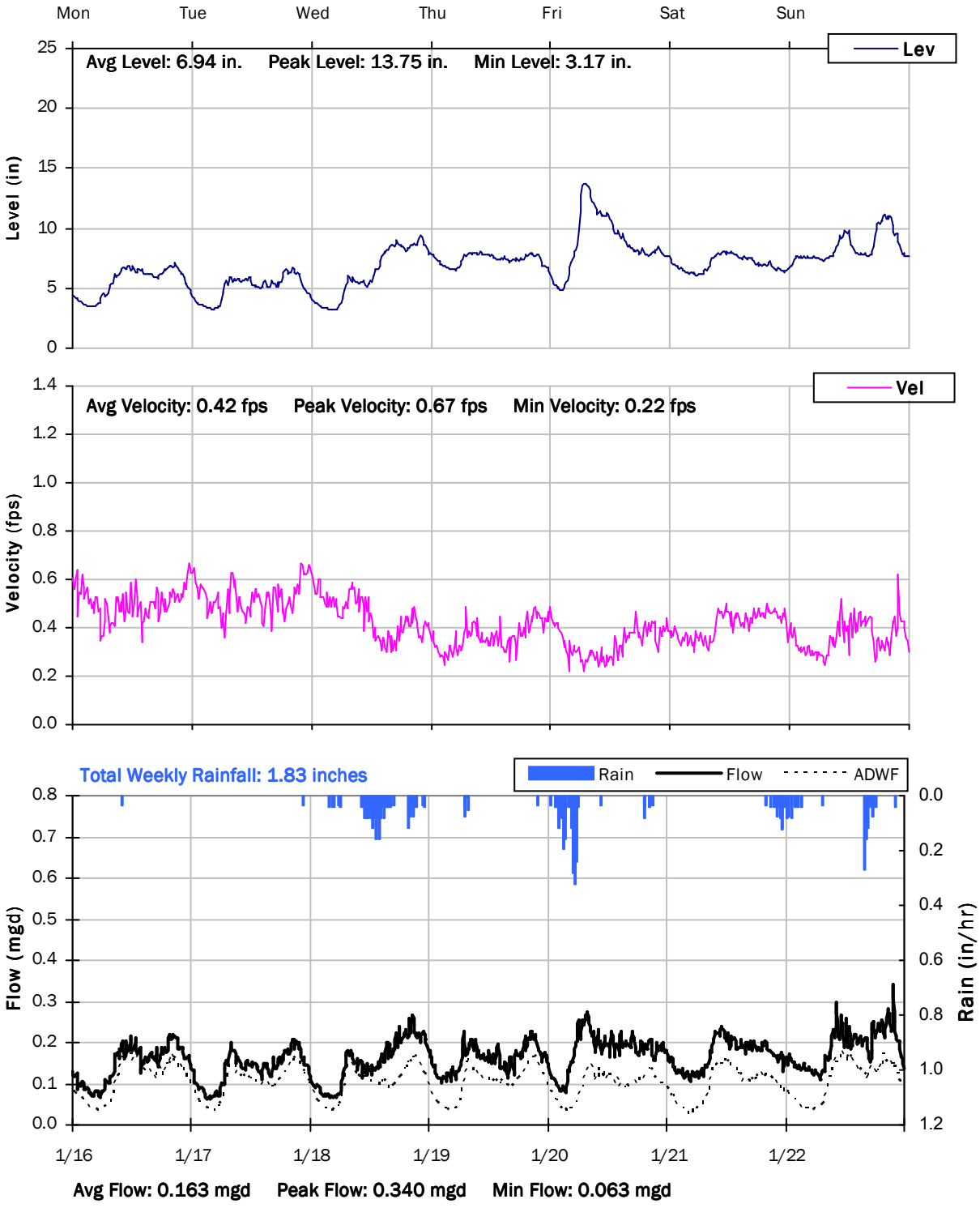
1/9/2017 to 1/16/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

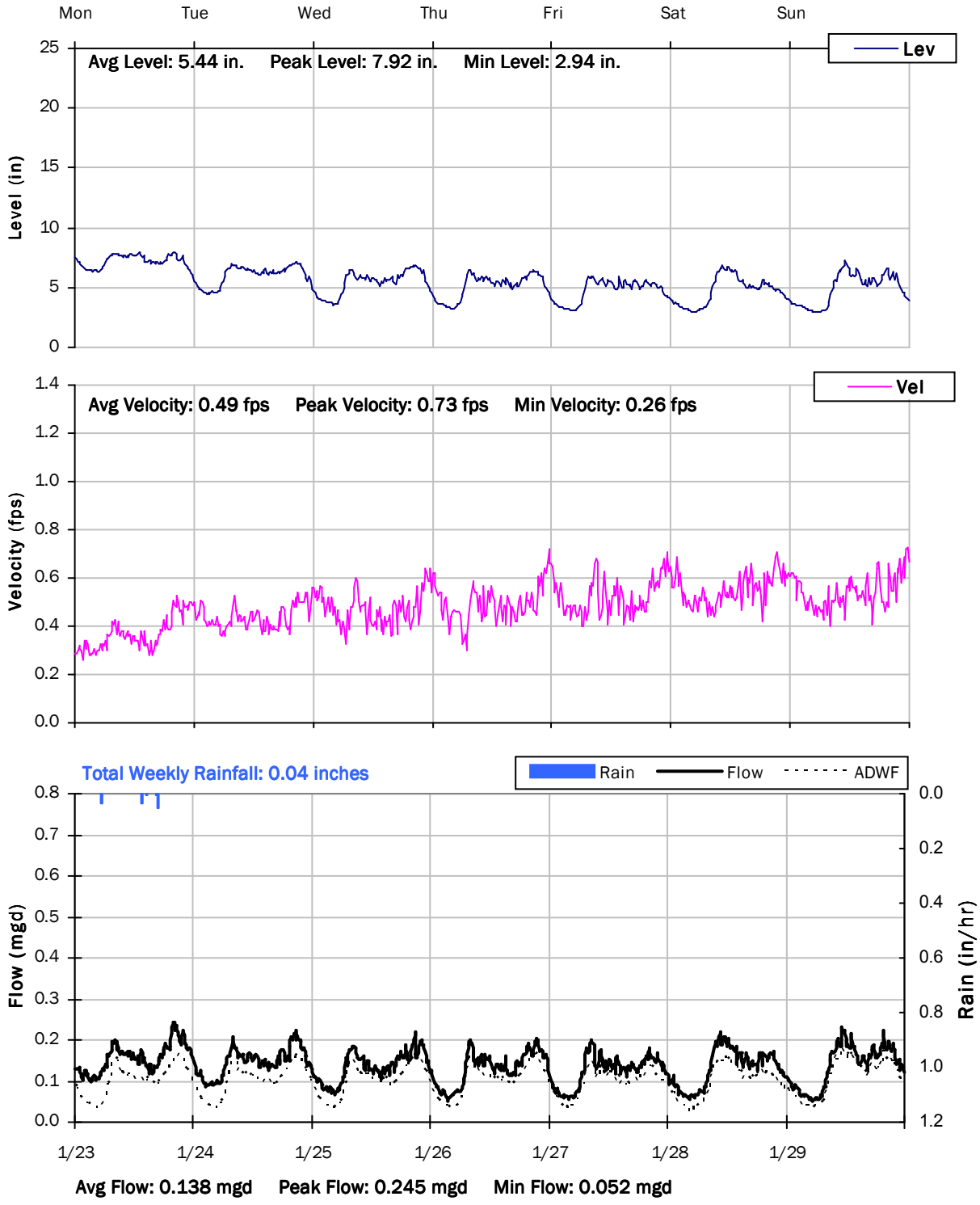
1/16/2017 to 1/23/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

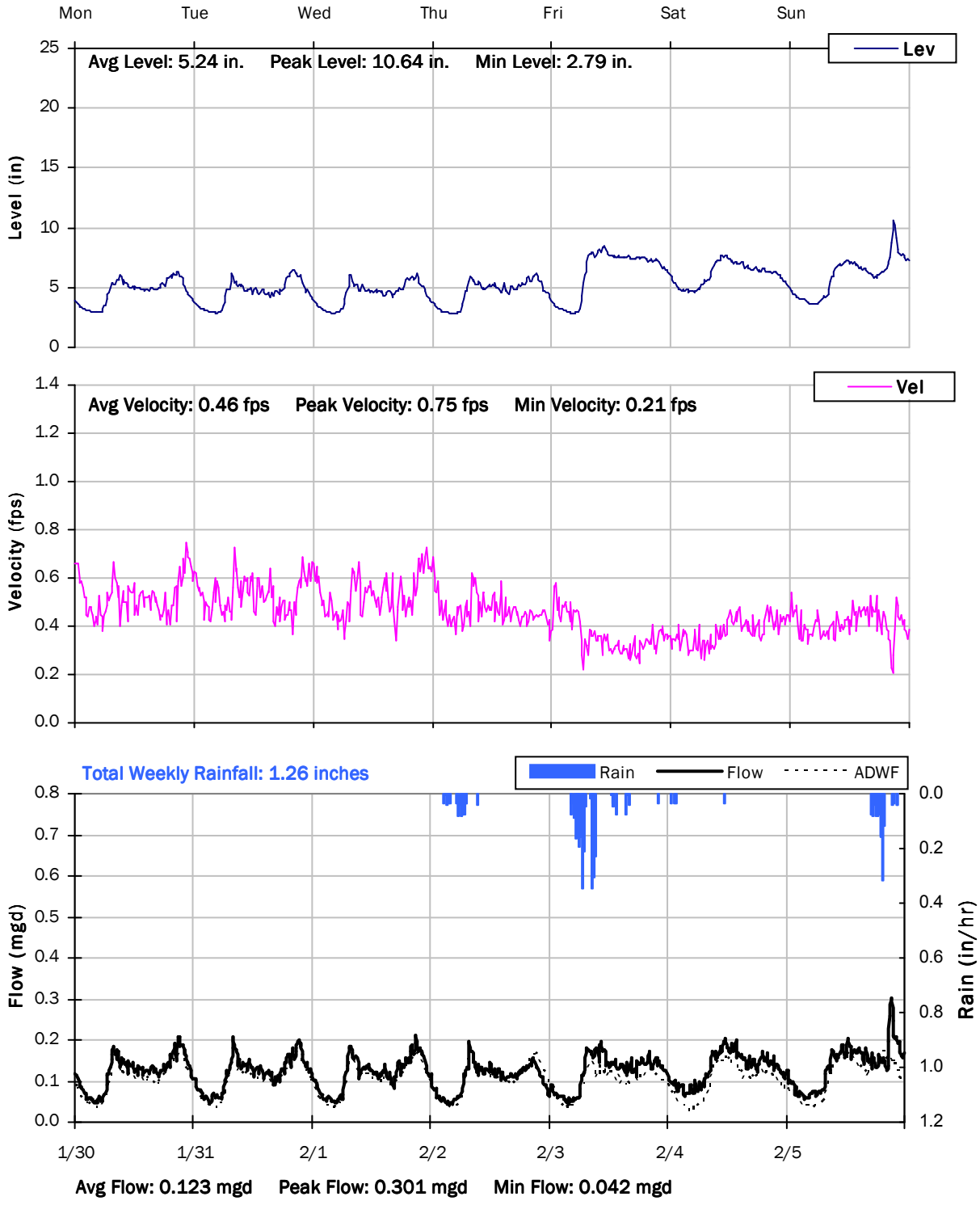
1/23/2017 to 1/30/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

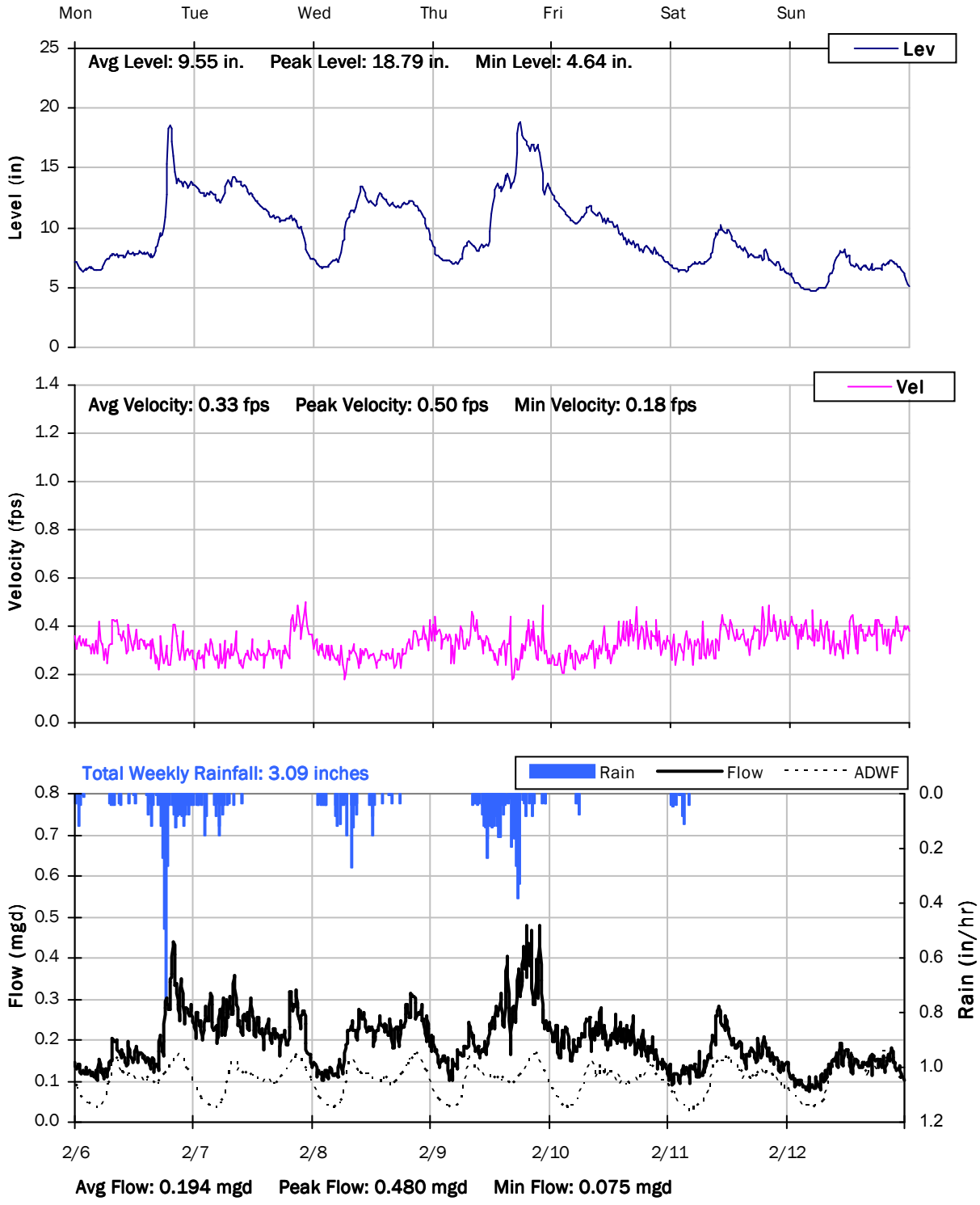
1/30/2017 to 2/6/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

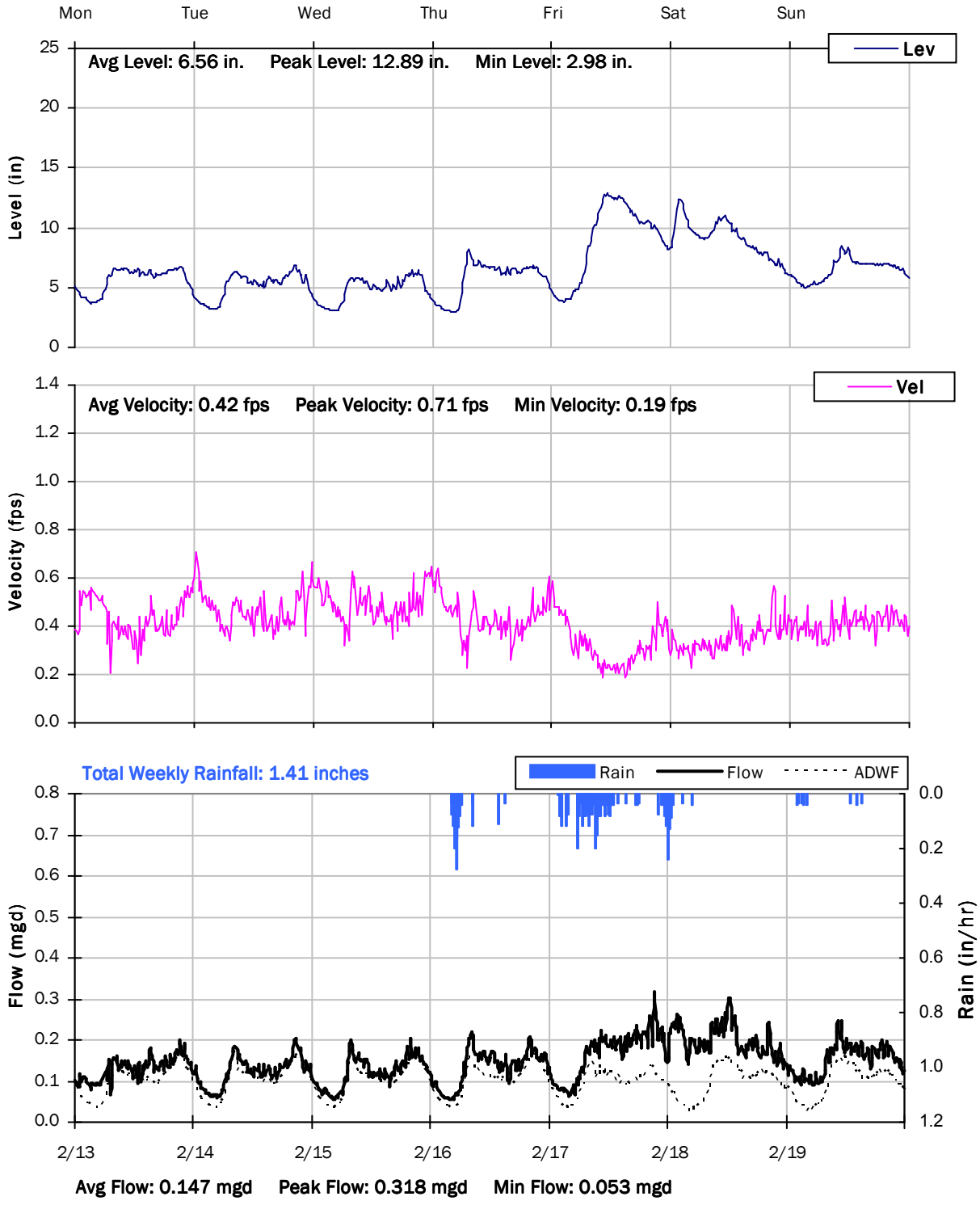
2/6/2017 to 2/13/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

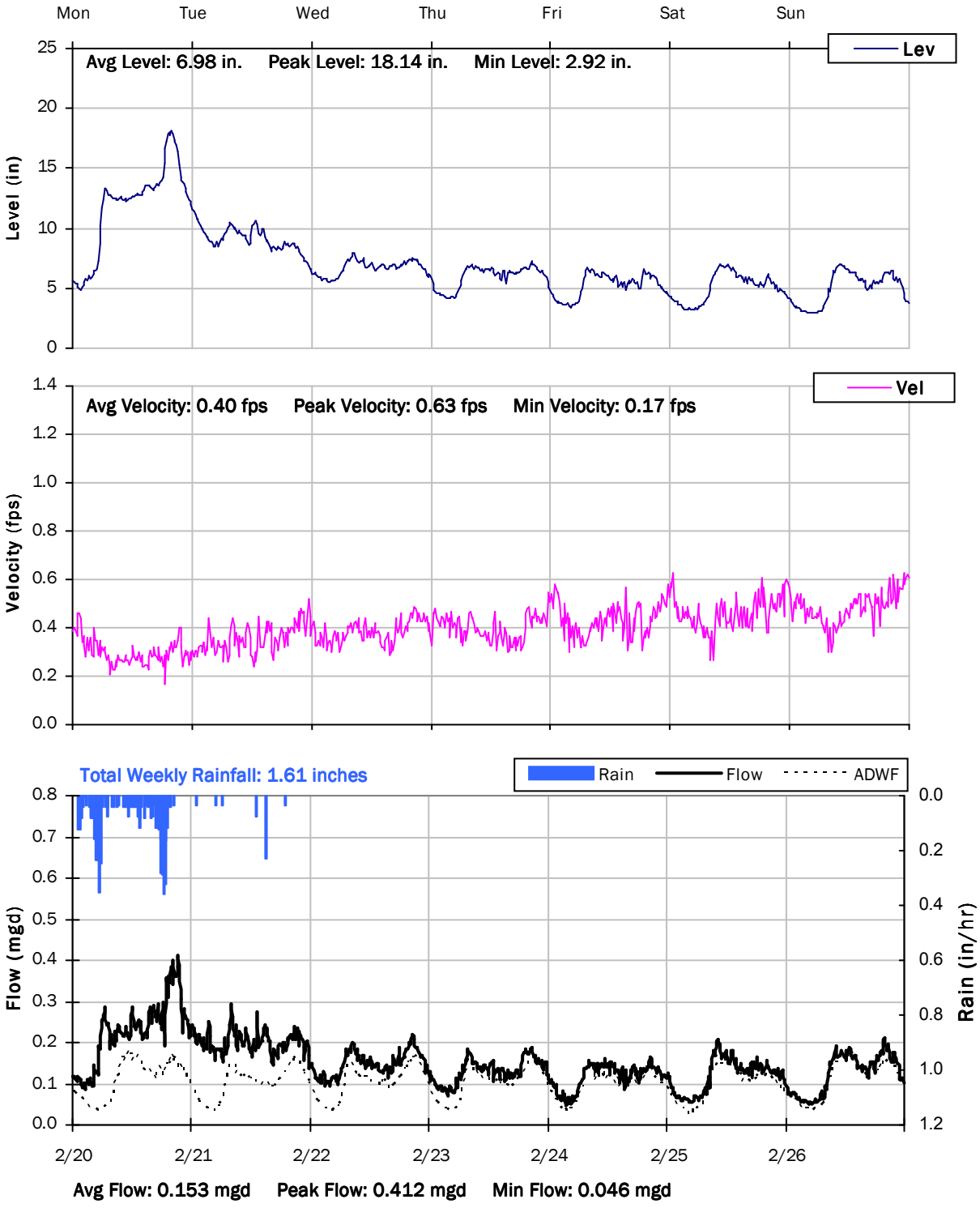
2/13/2017 to 2/20/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

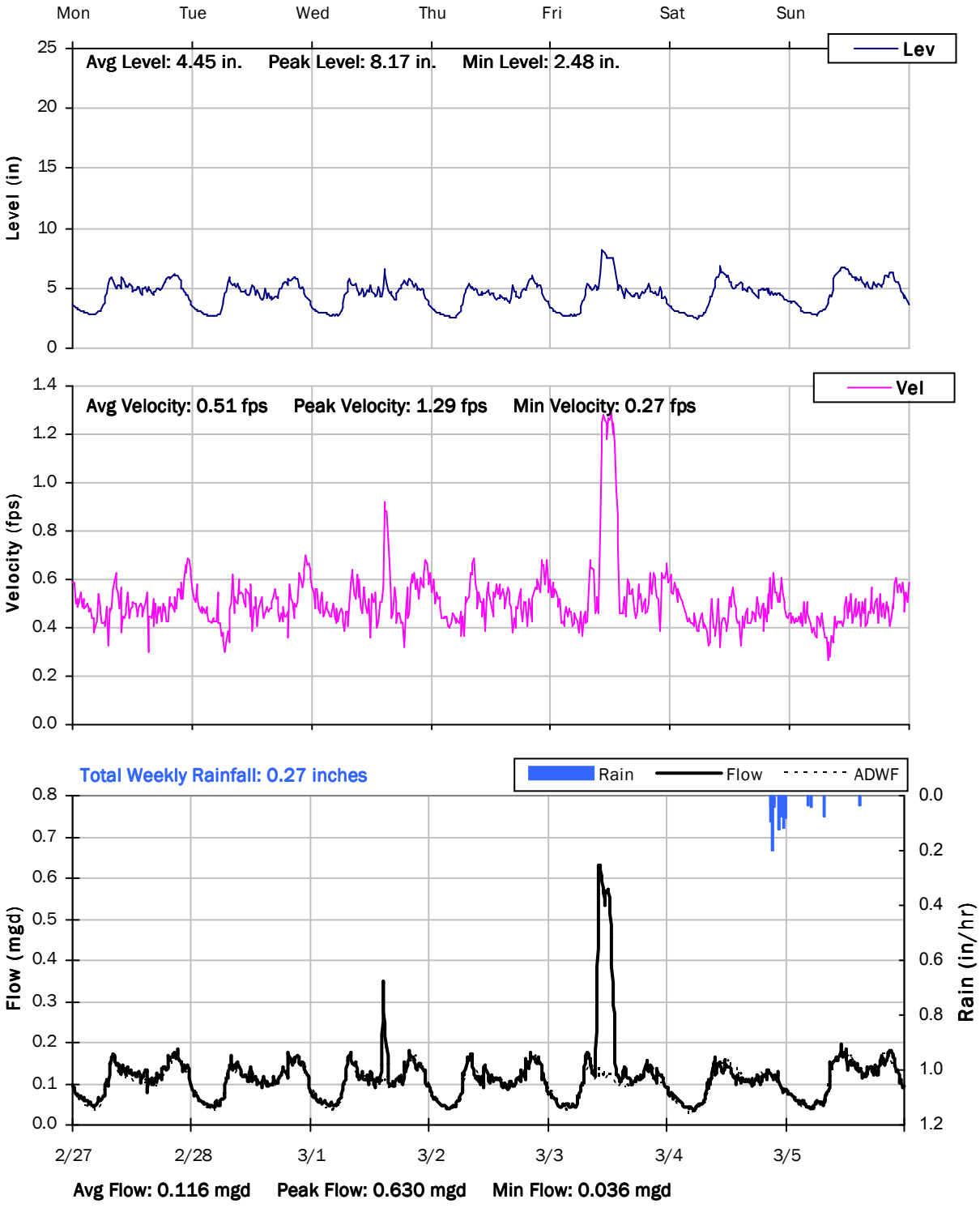
2/20/2017 to 2/27/2017



SITE 02

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



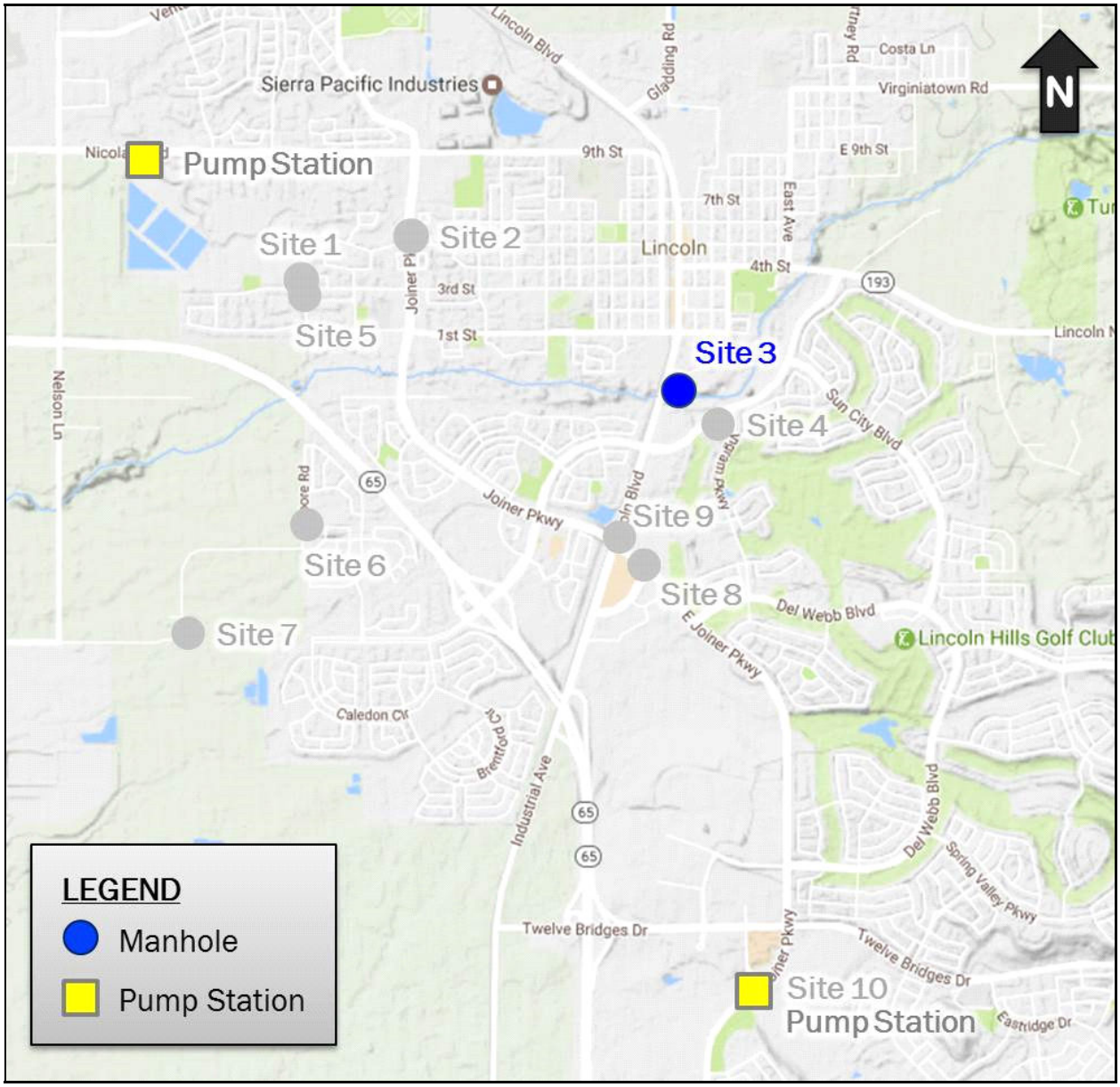
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 03

Location: In field southeast of Lincoln Boulevard and Gateway Drive

Data Summary Report



Vicinity Map: Site 03

SITE 03

Site Information

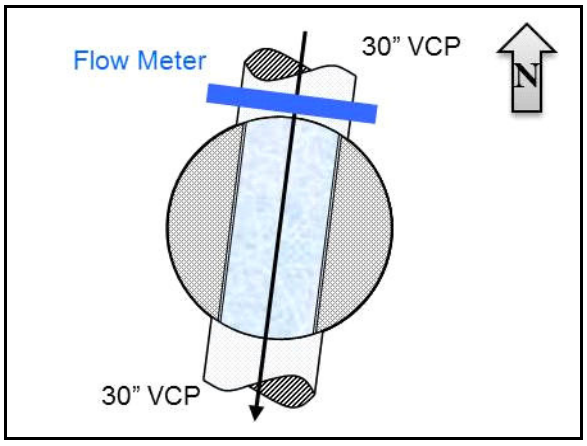
Location: In field southeast of Lincoln Boulevard and Gateway Drive

District ID: NE492SS15

Coordinates:	121.2932° W, 38.8832° N
Expected Pipe Diameter (Orig. if Relocated):	30 inches
Measured Pipe Diameter:	30 inches
ADWF:	0.412 mgd
Peak Measured Flow:	3.162 mgd
Rim Elevation (GEarth):	156 feet

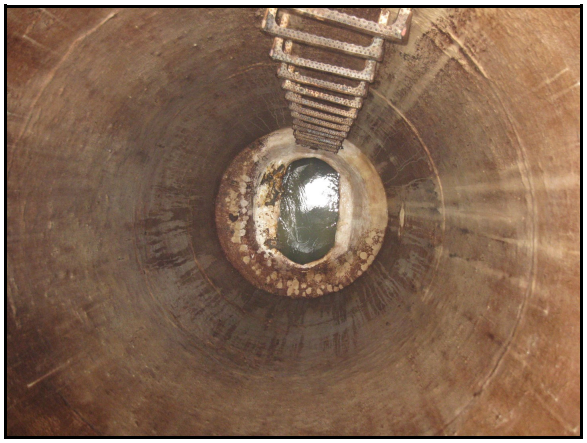
Satellite Map

Sewer Map



Flow Sketch

Street View



Plan View

SITE 03

Additional Site Photos

Effluent Pipe

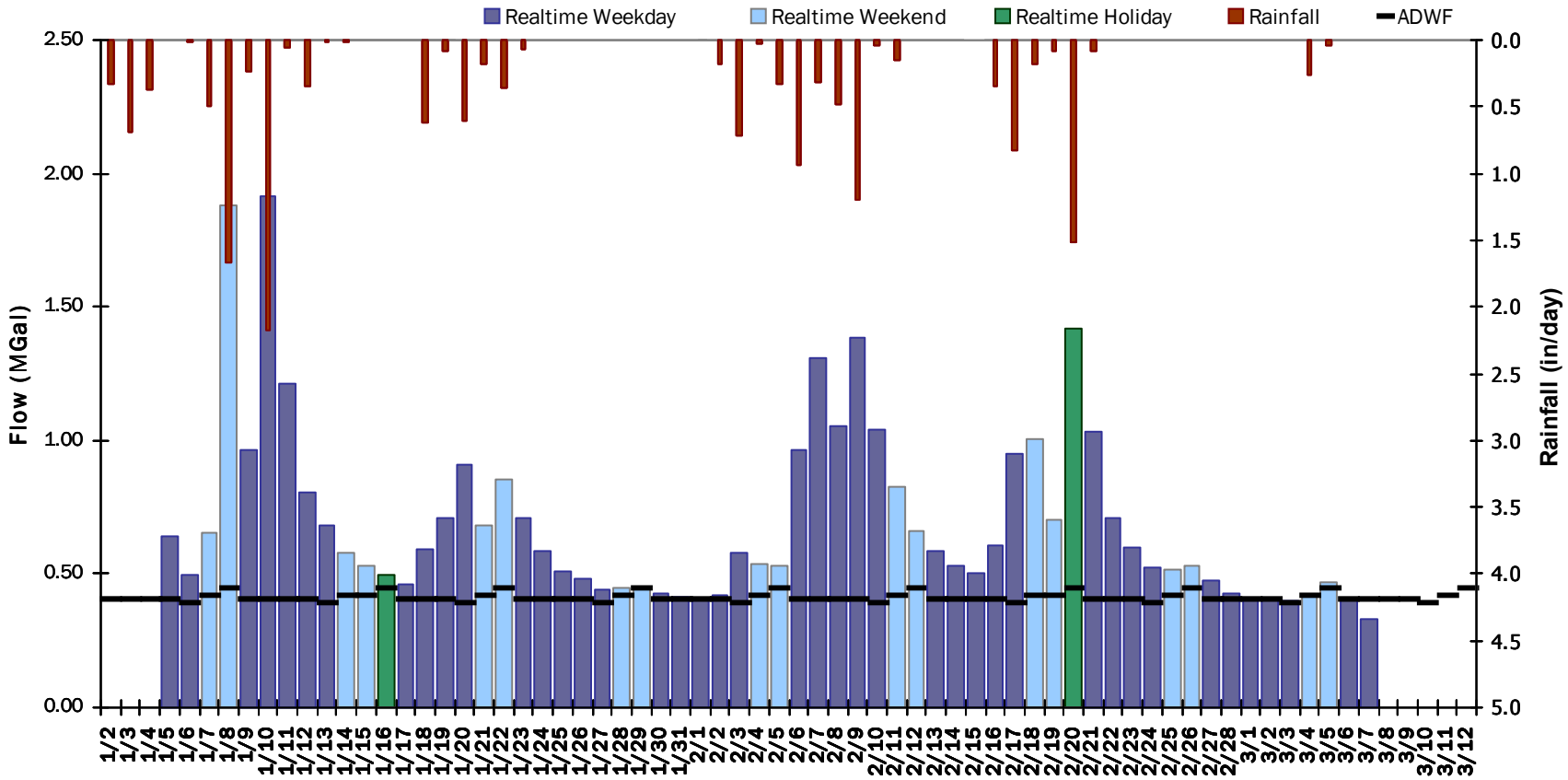
Influent Pipe

SITE 03

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 0.696 MGal Peak Daily Flow: 1.918 MGal Min Daily Flow: 0.333 MGal

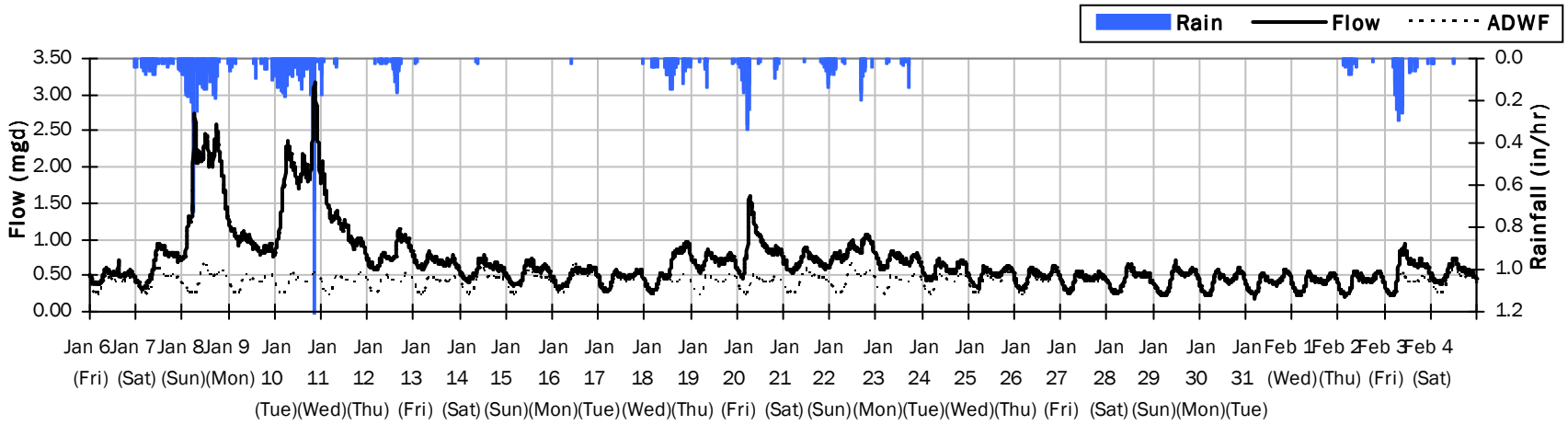
Total Period Rainfall: 16.06 inches

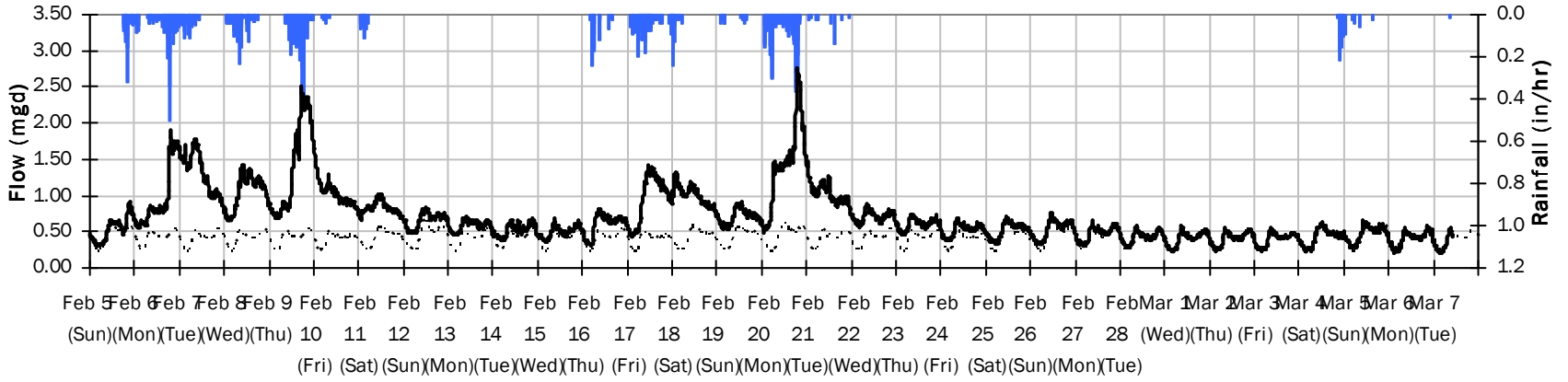


SITE 03

Flow Summary: 1/6/2017 to 3/7/2017

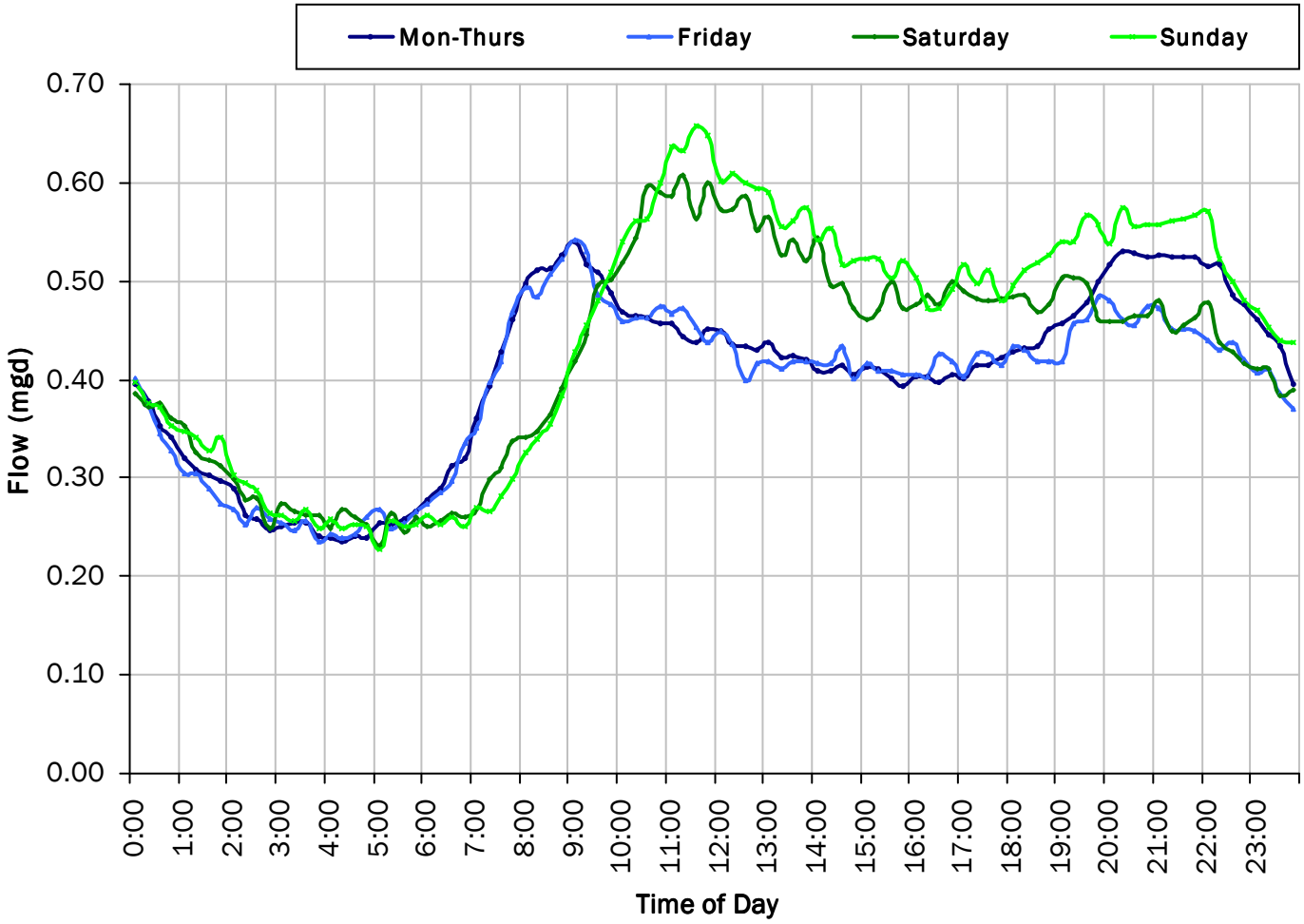
Total Period Rainfall: 14.66 inches **Avg Flow: 0.701 mgd** **Peak Flow: 3.162 mgd** **Min Flow: 0.183 mgd**





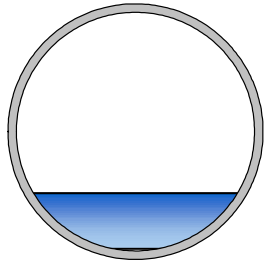
SITE 03

Average Dry Weather Flow Hydrographs



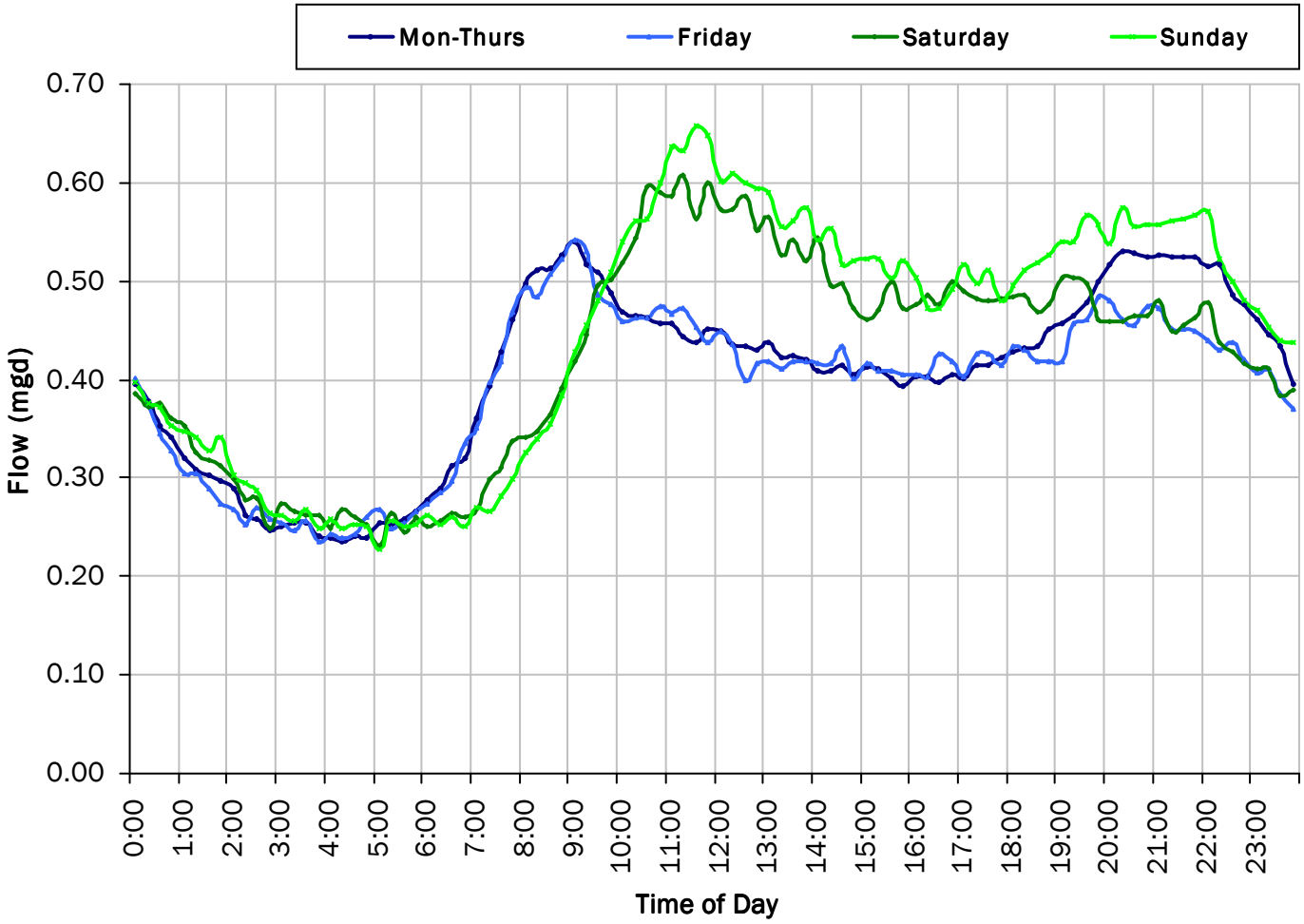
ADWF:

0.412 *mgd*



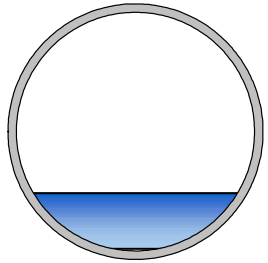
SITE 03

Average Dry Weather Flow Hydrographs



ADWF:

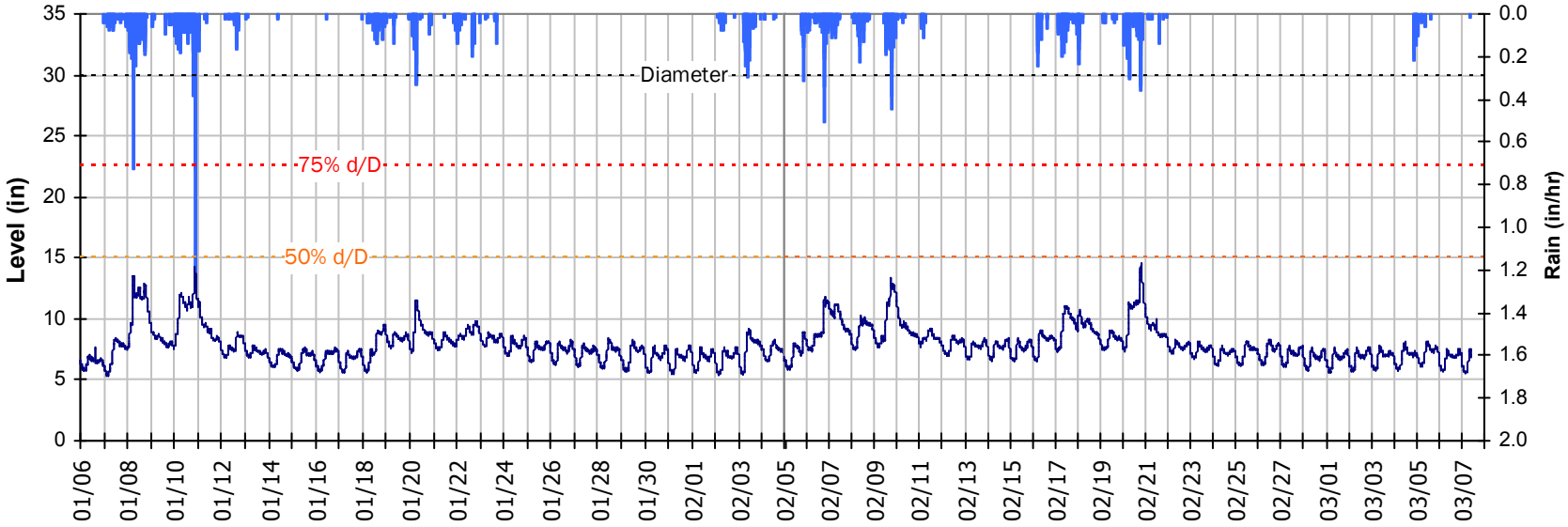
0.412 *mgd*

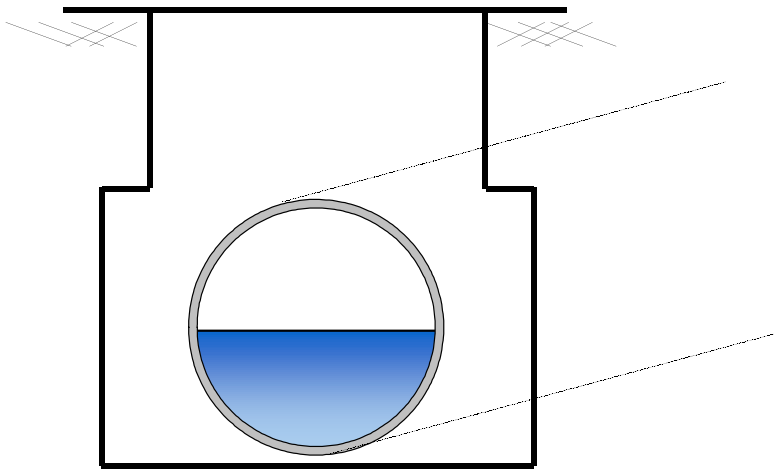


SITE 03

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period

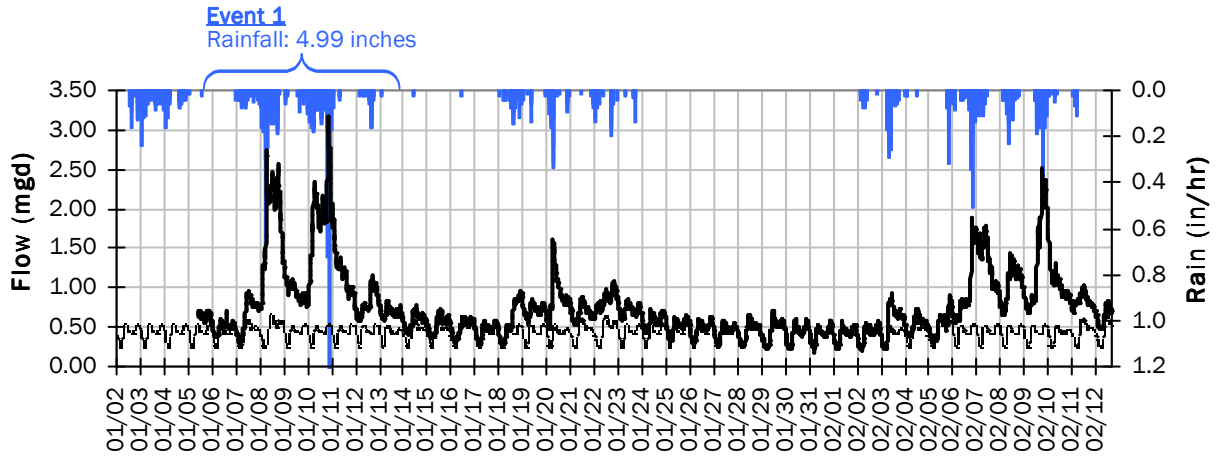




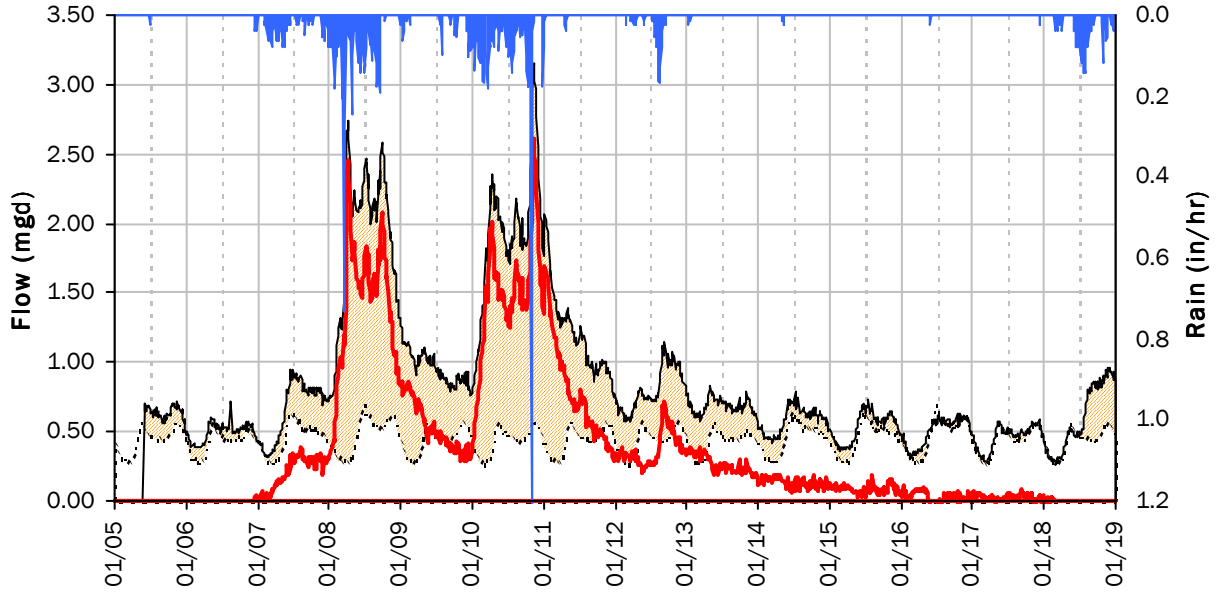
Pipe Diameter:	30	*inches*
Peak Measured Level:	14.6	*inches*
Peak d/D Ratio:	0.49	

SITE 03
I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph



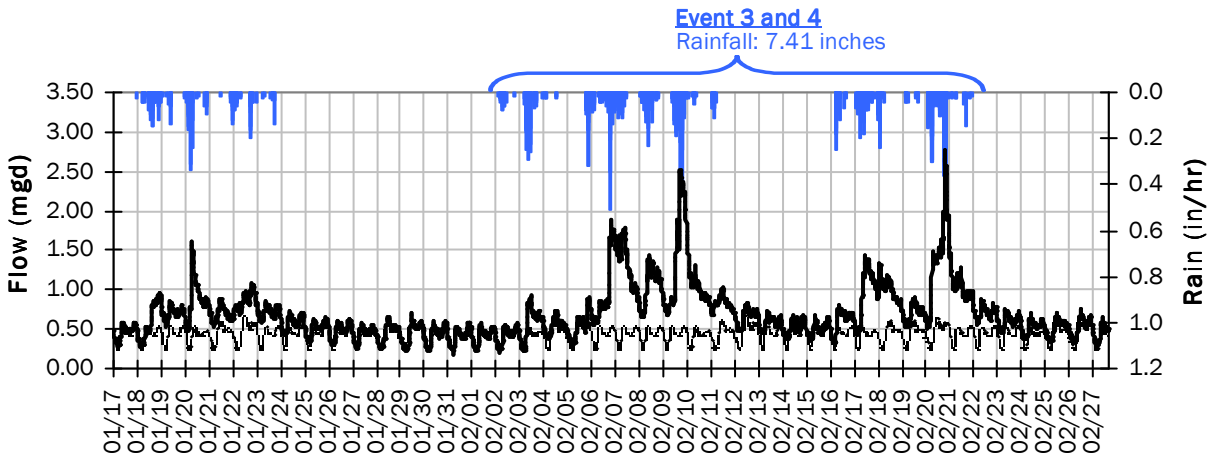
Storm Event I/I Analysis (Rain = 4.99 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	3.16 *mgd*	**Peak I/I Rate:**	2.61 *mgd*
PF:	7.68	**Total I/I:**	5,328,000 *gallons*
Peak Level:	14.28 *in*		
d/D Ratio:	0.48		

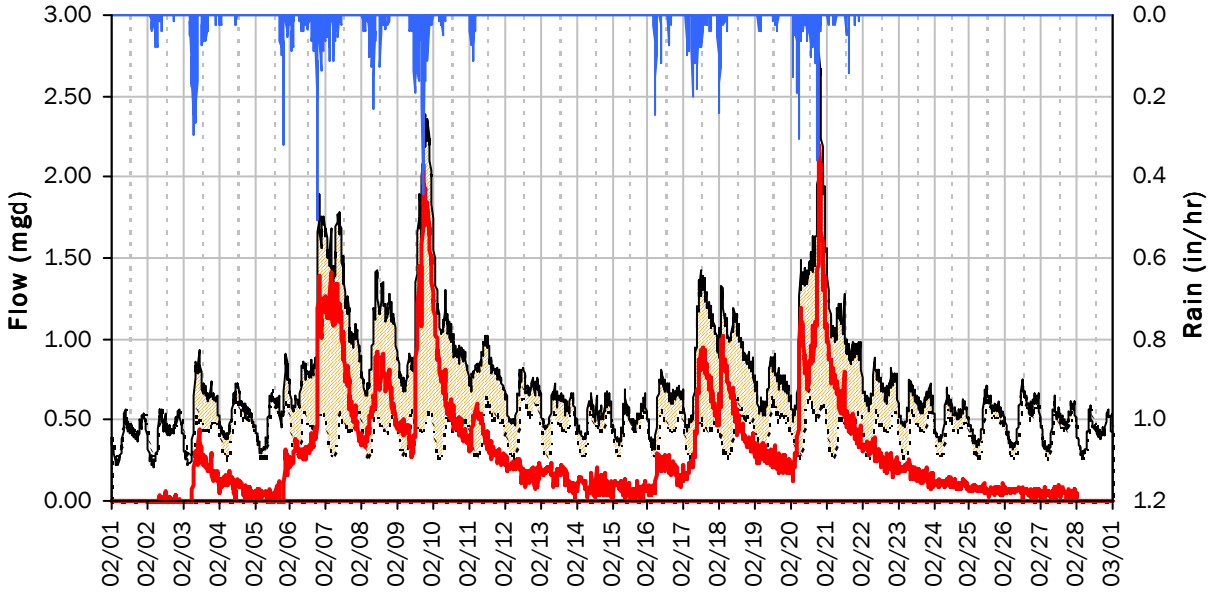
SITE 03

I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



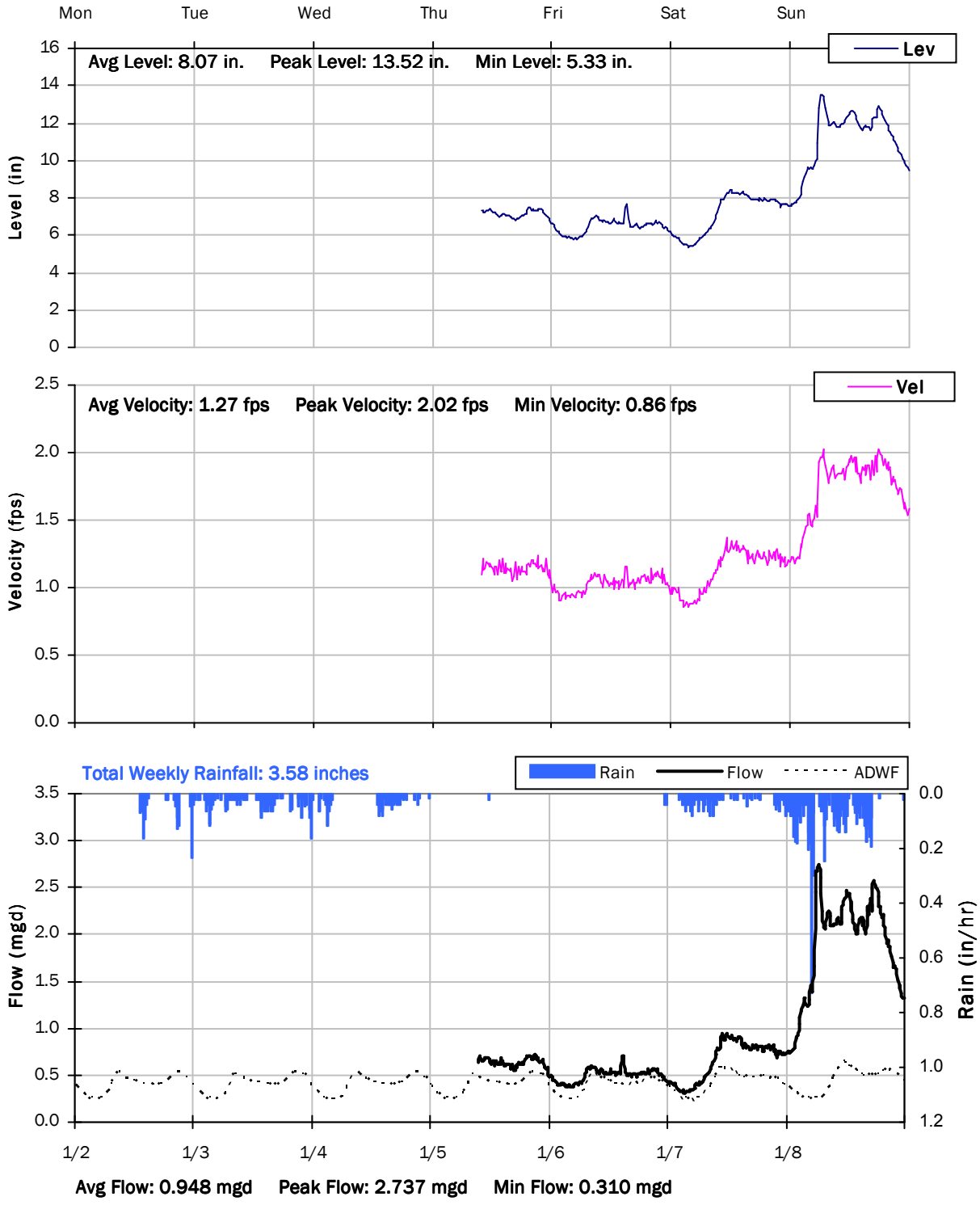
Storm Event I/I Analysis (Rain = 7.41 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	2.76 *mgd*	**Peak I/I Rate:**	2.20 *mgd*
PF:	6.71	**Total I/I:**	8,588,000 *gallons*
Peak Level:	14.55 *in*		
d/D Ratio:	0.49		

SITE 03

Weekly Level, Velocity and Flow Hydrographs

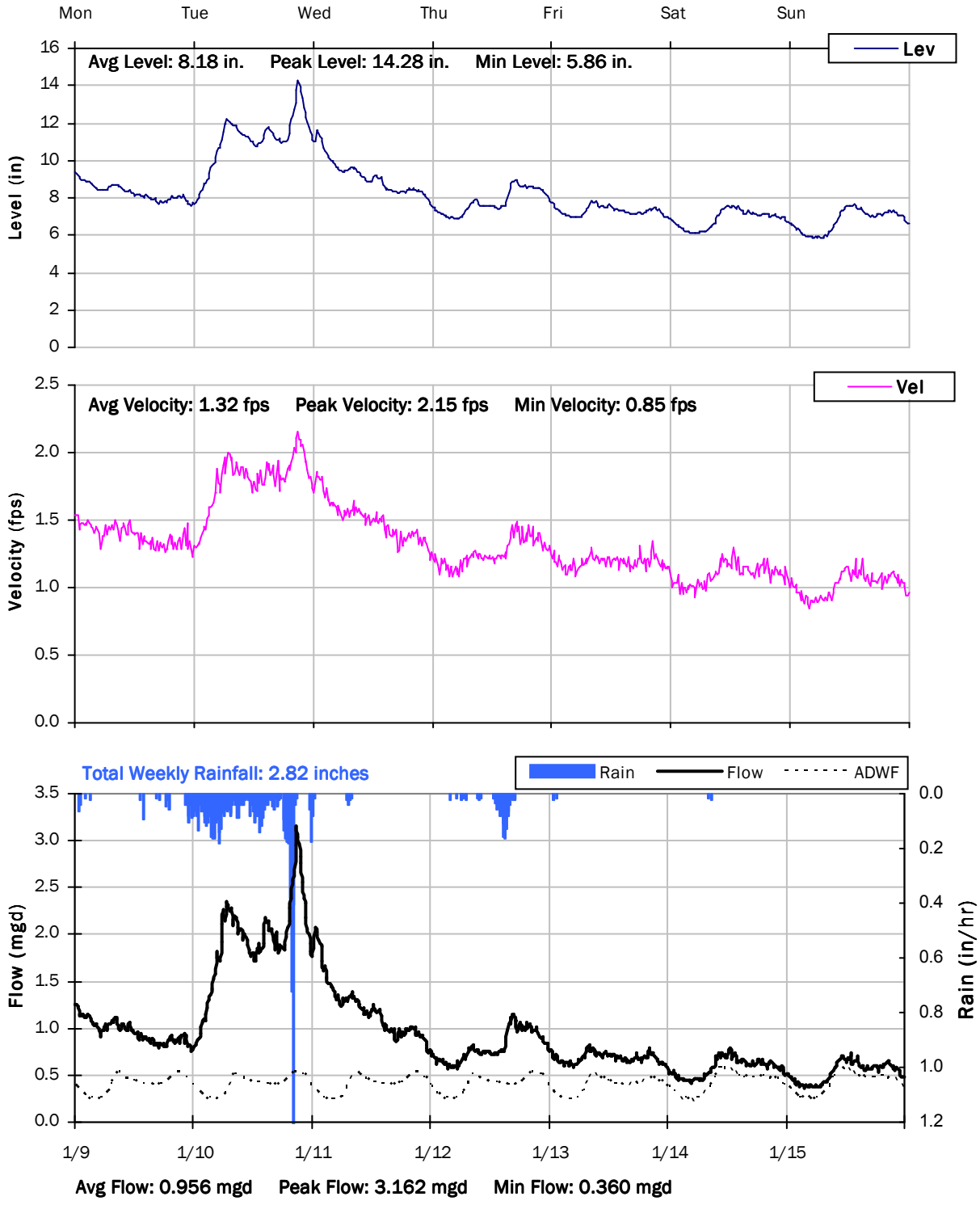
1/2/2017 to 1/9/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

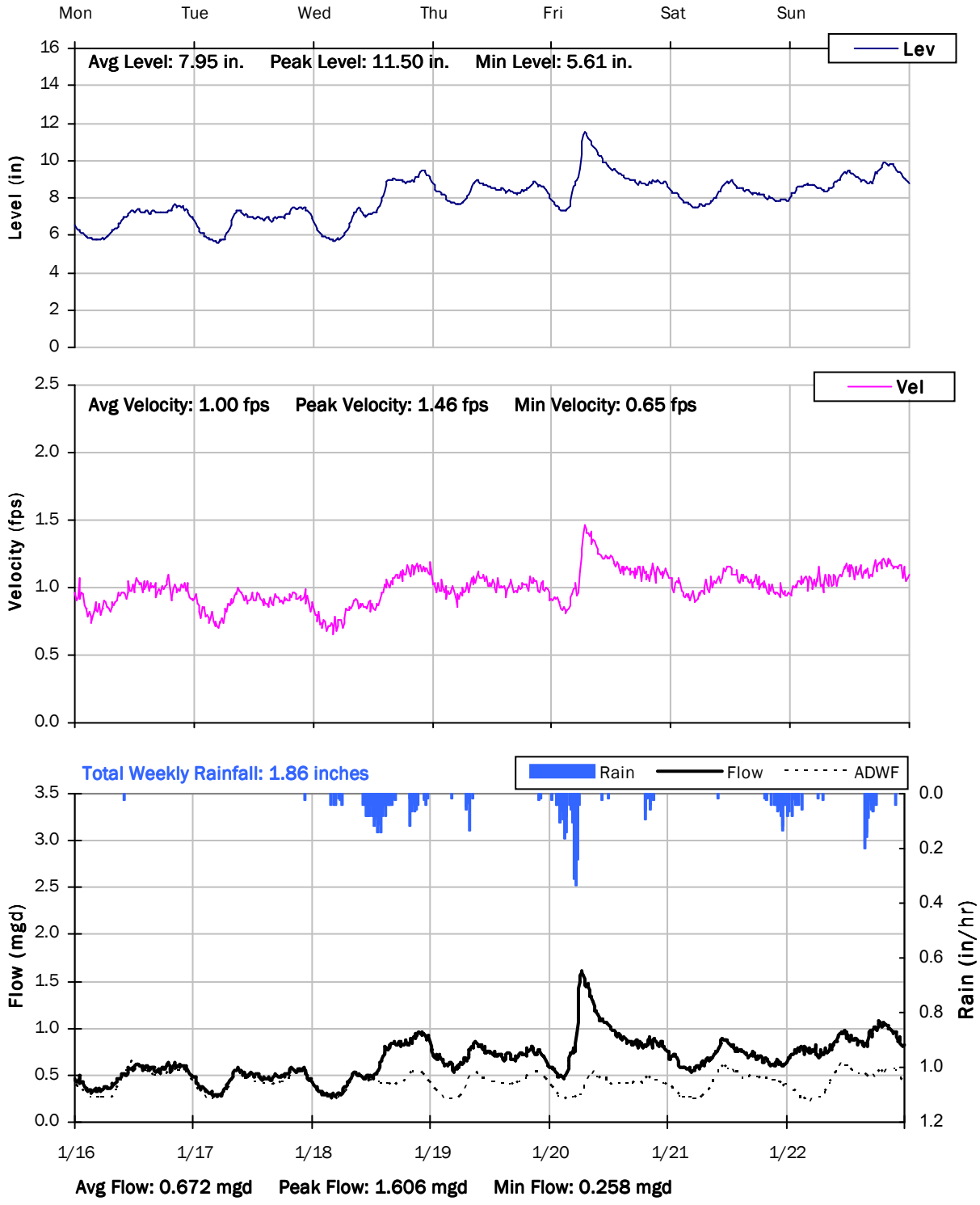
1/9/2017 to 1/16/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

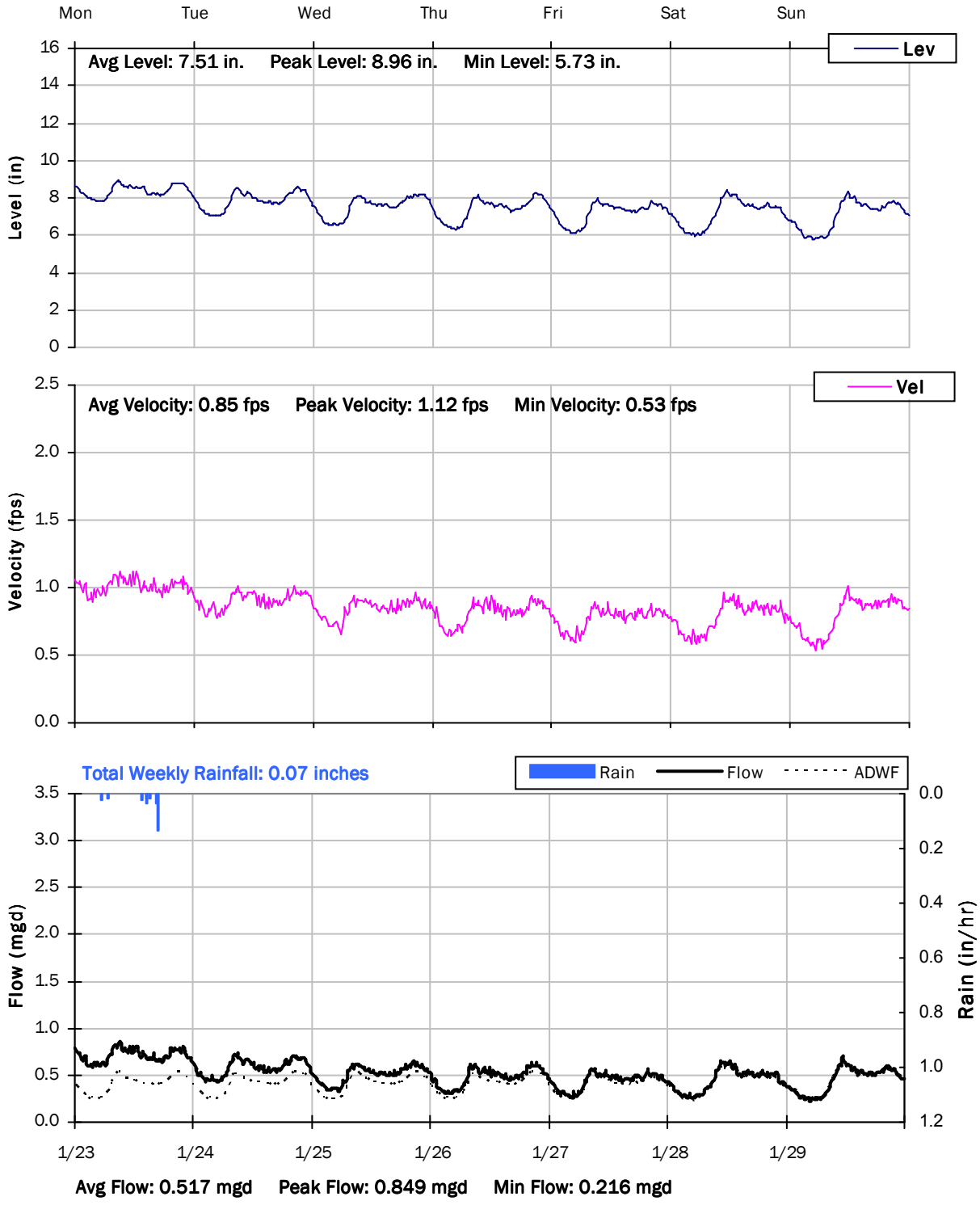
1/16/2017 to 1/23/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

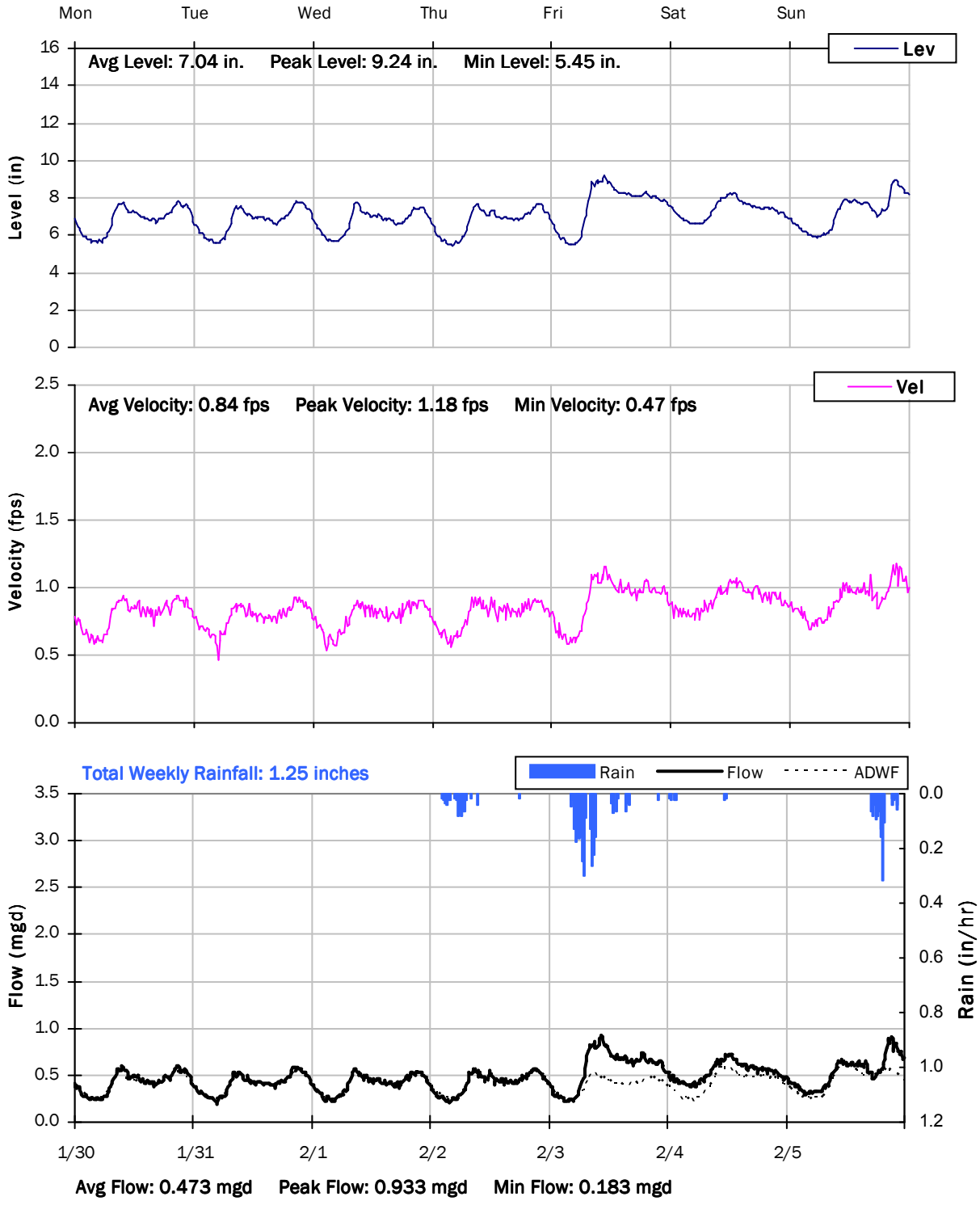
1/23/2017 to 1/30/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

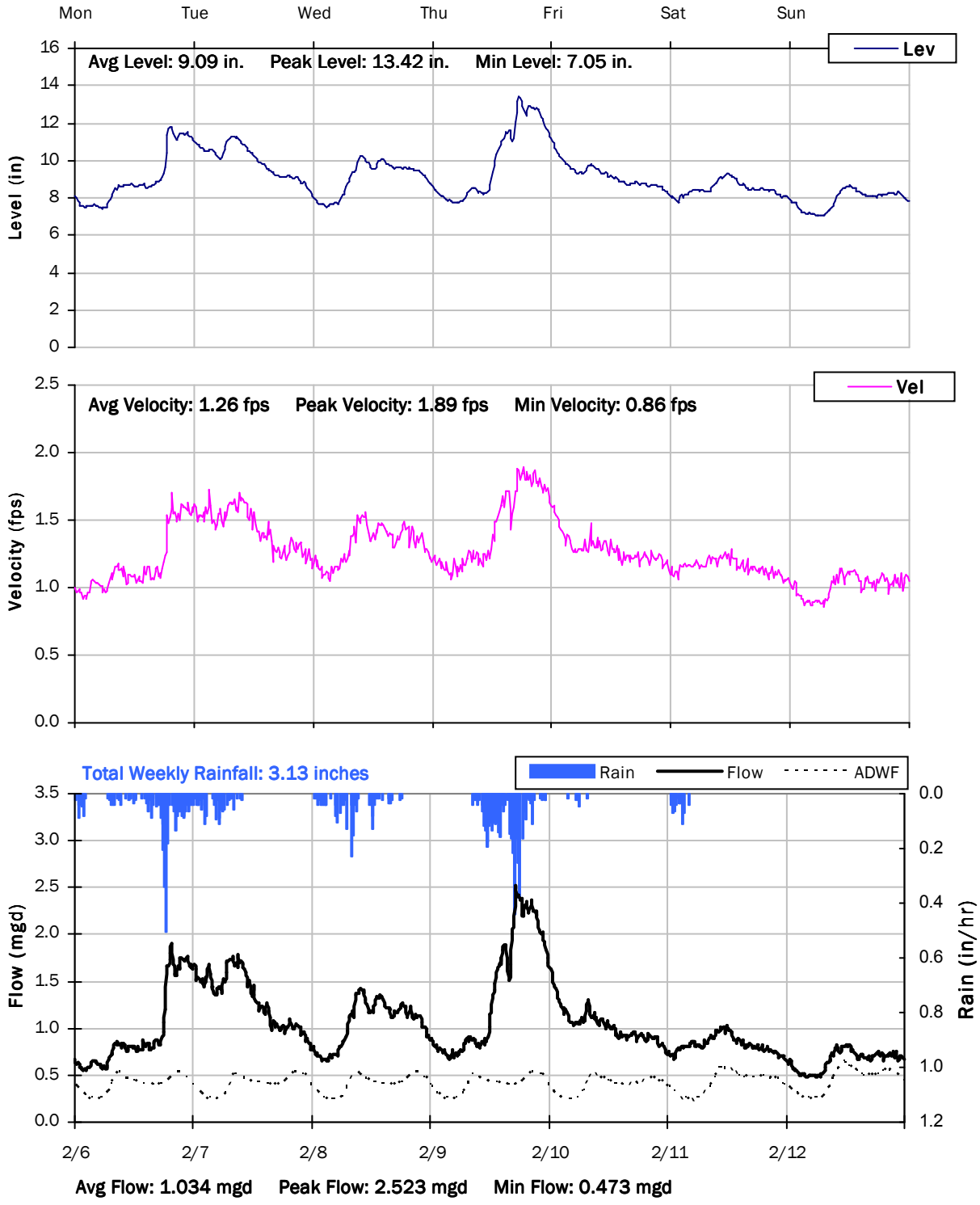
1/30/2017 to 2/6/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

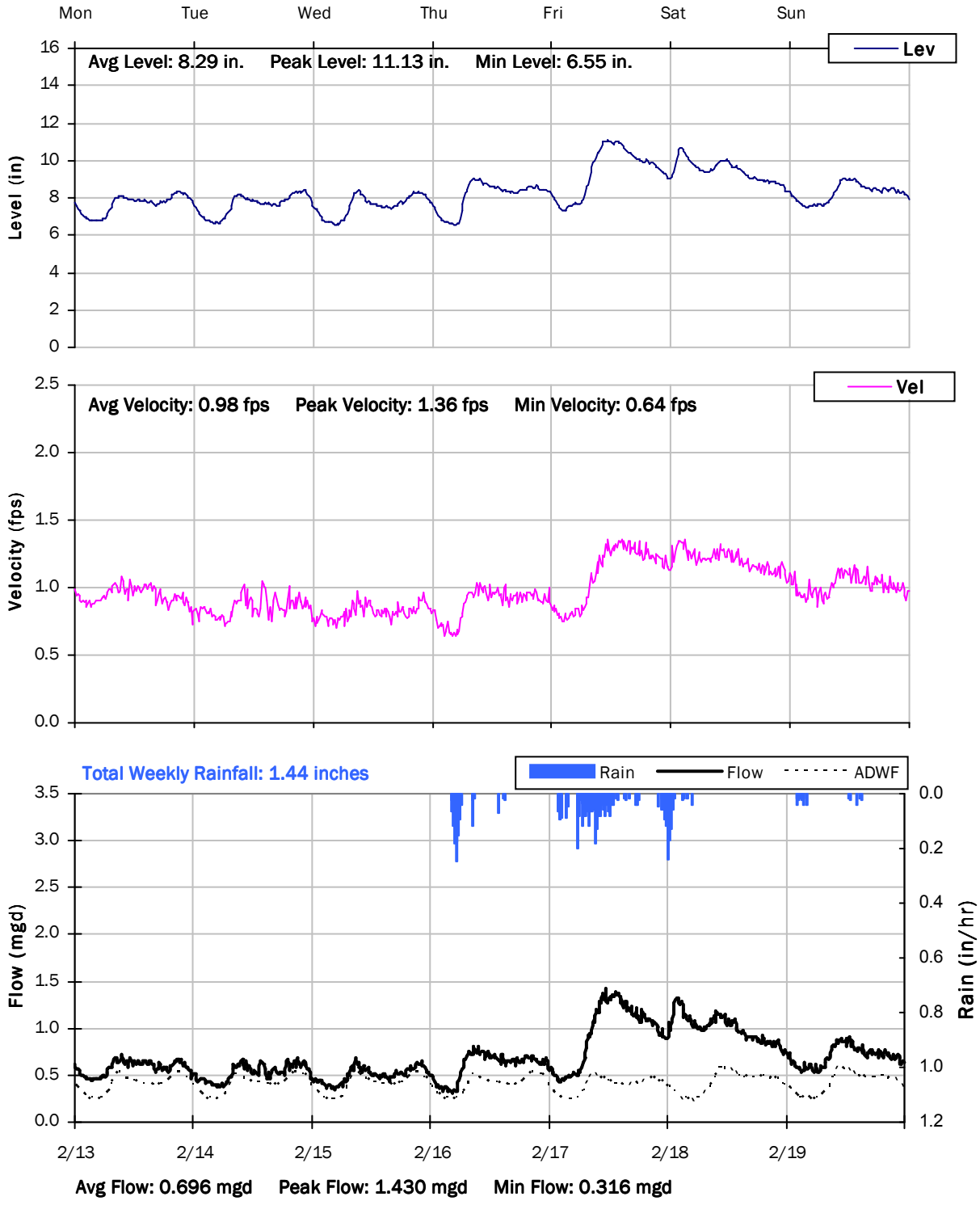
2/6/2017 to 2/13/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

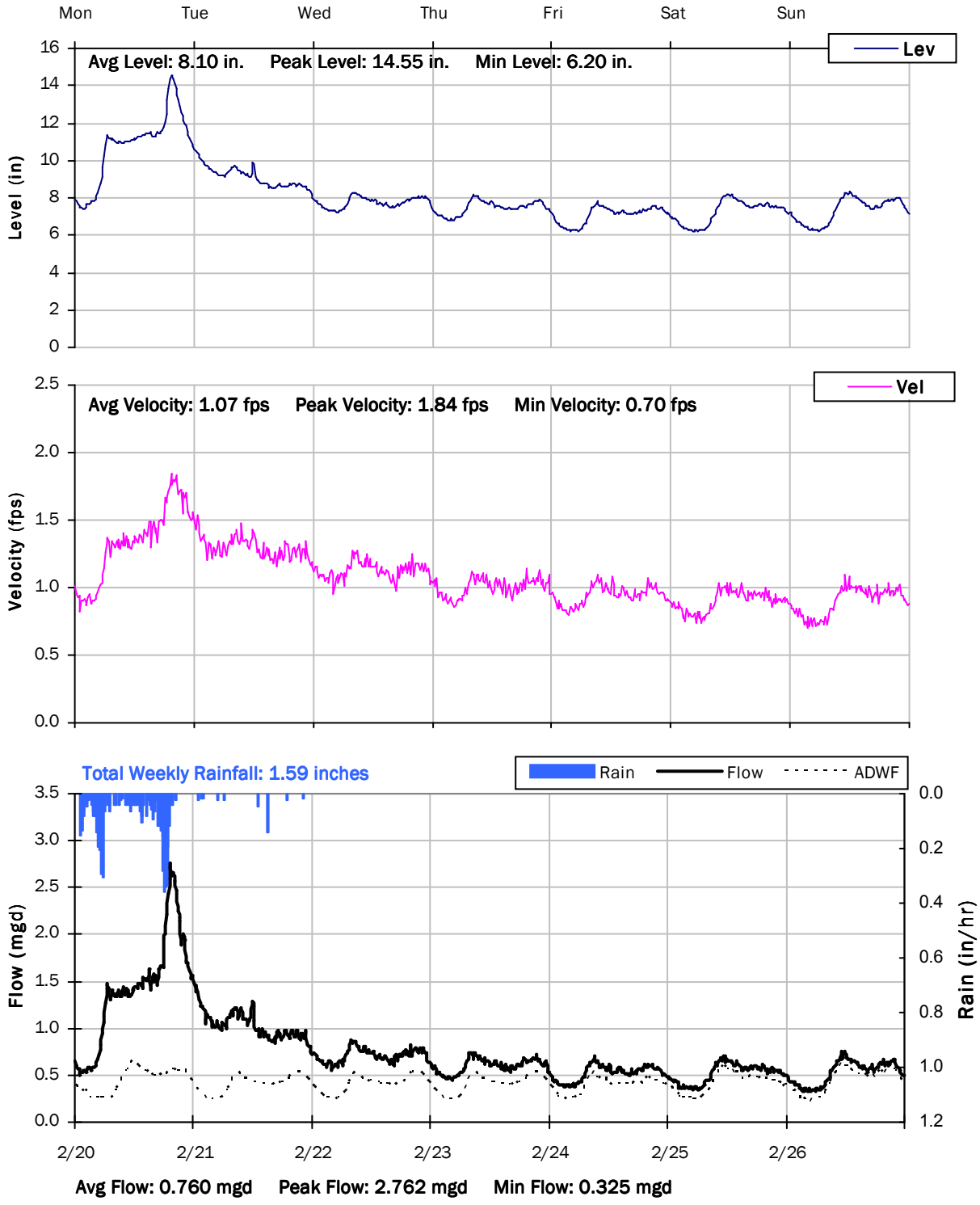
2/13/2017 to 2/20/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

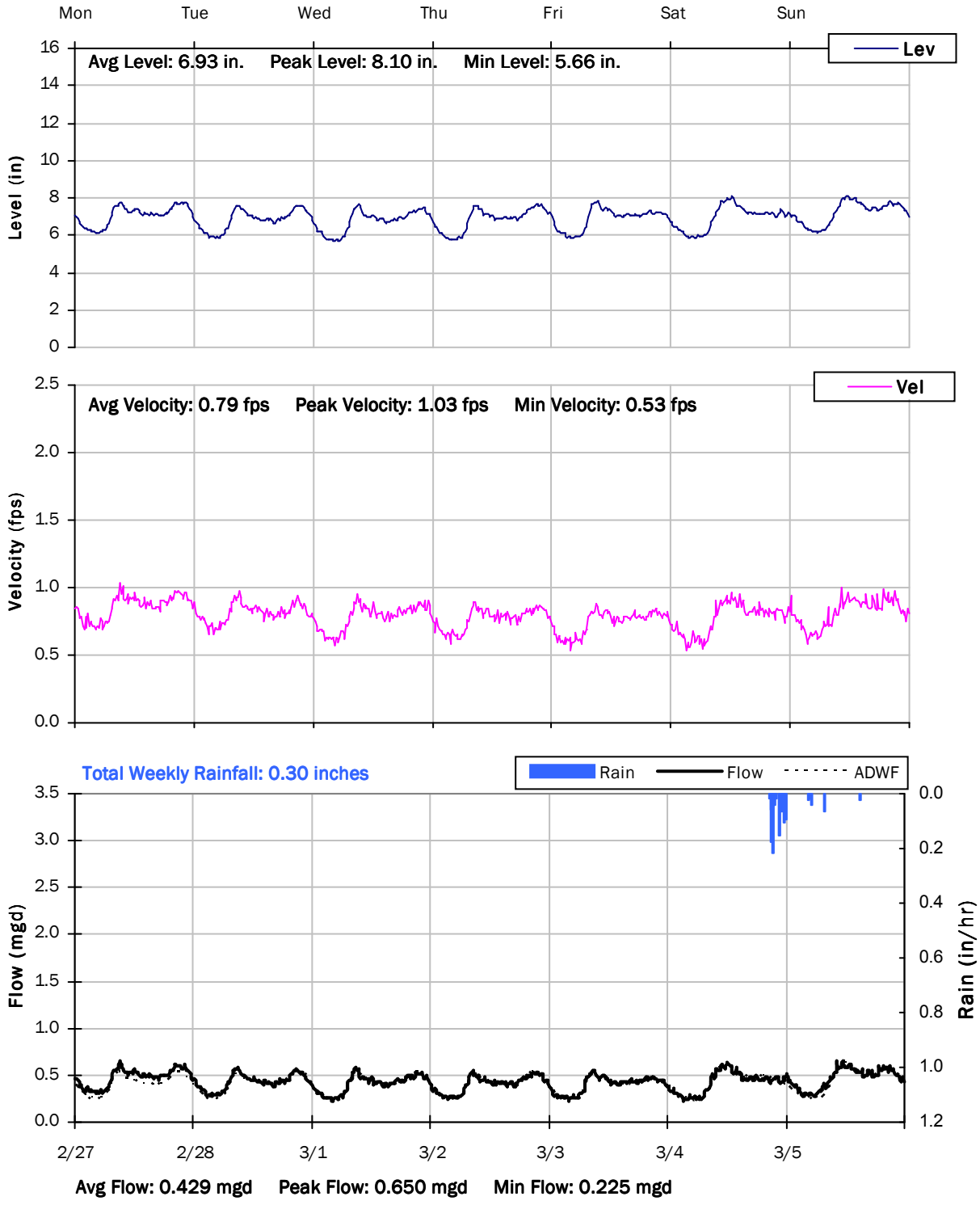
2/20/2017 to 2/27/2017



SITE 03

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



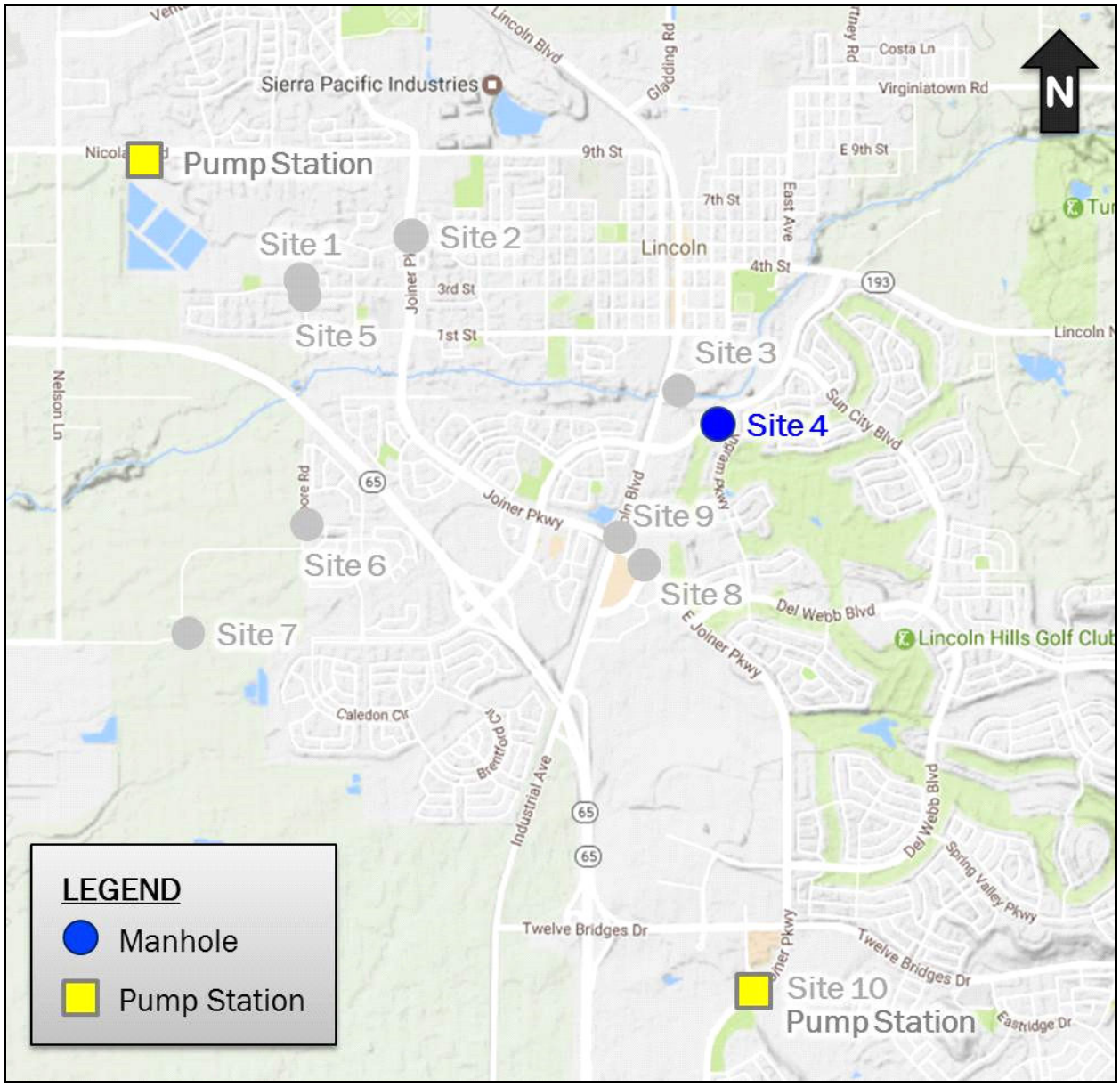
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 04

Location: In field north of Ferrari Ranch Road

Data Summary Report



Vicinity Map: Site 04

SITE 04

Site Information

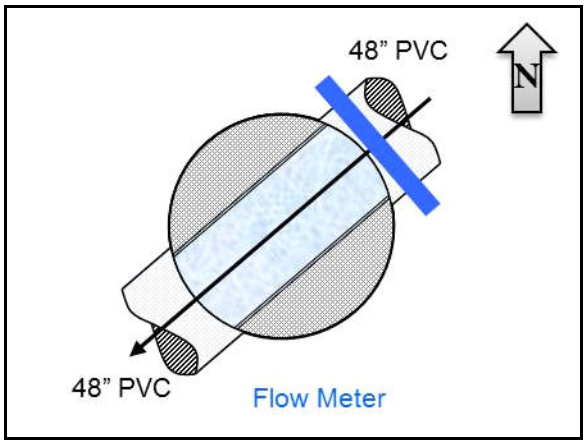
Location: In field north of Ferrari Ranch Road

District ID: SE493SS03

Coordinates:	121.2908° W, 38.8815° N
Expected Pipe Diameter (Orig. if Relocated):	48 inches
Measured Pipe Diameter:	48 inches
ADWF:	1.654 mgd
Peak Measured Flow:	11.471 mgd
Rim Elevation (GEarth):	148 feet

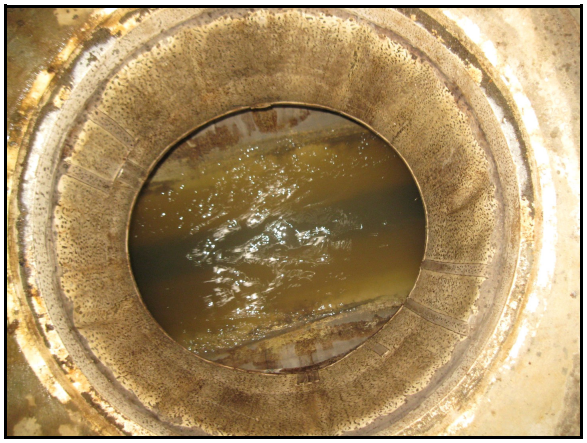
Satellite Map

Sewer Map



Flow Sketch

Street View



Plan View

SITE 04

Additional Site Photos

Effluent Pipe

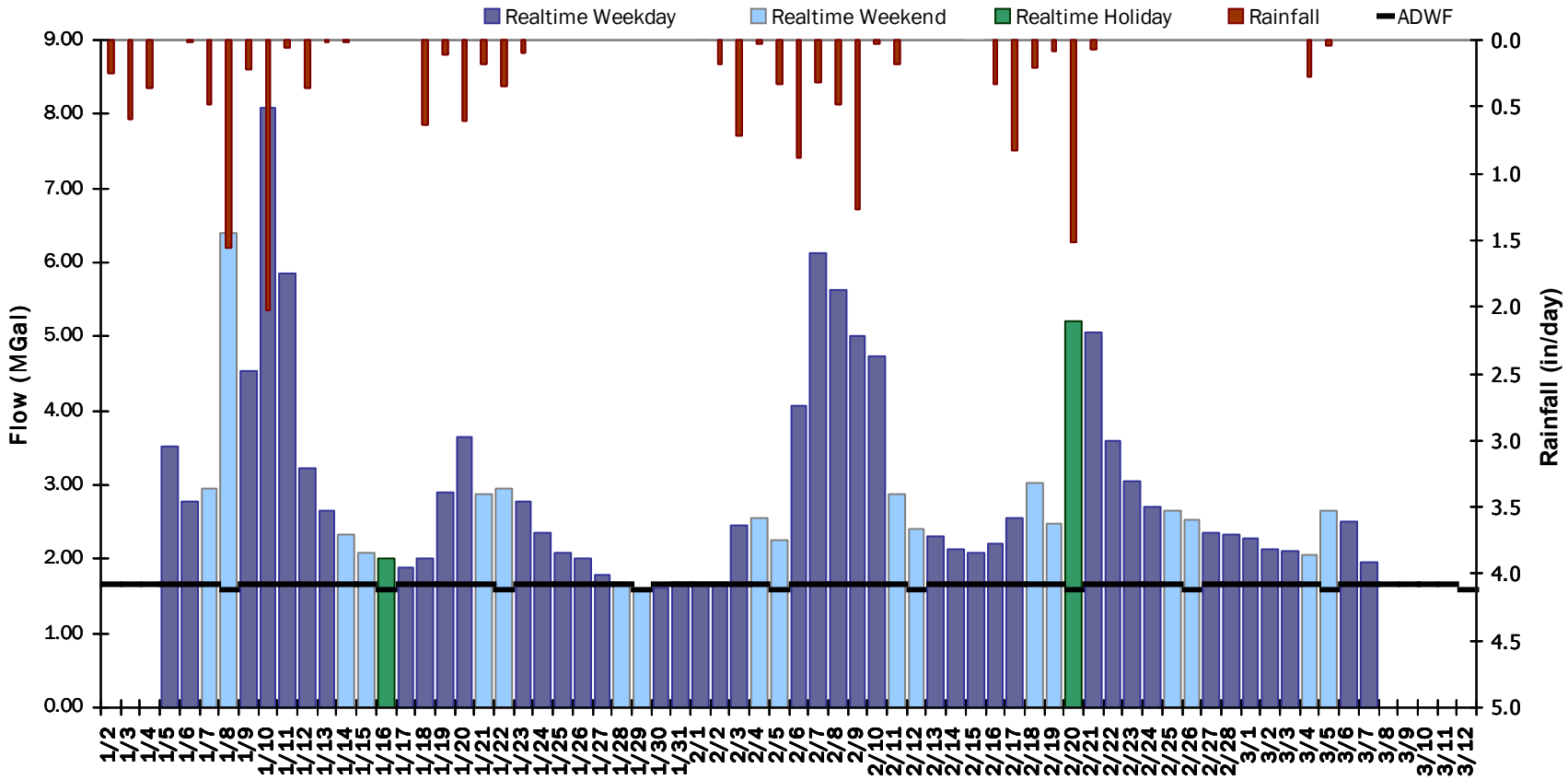
Influent Pipe

SITE 04

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 2.964 MGal Peak Daily Flow: 8.093 MGal Min Daily Flow: 1.557 MGal

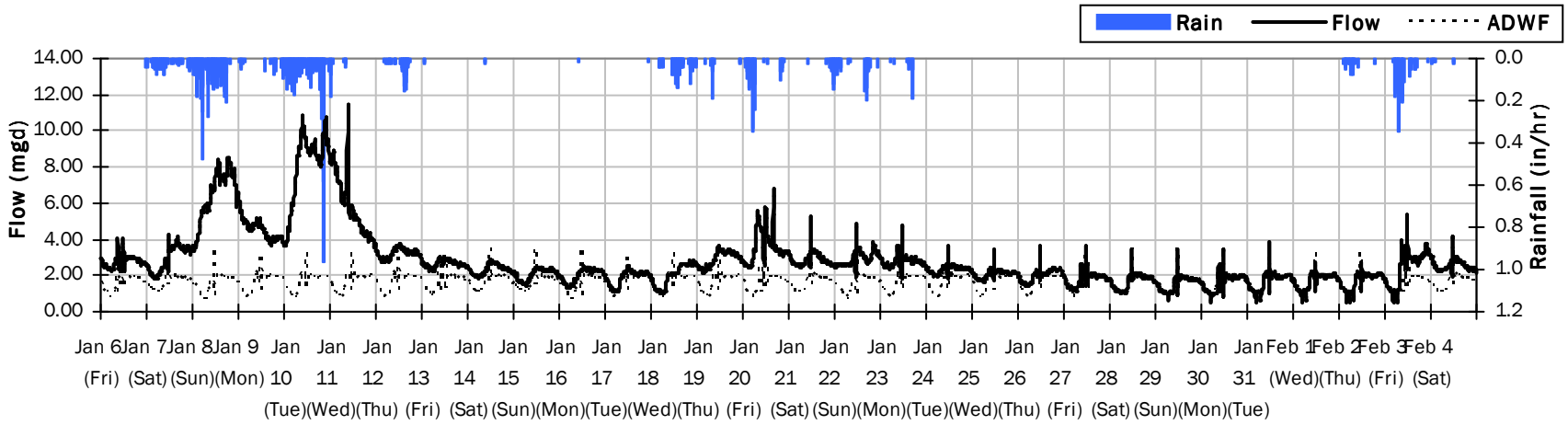
Total Period Rainfall: 15.69 inches

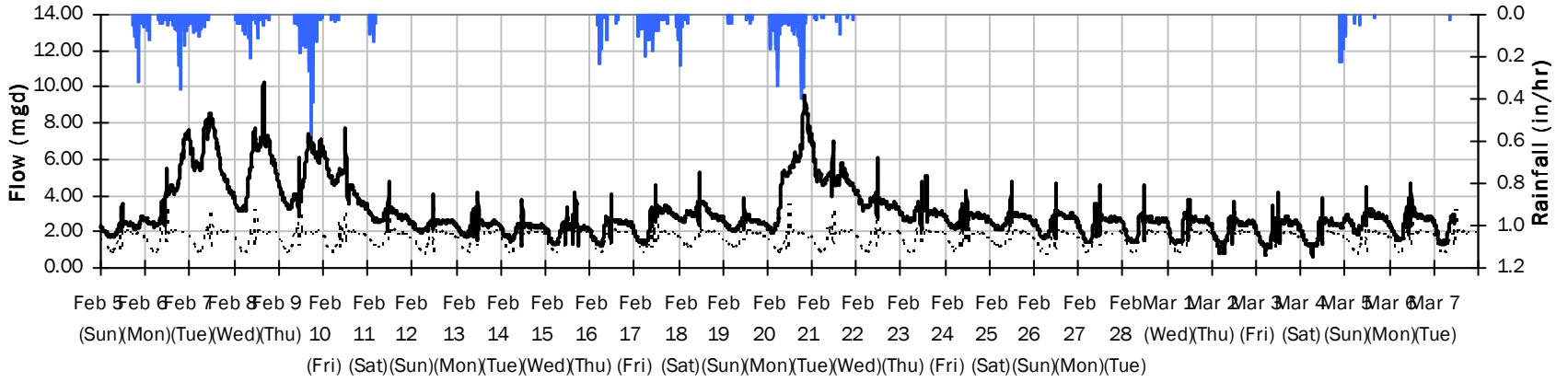


SITE 04

Flow Summary: 1/6/2017 to 3/7/2017

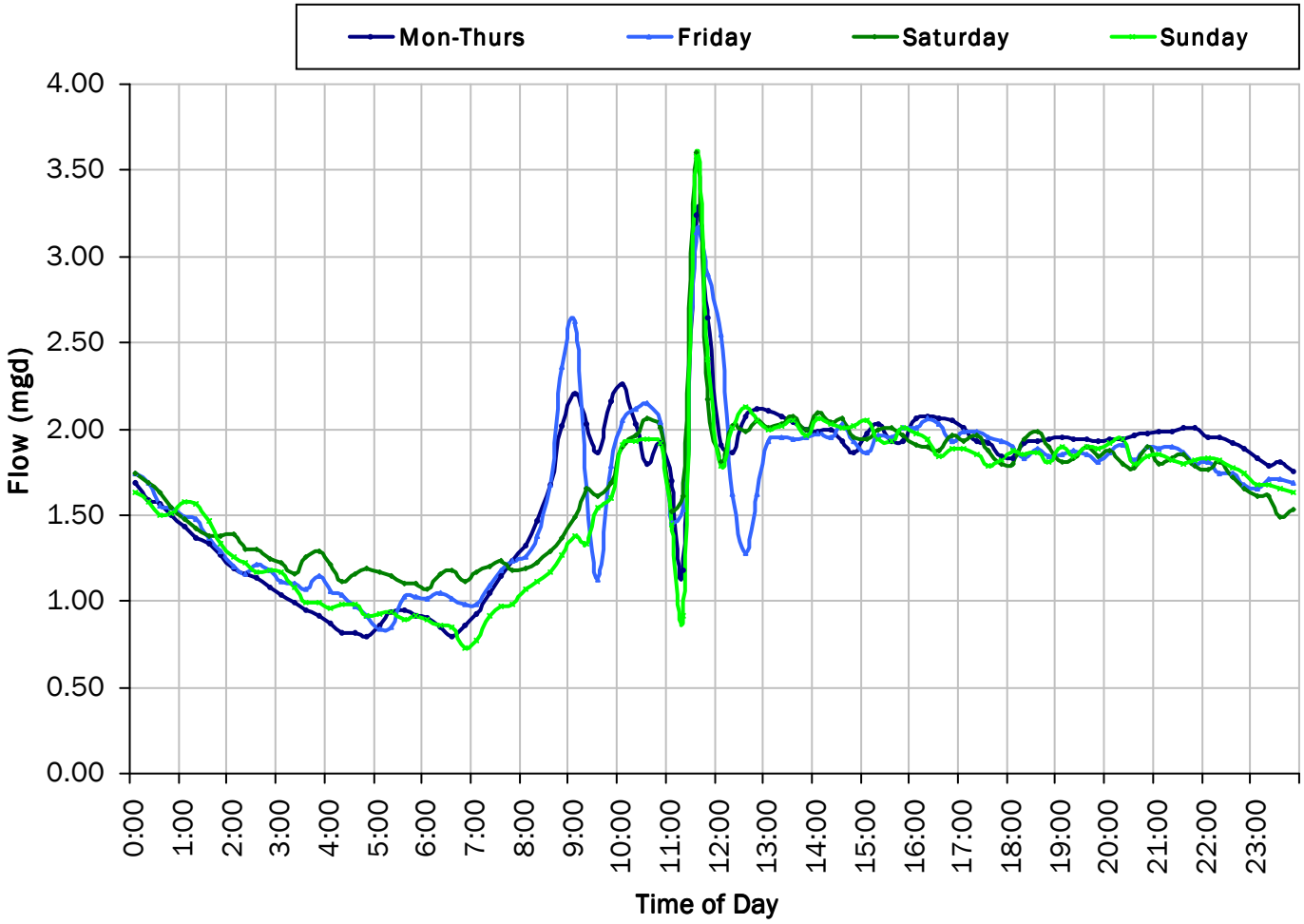
Total Period Rainfall: 14.49 inches **Avg Flow: 2.963 mgd** **Peak Flow: 11.471 mgd** **Min Flow: 0.501 mgd**





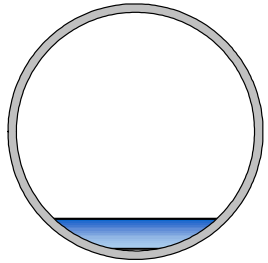
SITE 04

Average Dry Weather Flow Hydrographs



ADWF:

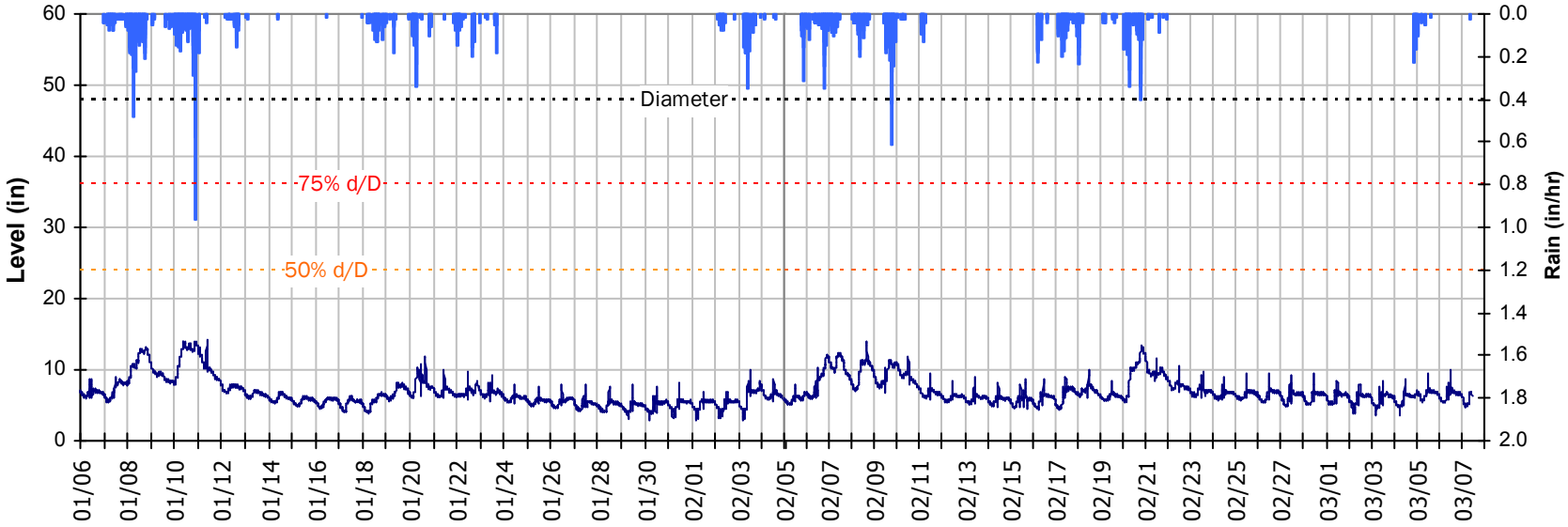
1.654 *mgd*

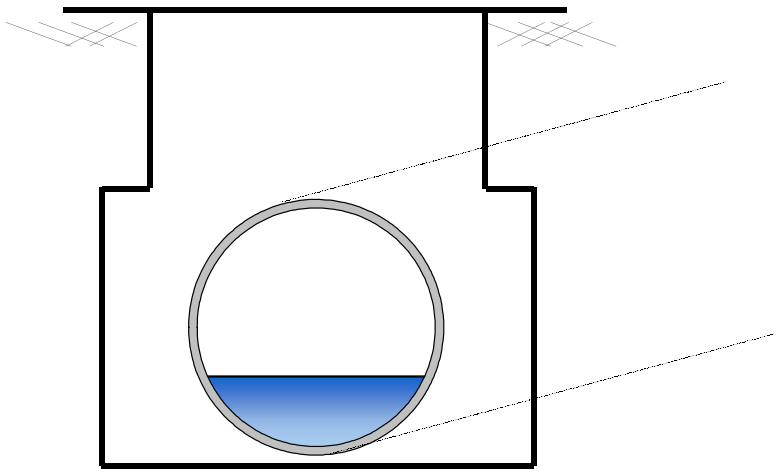


SITE 04

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period



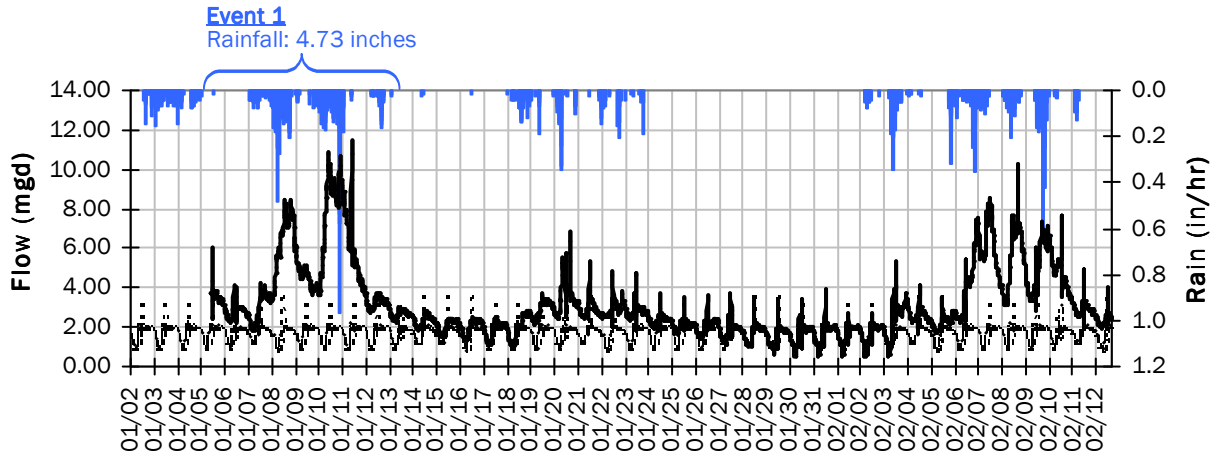


Pipe Diameter:	48	*inches*
Peak Measured Level:	14.1	*inches*
Peak d/D Ratio:	0.29	

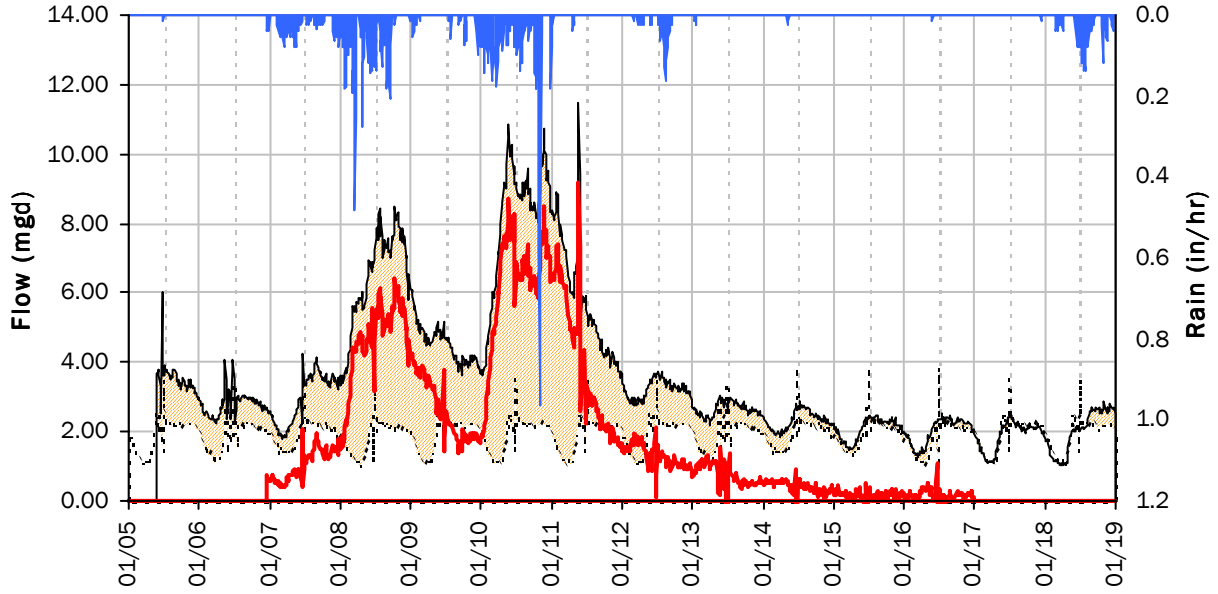
SITE 04

I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

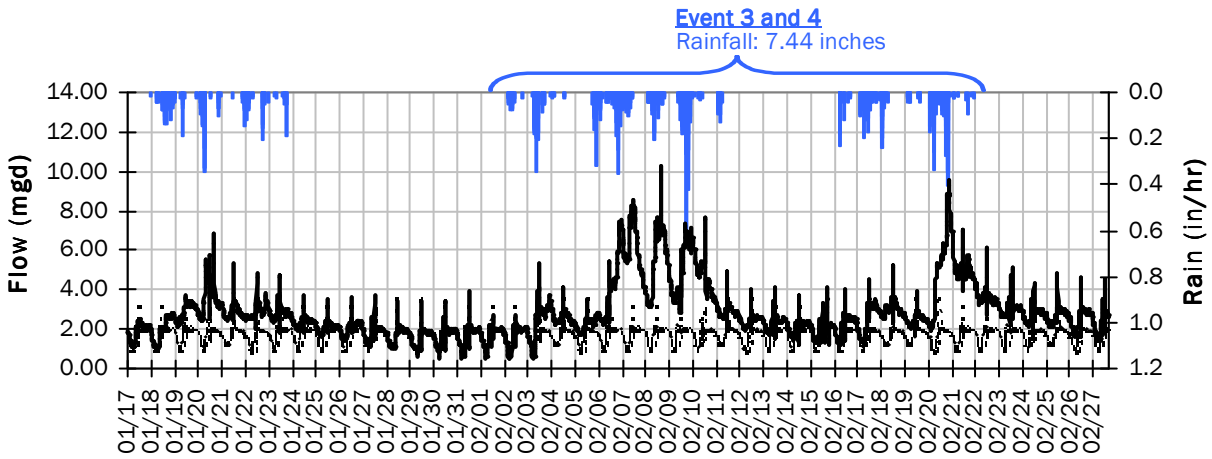


Storm Event I/I Analysis (Rain = 4.73 inches)

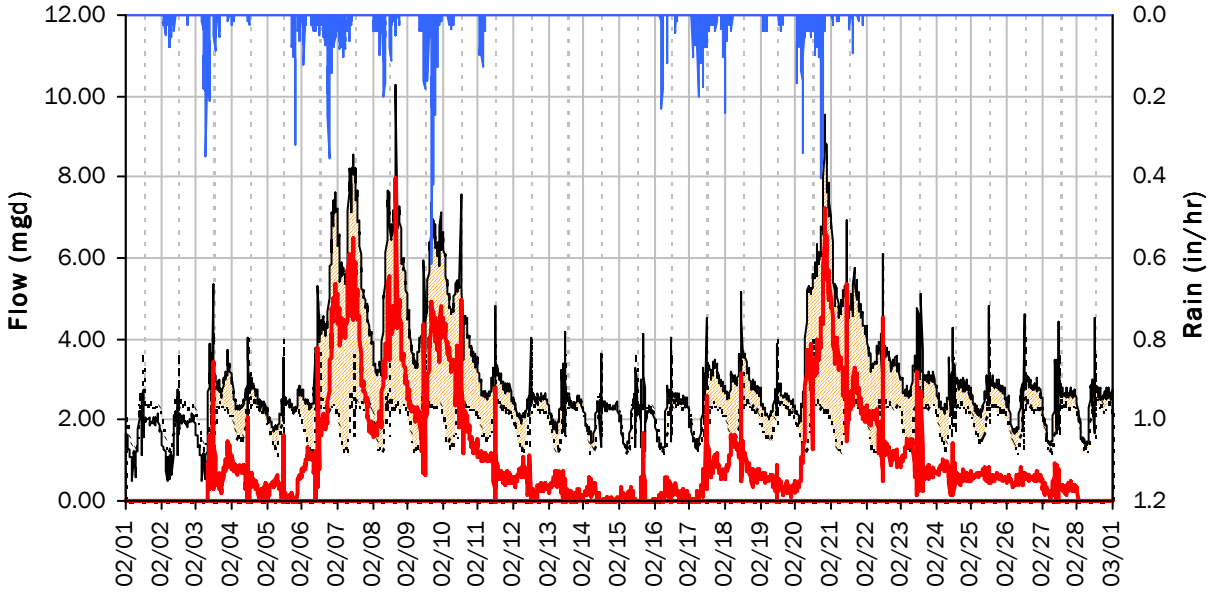
Capacity		Inflow / Infiltration	
Peak Flow:	11.47 *mgd*	**Peak I/I Rate:**	9.19 *mgd*
PF:	6.94	**Total I/I:**	21,181,000 *gallons*
Peak Level:	14.09 *in*		
d/D Ratio:	0.29		

SITE 04
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



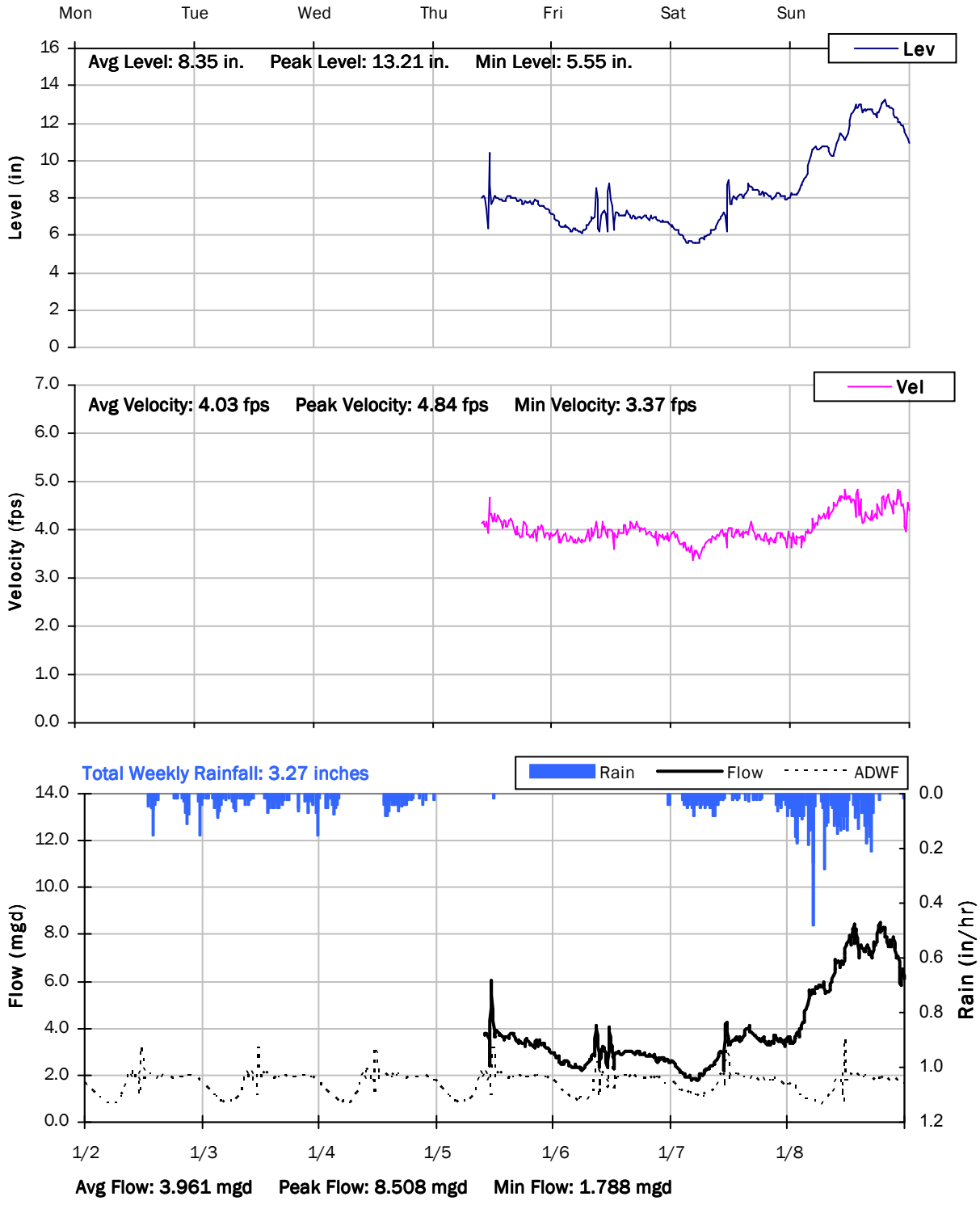
Storm Event I/I Analysis (Rain = 7.44 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	10.29 *mgd*	**Peak I/I Rate:**	7.97 *mgd*
PF:	6.22	**Total I/I:**	31,262,000 *gallons*
Peak Level:	13.99 *in*		
d/D Ratio:	0.29		

SITE 04

Weekly Level, Velocity and Flow Hydrographs

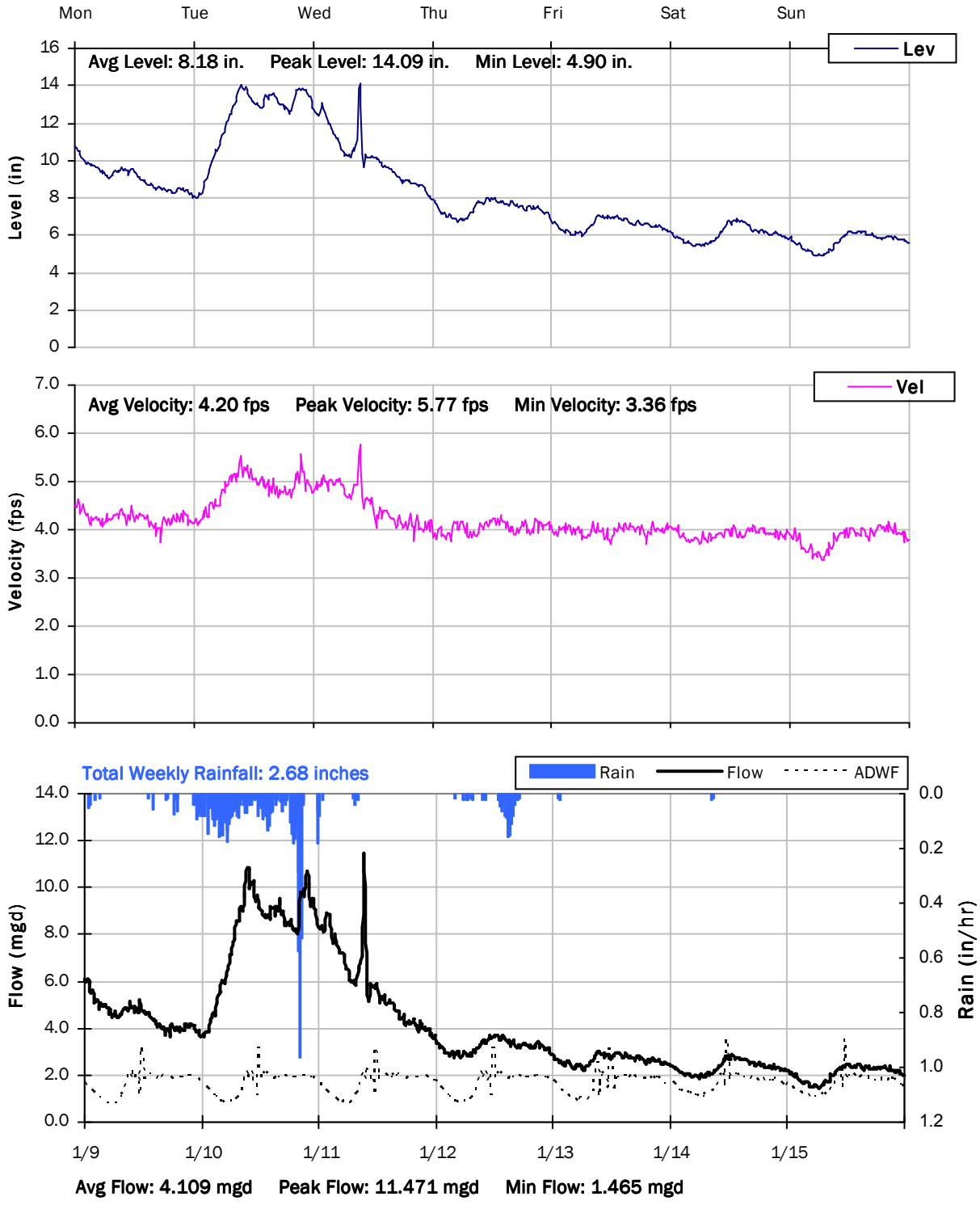
1/2/2017 to 1/9/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

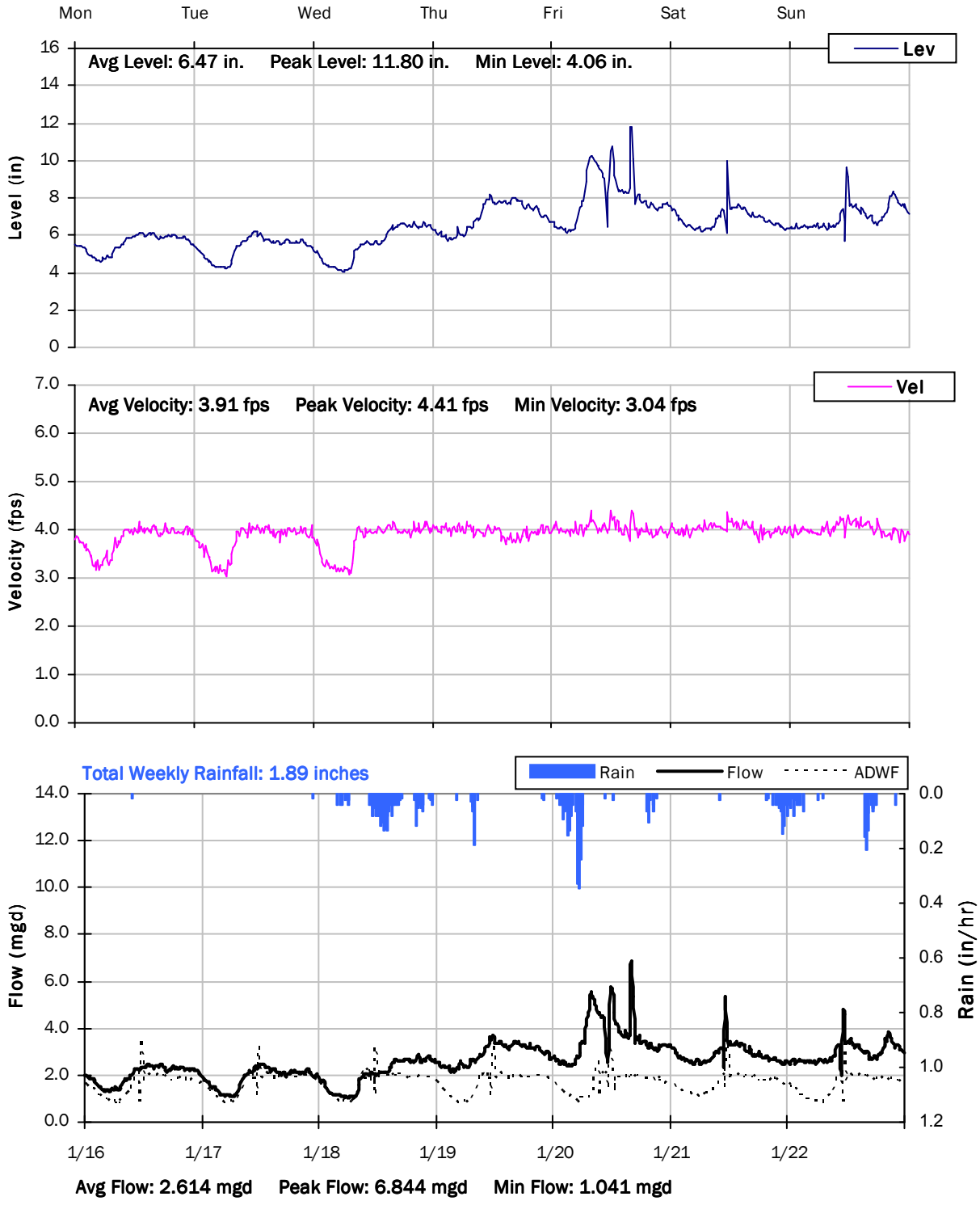
1/9/2017 to 1/16/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

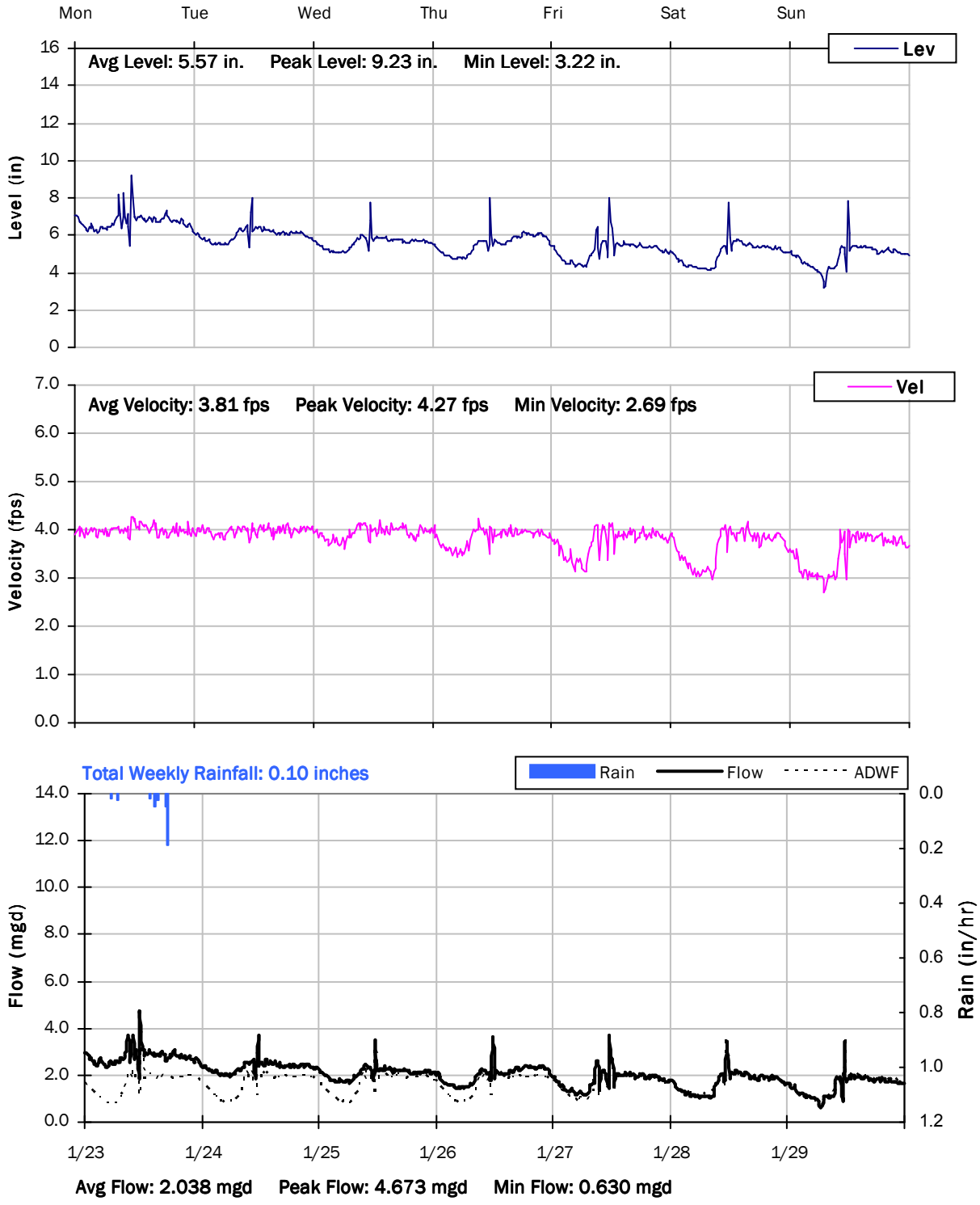
1/16/2017 to 1/23/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

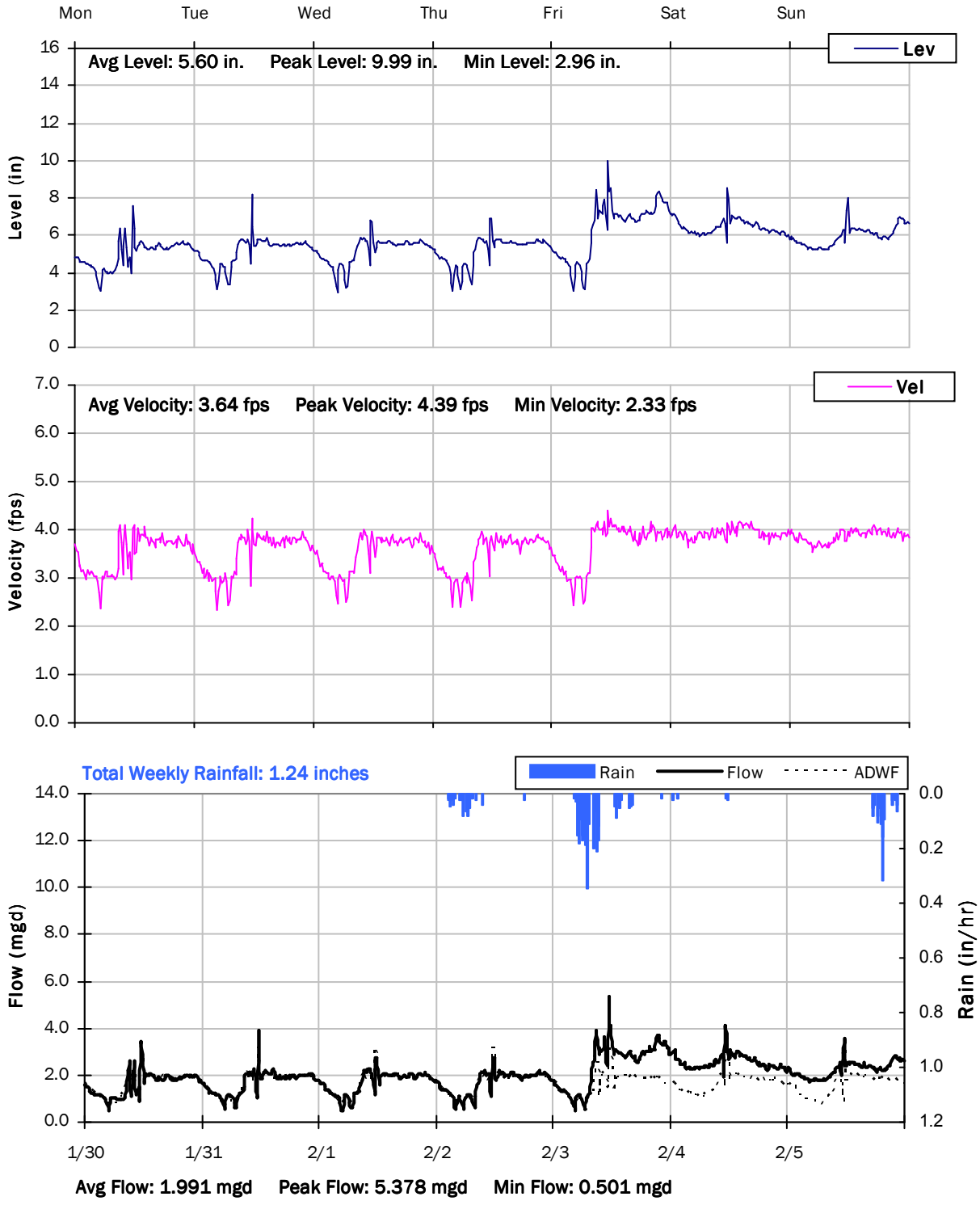
1/23/2017 to 1/30/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

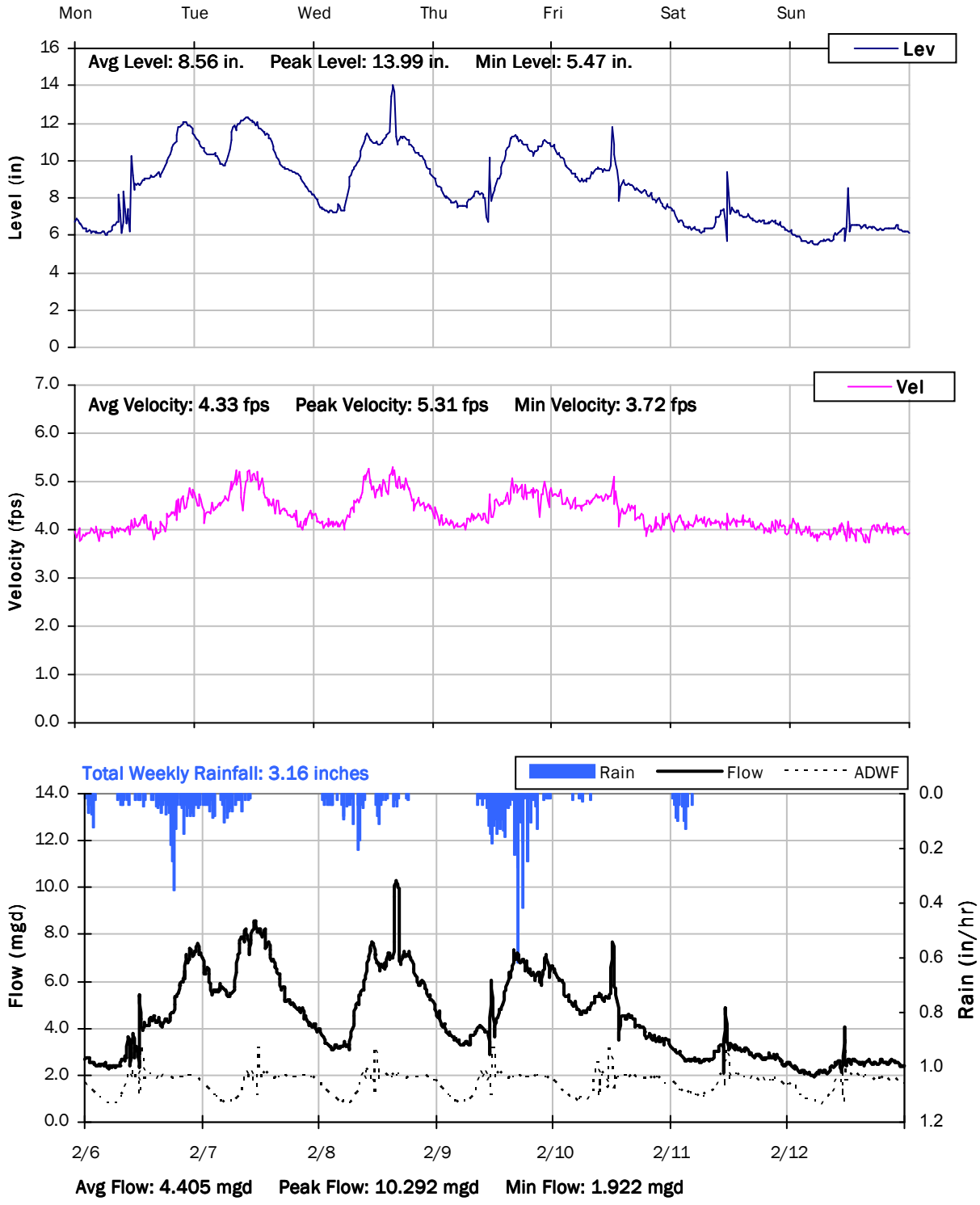
1/30/2017 to 2/6/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

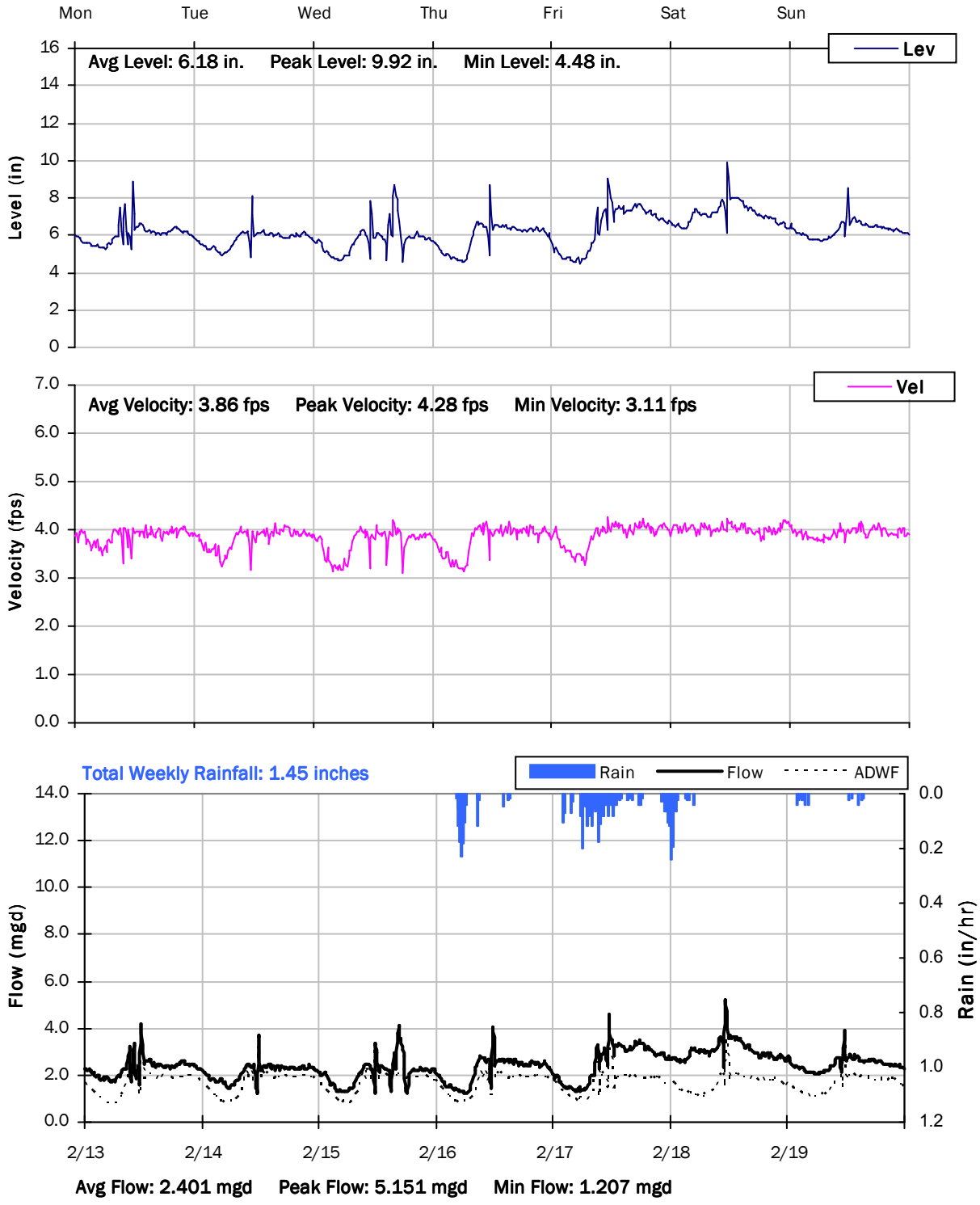
2/6/2017 to 2/13/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

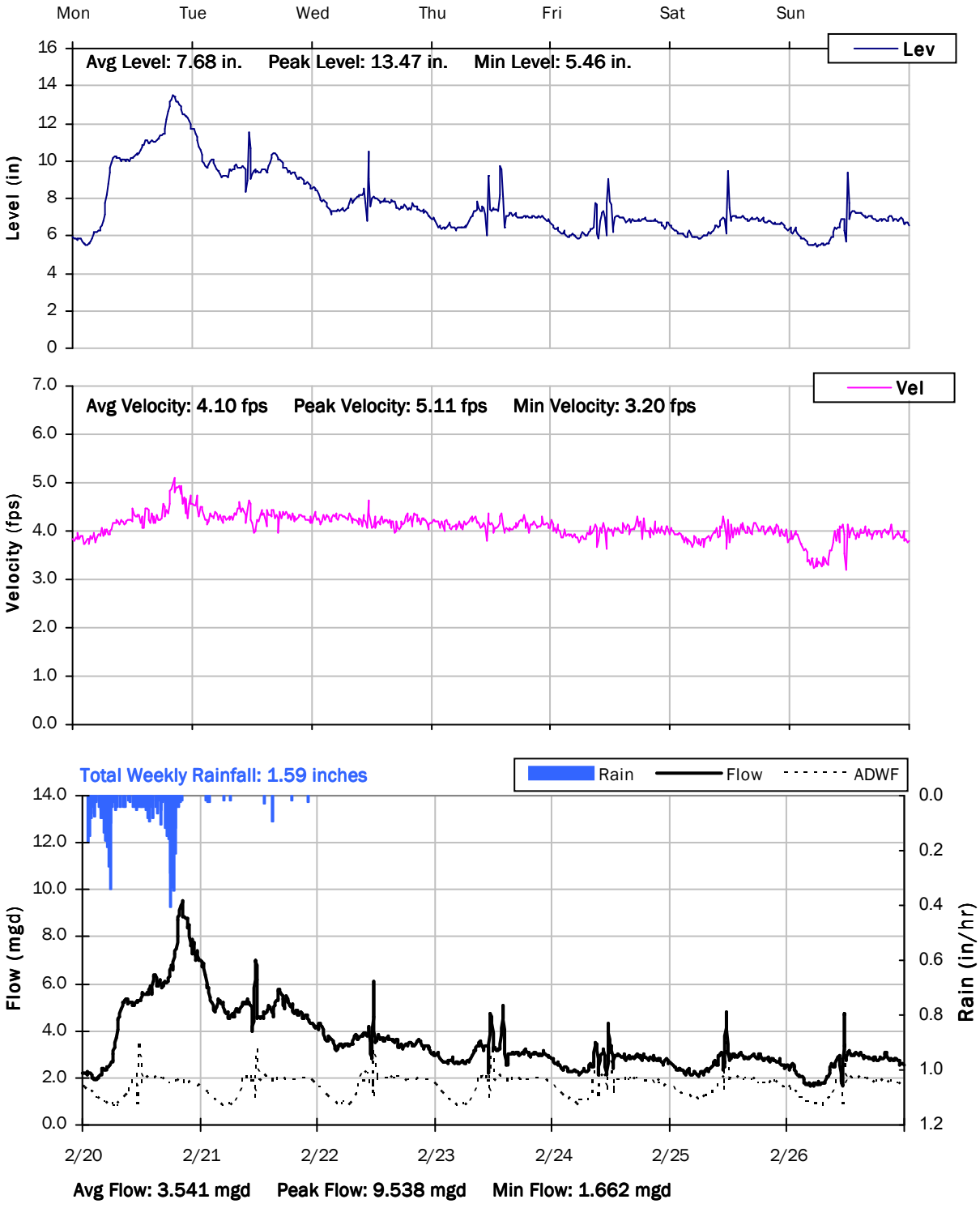
2/13/2017 to 2/20/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

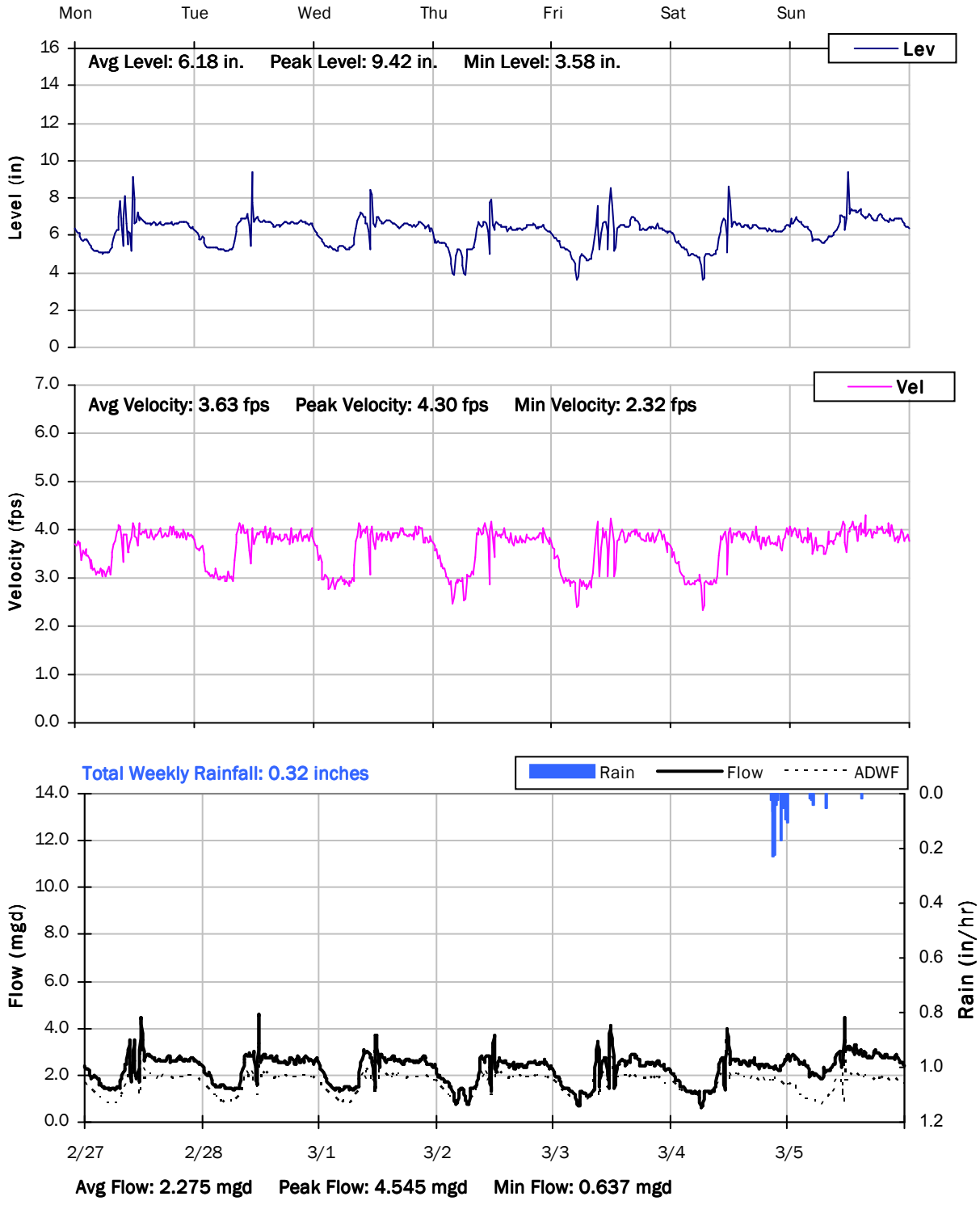
2/20/2017 to 2/27/2017



SITE 04

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



City of Lincoln

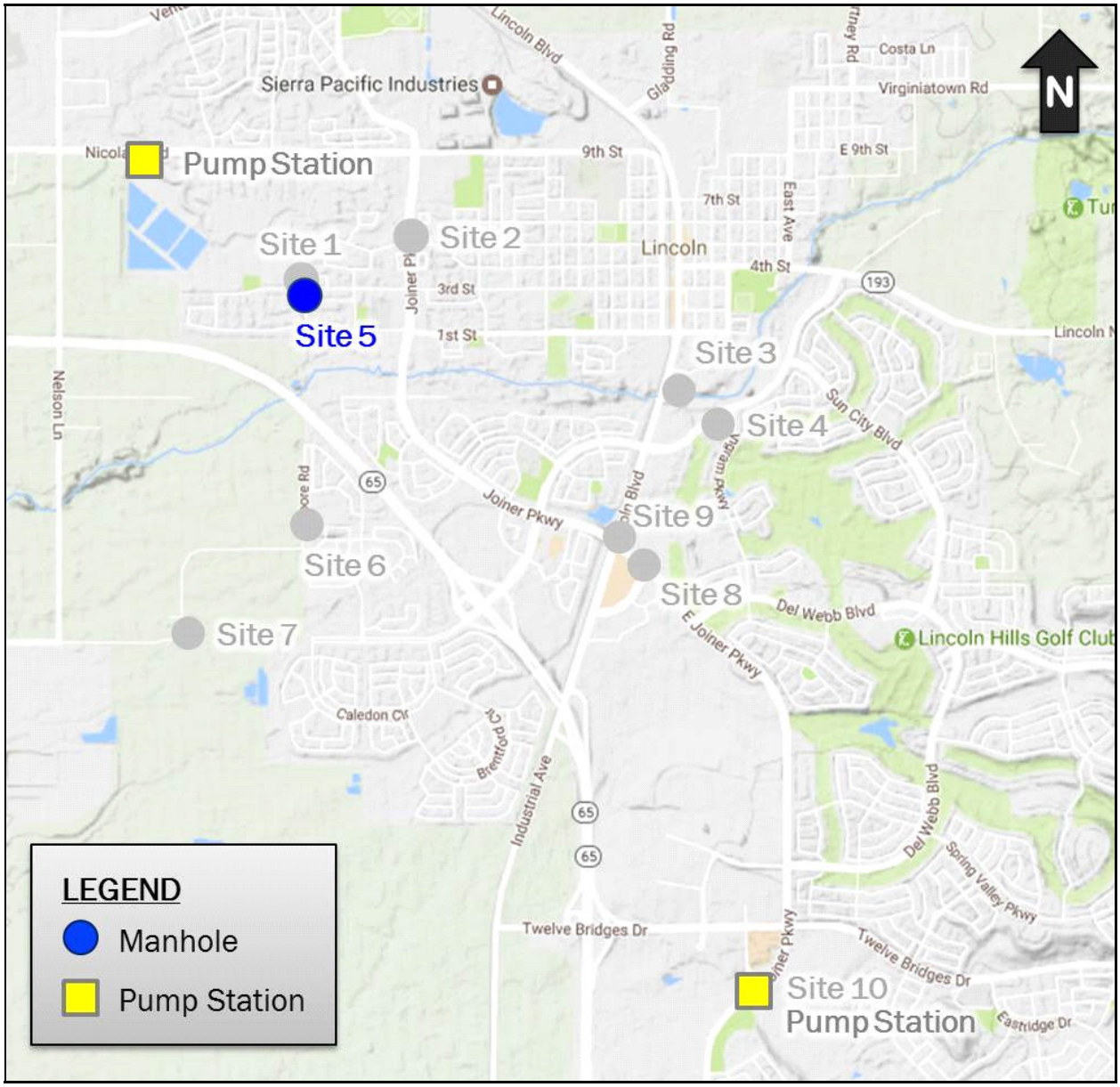
Sanitary Sewer Flow Monitoring

Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 05

Location: 2161 Boyden Drive

Data Summary Report



Vicinity Map: Site 05

SITE 05

Site Information

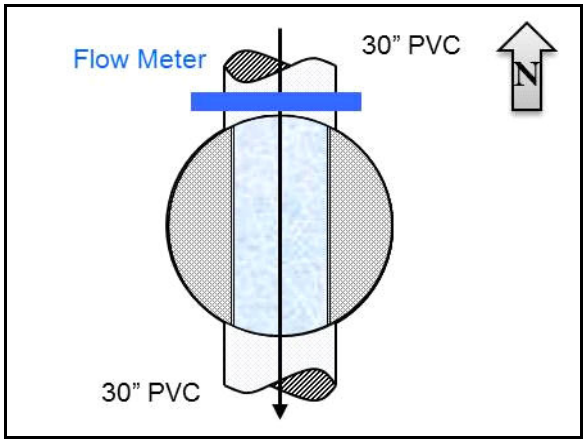
Location: 2161 Boyden Drive

District ID: NW355SS27

Coordinates:	121.3213° W, 38.8884° N
Expected Pipe Diameter (Orig. if Relocated):	30 inches
Measured Pipe Diameter:	30 inches
ADWF:	1.116 mgd
Peak Measured Flow:	8.171 mgd
Rim Elevation (GEarth):	133 feet

Satellite Map

Sewer Map



Flow Sketch

Street View

Plan View

SITE 05

Additional Site Photos

Effluent Pipe

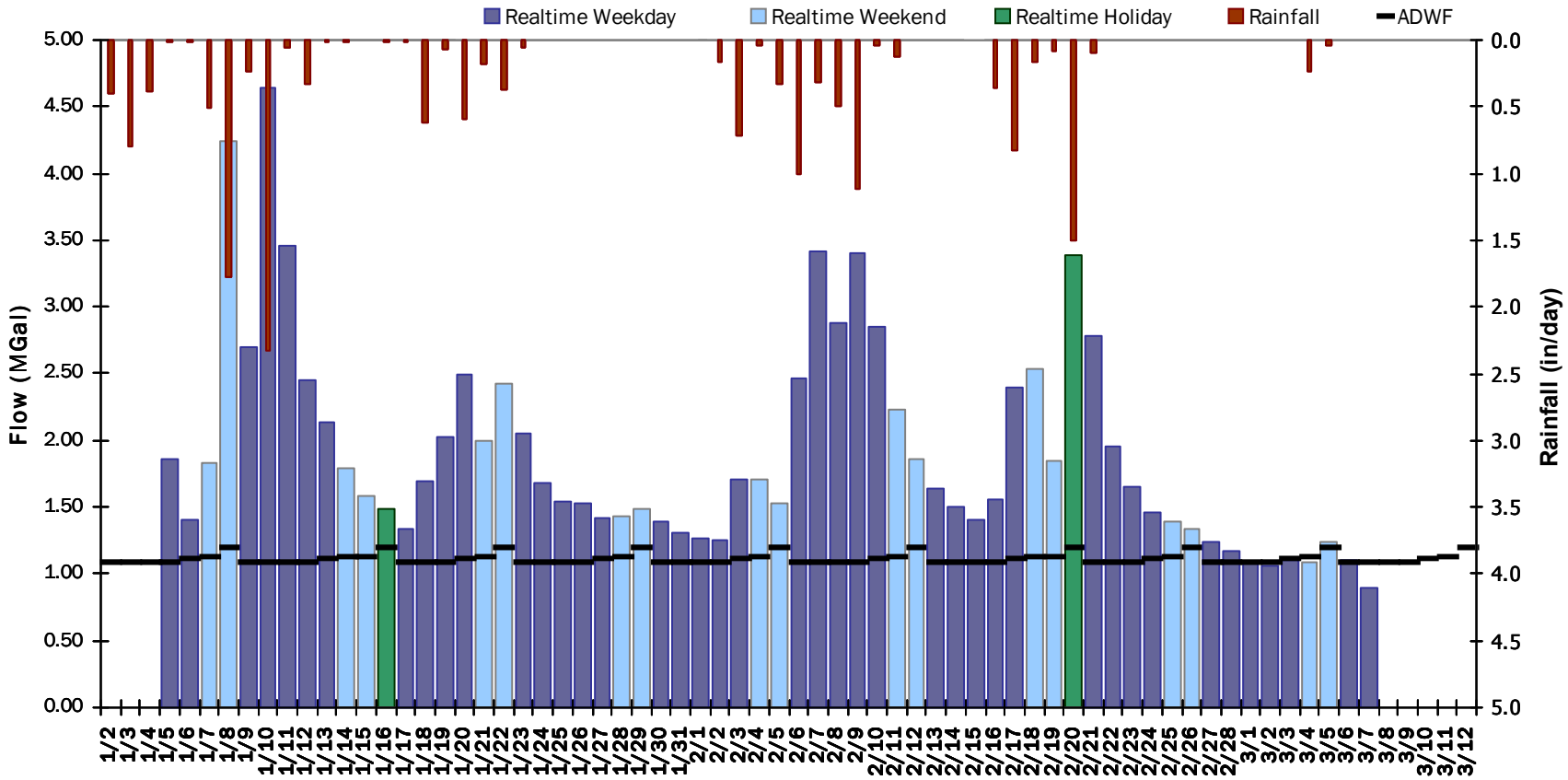
Influent Pipe

SITE 05

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 1.917 MGal Peak Daily Flow: 4.641 MGal Min Daily Flow: 0.896 MGal

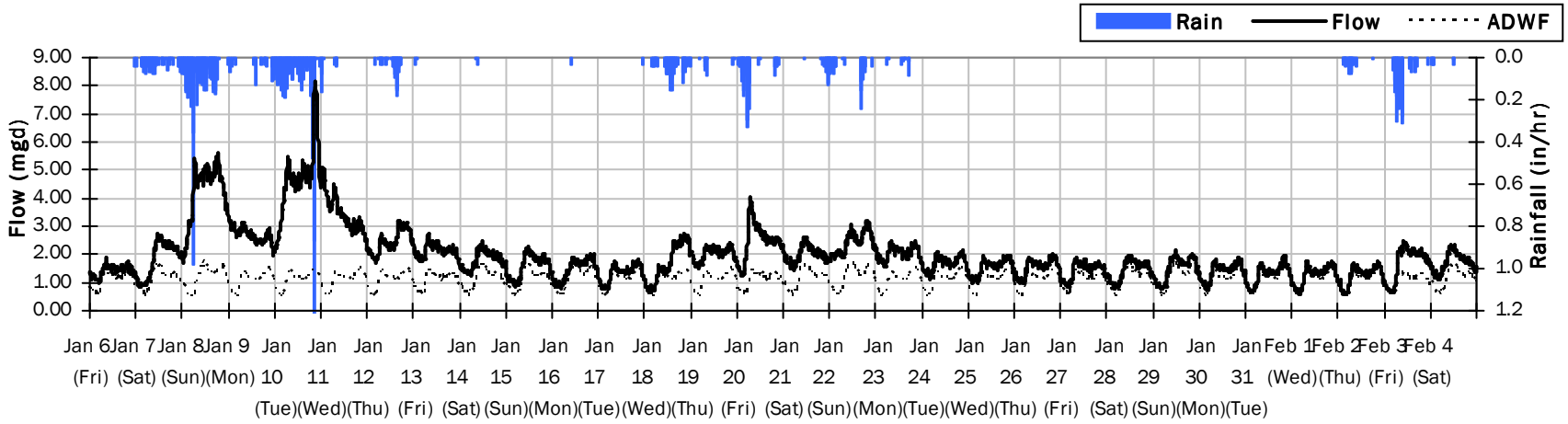
Total Period Rainfall: 16.43 inches

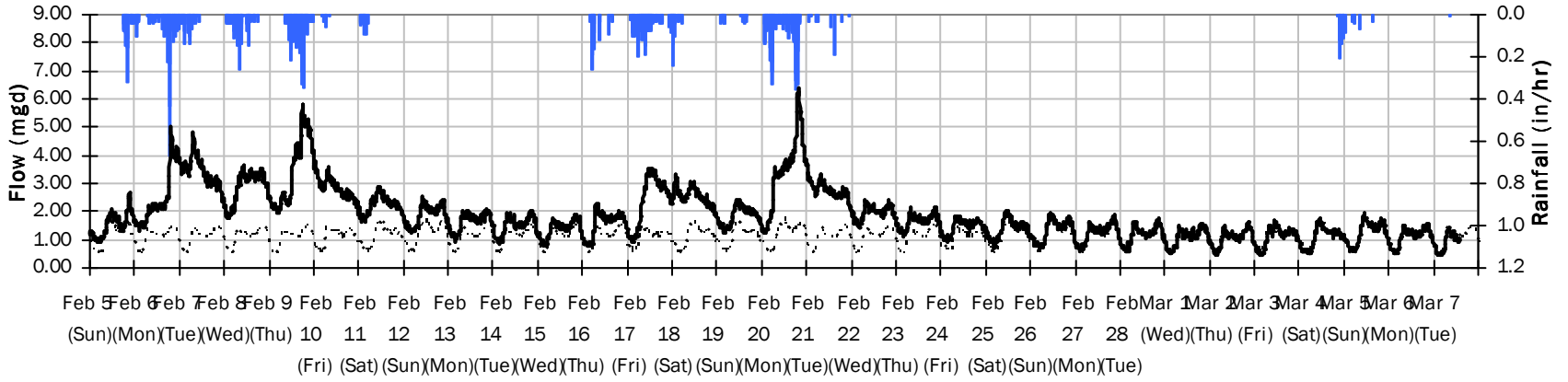


SITE 05

Flow Summary: 1/6/2017 to 3/7/2017

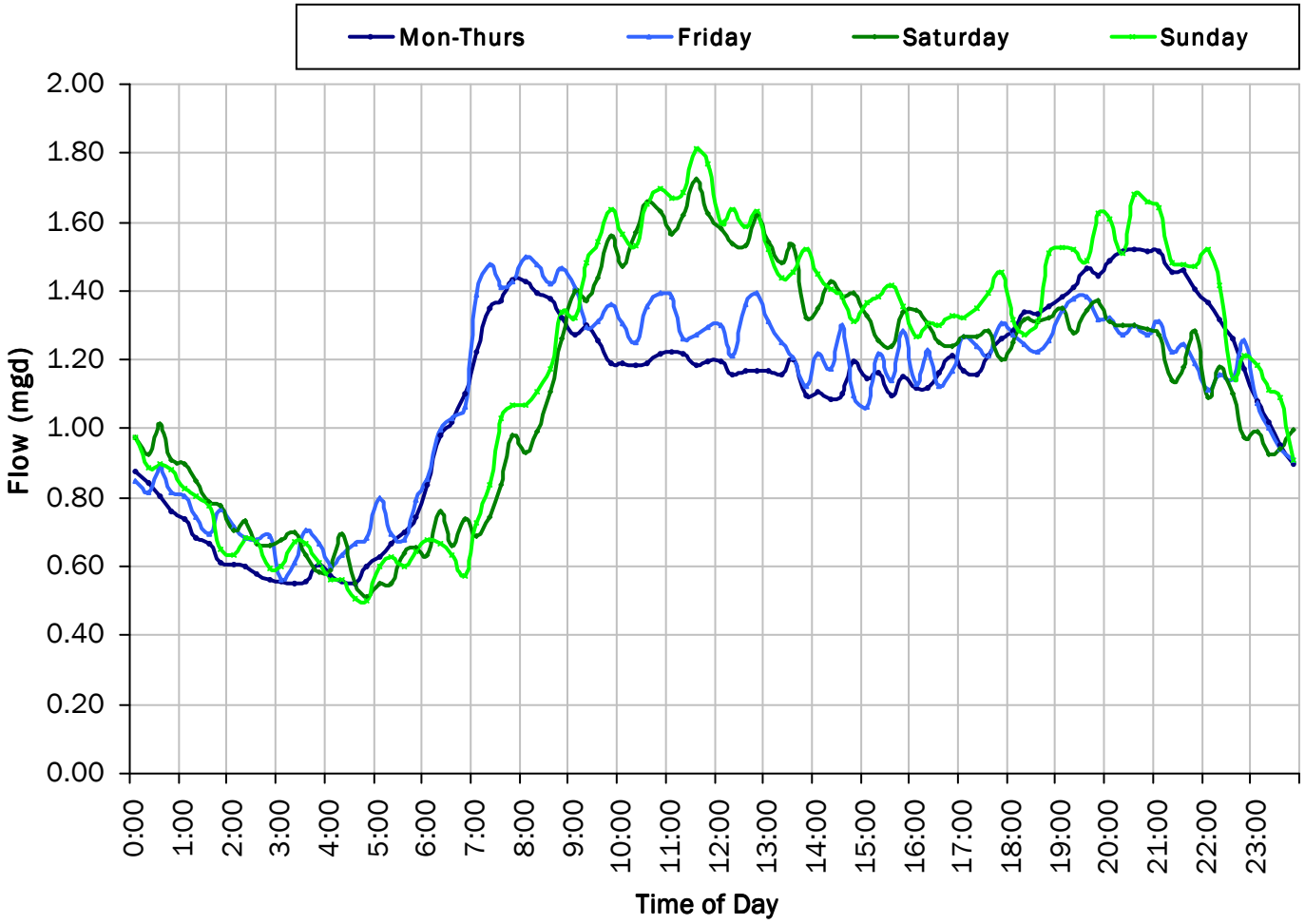
Total Period Rainfall: 14.83 inches **Avg Flow: 1.925 mgd** **Peak Flow: 8.171 mgd** **Min Flow: 0.434 mgd**





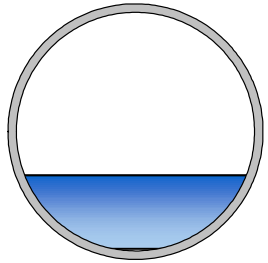
SITE 05

Average Dry Weather Flow Hydrographs



ADWF:

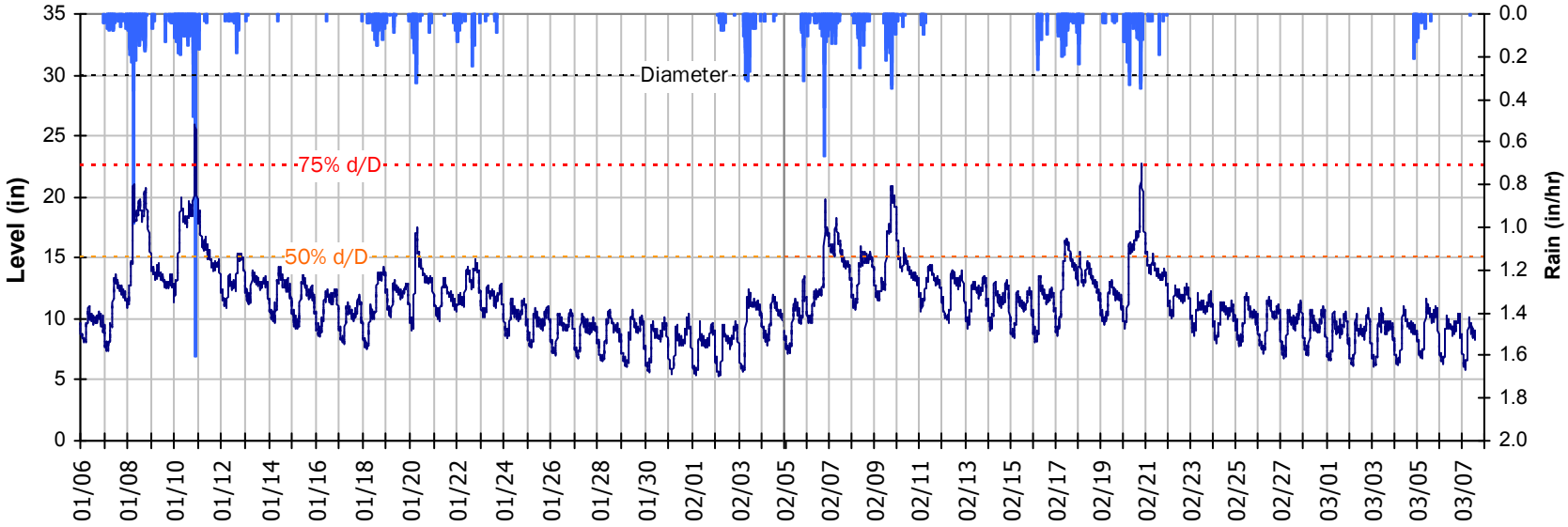
1.116 *mgd*

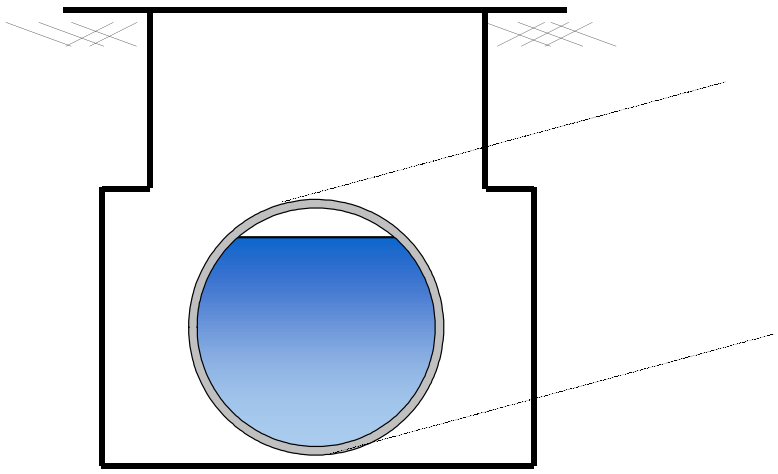


SITE 05

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period

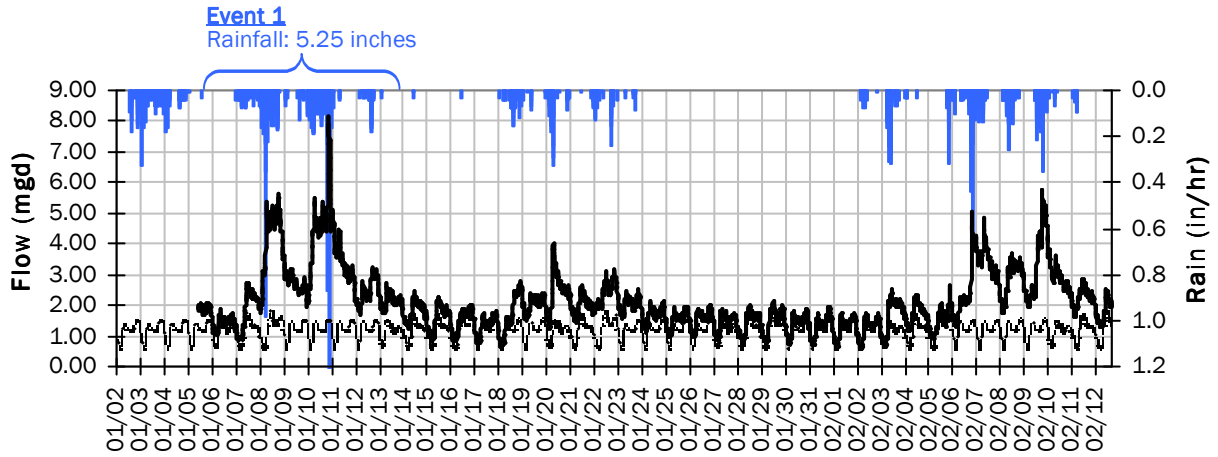




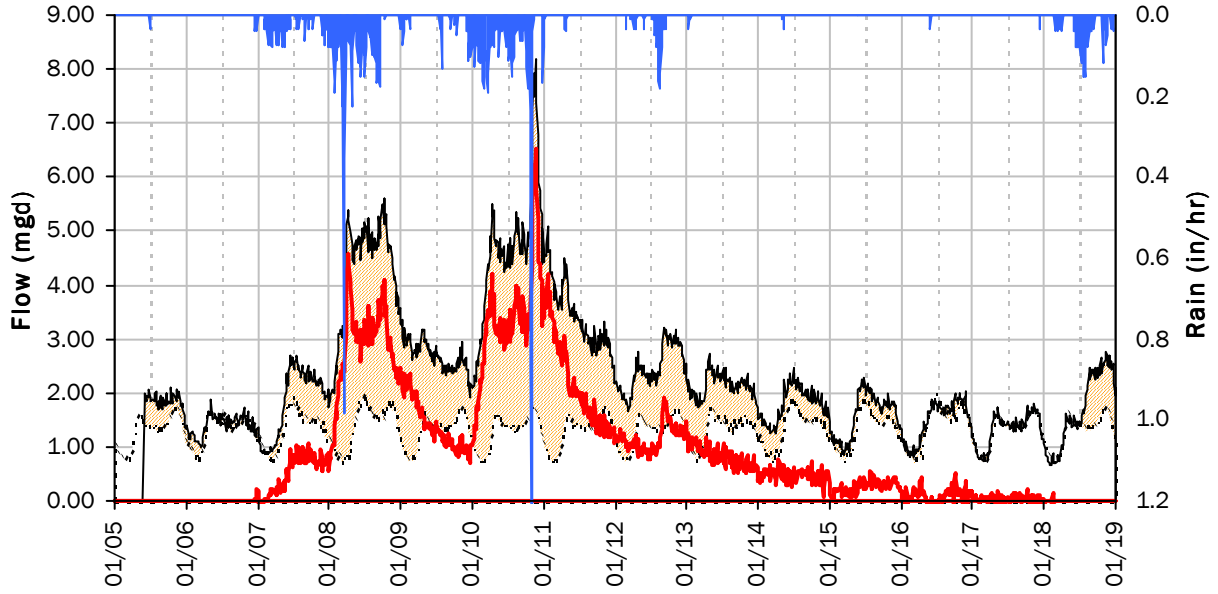
Pipe Diameter:	30	*inches*
Peak Measured Level:	26	*inches*
Peak d/D Ratio:	0.87	

SITE 05
I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

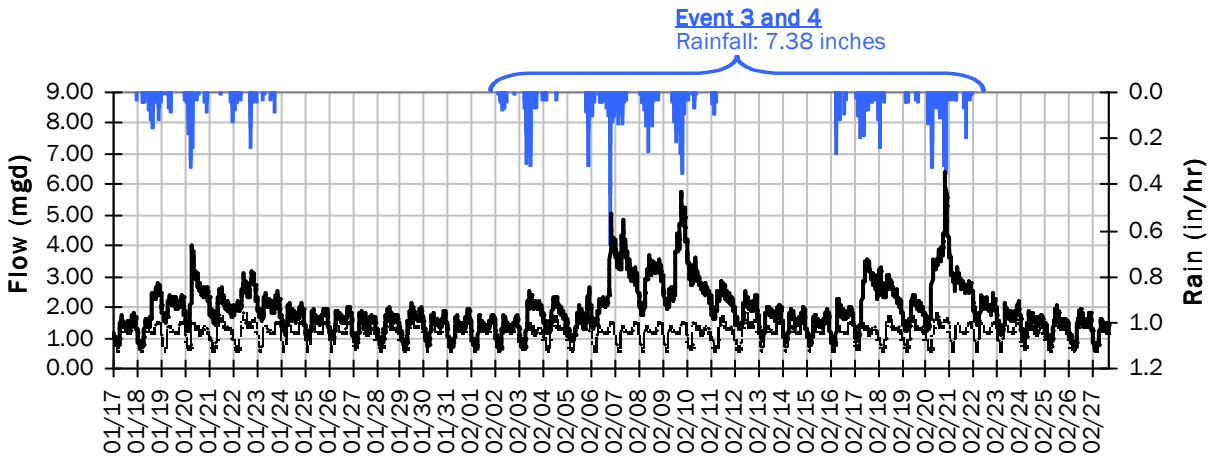


Storm Event I/I Analysis (Rain = 5.25 inches)

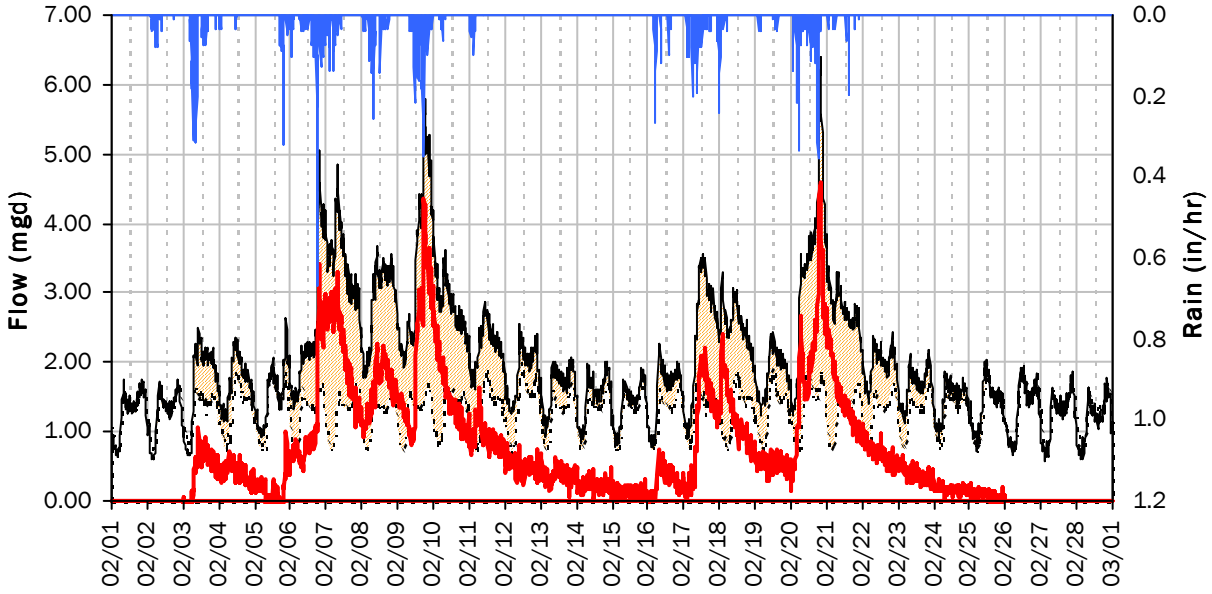
Capacity		Inflow / Infiltration	
Peak Flow:	8.17 *mgd*	**Peak I/I Rate:**	6.52 *mgd*
PF:	7.32	**Total I/I:**	13,200,000 *gallons*
Peak Level:	25.96 *in*		
d/D Ratio:	0.87		

SITE 05
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



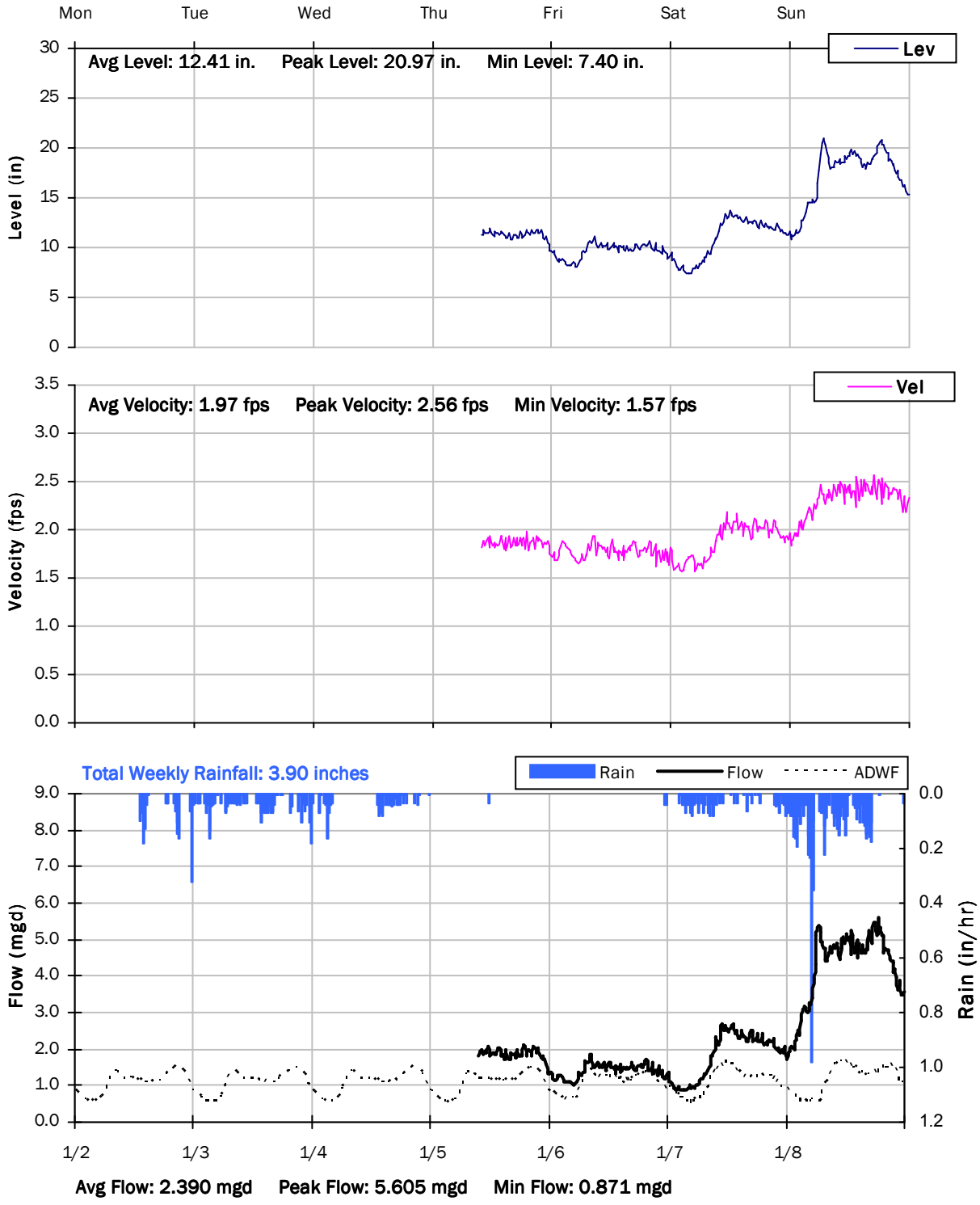
Storm Event I/I Analysis (Rain = 7.38 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	6.39 *mgd*	**Peak I/I Rate:**	4.60 *mgd*
PF:	5.73	**Total I/I:**	19,749,000 *gallons*
Peak Level:	22.65 *in*		
d/D Ratio:	0.75		

SITE 05

Weekly Level, Velocity and Flow Hydrographs

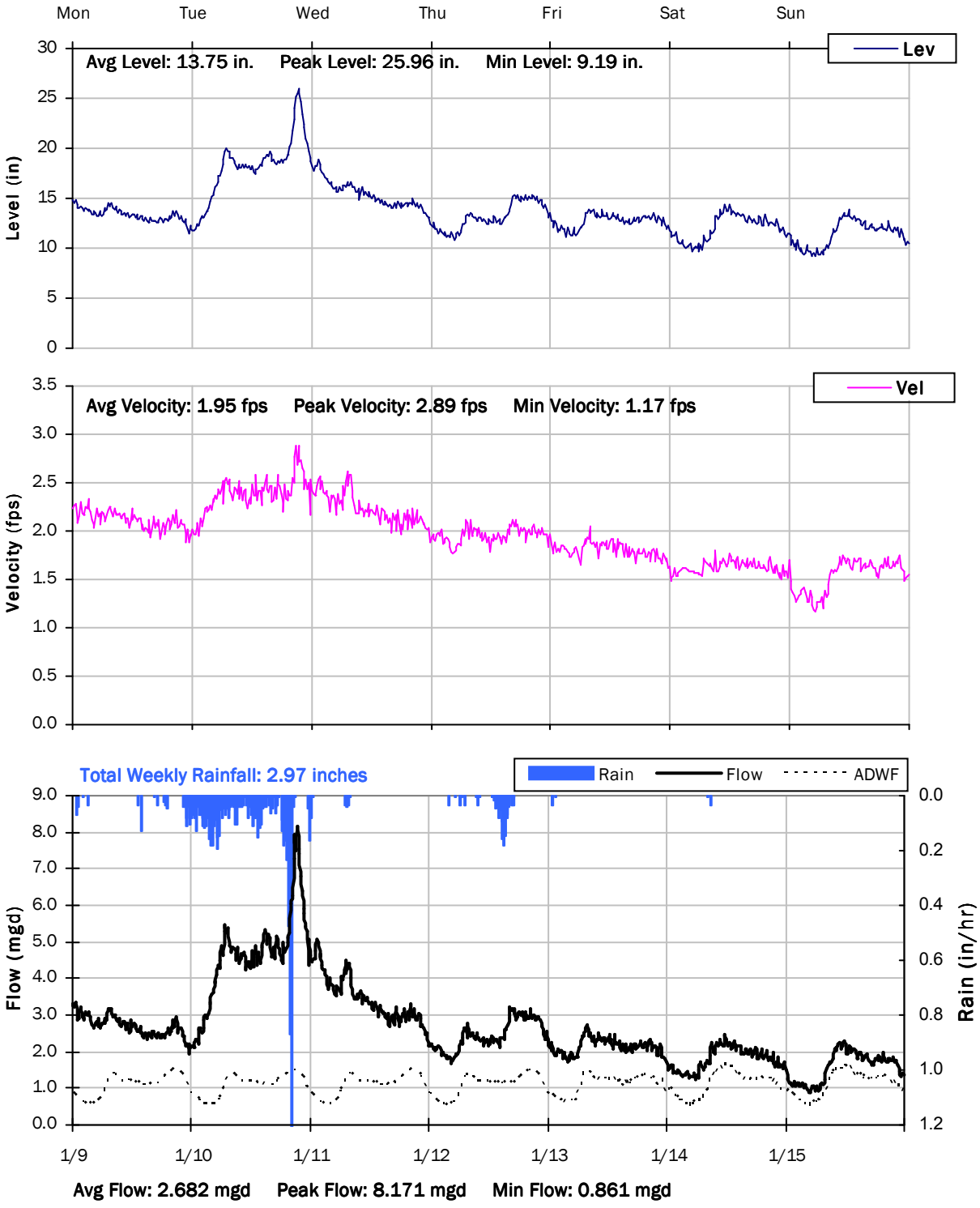
1/2/2017 to 1/9/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

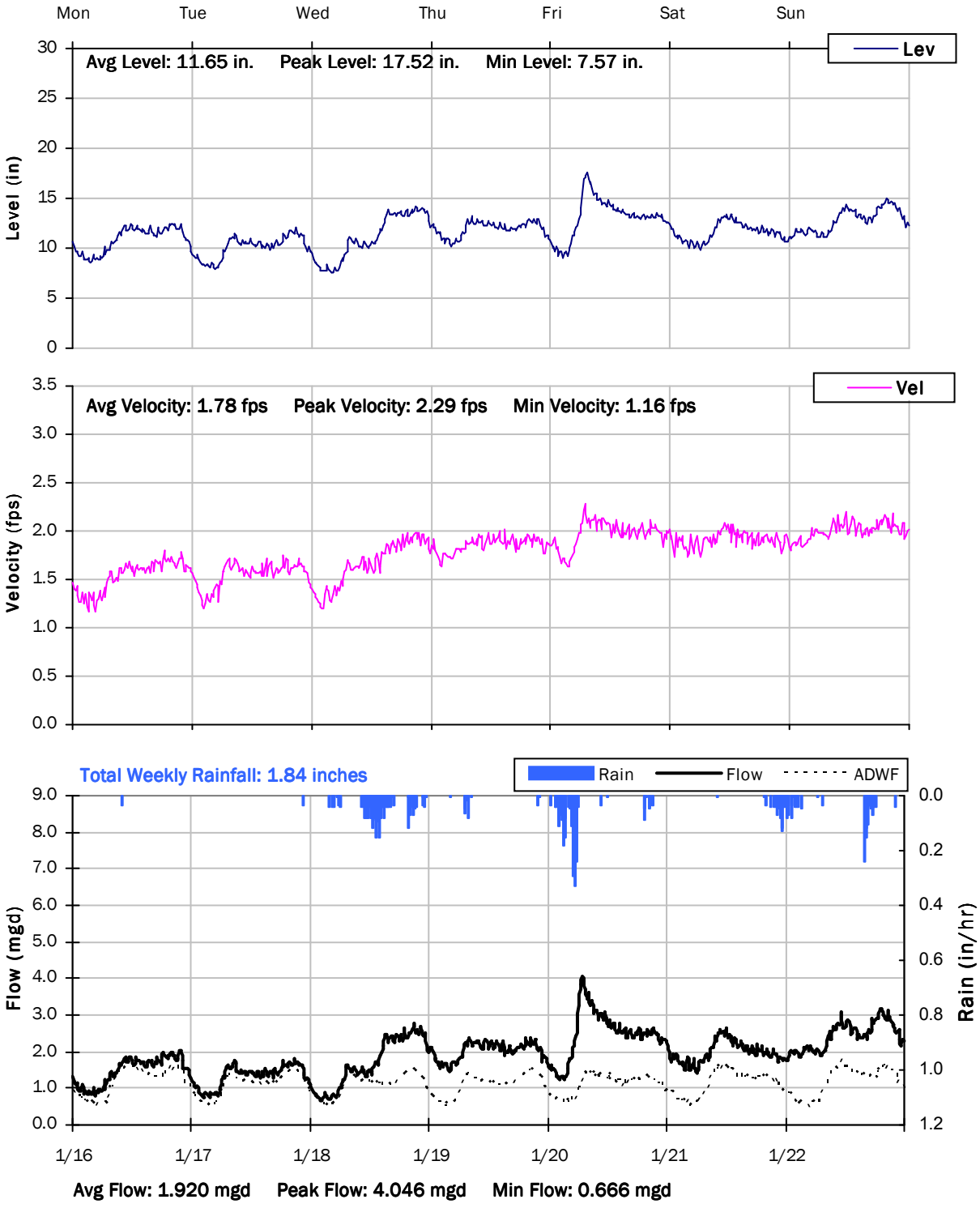
1/9/2017 to 1/16/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

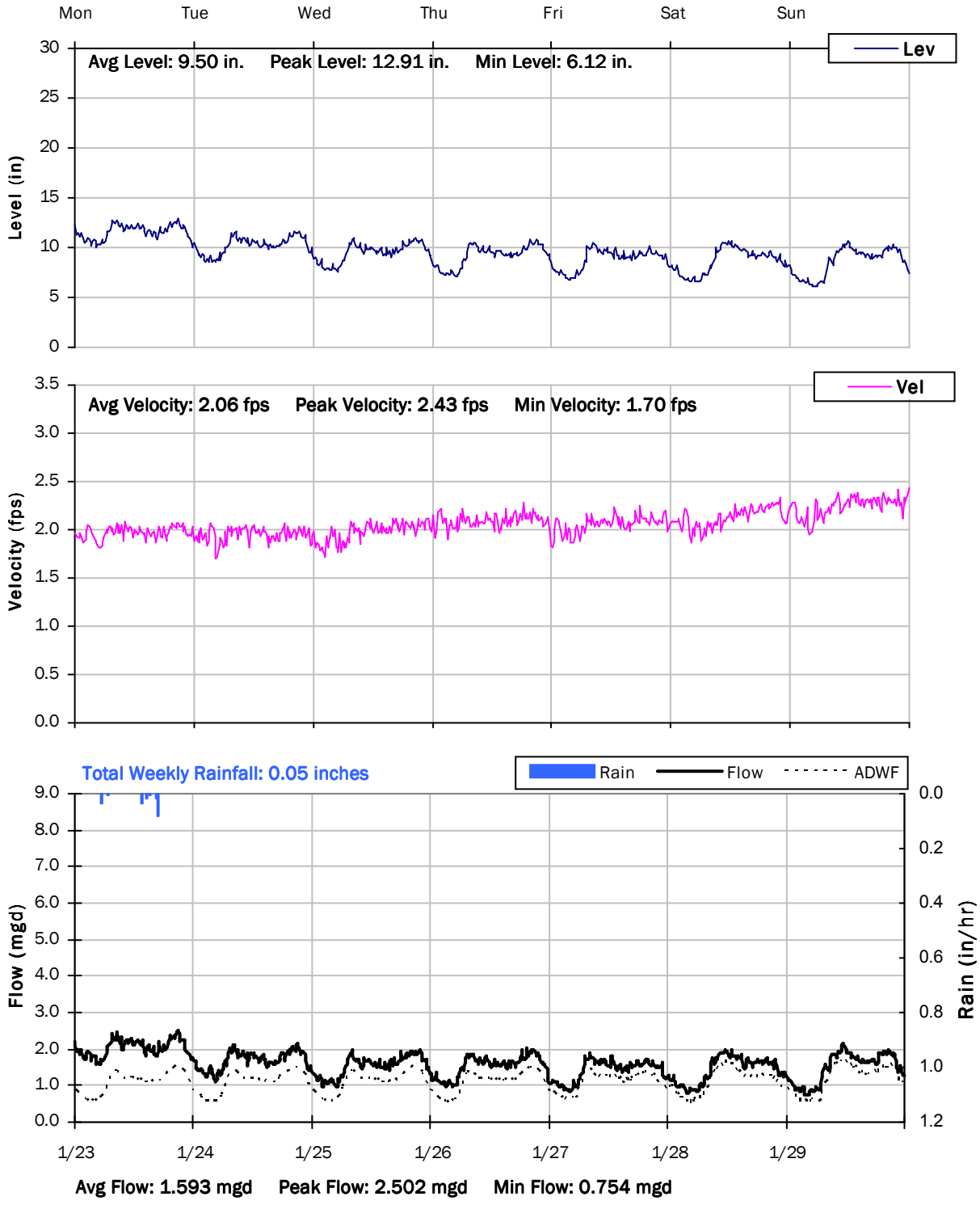
1/16/2017 to 1/23/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

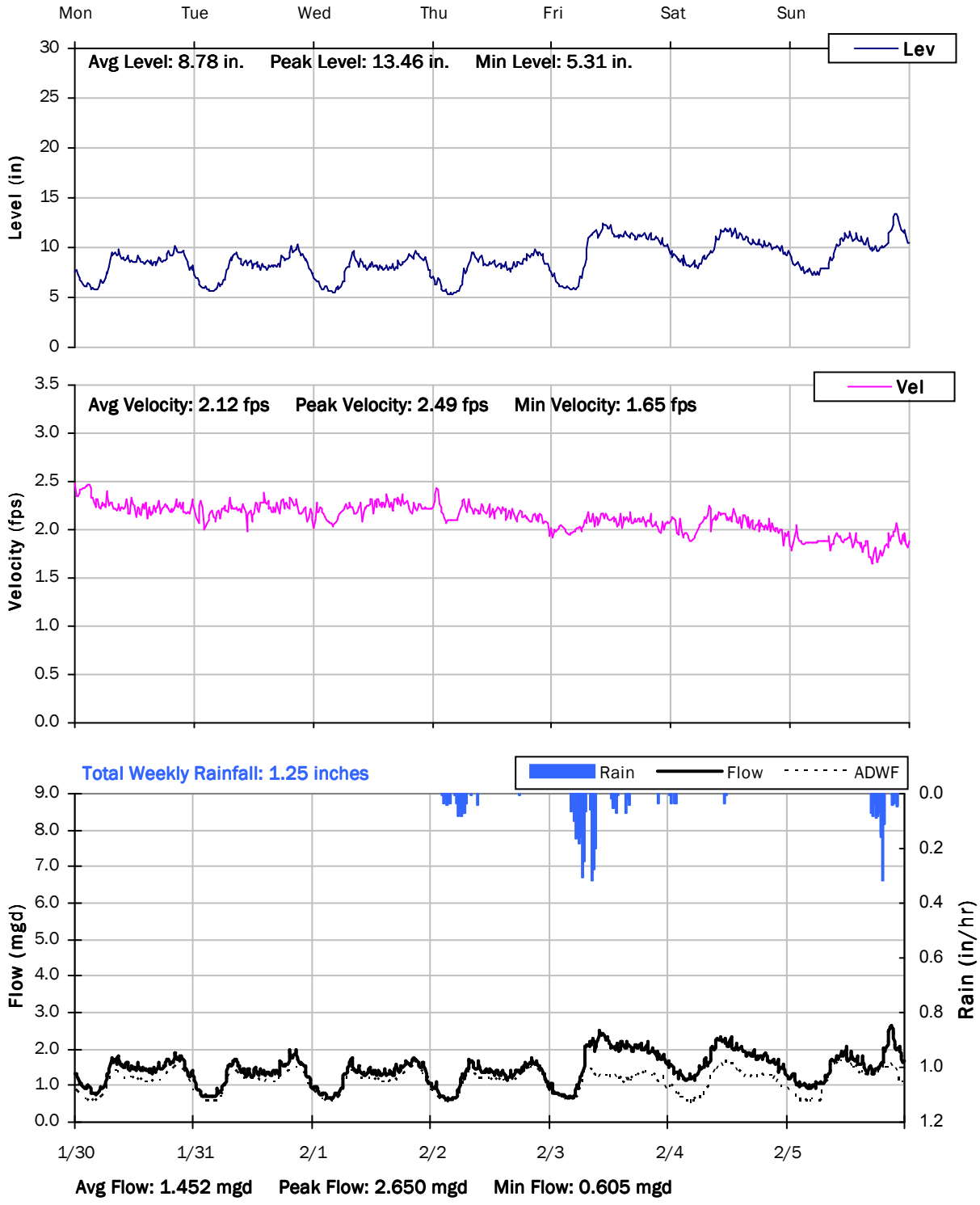
1/23/2017 to 1/30/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

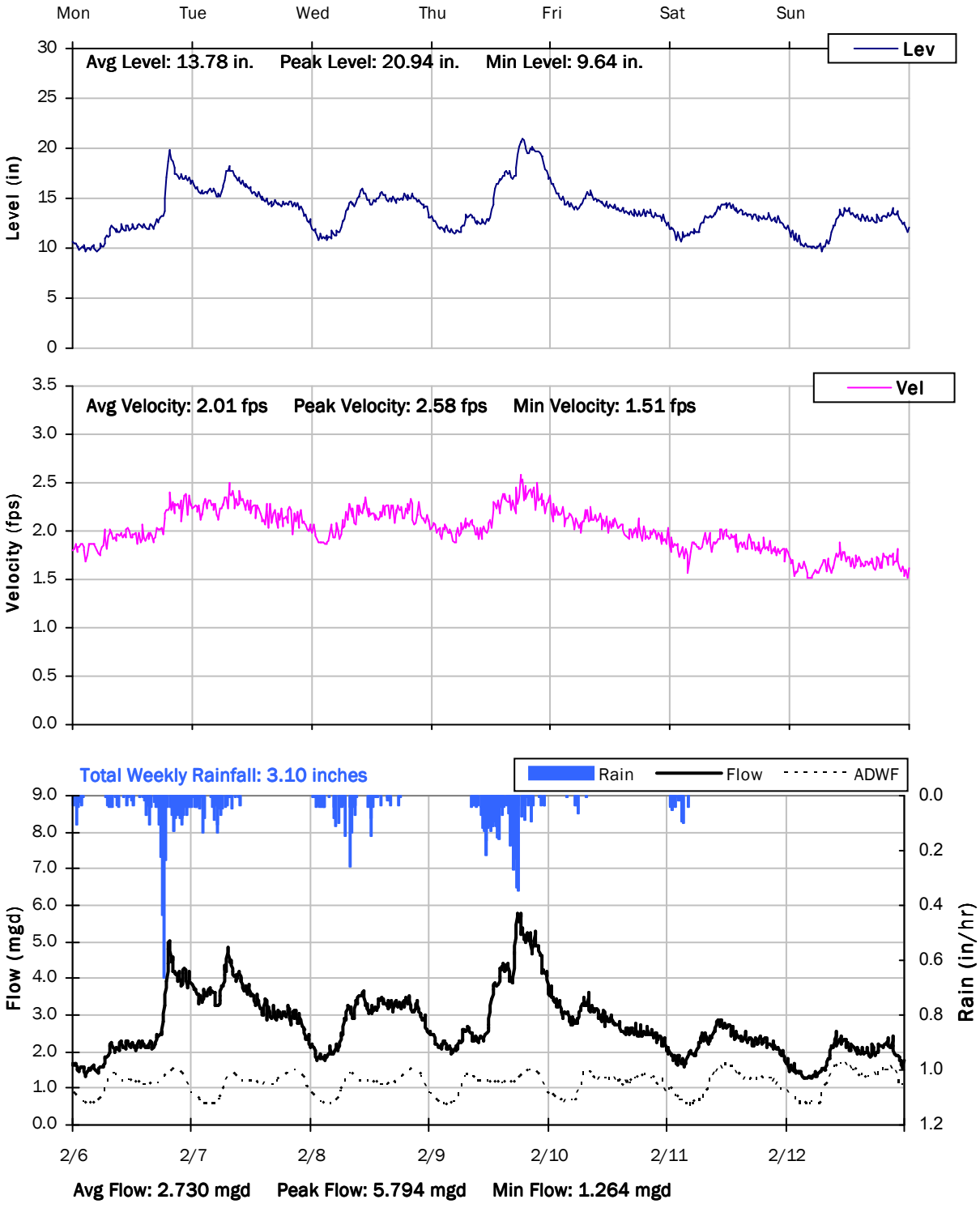
1/30/2017 to 2/6/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

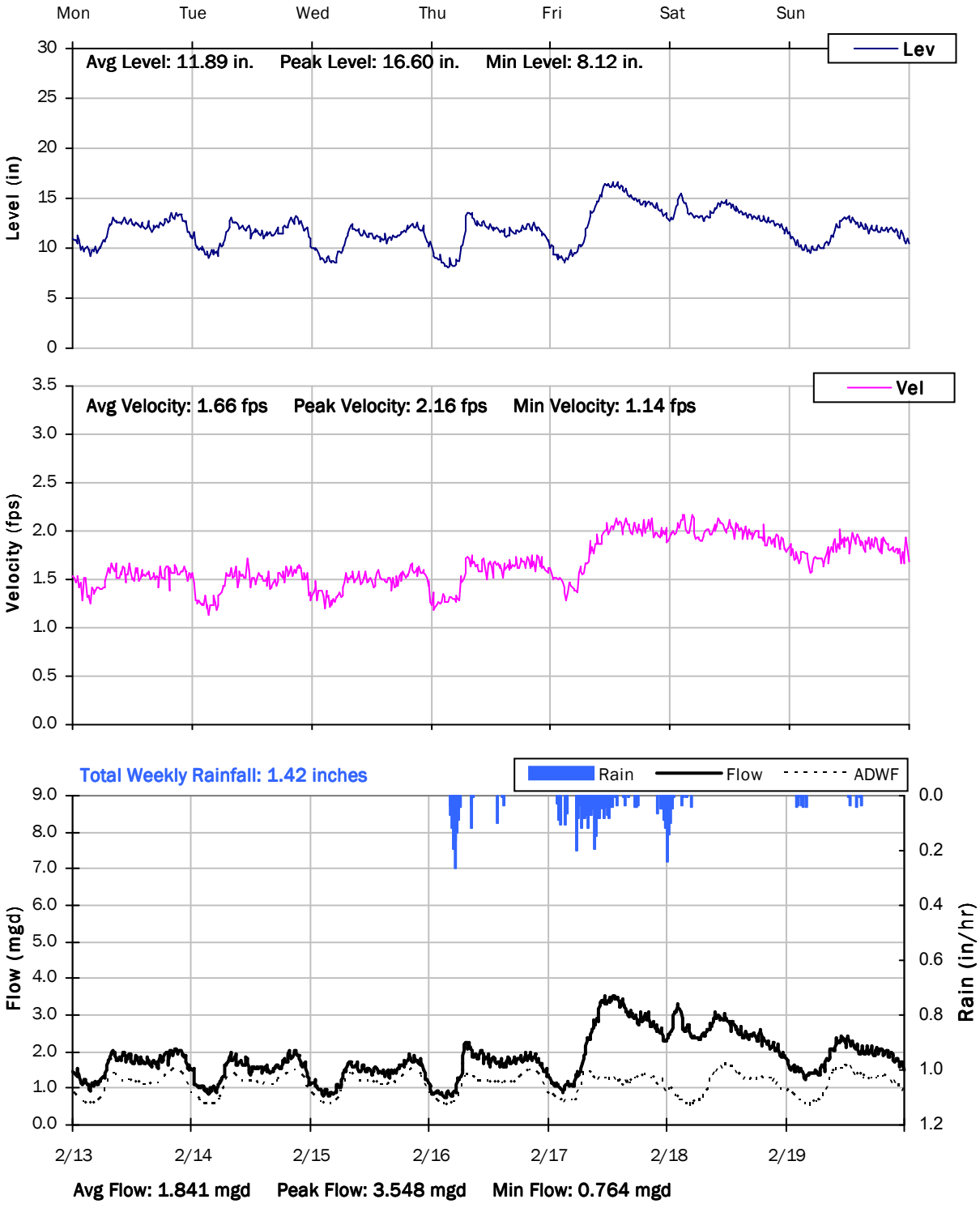
2/6/2017 to 2/13/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

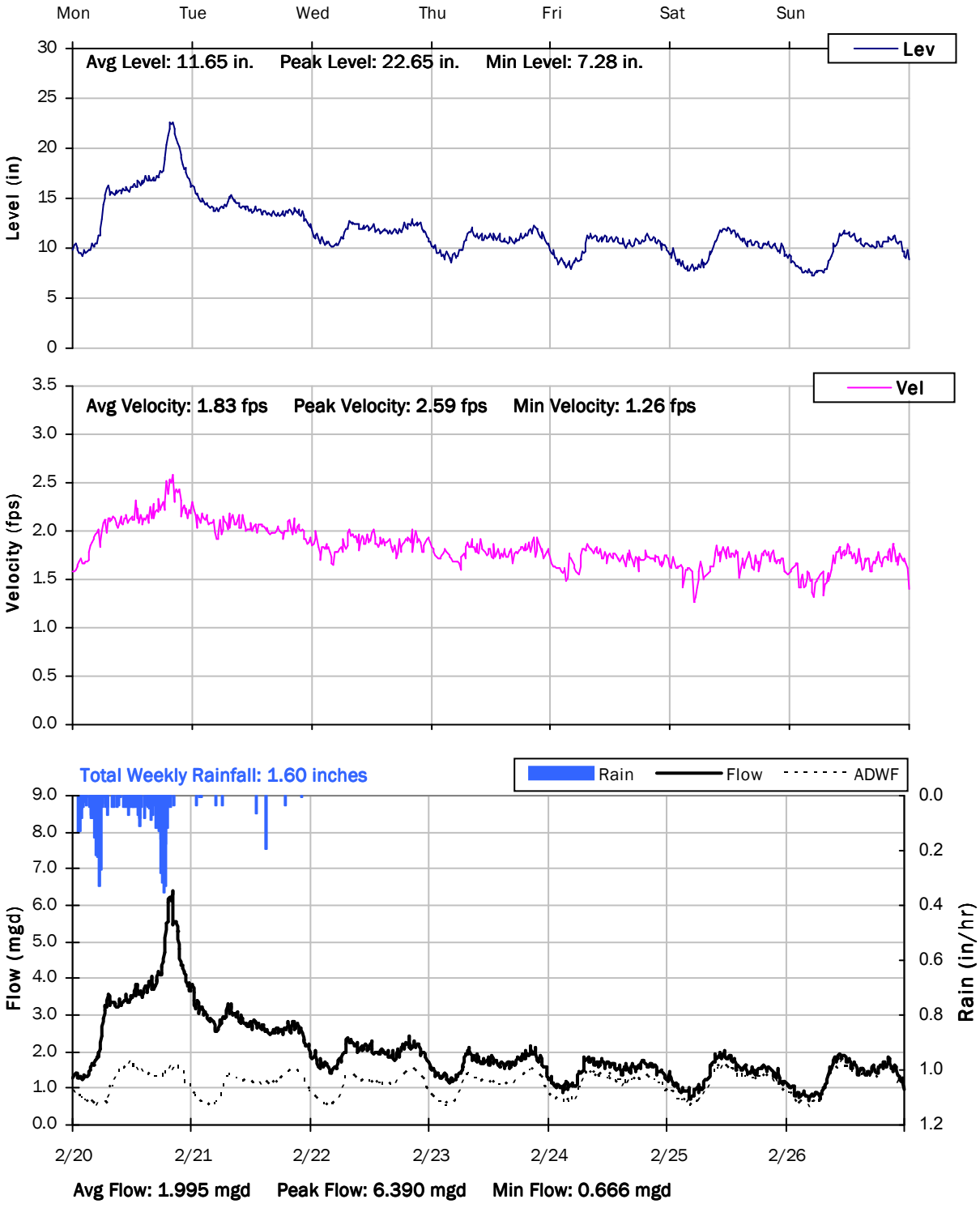
2/13/2017 to 2/20/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

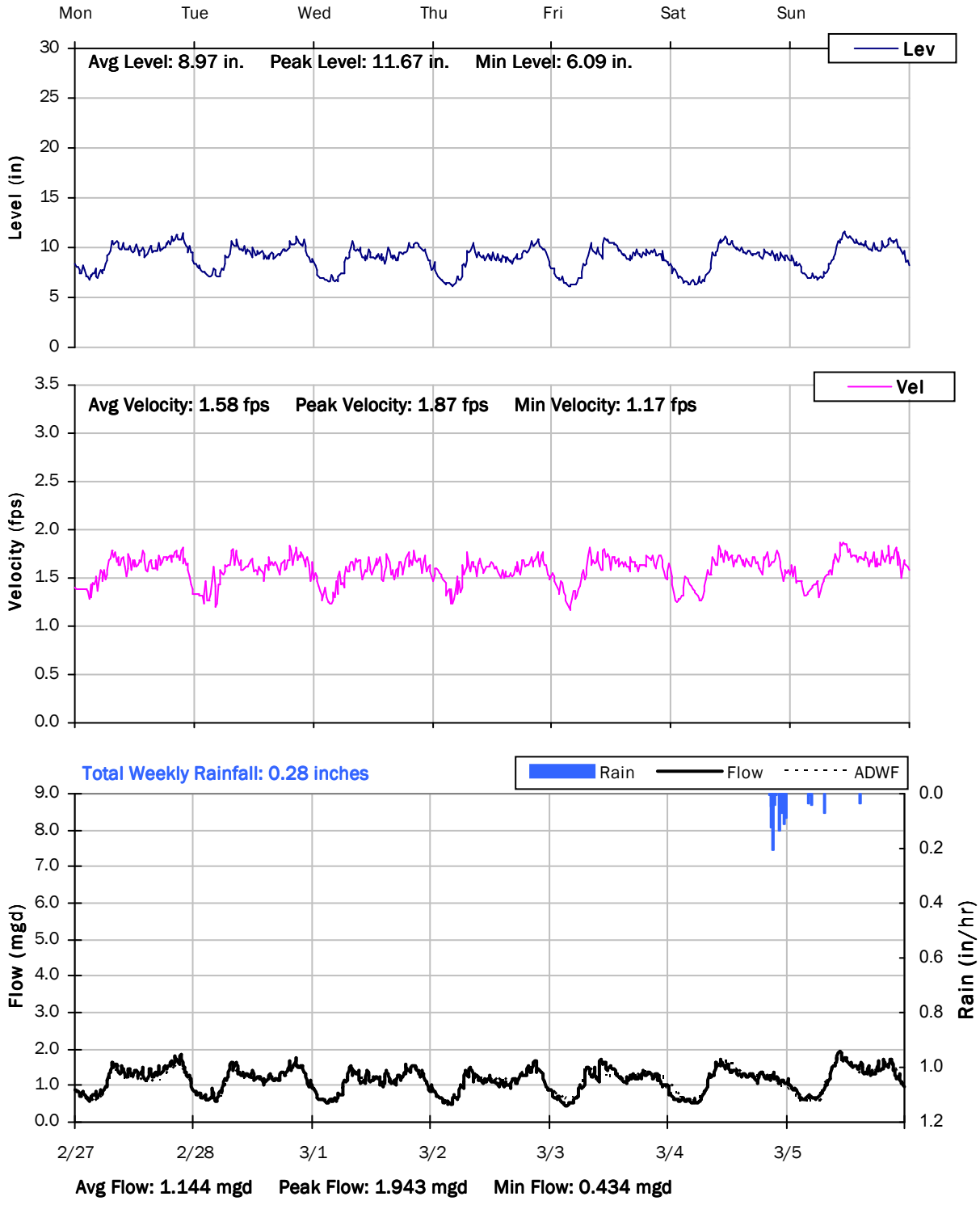
2/20/2017 to 2/27/2017



SITE 05

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



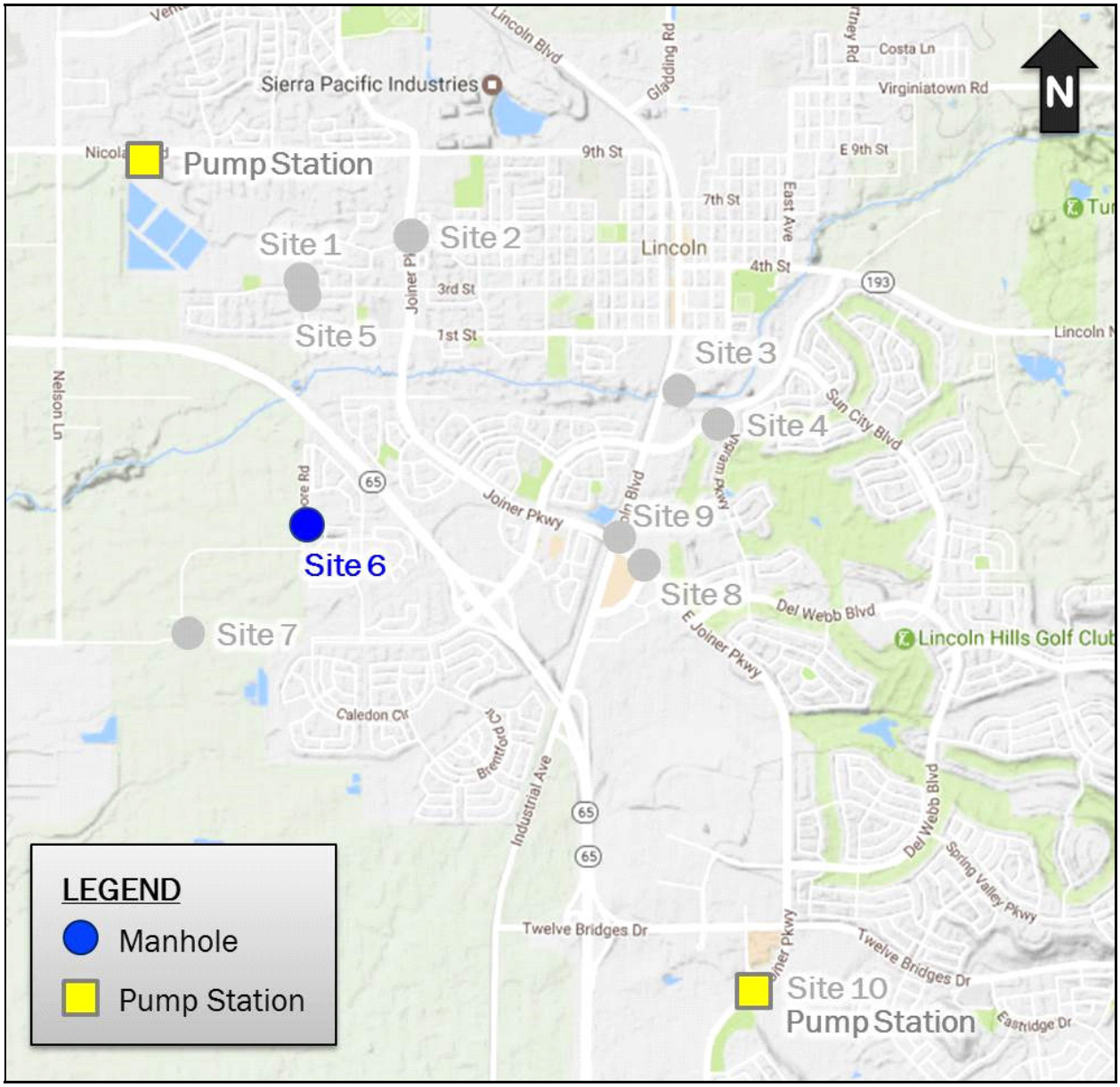
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 06

Location: Moore Road north of Sorrento Parkway

Data Summary Report



Vicinity Map: Site 06

SITE 06

Site Information

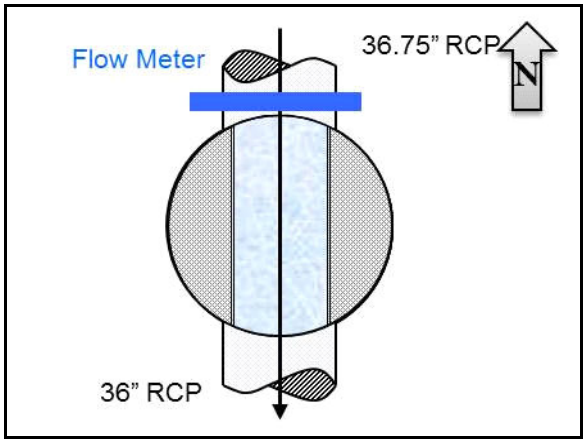
Location: Moore Road north of Sorrento Parkway

District ID: SW359SS001

Coordinates:	121.3215° W, 38.8753° N
Expected Pipe Diameter (Orig. if Relocated):	36 inches
Measured Pipe Diameter:	36.75 inches
ADWF:	1.298 mgd
Peak Measured Flow:	8.781 mgd
Rim Elevation (GEarth):	139 feet

Satellite Map

Sewer Map



Flow Sketch

Street View

Plan View

SITE 06

Additional Site Photos

Effluent Pipe

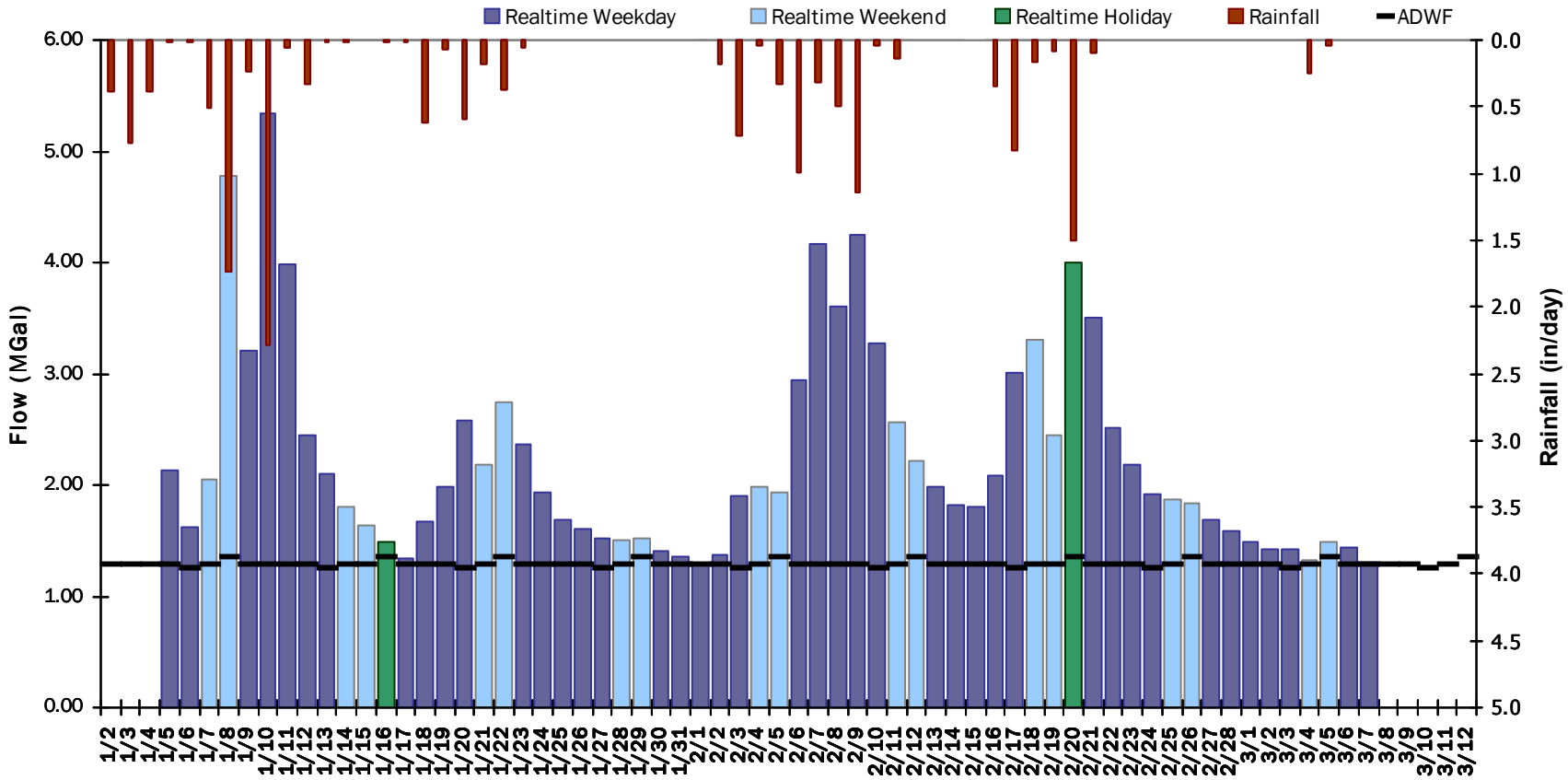
Influent Pipe

SITE 06

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 2.240 MGal Peak Daily Flow: 5.345 MGal Min Daily Flow: 1.293 MGal

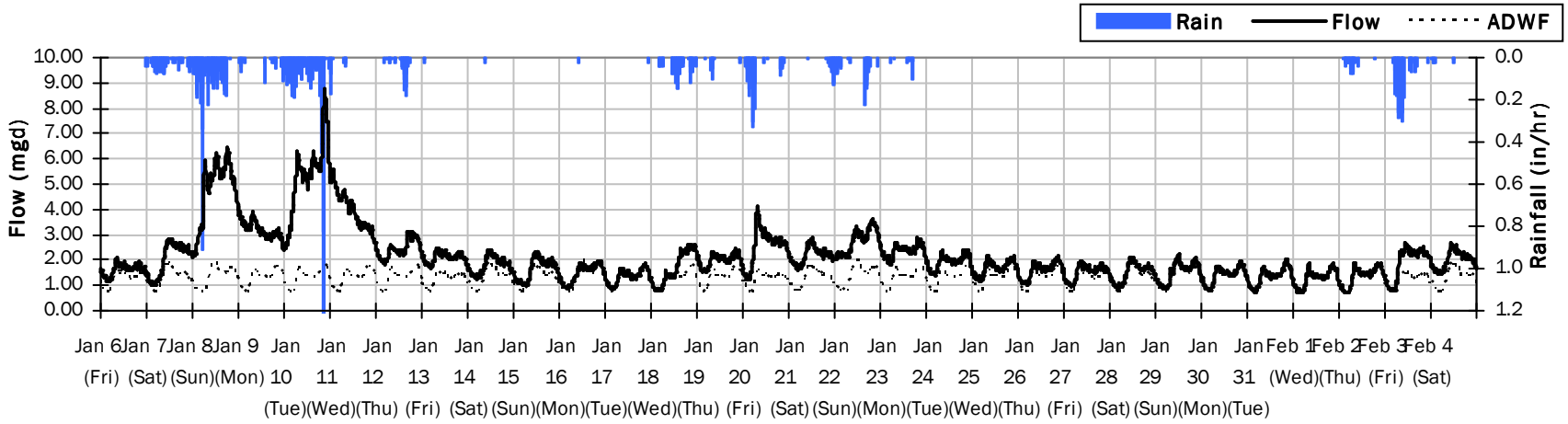
Total Period Rainfall: 16.32 inches

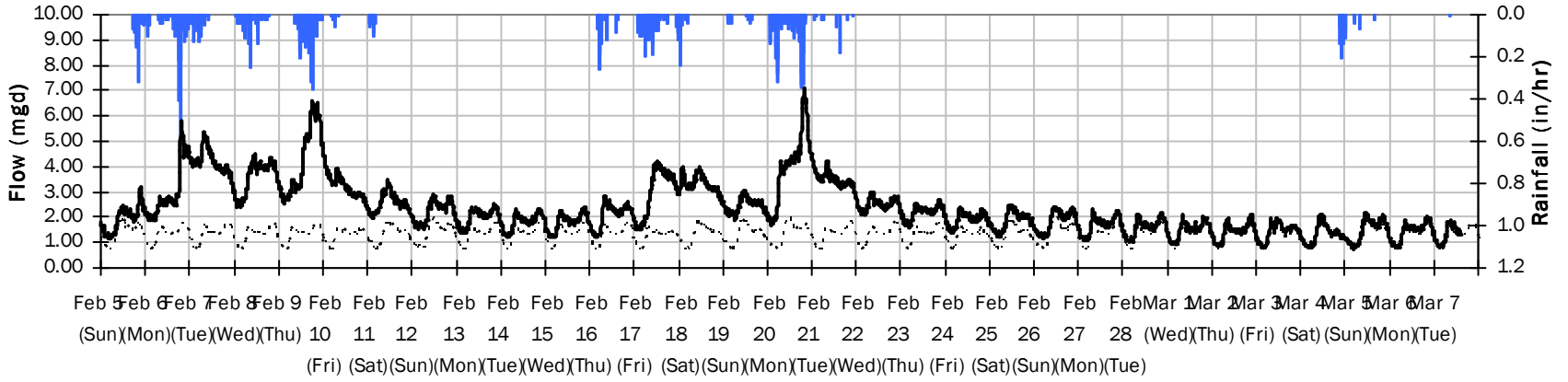


SITE 06

Flow Summary: 1/6/2017 to 3/7/2017

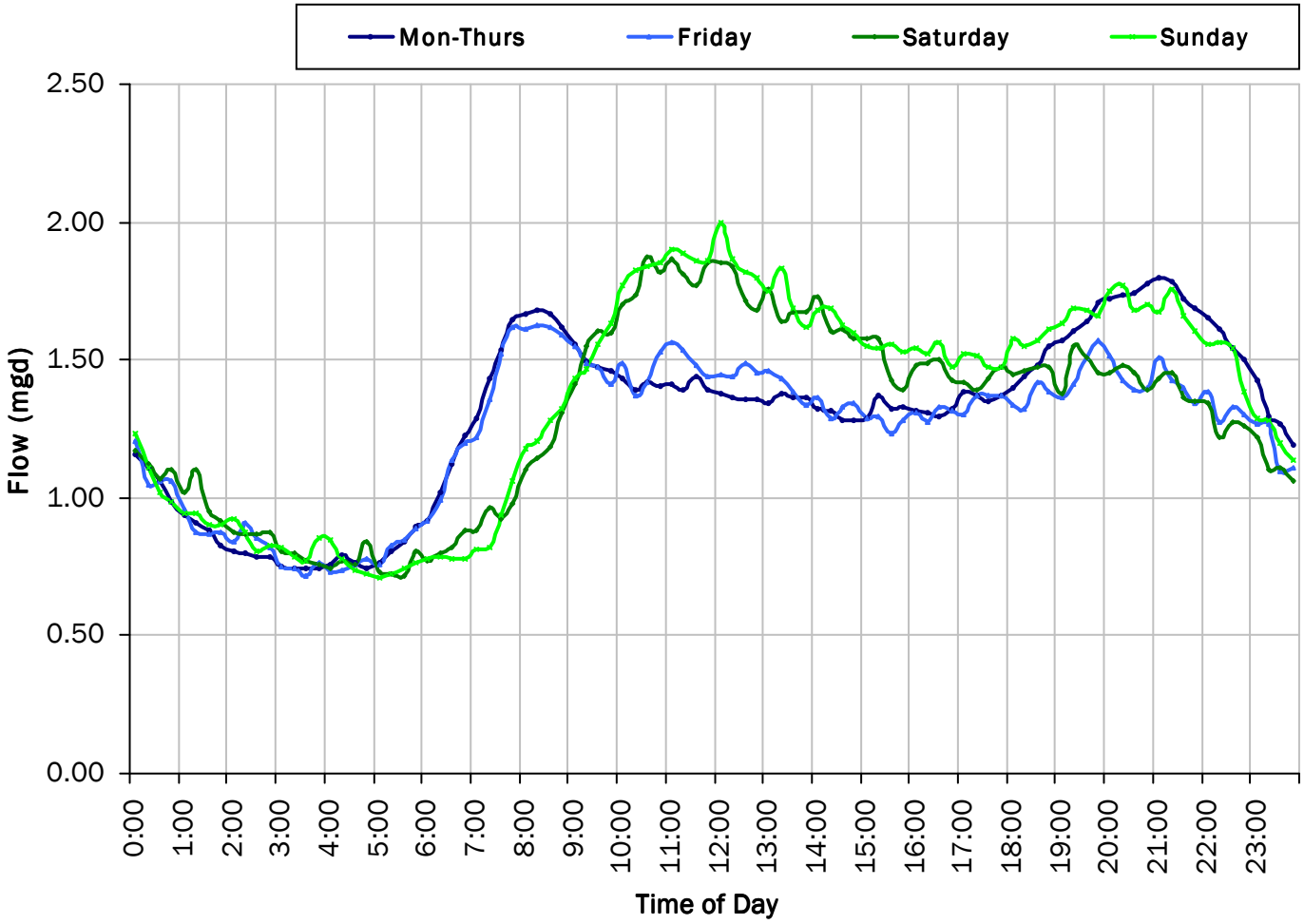
Total Period Rainfall: 14.78 inches **Avg Flow: 2.248 mgd** **Peak Flow: 8.781 mgd** **Min Flow: 0.715 mgd**





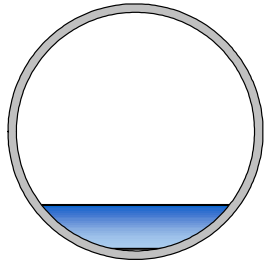
SITE 06

Average Dry Weather Flow Hydrographs



ADWF:

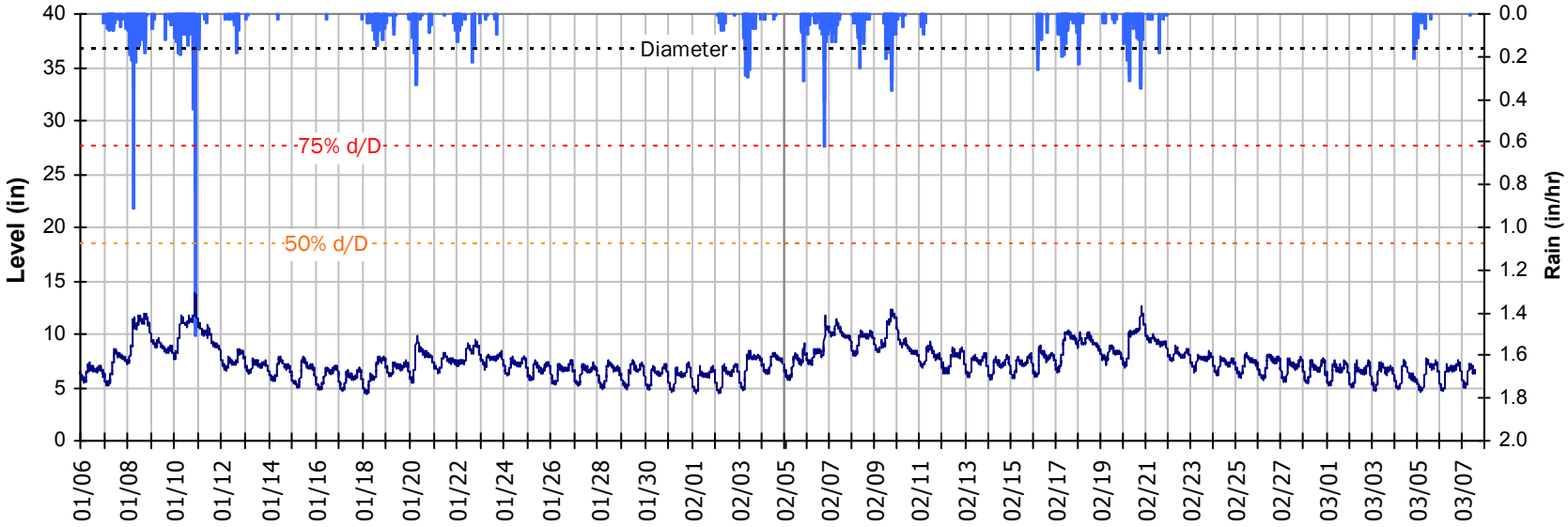
1.298 *mgd*

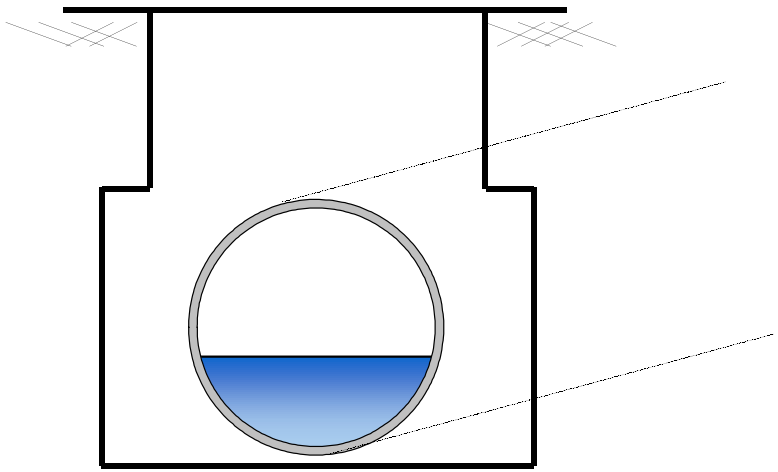


SITE 06

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period

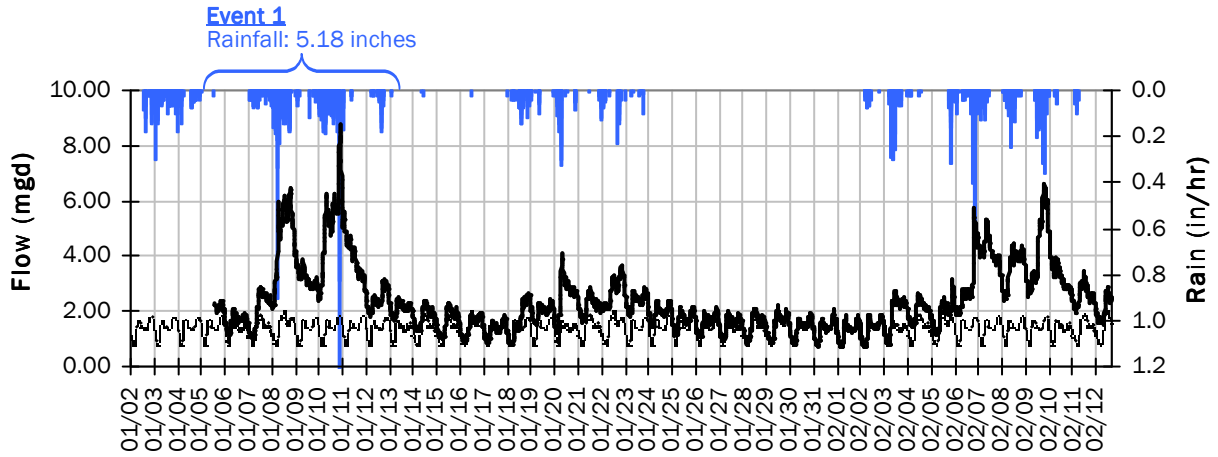




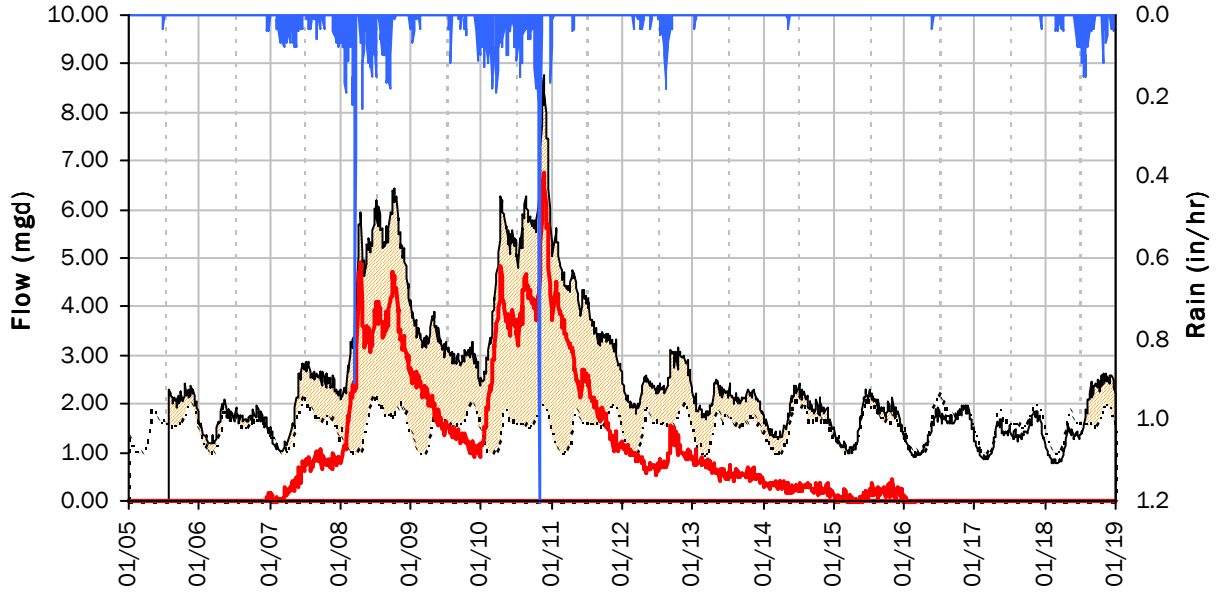
Pipe Diameter:	36.8	*inches*
Peak Measured Level:	13.9	*inches*
Peak d/D Ratio:	0.38	

SITE 06
I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

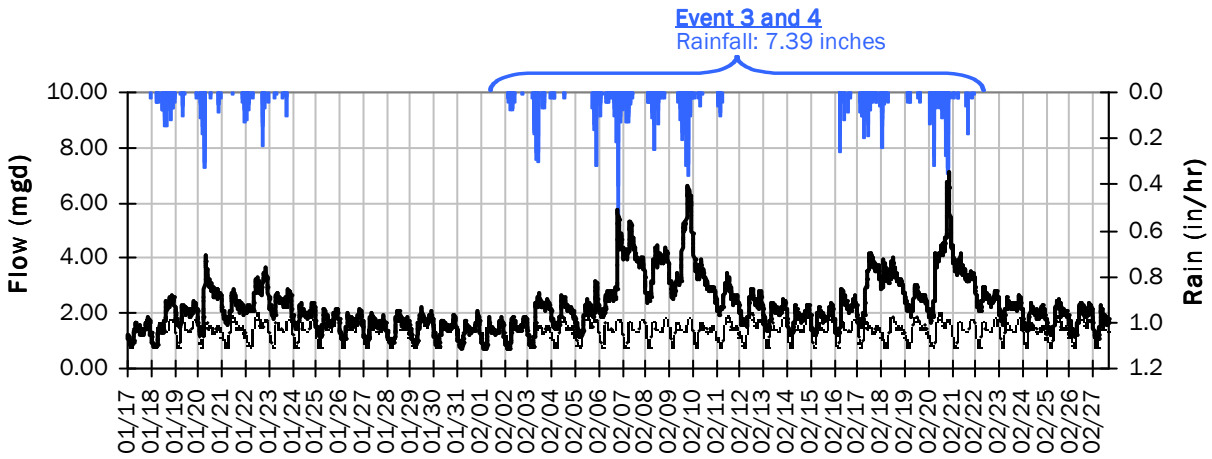


Storm Event I/I Analysis (Rain = 5.18 inches)

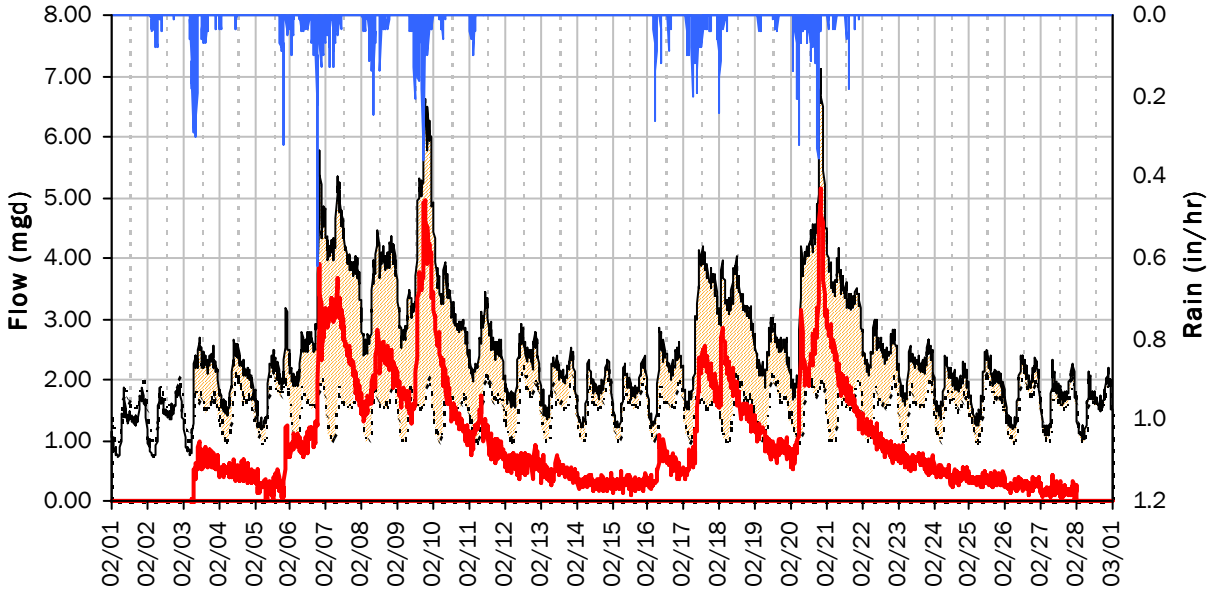
Capacity		Inflow / Infiltration	
Peak Flow:	8.78 *mgd*	**Peak I/I Rate:**	6.77 *mgd*
PF:	6.77	**Total I/I:**	13,619,000 *gallons*
Peak Level:	13.88 *in*		
d/D Ratio:	0.38		

SITE 06
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



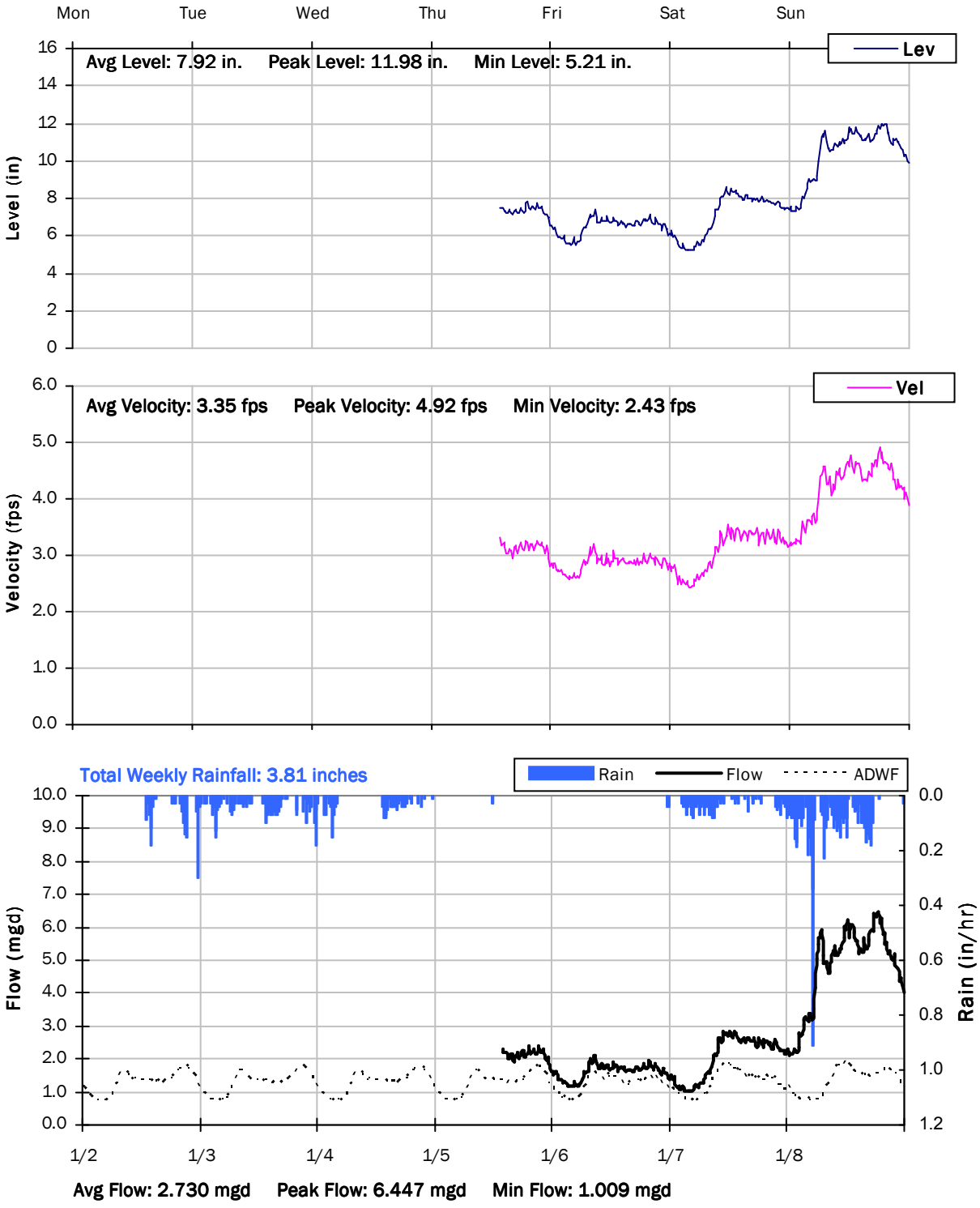
Storm Event I/I Analysis (Rain = 7.39 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	7.13 *mgd*	**Peak I/I Rate:**	5.16 *mgd*
PF:	5.49	**Total I/I:**	26,741,000 *gallons*
Peak Level:	12.60 *in*		
d/D Ratio:	0.34		

SITE 06

Weekly Level, Velocity and Flow Hydrographs

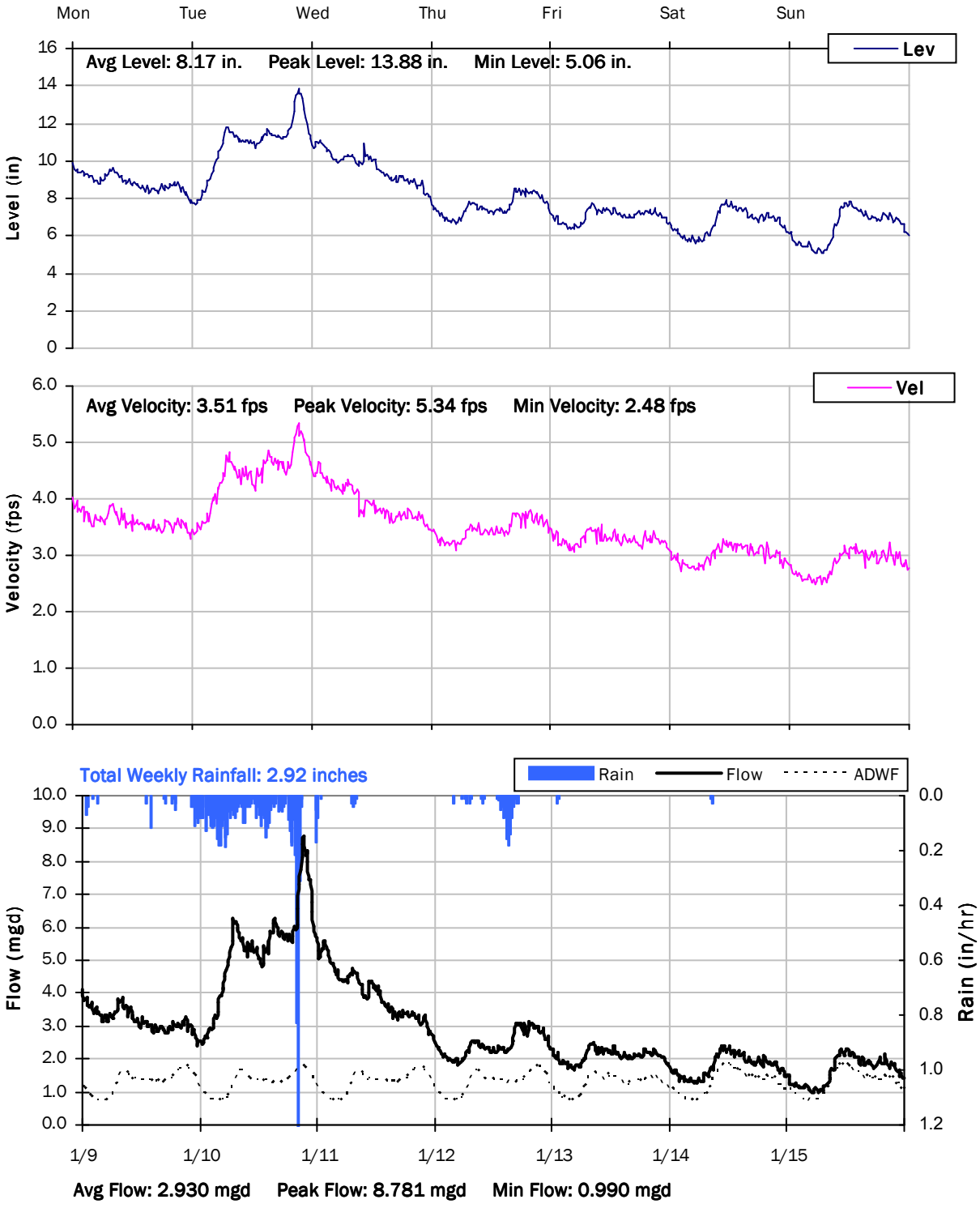
1/2/2017 to 1/9/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

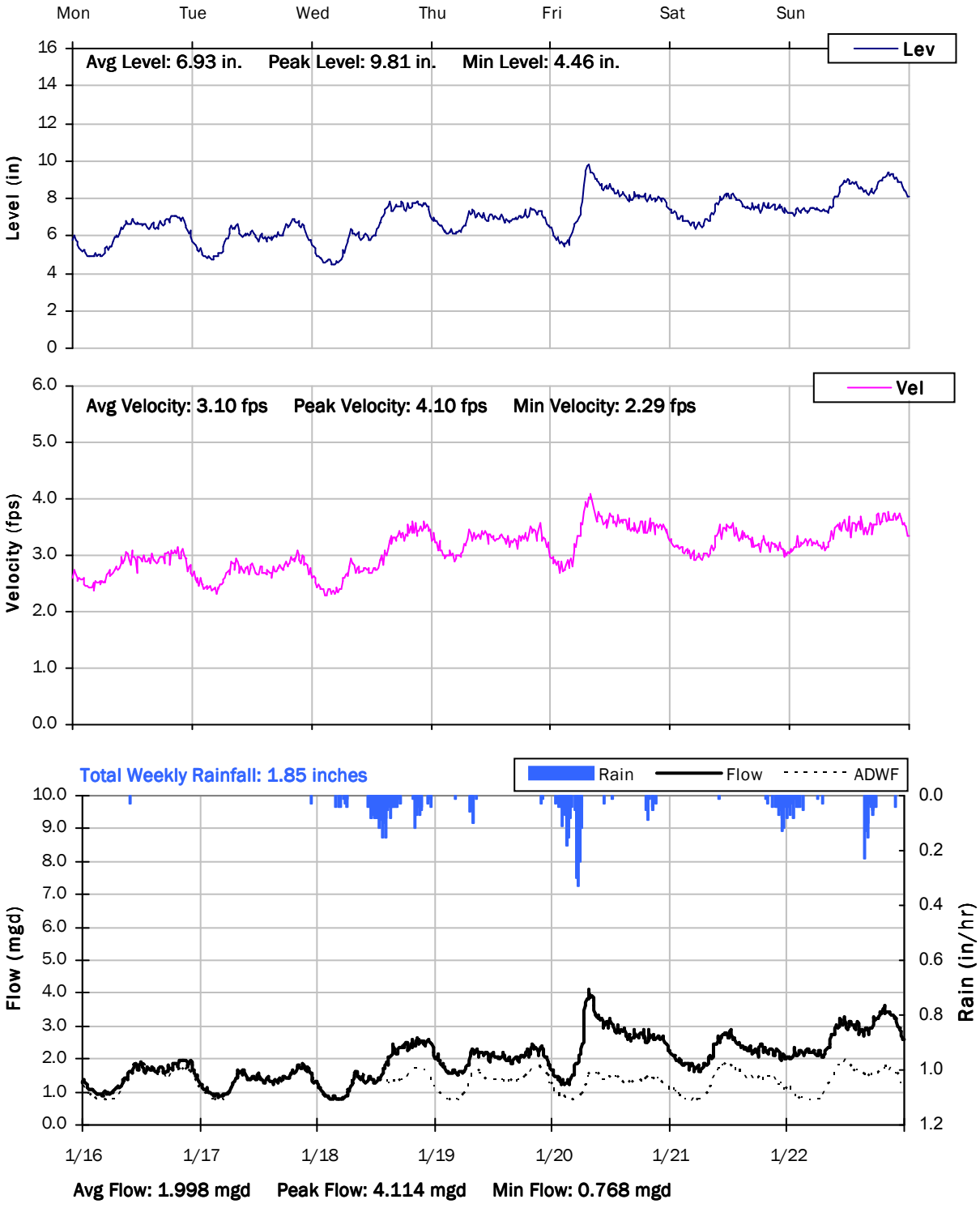
1/9/2017 to 1/16/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

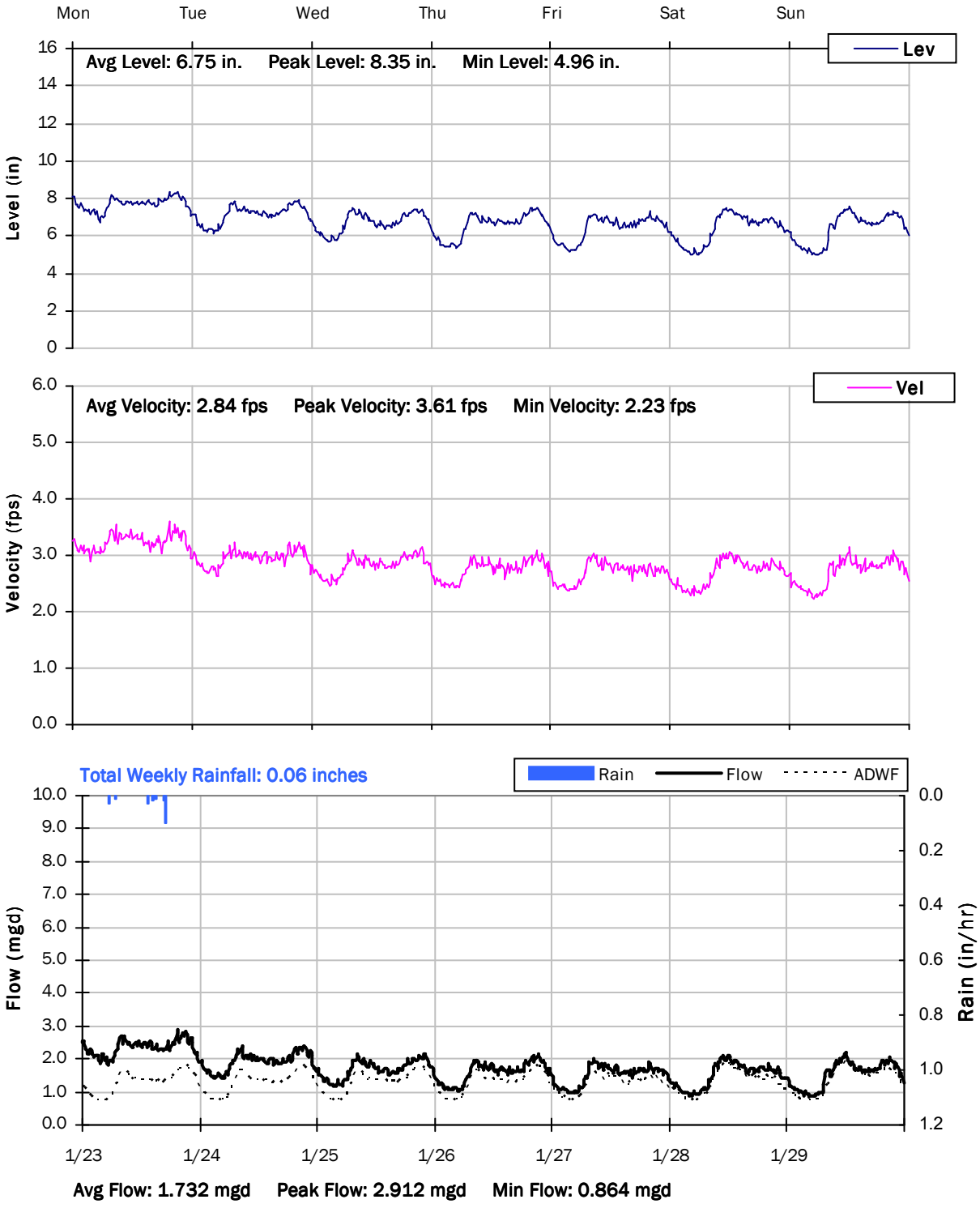
1/16/2017 to 1/23/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

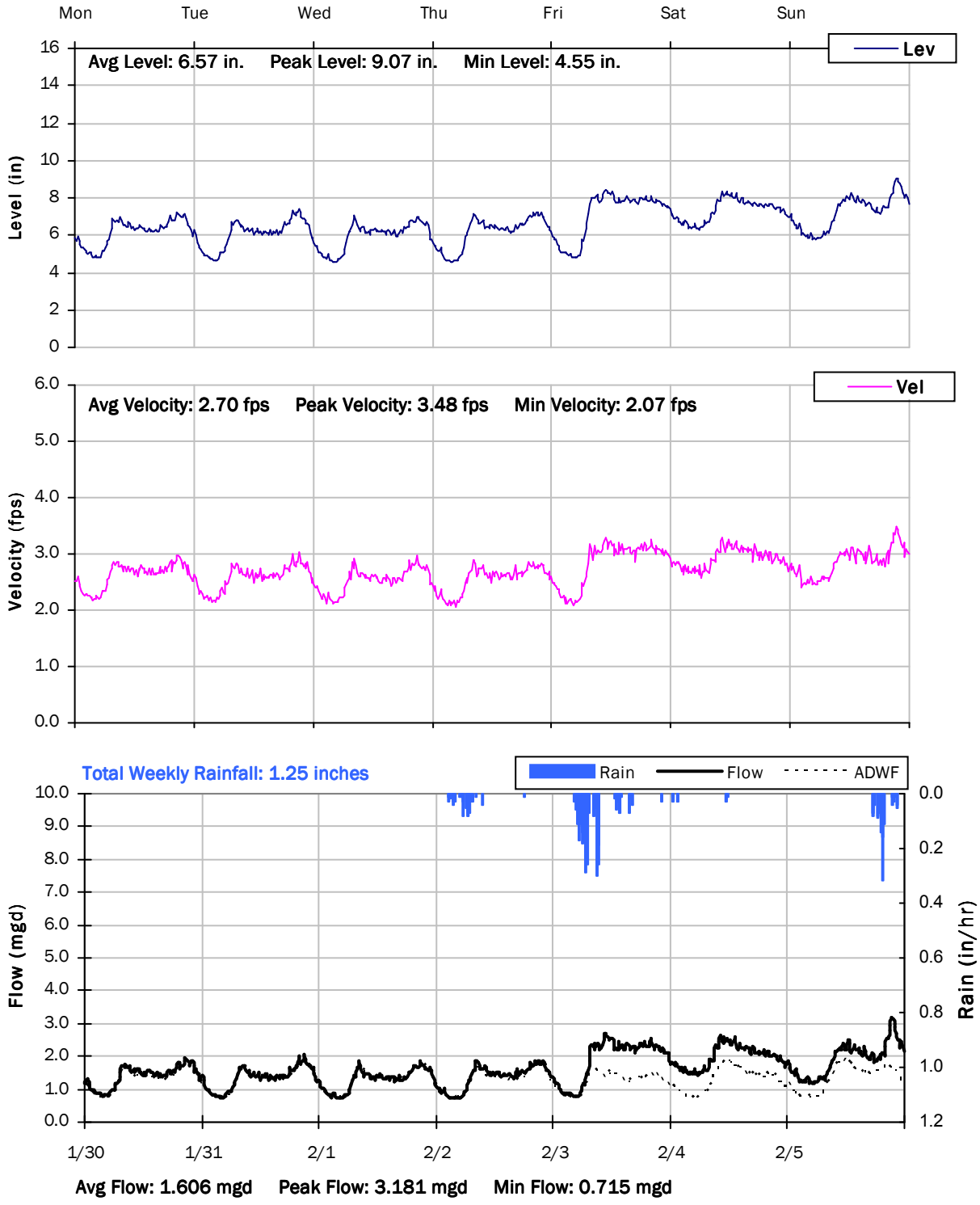
1/23/2017 to 1/30/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

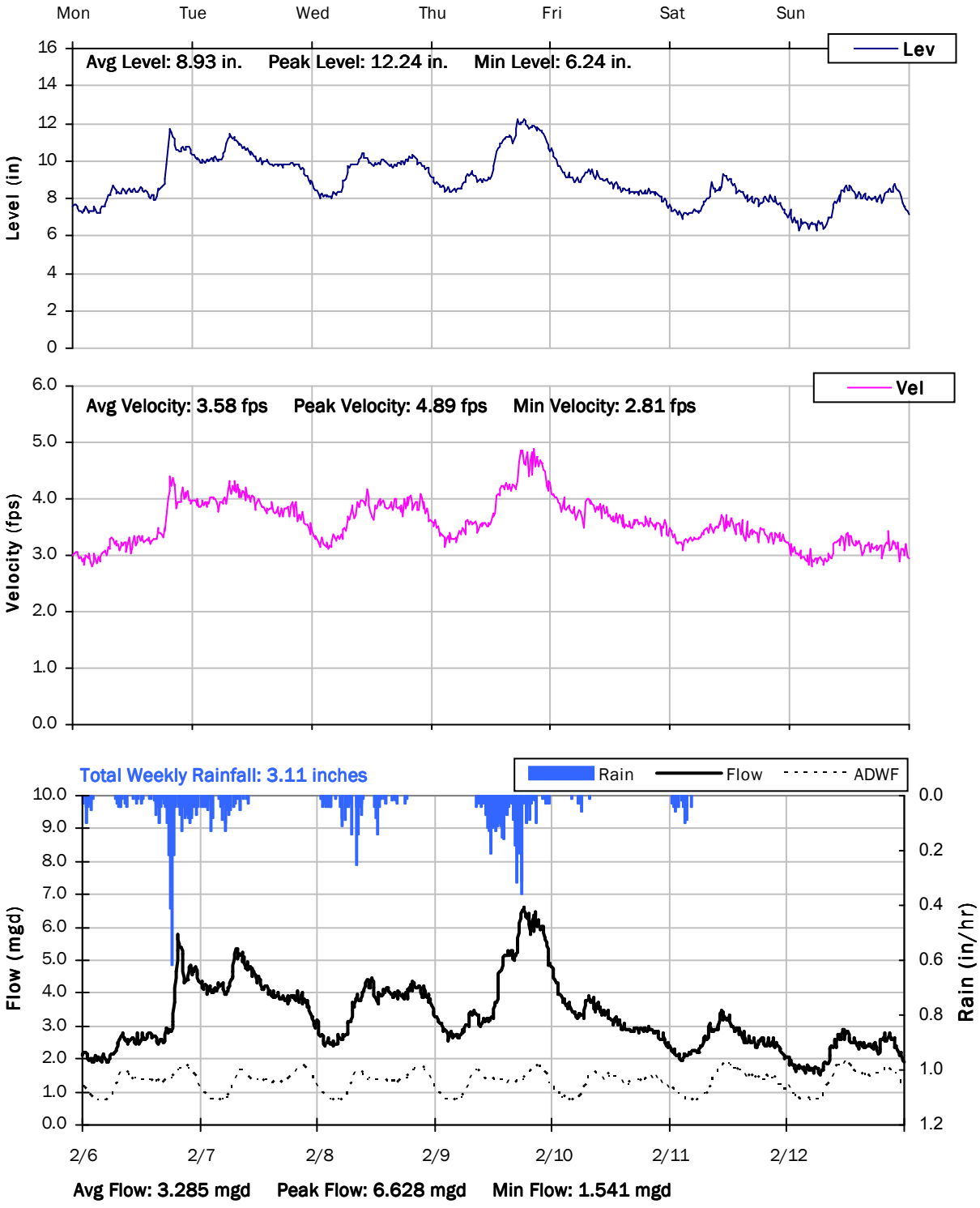
1/30/2017 to 2/6/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

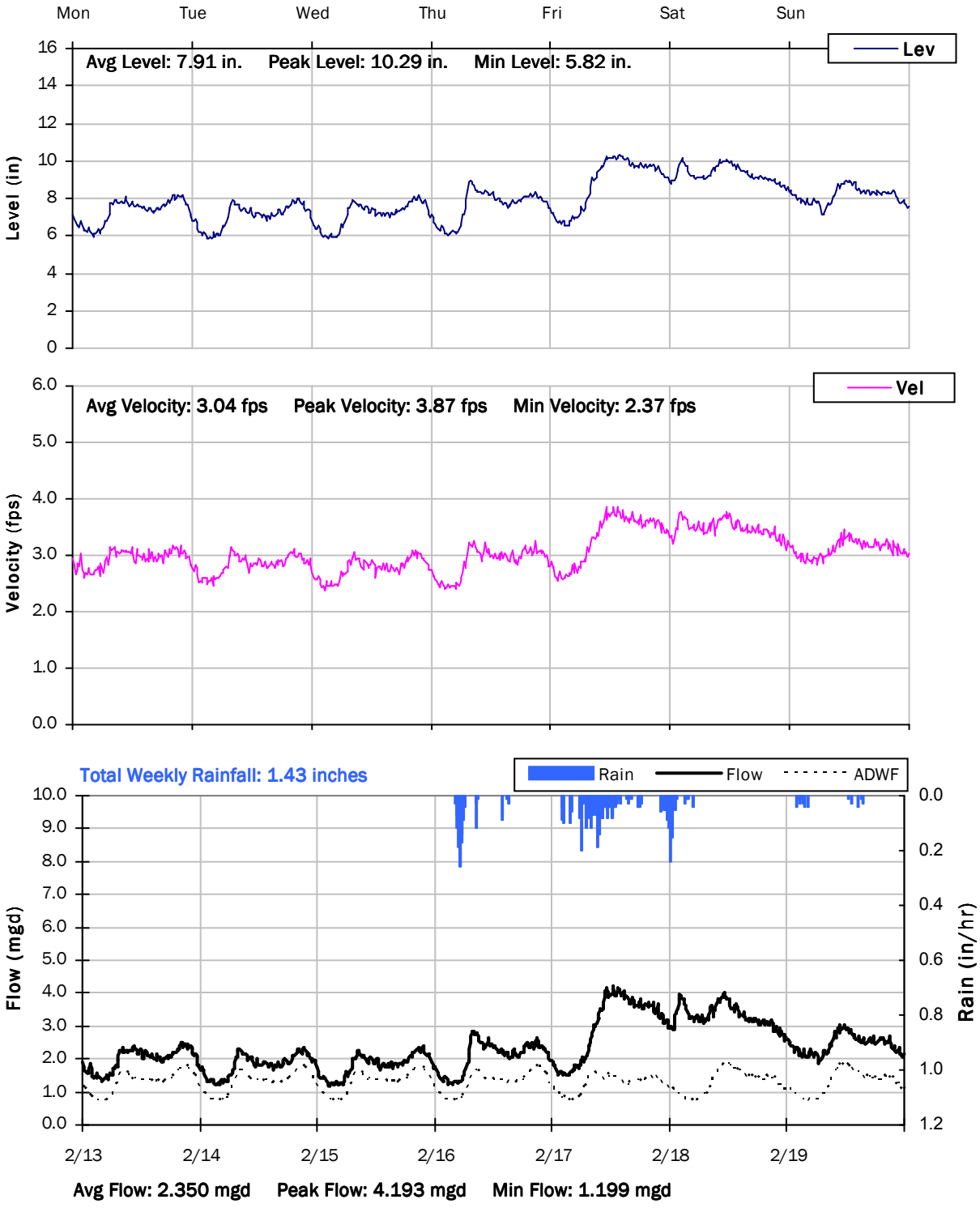
2/6/2017 to 2/13/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

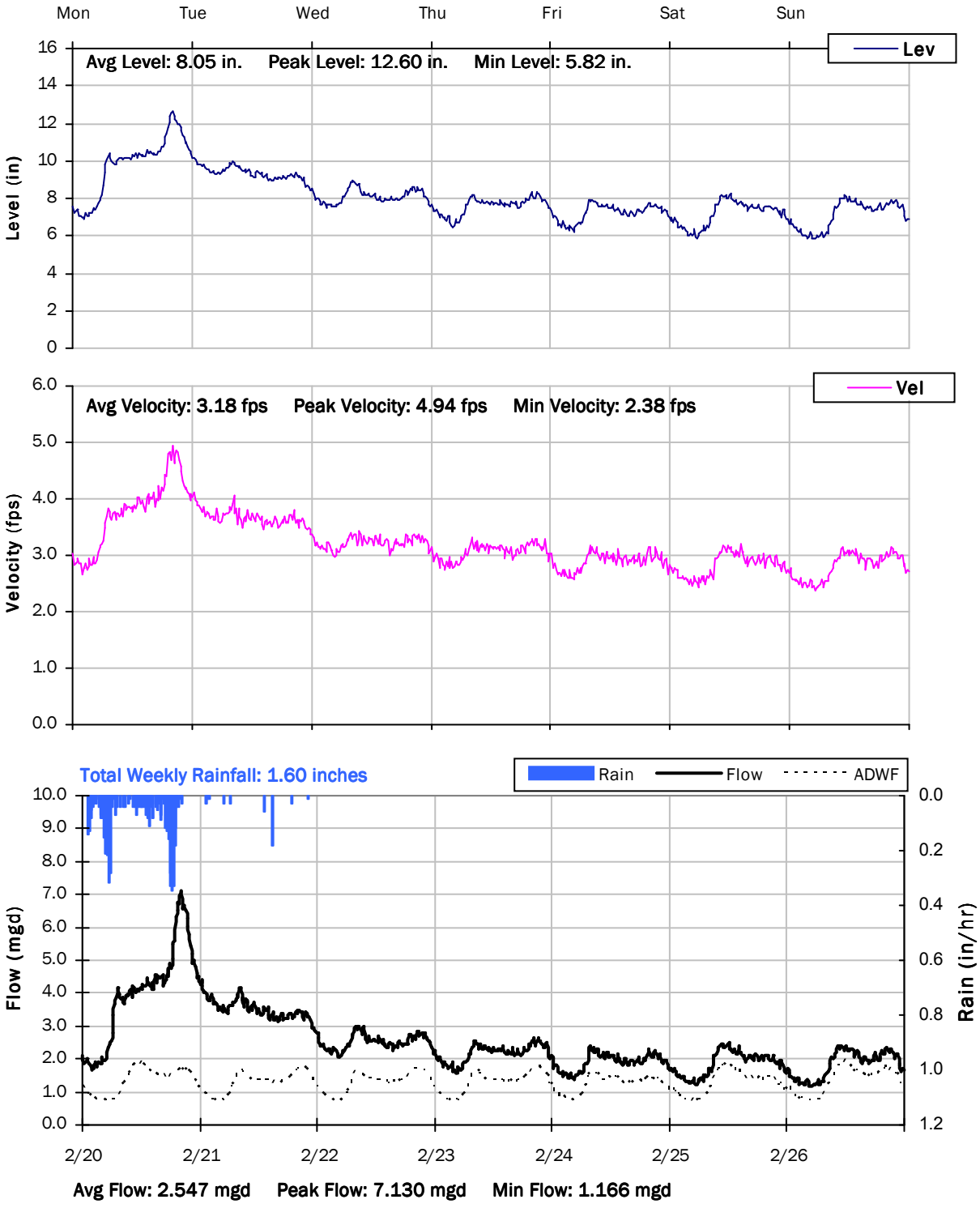
2/13/2017 to 2/20/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

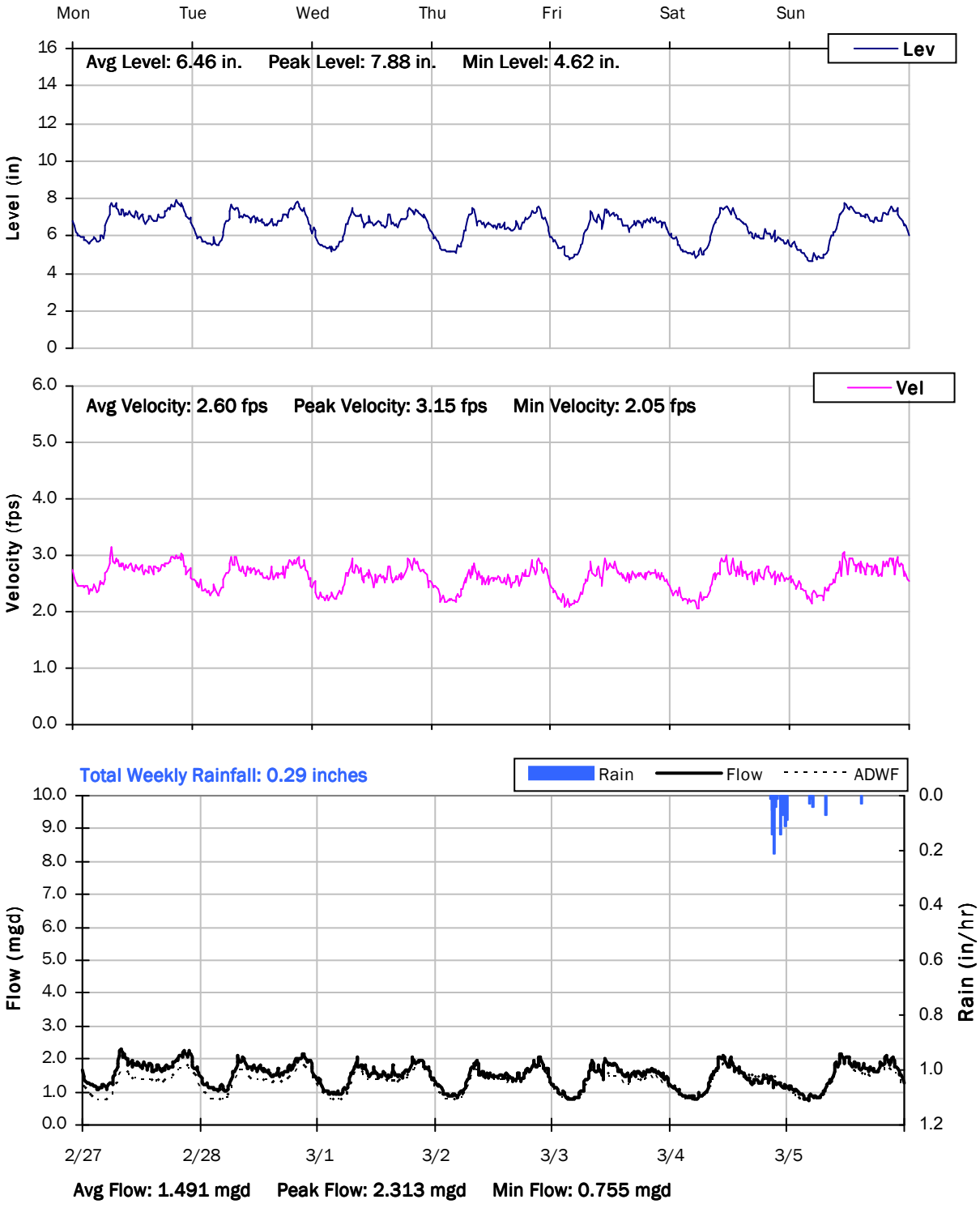
2/20/2017 to 2/27/2017



SITE 06

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



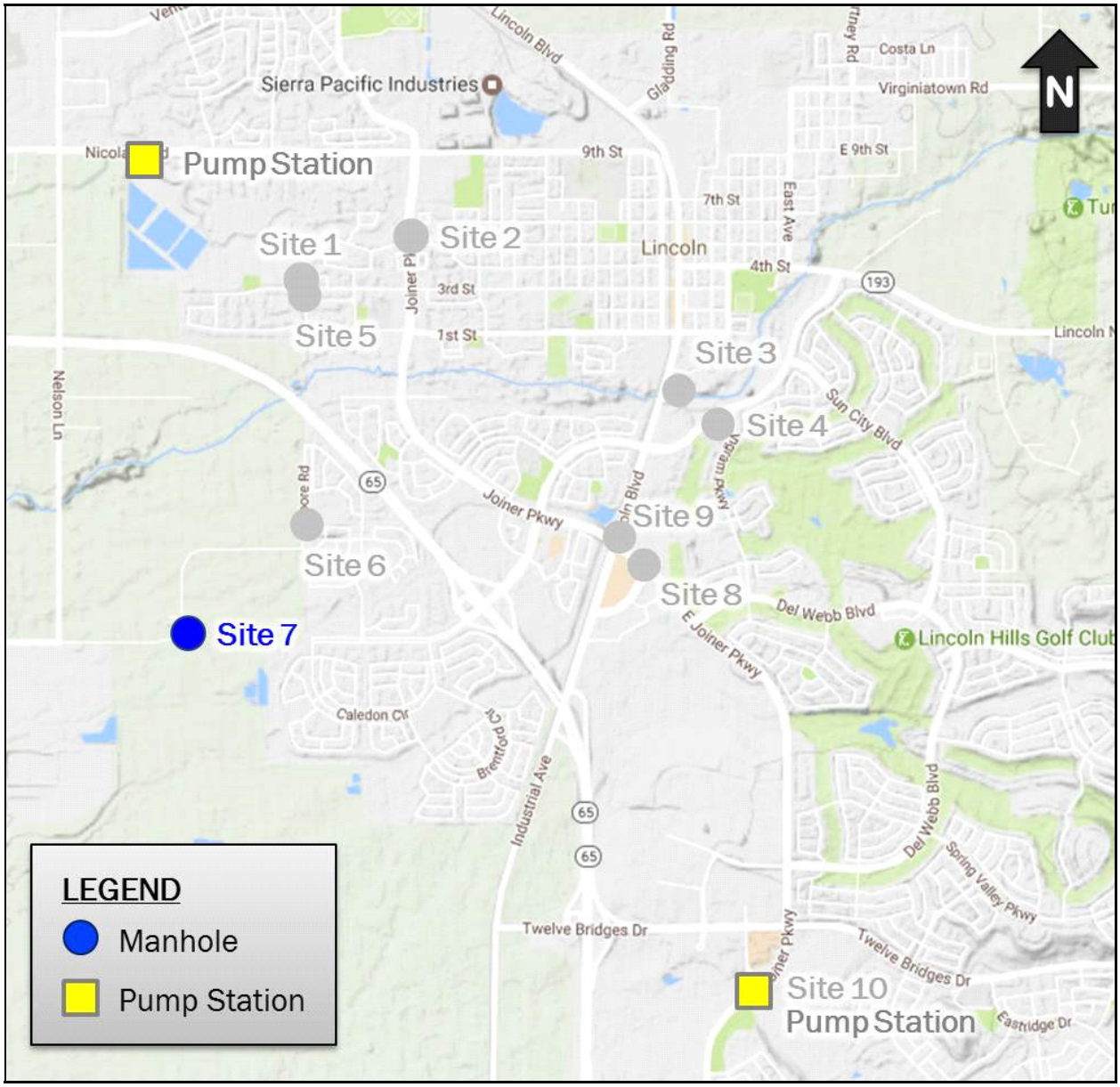
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 07

Location: In field near 2675 Moore Road

Data Summary Report



Vicinity Map: Site 07

SITE 07

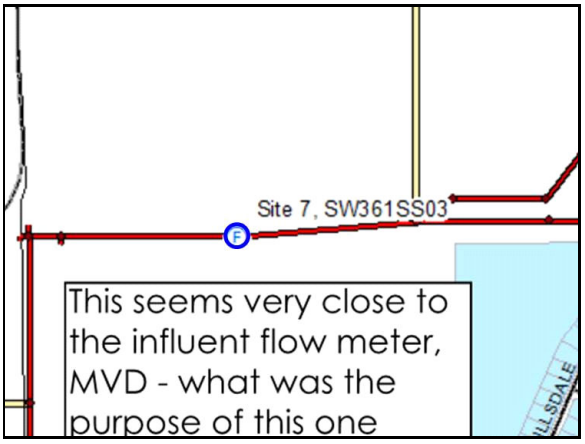
Site Information

Location: In field near 2675 Moore Road

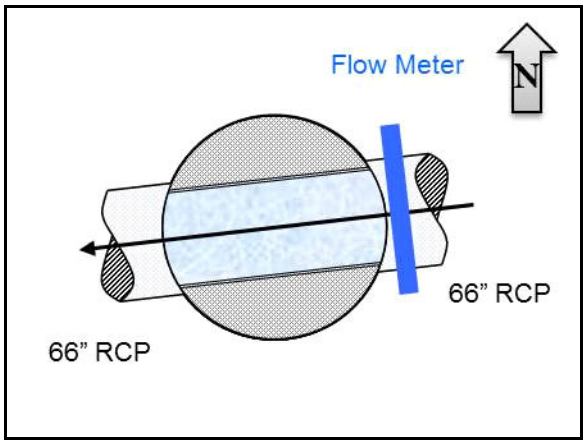
District ID: SW361SS02

Coordinates:	121.3301° W, 38.8682° N
Expected Pipe Diameter (Orig. if Relocated):	66 inches
Measured Pipe Diameter:	66 inches
ADWF:	5.681 mgd
Peak Measured Flow:	39.755 mgd
Rim Elevation (GEarth):	131 feet

Satellite Map



Sewer Map



Flow Sketch

Street View

Plan View

SITE 07

Additional Site Photos

Effluent Pipe

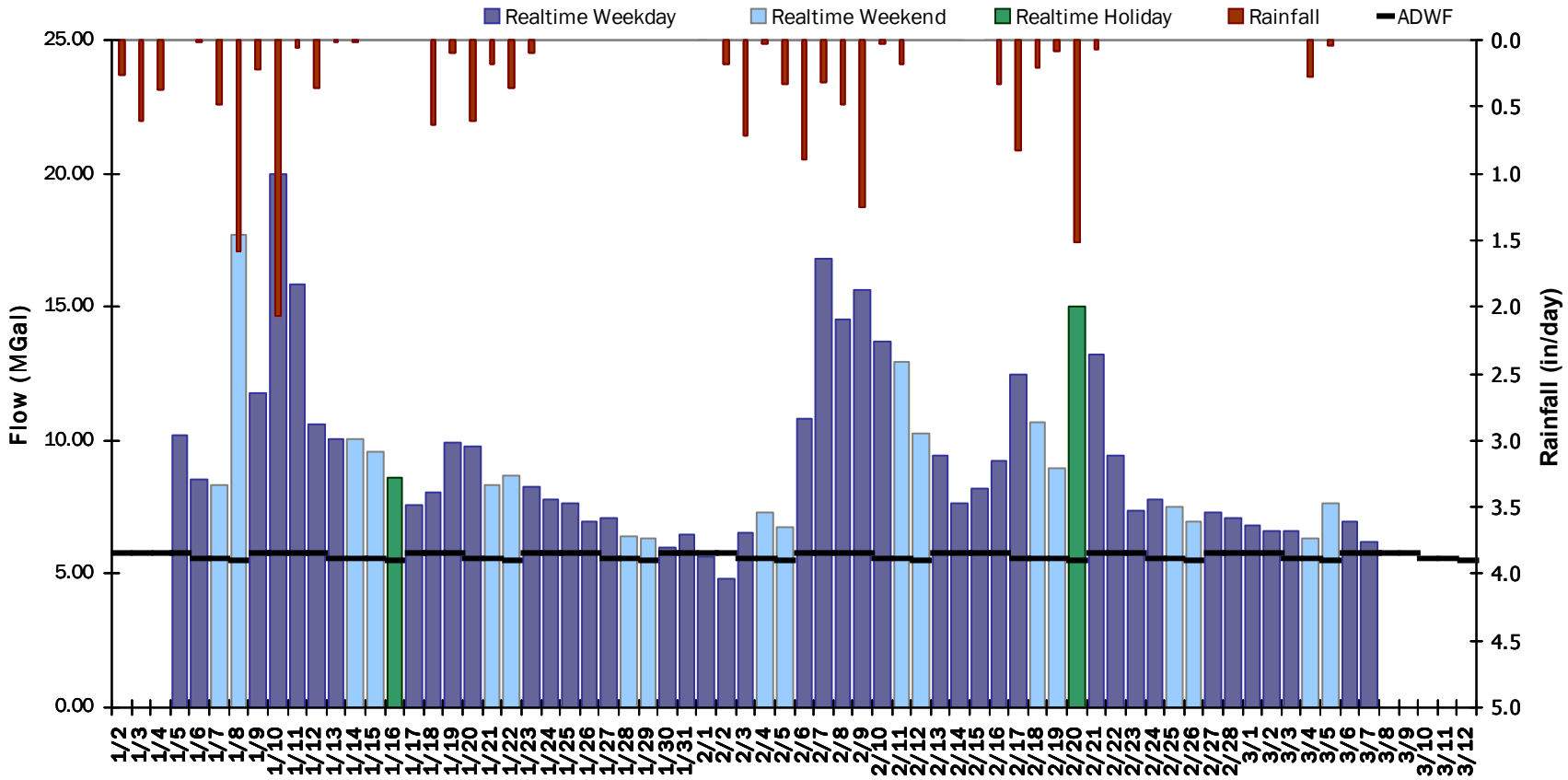
Influent Pipe

SITE 07

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 9.314 MGal Peak Daily Flow: 19.959 MGal Min Daily Flow: 4.793 MGal

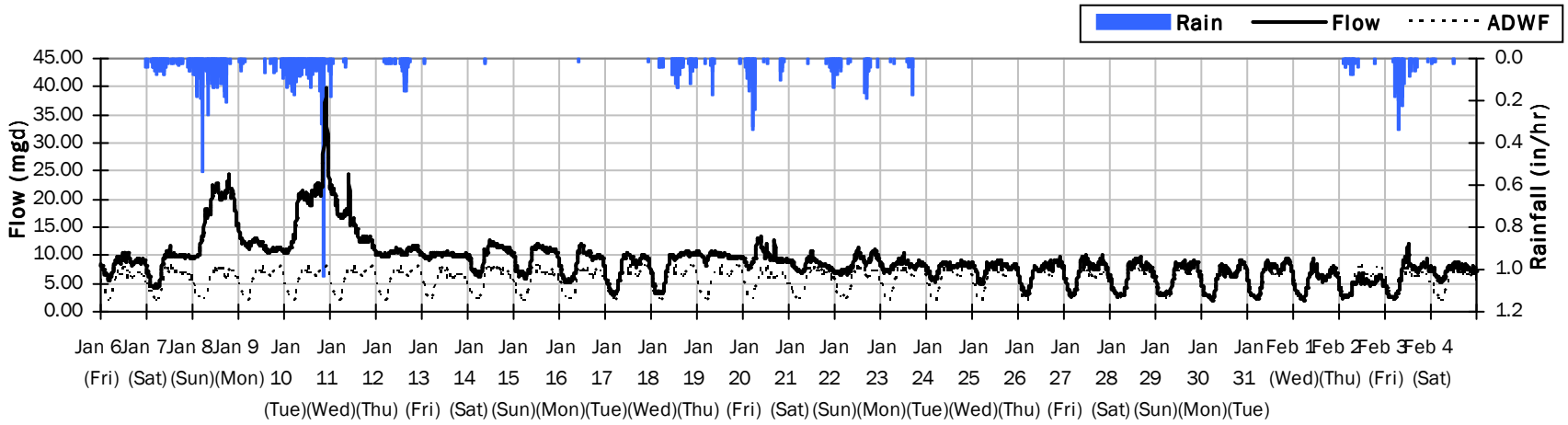
Total Period Rainfall: 15.78 inches

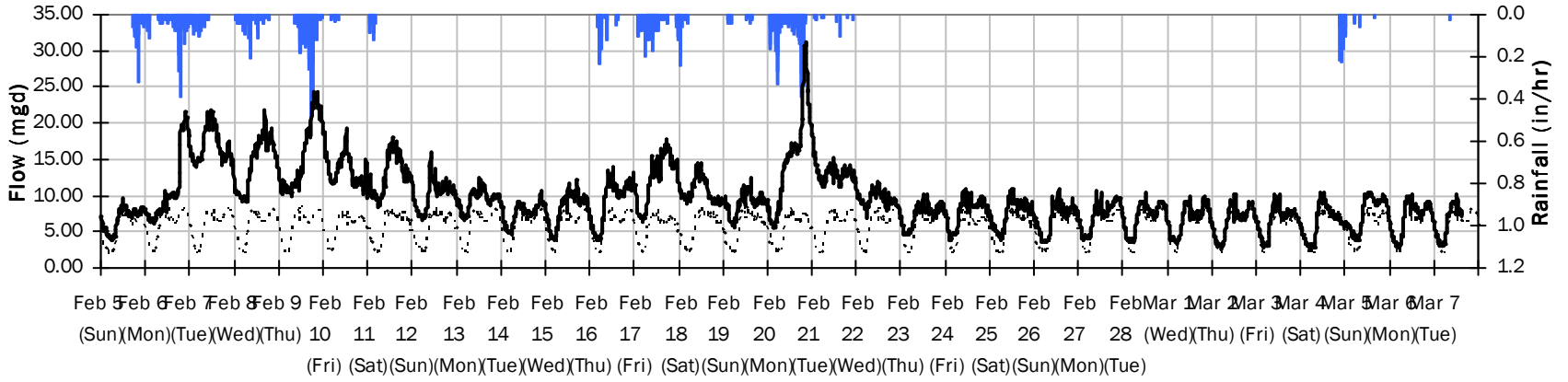


SITE 07

Flow Summary: 1/6/2017 to 3/7/2017

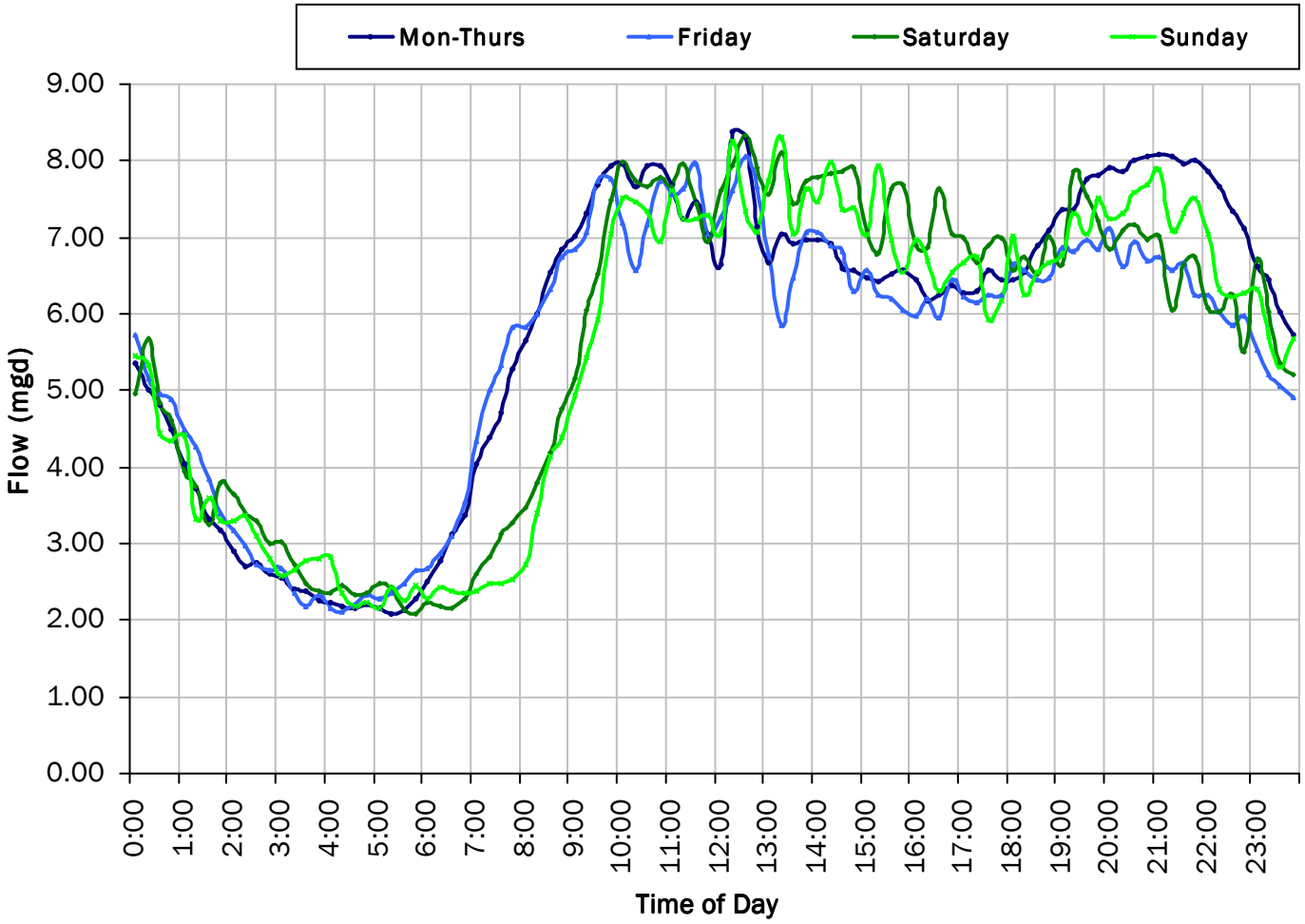
Total Period Rainfall: 14.53 inches **Avg Flow: 9.317 mgd** **Peak Flow: 39.755 mgd** **Min Flow: 1.879 mgd**





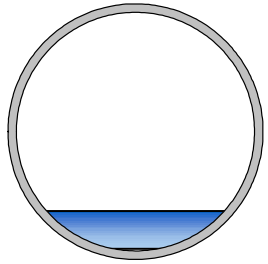
SITE 07

Average Dry Weather Flow Hydrographs



ADWF:

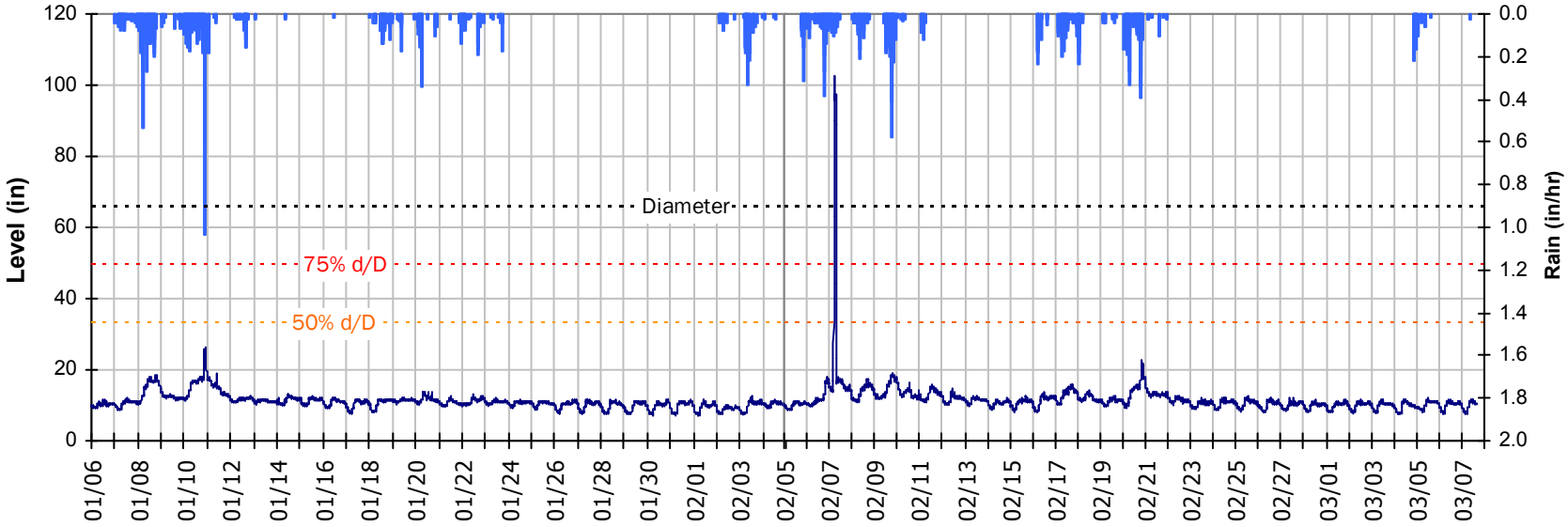
5.681 *mgd*

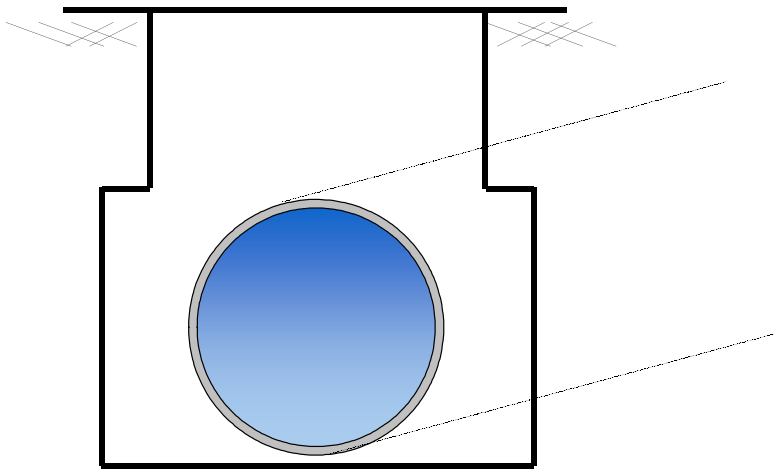


SITE 07

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period



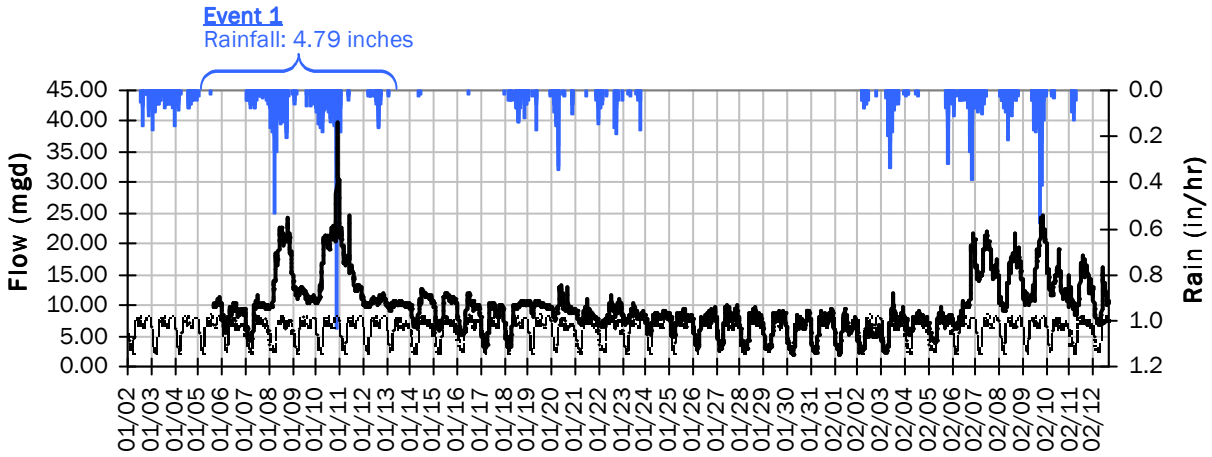


Pipe Diameter:	66	*inches*
Peak Measured Level:	103	*inches*
Peak d/D Ratio:	1.56	

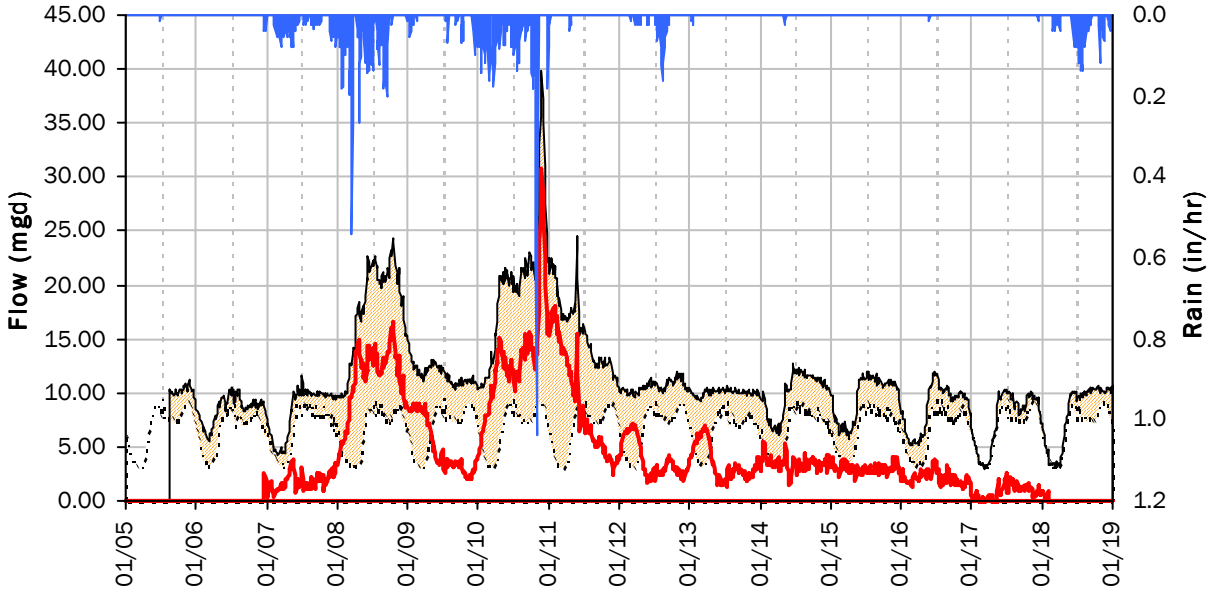
Surcharged 36.8 inches over crown

SITE 07
I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

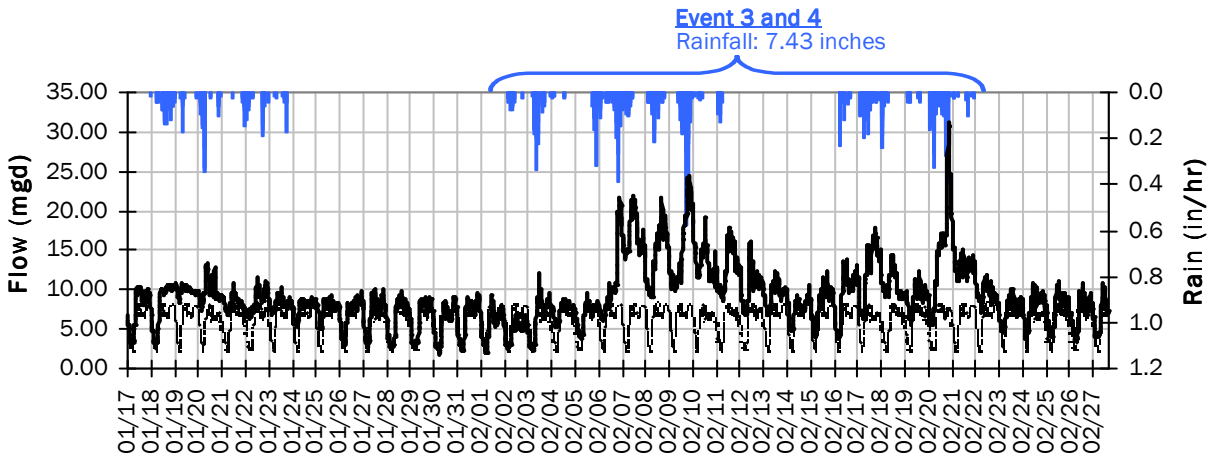


Storm Event I/I Analysis (Rain = 4.79 inches)

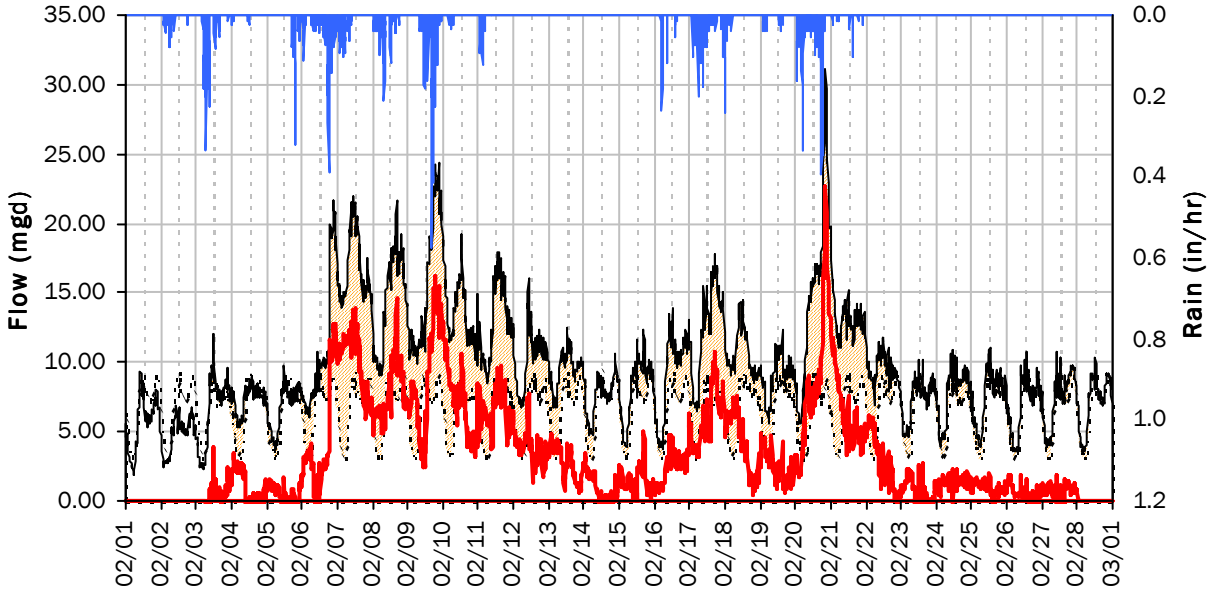
Capacity		Inflow / Infiltration	
Peak Flow:	39.76 *mgd*	**Peak I/I Rate:**	30.80 *mgd*
PF:	7.00	**Total I/I:**	57,475,000 *gallons*
Peak Level:	26.30 *in*		
d/D Ratio:	0.40		

SITE 07
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



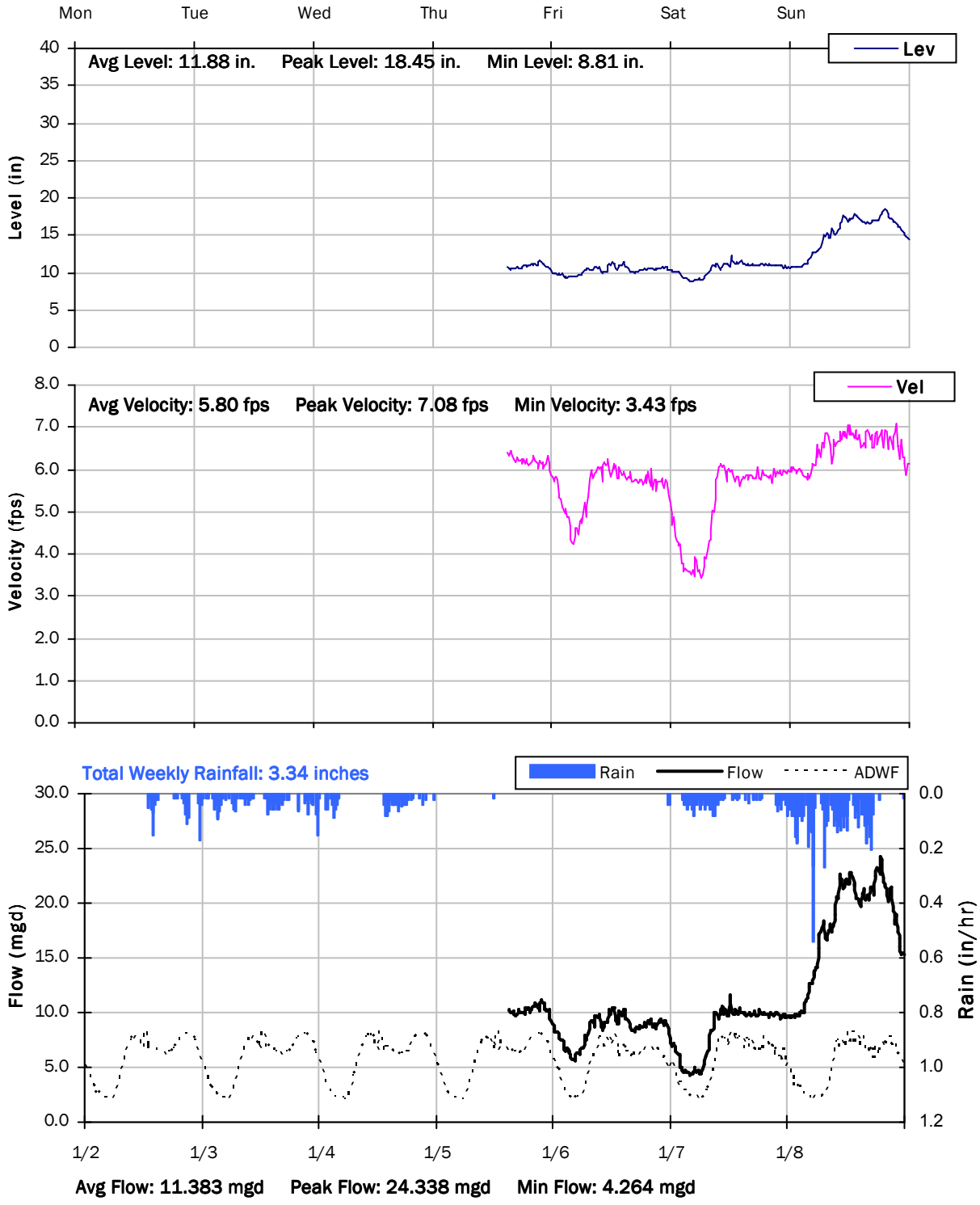
Storm Event I/I Analysis (Rain = 7.43 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	31.11 *mgd*	**Peak I/I Rate:**	22.60 *mgd*
PF:	5.48	**Total I/I:**	92,383,000 *gallons*
Peak Level:	102.79 *in*		
d/D Ratio:	1.56		

SITE 07

Weekly Level, Velocity and Flow Hydrographs

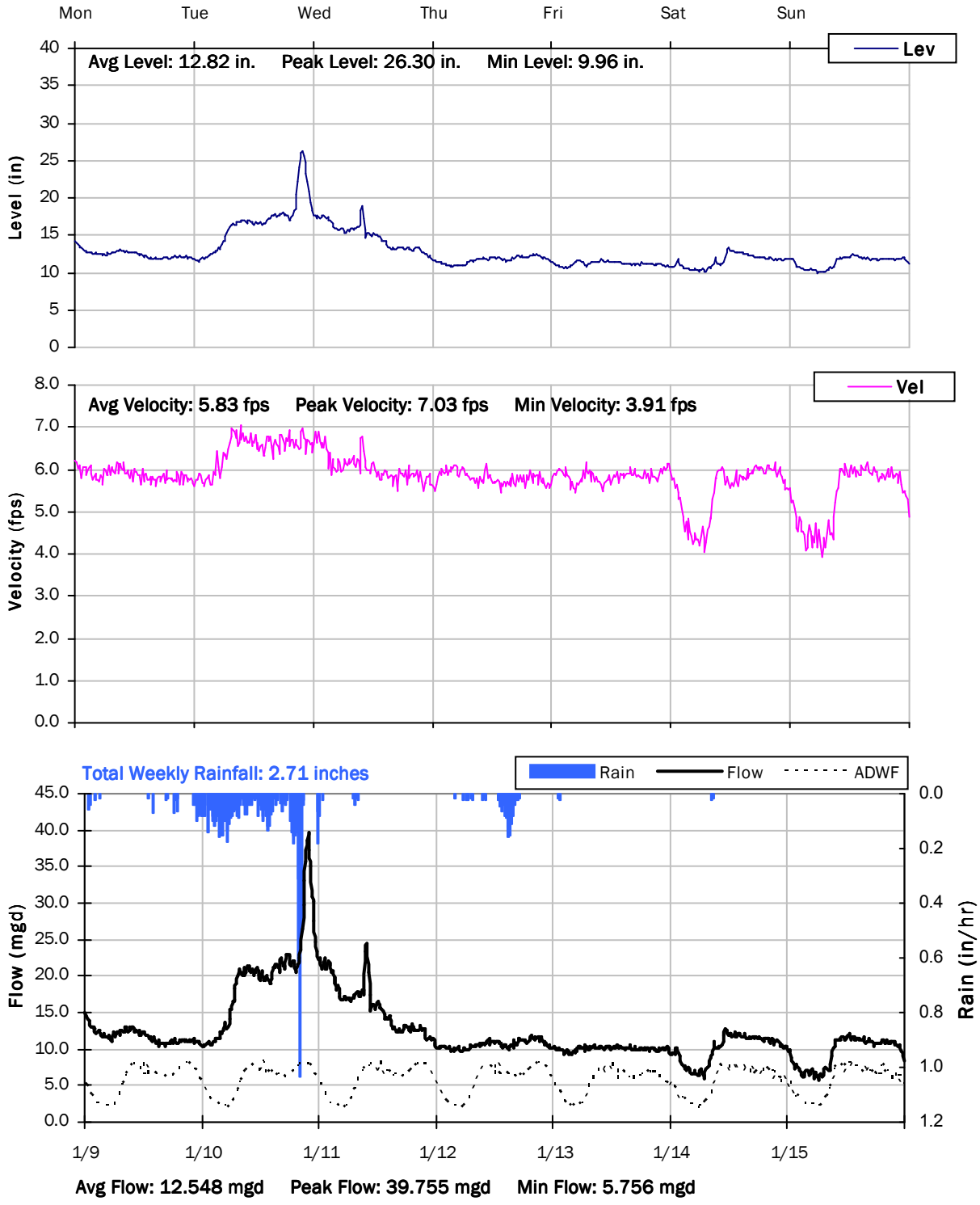
1/2/2017 to 1/9/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

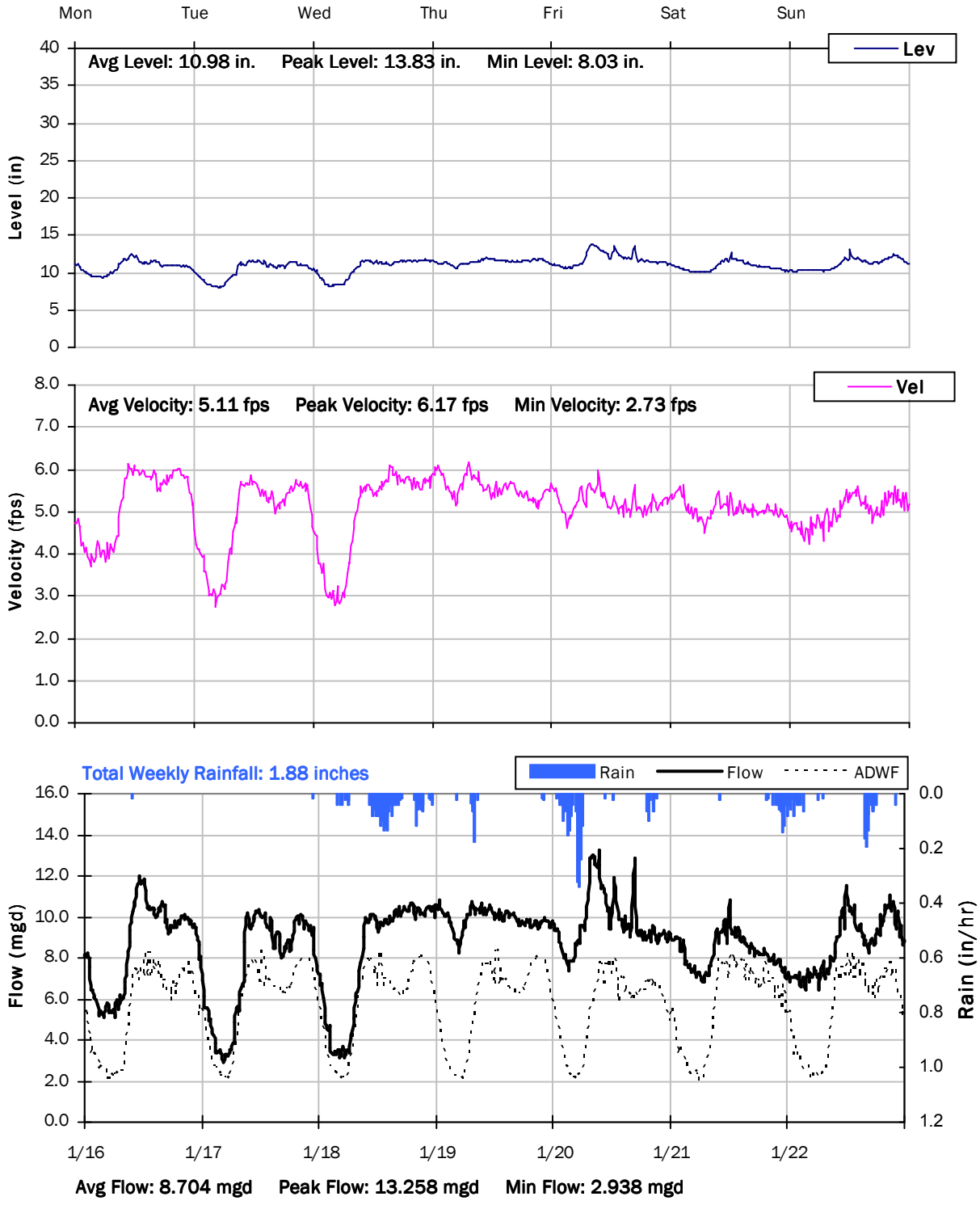
1/9/2017 to 1/16/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

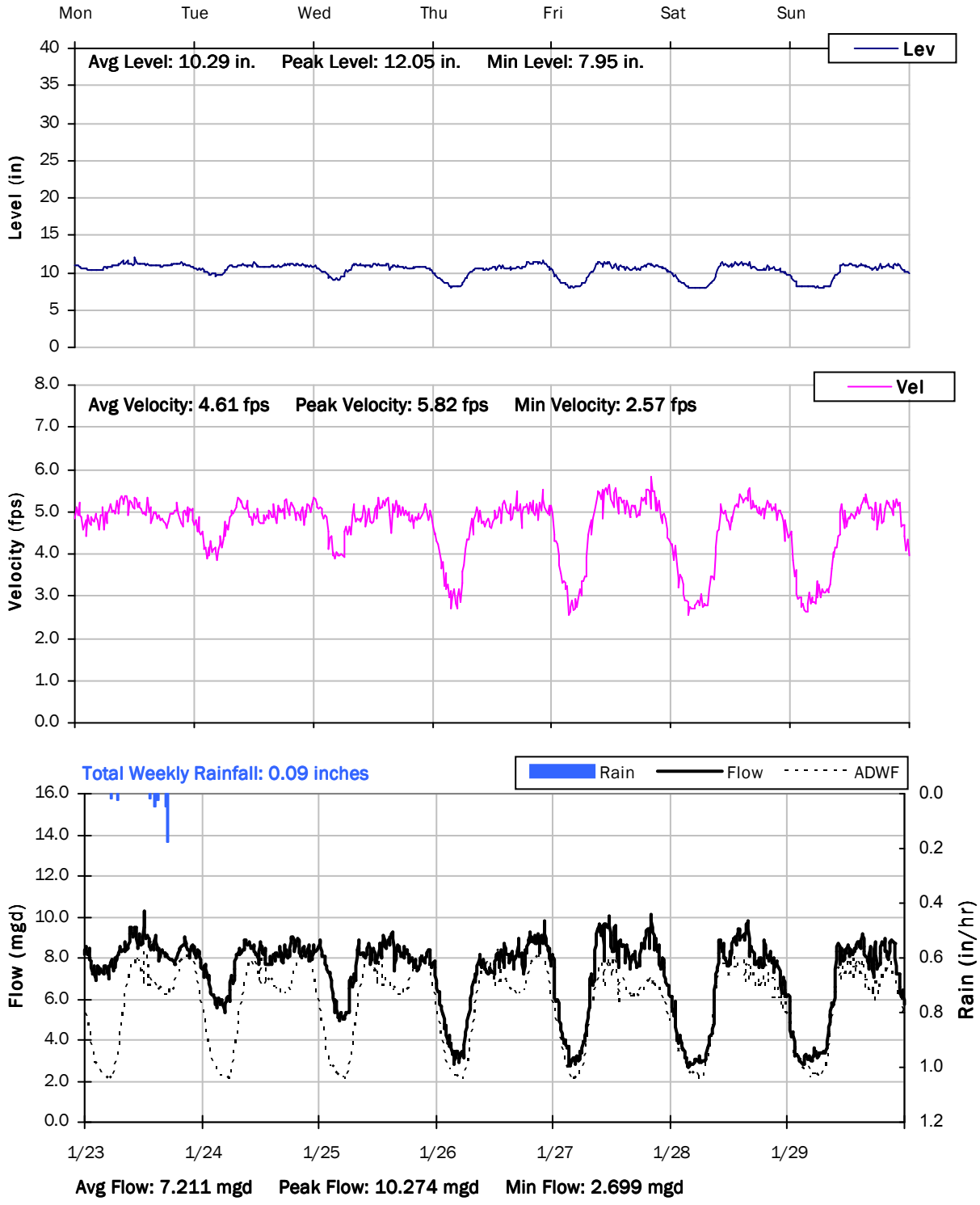
1/16/2017 to 1/23/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

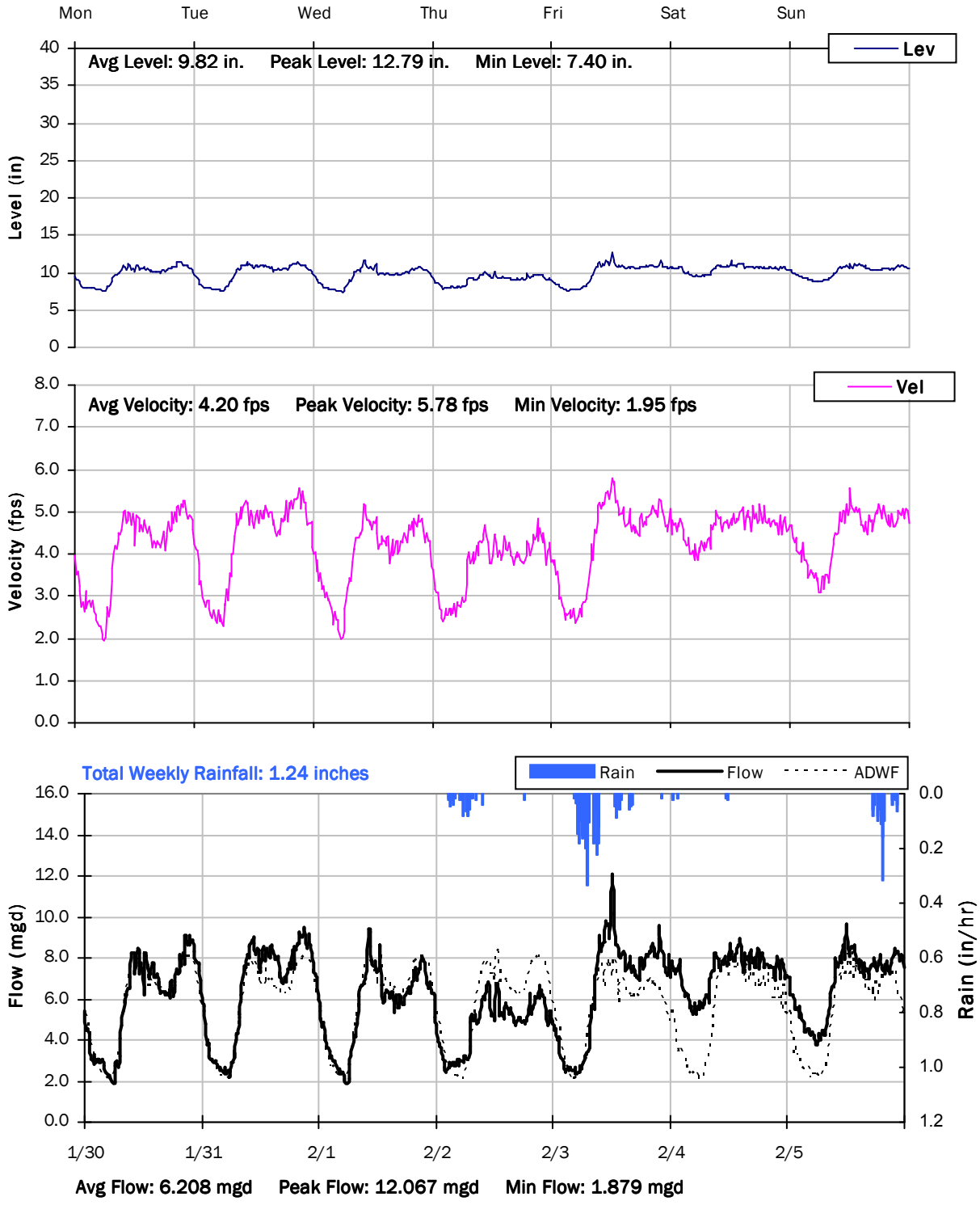
1/23/2017 to 1/30/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

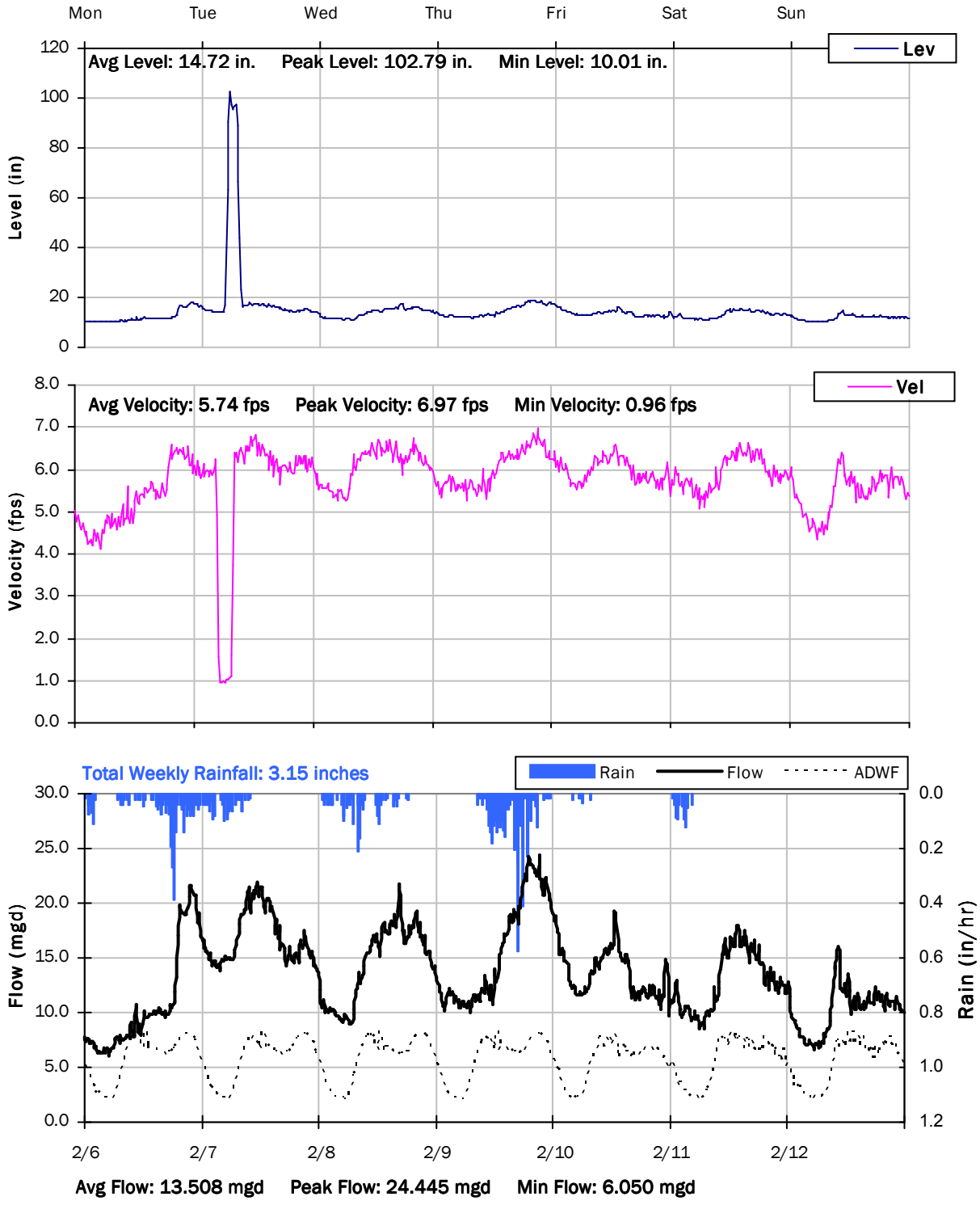
1/30/2017 to 2/6/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

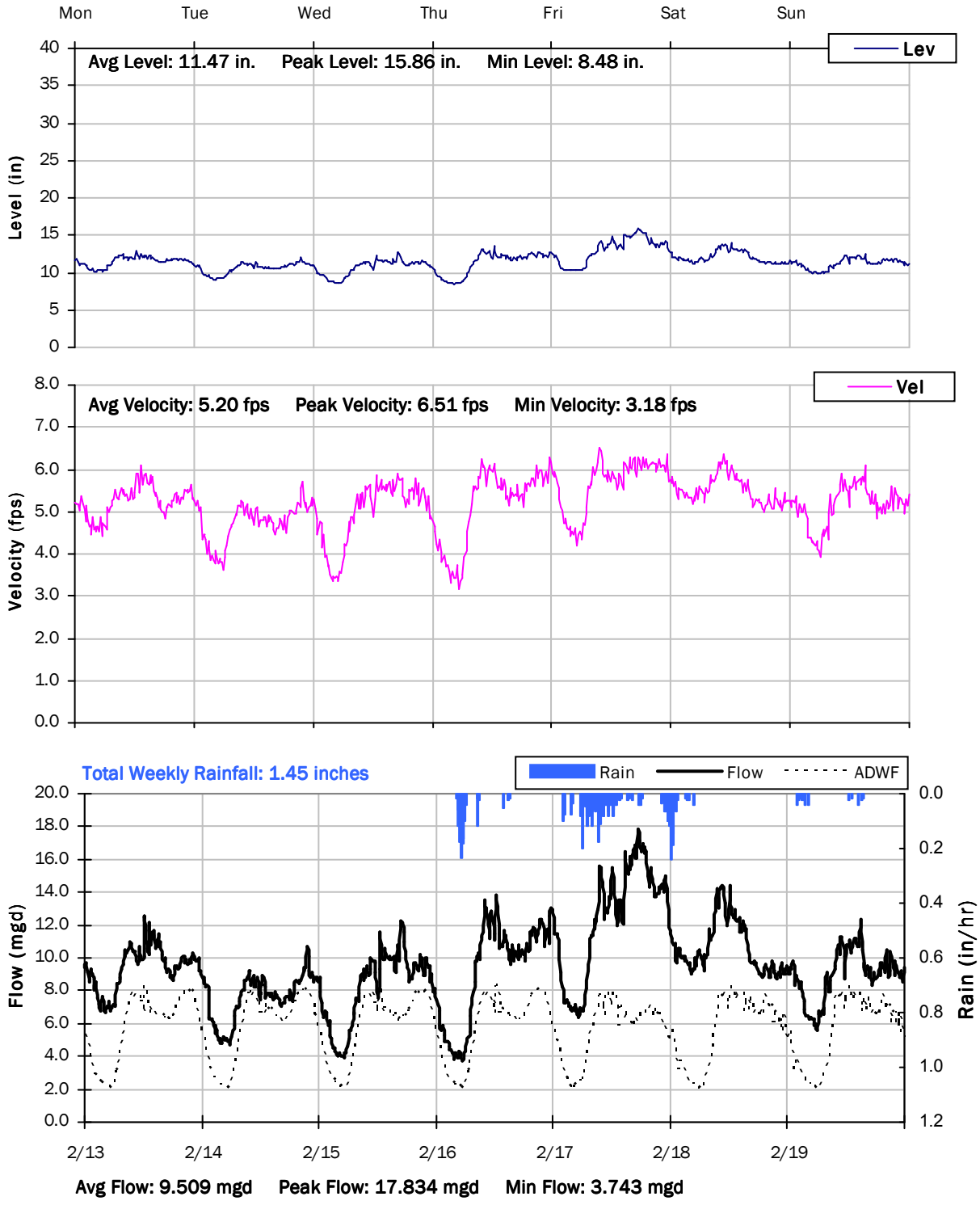
2/6/2017 to 2/13/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

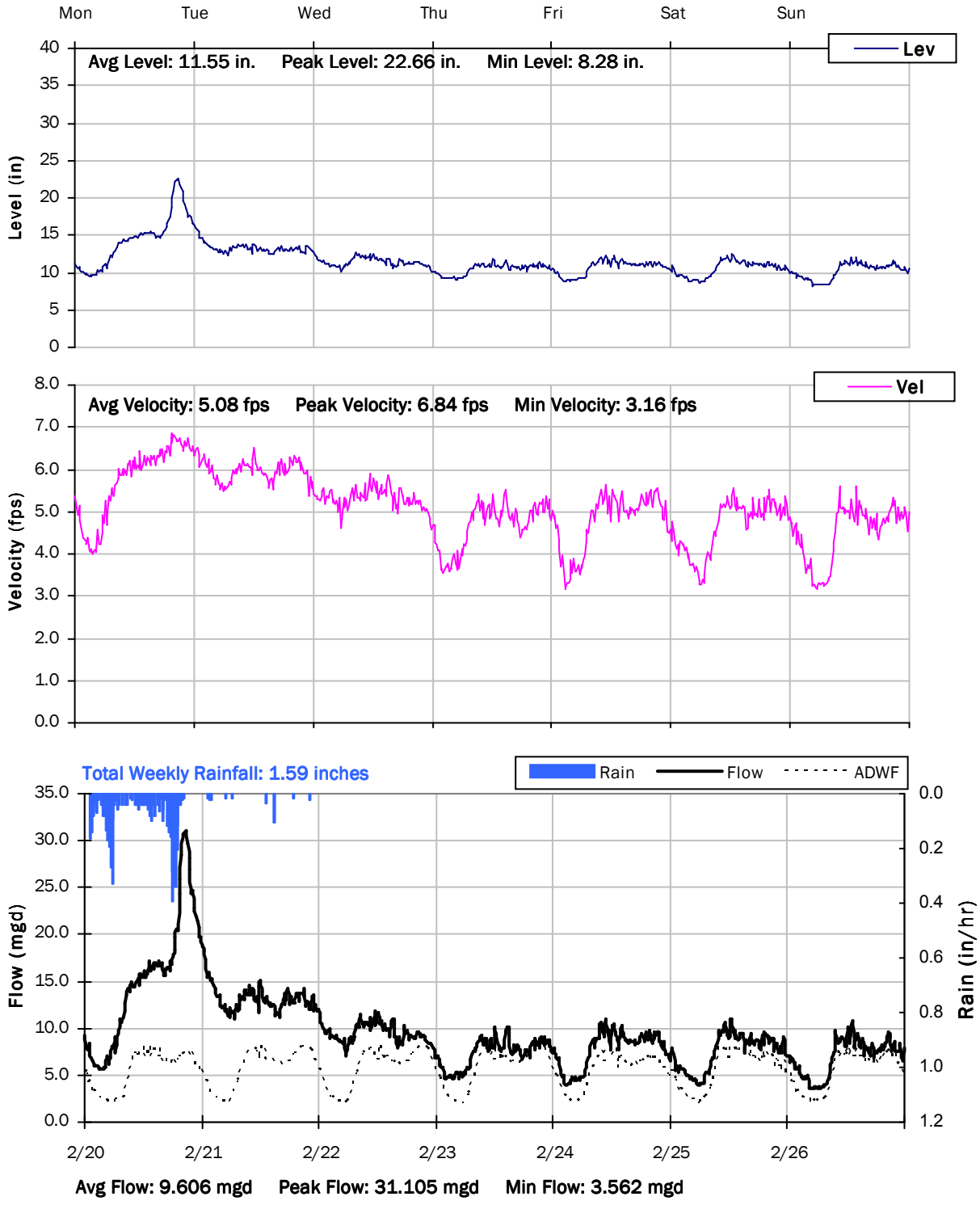
2/13/2017 to 2/20/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

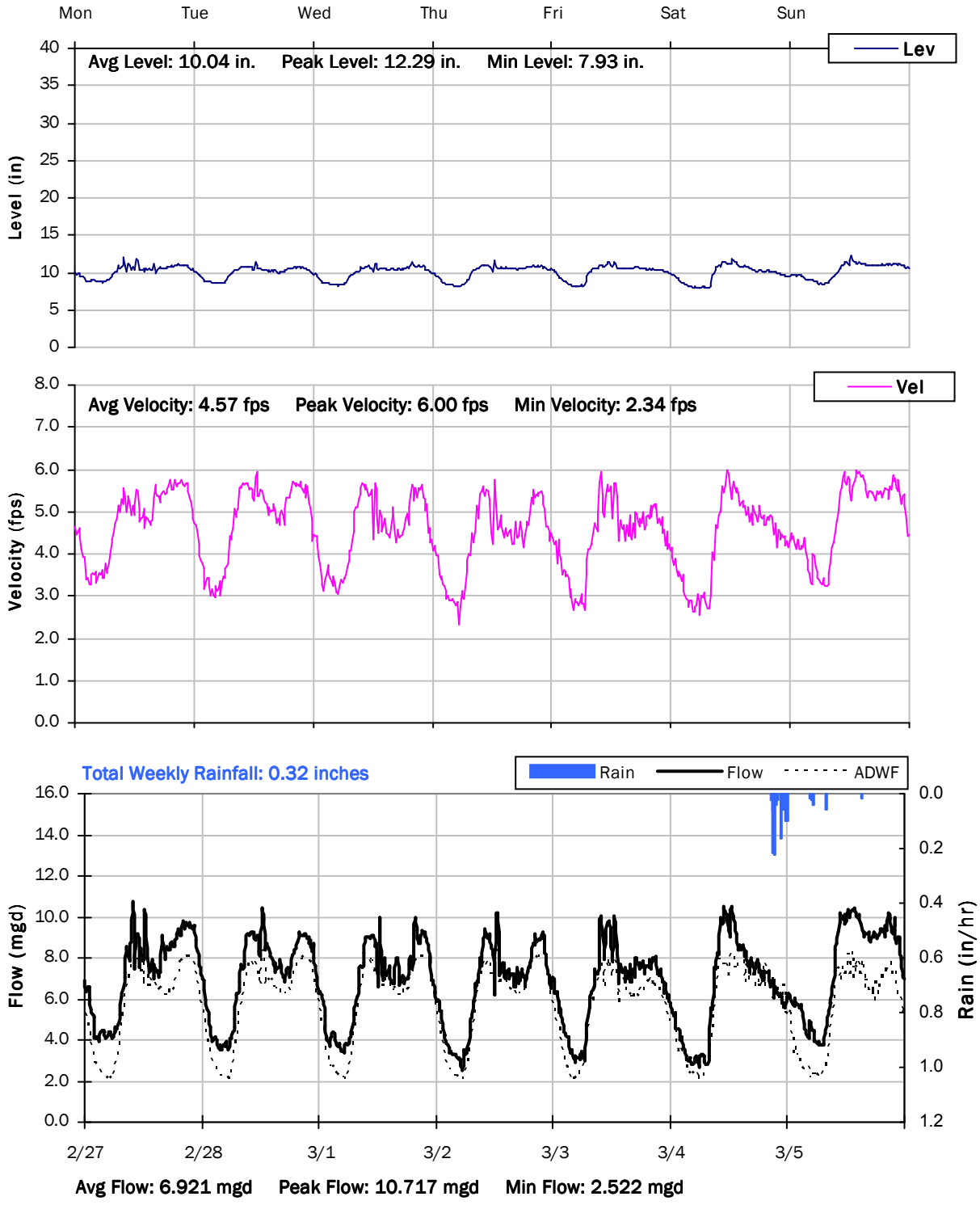
2/20/2017 to 2/27/2017



SITE 07

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



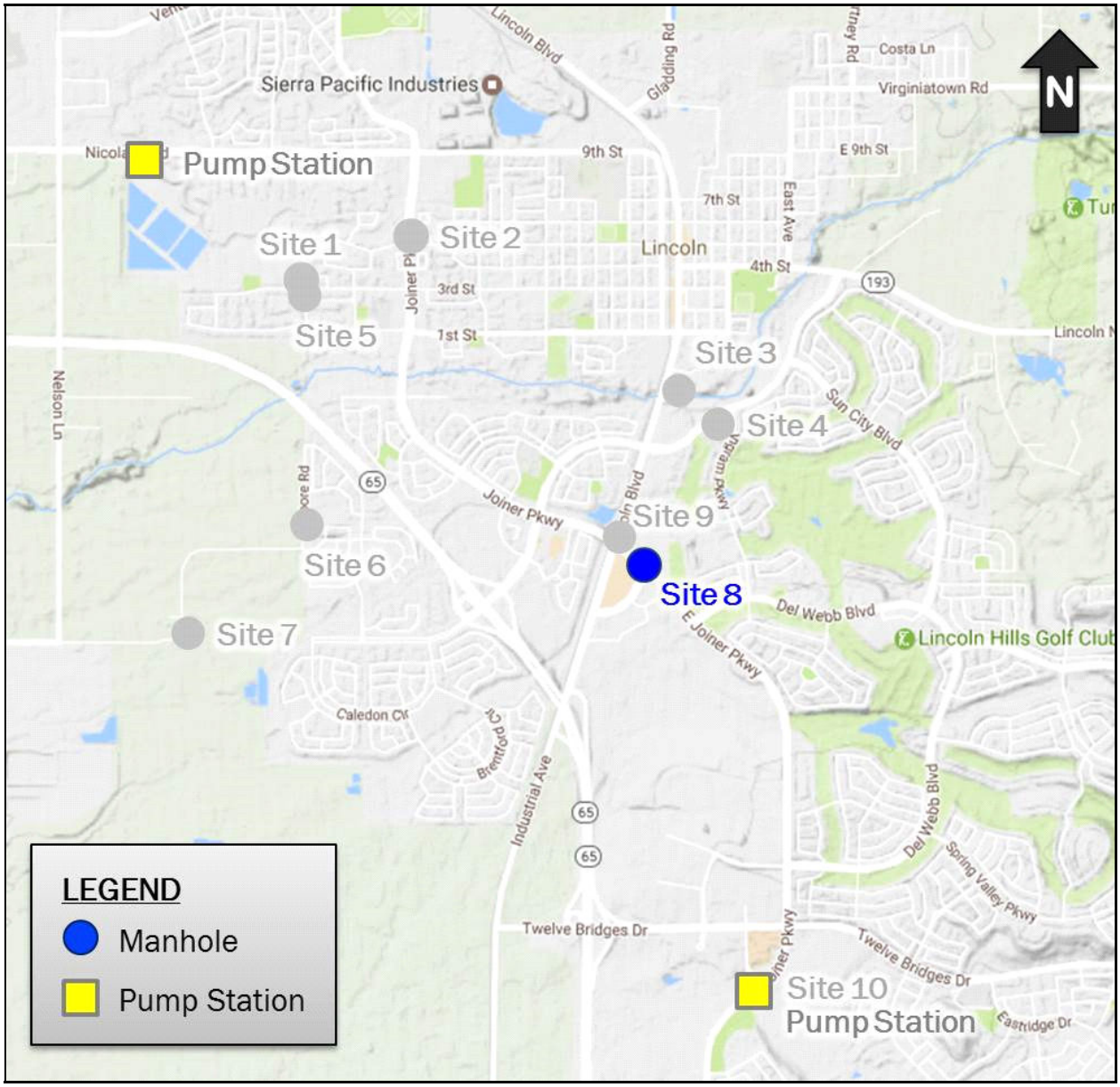
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 08

Location: Parking lot behind Raleys Supermarket at Sterling Parkway and Joiner Parkway

Data Summary Report



Vicinity Map: Site 08

SITE 08

Site Information

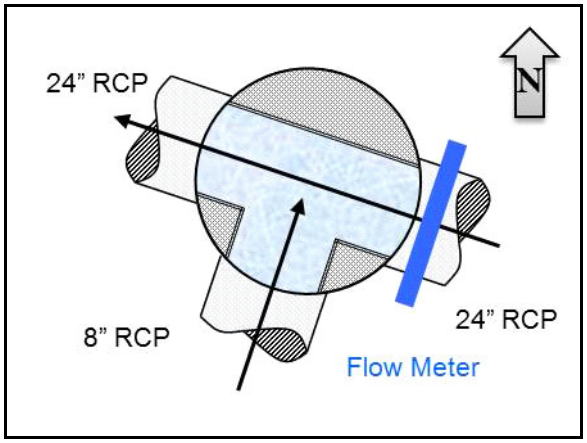
Location: Parking lot behind Raleys Supermarket at Sterling Parkway and Joiner Parkway

District ID: SE461SS09

Coordinates:	121.2961° W, 38.8728° N
Expected Pipe Diameter (Orig. if Relocated):	24 inches
Measured Pipe Diameter:	24 inches
ADWF:	0.982 mgd
Peak Measured Flow:	5.209 mgd
Rim Elevation (GEarth):	154 feet

Satellite Map

Sewer Map



Flow Sketch

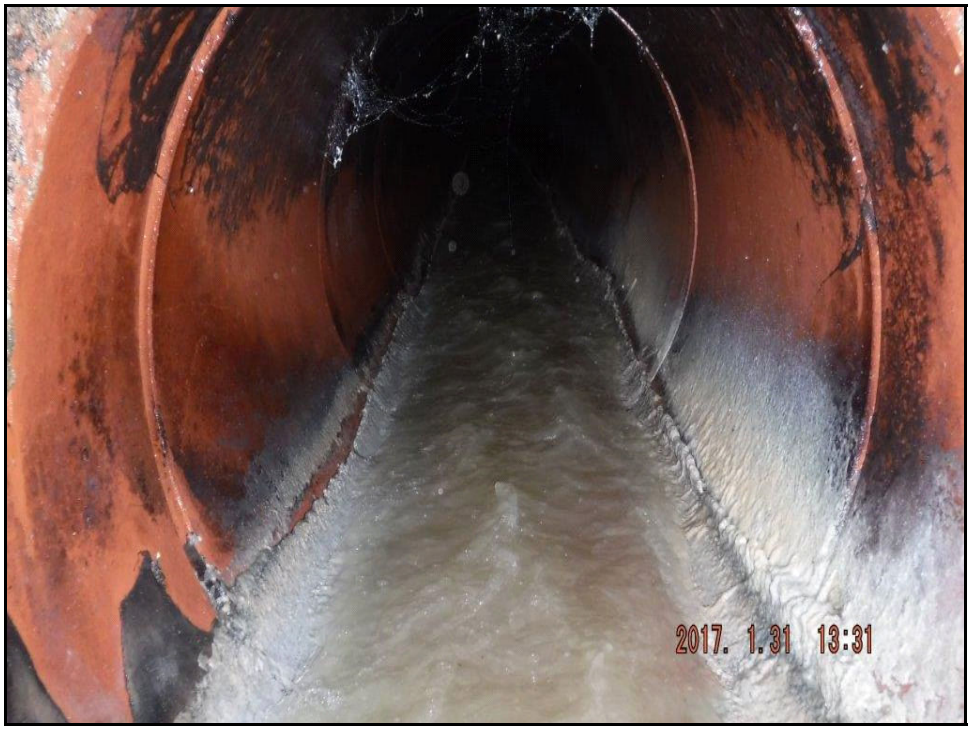
Street View

Plan View

SITE 08

Additional Site Photos

Effluent Pipe

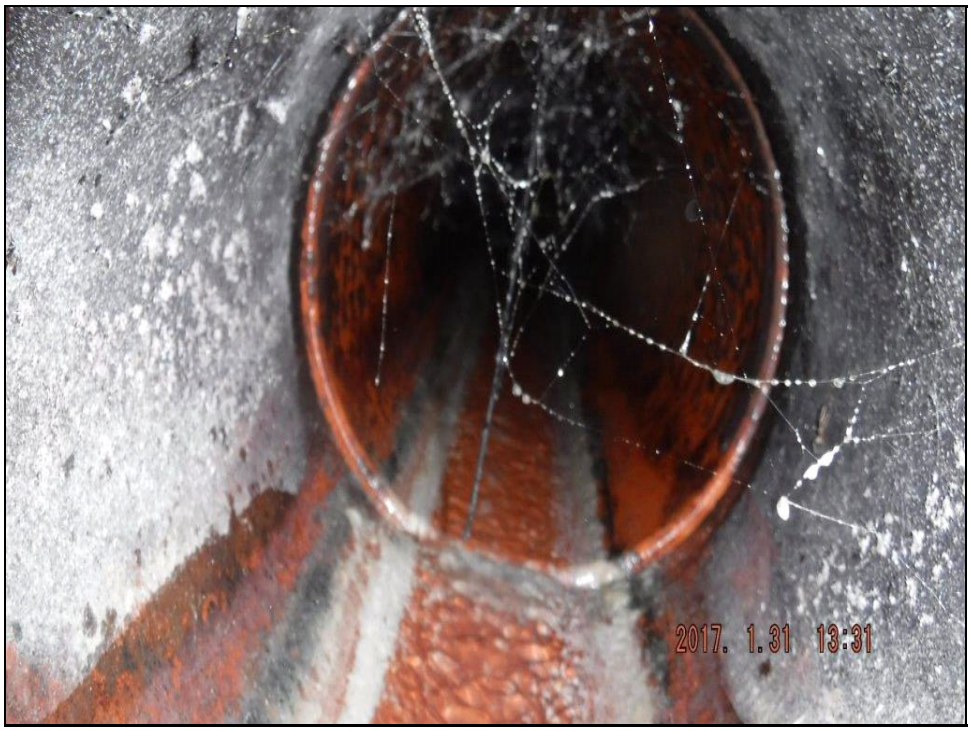


East Influent Pipe

SITE 08

Additional Site Photos

South Influent Pipe

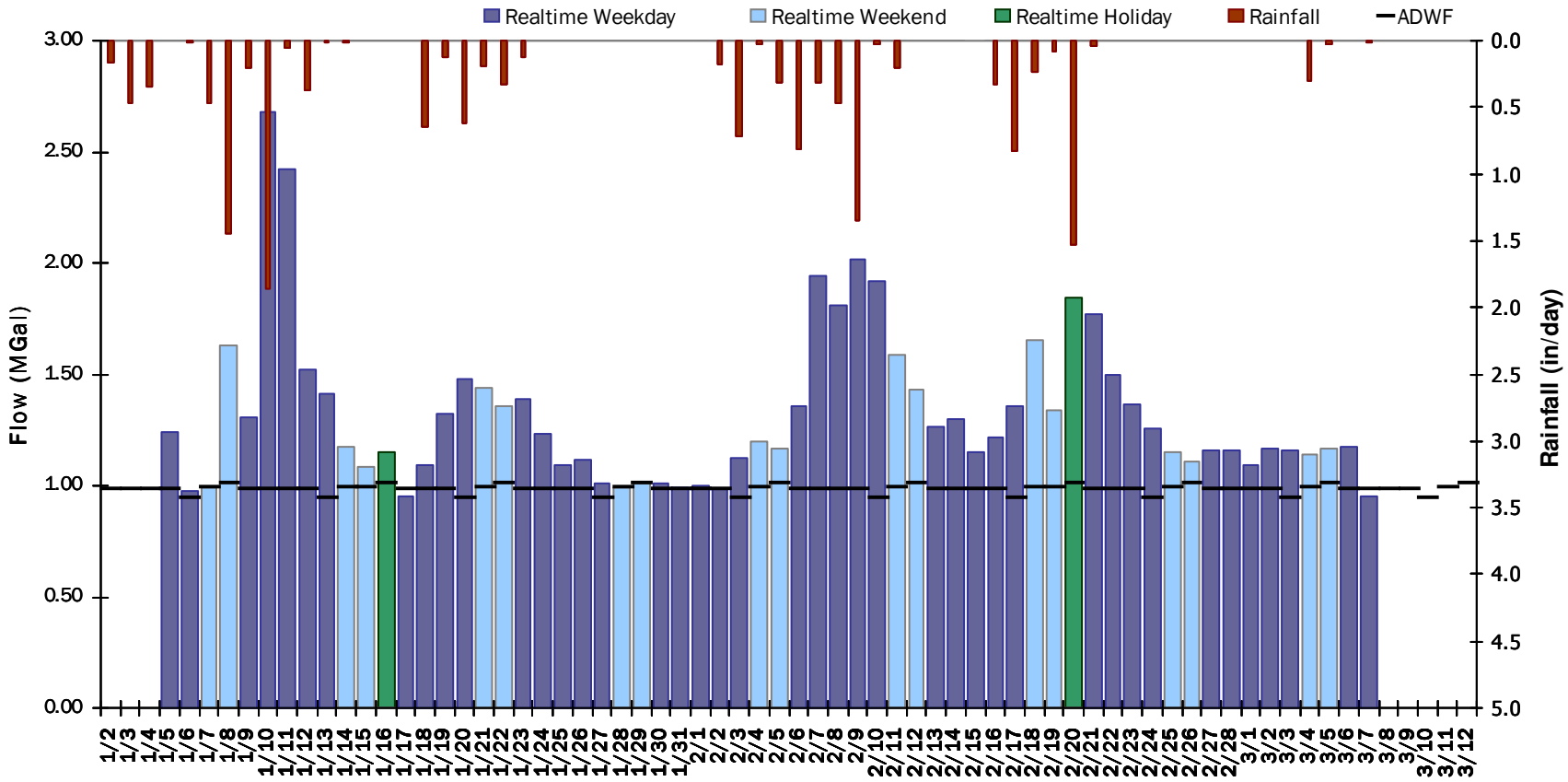


SITE 08

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 1.322 MGal **Peak Daily Flow: 2.677 MGal** **Min Daily Flow: 0.948 MGal**

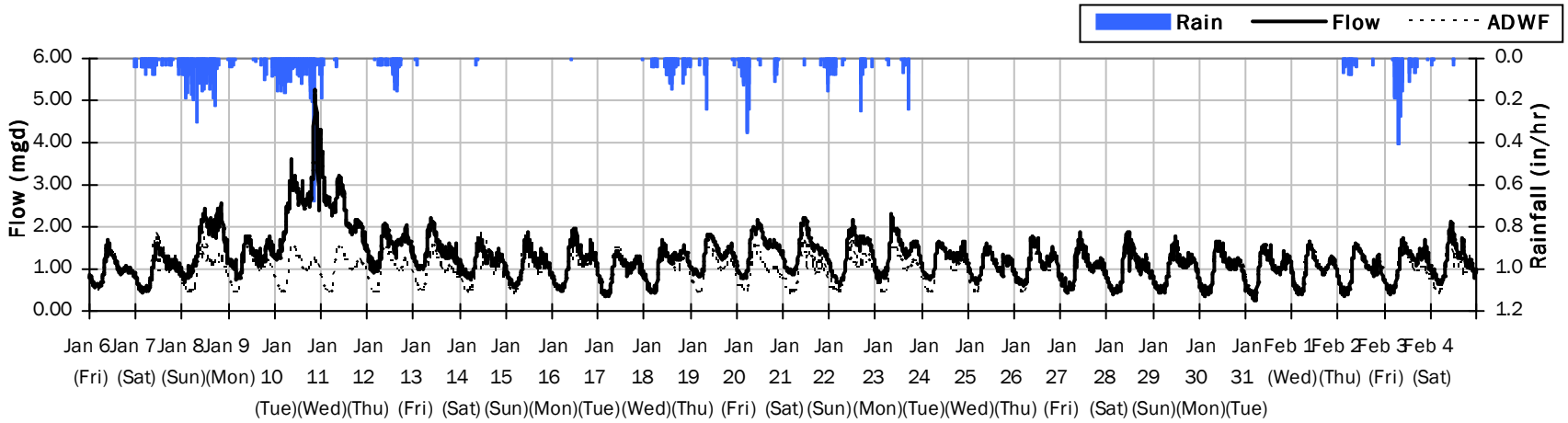
Total Period Rainfall: 15.28 inches

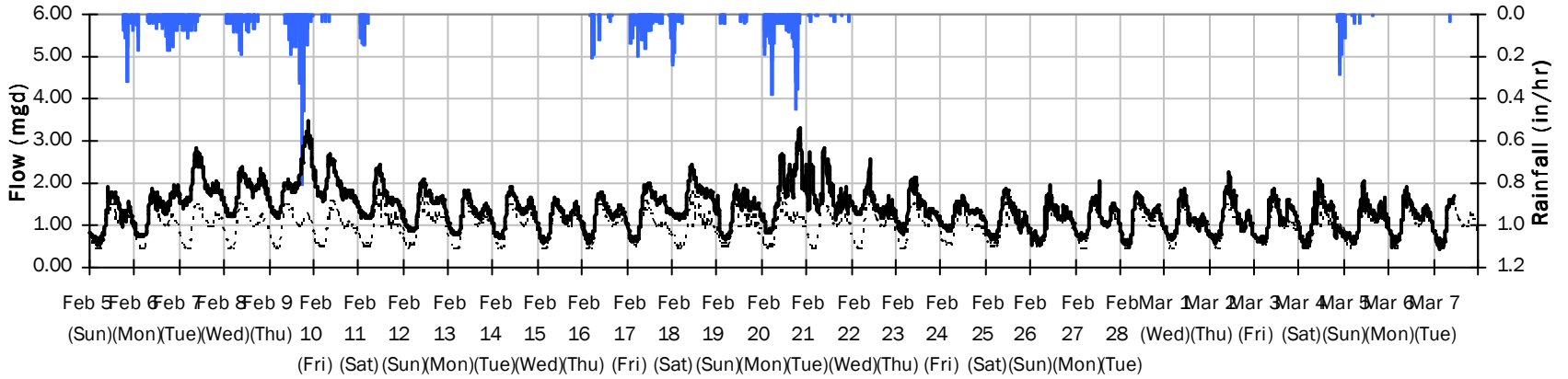


SITE 08

Flow Summary: 1/6/2017 to 3/7/2017

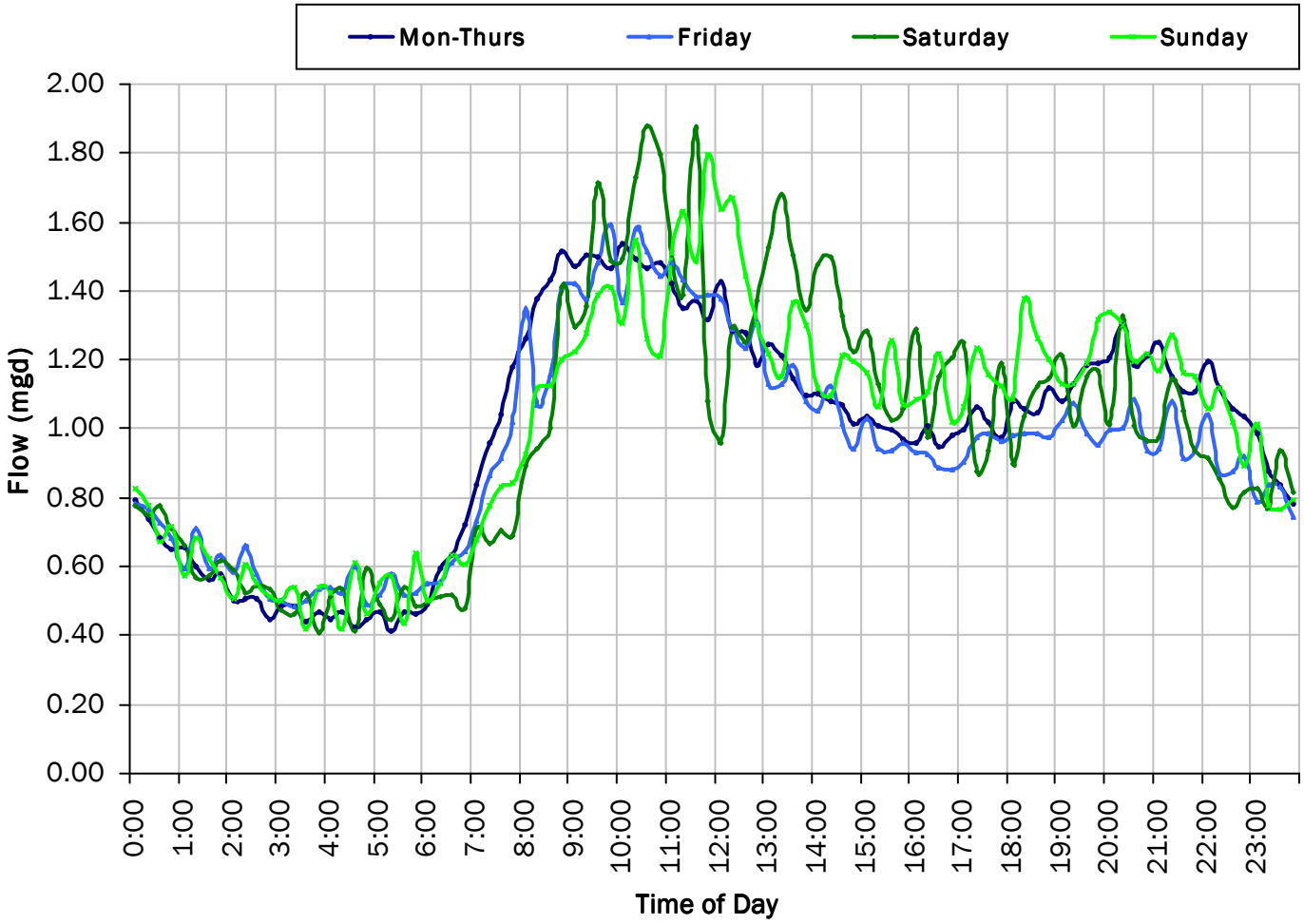
Total Period Rainfall: 14.30 inches **Avg Flow: 1.327 mgd** **Peak Flow: 5.209 mgd** **Min Flow: 0.275 mgd**





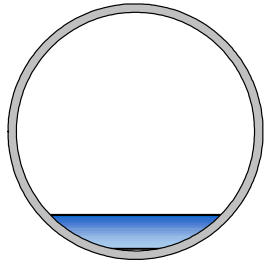
SITE 08

Average Dry Weather Flow Hydrographs



ADWF:

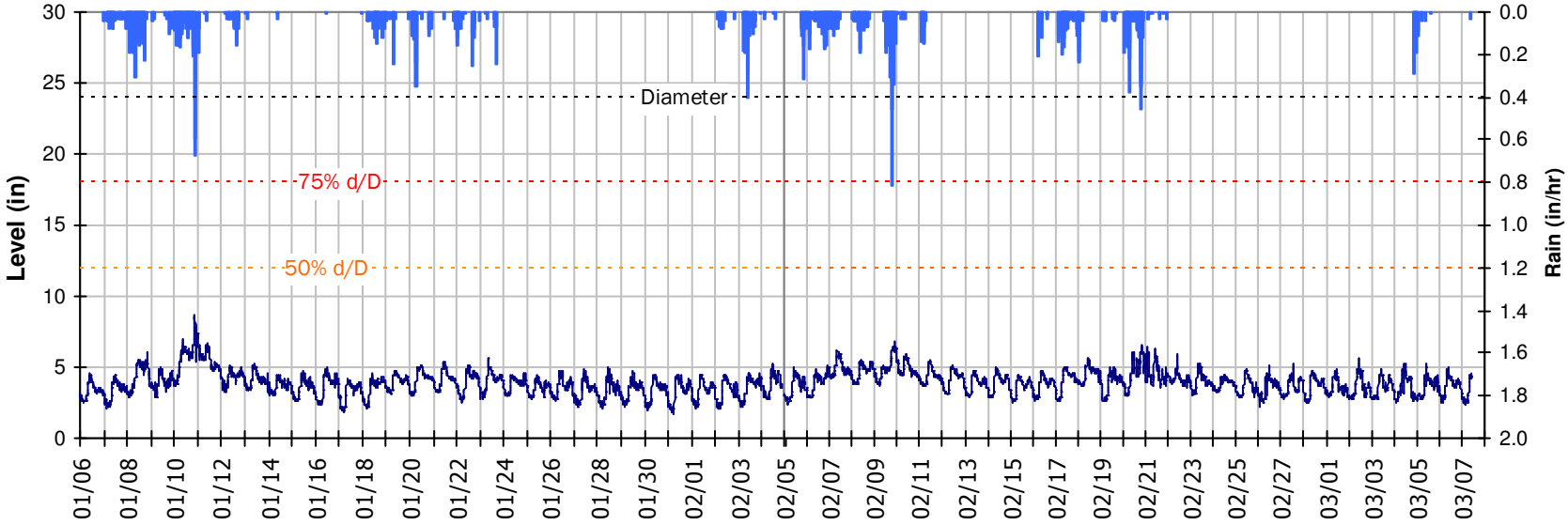
0.982 *mgd*

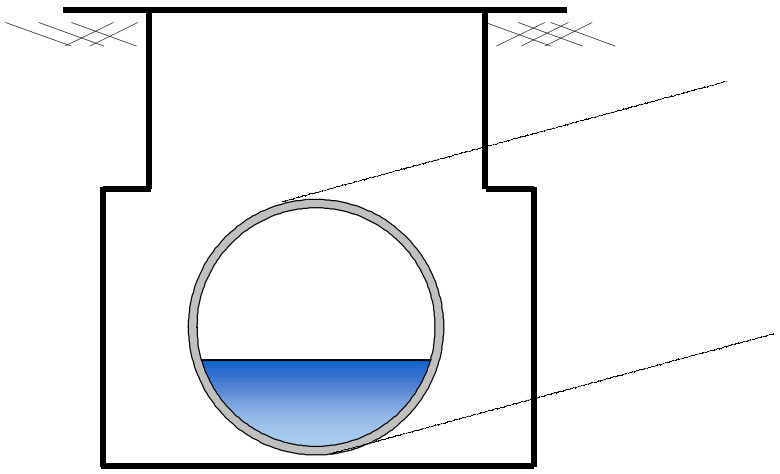


SITE 08

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period



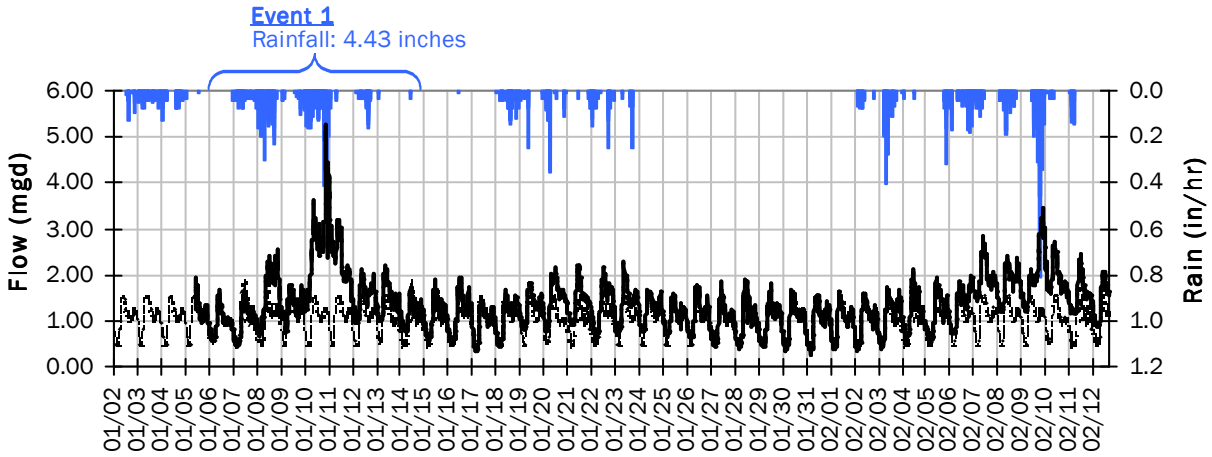


Pipe Diameter:	24	*inches*
Peak Measured Level:	8.74	*inches*
Peak d/D Ratio:	0.36	

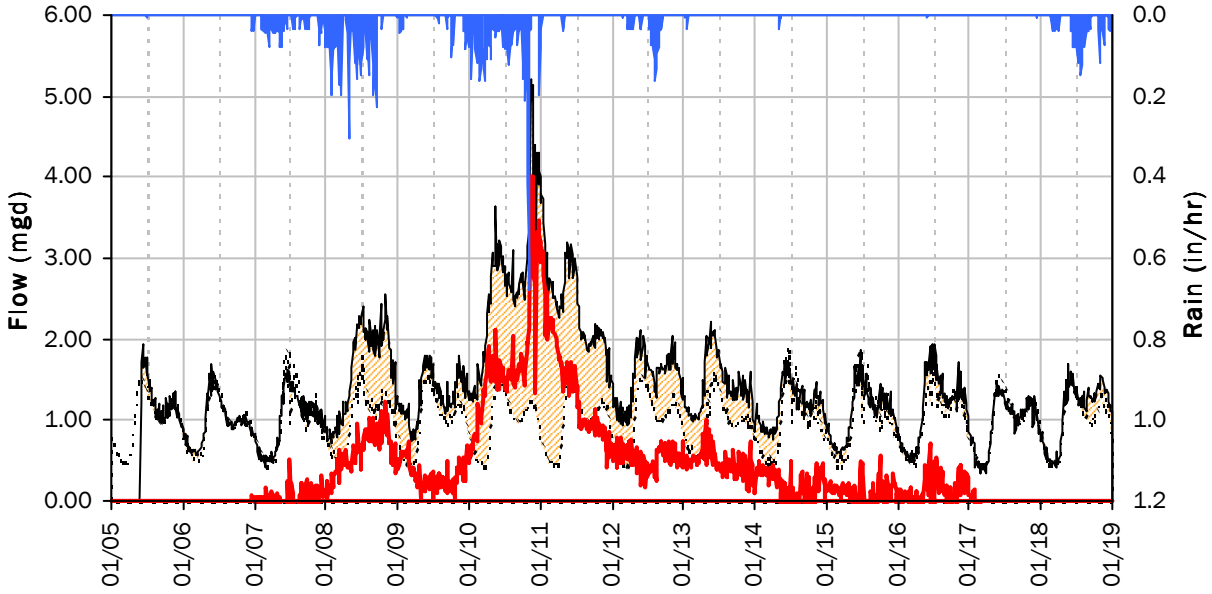
SITE 08

I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph



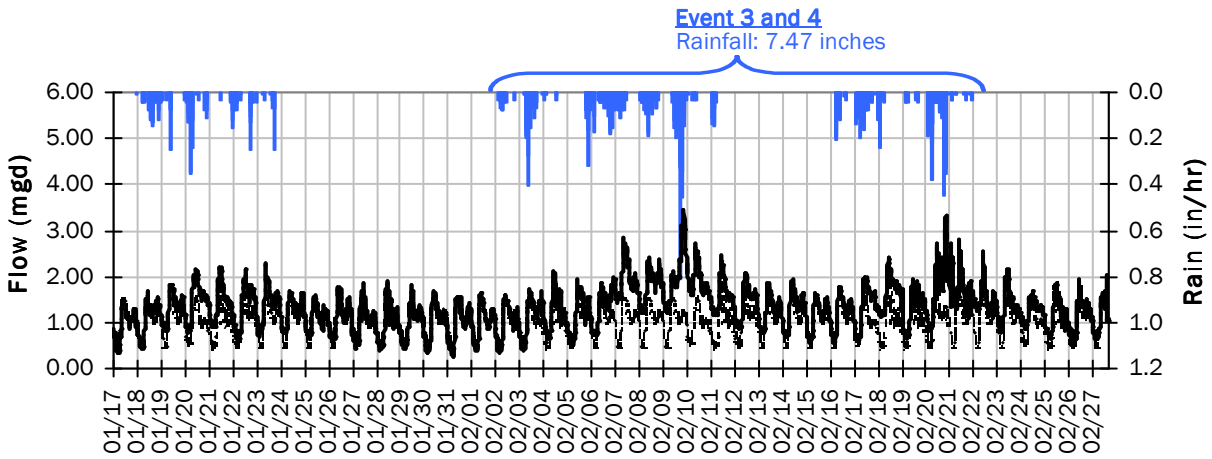
Storm Event I/I Analysis (Rain = 4.43 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	5.21 *mgd*	**Peak I/I Rate:**	4.00 *mgd*
PF:	5.30	**Total I/I:**	5,504,000 *gallons*
Peak Level:	8.74 *in*		
d/D Ratio:	0.36		

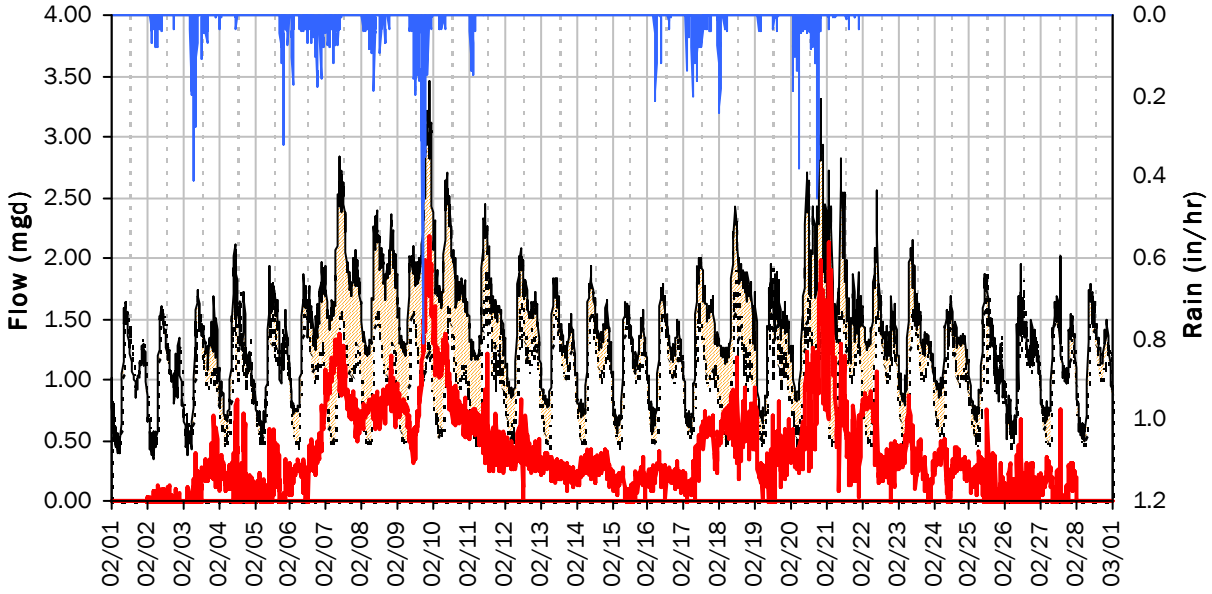
SITE 08

I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



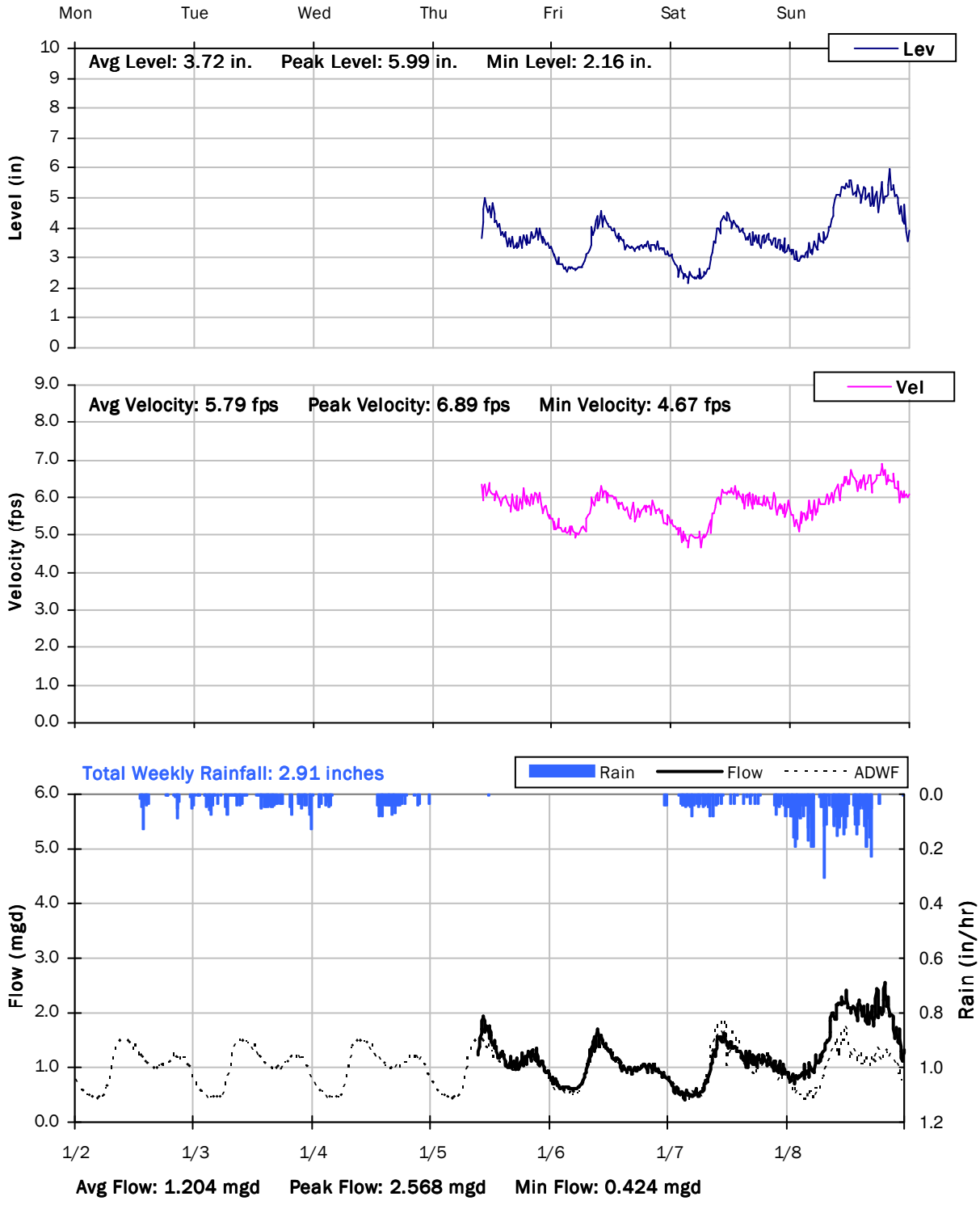
Storm Event I/I Analysis (Rain = 7.47 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	3.46 *mgd*	**Peak I/I Rate:**	2.18 *mgd*
PF:	3.52	**Total I/I:**	10,668,000 *gallons*
Peak Level:	6.79 *in*		
d/D Ratio:	0.28		

SITE 08

Weekly Level, Velocity and Flow Hydrographs

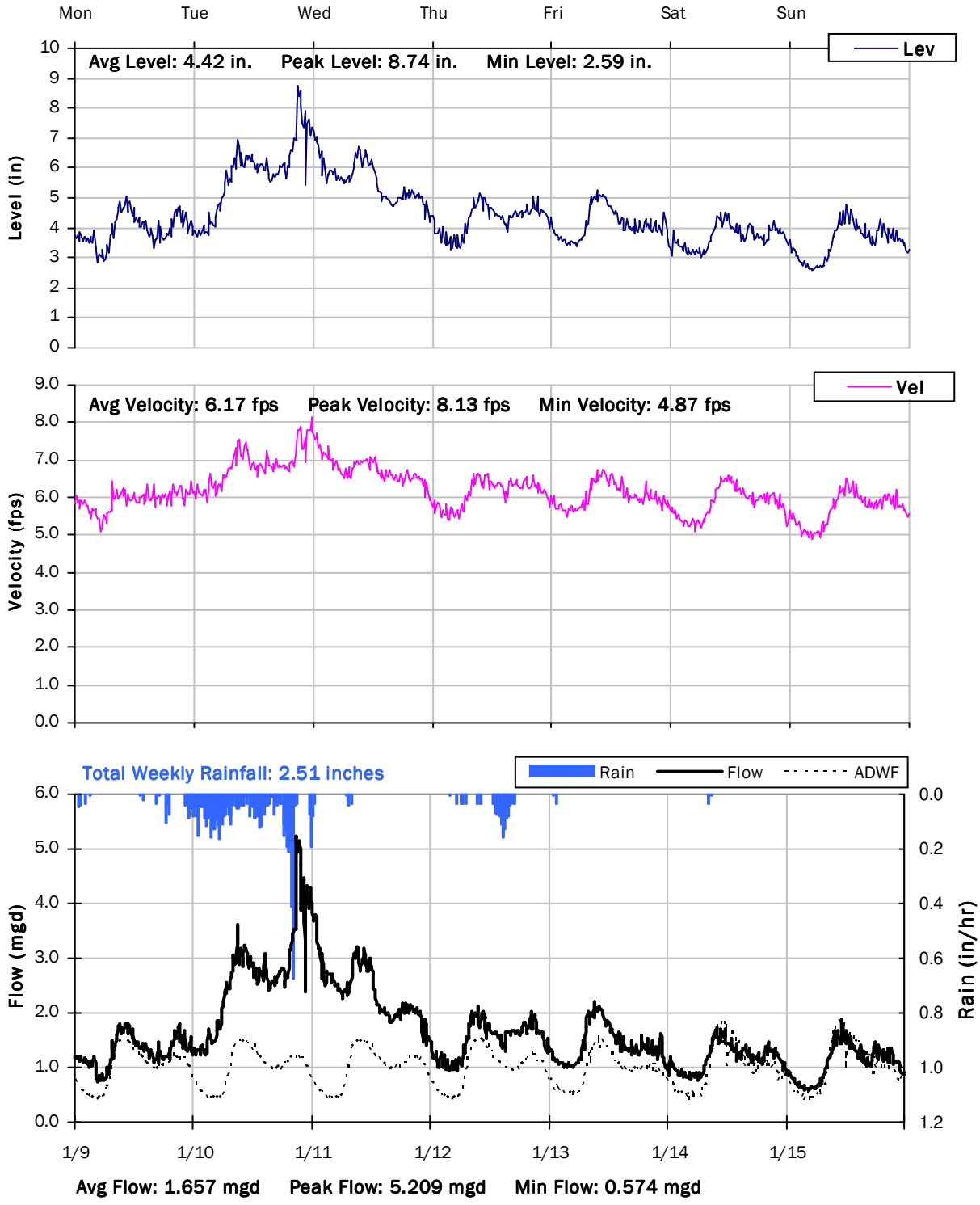
1/2/2017 to 1/9/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

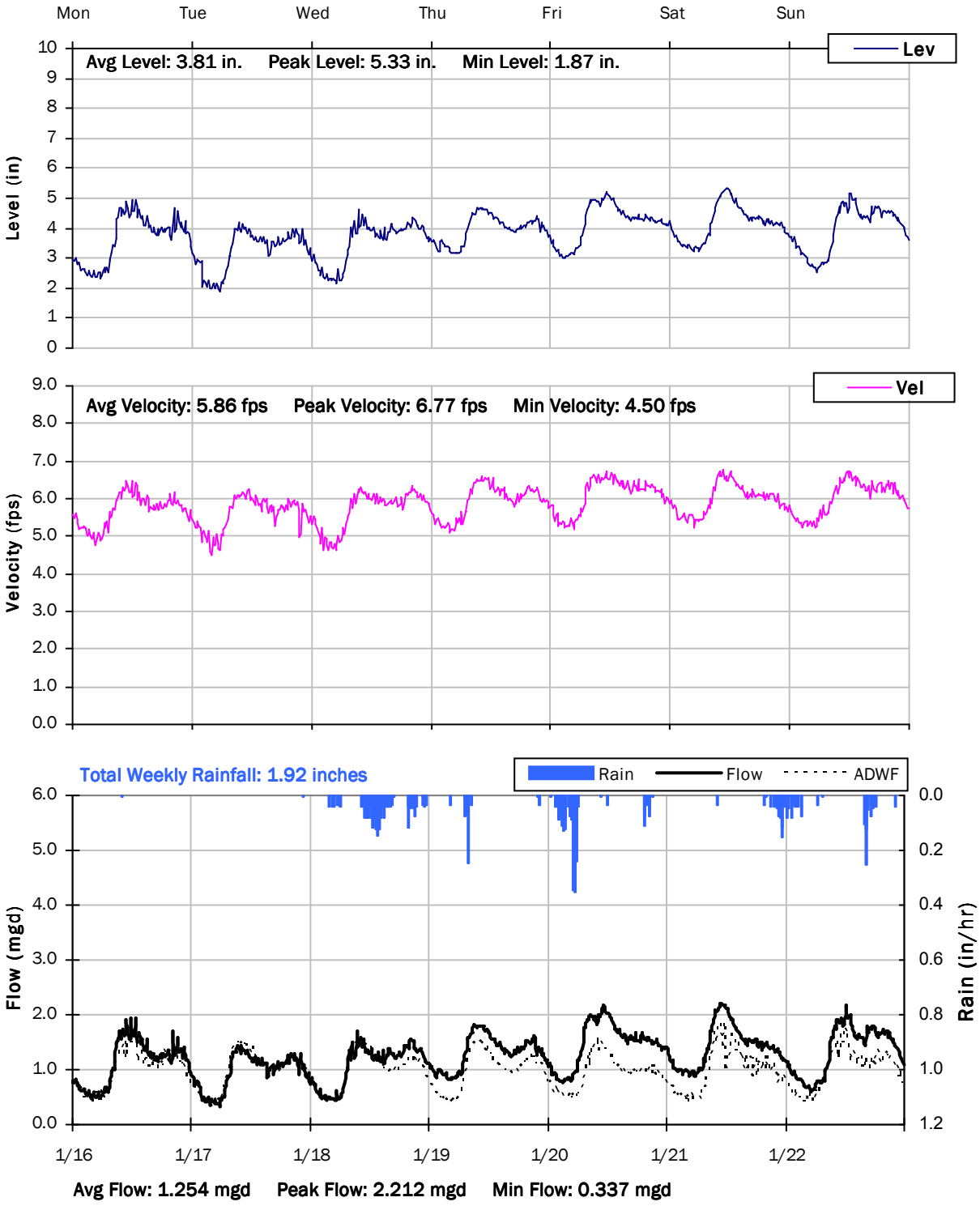
1/9/2017 to 1/16/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

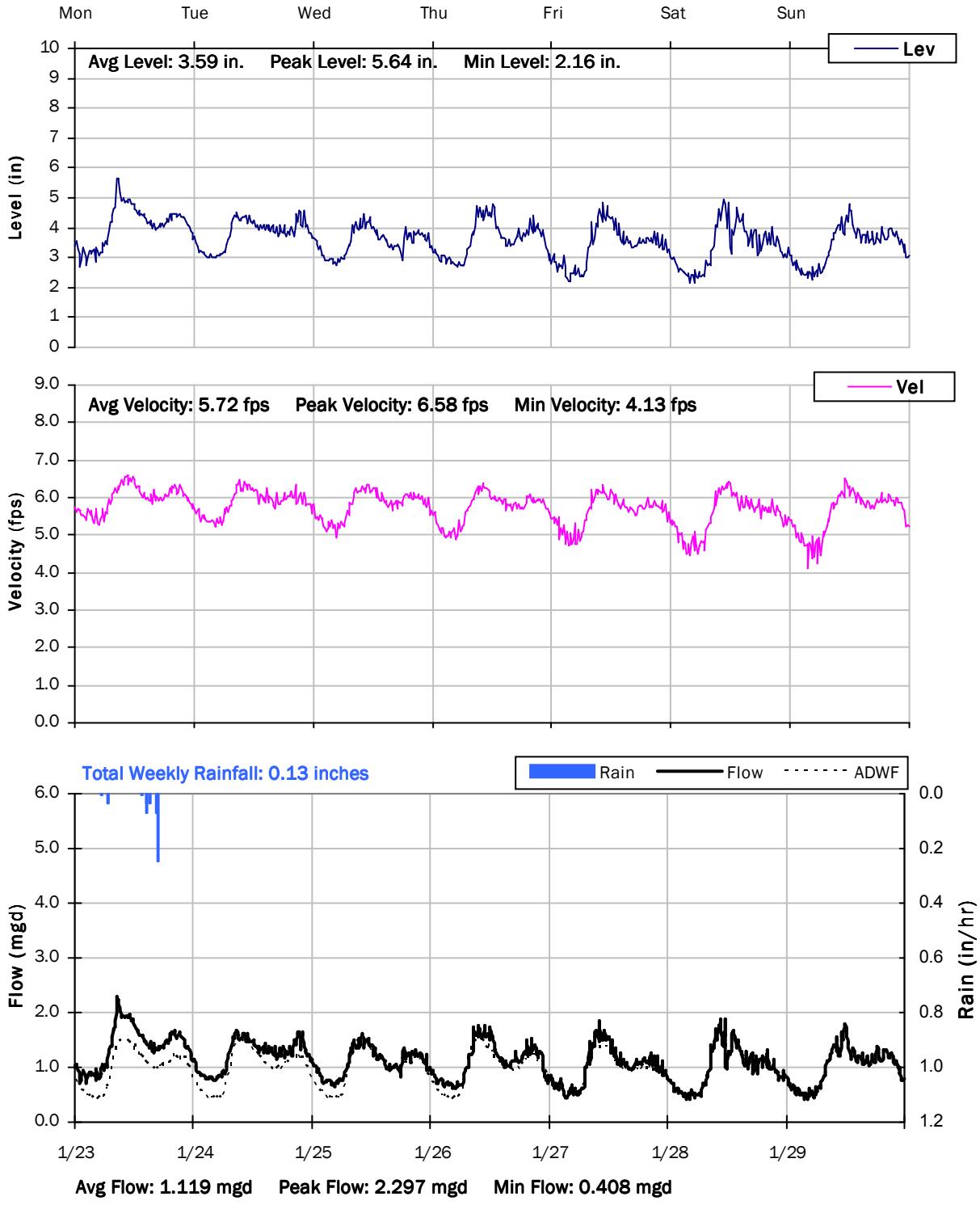
1/16/2017 to 1/23/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

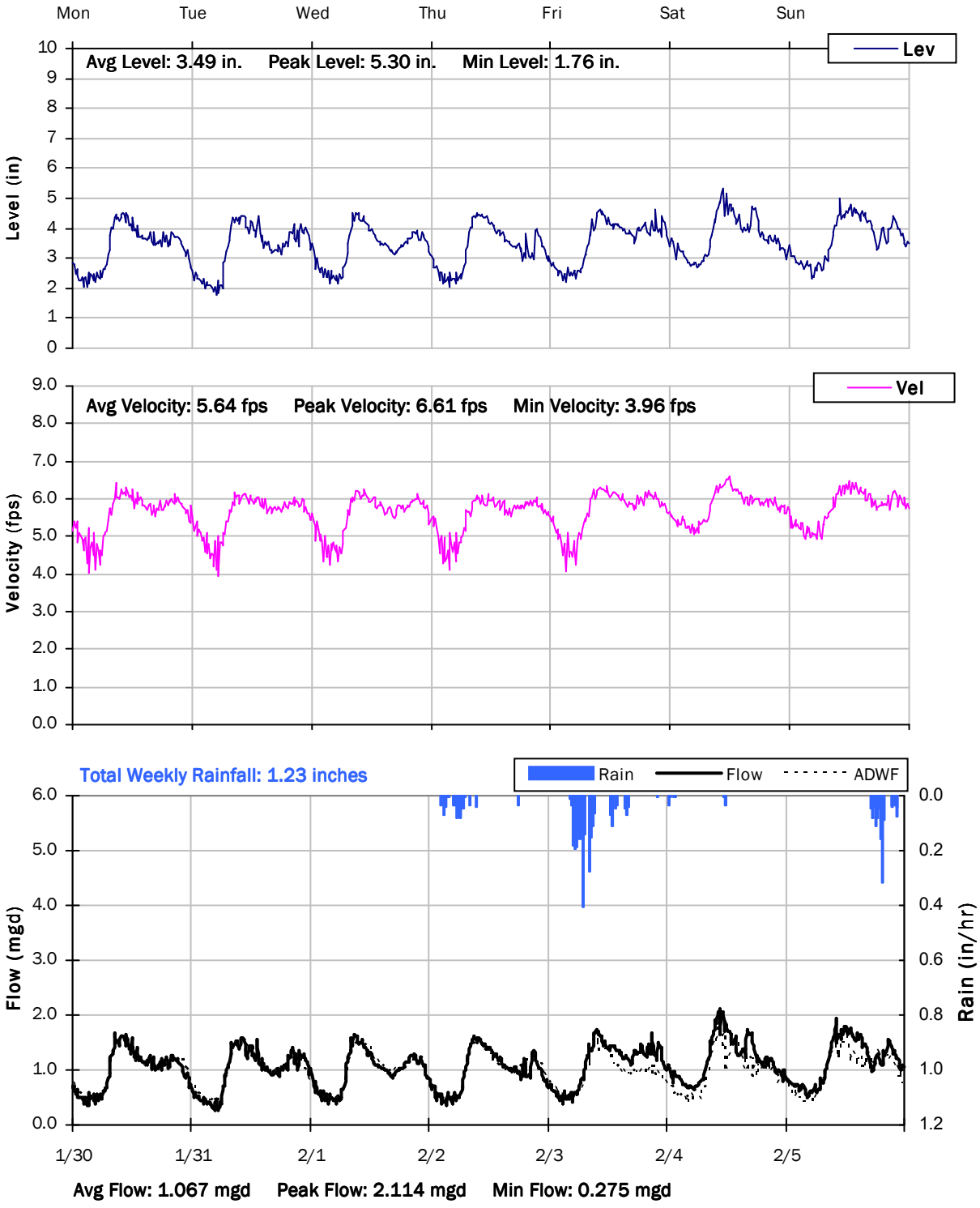
1/23/2017 to 1/30/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

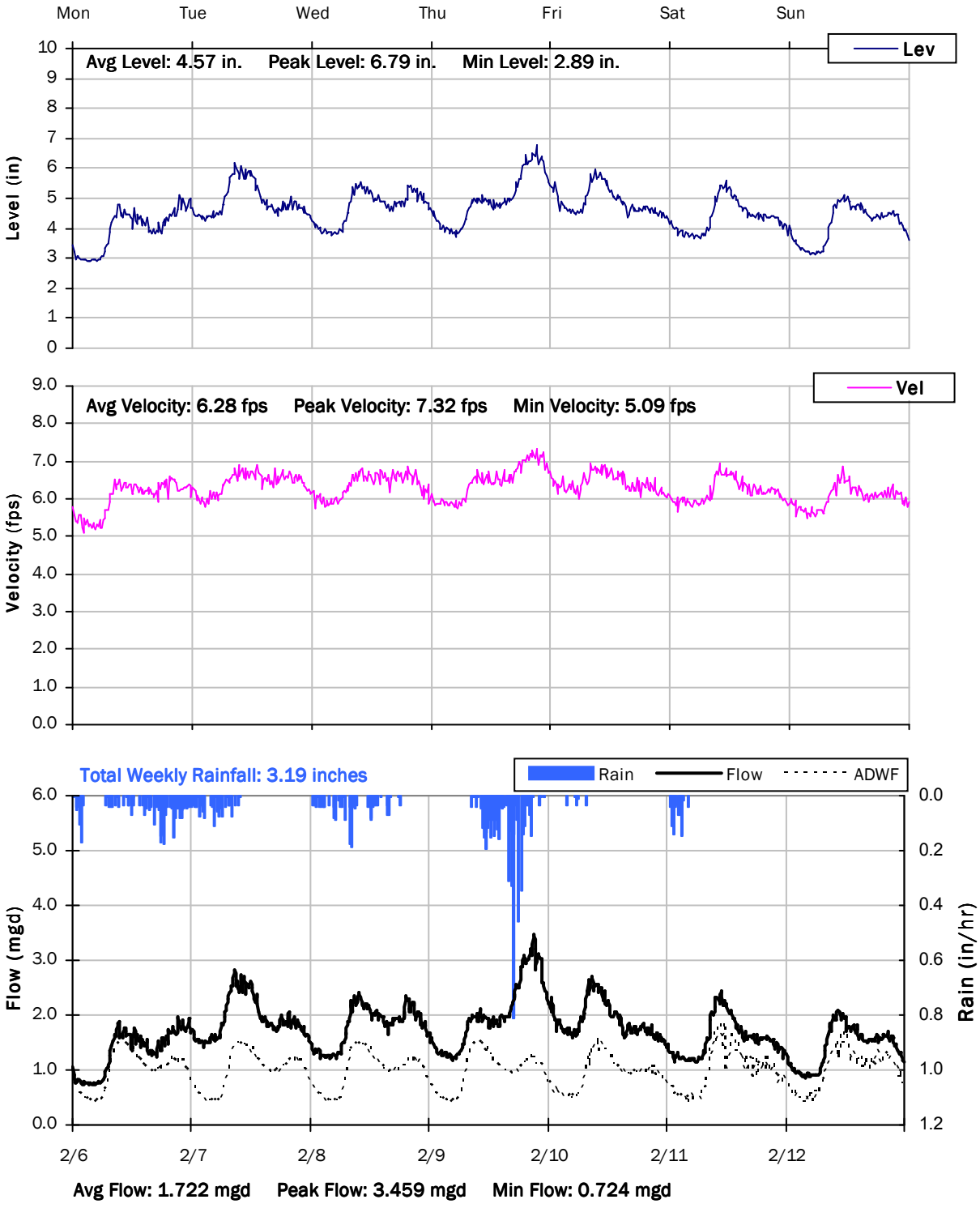
1/30/2017 to 2/6/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

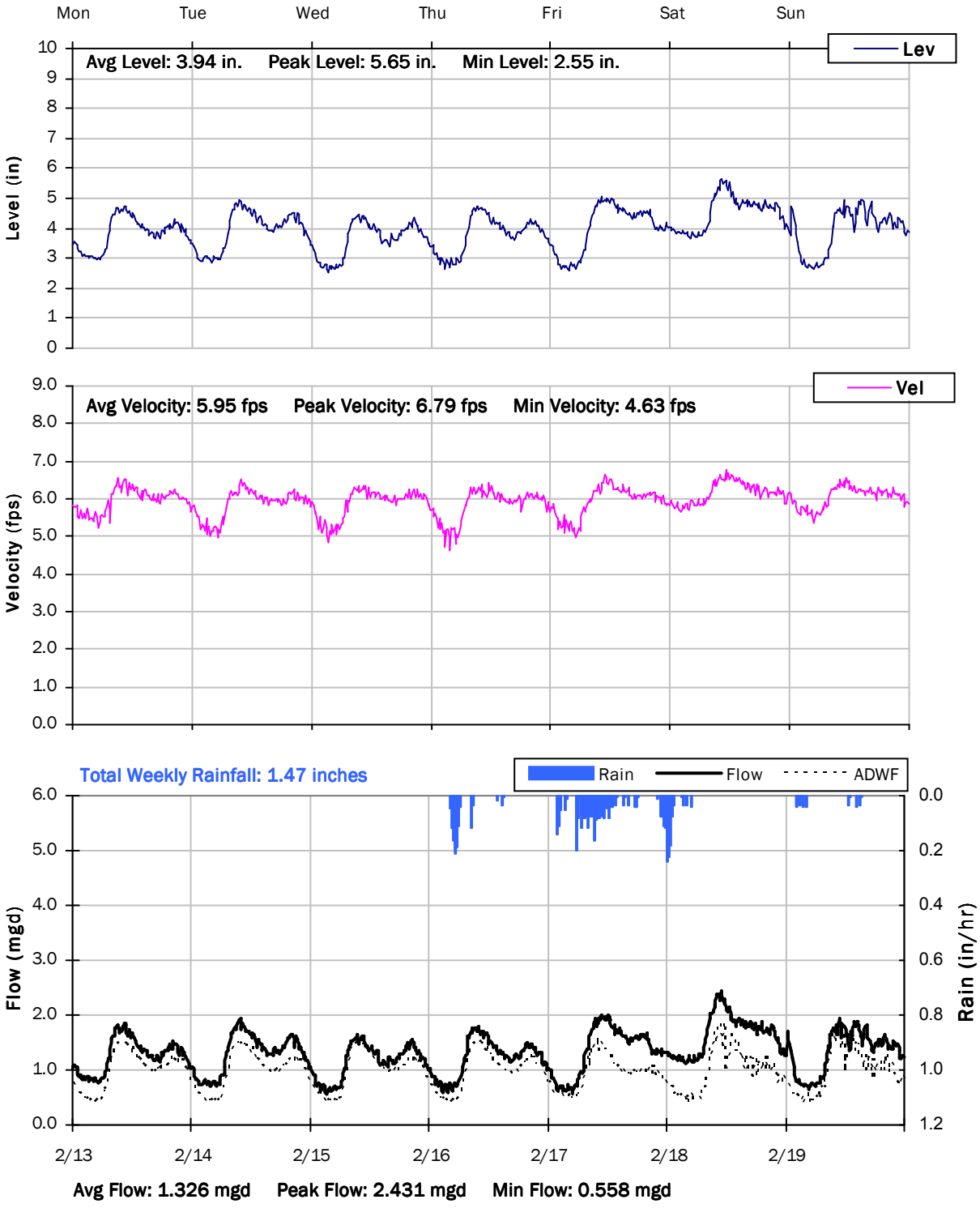
2/6/2017 to 2/13/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

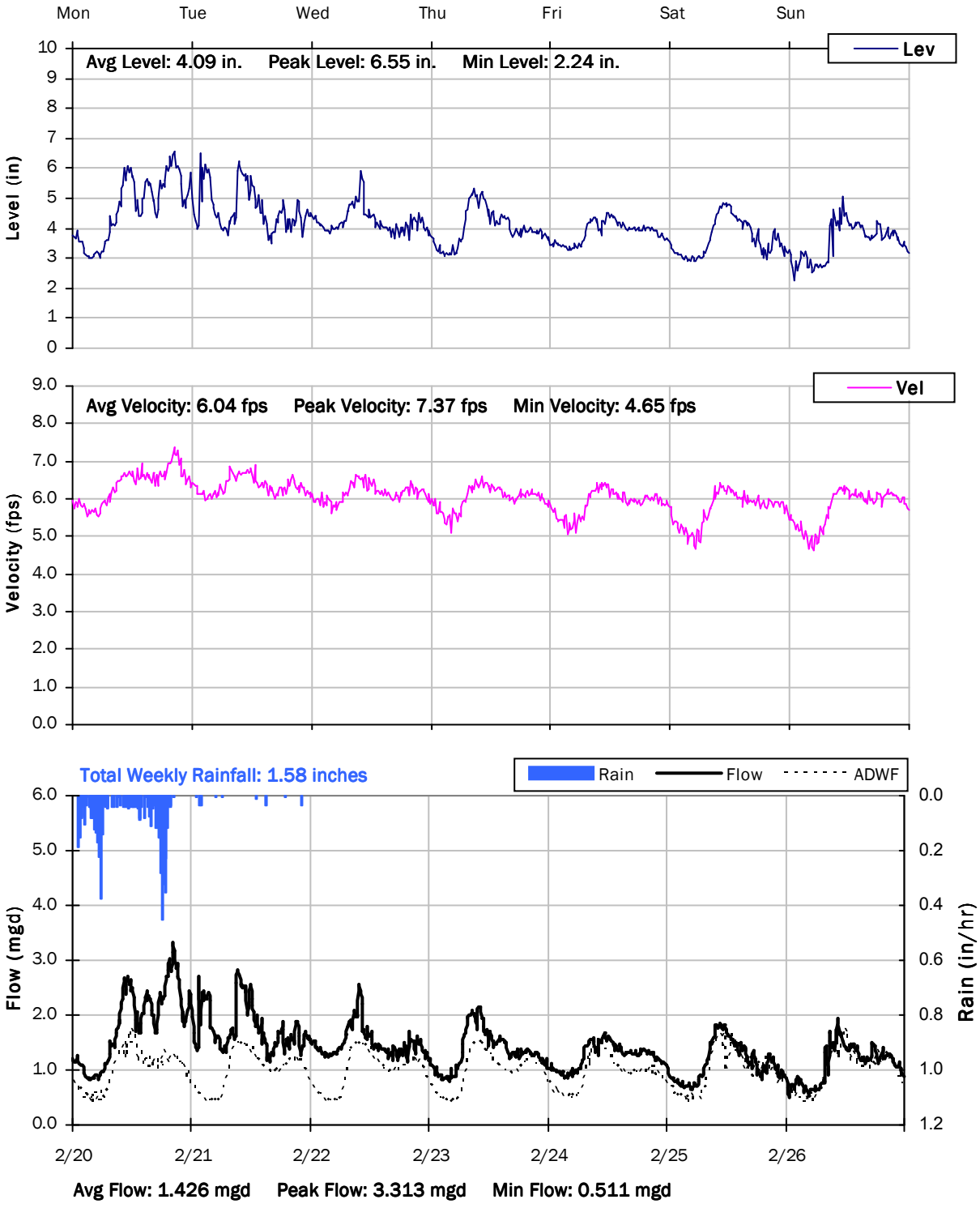
2/13/2017 to 2/20/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

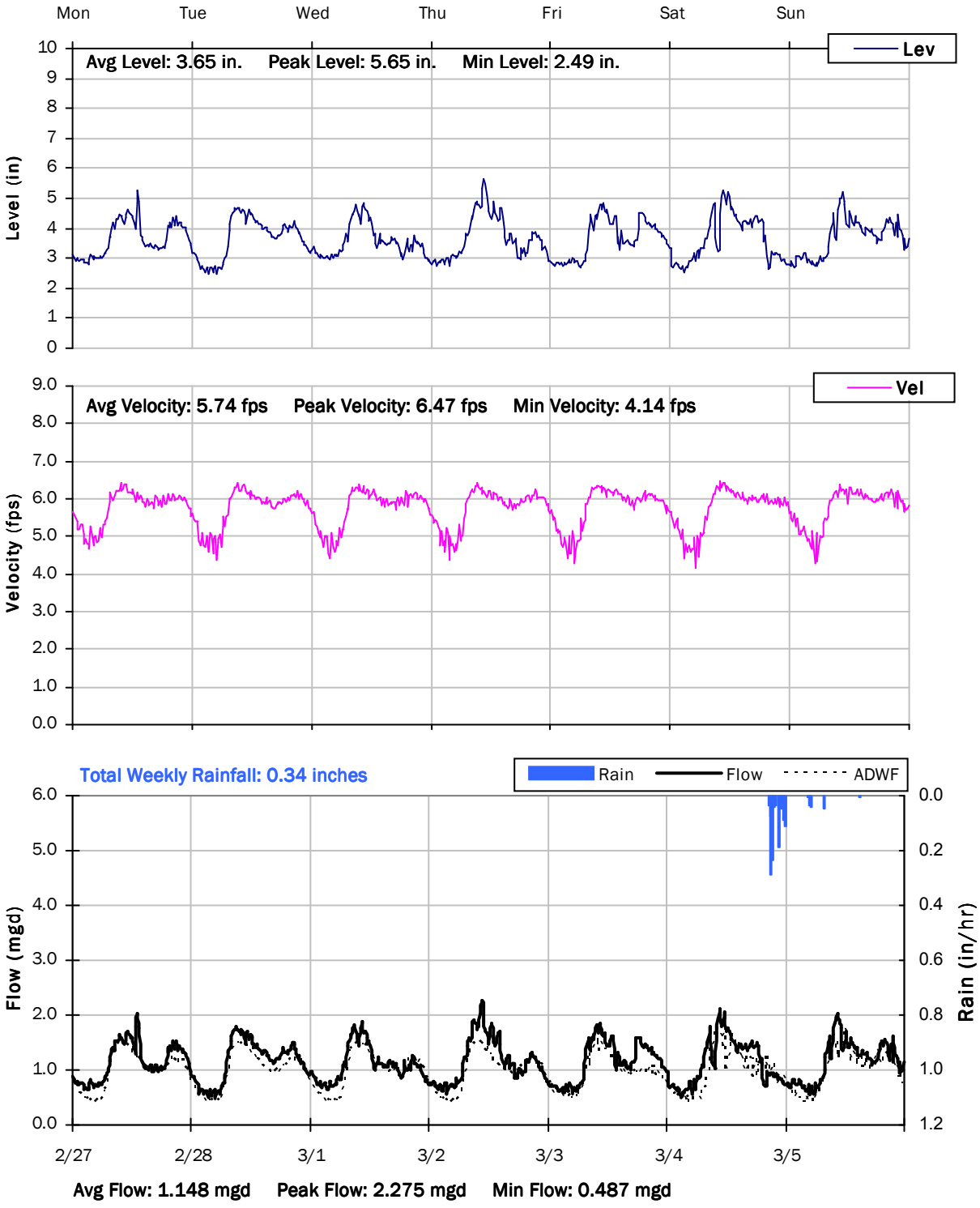
2/20/2017 to 2/27/2017



SITE 08

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



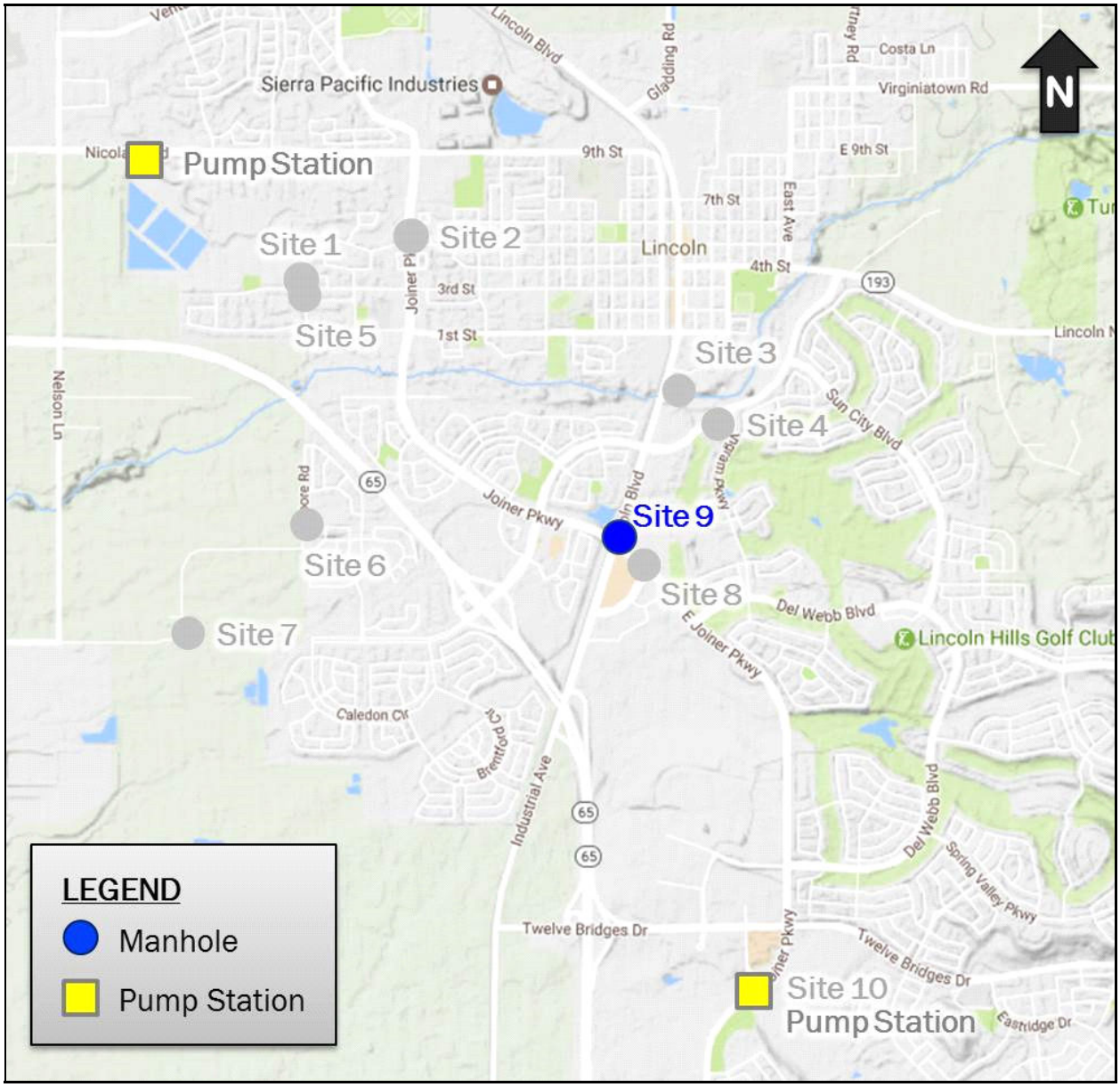
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 09

Location: Lincoln Boulevard sidewalk next to Arco gas station

Data Summary Report



Vicinity Map: Site 09

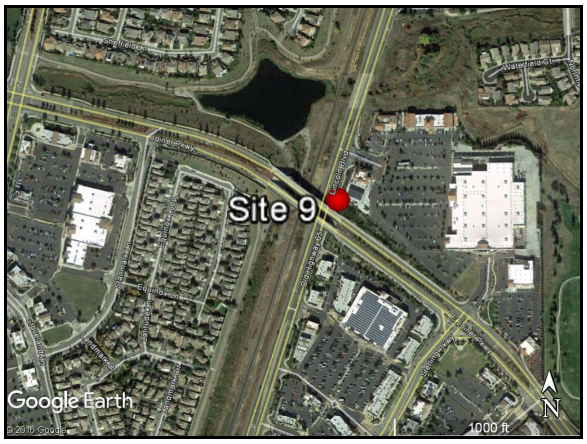
SITE 09

Site Information

Location: Lincoln Boulevard sidewalk next to Arco gas station

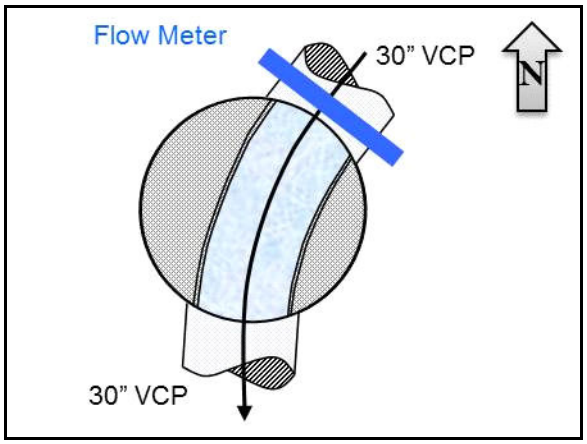
District ID: SE461SS05

Coordinates:	121.2974° W, 38.8742° N
Expected Pipe Diameter (Orig. if Relocated):	30 inches
Measured Pipe Diameter:	30 inches
ADWF:	0.777 mgd
Peak Measured Flow:	2.179 mgd
Rim Elevation (GEarth):	150 feet



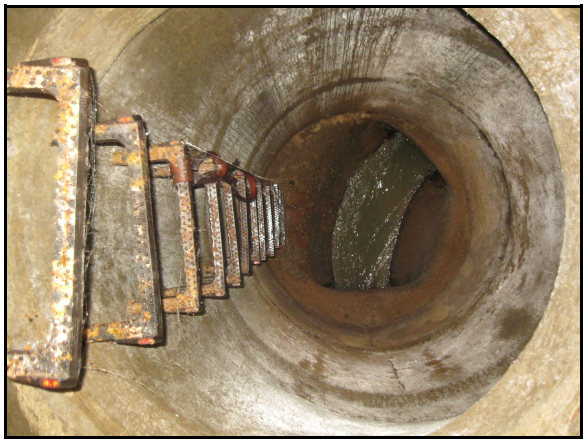
Satellite Map

Sewer Map



Flow Sketch

Street View



Plan View

SITE 09

Additional Site Photos

Effluent Pipe

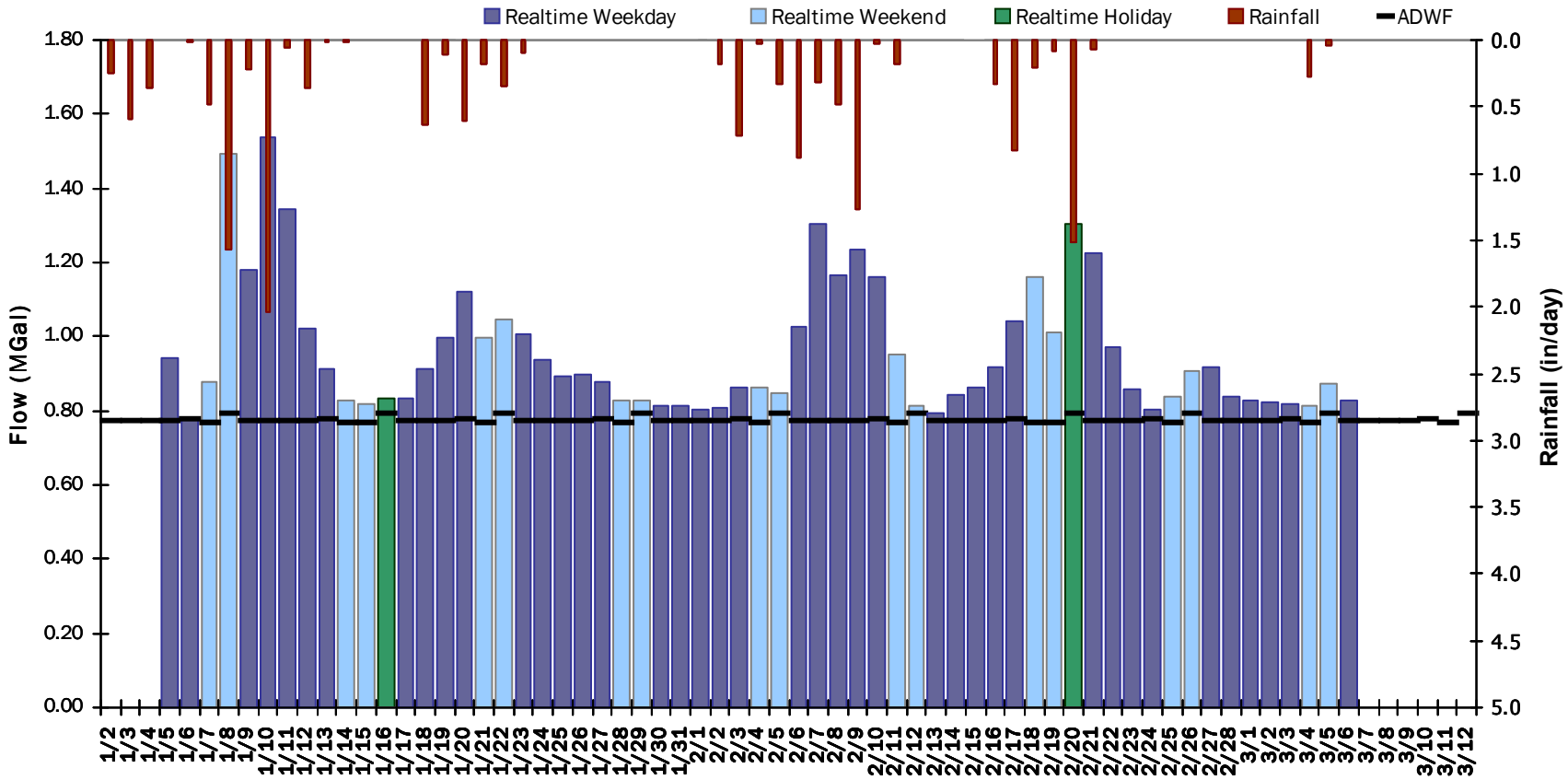
Influent Pipe

SITE 09

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 0.959 MGal Peak Daily Flow: 1.539 MGal Min Daily Flow: 0.778 MGal

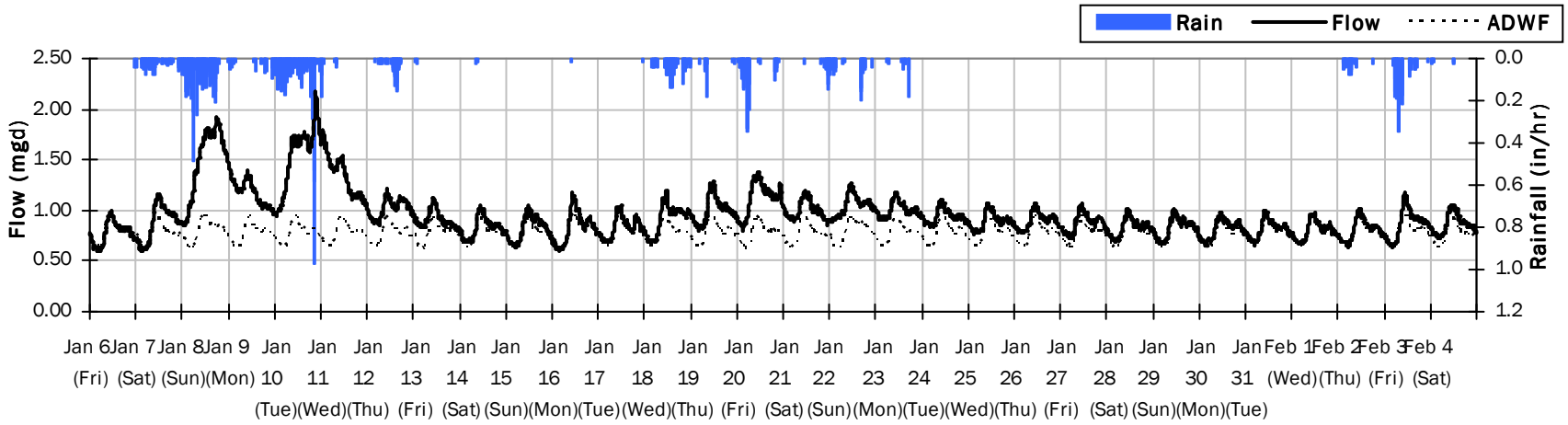
Total Period Rainfall: 15.71 inches

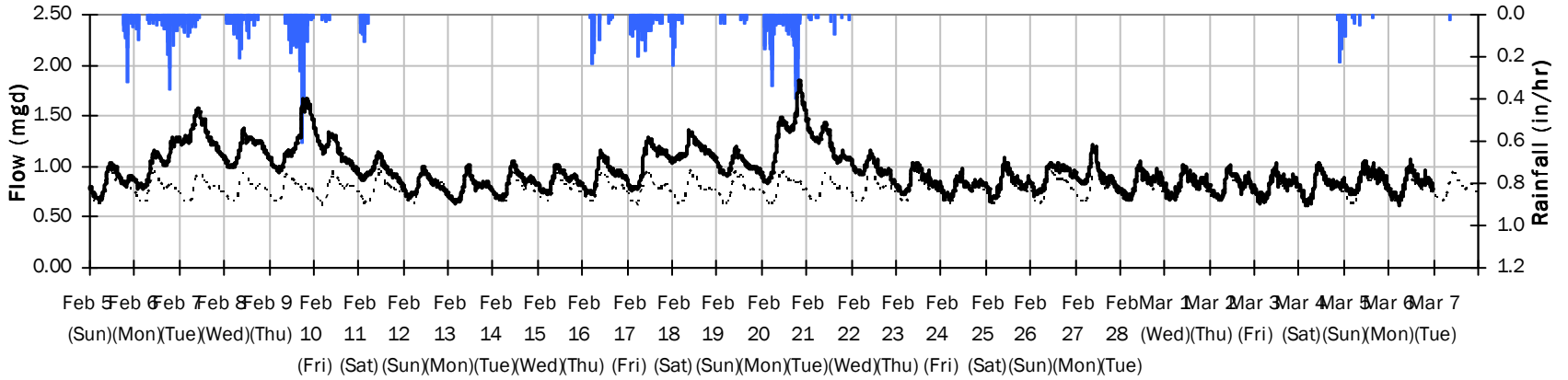


SITE 09

Flow Summary: 1/6/2017 to 3/7/2017

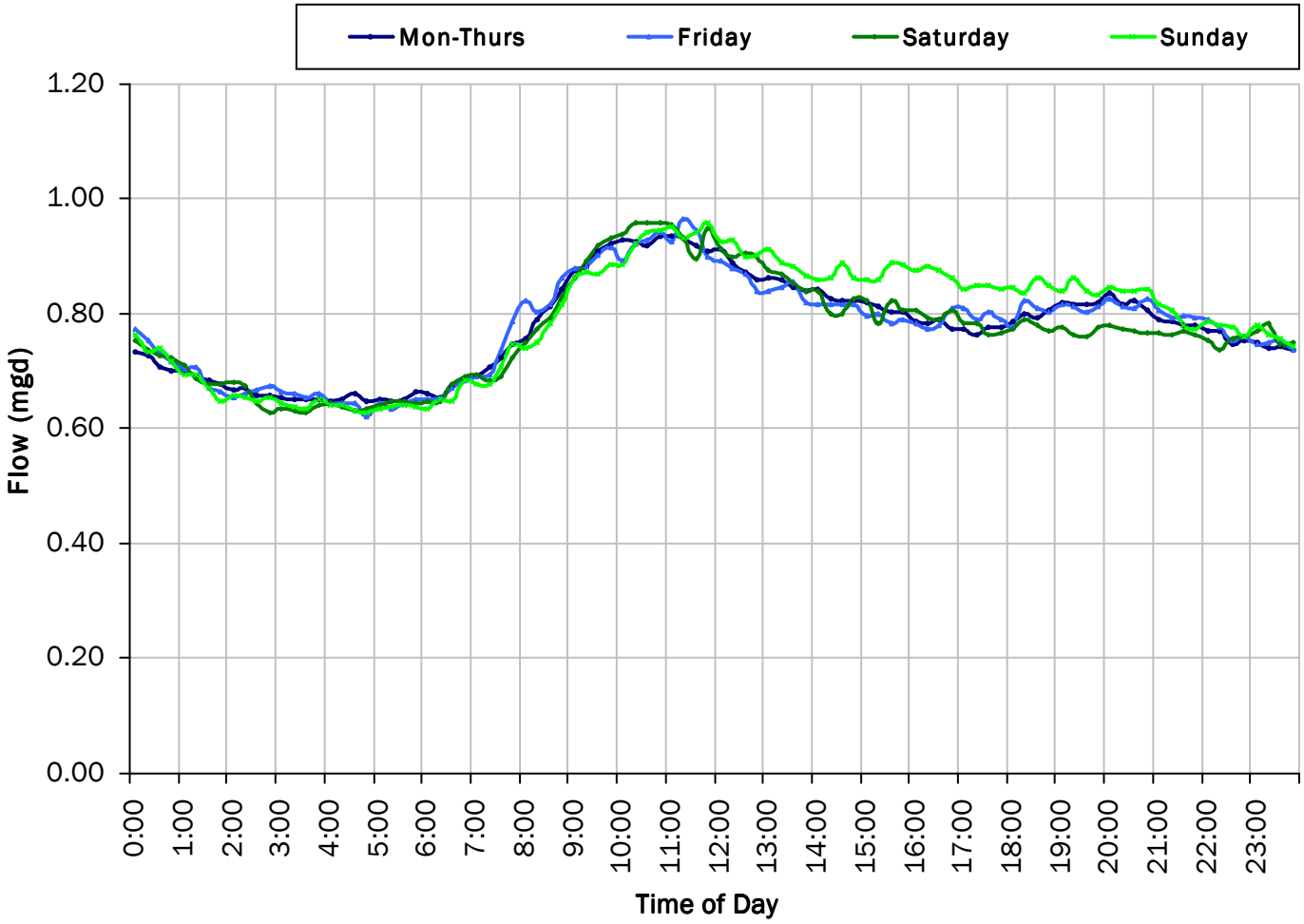
Total Period Rainfall: 14.50 inches **Avg Flow: 0.959 mgd** **Peak Flow: 2.179 mgd** **Min Flow: 0.590 mgd**





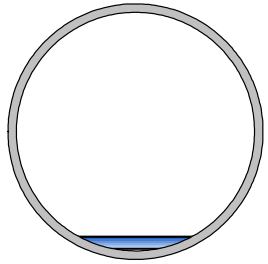
SITE 09

Average Dry Weather Flow Hydrographs



ADWF:

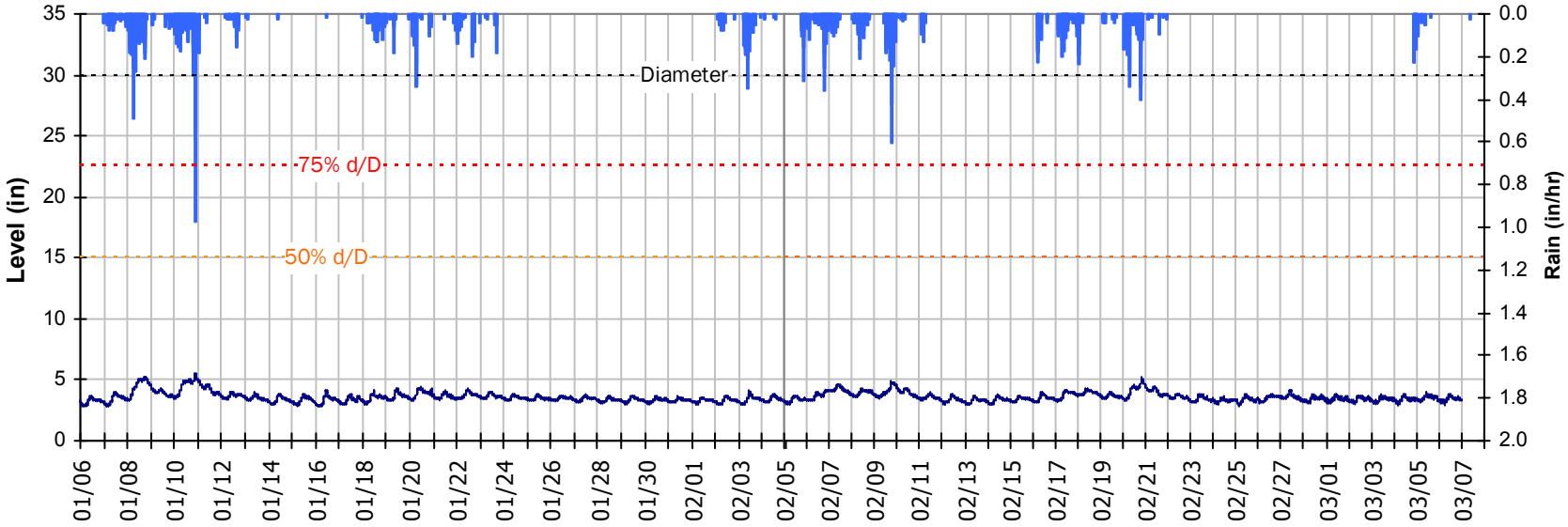
0.777 *mgd*

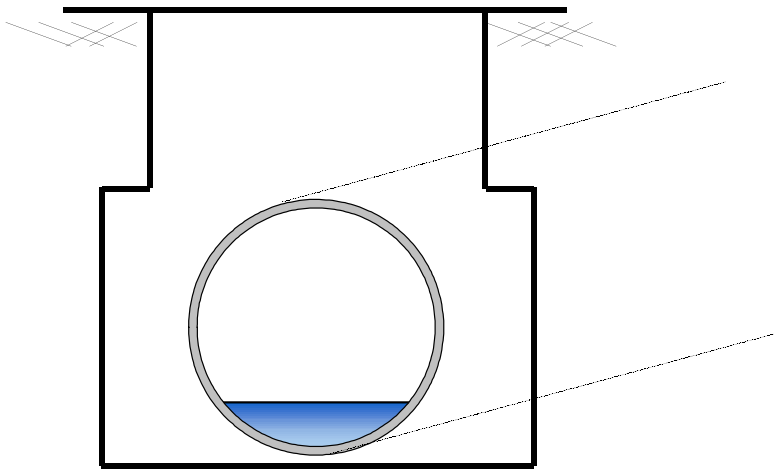


SITE 09

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period



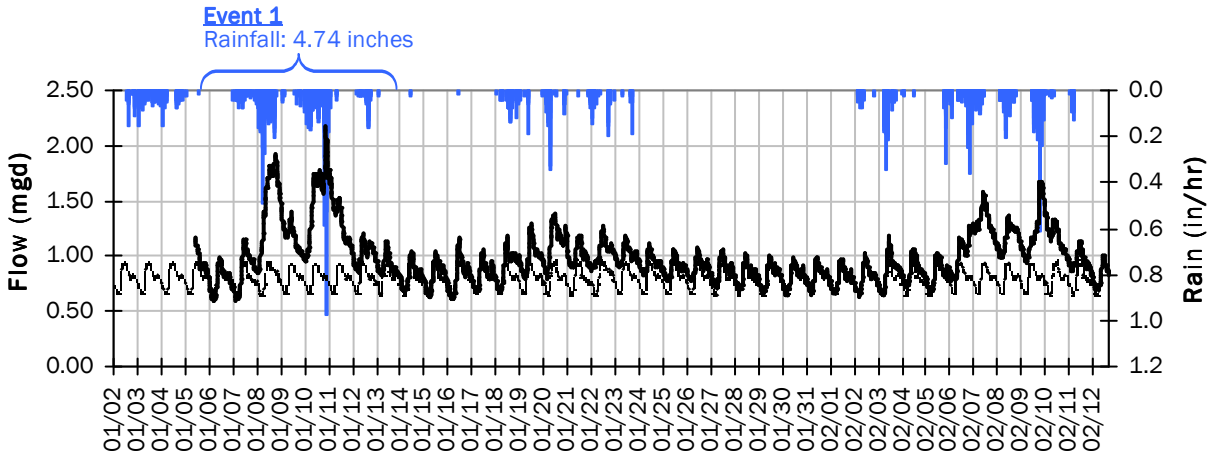


Pipe Diameter:	30	*inches*
Peak Measured Level:	5.58	*inches*
Peak d/D Ratio:	0.19	

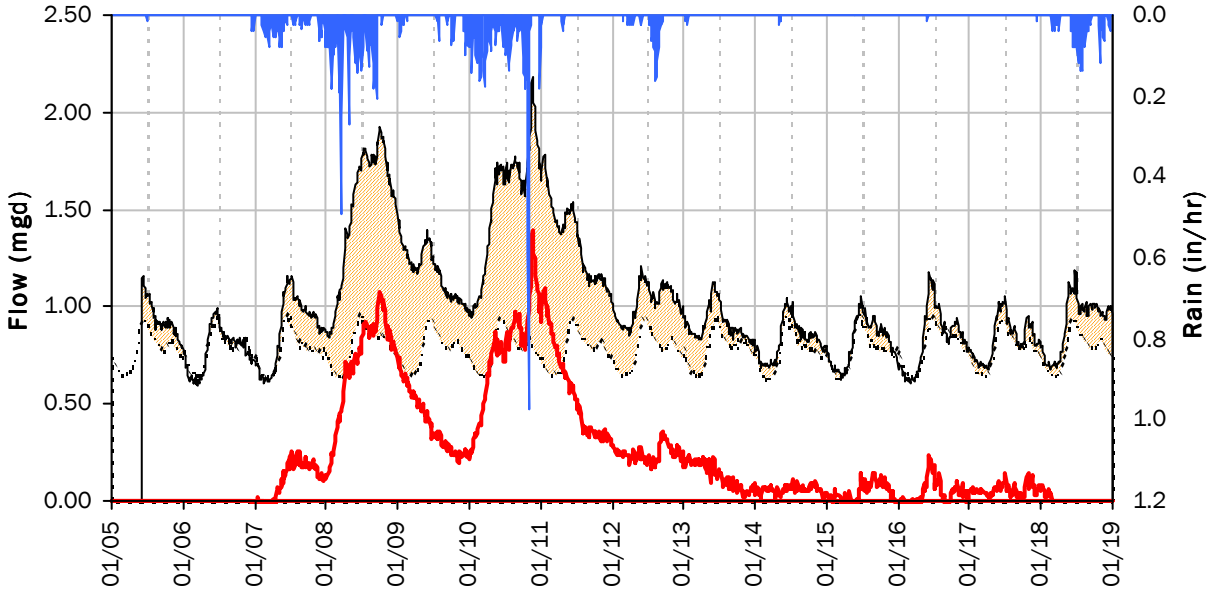
SITE 09

I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

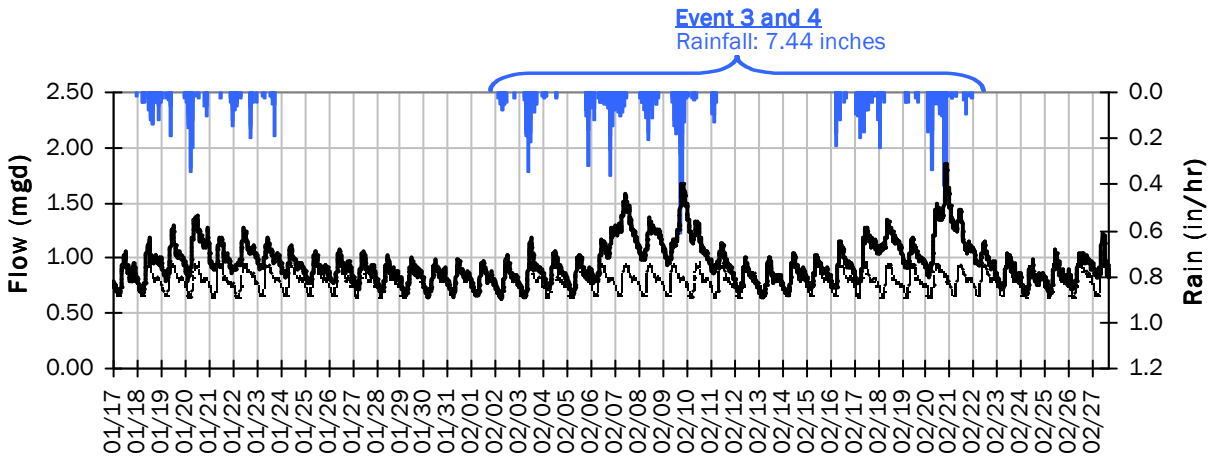


Storm Event I/I Analysis (Rain = 4.74 inches)

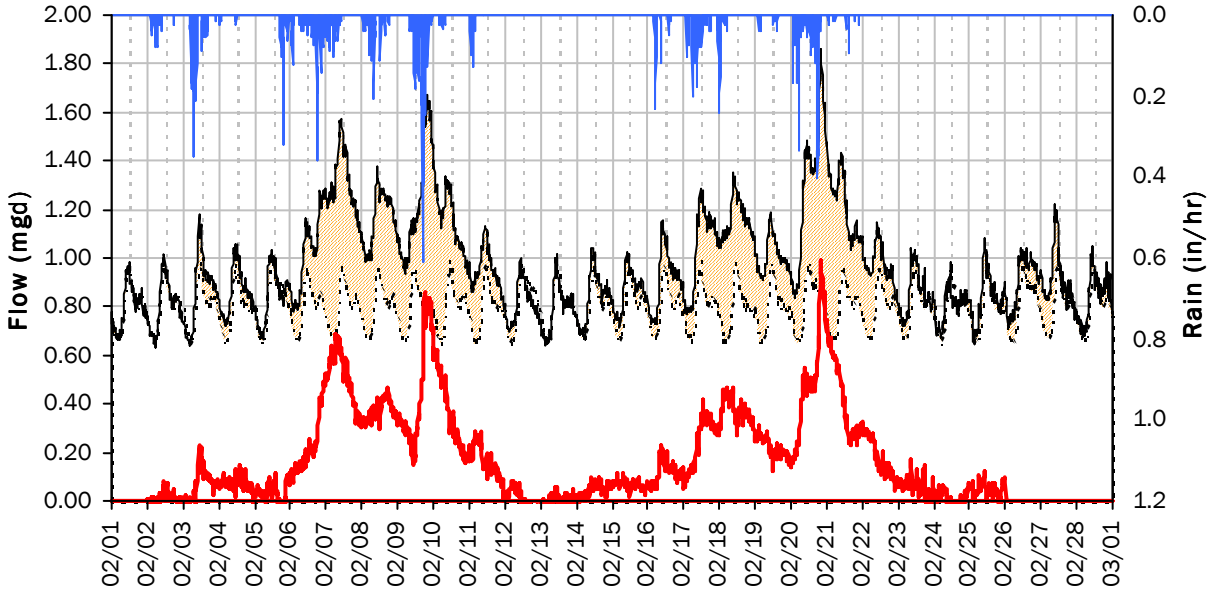
Capacity		Inflow / Infiltration	
Peak Flow:	2.18 *mgd*	**Peak I/I Rate:**	1.39 *mgd*
PF:	2.80	**Total I/I:**	3,134,000 *gallons*
Peak Level:	5.58 *in*		
d/D Ratio:	0.19		

SITE 09
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph



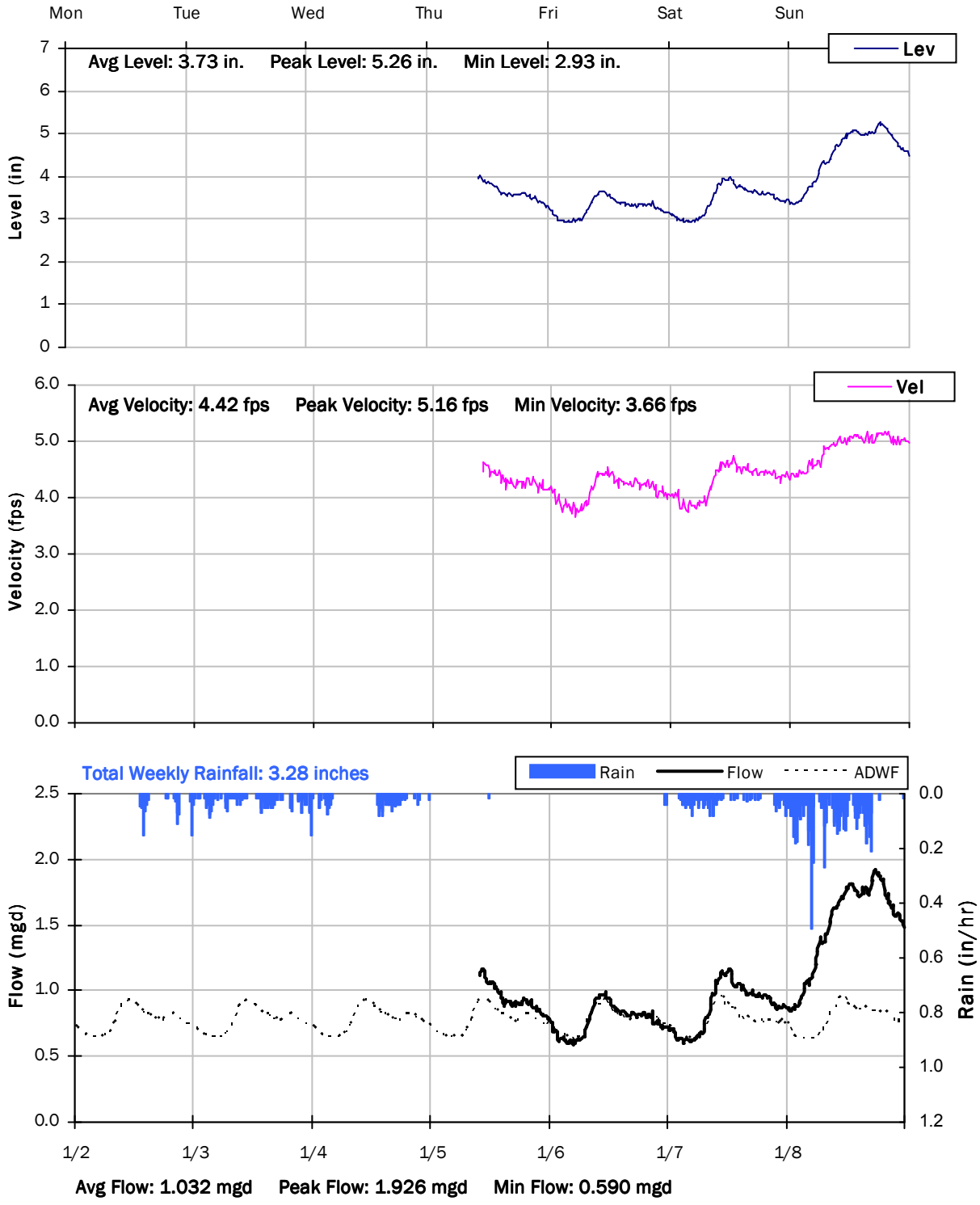
Storm Event I/I Analysis (Rain = 7.44 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	1.86 *mgd*	**Peak I/I Rate:**	0.99 *mgd*
PF:	2.39	**Total I/I:**	4,541,000 *gallons*
Peak Level:	5.15 *in*		
d/D Ratio:	0.17		

SITE 09

Weekly Level, Velocity and Flow Hydrographs

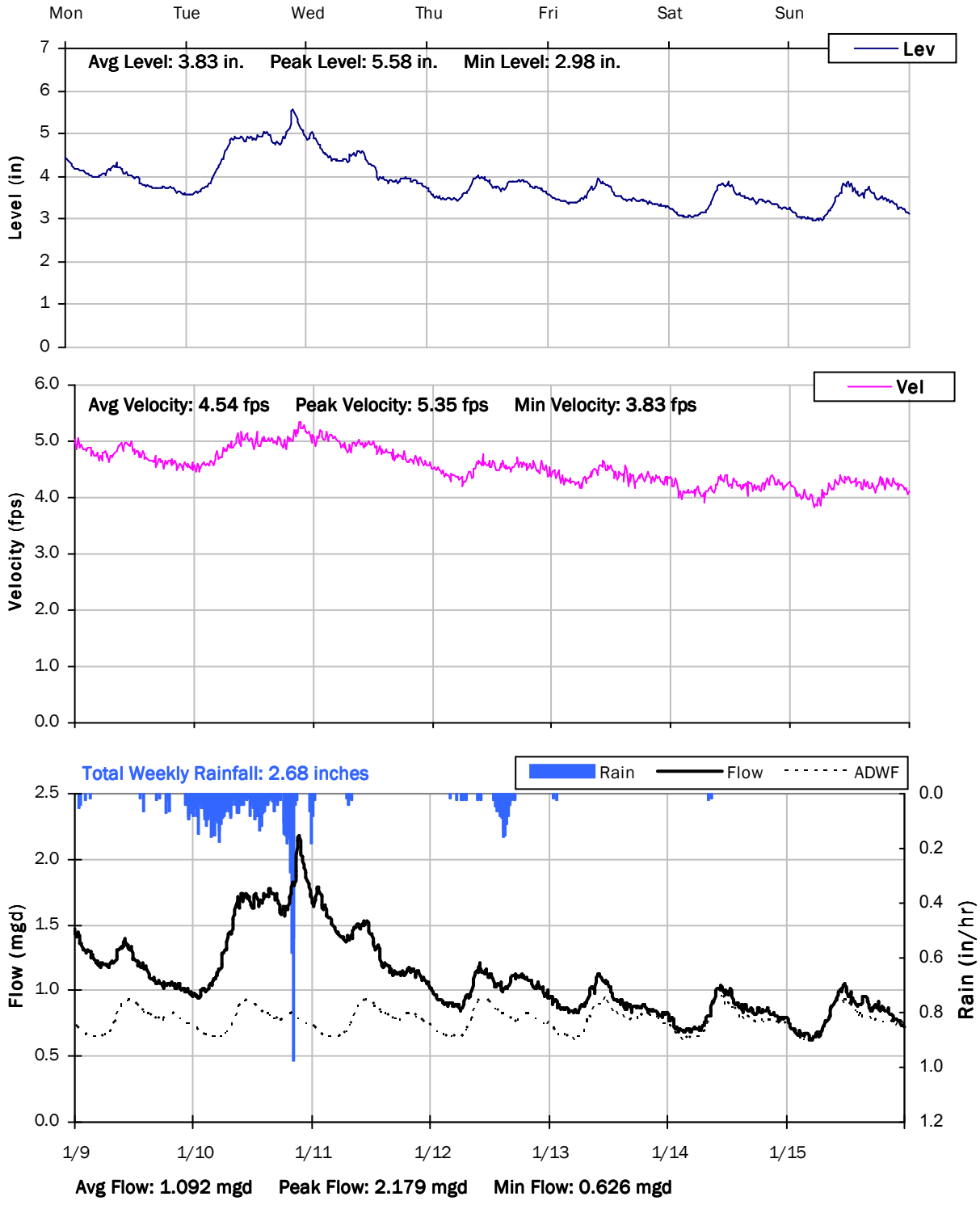
1/2/2017 to 1/9/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

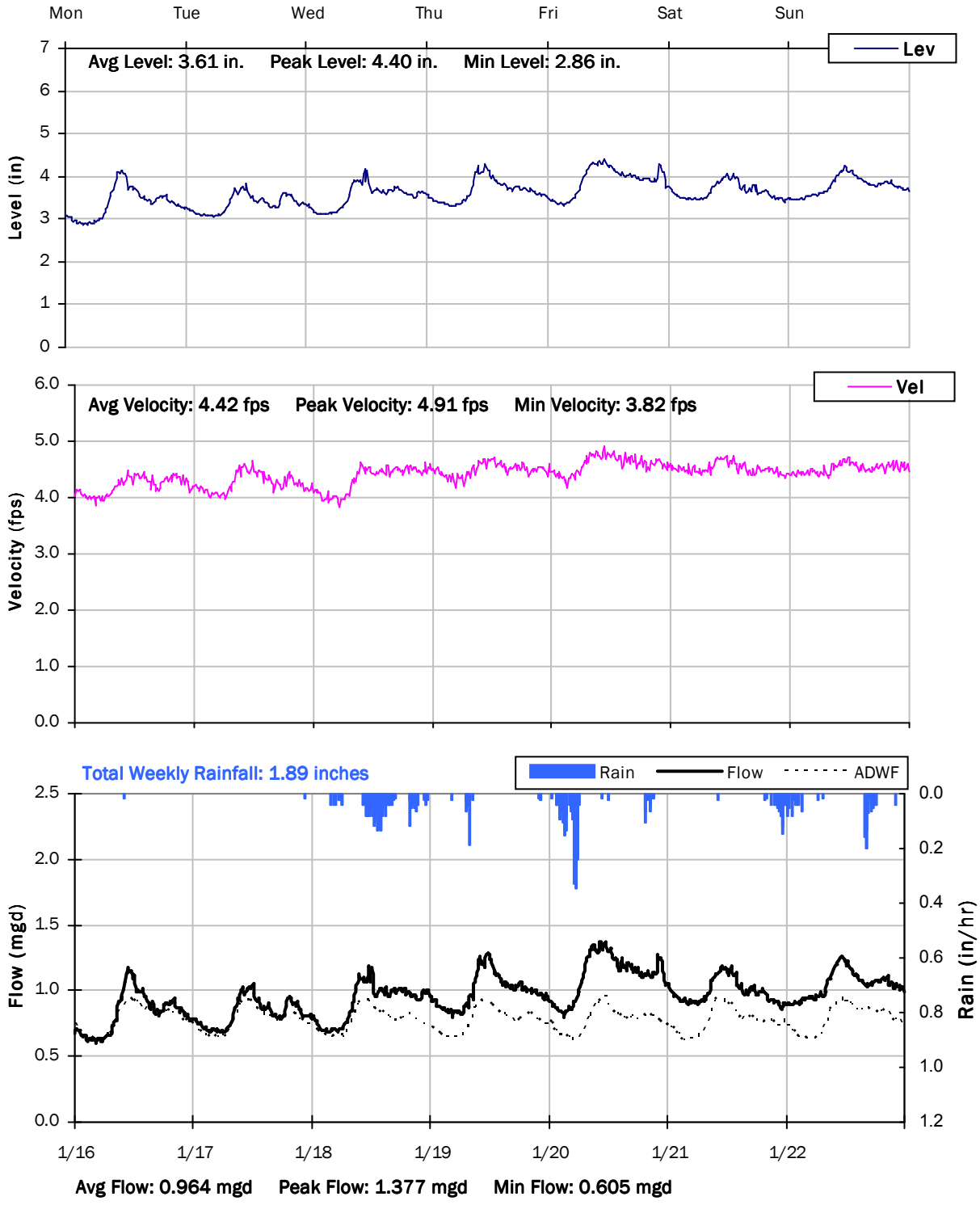
1/9/2017 to 1/16/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

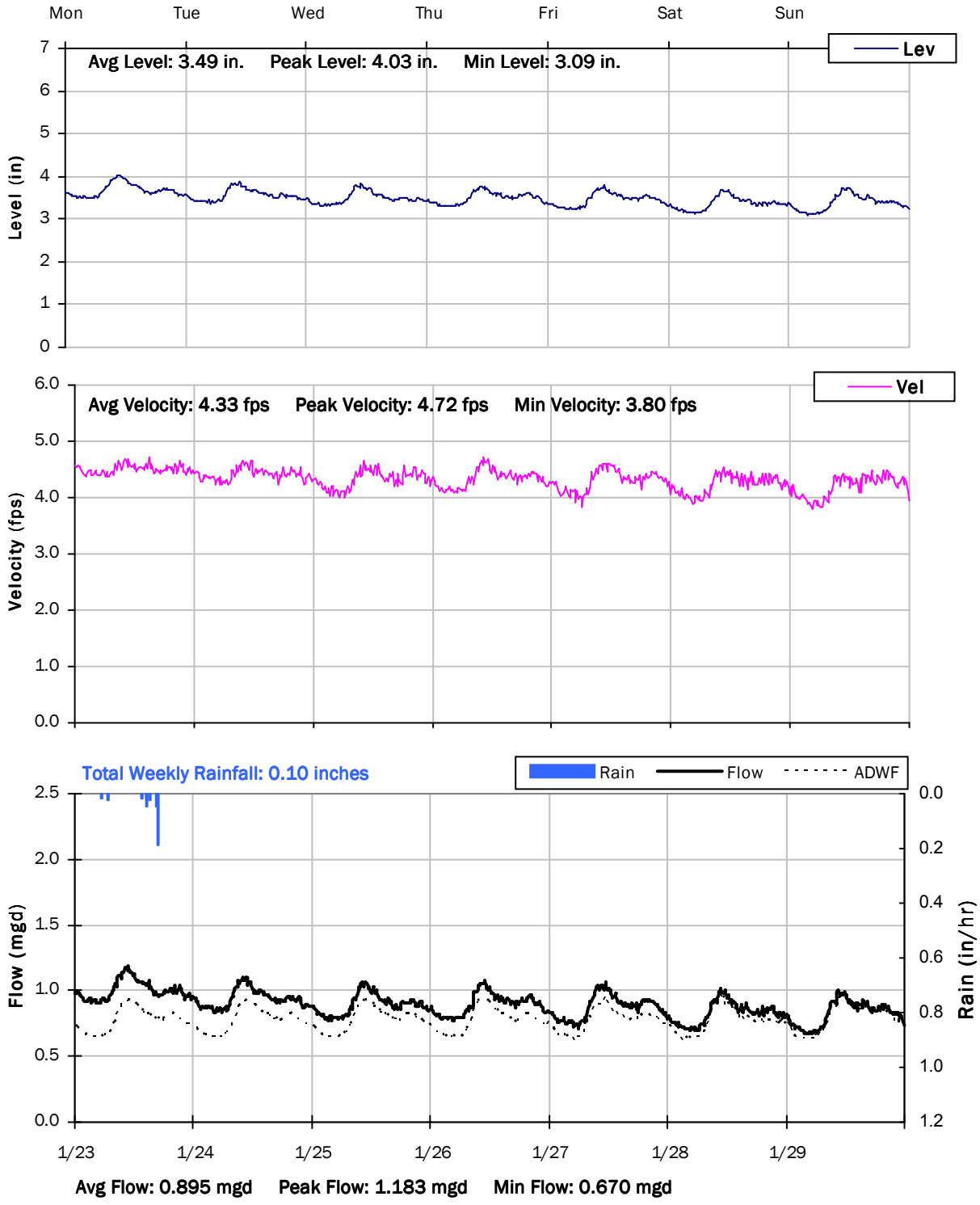
1/16/2017 to 1/23/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

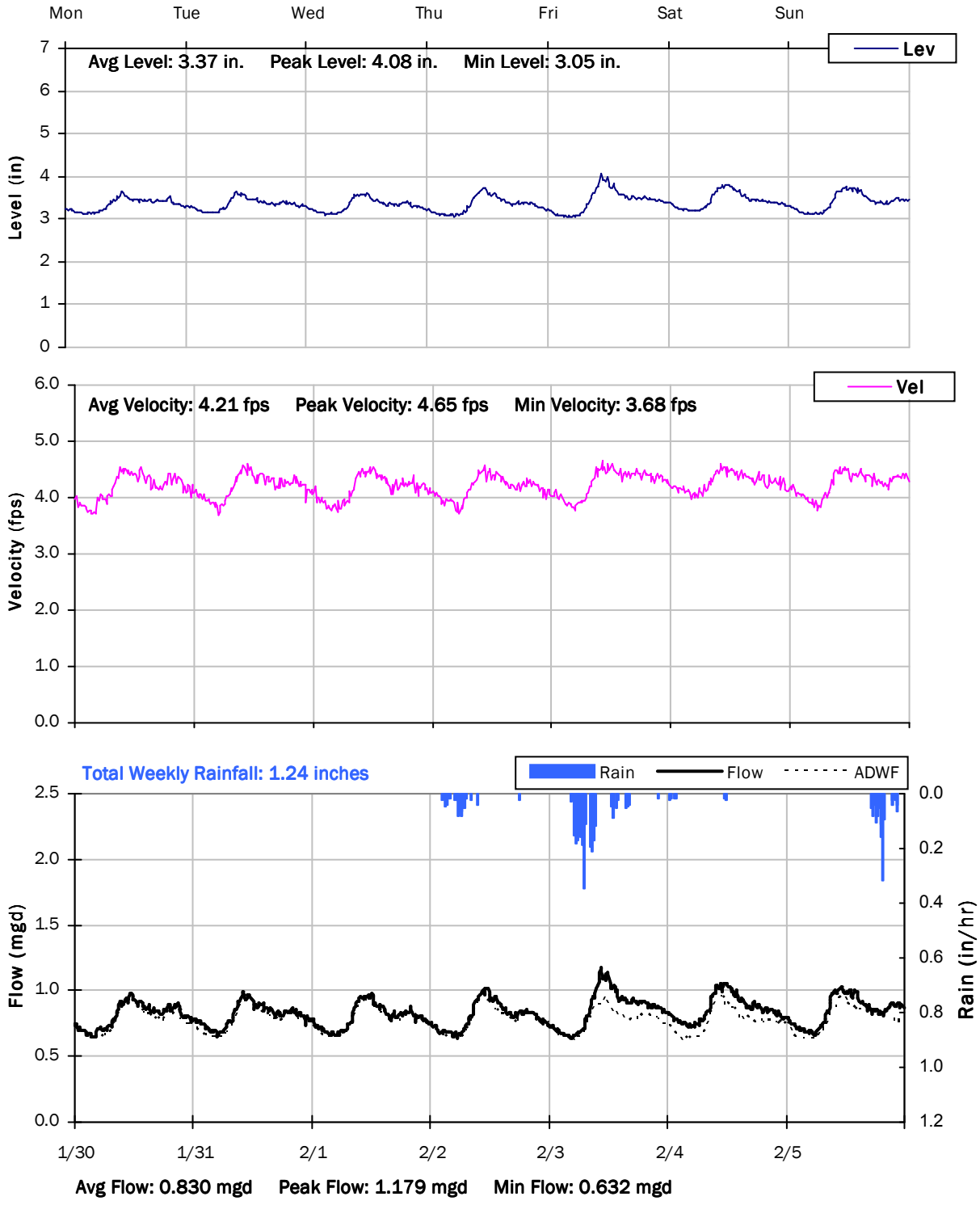
1/23/2017 to 1/30/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

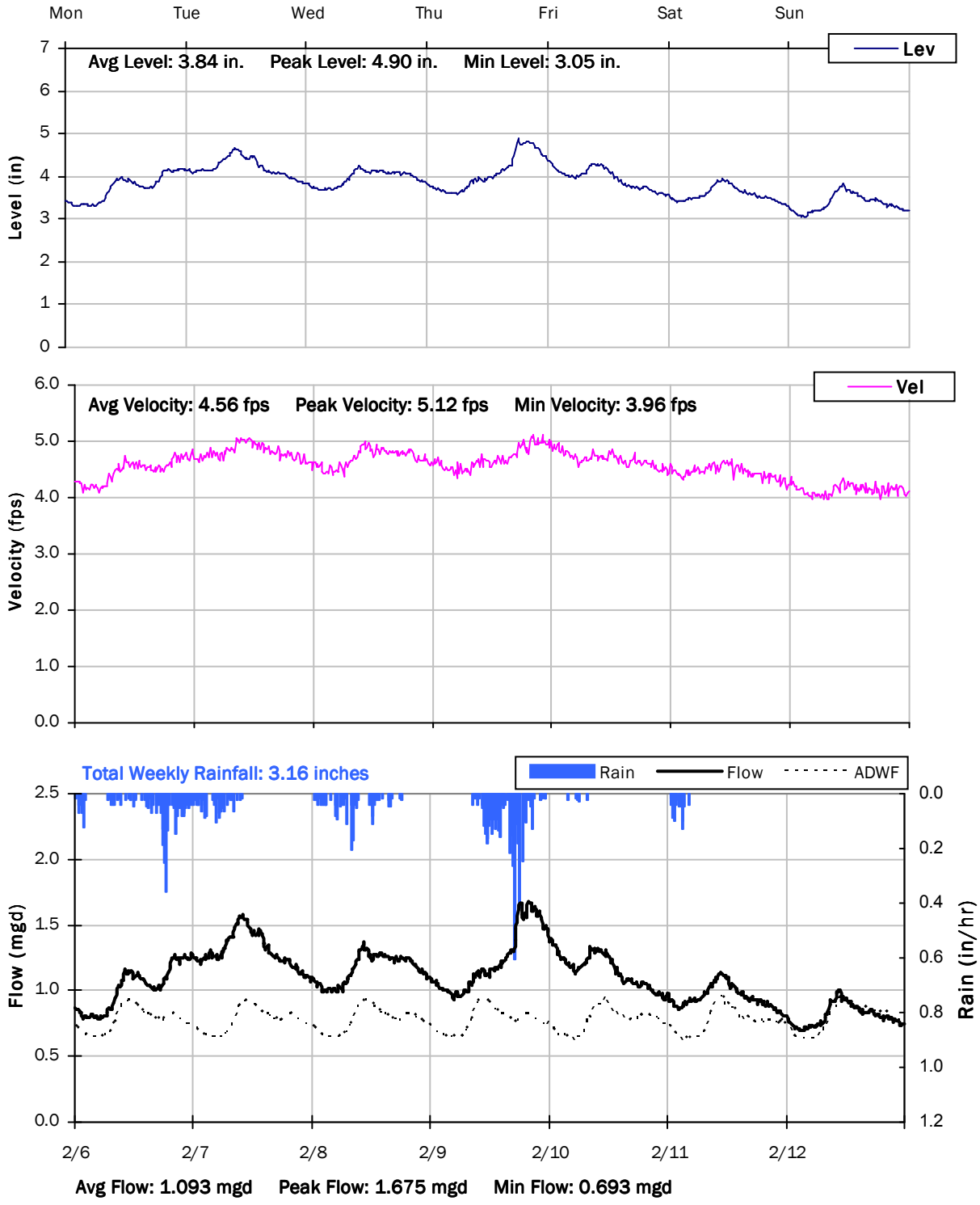
1/30/2017 to 2/6/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

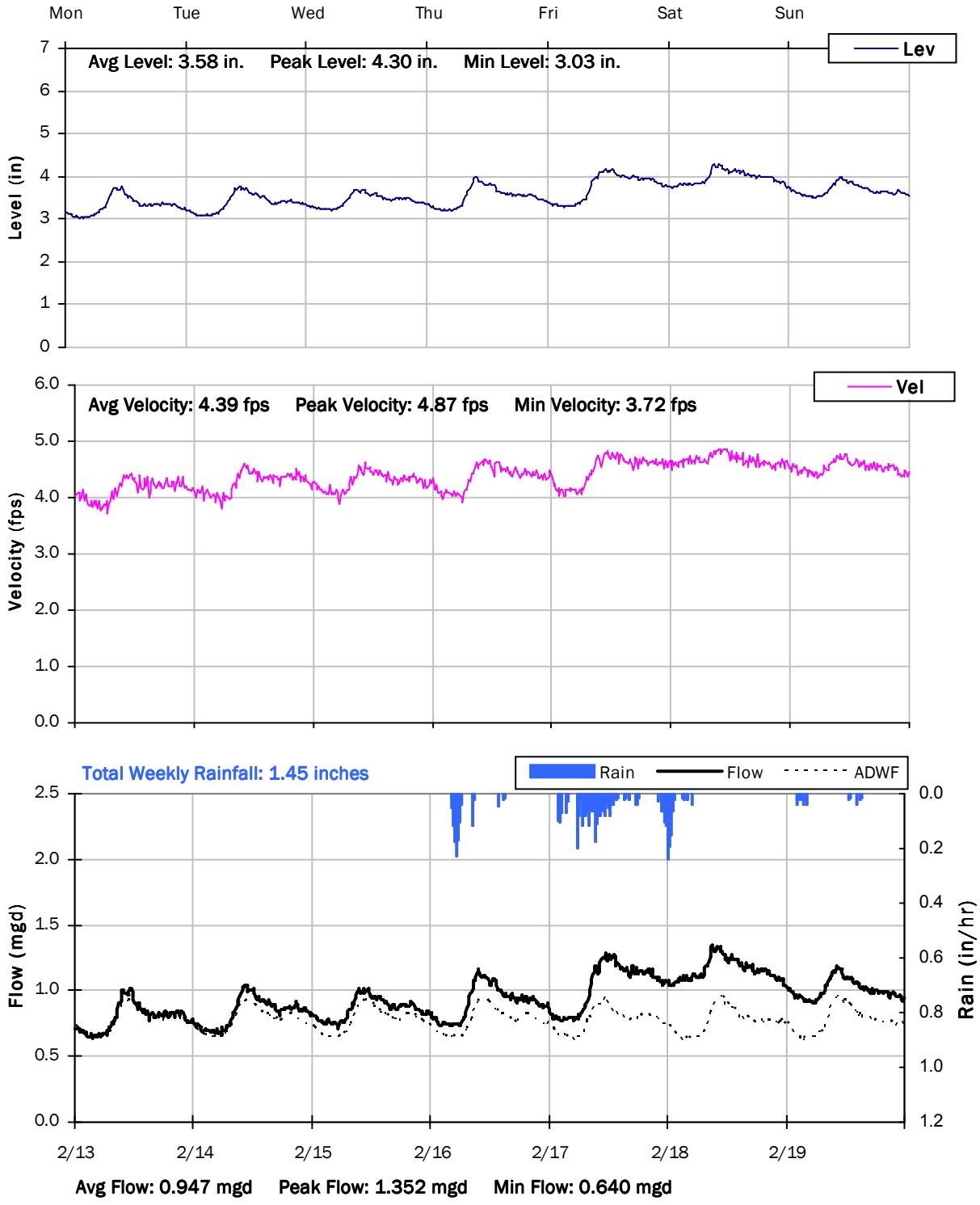
2/6/2017 to 2/13/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

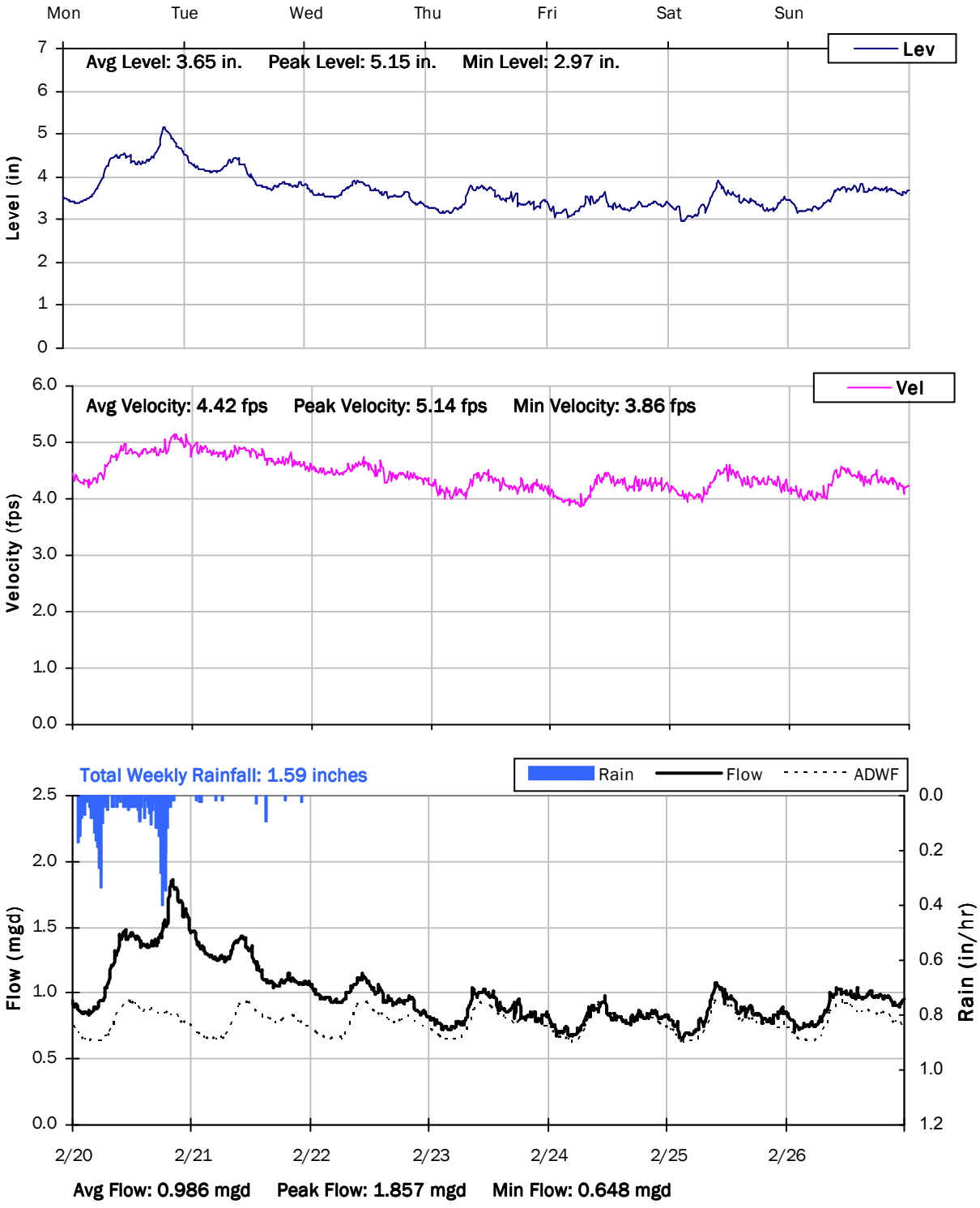
2/13/2017 to 2/20/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

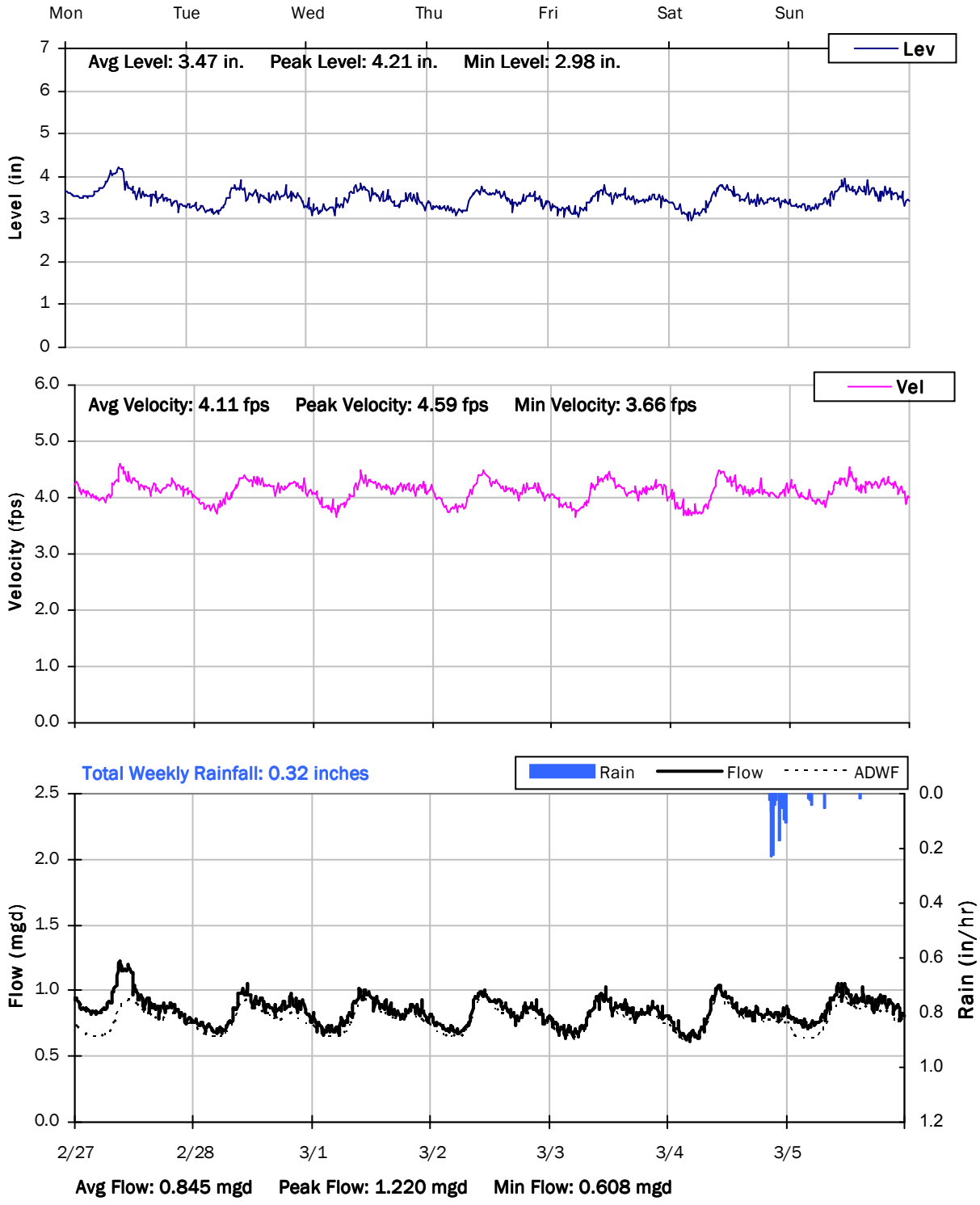
2/20/2017 to 2/27/2017



SITE 09

Weekly Level, Velocity and Flow Hydrographs

2/27/2017 to 3/6/2017



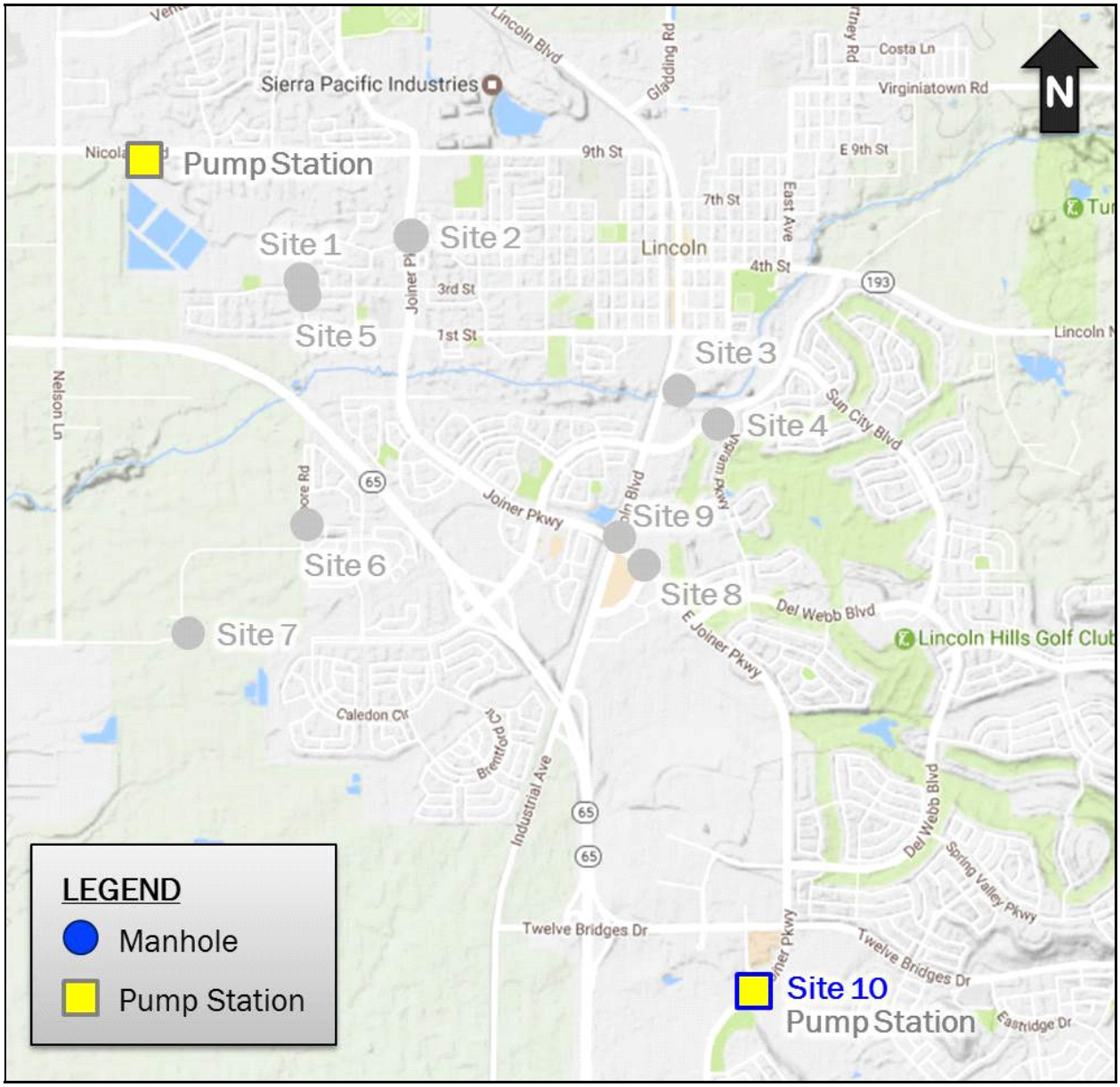
City of Lincoln

Sanitary Sewer Flow Monitoring
Temporary Monitoring: January 2017 - March 2017

Monitoring Site: Site 10

Location: East Joiner Parkway west of Fieldstone Drive

Data Summary Report



Vicinity Map: Site 10

SITE 10

Site Information

Location: East Joiner Parkway west of Fieldstone Drive

District ID: East Joiner PS

Coordinates: 121.2873° W, 38.8475° N

Expected Pipe Diameter (Orig. if Relocated): N/A

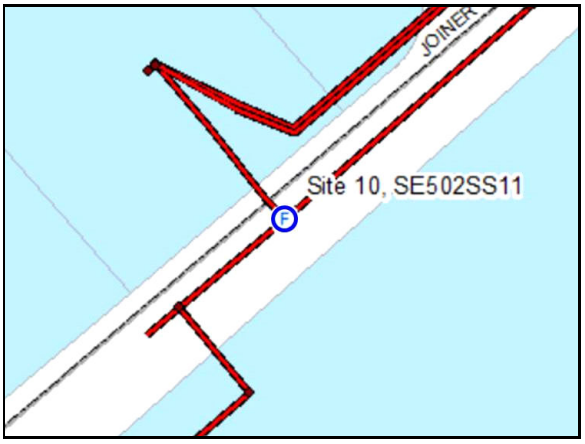
Measured Pipe Diameter: N/A

ADWF: 0.502 mgd

Peak Measured Flow: 2.081 mgd

Rim Elevation (GEarth): 147 feet

Satellite Map



Sewer Map

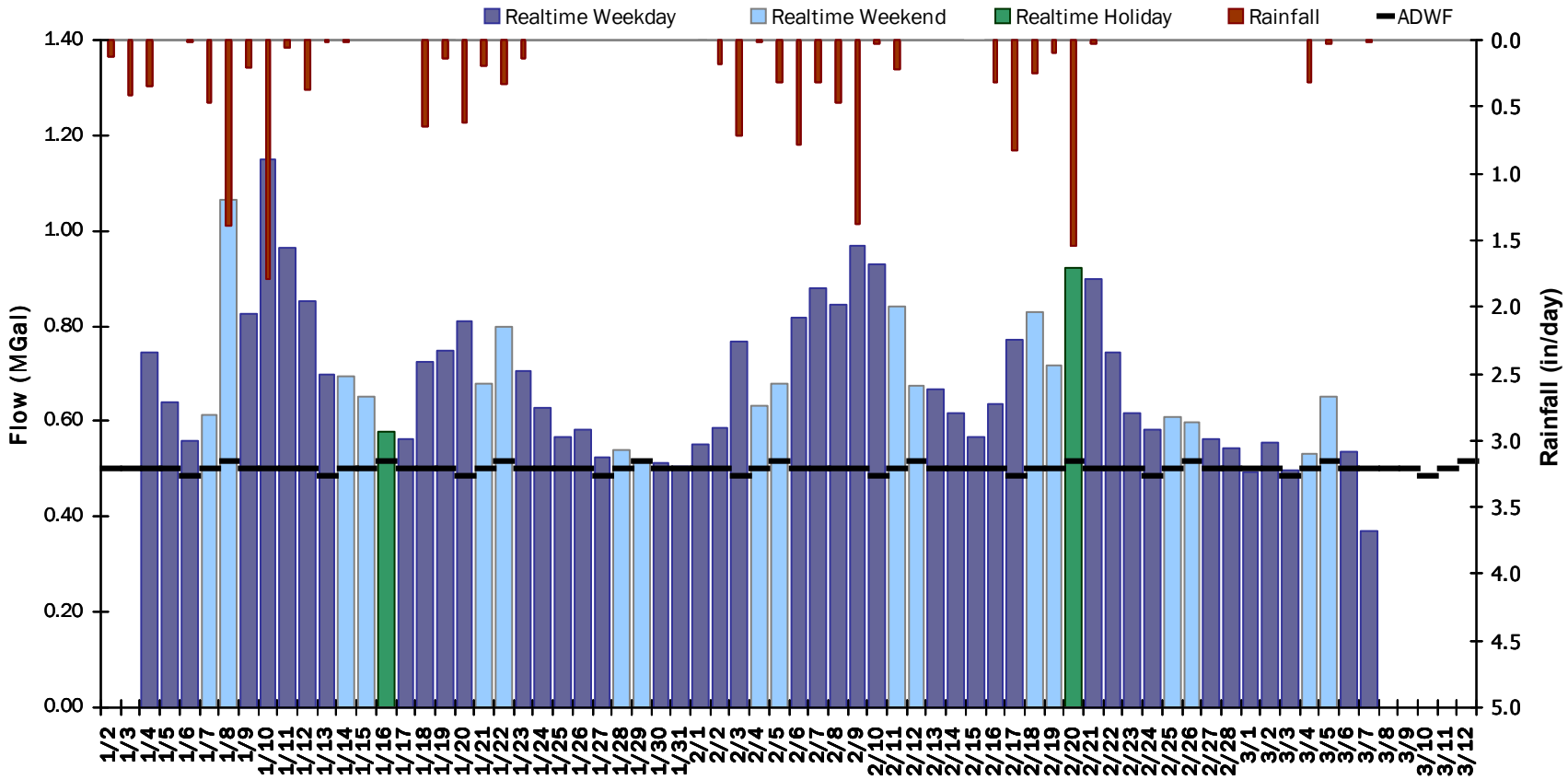
Street View

SITE 10

Period Flow Summary: Daily Flow Totals

Avg Period Flow: 0.685 MGal Peak Daily Flow: 1.151 MGal Min Daily Flow: 0.369 MGal

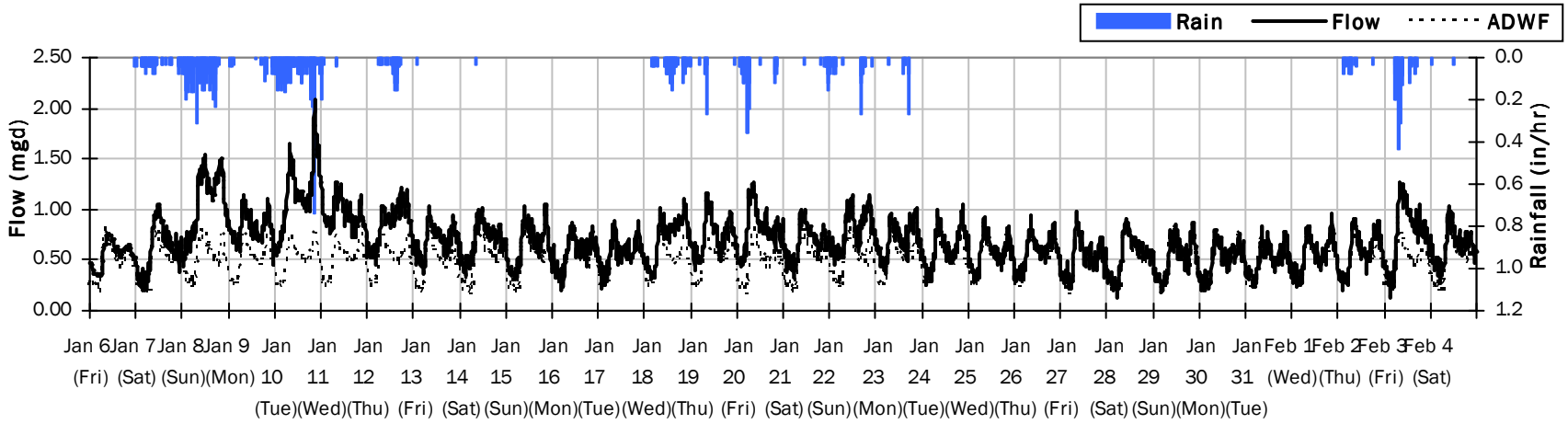
Total Period Rainfall: 15.10 inches

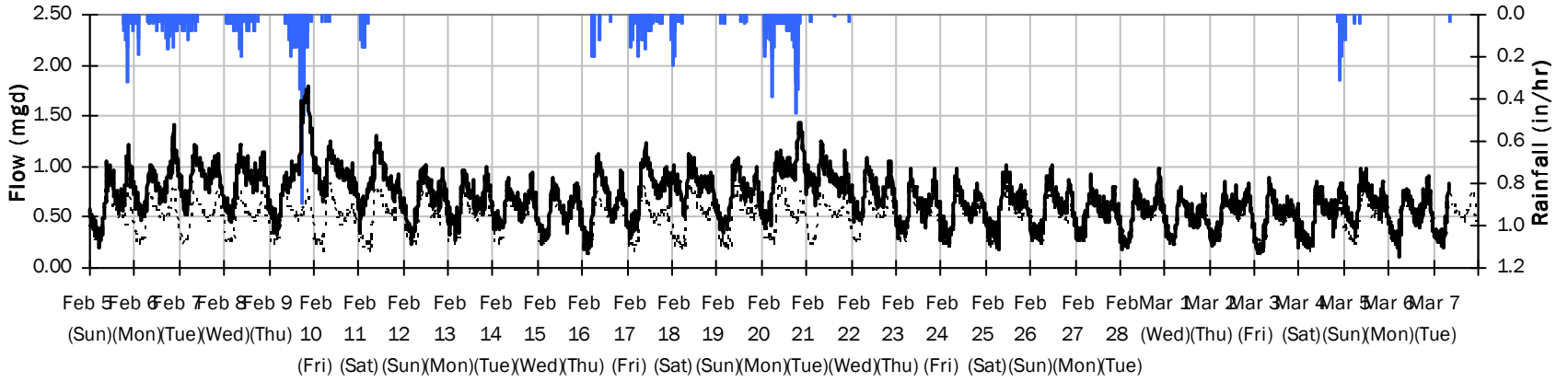


SITE 10

Flow Summary: 1/6/2017 to 3/7/2017

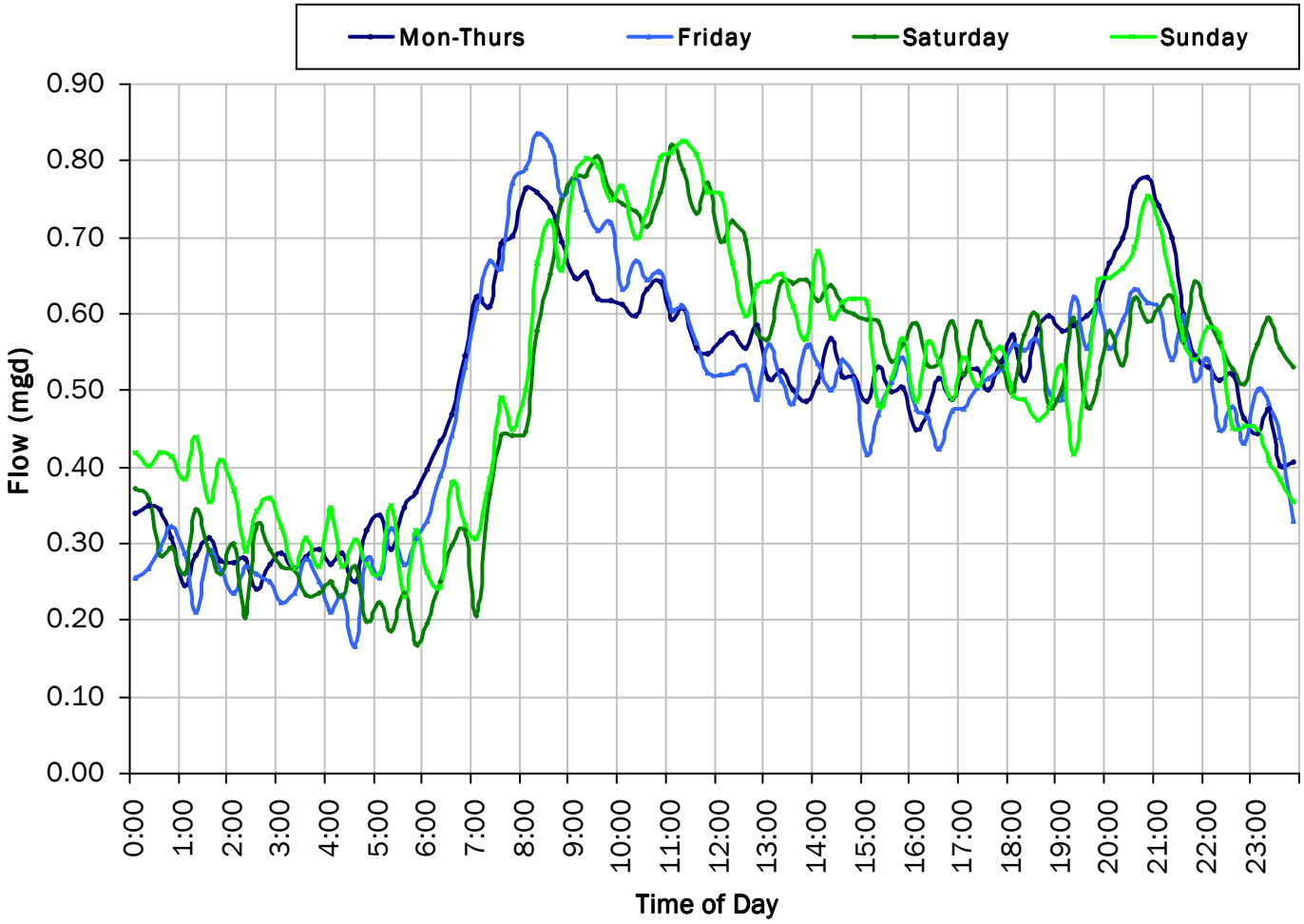
Total Period Rainfall: 14.22 inches **Avg Flow: 0.688 mgd** **Peak Flow: 2.081 mgd** **Min Flow: 0.116 mgd**





SITE 10

Average Dry Weather Flow Hydrographs

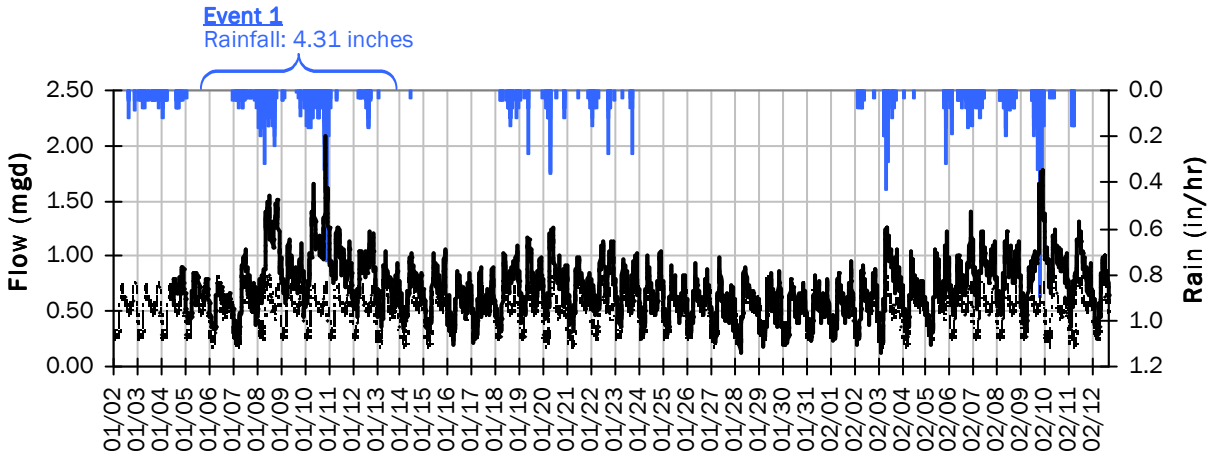


ADWF:

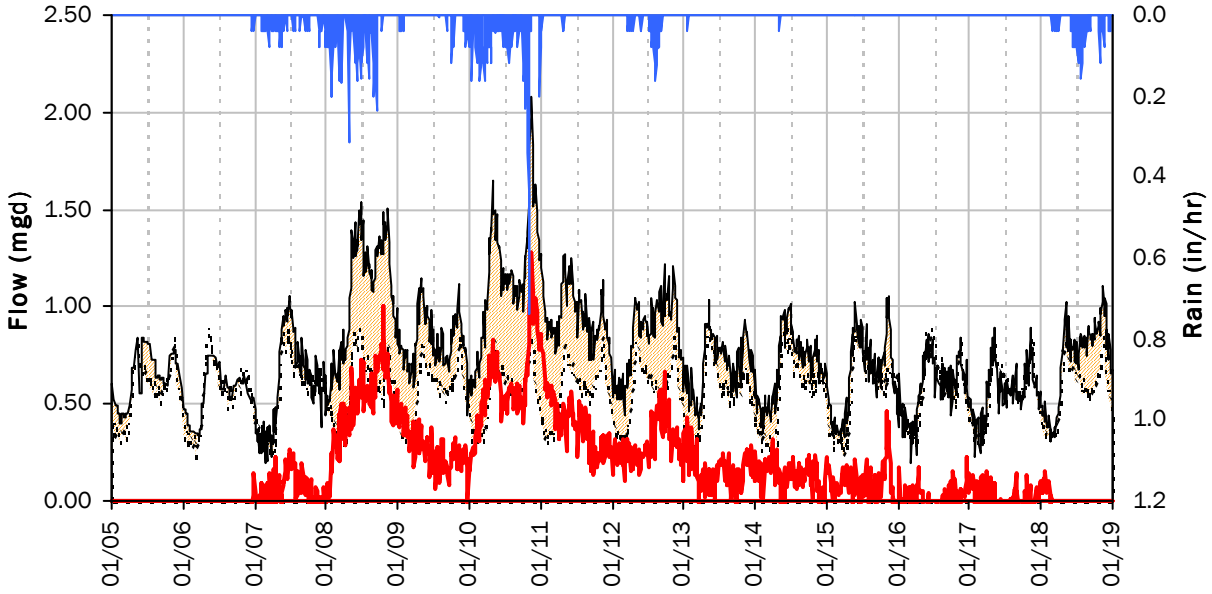
0.502 *mgd*

SITE 10
I/I Summary: Event 1

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 1 Detail Graph

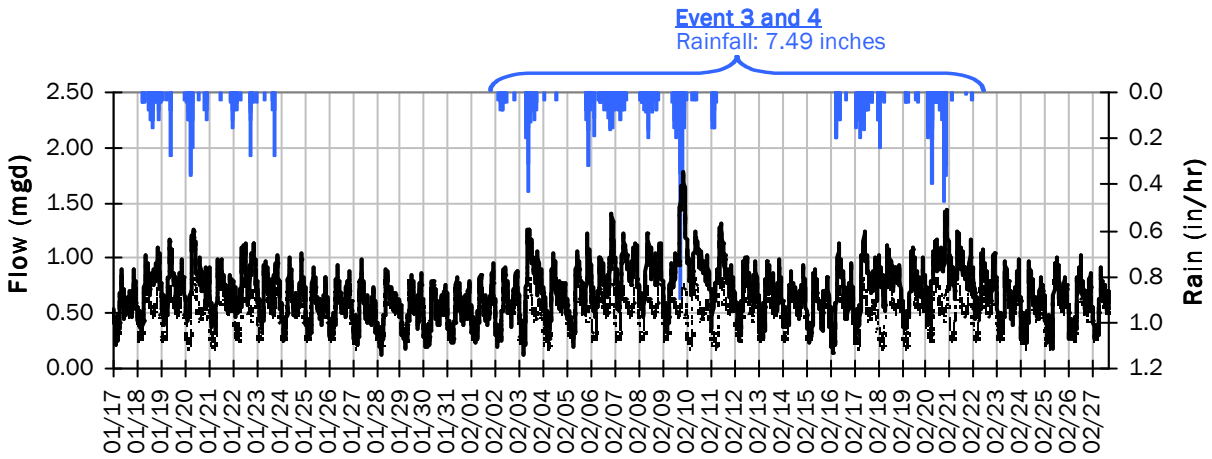


Storm Event I/I Analysis (Rain = 4.31 inches)

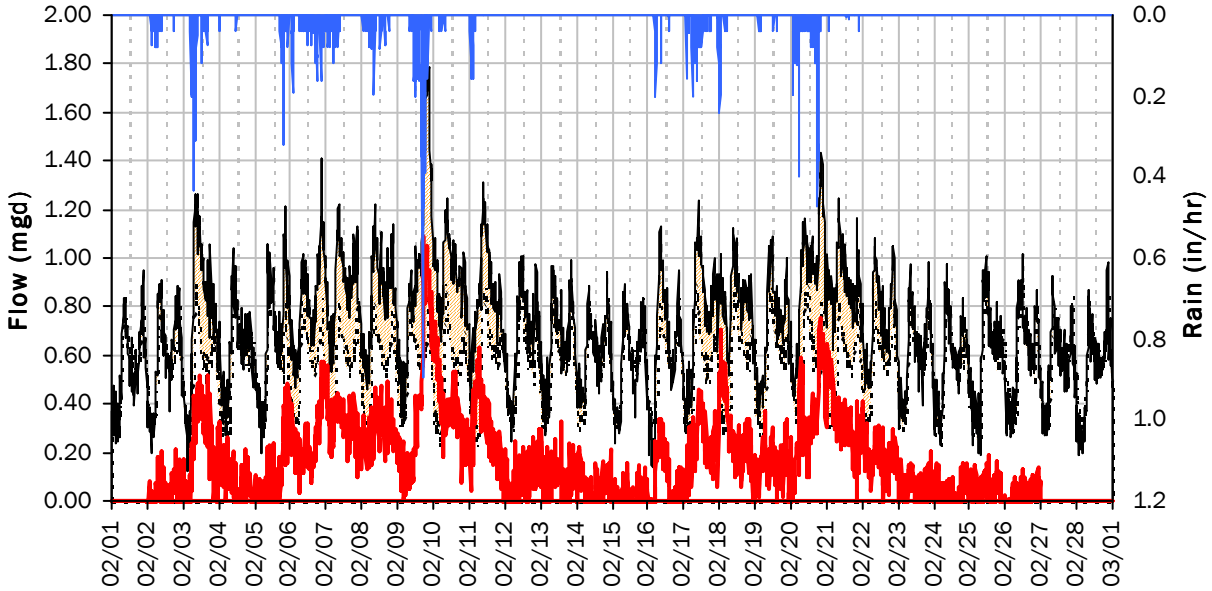
Capacity		Inflow / Infiltration	
Peak Flow:	2.08 *mgd*	**Peak I/I Rate:**	1.28 *mgd*
PF:	4.14	**Total I/I:**	2,499,000 *gallons*
Peak Level:	N/A		
d/D Ratio:			

SITE 10
I/I Summary: Event 3 and 4

Baseline and Realtime Flows with Rainfall Data over Monitoring Period



Event 3 and 4 Detail Graph

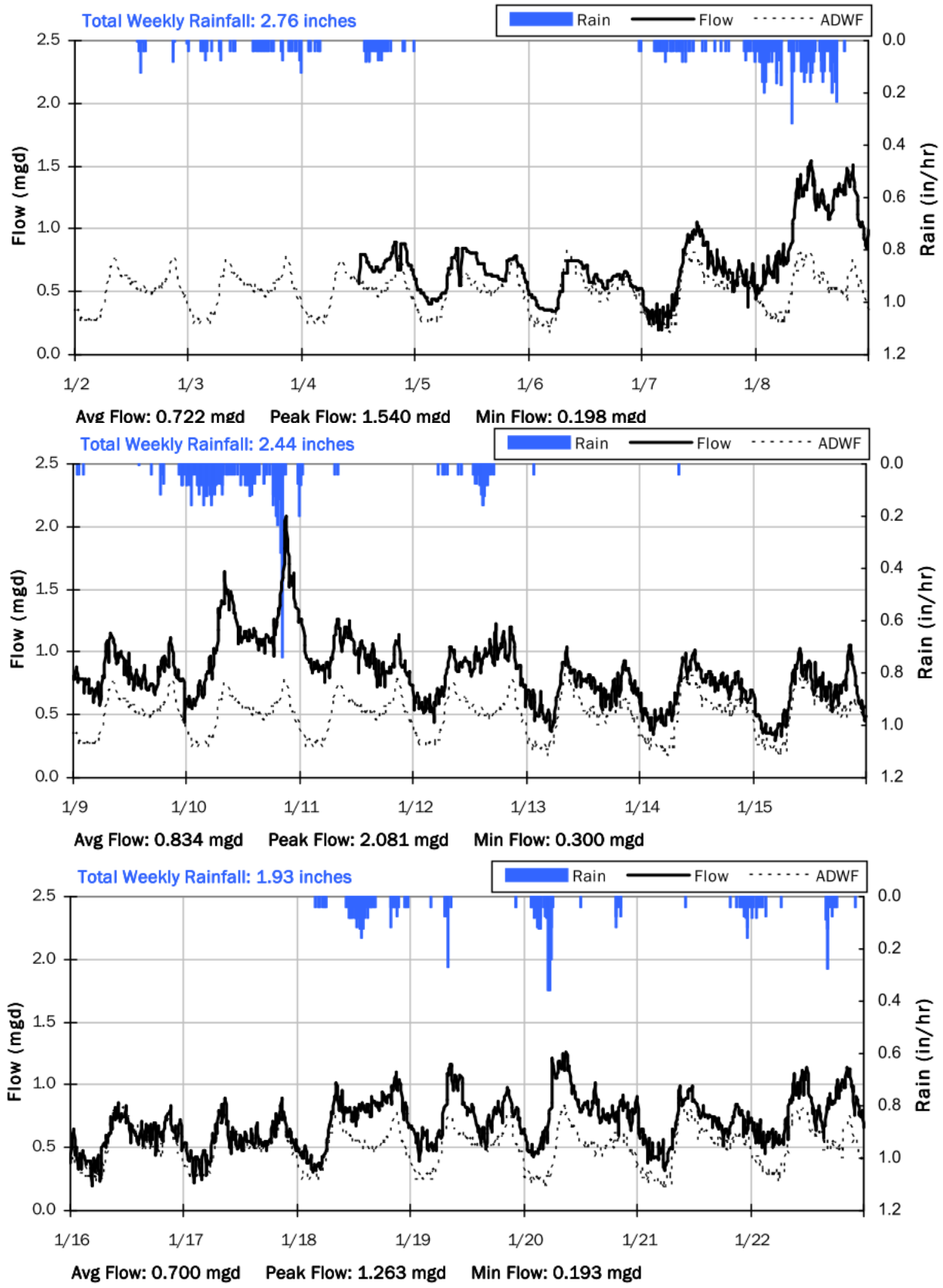


Storm Event I/I Analysis (Rain = 7.49 inches)

Capacity		Inflow / Infiltration	
Peak Flow:	1.79 *mgd*	**Peak I/I Rate:**	1.09 *mgd*
PF:	3.56	**Total I/I:**	4,418,000 *gallons*
Peak Level:	N/A		
d/D Ratio:			

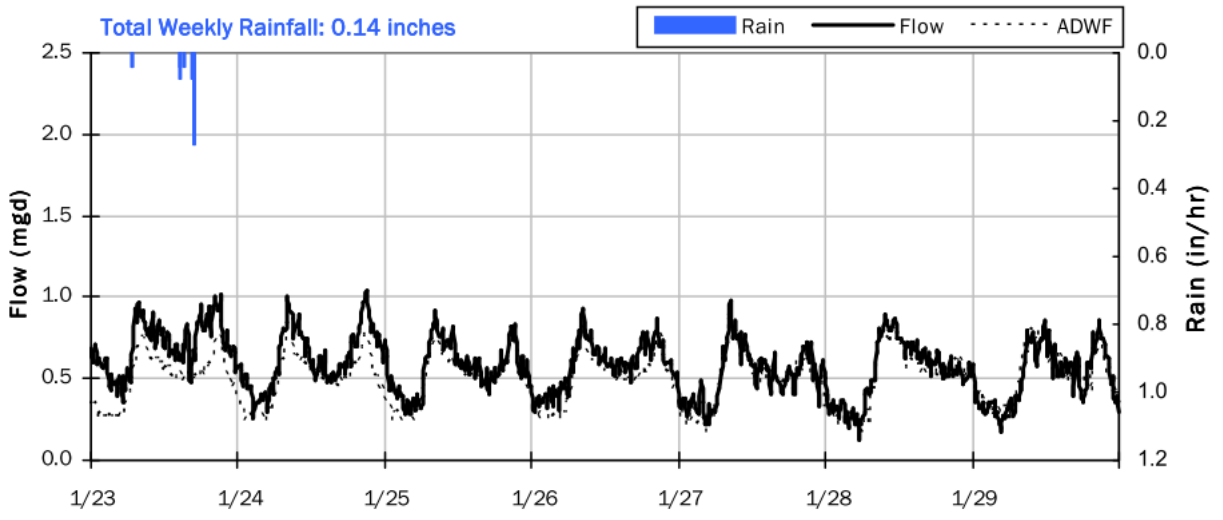
SITE 10

Weekly Flow Hydrographs

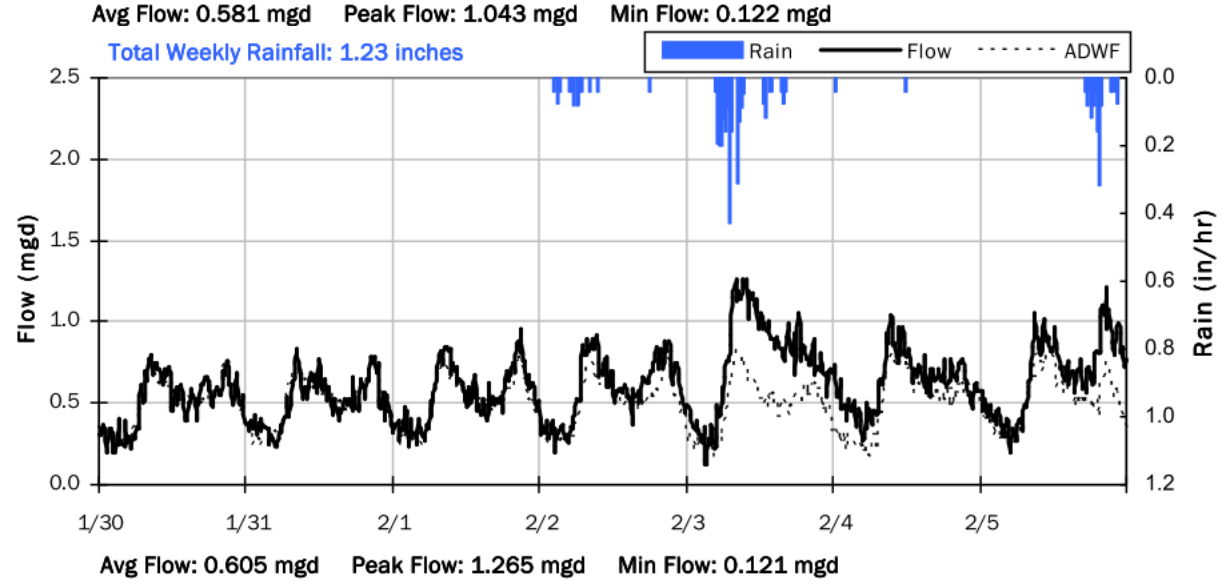


SITE 10

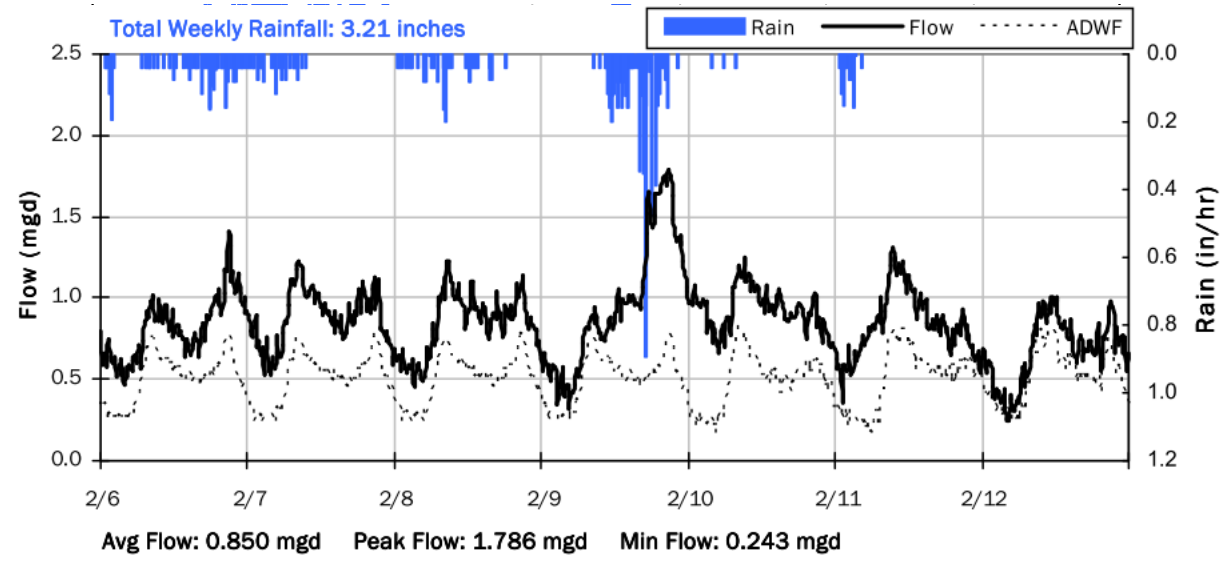
Weekly Flow Hydrographs



Avg Flow: 0.581 mgd **Peak Flow: 1.043 mgd** **Min Flow: 0.122 mgd**



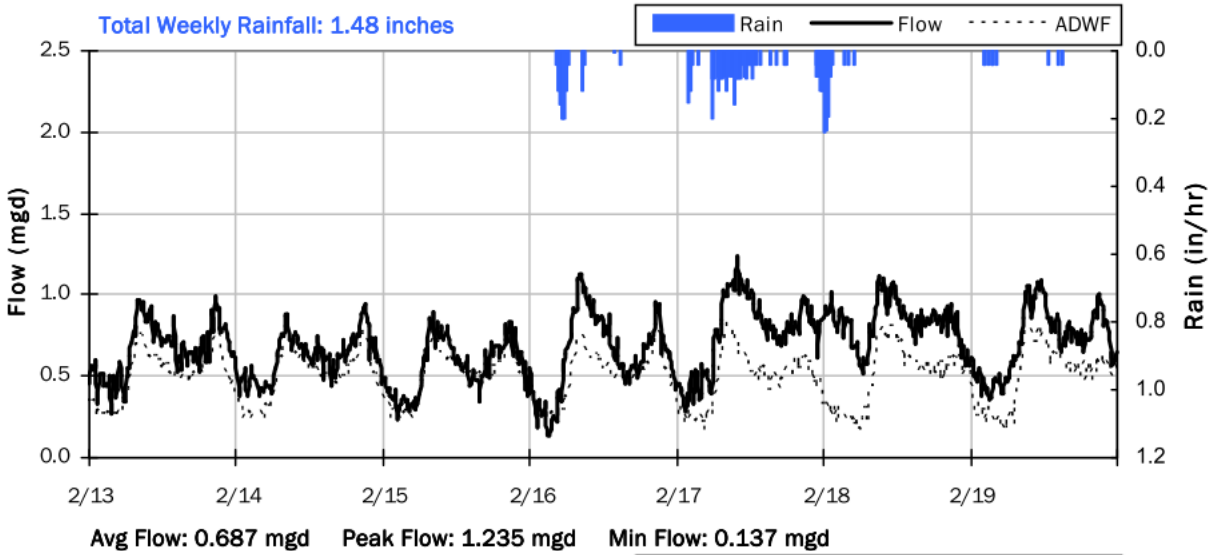
Avg Flow: 0.605 mgd **Peak Flow: 1.265 mgd** **Min Flow: 0.121 mgd**



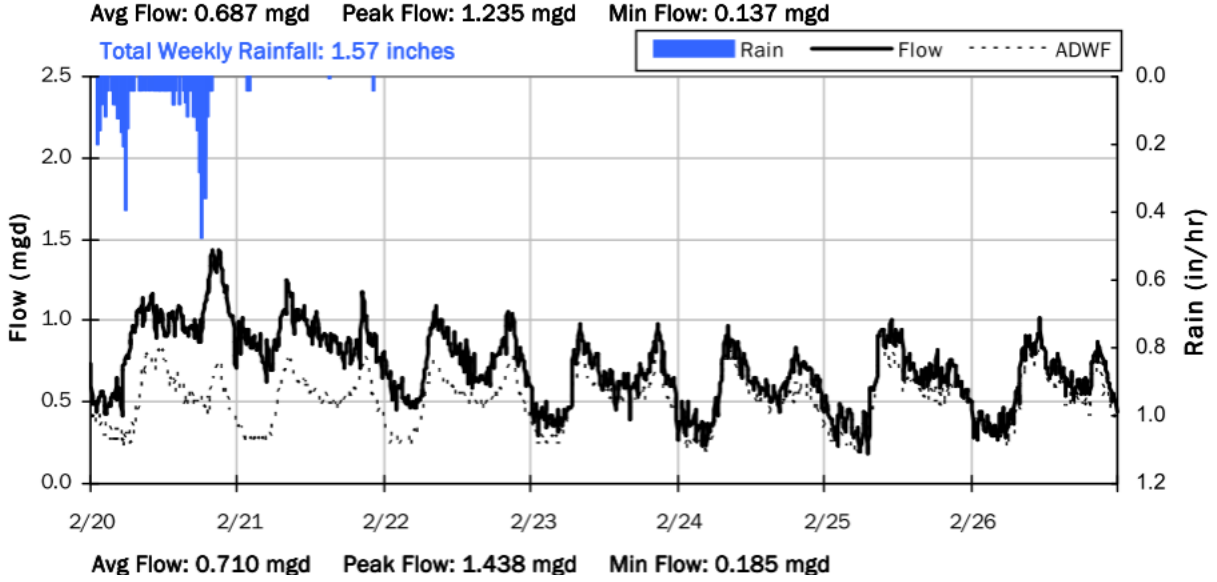
Avg Flow: 0.850 mgd **Peak Flow: 1.786 mgd** **Min Flow: 0.243 mgd**

SITE 10

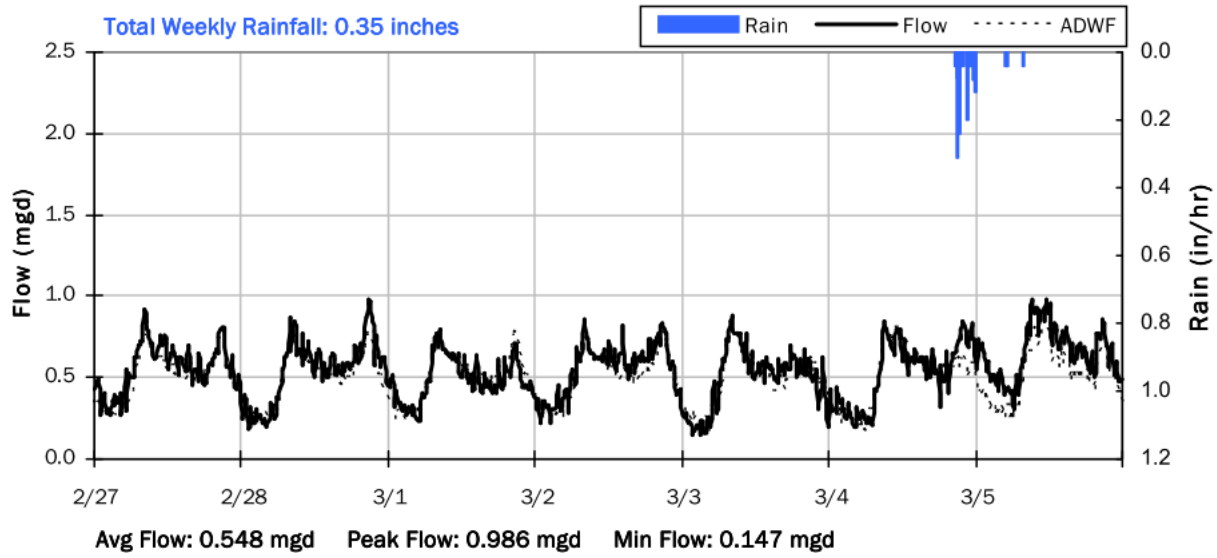
Weekly Flow Hydrographs



Avg Flow: 0.687 mgd Peak Flow: 1.235 mgd Min Flow: 0.137 mgd



Avg Flow: 0.710 mgd Peak Flow: 1.438 mgd Min Flow: 0.185 mgd



Avg Flow: 0.548 mgd Peak Flow: 0.986 mgd Min Flow: 0.147 mgd

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