City of Richmond
Sewer Collection System Master Plan

Prepared for

Veolia Water, N.A.

November 2011

WEST YOST ASSOCIATES
Consulting Engineers

356-02-10-05

Table of Contents

Executive Summary

ES.1 Background and Introduction ES-1

ES.2 Existing Wastewater System ES-2
- ES.2.1 Population Served & Land Use Characteristics ES-3
- ES.2.2 Collection System Facilities ES-3
- ES.2.3 Overview of Legal and Regulatory Mandates ES-3

ES.3 System Flows ES-3

ES.4 Flow monitoring and inflow & infiltration analysis ES-4

ES.5 capacity analysis ES-5
- ES.5.1 Dry Weather Flow Generation ES-6
- ES.5.2 Wet Weather Flow Generation ES-6

ES.6 Planning Criteria ES-7

ES.7 Hydraulic Capacity Analysis Results ES-8

ES.8 Pipeline Rehabilitation and Replacement Program ES-9

ES.9 prioritized capital improvement plan ES-10

Chapter 1. Introduction

1.1 Background and project Objectives 1-1
- 1.1.1 Background 1-1
- 1.1.2 Project Objectives 1-1

1.2 Report Organization 1-2
- 1.2.1 Chapter 1 – Introduction 1-2
- 1.2.2 Chapter 2 – Existing Wastewater System 1-2
- 1.2.3 Chapter 3 – System Flows 1-2
- 1.2.4 Chapter 4 – Flow Monitoring and Inflow/Infiltration Analysis 1-2
- 1.2.5 Chapter 5 – Hydraulic Model Development 1-3
- 1.2.6 Chapter 6 – Planning Criteria 1-3
- 1.2.7 Chapter 7 – Capacity Analysis 1-3
- 1.2.8 Chapter 8 – Pipeline Repair and Replacement Program 1-3
- 1.2.9 Chapter 9 – Capital Improvement Plan 1-3
- 1.2.10 Appendices 1-3

1.3 Acronyms and Abbreviations 1-4

Chapter 2. Existing Wastewater System

2.1 Existing Service Area 2-1

2.2 Population Served & Land Use Characteristics 2-2

2.3 Existing and Anticipated Collection System Facilities 2-3
- 2.3.1 Pipeline Characteristics 2-3
- 2.3.2 Pump Station Characteristics 2-4
- 2.3.3 Potential Regional Wet Weather Storage Facility 2-4

2.4 Overview of Legal and Regulatory Mandates 2-5
- 2.4.1 RWQCB NPDES Permit 2-5
- 2.4.2 RWQCB SSMP and Statewide WDR Requirements 2-5
- 2.4.3 Baykeeper Settlement Agreement 2-6

Table of Contents

Chapter 3. System Flows

3.1 Sources of System Data 3-1
3.1.1 Land Use Information and Aerial Photography 3-1
3.1.2 Industrial Discharge Data 3-1
3.1.3 Service Area Boundary and Sewer Network 3-1
3.1.4 Wastewater Flow Monitoring Reports 3-2

3.2 Calculation of Dry Weather Flows 3-2

Chapter 4. Flow Monitoring and Inflow/Infiltration Analysis

4.1 Findings and Recommendations 4-1
4.1.1 Findings 4-1
4.1.2 Recommendations 4-2
4.1.2.1 Tidal Inflow 4-2
4.1.2.2 Sources of Non-Tidal Groundwater Inflow 4-2
4.1.2.3 Rainfall-Dependent Inflow and Infiltration 4-3
4.1.2.4 Other Improvements 4-3

4.2 General Sources of Inflow and Infiltration 4-3
4.2.1 Inflow 4-3
4.2.2 Infiltration 4-4

4.3 System-wide Flow Monitoring Program 4-4
4.3.1 Data Collection 4-4
4.3.2 Rainfall Data 4-5

4.4 Tidal Area Flow Monitoring 4-6

4.5 description of flows 4-6
4.5.1 Dry Weather Flows 4-7
4.5.2 Wet Weather Flow 4-7

4.6 Inflow and Infiltration Analysis 4-9
4.6.1 Inflow Analysis 4-9
4.6.2 Rainfall Dependent Infiltration Analysis 4-10
4.6.3 Groundwater Infiltration Analysis 4-11

Chapter 5. Hydraulic Model Development

5.1 Model Development 5-1
5.1.1 Model Description 5-2

5.2 Data Validation 5-4

5.3 Load Allocation 5-5
5.3.1 Dry Weather Flow Generation 5-5
5.3.1.1 Base Wastewater Flows 5-5
5.3.1.2 Diurnal (24-Hour) Flows 5-6
5.3.1.3 Tidal Saturation Infiltration (TSI) 5-6
5.3.1.4 Tidal Inflows 5-7
5.3.2 Wet Weather Flow Generation 5-7

5.4 Dry Weather Flow Calibration 5-9
5.4.1 Calibration Results 5-9

5.5 Wet Weather Flow Calibration 5-11
5.5.1 Hydraulic Model Calibration Findings and Conclusions 5-12

Table of Contents

Chapter 6. Planning Criteria

6.1 Design Storm 6-1

6.2 Hydraulic Deficiency Criteria 6-1

6.3 New Pipeline Design Criteria 6-2

Chapter 7. Capacity Analysis

7.1 Hydraulic Capacity Analysis Results 7-1
- 7.1.1 Pipelines 7-2
- 7.1.2 Pump Station Firm Capacity 7-2

7.2 Recommended Projects 7-3
- 7.2.1 Hensley Street Wet Weather Storage Project 7-4
- 7.2.2 Cutting Boulevard Sewer Capacity Improvements 7-7
- 7.2.3 Hoffman Boulevard Capacity Improvements 7-7
- 7.2.4 First Street Sewer Capacity Improvements 7-8
- 7.2.5 Virginia Avenue at Harbour Way, MacDonald Avenue at 23rd Street and Carlson Boulevard Capacity Improvements 7-8
- 7.2.6 San Pablo Sewer Capacity Improvements 7-8

7.3 Conceptual Costs 7-9
- 7.3.1 Cost Estimating Basis 7-9
- 7.3.2 Estimated Project Costs 7-10

Chapter 8. Pipeline Repair and Replacement Program

8.1 Summary of Recommendations from Prior Studies 8-1

8.2 Critical Projects and Updated Priorities 8-2

8.3 Long-Term Replacement Strategy 8-4

Chapter 9. Capital Improvement Program

9.1 Basis for Capital Improvement PRogram Development 9-1

9.2 Proposed CIP 9-1
- 9.2.1 Capacity Improvement Projects 9-3
- 9.2.2 Rehabilitation and Replacement Projects 9-3

List of Tables

Table ES-1. Capacity Improvement Project Estimated Costs ES-10

Table 2-1. Summarized Land Use Categories 2-2

Table 2-2. Percentage of Pipe by Diameter 2-3

Table 2-3. RMSD Pump Station Descriptions 2-4

Table 3-1. Consolidation of Land Use Designations 3-3

Table 3-2: Initial Unit Flow Factors by Land Use 3-4

Table 3-3. Industrial Discharge Flow Data Provided by City of Richmond 3-5

Table 4-1. Flow Meter Locations and Associated Drainage Basins 4-5

Table 4-2. Rainfall Data from the 2010 Flow Monitoring Program 4-5

Table 4-3. Tidal Flow Meter Locations and Associated Drainage Basins 4-6
Table 4-4. Average Dry Weather Flow Data 4-7
Table 4-5. Summary of Wet Weather Flow Monitoring Data 4-8
Table 4-6. Inflow Analysis 4-9
Table 4-7. Rainfall Dependent Infiltration (RDI) Analysis 4-10
Table 4-8. Groundwater Infiltration Analysis 4-12
Table 5-1. Pump Station Model Parameters 5-3
Table 5-2. System Flags 5-4
Table 5-3. Dry Weather Flow Calibration Results 5-10
Table 5-4. Wet Weather Flow Calibration Results for April 12, 2010 5-12
Table 7-1. Pump Station Capacities 7-3
Table 7-2. Recommended Capacity Improvement Projects 7-4
Table 7-3. Capacity Improvement Project Estimated Costs 7-10
Table 9-1. City of Richmond Sewer Collection System Capital Improvement Program 9-2

List of Figures

Figure ES-1. Service Area Boundary ES-13
Figure ES-2. Modeled Land Uses ES-14
Figure ES-3. Flow Meter and Rain Gauge Locations and Associated Basins ES-15
Figure ES-4. Modeled Sewer Collection System Facilities ES-16
Figure ES-5. Recommended Capacity Projects ES-17
Figure 2-1. Service Area Boundary 2-7
Figure 2-2. Modeled Land Uses 2-8
Figure 2-3. Collection System Facilities 2-9
Figure 2-4. Gravity Sewer Pipelines by Size 2-10
Figure 2-5. Modeled City Sewer Basins 2-11
Figure 2-6. Potential Wet Weather Storage Site on Chevron Property 2-12
Figure 4-1. Inflow and Infiltration Sources 4-13
Figure 4-2. Typical RDII Response 4-14
Figure 4-3. Flow Meter and Rain Gauge Locations and Associated Subbasins 4-15
Figure 4-4. Flow Direction and Metered Basin Interconnection 4-16
Figure 4-5. Tidal Flow Meter Locations 4-17
Figure 5-1. Modeled Sewer Collection System Facilities 5-13
Figure 5-2. Modeled Sewer Subcatchments 5-14
Figure 5-3. Representative Diurnal Flow Pattern (Meter Site 2) 5-15
Figure 5-4. Tidal Saturation Infiltration 5-16
Figure 5-5. Tidal Inflow for Meter 1 5-17

Figure 5-6. Components of RTK Hydrograph 5-8
Figure 5-7. Representative DWF Calibration Results (Meter 2) 5-18
Figure 5-8. Meter 2 Wet Weather Calibration using M1 Rainfall Data 5-19
Figure 6-1. Contra Costa County Mean Seasonal Isohyet Map 6-3
Figure 6-2. Contra Costa County 10-Year Recurrence Interval IDF Curves 6-4
Figure 7-1. Flow Characteristics from WWTP to South Harbour Basin 7-12
Figure 7-2. Recommended Capacity Projects 7-13
Figure 7-3. Hydraulic Profile with Design Storm Flow – Cutting Boulevard from Carlson Boulevard to Harbour Way 7-14
Figure 7-4. Hydraulic Profile with Design Storm Flow – First Street Alignment from Pennsylvania Ave. to Cutting Boulevard 7-15
Figure 7-5. Hydraulic Profile with Design Storm Flow – 23rd Street from Lincoln Avenue to Cutting Boulevard 7-16
Figure 7-6. Hydraulic Profile with Design Storm Flow – Coalinga Sewer Capacity Improvements 7-17
Figure 7-7. Hydraulic Profile with Design Storm Flow – Amador Street to San Pablo Avenue 7-18

Appendices

Appendix A. Exceptions to the 50% Rule for Land Use Unit Flow Factor Assignments
Appendix B. V&A Flow Monitoring Reports
Appendix C. Dry Weather Flow Diurnal Curves
Appendix D. Dry Weather Calibration Hydrographs
Appendix E. Wet Weather Calibration Hydrographs
Appendix F. West Yost TMs Describing Recommended Pipeline Replacement and Repair Projects
Appendix G. Capacity Improvement Project Detailed CIP Cost Estimates

In June 2010, Veolia Water (Veolia), the contract operator for the City of Richmond (City) collection system, retained West Yost Associates (West Yost) to complete a wastewater collection system master plan. The master plan assesses the conveyance capacity of the City's collection system within the Richmond Municipal Sewer District (RMSD). The draft Master Plan was completed in March 2011. Since this time, additional flow monitoring and alternatives analyses have been conducted, and some priority projects are underway. In November 2010, the City and Veolia asked West Yost to update the Master Plan to reflect the recent findings and activities.

ES.1 BACKGROUND AND INTRODUCTION

The primary purpose of this sewer collection system master plan (Master Plan) is to evaluate the City of Richmond gravity sewer collection system under a specific design storm, using a computerized hydraulic model, to determine whether the system can convey flows without sewer system overflows (SSOs). Where SSOs are predicted by the hydraulic model, this Master Plan provides recommended solutions.

The City and Veolia have developed two prior master planning studies, in 2006 and 2007. However, both of these studies relied on incomplete flow data. As a result, neither of these studies was able to replicate system operational conditions or to identify surcharge and capacity issues to the level of assurance of this Master Plan.

In 2010, the City and Veolia completed a new flow monitoring study upon which this Master Plan is based. In 2011, Veolia conducted additional flow monitoring with a specific focus on measuring tidal response in the southern portion of the system. The 2010 and 2011 flow monitoring studies were successful in capturing flow data throughout the system during several reasonably sized storm events and additional tidal events. This Master Plan benefits from this additional data, and is intended to supersede the prior planning studies completed by the City and Veolia for the sewer collection system.

This Master Plan is comprised of the following nine chapters:

- Chapter 1 – Introduction
- Chapter 2 – Existing Wastewater System
- Chapter 3 – System Flows
- Chapter 4 – Flow Monitoring Program
- Chapter 5 – Hydraulic Model Development
- Chapter 6 – Planning Criteria
- Chapter 7 – Capacity Analysis
- Chapter 8 – Pipeline Repair and Replacement Program
- Chapter 9 – Capital Improvement Plan

The Master Plan was developed to meet the following objectives:

- Evaluate system-wide flow characteristics to identify areas contributing to high inflow and infiltration (I&I);
- Assess the existing hydraulic capacity of the collection system;
- Evaluate modeled pump station firm capacity under design storm conditions;
- Summarize previously developed pipeline condition and replacement needs; and
- Develop a prioritized capital improvement program (CIP) that strategically replaces or repairs facilities over time to first meet the requirements of the settlement agreement between the City and San Francisco Baykeeper, and also provide long-term system reliability.

The recommendations that are presented in this Master Plan must be considered in conjunction with proposed improvements at the City's wastewater treatment plant. Master planning activities for the treatment plant are in progress by others. The success of the recommended collection system improvements in addressing wet weather sewer system overflows (SSOs) depends on the City's ability to maintain 42 million gallons per day (mgd) of pumping capacity[1] at the wastewater treatment plant influent pump station, and subsequently, to maintain or exceed this capacity in the primary and secondary processes at the plant.

ES.2 EXISTING WASTEWATER SYSTEM

The City's Richmond Municipal Sewer District (RMSD) provides wastewater collection service to a majority of the City of Richmond, as well as a small area within unincorporated county limits, all located within Contra Costa County in the San Francisco Bay Area. The City of Richmond and RMSD collection system service area are shown on Figure ES-1.

Abutting the City of Richmond's service area, West County Wastewater District (WCWD) provides sewer collection service to a small portion of the City on the northern border of the City, adjacent to the City of San Pablo, and Stege Sanitary District (Stege) collects wastewater for a portion of the City in the eastern hills, adjacent to the City of El Cerrito. The City, WCWD, and Stege convey flows to three separate wastewater treatment plants.

The City's existing sewer collection system is comprised of approximately 187 miles of active gravity sewer pipelines with sizes ranging from 4 to 66 inches in diameter, 15 miles of pressure pipelines, and 14 pump stations, according to the California Integrated Water Quality System (CIWQS) database. The City conveys all flows to its wastewater treatment plant that is located on Canal Boulevard, south of I-580. Information on the existing system is summarized in this section and is also presented in Chapter 2 of this report.

[1] Maximum influent pump station pumping capacity as provided by Veolia.

ES.2.1 Population Served & Land Use Characteristics

The estimated population for the City of Richmond is 103,701 based on the 2010 census. The City's RMSD service area includes a wide range of mixed land uses, as shown in Figure ES-2. These land uses were provided by the City and were supplemented with Contra Costa County public GIS resources.

ES.2.2 Collection System Facilities

The City's sewer system is comprised of approximately 187 miles of pipe ranging in diameter from 4 to 66 inches. The predominant pipeline material for small diameter pipelines is vitrified clay pipe. The City's service area is comprised of ten sewer drainage basins. Flows from each of the sewer basins were monitored by the City under a flow monitoring program that began in February 2010 and was concluded in June 2010. This flow monitoring program collected system data and also collected additional flow data to pinpoint the impact and locations of tidal infiltration in the southern portions of the service area. A subsequent flow monitoring study to further evaluate tidal inflow was completed in July 2011.

The City owns and operates 14 pump stations. Three of these pump stations, Canyon Estates 1, 2, and 3, are considered outside of the RMCD service area because they discharge to the Stege Sanitary District. Five of the City's pump stations were included in the hydraulic model; these stations, which include the Keller Beach, Ferry Point, ICI, Marina Bay Cove, and Marina Bay Parkway pump stations each convey flow directly to a modeled trunk sewer.

ES.2.3 Overview of Legal and Regulatory Mandates

Veolia and the City operate and maintain the City's collection system plant in accordance with a number of regulatory documents, including:

- Regional Water Quality Control Board (RWQCB) National Pollution Discharge Elimination System permit,
- RMSD Sewer System Management Plan (SSMP), and
- 2006 City of Richmond-Baykeeper settlement agreement.

These mandates form the basis for recommendations in the Master Plan, and are discussed further in Chapter 2 of this report.

ES.3 SYSTEM FLOWS

Sewer system dry weather flows were estimated using land use information, unit flow factors, aerial photography, industrial discharge data, service area boundary data, the sewer network, and data collected during the City's 2010 flow monitoring program.

Land use information was provided in GIS format from the City of Richmond, and supplemented by public GIS information available through Contra Costa County. The City also provided West Yost with industrial wastewater discharge data. These flows were added as calculated point loads to the more generalized land use-based flows more accurately depict basin-specific dry weather flows.

Because the RMSD service area limits are not the same as the City limits, parcels that straddled the service area boundary were included or excluded from flow calculations using a 50 percent rule. This rule included flow from parcels when at least 50% of the parcel's area was included within the service area boundary. There were numerous exceptions to this rule, as defined in Chapter 3 of this report.

The City's demographics and stable population base justified calculation of average dry weather flow using unit flow factors and land use designations. Flow factors for each land use category, ranging from very low residential to various categories of commercial and industrial uses were developed and applied to the land use on a sewershed by sewershed basis (the system included 883 individual sewersheds).

Flows from twelve large industries as provided by the City were then added to the calculation to ensure that the absence of large discharger data would not skew calculated results. The combined flows were then adjusted until calculated flows per basin were within approximately ten percent of measured flows. The segregated industries included the following:

- Chevron
- Department of Health Services
- Bio-Rad Laboratories
- Kinder Morgan
- Kaiser Foundation
- California Fats and Oils
- West Contra Costa Unified School District
- Social Security
- U.C. Richmond Field Station
- Catellus Development Corp
- U.C. Regents
- T&T Richmond LP

Diurnal patterns were applied to the flows to most accurately represent flow patterns that were measured during the flow monitoring program.

ES.4 FLOW MONITORING AND INFLOW & INFILTRATION ANALYSIS

In early 2010, the City and Veolia completed a system-wide flow monitoring program. The program was conducted by V&A from February to June 2010. In addition, from May 2010 to June 2010, five additional flowmeters were installed at new locations within the southern portion of the service area to refine and supplement data for areas with tidal inflow and high groundwater infiltration. In July 2011, six flowmeters were installed in the southern basins to further evaluate potential tidal inflows. Data and results are presented in the V&A reports titled, *Flow Monitoring and Inflow/Infiltration Study (December, 2010, Flow Monitoring of Five Tidal Sites (September, 2010), and Sanitary Sewer Flow Monitoring and Tidal Inflow and Infiltration*

Study (September, 2011). The V&A Reports are included in Appendix B. The flow monitoring program and results are discussed further in Chapter 4 of this report.

The flow monitoring program included twelve (12) gravity meters that measured flows from ten basins, and two (2) rain gauges. Figure ES-3 presents the flow meter locations and associated collection system basins. The basins were named by West Yost in development of the hydraulic model.

The 2010 flow monitoring program captured rainfall events with a statistical recurrence interval of less than 2 years (*i.e.,* 50 percent probability of occurring in any given year) through twelve gravity meters that measured flows from ten drainage basins. Peak flows generated by these rainfall events resulted in surcharge conditions in all but two of the metered locations throughout the collection system.

The primary contributors to wet weather I&I in the City's system are 1) direct tidal inflow in the southern basins, 2) groundwater infiltration including a tidal saturation infiltration component, 3) storm runoff inflow from direct connections between stormwater facilities and the sewer system, and 4) rainfall dependent infiltration.

The highest level of tidal inflow was found in the southern sewer basins. After the flow monitoring period, Veolia addressed several sources of tidal inflow through the installation of duck-bill check valves on the wet weather outfall structures. The 2011 flow monitoring effort has confirmed the positive impact that these activities have had on reducing tidal inflows. The highest levels of rainfall dependent inflow and infiltration (RDII) were found in the Castro, 1st Street, and Canal Boulevard basins, which were monitored by Meters 1, 3, and 4, respectively.

ES.5 CAPACITY ANALYSIS

A capacity analysis was conducted using a computer-based hydraulic model of the City's RMSD wastewater collection system, developed using Innovyze® InfoWorks™ CS software. The hydraulic model includes the City's main trunk sewers (typically 12-inch diameter and larger) and associated facilities, and is a skeletonized representation of the City's RMSD sewer system in its configuration and operation. This section summarizes the components of the capacity analysis that are discussed further in Chapter 5 of this report.

Veolia Water developed the hydraulic model network and provided this network to West Yost for further development and analysis. The hydraulic model comprises a skeletonized network of nodes (*e.g.*, manholes) and conduits (*e.g.,* pipelines).

The structural components of the hydraulic model network, (*i.e.*, nodes and conduits) were initially developed by Veolia staff and provided to West Yost in September 2010. The hydraulic model consists of approximately 47 miles of sewer pipeline ranging in diameter from 4-inches to 66-inches. The model includes all 12-inch diameter and larger trunk lines, and associated manholes and lift stations. Many 10-inch diameter pipelines have been included, as provided by Veolia staff, as well as 4-inch, 6-inch and 8-inch diameter lines in selected areas as needed to provide connectivity. The 47 miles of pipeline represent approximately 25 percent of the City's RMSD system.

Five of the City's fourteen pump stations are included in the hydraulic model: Marina Bay Parkway, ICI, Ferry Point, Marina Bay Cove, and Keller Beach. In addition, the hydraulic model includes the influent pump station wet well at the wastewater treatment plant. Figure ES-4 shows the RMSD sewer network and modeled assets.

ES.5.1 Dry Weather Flow Generation

West Yost delineated 883 subcatchments within the hydraulic model. Subcatchments were generally defined to encompass a single land use that flows to a single model node. Wastewater flows were generated for each subcatchment or sewershed, and were comprised of one or more of the following components:

- Base wastewater flow (BWF);
- Tidal saturation infiltration (TSI), which results when tidal activity saturates the soil and infiltrates into the pipeline network through defects in the system, during dry weather and wet weather periods; and
- Rainfall-dependent Infiltration and Inflow (RDII).

Base wastewater flows were calculated based on land uses, with the exception of twelve industrial point loads that were provided by the City and applied to specific nodes. For the City's hydraulic model, industry-standard unit flow factors (verified through flow monitoring data) were applied to land use to generate BWF. Diurnal patterns were applied to the flows in each monitoring basin as needed to match the flow pattern in each basin to measured flows.

Tidal Saturation Infiltration (TSI) was then included in the model to account for measured groundwater infiltration in the southern sewer basins. TSI was calculated using base flow measurements that were consistently present and that exceeded anticipated dry weather flows during off-peak (*i.e.*, nighttime) hours. Calculated TSI was distributed across selected pipe segments based on the product of pipe diameter and length.

These dry weather flows were calibrated within the hydraulic model to closely reflect measured flow values. The average dry weather weekday flow measured during the 2010 flow monitoring period was 6.3 mgd.

ES.5.2 Wet Weather Flow Generation

The City's model uses the RTK method to calculate wet weather inputs to the hydraulic model. The RTK method generates hydrographs from each subcatchment that represent flows during and immediately after rainfall events caused by seepage of water into the collection system. The RTK method generates a series of three triangular hydrographs that represent short-term, medium-term, and long-term rainfall response. The RTK parameters include:

1. R is the area of the graph representing the portion of rainfall falling on a subcatchment that enters the sewer collection system.
2. T is the time from the onset of rainfall to the peak of the triangle.
3. K is the ratio of the "time to recession" to the "time to peak" of the hydrograph.

RTK parameters were adjusted by basin, beginning with the upstream basins, until measured flows during the calibration storm closely matched model-generated flows in temporal distribution and volume.

Tidal Inflows (TI) were also included in the model for use during wet weather flow simulations. TI were derived to represent measured flows in excess of dry weather flows during non-rainfall periods.

During the calibration storm, significant surcharging occurred throughout the system. During the flow monitoring period, incoming flows exceeded the available pumping capacity of the WWTP's influent pump station and the wet well water level rose to its maximum level. The wet well level created a hydraulic gradeline that was carried back through all of the low-lying portions of the service area. As a result, in some basins, measured flow peaks were difficult to replicate in the model.

However, despite the surcharge condition, only one meter, Meter 10, experienced consistent backwater effects. Therefore, the data collected during the calibration storm was sufficient to calibrate the hydraulic model to measured flow volumes and general flow patterns. The peak hourly measured wet weather flow during the flow monitoring season was approximately 33 mgd.

ES.6 PLANNING CRITERIA

Planning criteria addresses items such as collection system capacity, gravity sewer slopes, and maximum depth of flow. As required by the City-Baykeeper settlement agreement, the City evaluated the system under a design storm with a recurrence interval of 10 years (*i.e.*, 10 percent probability of occurring in any given year) and duration of 24 hours.

Flow characteristics for the 10-year, 24-hour design storm were derived from data that is maintained by the Contra Costa County Flood Control District. Using the County's depth-frequency-duration curves in conjunction with the County's Mean Seasonal Isohyet map, total rainfall depth of 4.2 inches was used to represent a 10-year, 24-hour design storm in the City of Richmond. This rainfall depth was then distributed using the Natural Resource Conservation Service SCS Type 1 rainfall distribution curve.

Pipelines were considered to have a capacity deficiency when, under peak wet weather flow conditions for the design storm, the water level or hydraulic grade line (HGL) exceed ground surface level.

A lift station was considered capacity deficient if the station did not have sufficient firm capacity, *i.e.* capacity with the largest pump out of service, to convey peak hourly flows during the design storm. Based on pump station characteristics that were documented in the City's prior master planning efforts, all pump stations were sufficiently sized to convey design flows.

New or replacement pipelines were sized to convey model-generated peak flows without significant surcharge. Capacity constraints were addressed through the addition of parallel pipelines, located along the same alignment and depth as the existing, surcharged pipe. Optimized pipeline alignments were not included this Master Plan. Optimizations to pipeline

alignments and flow diversions should be considered during the preliminary design phase for each project.

ES.7 HYDRAULIC CAPACITY ANALYSIS RESULTS

The City's modeled collection system network was evaluated for its capacity to convey flows that are predicted to occur during a design storm event. The analysis was completed using a design storm with a published recurrence interval of 10 years and duration of 24 hours (10-year, 24-hour design storm). The system was evaluated for its ability to convey all flows from the design storm without overflows. Recommended capacity assurance projects are shown in Figure ES-5. Additional information on the projects listed below is presented in Chapter 7 of this Master Plan.

Due to the relatively flat topography of the lower third of the service area, wet weather flows are significantly impacted by the operating level at the wastewater treatment plant influent pump station. The proposed capacity improvements reduce flows to the wastewater treatment plant to more closely match the influent pump station capacity of 42 mgd. Flows are controlled through the addition of a new relief sewer and wet weather storage facility. Following the wet weather event, stored flows are conveyed through existing pipelines to the treatment plant.

The hydraulic model identified the need to store flows of approximately 7.5 million gallons during the design storm event, in order to control and reduce flows to the treatment plant. The preferred location for wet weather storage is a location near or within the existing Chevron facility at West Gertrude Avenue and Richmond Parkway. This location has received preliminary discussion between the City and Chevron regarding the potential for Chevron to allow the City to use the basins as wet weather storage, thereby establishing a beneficial use for the facility as desired by Chevron. Chevron believes that they have up to 20 million gallons of storage available for use by the City for wet weather storage.

The storage location would include a pumping facility to return flows back to the system after the rainfall event. The storage facility would include pre-screening, and should be designed to maximize scouring velocities and minimize odors. Storage will likely require the acquisition of easements and/or property, as well as community endorsement. The addition of storage will require environmental clearance under the California Environmental Quality Act.

The hydraulic model identified eight project areas where the water surface or hydraulic gradeline exceeded the ground surface elevation. These locations were identified as having sewer system overflows during the design storm event. General descriptions for the associated capacity improvement projects are listed below. More detailed information on each project is presented in Chapter 7 of this Master Plan.

- Hensley Street Capacity Improvements. 3.8 miles of relief sewers conveying flows from the northern half of the service area west, to a new storage location near the existing Chevron pond facility.
- Cutting and Hoffman Boulevard Sewer Capacity Improvements – 2.4 miles of relief sewers from Carlson Boulevard to Harbour Way South, and along Hoffman Boulevard south of Cutting Boulevard.

- 1st Street, MacDonald, and Virginia Avenue Sewer Capacity Improvements - 1.8 miles of relief and replacement sewers from Pennsylvania and 4th Street down to 1st Street and West Cutting Boulevard, on MacDonald Avenue near 23rd Street, and on Virginia Avenue near Harbour Way.
- San Pablo Avenue and Carlson Boulevard Sewer Capacity Improvements – 1.7 miles of new and relief sewers from Amador Street and Eastmond Avenue to San Pablo Avenue, ending at the intersection of Richmond Greenway Trail and South 47th Street, and on Carlson Boulevard.

The hydraulic model identified sufficient capacity in each of the five modeled pump stations to convey design flows. In addition to the five modeled pump stations, the City operates nine smaller stations within the sewer collection system. This Master Plan did not assess the capacity of these smaller stations to convey design flows. As trunk sewers and associated infrastructure are replaced over time, the City should review the firm capacity of these unmodeled collection system pump stations.

Table ES-1, also presented as Table 7-4 in the report, summarizes the capacity improvement projects and associated costs. Construction costs include the total construction cost estimate including contingency. Total costs add project design and construction administration to the total construction cost.

Table ES-1. Capacity Improvement Project Estimated Costs

Project Name	Project	Estimated Construction Cost	Estimated Total Cost
Hensley Street Pipelines	Parallel Relief Sewer and New Trunk Sewer	$13.7M	$16.1M
Cutting & Hoffman Boulevards	Parallel Relief Sewers	$6.5M	$7.6M
First Street, MacDonald Avenue, Virginia Avenue	Parallel Relief and Trunk Sewers	$6.5M	$7.7M
San Pablo & Carlson Boulevards	Parallel Relief and Trunk Sewers	$3.6M	$4.2M
Total Estimate for Pipeline Projects		$30.3M	$35.6M
Total Estimate for Storage (8MG)		$20.8M	$24.4M

ES.8 PIPELINE REHABILITATION AND REPLACEMENT PROGRAM

This Master Plan scope included a review and reprioritization of previously-generated system rehabilitation and replacement (R&R) projects. Two documents previously prepared by West Yost summarize the City's previously-defined R&R needs, which are also listed in priority order below. These documents are included as an appendix to Chapter 8 of this Master Plan.

- Elimination of stormwater inflow: This description includes multiple projects over time to systematically address sources of tidal inflow into the collection system.

- Cypress Point sewer replacement project: Original a component of the Keller Beach interceptor replacement project, this project has been identified as a standalone project due to its criticality and history of sewer system overflows.
- Keller Beach interceptor replacement project: This project replaces existing pipelines and collectors sewers in the Point Richmond neighborhood of the City. A large portion of the interceptor system is submerged within the San Francisco Bay.
- Ongoing pipeline repairs and replacements: This project summarizes point repairs and pipeline replacements that were previously identified to eliminate the City's most significant pipeline structural defects, including pipe failures and significant offsets.

ES.9 PRIORITIZED CAPITAL IMPROVEMENT PLAN

Chapter 9 of this Master Plan presents the recommended Capital Improvement Program (CIP) for the City's RMSD gravity sewer collection system. The recommended CIP identifies the needed improvements at a master planning level, and does not constitute conceptual or preliminary design of these improvements. Subsequent alignment studies and preliminary designs are required to finalize pipeline configuration and alignment, and to determine the final sizes, locations, and details of the proposed improvements.

The CIP was developed to create a fundable program that addresses the City's competing needs for capacity improvement and reliability. The following criteria were used to prioritize the various projects and develop a timeline for implementation.

- Projects to Eliminate SSOs in compliance with the existing settlement agreement between the City and San Francisco Baykeeper.
- Projects to Reduce Maintenance-Related SSOs, including critical condition-related rehabilitation projects and projects that are needed to render the collection system pipes accessible to CCTV inspection equipment.

The proposed CIP begins implementation in Fiscal Year 2011/12 and extends into Fiscal Year 2020/2021. The total estimated 10-year CIP cost is $98.5 million. Of this amount, $60.2 million is needed to meet the capacity requirements that are included in the City-Baykeeper settlement agreement, and are recommended for completion within the Baykeeper settlement agreement timeframe. If this schedule is not achievable, these improvements are recommended within the 10-year CIP timeframe. The remaining costs were spread through the 10-year timeframe of this CIP, but can be further distributed into future programs.

The City-Baykeeper settlement agreement requires completion of the proposed capacity improvement projects by September 1, 2014. However, the schedule for implementation of the capacity improvements is constrained by the timeframe needed to secure environmental clearances for the proposed storage project, which must be initiated first, as well as currently available funds. Therefore, as desired by the City and Veolia, projects needed to provide in-system storage are planned for completion by 2013/14, in order to substantially meet the contractual requirement. The storage facility will help address the most significant historical capacity issues for the City, including the two combined sewer/stormwater discharges to the Richmond Inner Harbor. The remaining pipeline capacity improvements will eliminate more localized predicted sewer system overflow issues over time. If the City is able to implement the

proposed project on an accelerated schedule, then the project implementation timelines will be adjusted accordingly.

The proposed rehabilitation projects that are discussed above provide needed ongoing rehabilitation on a parallel track with the City's capacity improvements. The estimated cost of the City's priority rehabilitation and replacement projects is $28.3 million.

The balance of the CIP provides a $10 million placeholder for unknown project that arise during the implement of the capital program. This item includes the project needed to eliminate the Harbour and Wright overflow structure that is currently under discussion outside of the recommendations of this master plan.

The proposed CIP is presented as Table ES-1, and again as Table 9-1.

ES.10 NEXT STEPS

This Master Plan is designed to be a working document that is updated over time to reflect current knowledge about system issues and needs. The City's highest priority in the implementation of the Master Plan recommendations is to address SSOs to meet the requirements of San Francisco Baykeeper, and to meet the requirements established by the Regional and State Water Resources Control Board. The following specific tasks are recommended in the near term as the City implements the recommendations in this Master Plan:

- Conduct system-wide wet weather flow and rainfall monitoring in 2011/12, and include locations in the system that are needed to refine the requirements of the proposed Barrett Avenue Relief Sewer project. The objective of the 2011/12 flow monitoring program is to capture additional data that will assist in refining model development and calibration in order to remove possible conservatism in predicted results.
- Complete the I&I reduction projects (pipeline rehabilitation and replacement) that are currently underway. After the current projects are completed, the City should consider conserving remaining available funds for capacity improvement projects and emergency/urgent rehabilitation needs.
- Continue planning activities for the Hensley Street Wet Weather Storage project, and begin planning and design for the other proposed capacity improvement projects.
- Confirm that the City's permitted dry weather flow dischargers are holding flow during periods of dry weather and also periods of high tide.
- Continue to investigate and address tidal inflow from the 1st Street basin and also from the South Harbour area.
- Evaluate and address storm drain cross-connections that may be present in North Harbour basin, as indicated by the City's previous smoke testing activities.
- Evaluate operational activities that may unnecessarily elevate WWTP influent pump station levels, as these levels have a direct and significant impact on system flows during both wet and dry weather.

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure ES-1 (Service Area Boundary).mxd 3/16/2011

FIGURE ES-1

City of Richmond
Sewer Collection System
Master Plan

SERVICE AREA BOUNDARY

N

0 1 2

Miles

San Francisco Bay

Richmond Inner Harbor

Notes
1. Area within dashed border is not within Service Area boundary but served by the City

LEGEND

- Sewer Mains
- Service Area
- City of Richmond

VEOLIA WATER

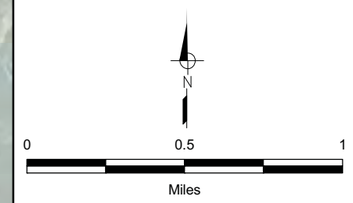
WEST YOST ASSOCIATES
Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure ES-2 (Modeled Land Uses).mxd 3/18/2011

FIGURE ES-2

City of Richmond
Sewer Collection System
Master Plan

MODELED LAND USES



Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

San Francisco Bay

Richmond Inner Harbor

LEGEND

- Very Low Density Residential
- Low Density Residential
- Medium Density Residential
- High Density Residential
- Neighborhood Retail / General Commercial
- Regional Office / Shopping / City Center
- Industrial / Office Flex / Light Industry
- Heavy Industry
- Port / Marine Terminal / Ship Repair
- Public and Institutional
- Water Related Commerce and Commercial Recreation
- Open Space
- Service Area
- Non-WW Generating
- Vacant

VEOLIA WATER

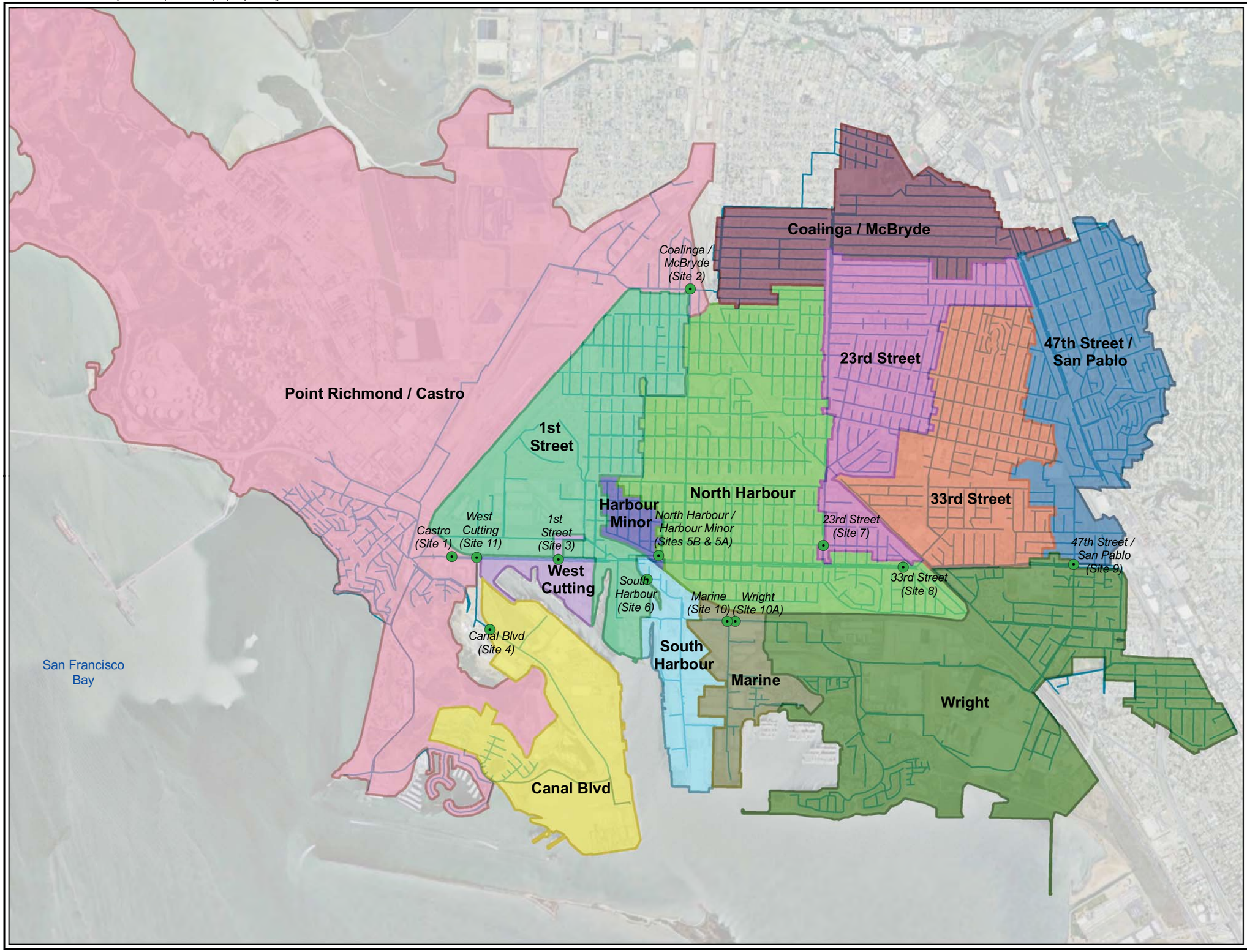
WEST YOST ASSOCIATES
Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure ES-3.mxd 3/18/2011

FIGURE ES-3

City of Richmond
Sewer Collection System Master Plan

FLOW METER AND RAIN GAUGE LOCATIONS AND ASSOCIATED BASINS



N

0 1,000 2,000

Scale in Feet

Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

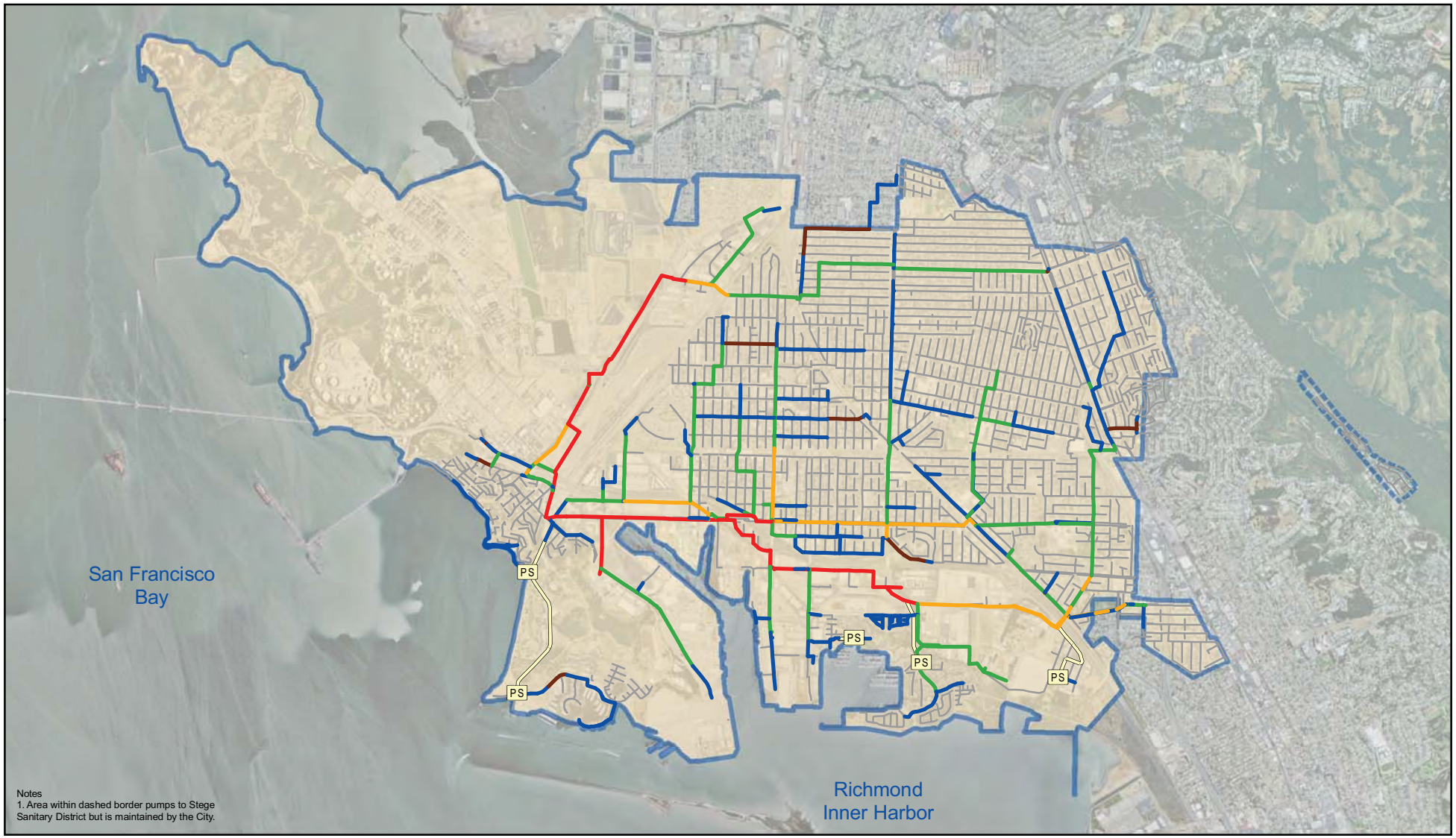
- Metering Site
- Sewer Pipe Segment

Basin

- 1st Street
- 23rd Street
- 33rd Street
- 47th Street / San Pablo
- Canal Boulevard
- Coalinga / McBryde
- Harbour Minor
- Marine
- North Harbour
- Point Richmond / Castro
- South Harbour
- West Cutting
- Wright

VEOLIA WATER

WEST YOST ASSOCIATES Consulting Engineers



LEGEND

Modeled Pipes

- 4" - 8"
- 10" - 12"
- 15" - 21"
- 24" - 30"
- > 30"

PS Modeled Pump Station

Force Main

Unmodeled Sewer Pipes

Service Area

N

0 0.5 1

Miles

FIGURE ES-4

City of Richmond
Sewer Collection System Master Plan

MODELED SEWER COLLECTION SYSTEM FACILITIES

VEOLIA WATER

WEST YOST ASSOCIATES Consulting Engineers

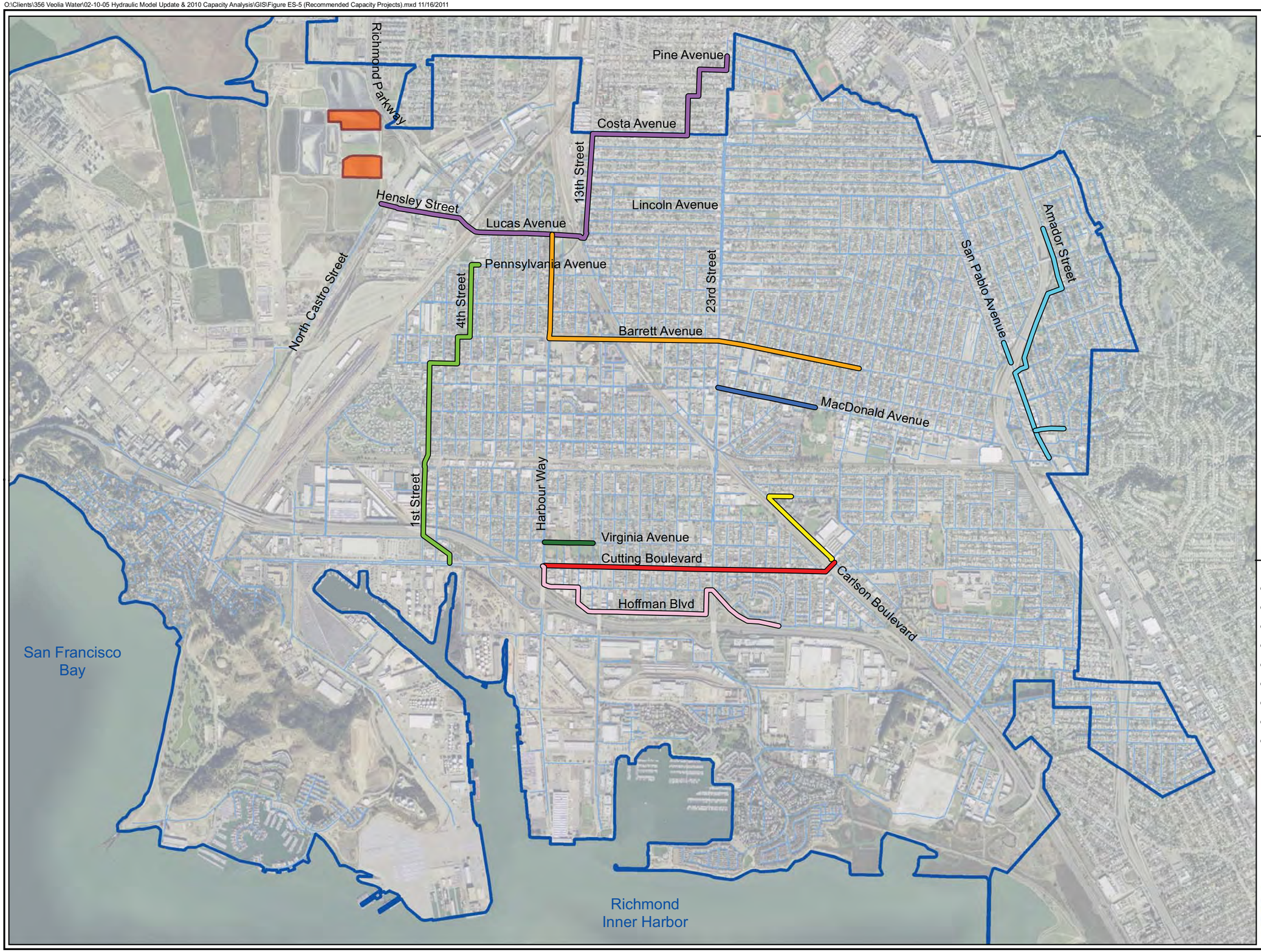
O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure ES-4 (Modeled Collection System).mxd 3/18/2011

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure ES-5 (Recommended Capacity Projects).mxd 11/16/2011

FIGURE ES-5

City of Richmond
Sewer Collection System
Master Plan

RECOMMENDED CAPACITY PROJECTS



N

0 0.2 0.4

Miles

Notes
1. See Figure 2-1 for location of the area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

Sewer Capacity Improvements
- 13th Street
- Barrett Avenue Relief Sewer
- Cutting Boulevard
- Hoffman Boulevard
- 1st Street
- MacDonald at 23rd Street
- Virginia Avenue at Harbour Way
- San Pablo
- Carlson Boulevard

Potential Wet Weather Storage Location
- Storage Location

Other
- Sewer Pipe Segment
- Service Area

VEOLIA WATER

WEST YOST ASSOCIATES
Consulting Engineers

This Chapter provides background information on the scope and objectives of the City of Richmond Collection System Master Plan (Master Plan). The Master Plan was completed in draft form in March 2011. Since that time, additional flow monitoring and alternatives analyses were completed, thereby changing the Master Plan results and recommendations. This final Master Plan continues to be a working document, and reflects the information known by Veolia and the City as of the November 2011.

1.1 BACKGROUND AND PROJECT OBJECTIVES

1.1.1 Background

In June 2010, Veolia Water (Veolia), the contract operator for the City of Richmond (City) collection system, retained West Yost Associates (West Yost) to complete the Master Plan. The master plan assesses the conveyance capacity of the City's collection system within the Richmond Municipal Sewer District (RMSD). The original schedule for completion of the Master Plan was accelerated, with the objective of completing the Master Plan document within seven months from the Notice to Proceed.

The original project included development of the hydraulic model network by Veolia. Veolia provided the network to West Yost in September 2011. Upon request by Veolia, the draft Master Plan report was completed in less than six months following delivery of the hydraulic model network. In order to meet this schedule, the recommendations that were presented in draft Chapter 7, Capacity Analysis, were conceptual in nature.

During July 2011, additional flow monitoring was conducted. Also, in August and September 2011, an additional project concept was evaluated for relief capacity and wet weather storage. As a result of this work, the hydraulic analyses and recommended projects have evolved since the development of the draft Master Plan report. This final draft Master Plan incorporates the most recent findings.

Additional project planning tasks, including supplemental flow monitoring and survey, are required to further define the presented projects and their associated costs. It is recommended that the City complete these planning studies as an early component of the preliminary design phase for each project.

1.1.2 Project Objectives

Collector sewers convey flows throughout the RMSD to the City's wastewater treatment plant. Additional gravity sewer pipelines are located within City limits, but outside of RMSD jurisdiction. These facilities, which are managed and maintained by the West County Wastewater District and the Stege Sanitary District, were not included in this study. All future reference to the City's collection system implies the portion owned and operated by RMSD only.

The wastewater collection system master plan meets multiple objectives established by West Yost, Veolia, and the City as follows:

- Evaluate system-wide flow characteristics to identify areas contributing to high inflow and infiltration (I&I);
- Assess the existing hydraulic capacity of the collection system;
- Evaluate modeled pump station firm capacity under design storm conditions;
- Summarize previously developed pipeline condition and replacement needs; and
- Develop a prioritized capital improvement program (CIP) that strategically replaces or repairs facilities over time to meet regulatory and legal mandates, maximize useful life, and reduce operational and financial risk.

The Master Plan serves as a roadmap for both near-term and long-term sewer system infrastructure management.

1.2 REPORT ORGANIZATION

The Master Plan report is comprised of the following nine chapters. This section describes the contents of each of the chapters and appendices.

1.2.1 Chapter 1 – Introduction

This introductory chapter provides background information on the scope and objectives of the Master Plan, and presents the contents and organization of this report.

1.2.2 Chapter 2 – Existing Wastewater System

This chapter describes the City's existing service area, presents land uses for the service area, and describes existing collection system facilities including pump stations, pipelines, and potential wet weather storage facilities.

1.2.3 Chapter 3 – System Flows

This chapter presents the methodology used to determine existing dry weather and wet weather wastewater flows for the purposes of collection system hydraulic modeling.

1.2.4 Chapter 4 – Flow Monitoring and Inflow/Infiltration Analysis

This chapter summarizes contributions to system-wide inflow and infiltration based on results from the City's 2010 flow monitoring program that was conducted by V&A Consultants (V&A), and also describes the findings from the City and Veolia's July 2011 tidal flow monitoring project.

1.2.5 Chapter 5 – Hydraulic Model Development

This chapter documents the tasks required to validate and calibrate the MWHSoft® InfoWorks™ CS hydraulic model. The hydraulic model is the primary analytical tool that was used to determine the flows and capacities of the City's trunk sewers, and to identify needed capacity improvements, including wet weather storage requirements. The initial pipeline network, developed by Veolia, included the City's large diameter trunk sewers and five pump stations. West Yost reviewed the network, added relief pipelines and other sewers required for connectivity, and added pump station wet well and operational control information.

1.2.6 Chapter 6 – Planning Criteria

This chapter documents the planning criteria that was used to assess whether hydraulic deficiencies occur in the collection system. These criteria are based on standard planning criteria in use by the City or within the industry.

1.2.7 Chapter 7 – Capacity Analysis

This chapter presents the results of the existing system hydraulic capacity analysis for the City's wastewater collection system. This chapter presents analysis results, identifies existing pipelines and pump stations requiring capacity relief, and describes required capital improvement projects.

1.2.8 Chapter 8 – Pipeline Repair and Replacement Program

This chapter reviews pipeline rehabilitation project recommendations that were developed in early 2010. The recommendations are reviewed, updated, and integrated into this Master Plan.

1.2.9 Chapter 9 – Capital Improvement Plan

This chapter consolidates recommendations presented in Chapters 7 and 8 and combines the projects into a prioritized capital improvement plan (CIP) that addresses the most critical projects first, balances facility replacements to enable completion of a variety of projects in each year, and distributes cost to form a fundable long-term program.

1.2.10 Appendices

The following appendices to this Master Plan contain additional technical information and assumptions:

- Appendix A – Exceptions to the 50% Rule for Land Use Unit Flow Factor Assignments
- Appendix B – V&A Flow Monitoring Reports
- Appendix C – Dry Weather Flow Diurnal Curves
- Appendix D – Dry Weather Calibration Hydrographs
- Appendix E – Wet Weather Calibration Hydrographs

- Appendix F – West Yost TM Describing Recommended Pipeline Replacement and Repair Projects
- Appendix G – Capacity Improvement Project Detailed CIP Cost Estimates

1.3 ACRONYMS AND ABBREVIATIONS

The following acronyms and abbreviations have been used throughout this Master Plan to improve document clarity and readability.

ADWF	Average Dry Weather Flow
Baykeeper	San Francisco Baykeeper
BWF	Base Wastewater Flows
CCTV	Closed Circuit Television
CIP	Capital Improvement Program
City	City of Richmond
CIWQS	California Integrated Water Quality System
fps	Feet Per Second
GIS	Geographical Information System
gpcpd	Gallons Per Capita Per Day
GWI	Groundwater Infiltration
HGL	Hydraulic Grade Line
I&I	Inflow and Infiltration
Master Plan	City of Richmond Collection System Master Plan for the Richmond Municipal Sewer District
MG	Million Gallons
mgd	Million Gallons Per Day
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge and Elimination System
PDWF	Peak Dry Weather Flow
PWWF	Peak Wet Weather Flow
Q_a	Average Daily Dry Weather Flow
Q_{pdwf}	Peak Hourly Dry Weather Flow
Q_{pwwf}	Peak Wet Weather Flow
RDI	Rainfall-Dependent Inflow
RDII	Rainfall-Dependent Inflow and Infiltration
RMSD	Richmond Municipal Sewer District
RWQCB	Regional Water Quality Control Board
SECAP	System Evaluation and Capacity Assurance Plan
SSMP	Sewer System Management Plan
SSO	Sewer System Overflow
Stege	Stege Sanitary District
SUH	Synthetic Unit Hydrograph
SWRCB	State Water Resources Control Board

TI	Tidal Inflows
TSI	Tidal Saturation Infiltration
V&A	V&A Consulting
Veolia	City of Veolia Water
WCWD	West County Wastewater District
WDR	Waste Discharge Requirements
West Yost	West Yost Associates
WWF	Wet Weather Flow

The purpose of this chapter is to describe the City's RMSD wastewater collection system and the regulatory mandates that define sewer system management. System information was obtained through the review of previous reports, maps, plans, operating records, general plans, and other available data. The following sections of this chapter describe the components of the City's existing wastewater collection system and the setting in which the City operates this system:

- Existing Service Area,
- Population Served and Land Use Characteristics,
- Existing and Anticipated Collection System Facilities, and
- Overview of Legal and Regulatory Mandates.

2.1 EXISTING SERVICE AREA

The RMSD currently provides wastewater collection service to a majority of the City, as well as a small area within unincorporated county limits, all located within Contra Costa County in the San Francisco Bay Area. The City and RMSD collection system service area are shown on Figure 2-1.

The City's service area is diverse, ranging from hilly, tree-covered residential areas along the eastern boundary to relatively low-topography communities from San Pablo Avenue west and south to the Bay. A small community named Point Richmond, located on the far western boundary, is comprised of steep, narrow roadways. Flows from this community are conveyed by gravity to the Keller Beach interceptor, which is located below sea level. In addition to the predominantly residential areas, the service area includes heavily traveled transportation corridors, significant acreage within the tidal zones adjacent to the San Francisco Bay, and heavy industrial areas including various properties owned and operated by Chevron Corporation. Chevron holds a National Pollution Discharge Elimination System (NPDES) permit for discharge of stormwater into the City's sewer collection system.

The City encompasses a total area of 52.6 square miles consisting of over 30 square miles of land. Much of this land comprises open space; approximately ¼ of this acreage is included within the City's sewer service area. Abutting the RMSD's service area, West County Wastewater District (WCWD) provides sewer collection service to a small portion of the City on the northern border of the City, adjacent to the City of San Pablo, and Stege Sanitary District (Stege) collects wastewater for a portion of the City in the eastern hills, adjacent to the City of El Cerrito. The City, WCWD, and Stege convey flows to three separate wastewater treatment plants.

The City's existing sewer collection system is comprised of approximately 187 miles of active gravity sewer pipelines with sizes ranging from 4 to 66 inches in diameter, 15 miles of pressure pipelines, and 14 pump stations, according to the California Integrated Water Quality System (CIWQS) database. The City conveys all flows to its Wastewater Treatment Plant located on Canal Boulevard, south of I-580.

2.2 POPULATION SERVED & LAND USE CHARACTERISTICS

This section describes current population projections, and associated land use as outlined in the City's General Plan.

The estimated population for the City is 103,701 based on the 2010 census. The City's RMSD service area includes a wide range of mixed land uses. Land use information was derived from the City and Contra Costa County geographical information system (GIS) resources. Land-use derived flows were further confirmed through a review of aerial photographs of the service area, discussions with Veolia and City staff, discussions with Chevron staff (related to permitted discharge), and review of discharge records from large commercial and industrial users.

Figure 2-2 shows existing land use designations for the City of Richmond. This information served as the basis for initial flow calculations from the City's RMSD service area. Land use categories with similar characteristics were grouped as listed in Table 2-1.

Table 2-1. Summarized Land Use Categories

Land Use Designation	Parcels (residential only)	Developed, acres	Undeveloped[a], acres	Total, acres	Total Percentage
Residential	17,901	2,095	21	2,116	30%
Very Low Density	569	72	3	75	1%
Low Density	11,062	1,242	7	1,250	18%
Medium Density	4,410	581	9	590	8%
High Density	1,860	200	1	201	3%
Commercial and Industrial		3,025	227	3,253	47%
Neighborhood Retail/ General Commercial		203	24	227	3%
Regional Office/Shopping/City Center		61	6	67	1%
Industrial/Office Flex/Light Industrial		671	86	757	11%
Heavy Industry		1,574	86	1,659	24%
Port/Marine Terminal/Ship Repair		434	0	434	6%
Water Related Commerce and Commercial Recreation		83	25	108	2%
Other		1,621	13	1,635	23%
Public and Institutional		211	13	225	3%
Open Space (Wastewater Generating)[b]		4		4	0%
Open Space (Non-Wastewater Generating)[c]		1,406		1,406	20%
Total	17,901	6,974	262	7,004	100%

[a] Undeveloped includes vacant parcels that could generate wastewater in the future. This does not include open space designations.

[b] Includes the buildings and improved portions of the Community Parks and Facilities, Regional Parks and Facilities, and Golf Courses only.

[c] Includes Archeological and Cultural Resources, Preservation Resource Areas, Community Open Space, Trails, Sanitary Landfill, Cemeteries, and Water. Also includes the unimproved portions of the Community Parks and Facilities, Regional Parks and Facilities, and Golf Courses.

2.3 EXISTING AND ANTICIPATED COLLECTION SYSTEM FACILITIES

This section describes facilities that are owned and maintained by the City, and also discusses opportunities for regional wastewater storage. Existing facility information was derived from the City's GIS database and existing documents. Figure 2-3 shows the RMSD pipeline and pump station facilities, as documented in GIS. Veolia provided the pipeline network in an InfoWorks™ database to West Yost. The network provided by Veolia compared well to the City's GIS database. West Yost supplemented this network by adding relief pipelines included in the GIS database, and by adding pump station wet well dimensions and operational criteria obtained from Veolia.

Subsequent to the development of the hydraulic model, some survey data has been collected for projects to repair or replace some neighborhood collector sewers. The survey data has not been consistent with elevation data that is included in the City and Veolia GIS files. In the future, as additional survey data is obtained for the City's trunk sewers, the hydraulic model should be reviewed and updated to reflect the collected data. The feasibility and complexity of future updates will depend on the extent that survey data varies from GIS data.

2.3.1 Pipeline Characteristics

The City's sewer system is comprised of approximately 187 miles of pipe ranging in diameter from 4 to 66 inches. The predominant pipeline material for small diameter pipelines is vitrified clay pipe. Table 2-2 and Figure 2-4 show the breakdown of pipes by size.

Table 2-2. Percentage of Pipe by Diameter

Pipe Diameter	Percent of System, %
6-inch and smaller	58
8- to 10-inch	15
12- to 16-inch	7
18- to 24-inch	7
27- to 36-inch	2
39- to 66-inch	1
Unidentified (small diameter)	10
Total Percentage	100

The City's service area is comprised of ten sewer basins as shown in Figure 2-5. From February through June 2010, the City monitored flows from these basins to provide data for use in model calibration and Inflow/Infiltration (I&I) analysis. Results from this flow monitoring effort and additional information regarding the City's sewer basin flows are included in Chapter 4, Flow Monitoring and I&I Analysis.

2.3.2 Pump Station Characteristics

The City owns and operates 14 pump stations, as shown in Figure 2-3. Of these stations, three stations, Canyon Estates 1, 2, and 3, are considered outside of the RMCD service area because they discharge to the Stege Sanitary District. Characteristics of the remaining 11 pump stations are listed in Table 2-3. Five of these stations were included by Veolia in the development of the hydraulic model network.

As part of the City's previous sewer master plan (Boyle, 2006) and System Evaluation and Capacity Assurance Plan (SECAP) (Psomas, 2007), the City assessed the firm pumping capacity for each pump station. The pump station capacities listed in Table 2-3 draw from the Boyle analysis, and were determined by Veolia to represent the maximum pumping capacity for each station with the largest pump out of service. The previous master plans did not evaluate the Port Booster Pump Station. Therefore, the capacity for this station has been left as unknown until additional information can be gathered for this specific facility. Also, the Port Booster Pump Station does not have firm capacity in that it does not have a backup pump.

Table 2-3. RMSD Pump Station Descriptions

Pump Station Name	Number of Pumps	Pump Type	Year Built/Upgraded	Firm Capacity, gpm
Keller Beach	2	Flygt, 15hp	1996	780
Ferry Point	2	Smith & Loveless, 15hp	1961	450
Brickyard Cove	2	Flygt, 3hp	2006	200
Brickyard Booster	2	Flygt, 8hp	2005	510
Port	2	Flygt, 3hp	2006	300
Sunset Pointe	2	Homa, 5hp		100
Marina Bay Cove	2	Homa, 5hp, 8hp	1981	440
Marina Bay Parkway	3	Flygt, 35hp	1987	4200
ICI	2	Flygt, 7.5 hp and 10 hp	1992	440
West Nevin & A	2	Flygt, 5hp	1996	440
Port Booster	1	To be completed	To be completed	To be completed

2.3.3 Potential Regional Wet Weather Storage Facility

Veolia, the City, WCWD, and Chevron Corporation have held introductory discussions regarding the use of existing Chevron storage ponds for wet weather storage. The storage ponds are located at the intersection of Richmond Parkway and West Gertrude Avenue in Richmond. Figure 2-6 presents an aerial view of the Chevron ponds.

Currently, Chevron uses a portion of this facility for stormwater storage, and discharges this flow during dry weather periods to the City's collection system. Chevron is interested in discussing with WCWD and the City the option to utilize two large, unused storage basins for wet weather storage. The basins are currently shallow, and not ideally designed to store raw wastewater.

Chevron has expressed interest in making needed improvements to the basins, including assessing and replacing the existing HDPE liners and installing berms to increase capacity and deepen the basins.

This storage location is an attractive alternative to building other off-site storage, and is receiving consideration by the City as a key component of the City's wet weather flow management program. The City's draft wastewater treatment plant master planning documents estimate a need for approximately 20 million gallons (MG) of storage. The hydraulic model predicts a lower estimate of approximately 8 MG of required storage for a single event, without contingency. The Chevron facility appears to have sufficient volume to accommodate this need.

2.4 OVERVIEW OF LEGAL AND REGULATORY MANDATES

Veolia and the City operate and maintain the City's collection system and treatment plant in accordance with a number of regulatory documents, including: 1) Regional Water Quality Control Board (RWQCB) NPDES permit, and 2) RMSD Sewer System Management Plan (SSMP). The SSMP is currently being updated, and addresses RWQCB guidelines and State Water Resources Control Board (SWRCB) Statewide Collection System Waste Discharge Requirements (WDR). In addition, the City is required to meet aggressive requirements for the elimination of sewer spills through system-wide infrastructure improvements, as set forth in the 2006 Baykeeper settlement agreement. This section describes these requirements, which form the basis for developing and prioritizing capital improvements for the City.

2.4.1 RWQCB NPDES Permit

The City's NPDES permit, most recently adopted by the RWQCB in 2008, requires re-adoption by the RWQCB every five years. The permit establishes numerical limits for discharge of pollutants to the San Francisco Bay pursuant to the federal Clean Water Act and California's Porter-Cologne Water Quality Control Act. The permit also establishes requirements for monitoring wastewater to ensure that the permit holder meets all requirements. In order to meet NPDES permit requirements, the City must continuously maintain its treatment facilities, ensure that these facilities are sufficiently sized to treat wastewater volumes without system upsets, and operate the facilities with certified plant operators. The RWQCB routinely inspects treatment and collection facilities and enforces permit requirements. Violations of permit requirements often lead to significant fines, compliance orders, cease and desist orders, and/or third party lawsuits that specify capital improvements that are needed to bring the permit holder back into compliance.

2.4.2 RWQCB SSMP and Statewide WDR Requirements

The City's RMSD SSMP follows a prescribed outline that describes the City's collection system operating and maintenance practices, including guidelines for reducing and reporting sewer system overflows; preventive activities and metrics to minimize overflows; control of fats, oils, and grease; predictive system modeling to plan for future increases in sewer flows; sewer design and construction standards; and legal authority to enforce these measures. In conjunction with the SSMP, the City is required to report specific details about every sewer spill through an online reporting system that makes the data available to regulators and the public. At the end of every year, the City must complete an audit of the SSMP and also submit an annual sewer system

overflow (SSO) report to the RWQCB. The RWQCB expects to see continuous improvement in maintenance activities, as evidenced by reductions in the number of SSOs. Agencies with high numbers and volumes of SSOs may be subjected to fines, compliance orders, cease and desist orders, and/or third party lawsuits demanding improvements in the wastewater collection system.

2.4.3 Baykeeper Settlement Agreement

In approximately 2005, after documenting large wastewater spills from the City's collection system[1] and violations at the wastewater treatment plant, San Francisco Baykeeper (Baykeeper) filed a lawsuit against the City for violations of the Clean Water Act. In 2006, the City and Baykeeper finalized a settlement agreement that includes specific requirements needed to reduce spills within and from the wastewater collection system. The settlement agreement includes specific objectives that must be achieved within an aggressive schedule. If the City does not achieve these objectives, it becomes vulnerable to further legal actions, fines, and penalties.

The Baykeeper settlement requires $4 million per year in collection system improvements through 2011; elimination of overflows from the City's two collection system overflow structures by 2014; 90 percent system-wide spill reduction by 2016; and implementation of a $1 million sewer lateral replacement grant program. This Master Plan recommends the improvements that are needed to address these requirements.

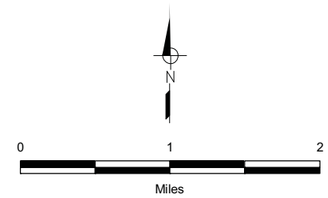
[1] As discussed in Chapter 7, Capacity Assessment, discharges from the City's Boat Ramp overflow and Harbour and Wright overflow are comprised of a combination of wastewater and stormwater. SSOs from the City's system enter a stormwater outfall to the Richmond Inner Harbour. Therefore, the SSO volumes that are reported from these two locations exceed the actual volume of wastewater that was discharged from the system.

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 2-1 (Service Area Boundary).mxd 3/17/2011

FIGURE 2-1

City of Richmond
Sewer Collection System
Master Plan

SERVICE AREA BOUNDARY



Notes
1. Area within dashed border pumps to Stege Sanitary District but is maintained by the City

LEGEND
- Sewer Mains
- Service Area
- City of Richmond

San Francisco Bay

Richmond Inner Harbor

VEOLIA WATER

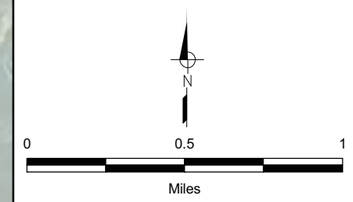
WEST YOST ASSOCIATES
Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 2-2 (Modeled Land Uses).mxd 3/18/2011

FIGURE 2-2

City of Richmond
Sewer Collection System
Master Plan

MODELED LAND USES



Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

San Francisco Bay

Richmond Inner Harbor

LEGEND

- Very Low Density Residential
- Low Density Residential
- Medium Density Residential
- High Density Residential
- Neighborhood Retail / General Commercial
- Regional Office / Shopping / City Center
- Industrial / Office Flex / Light Industry
- Heavy Industry
- Port / Marine Terminal / Ship Repair
- Public and Institutional
- Water Related Commerce and Commercial Recreation
- Open Space
- Service Area
- Non-WW Generating
- Vacant

VEOLIA WATER

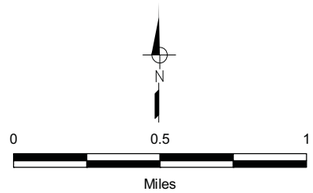
WEST YOST ASSOCIATES
Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 2-3 (Collection System Facilities).mxd 3/17/2011

FIGURE 2-3

City of Richmond
Sewer Collection System Master Plan

COLLECTION SYSTEM FACILITIES



Notes
1. Area within dashed border pumps to Stege Sanitary District but is maintained by the City.

West Nevia & A PS
Keller Beach PS
Ferry Point PS
Brickyard Cove PS
Brickyard Booster PS
Port PS
Marina Bay Cove PS
Marina Bay Parkway PS
ICI PS
Sunset Point PS
Canyon Estates #3 PS
Canyon Estates #2 PS
Canyon Estates #1 PS
San Francisco Bay
Richmond Inner Harbor

LEGEND

- Sewer Manhole
- Sewer Pipe Segment
- Force Main
- Pump Station
- Service Area

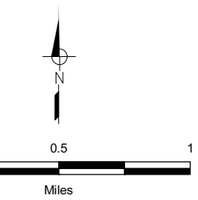
VEOLIA WATER
WEST YOST ASSOCIATES Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 2-4 (Gravity Sewer Pipelines by Size).mxd 3/17/2011

FIGURE 2-4

City of Richmond
Sewer Collection System Master Plan

GRAVITY SEWER PIPELINES BY SIZE



Notes
1. Area within dashed border pumps to Stege Sanitary District but is maintained by the City

LEGEND

- Force Main
- Service Area

Diameter

- 4" - 6"
- 8" - 10"
- 12" - 16"
- 18" - 24"
- 27" - 36"
- 39" - 66"
- Unidentified

San Francisco Bay

Richmond Inner Harbor

VEOLIA WATER

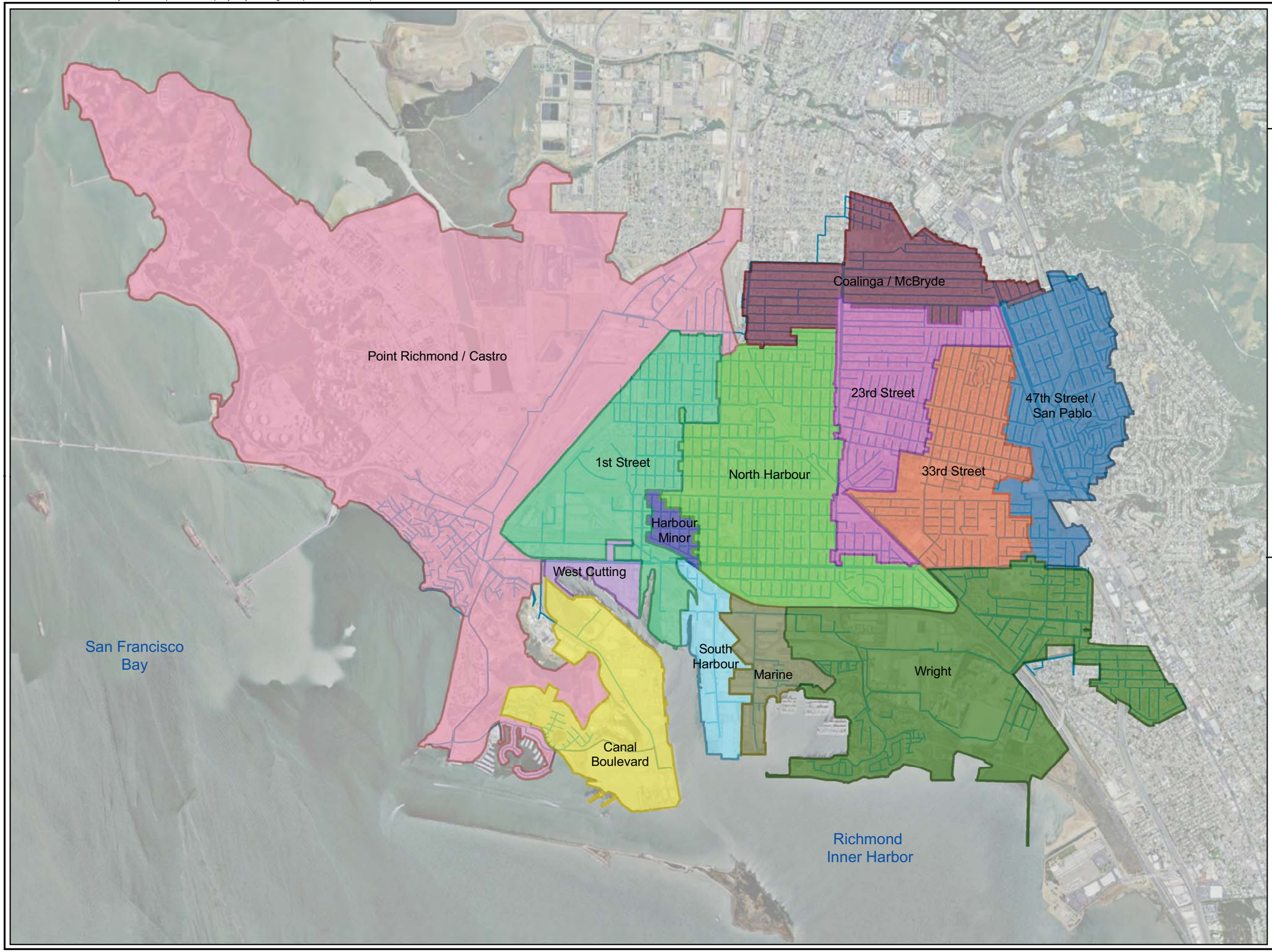
WEST YOST ASSOCIATES
Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 2-5 (Modeled Sewer Basins).mxd 3/18/2011

FIGURE 2-5

City of Richmond
Sewer Collection System
Master Plan

MODELED CITY SEWER BASINS



N

0 0.5 1

Miles

Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

- 1st Street
- 23rd Street
- 33rd Street
- 47th Street / San Pablo
- Canal Boulevard
- Coalinga / McBryde
- Harbour Minor
- Marine
- North Harbour
- Point Richmond / Castro
- South Harbour
- West Cutting
- Wright
- Sewer Pipe Segment

VEOLIA WATER

WEST YOST ASSOCIATES
Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 2-6 (Potential Wet Weather Storage Site on Chevron Property).mxd 3/11/2011

FIGURE 2-6

City of Richmond
Sewer Collection System Master Plan

POTENTIAL WET WEATHER STORAGE SITE ON CHEVRON PROPERTY

N

0 250 500

Feet

VEOLIA WATER

WEST YOST ASSOCIATES
Consulting Engineers

This chapter presents the background and methodology used to determine existing dry weather wastewater flows for input to the City's collection system hydraulic model. This chapter is organized as follows:

- Sources of System Data, and
- Calculation of Dry Weather Flows.

3.1 SOURCES OF SYSTEM DATA

The main sources of data used to estimate wastewater flows for the City's hydraulic model include land use information, aerial photography, industrial discharge data, service area boundary data, the sewer network, and data collected during the City's 2010 flow monitoring program, as discussed further in Chapter 4, Flow Monitoring and Inflow/Infiltration Analysis.

3.1.1 Land Use Information and Aerial Photography

The following resources were used to develop and assign land uses within the City's RMSD service area as shown in Figure 2-2.

- City of Richmond (Contra Costa County). The City provided land use information in GIS format. Also, the County's public GIS site provided data for the small, unincorporated area served by the City at the eastern boundary of the service area.
- Aerial Photography. In addition to land use information, West Yost reviewed aerial photography obtained for the City's service area, primarily to confirm the general plan land use data and also to identify parcels that are currently vacant or parcels that include large areas of unoccupied land.

3.1.2 Industrial Discharge Data

The City provided West Yost with industrial wastewater discharge data. This data was particularly useful for isolating industries that produce large quantities of wastewater. Industrial wastewater discharges, if significant, cause inaccuracy in dry whether flow calculations if not considered independently from flows estimated using standard wastewater flow generation factors. Chevron was the largest industrial flow contributor.

3.1.3 Service Area Boundary and Sewer Network

The City provided West Yost with a GIS file that included the City's service area. The service area boundary was essential for determining which parcels would be used to calculate wastewater flows within the collection system. Some parcels were only partially included within the service area. In these cases, if at least 50 percent of the parcel's area was included within the service area boundary, this parcel was considered to contribute wastewater to the system. All exceptions to this rule were documented and are included in Appendix A.

Also, in several basins the sewer network either did not extend to the service area boundary, or extended beyond the boundary. In these cases, parcels were reviewed on a case by case basis to determine whether they contribute flow to the collection system, irrespective of their location relative to the service area boundary. All of these occurrences were documented and are included in Appendix A.

3.1.4 Wastewater Flow Monitoring Reports

Veolia's flow monitoring consultant, V&A, provided two flow monitoring reports that document the flow monitoring program that was conducted from February to June 2010. The results from this program are discussed further in Chapter 4, Flow Monitoring and Inflow/Infiltration Analysis. During model development, West Yost used average dry weather flow data developed by V&A to confirm initial flow factors.

In July 2011, V&A conducted additional tidal flow monitoring to evaluate the effectiveness of projects that were implemented during 2010 to alleviate tidal inflow. The results confirmed a reduction in tidal inflow, and were incorporated into the hydraulic model. The results from this supplemental tidal flow monitoring program are also discussed in Chapter 4.

3.2 CALCULATION OF DRY WEATHER FLOWS

This section summarizes the methodology that was used to develop the initial average dry weather flow (ADWF) component of the collection system hydraulic model. These initial flows were further refined through the hydraulic model calibration process, as discussed in Chapter 5, Hydraulic Model Development.

Numerous methodologies are available to estimate ADWF that rely on population estimates, water usage, land use designations, and other resources. When a service area has complex flow characteristics caused by factors such as extensive mixed land use or rapidly changing occupancy rates, a highly detailed methodology is recommended to accurately predict ADWF. The City's service area has minimal mixed land use and is nearly built out. Although commercial occupancy rates have declined in recent years due to economic factors, the City's occupancy rate is generally stable. These attributes justify a more straightforward calculation of ADWF using flow factors and land use designations.

The initial ADWF component was calculated using the following steps:

- Consolidation of the City's planning level detailed land use categories into summarized categories as shown in Table 3-1.
- Designation of each parcel within the service area with a land use designation corresponding to the summarized categories. For parcels that straddled the boundary of two different land use designations, a 50 percent rule was used as discussed in Section 3.1.3.
- Assignment of specific flows to industrial or commercial parcels for which more customized large wastewater flows have been provided by the City, as discussed in Section 3.1.2 and shown in Table 3-2.

- Assignment of unit flow factors for each basin and adjust these factors so that estimated dry weather sanitary sewer flows agree with the metered flows provided in flow monitoring reports.

Adjust flow factors and/or flows for specific parcels for which actual use varies from the land use description, as apparent through review of aerial photography for the specific parcel. For occupied parcels with large fields, parking lots, open space, or non-wastewater generating areas, the parcel was designated as non-wastewater generating, and only the occupied areas of the parcel were isolated and designated as wastewater generating.

Table 3-1. Consolidation of Land Use Designations

General Plan Land Use	Consolidated Land Use
Very Low Residential	Very Low Residential
Low Residential	Low Residential
Medium Residential	Medium Residential
High Residential	High Residential
Neighborhood Retail	Neighborhood Retail / General Commercial
General Commercial	
Regional Office / Shopping	Regional Office / Shopping / City Center
City Center	
Industrial / Office Flex	Industrial / Office Flex / Light Industry
Light Industry	
Heavy Industry	Heavy Industry
Port / Marine Terminal / Ship Repair	Port / Marine Terminal / Ship Repair
Public and Institutional	Public and Institutional
Water Related Commerce and Commercial Recreation	Water Related Commerce and Commercial Recreation
Recreation Lands	Open Space
Preservation / Resource Areas	
Other Types of Open Space	

Note: Some areas of the general plan had mixed designations. For these areas, aerial photography was used for assigning parcels or groups of parcels with the appropriate land use designations.

Initial adjusted flow factors that were assigned to each basin in the hydraulic model are listed in Table 3-2. Basins where adjusted flow factors were representative of a land use that was different than the land use provided by the City are documented in Appendix A.

Table 3-2. Initial Unit Flow Factors by Land Use

Land Use	Units	33rd Street	47th Street / San Pablo	Harbour Minor	North Harbour	Canal Blvd	Castro	Coalinga / McBryde	Wright	23rd Street	1st Street	Marine	West Cutting	South Harbour
Very Low Density Residential	gpd/parcel		155				150							
Low Density Residential	gpd/parcel	150	155	145	165		150	220	175	265	320			
Medium Density Residential	gpd/acre	1,600	1,650		1,750	1,600	1,300	2,400	2,200	2,700	2,900	4,000		
High Density Residential	gpd/acre	2,600	2,650		2,800				3,200	3,800		5,000		
Neighborhood Retail / General Commercial	gpd/acre	900	900		1,000		1,000	1,000	1,000	1,000	1,450			3,400
Regional Office / Shopping / City Center	gpd/acre	900	900		1,000						1,450			
Industrial / Office Flex / Light Industry	gpd/acre	900		900	1,000	1,000	1,000		1,000	1,000	1,450	1,700	1,300	3,400
Heavy Industry	gpd/acre						1,150		1,200					
Port / Marine Terminal / Ship Repair	gpd/acre					250					700		550	1,200
Public and Institutional	gpd/acre	900	900		1,000		1,000	1,000	1,000	1,000	1,600			
Water Related Commerce and Commercial Recreation	gpd/acre													
Open Space	gpd/acre	50			200				200		250			

To supplement land-use based flows, flows from twelve individual large industries were evaluated and included as point loads in the hydraulic model. These industries, which are listed in Table 3-3, are large contributors of wastewater. The City provided annual flows in units of cubic feet, along with corresponding parcel IDs. These flows were converted into gallons for input into the hydraulic model. To avoid double-counting the flows that might be generated based on acreage from each of these parcels, the parcel received a non-wastewater generating land use designation.

Table 3-3. Industrial Discharge Flow Data Provided by City of Richmond

Industrial Dischargers	Domestic Volume, cubic feet	Industrial Volume, cubic feet	Total Usage, cubic feet (Jan-Dec)
Standard Oil Company of California Chevron Services Co.	35,000	7,609,282	7,644,282
California State of Facilities Management Section (DOHS)	-	3,442,900	3,442,900
Bio-Rad Laboratories Inc.	52,500	3,018,279	3,070,779
Kinder Morgan Energy Partners	19,600	1,648,712	1,668,312
Kaiser Foundation Hospitals Department of Taxation	-	1,663,900	1,663,900
California Fats & Oils Inc.	46,900	1,505,040	1,551,940
West Contra Costa Unified School District	-	1,502,900	1,502,900
United States of America GSA (Social Security)	1,085,000	324,065	1,409,065
University of California Richmond Field Station	-	1,394,900	1,394,900
Catellus Development Corp Thomson Property Tax Services	-	1,276,100	1,276,100
Regents of University of California (USEPA)	-	1,169,100	1,169,100
T & T Richmond LP	-	840,900	840,900

In early 2010, the City and Veolia completed a system-wide flow monitoring program. The program was conducted by V&A from February to June 2010. In addition, from May 2010 to June 2010, five additional flowmeters were installed at new locations within the southern portion of the service area to refine and supplement data for areas with tidal inflow and high groundwater infiltration. Data and results are presented in the V&A reports titled, "*Flow Monitoring and Inflow/Infiltration Study (December, 2010)*" and "*Flow Monitoring of Five Tidal Sites (September, 2010)*".

During this period, Veolia completed several projects to reduce tidal inflow from cross connections between the stormwater system (through which tidal flows entered the City's infrastructure) and sewer system. The City and Veolia conducted additional tidal flow monitoring in July 2011 to estimate the amount of inflow reduction that was achieved through these projects. Results are presented in the V&A report titled, *"Sanitary Sewer Flow Monitoring and Tidal Inflow and Infiltration Study (September, 2011)"*.

The V&A Reports are included in Appendix B.

This chapter highlights the findings from these reports that are key factors in the development of a strategic I&I reduction program. This chapter is organized as follows:

- Findings and Recommendations,
- General Sources of Inflow and Infiltration,
- System-Wide Flow Monitoring Program,
- Tidal Area Flow Monitoring,
- Description of Flows, and
- Inflow and Infiltration Analysis.

4.1 FINDINGS AND RECOMMENDATIONS

The following findings and recommendations were developed to quickly address the issues within the system that are the most significant contributors to I&I. Through the control of I&I, over time, the City will also reduce wet weather related SSOs.

4.1.1 Findings

The 2010 flow monitoring program captured rainfall events with a statistical recurrence interval of less than 2 years (*i.e.*, 50 percent probability of occurring in any given year). Peak flows generated by these rainfall events resulted in surcharge conditions in all but two of the metered locations throughout the collection system.

By contrast, the Richmond-Baykeeper settlement agreement requires the City to eliminate SSOs that would result from a design storm with 10-year recurrence interval and 24-hour duration. Based on flows observed during the 2010 wet weather season, it is expected that the system will experience significant capacity issues, including SSOs, during the 10-year design storm.

The recommendations presented in this chapter prioritize areas for I&I reduction. Although addressing the highest impact contributors to I&I will reduce system flows, I&I reduction in itself will not eliminate SSOs. Capacity improvements and wet weather storage are required in addition to I&I abatement in order for the City to meet the requirements of the Baykeeper agreement. Capacity improvements are discussed further in Chapter 7, and a prioritized capital improvement program is presented in Chapter 9.

4.1.2 Recommendations

The primary contributors to wet weather I&I in the City's system are: 1) direct tidal inflow in the southern basins, 2) groundwater infiltration including a tidal saturation infiltration component, 3) storm runoff inflow from direct connections between stormwater facilities and the sewer system, and 4) rainfall dependent infiltration. Veolia has addressed the most prominent sources of tidal inflow through the disconnection of storm drains from the sewer system and the installation of duckbill check valves on the City's two wet weather overflow outlets. It is recommended that the City continue to prioritize the elimination of other sources of tidal and industrial inflow, as recent flow monitoring efforts have confirmed that an immediate reduction in flow has resulted from these activities.

4.1.2.1 Tidal Inflow

Although tidal inflow is prevalent along all of the coastal areas within the service area, the 2010 flow monitoring program indicated that the South Harbour area, which includes the area south of I-580 between Canal Boulevard and Marina Way, added the most significant tidal contribution to the collection system. The significant peak flows measured in this area indicated direct inflow correlating with high tide, in lieu of tidal groundwater infiltration.

The projects that were completed by Veolia during 2010 appear to have significantly reduced these inflows. However, based on the 2011 flow monitoring program, it appears that additional tidal flow originates north of Cutting Boulevard in the 1st Street basin. Additional investigations to identify the potential sources of this inflow are recommended.

4.1.2.2 Sources of Non-Tidal Groundwater Inflow

The highest level of direct non-tidal stormwater inflow was found in the eastern portion of the service area. Further review of stormwater maps supplemented with smoke testing may identify potential connections that, if disconnected, would reduce wet weather flows. Recently, however, Veolia conducted smoke testing in the upper San Pablo area. Smoke test results were not conclusive as to identifying direct connections. Although reduction of stormwater inflow is recommended for long-term I&I reduction, this effort is not likely to result in the significant flow reductions required to meet the terms of the Baykeeper agreement.

Separate from this Master Plan, in October 2011 the results from previous smoke testing activities were reviewed and compared to measured I&I, as well as other factors. Based on this evaluation, Veolia and the City are investigating the potential cross-connection of up to eight storm drains in the North Harbour basin. More information related to these activities will be included in a subsequent update to the Master Plan.

4.1.2.3 Rainfall-Dependent Inflow and Infiltration

The highest level of rainfall dependent inflow and infiltration (RDII) was found in the western portion of the system. Veolia and the City are currently planning rehabilitation of the Keller Beach pipelines to resolve known SSOs and also to improve reliability of the Keller Beach gravity interceptor. This and similar projects will result in I&I reduction through the replacement of aging pipelines. However, similar to inflow reduction, RDII reductions will be realized over time, and these projects will not likely result in the rapid flow reductions that are needed by the City to meet the requirements of the Baykeeper agreement.

4.1.2.4 Other Improvements

In addition to eliminating the most prevalent locations of tidal inflow and implementing a systematic replacement program that addresses inflow and infiltration, the City has initiated planning activities for components of the capacity improvement program that were identified in the draft submittal of this Master Plan. The capacity improvement program will upsize trunk sewers throughout the service area to convey flows to the wastewater treatment plant. Conveyance of flows upstream of the wastewater treatment plant to in-system storage will also be required to control influent flows to the treatment plant. Pipeline and wet weather storage recommendations are discussed further in Chapter 7, Capacity Analysis.

Upsized pipelines will likely increase peak flows that are currently constricted and attenuated in the upper sewer basins, and may create issues that are currently not found in the downstream conveyance system. Therefore, capacity improvements should consider a progression that begins in the downstream portions of the system. If pipes must be upsized in the upstream reaches of the system in order to address localized SSOs, then consideration should be given to achieving the upsize in two phases – the first phase would improve capacity to accommodate low recurrence frequency rain events, and a second phase would provide relief capacity to address the 10-year, 24-hour design storm.

4.2 GENERAL SOURCES OF INFLOW AND INFILTRATION

I&I defines extraneous flows that enter the sanitary sewer system. I&I can adversely impact the capacity of wastewater collection systems by increasing both peak flows and total flow volume. I&I can be rainfall induced (RDII), the result of groundwater (or tidal) intrusion (groundwater infiltration [GWI]), or the result of illicit connections (inflow). Figure 4-1 provides examples of common I&I sources. The figures in this chapter were taken from the V&A flow monitoring report for consistency, and further annotated when needed.

4.2.1 Inflow

I&I enters the collection system through different mechanisms. Inflow is water that enters the collection system through a direct, unpermitted connection. Inflow enters the sewer pipe independent of groundwater level and can be seen in the collection system immediately following a rainfall event. Examples of inflow sources are direct connections such as roof leaders, foundation or yard drains, open cleanouts in low-lying areas, storm drain cross-connections, and leaky manhole covers.

4.2.2 Infiltration

Infiltration is water that enters the collection system by percolating through the soil and then into the collection system through defects in pipelines, manholes, and joints. Infiltration occurs over a longer period of time, and depending on soil conditions, can occur for days or weeks following a storm, or seasonally with rising groundwater tables. Examples of RDII and GWI sources are cracked or broken pipes and laterals, misaligned joints, pipe offsets and sags, deteriorated manholes, and root intrusion.

Figure 4-2 shows typical RDII response found in flow monitoring data. RDII occurs after a rainfall event and can enter the collection system within a day of the rainfall event and last for several days after the rain event has ceased. GWI varies seasonally as the groundwater table fluctuates, and is typically seen in flow data as a mounding effect into the collection system over the entire wet weather season. GWI patterns reflect movement of the groundwater table, which rises gradually during the wet weather season and falls during the dry weather season. On a day-to-day basis, GWI occurs relatively steadily throughout the day and even over several weeks.

Within the low lying areas surrounding the San Francisco Bay, tidal infiltration is a separate and significant source of GWI into the City's collection system. Tidal infiltration rates vary daily and fluctuate with the tide table. The extent of tidal infiltration depends on the proximity to the San Francisco Bay, pipe bedding characteristics, and the depth of these pipelines and manholes relative to the tide elevation.

4.3 SYSTEM-WIDE FLOW MONITORING PROGRAM

This section describes the 2010 system-wide flow monitoring program, including meter and rain gauge locations, and basin delineations.

4.3.1 Data Collection

The flow monitoring program included twelve (12) gravity meters that measured flows from ten basins, and two (2) rain gauges. Figure 4-3 presents the flow meter locations and associated collection system basins. The basins were named by West Yost in development of the hydraulic model.

Meter numbers, the associated manhole ID, and contributing drainage basins are listed in Table 4-1. Manhole IDs use the numbering system that was established by Veolia Water, which is different than the nomenclature available through the City's GIS maps.

Depth and velocity readings were collected at each flow meter in 15-minute increments. This data was compiled into hourly flows for the evaluation of system-wide I&I. Figure 4-4 was developed by West Yost to supplement information provided by V&A, and illustrates the direction of flow and interconnection between basins.

Table 4-1. Flow Meter Locations and Associated Drainage Basins			
Meter Site No.	Veolia Manhole ID	Diameter, Inches	Basin Name
1	G7MH750	54	Point Richmond/Castro
2	J10MH2266	21	Coalinga/McBryde
3	G8MH1364	54	1st Street
4	F8MH965	18	Canal Boulevard
5A	G9MH2248	18	Harbour Minor
5B	G9MH2448	48	North Harbour
6	F9MH1335	36	South Harbour
7	G11MH892	21	23rd Street
8	G11MH833	24	33rd Street
9	G13MH1600	21	47th Street/San Pablo
10	F10MH1640	36	Marine
10[(a)]	F10MH1546	36	Wright
11[(b)]	G8MH1209	66	West Cutting

(a) On March 18, 2010, Meter 10 was relocated three manholes upstream from the initial manhole to capture tidal infiltration within the same basin but at a different location.
(b) Meter 11 measured flows in the main interceptor that is influent to the WWTP.

4.3.2 Rainfall Data

Two rain gauges were installed by V&A within the City's service area during the 2010 flow monitoring program. Rain Gauge No. 1 was installed in the eastern portion of the service area at Poinsett Avenue, north of Jordan Avenue. Rain Gauge No. 2 was installed at the City of Richmond Wastewater Treatment Plant on Canal Boulevard. Table 4-2 presents the recorded rainfall during the flow monitoring period.[1]

The largest rainfall event during the flow monitoring period occurred from April 11 to 13, 2010. Several smaller storms occurred from February 21 to 24, 2010 and March 2 to 4, 2010.

Table 4-2. Rainfall Data from the 2010 Flow Monitoring Program		
Dates	Rain Gauge 1, inches	Rain Gauge 2, inches
4/11 to 4/13/2010	1.52	2.32
2/21 to 2/24/2010	1.14	1.66
3/2 to 3/4/2010	1.19	1.18

[1] During the wet weather calibration described in Chapter 5, it became apparent that the central part of the City experienced rainfall with a temporal distribution that was substantially different than recorded by the two V&A gauges. A public rain gauge at City Hall was located and used in conjunction with Gauges 1 and 2 for model calibration.

Rainfall events are classified based on duration and recurrence interval. The National Oceanic and Atmospheric Administration (NOAA) has developed atlas maps, based on long-term historical rainfall data (NOAA Western U.S. Precipitation Frequency Maps Atlas 2, 1973), that provide classifications for storms of different recurrence intervals and durations. Based on the data points provided in the NOAA atlas maps, the rainfall events that were captured during the flow monitoring program had less than a 2-year recurrence interval.

4.4 TIDAL AREA FLOW MONITORING

To supplement the 2010 flow monitoring results, V&A implemented a 2010 tidal monitoring program to further define locations and quantities of tidal inflow. The tidal monitoring program included five (5) gravity meters that were installed after the wet weather season, but prior to completion of the system-wide flow monitoring program. The five meters were located in manholes in basins where wet weather flow data signified the presence of significant tidal groundwater inflow.

Table 4-3 and Figure 4-5 present the tidal flow meter locations.

Table 4-3. Tidal Flow Meter Locations and Associated Drainage Basins

Tidal Meter Site No.	Veolia Manhole ID	Pipe Diameter, inches	Basin Name	Supplements Primary Meter
1A	H7MH976	42	Castro	1
2A	F9MH1345	18	South Harbour	6
3A	E11MH1251	30	West Cutting	10
4A	E12MH2376	24	West Cutting	10
4B	E12MH1940	24	West Cutting	10

Also, in July 2011, V&A implemented a subsequent tidal monitoring program to estimate the amount of inflow that was abated as a result of capital improvements that were installed in 2010. The 2011 flow monitoring program included six (6) gravity meters that were located in manholes for which tidal flows were measured in the earlier programs. The meters collected data on flow and temperature through two periods of high tide. The collected data was correlated with tidal patterns and was also compared to previously collected data. In addition to measuring tidal inflow, the data indicated the presence of industrial (cold water) discharges, and also showed that during the dry weather monitoring period, the system experienced some surcharging resulting from operations at the WWTP.

4.5 DESCRIPTION OF FLOWS

This section summarizes the V&A analysis of dry weather and wet weather flows collected during the system-wide flow monitoring program and the supplemental tidal flow monitoring efforts.

4.5.1 Dry Weather Flows

V&A calculated ADWF or base wastewater flows (BWF) from data collected during the system-wide flow monitoring period, and also for the tidal flowmeters. BWF includes the wastewater generated from residential, commercial, and public users. V&A reported these flows in Tables 7 and 10 of the flow monitoring report and Table 3 of the tidal report. V&A Table 7 lists ADWF with the groundwater infiltration component included, and Table 10 removes the excessive groundwater infiltration component from ADWF. Table 10 assumes that it is reasonable to expect a typical amount of groundwater in the ADWF.

BWF and calculated GWI are also reported in Table 4-4, below. Based on the widespread nature and volume of GWI, the City's ADWF is higher on average relative to other systems similar in size and age.

Table 4-4. Average Dry Weather Flow Data

Meter Site No.	Veolia Manhole ID	Basin Name	Weekday ADWF with GWI, mgd	Excess GWI, mgd
1	G7MH750	Pt. Richmond/Castro	1.11	0.11
2	J10MH2266	Coalinga/McBryde	0.53	0.30
3	G8MH1364	1st Street	4.67	0.92
4	F8MH965	Canal Boulevard	0.12	0.06
5A	G9MH2248	Harbour Minor	0.04	0.01
5B	G9MH2448	North Harbour	1.96	0.08
6	F9MH1335	South Harbour	1.84	0.34
7	G11MH892	23rd Street	0.68	0.06
8	G11MH833	33rd Street	0.46	n/a
9	G13MH1600	47th Street/San Pablo	0.40	0.05
10	F10MH1640	Marine	1.66	0.48
10A	F10MH1546	Wright	1.46	0.19
11	G8MH1209	n/a	6.18	n/a
1A	H7MH976	Pt. Richmond/Castro	0.81	Not analyzed by V&A
2A	F9MH1345	South Harbour	0.03	
3A	E11MH1251	Wright	1.10	
4A	E12MH2376	Wright	0.65	
4B	E12MH1940	Wright	0.46	

4.5.2 Wet Weather Flow

Wet weather flows occur in a collection system during a rainfall event, and can continue for several days after the rainfall event ceases, depending on soil conditions. Wet weather flows captured during the flow monitoring event provide a means to quantitatively estimate the peak and volume of I&I that enters the system.

For the City's system, wet weather flow results were likely impacted by wet weather system operations. During the recorded storm events, the system was required to store flow upstream of the treatment plant. As a result, peak flows were dampened during the rainfall period due to surcharging. Also, in locations with backwater, peak flows may have recorded high due the flushing effect that often occurs after a backwater condition is released. Surcharge and backwater effects on measured flows were considered by V&A in their analysis of wet weather flows.

During the rainfall events that were recorded during the monitoring period, peak flows exceeded the City's system capacity, causing surcharge conditions. Nine of the eleven metered locations measured depths greater than the pipe diameter. During the monitored storms, these locations did not overflow because the City's pipes are generally deep. However, based on the data collected, it is anticipated that the City will have overflows at many of these locations during the design storm. The design storm is discussed in Chapter 6, Planning Criteria.

Peak wet weather hourly flows and depths of surcharge recorded at each monitoring site are presented in V&A Table 12 and also Table 4-5, below. Table 4-5 also includes an estimate of remaining freeboard, which was computed by West Yost by determining the distance from the manhole rim elevation to crown of pipe, as documented in the Veolia GIS maps, and subtracting the surcharge level above pipe crown as reported by V&A. The total peak hourly flow rate, measured by Meters 4 and 11, was 33 million gallons per day (mgd). The ADWF reported in Table 4-5 is the "overall" ADWF presented by V&A in Table 7, which is the weighted weekday and weekend average.

Table 4-5. Summary of Wet Weather Flow Monitoring Data

Meter Site No.	Veolia Manhole ID	Pipe Diameter, inches	Basin Name	Overall ADWF, mgd	Peak Flow, mgd	Surcharge Above Crown of Pipe, ft	Remaining Freeboard, ft
1	G7MH750	54	Pt. Richmond/Castro	1.13	5.88	6.8	10.5
2	J10MH2266	21	Coalinga/McBryde	0.54	4.62	n/a	15.2
3	G8MH1364	54	1st Street	4.70	23.81	7.0	10.6
4	F8MH965	18	Canal Boulevard	0.12	1.23	6.1	11.0
5A	G9MH2448	18	Harbour Minor	0.04	1.06	4.2	12.7
5B	G9MH2448	48	North Harbour	1.97	17.70	7.5	9.4
6	F9MH1335	36	South Harbour	1.85	7.70	8.2	7.9
7	G11MH892	21	23rd Street	0.68	5.19	n/a	16.1
8	G11MH833	24	33rd Street	0.46	5.66	0.6	14.9
9	G13MH1600	21	47th Street/San Pablo	0.41	5.55	6.0	4.9
10	F10MH1640	36	Marine	1.69	11.01	4.8	9.0
10A[1]	F10MH1546	36	Wright	1.46	5.15	4.4	8.2
11[2]	G8MH1209	66	West Cutting	6.24	31.76	8.0	9.5

4.6 INFLOW AND INFILTRATION ANALYSIS

V&A completed an I&I evaluation based on the 2010 flow monitoring data to quantify the extent of I&I entering the collection system by basin during this period. This section summarizes these results as related to their relevance to the City's collection system master planning needs.

This section includes the following discussions:

- Inflow Analysis,
- Rainfall Dependent Infiltration Analysis, and
- Groundwater Infiltration Analysis.

4.6.1 Inflow Analysis

Inflow comprises water that is discharged directly into the sewer system from direct connections such as downspouts and yard drains, as well as public and private storm drain systems. The effects of inflow can be seen in a collection system immediately following a rainfall event. Because of this quick response, inflow is typically quantified using peaking factors. A peaking factor is defined as the peak hourly wet weather flow divided by the average dry weather flow.

Table 4-6 presents the inflow analysis for each basin using peak flow data from the 2010 flow monitoring period. Inflow was evaluated based on a comparison of peak I&I to average dry weather flow, and also by calculating and comparing peak I&I per tributary acre. Based on these comparisons, the basins were ranked from 1 to 11, with a ranking of 1 signifying the highest inflow. Overall basin ranking is included in V&A Table 8, and also in Table 4-6 below.

Table 4-6. Inflow Analysis

Meter Site No.	Basin Name	Overall Inflow Ranking	Comments
1	Pt. Richmond/Castro	9	
2	Coalinga/McBryde	6	
3	1st Street	10	
4	Canal Boulevard	8	
5A	Harbour Minor	1	Smaller line discharges to large trunk sewer. Inflow values are likely skewed by backwater effects from WWTP/trunk sewer.
5B	North Harbour	4	
6	South Harbour	11	
7	23rd Street	5	
8	33rd Street	2	Inflow is above average for the system.
9	47th Street/San Pablo	3	Inflow is above average for the system. Available freeboard is the lowest of all monitored sites (See Table 4-5).
10	Marine	7	
10A	Wright	7	

The Harbour Minor basin, measured by Meter 5A, has the highest measured inflow. However, this is a very small basin relative the remaining collection system, and basins with smaller flows will yield higher peaking factors for both dry and wet weather flows than larger basins. Also, a small line exits the basin into the large trunk sewer on Cutting Boulevard. Due to this configuration, backwater effects from the trunk sewer may cause unusually high wet weather response in the smaller pipe. Finally, addressing inflow issues in a very small basin will not have a notable effect on reducing overall system flows. Therefore, although the highest inflow was measured in Basin 5A, it is recommended that inflow reduction projects place a higher priority on improvements in the 33rd Street basin, monitored by Meter 8, and the San Pablo basin, monitored by Meter 9.

4.6.2 Rainfall Dependent Infiltration Analysis

V&A measured I&I for a period of 24 to 48 hours after the storm event to quantify rainfall dependent infiltration. Using this data, V&A evaluated rainfall dependent infiltration by comparing infiltration per acre of drainage area, and infiltration as a percent of ADWF. The volume of infiltration is defined as the total flow volume minus the baseflow (or ADWF) volume.

A third commonly applied methodology that evaluates rainfall dependent infiltration per inch-diameter-mile of sewer was not used for the V&A analysis. However, it appears that the two methods used generated consistent results, and a third comparison is not necessary.

Basins were ranked from 1 to 11, with a ranking of 1 signifying the basin with the highest infiltration. Overall basin rankings are presented in V&A Table 9 and also in Table 4-7, below.

Table 4-7. Rainfall Dependent Infiltration (RDI) Analysis

Meter Site No.	Basin Name	RDI Ranking, gallons per acre per day	RDI Ranking (% of ADWF)	Comments
1	Pt. Richmond/Castro	1	2	RDI is above average for the system.
2	Coalinga/McBryde	10	10	
3	1st Street	2	4	RDI is above average for the system.
4	Canal Boulevard	11	1	Basin 4 has low density relative to total acreage. Therefore, RDII as a % of ADWF should be utilized for this analysis.
5A	Harbour Minor	3	3	RDI is above average for the system.
5B	North Harbour	6	7	
6	South Harbour	9	9	
7	23rd Street	7	11	
8	33rd Street	5	5	
9	47th Street/ San Pablo	8	6	
10	Marine	4	8	
10A	Wright	4	8	

Based on the V&A infiltration analysis results, the City should focus its RDI reduction program in the Castro, 1st Street, and Canal Boulevard. basins, monitored by Meters 1, 3, and 4, respectively. Also showing high infiltration is the Harbour Minor basin, monitored by Meter 5A. However, as discussed in the inflow analysis, due to the small size of this basin, improvements in this basin will likely not have a notable effect on reducing system-wide flows.

4.6.3 Groundwater Infiltration Analysis

GWI is typically considered a part of wastewater baseflow when it occurs in relatively small amounts compared to the flow generated from residential, commercial and public users. Small quantities of GWI are common in a collection system and are not usually considered problematic unless the volume of flow becomes excessive.

Typically, wastewater flow generated in the system follow a predictable diurnal pattern. A diurnal pattern will peak in the morning between 8 and 11 am, and in the evening between 6 and 9 pm, and recede slightly in the afternoon and substantially at night. When a basin has a large quantity of GWI occurring, the basin diurnal pattern has distinctly flatter peaks, with a noticeable quantity of flow occurring at night.

V&A evaluated groundwater infiltration based on rate per acre and rate as a percentage of ADWF. For the GWI analysis, weekday ADWF was used to avoid the potential for large industrial and commercial weekend flow patterns to skew the results. V&A Table 10 and Table 4-8, below, list the result of this analysis, and provide an overall GWI ranking. A ranking of 1 signifies the highest rate of GWI.

Groundwater infiltration in the City's system is unusually high, and in most areas, impacted by tidal infiltration. Based on data from the supplemental tidal monitoring program, monitoring site 2A appeared to have dry weather capacity issues due to groundwater inflow. Tidal effects at Site 2A resulted in a peaking factor (peak flow to ADWF) of 50.3. Based on this additional data, abating tidal GWI in the South Harbour basin, monitored by Meter 6, was a top priority for the City in 2010.Since this time, tidal I&I abatement activities have removed a significant portion of this direct inflow

Table 4-8. Groundwater Infiltration Analysis

Meter Site No.	Basin Name	Overall GWI Ranking	Comments
1	Pt. Richmond/Castro	9 (tied)	
2	Coalinga/McBryde	9 (tied)	
3	1st Street	3	Tidal infiltration is a significant component of GWI.
4	Canal Boulevard	4	Tidal infiltration is a significant component of GWI.
5A	Harbour Minor	2	
5B	North Harbour	10	
6	South Harbour	5	Tidal infiltration is a significant component of GWI.
7	23rd Street	7	
8	33rd Street	11	
9	47th Street/San Pablo	6	
10	Marine	1	Tidal infiltration is a significant component of GWI.
10A	Wright	8	

Figure 4-1. Inflow and Infiltration Sources

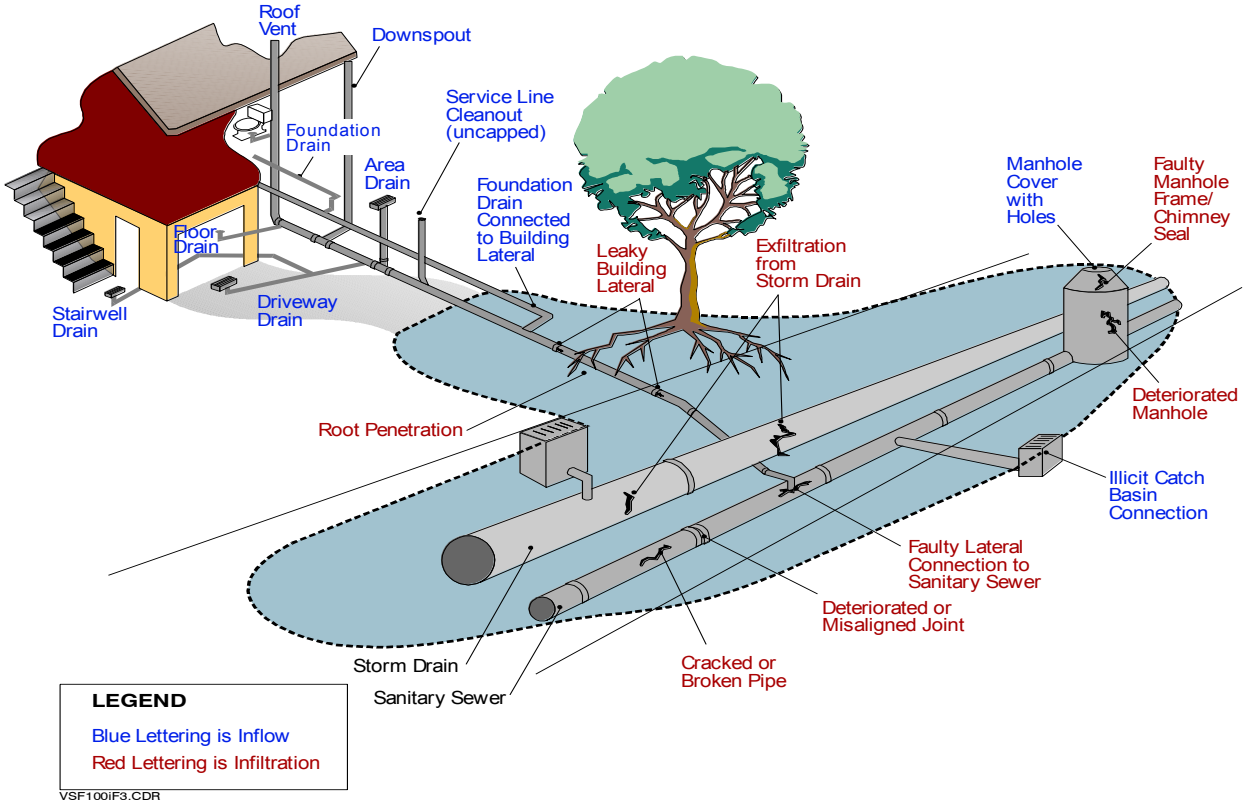
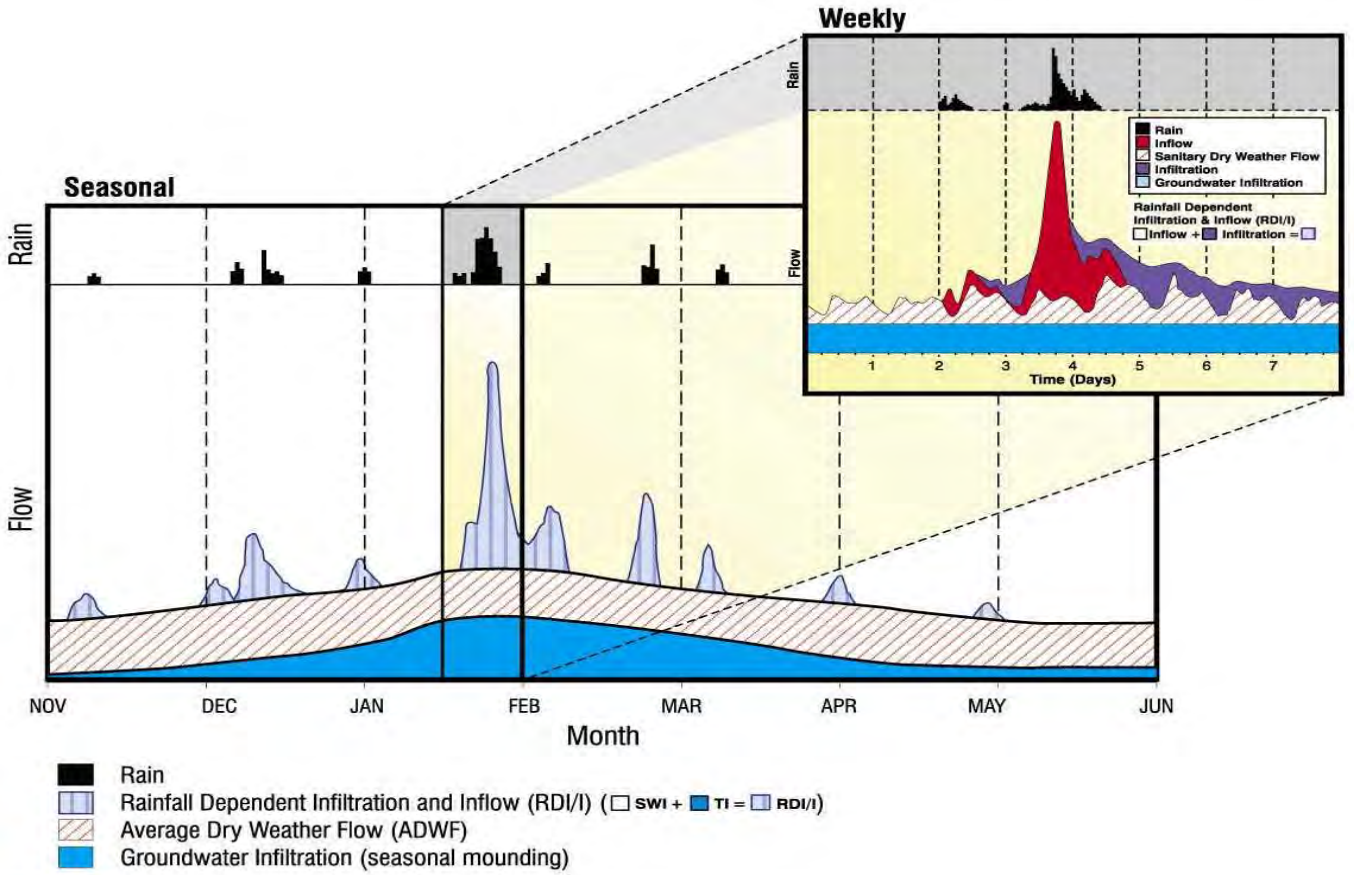


Figure 4-2. Typical RDII Response

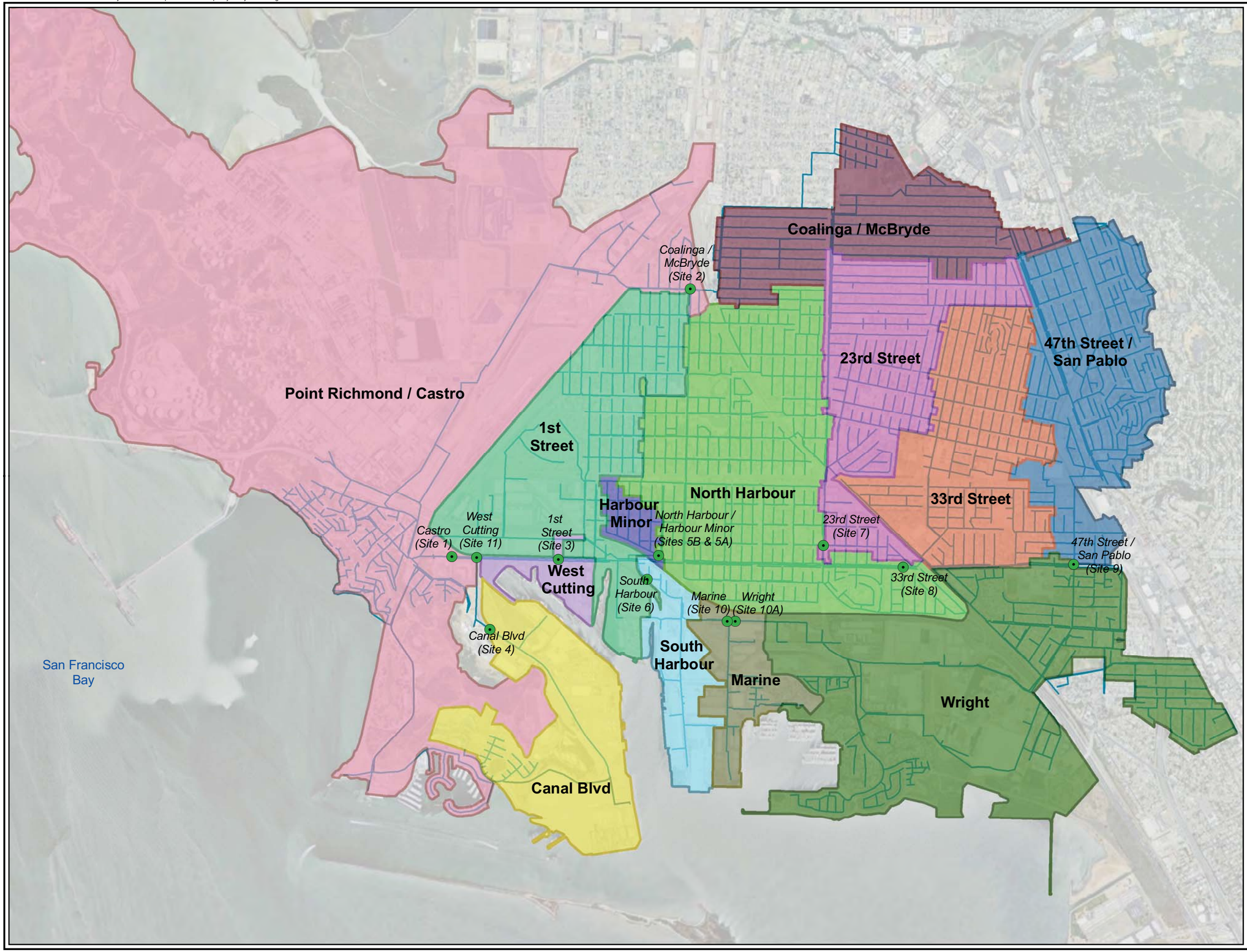


O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 4-3.mxd 3/18/2011

FIGURE 4-3

City of Richmond
Sewer Collection System Master Plan

FLOW METER AND RAIN GAUGE LOCATIONS AND ASSOCIATED BASINS



N

0 1,000 2,000

Scale in Feet

Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

- Metering Site
- Sewer Pipe Segment

Basin

- 1st Street
- 23rd Street
- 33rd Street
- 47th Street / San Pablo
- Canal Boulevard
- Coalinga / McBryde
- Harbour Minor
- Marine
- North Harbour
- Point Richmond / Castro
- South Harbour
- West Cutting
- Wright

VEOLIA WATER

WEST YOST ASSOCIATES Consulting Engineers

Figure 4-4. Flow Direction and Metered Basin Interconnection

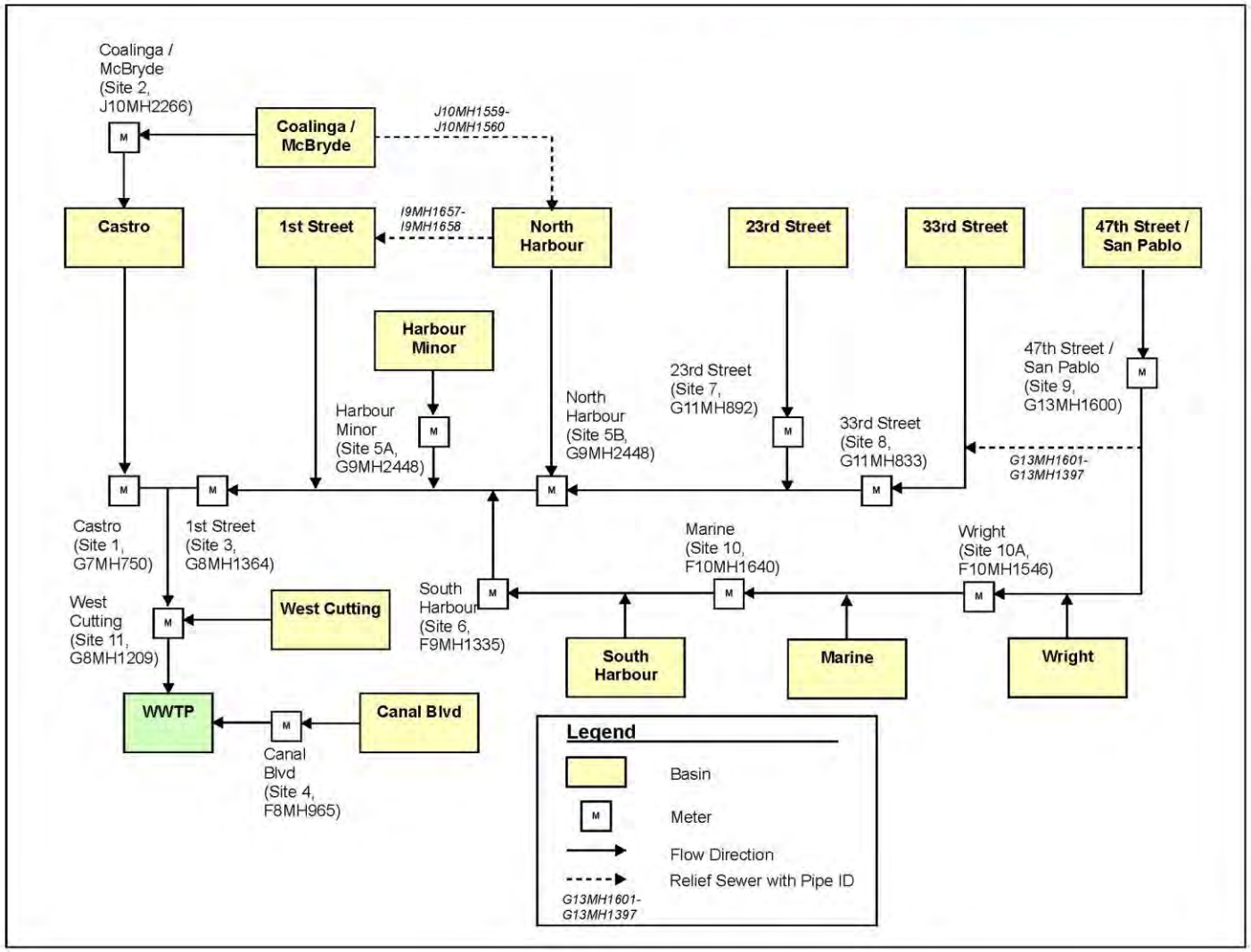


Figure 4-5. Tidal Flow Meter Locations

The computer-based hydraulic model of the City's RMSD wastewater collection system, developed using Innovyze® InfoWorks™ CS software, serves as a tool for assessing the flows and capacities of the City's trunk sewers, and for identifying solutions to sewer capacity issues. The hydraulic model is also a tool for performing "what if" scenarios to assess the impacts of future developments, land use changes, and system configuration changes.

The hydraulic model includes the City's main trunk sewers (typically 12-inch diameter and larger) and associated facilities, and is a skeletonized representation of the City's RMSD sewer system in its configuration and operation. Hydraulic model development usually focuses on trunk sewers only, as the local collector sewers are typically sized to facilitate maintenance, and are usually oversized for flow conveyance. The City's model also includes some smaller diameter sewers as needed to provide system connectivity or to represent available relief sewers (*e.g.*, parallel sewers or basin to basin connections).

This chapter presents a summary of hydraulic model development and calibration. The major sections of this chapter include:

- Model Development,
- Data Validation,
- Load Allocation,
- Dry Weather Flow Calibration, and
- Wet Weather Flow Calibration.

5.1 MODEL DEVELOPMENT

Veolia Water developed the hydraulic model network and provided this network to West Yost for further development and analysis. This hydraulic model transforms information about the physical and operational characteristics of the sewer system into a mathematical model. The model solves a series of differential equations for continuity and momentum (Saint-Venant equations) to simulate various flow conditions for specified sets of flow loads. The modeling results provide information on flows, flow depth, velocity, surcharging, and backwater conditions that are used to analyze system performance and identify system deficiencies. The model is also used to verify the adequacy of recommended or proposed system improvements.

The hydraulic model comprises a skeletonized network of nodes (*e.g.*, manholes) and conduits (*e.g.*, pipelines). Several types of nodes and links are used for defining the physical entities within a collection system. The following descriptions provide additional information on elements used in the development of the hydraulic model.

Node: Nodes represent manholes, split manholes, diversion structures (with no other physical component such as a weir), storage facilities, and outfalls in a collection system. Storage facilities include modeled lift station wet wells. All flows loaded into the model are attached to a node structure. The data required for node structures include elevation data (pipe invert and manhole rim) and manhole diameter.

Conduit: Conduits represent facilities that convey wastewater from one point in the system to another. Conduits include gravity pipes, force mains, pumps, and weirs. Several different types of pumps and weir structures are available as standard elements. The physical data for gravity pipes and force mains include invert elevation, size, length, and friction factor. The physical data for pumps include type of pump, elevation, head-discharge relationship, and operational parameters such as on/off elevations and sequencing.

Sewersheds or subcatchments: Subcatchments represent an area that flows tributary to an individual node in the model. Subcatchments usually represent a particular subdivision or grouping of parcels and collection of small diameter sewers (typically 6-inch to 8-inch diameter) that flow into one location along a major trunk sewer. The subcatchment layer serves several purposes, including defining land use, diurnal curves, and dry and wet weather flow inputs. The data required for subcatchments are node connection, land use, flow factors, total and contributing area, diurnal curve profile, rainfall profile, inflow and infiltration parameters, and groundwater parameters.

5.1.1 Model Description

The structural components of the hydraulic model network, (*i.e.*, nodes and conduits) were initially developed by Veolia staff and provided to West Yost in September 2010. The hydraulic model consists of approximately 47 miles of sewer pipeline ranging in diameter from 4-inches to 66-inches. The model includes all 12-inch diameter and larger trunk lines, and associated manholes and lift stations. Many 10-inch diameter pipelines have been included, as provided by Veolia staff, as well as 4-inch, 6-inch and 8-inch diameter lines in selected areas as needed to provide connectivity. The 47 miles of pipeline represent approximately 25 percent of the City's RMSD system. Where necessary to enable flow conveyance within the model, West Yost adjusted the structural components (*e.g.*, invert elevations and sewer diameters) of the model after discussion with and concurrence by Veolia.

Five of the City's fourteen pump stations are included in the hydraulic model: Marina Bay Parkway, ICI, Ferry Point, Marina Bay Cove, and Keller Beach. In addition, the hydraulic model includes the influent pump station wet well at the wastewater treatment plant. All pump station information was provided by Veolia, and verified through comparison to the City's 2008 System Evaluation and Capacity Assurance Plan. The pump station parameters in the model are summarized in Table 5-1. The modeled collection system facilities are presented in Figure 5-1.

West Yost delineated 883 subcatchments within the hydraulic model. Subcatchments were created from GIS data provided by the City, and were generally defined to encompass a single land use that flows to a single model node. Loads were developed and assigned to each catchment as described in Section 5.3, Load Allocation.

Table 5-1. Pump Station Model Parameters

Pump Station	Wet Well		Pumps				Force Main	
	Size	Base Elevation, ft	No. of Pumps	Lead/Lag Pump On Elevation, ft	Lead/Lag Pump Off Elevation, ft	Pump Discharge Rate	Diameter, inches	Length, ft
Marina Bay Parkway	215.1 ft^2 by 6.57 ft deep	-6.41	3	-3.58/-3.83/-4.082	-6.082	Variable	10	2039.9
ICI	50.2 ft^2 by 3.86 ft deep	3.20	2	7.20/7.37	5.083	Variable	6	2545.1
Ferry Point	9.2 ft^2 by 14.34 ft deep	3.34	2	10.84/2.00	9.339	Variable	6-10[a]	256.3[a]
Marina Bay Cove	42.2 ft^2 by 6.25 ft deep	-4.09	2	1.74/2.16	-0.339	Variable	4	507.5
Keller Beach	169 ft^2 by 6.66 ft deep	-6.48	2	0.01/0.18	-1.566	Variable	8-10[a]	1211.2[a]

(a) Keller Beach and Ferry Points discharge into common 10" force main.

5.2 DATA VALIDATION

After the model network was completed, West Yost conducted data validation to confirm that the model comprised a fully-connected network. Data validation included the following steps:

- Ensure each pipe and manhole has a unique identifier;
- Check the modeled network for connectivity, and add smaller pipes as needed to ensure no missing links or manholes in the network;
- Check for missing or inconsistent data such as missing manhole rim or pipe invert elevations, negative pipe slopes, or abrupt elevation changes;
- Identify manholes with more than one outlet pipe, constituting a potential flow split, that require further investigation in the field;
- Populate global parameters such as standard manhole diameters and Manning's "n" coefficient, which is entered as 0.013 for sewer pipelines; and
- Use system flags provided in InfoWorks™ CS to document identified issues and any changes made to the model.

Table 5-2 lists the system flags used primarily by Veolia, and supplemented by West Yost during model development and verification.

Table 5-2. System Flags

Flag	Source
#A	Asset Data
#D	System Default
#G	Data from GeoPlan
#I	Model Import
#V	CSV Import
AS	Assumed Data
CP	WY Capacity Improvement
G1	ManholeSMC_RIM_elevExport
GS	Data from GIS
IG	Inferred Values using the Ground TIN
IN	Veolia Inferred Data
JH	Veolia - Suggestion to Assumed Values
OF	Wright and Harbor Overflow Structure
P1	Veolia - Operating Set Points
PS	Pump Station Information Spreadsheet
RS	Veolia – Relief Sewer Data
SP	San Pablo Rehab Project
W1	WY QA/QC Changes
WI	WY Inferred Data
WP	Veolia QA/QC Changes

5.3 LOAD ALLOCATION

This section summarizes how sewer loads were calculated and input into the computerized hydraulic model. Wastewater flows for analysis and design of the City's sanitary sewers were divided into four categories. All of these flows are discussed further in this section:

- Base wastewater flow (BWF) includes the average daily dry weather sanitary flow contribution from permitted connections to the collection system;
- Tidal saturation infiltration (TSI) is caused when tidal activity saturates the soil and infiltrates into the pipeline network through defects in the system, during dry weather and wet weather periods;
- Tidal inflows (TI) is caused when estuary water flows directly into the network through storm outfalls connected to the sanitary sewer system or defects in the system, during dry weather and wet weather periods. Tidal inflows can range from constant streams to cyclical flows that vary with the tide level; and
- RDII results when flows from wet weather events infiltrate the system, either through defects in existing facilities, or unpermitted connections that convey stormwater into the sewer system.

Wastewater flows were estimated by sewershed or subcatchment and assigned to the node at the downstream end of the subcatchment. Each sewershed defines a geographic area where base wastewater flow generated in the area is assigned to a specific node (or manhole) in the model. Each sewershed encompasses a particular subdivision or grouping of lots that share a common land use and that flows to a single point in the collection system. Figure 5-2 shows the sewersheds that were included in the hydraulic model.

5.3.1 Dry Weather Flow Generation

This section describes the tasks completed in calculation of dry weather flows.

5.3.1.1 Base Wastewater Flows

BWF can be calculated based one or more factors, including population, population density, water consumption, and land uses. For the City's hydraulic model, industry-standard unit flow factors (verified through flow monitoring data) were applied to land use to generate BWF. The land use and unit flow factors are described further in Chapter 3, System Flows. The key elements of dry weather flow generation in the hydraulic model include:

- Average dry weather flow (Q_a)
- Peak dry weather flow (Q_{pdwf})

The Q_a calculation is based on the land use data provided by the City, as described in Chapter 3. The following equation was used to calculate flows for each Subcatchment:

(effective area or number of dwelling units) * (unit flow factor) = total subcatchment flow

For all land uses except Very Low Density Residential and Low Density Residential, the effective area was calculated as the sum of all parcel areas provided in the City's GIS database. For Very Low Density Residential and Low Density Residential land uses, the number of dwelling units (DU) was calculated as the total number of parcels within that catchment. Unit flow factors were then applied to this parcel count as described in Chapter 3, System Flows.

West Yost refined these unit flow factors by calculating the overall flow generated from each of the basins monitored during the City's 2010 flow monitoring program. The calculated average dry weather flows per basin were then compared with the metered flow data and adjusted until model predicted BWF was within approximately ten percent of measured data in every metered sewer basin. These flows served as initial base flow inputs to the hydraulic model.

In the hydraulic model, the effective area was assigned to each subcatchment by entering a value into the "Contributing Area" field associated with each subcatchment in the hydraulic model. Unit flow factors were entered into the "Population Density" field in the land use database in the model. Land use identifiers were provided for each subcatchment in the "Landuse ID" field for each catchment.

Industrial discharge flow data as described in Chapter 3, System Flows, were also added to the hydraulic model. Total flows in mgd were entered directly into the "trade flow" field associated with each subcatchment in the hydraulic model. To avoid double counting flows, the effective area associated with each industrial discharge was subtracted from the total effective area for the subcatchment.

In order to match calculated dry weather flows to measured flows, a scaling factor was then applied to the non-industrial flows per basin using the "Flow Per Capita" field of the wastewater group within the hydraulic model. Although the hydraulic model database fields are titled "Contributing Area", "Population Density" and "Flow Per Capita", the values for these fields are "acres or dwelling units," "flow per acre or flow per dwelling unit" and "unitless scale factors," respectively. Total measured BWF was 6.5 mgd or approximately 63 gallons per capita per day (gpcpd).

5.3.1.2 Diurnal (24-Hour) Flows

BWF typically varies throughout the day, with the peak flow generally occurring in the morning and late afternoon periods. West Yost obtained 24-hour diurnal patterns for each monitored basin from the V&A 2010 flow monitoring program report (December 2010). Flows were collected in 15 minute increments, 24 hours per day, for a 4-month period that included dry weather. A sample diurnal curve is presented in Figure 5-3 for the Coalinga McBryde basin (Metering Site 2). A complete set of diurnal curves from all flow monitors is included in Appendix C. Diurnal flow characteristics were applied to the individual land use Q_a within each monitored basin to distribute the Q_a over a 24-hour period.

5.3.1.3 Tidal Saturation Infiltration (TSI)

Tidal Saturation Infiltration (TSI) was included in the model to account for measured groundwater infiltration in the southern sewer basins. TSI was calculated using base flow measurements that were consistently present and that exceeded anticipated dry weather flows

during off-peak (*i.e.*, nighttime) hours. Calculated TSI was distributed across selected pipe segments based on the product of pipe diameter and length. Figure 5-4 shows the location of TSI segments and tabulates total TSI for three groups of pipe segments that were impacted by high groundwater flows.

5.3.1.4 Tidal Inflows

Tidal Inflows (TI) were also included in the model for use during wet weather flow simulations. TI represents measured flows in excess of dry weather flows during non-rainfall periods. Peak hourly TI was derived by V&A based on data collected during the 2011 tidal flow monitoring program. Tidal flows included the following:

- 0.247 mgd added at the Boat Ramp overflow node;
- 0.215 mgd added to the original location of Meter 1, on Cutting Boulevard west of Canal Boulevard; and
- 0.503 mgd added to the original location of Meter 11, at the intersection of Cutting Boulevard and Canal Boulevard.

5.3.2 Wet Weather Flow Generation

Extraneous water enters the sewer system during wet weather periods through cracks and open joints in sewer mains, manholes, and building laterals, as well as through direct connections between storm drains and the sanitary sewer, or from illegal drainage connections on private property. These extraneous flows can cause significant increases in peak flows in the system. Wet weather flows were calculated and input to the City's hydraulic model to replicate measured flow data. The key elements of wet weather flow generation in the model include:

- RDII or I&I
- Peak Wet Weather Flow (Q_{pwwf})

Several broad categories of RDII quantification are used in wastewater master planning, including the following:

- Constant unit rate method – calculates RDII as a fixed constant (*e.g.*, gal/acre in rainfall) multiplied by measurements of tributary sewershed characteristics (*e.g.*, area, land use, population, pipe diameter, pipe length, and pipe age);
- R-Value method – calculates RDII as a fixed percentage of rainfall;
- Synthetic unit hydrograph (SUH) method – calculates the RDII hydrograph from a specified "unit" hydrograph shape that relates RDII to unit precipitation volume and duration;
- Probabilistic method – calculates RDII of a given recurrence interval from long-term sewer flow records using probability theory. The method establishes the relationship of peak RDII flow to recurrence interval; and

- Rainfall/sewer flow regression method – calculates peak RDII flows from rainfall data through a relationship between rainfall and RDII flows. This regression, expressed as an equation, is derived from rainfall and flow monitoring data in sewers using multiple linear regression methods and considering dry and wet antecedent conditions.

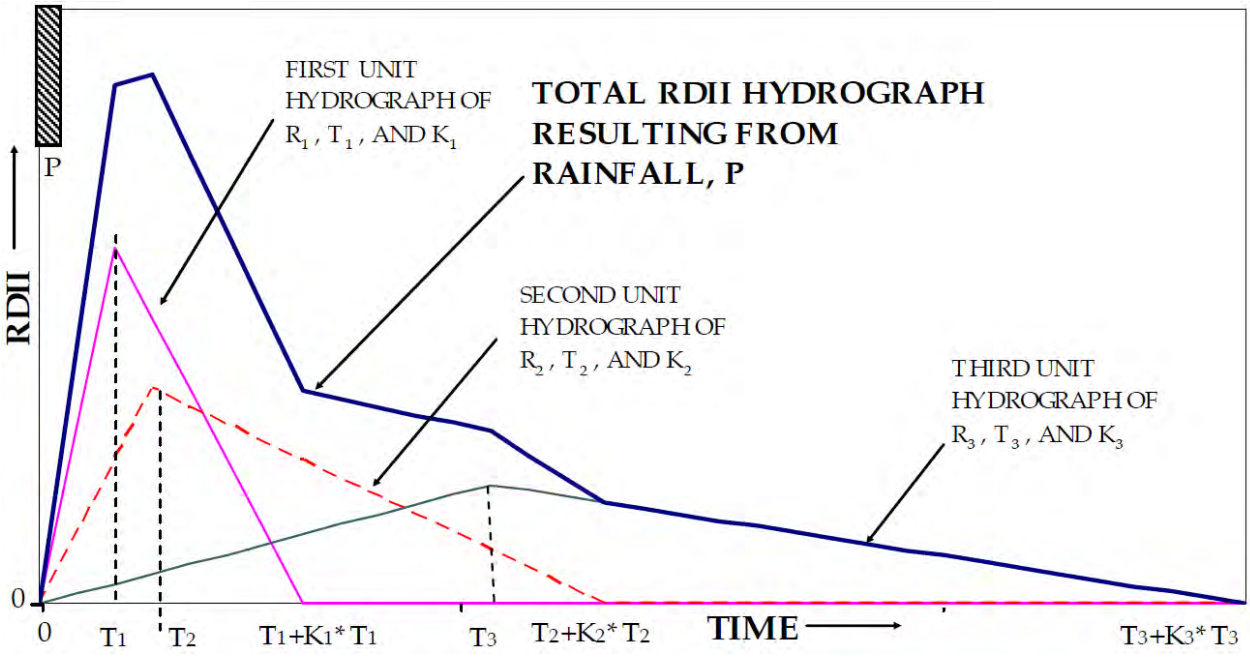
Studies conducted by the Water Environment Research Foundation have concluded that the SUH and rainfall/flow regression methods are the two most accurate methods for predicting peak flows and event volumes for storm events. The RTK method, described below, is the most widely used SUH prediction methodology for collection system model development.

West Yost used the RTK method to calculate RDII inputs to the City's hydraulic model. The RTK method generates hydrographs from each subcatchment that represent flows during and immediately after rainfall events caused by seepage of water into the collection system. The RTK method generates a series of three triangular hydrographs that represent short-term, medium-term, and long-term rainfall response. The RTK parameters include:

1. R = the area of the graph representing the portion of rainfall falling on a subcatchment that enters the sewer collection system.
2. T = the time from the onset of rainfall to the peak of the triangle.
3. K = the ratio of the "time to recession" to the "time to peak" of the hydrograph.

Components of the RTK hydrograph are provided courtesy of the United States Environmental Protection Agency (EPA) Office of Research and Development, and are presented in Figure 5-6.

Figure 5-6. Components of RTK Hydrograph



When a wet weather flow simulation is run in the model, the RTK parameters are applied to represent a specific rainfall event. These parameters generate a wet weather flow hydrograph for each sewershed.

Hourly peak wet weather flows (Q_{pwwf}) are generated in the model by combining the dry weather flow with flows from the I&I hydrographs, by sewershed. Typically, the peak wet weather flow will occur shortly after the hourly peak intensity of the rainfall event.

5.4 DRY WEATHER FLOW CALIBRATION

The City's hydraulic model was calibrated to confirm that the computer simulation will accurately represent the operation of the collection system under dry weather flow conditions. The major steps in the dry weather flow calibration included the following:

1. Determine the average dry weather 24-hour flow (Q_a) for the entire service area for the calibration period.
2. Determine Q_a at each flow metering site.
3. Compare the modeled Q_a values with the measured Q_a values for the entire service area and at each flow metering site.
4. Adjust the model flow factors to maximize agreement between the modeled and metered Q_a 24-hour values (maximum, minimum and average).
5. Adjust the diurnal curve for each basin to maximize agreement between the modeled and metered Q_a hourly values.

5.4.1 Calibration Results

Dry weather flow hydrographs provided by V&A were used for the dry weather calibration. The calibration steps listed above were repeated for each basin until calibration was considered complete. A completed calibration was achieved when minimum, maximum, and average modeled flows, as well as the temporal distribution of flow over a 24-hour period, were within approximately five percent of measured flows. Exceptions were made for basins that have very low dry weather flows; in these smaller basins, a minor increment in flow may constitute a large percentage change.

A sample dry weather flow calibration hydrograph for the Coalinga McBryde Basin (Meter Site 2) is provided in Figure 5-7. The remaining DWF calibration hydrographs are presented in Appendix D. The weekday dry weather flow calibration results for each meter are presented in Table 5-3.

Table 5-3. Dry Weather Flow Calibration Results

Flow Meter	Manhole ID	Meter			Model			Variance		
		Max	Min	Average	Max	Min Flow	Average	Max Flow	Min Flow	Average
1	G7MH750	1.613	0.555	1.110	1.412	0.428	1.072	12.48%	22.79%	3.48%
2	J10MH2266	0.729	0.233	0.530	0.728	0.230	0.532	0.05%	1.27%	0.40%
3	G8MH1364	5.698	2.873	4.674	5.757	2.531	4.617	1.03%	11.91%	1.22%
4	F8MH965	0.163	0.079	0.118	0.166	0.082	0.118	1.68%	3.38%	0.01%
5A	G9MH2248	0.054	0.020	0.036	0.054	0.020	0.036	0.25%	1.47%	0.77%
5B	G9MH2448	2.626	0.982	1.958	2.665	0.928	1.969	1.45%	5.52%	0.53%
6	F9MH1335	2.360	1.067	1.884	2.371	1.104	1.819	0.47%	3.47%	3.47%
7	G11MH892	0.901	0.330	0.677	0.894	0.328	0.671	0.81%	0.54%	0.78%
8	G11MH833	0.665	0.164	0.460	0.665	0.163	0.460	0.08%	0.95%	0.09%
9	G13MH1600	0.573	0.187	0.404	0.587	0.188	0.409	2.37%	0.52%	1.24%
10	F10MH1640	2.136	1.018	1.665	2.168	1.037	1.675	1.50%	1.82%	0.63%
10[(a)]	F10MH1546	1.968	0.772	1.460	1.943	0.784	1.435	1.30%	1.51%	1.71%
11[(b)]	G8MH1209	7.657	4.235	6.184	7.114	3.004	5.734	7.08%	29.07%	7.27%

(a) On March 18, 2010, Meter 10 was relocated three manholes upstream from the initial manhole to capture tidal infiltration within the same basin but at a different location.

(b) Meter 11 measured flows in the main interceptor that is influent to the WWTP.

5.5 WET WEATHER FLOW CALIBRATION

Following completion of dry weather calibration, West Yost calibrated the model for wet weather flow (WW) conditions. A model that is sufficiently calibrated to wet weather flow should be able to simulate I&I entering the sewer collection system during a rainfall event. WW calibration consisted of the following steps:

- Identifying a wet weather calibration event with heavy rainfall and collection system response (increased flows) from the flow monitoring data.
- Establishing appropriate methodology for I&I generation. The City's model uses the RTK method. Establishing I&I parameters per monitored basin based on collected flow monitoring data from the first calibration event and applying these parameters to the appropriate sewersheds.
- Generating system flows under wet weather loading, which included dry weather plus the I&I component. Compare metered data with model simulation results, and adjusting RTK parameters if necessary, to maximize agreement for the calibration event.

System flows showed substantial tidal influence in the southern basins through March 2010. This tidal contribution decreased starting April 2011. Based on Veolia reports, this flow reduction resulted from field activities that occurred in March to block known sources of tidal inflow. In order to achieve the most accurate calibration results, a wet weather calibration period of April 11 to 12 was selected. This timeframe occurs after the period of high tidal influence discussed above.

After reviewing initial wet weather flow patterns, it became apparent that the collected rainfall data, from the eastern and western portions of the service area were not representative of rainfall across the central part of the system. Therefore, the collected rainfall data was supplemented with measured rainfall at the public rain gauge that is located at City Hall.

For many basins, even with this supplemental rainfall data, the actual rainfall at the individual meter location had a different temporal pattern than predicted rainfall. The most apparent differences in rainfall distribution were accommodated during wet weather calibration as noted on the calibration graphs that are included in Appendix E.

During the calibration event, significant surcharging occurred throughout the system. As a result, measured flow peaks were difficult to replicate in the model. Surcharging in the lower (southerly) basins resulted from high wet well levels at the wastewater treatment plant influent pump station and the resulting surcharge condition in Cutting Boulevard. During the flow monitoring period, incoming flows exceeded the available pumping capacity of the WWTP's influent pump station and the wet well water level rose to its maximum level. The wet well level created a hydraulic gradeline that was carried back through all of the low-lying portions of the service area.

During the calibration event, only one meter, Meter 10, measured significant reverse flow or backwater. In the absence of backwater effects, the model should continue to replicate total flow volumes through the system. Therefore, as noted in Table 5-4 below, the meters that were impacted by surcharge, but not backwater, were calibrated first to total flow volume. In addition, temporal flow patterns generated by the model were confirmed visually to match the flow patterns that were measured during the flow monitoring program.

Figure 5-8 presents a sample of the wet weather flow calibration results. The remaining calibration graphs are presented in Appendix E. Wet weather flow calibration results are provided in Table 5-4.

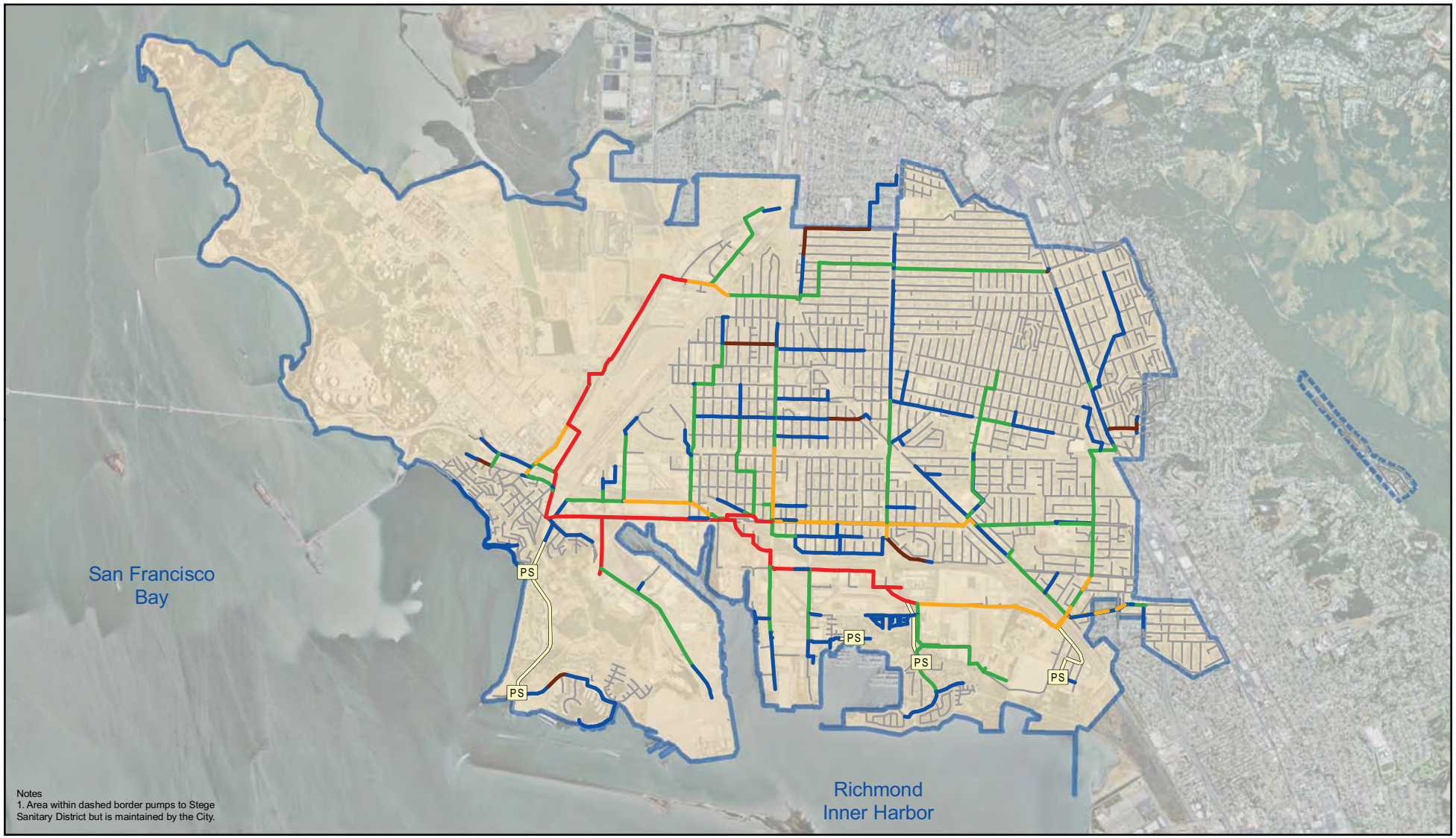
Table 5-4. Wet Weather Flow Calibration Results for April 12, 2010

Flow Meter	Meter Flow Volume, MG	Meter Peak Flow, mgd	Model Flow Volume, MG	Model Peak Flow, mgd	Difference in Flow Volume, %	Difference in Peak Flow, %
1	3.33	4.31	3.10	5.19	-6.99%	See note 1
2	1.95	4.62	1.88	4.63	-3.89%	0.15%
3	1503.2	20.25	1546.23	22.50	2.87%	See note 1
4	45.72	0.96	3.1	0.90	See note 2	-6.58%
5A	Meter measured backwater during the calibration storm. Use smaller storm on March 31 to estimate I&I contribution.					
5B	8.36	14.43	8.23	14.18	-1.52%	-1.71%
6	3.66	7.88	3.68	5.83	0.47%	See note 1
7	2.10	4.96	2.07	4.18	-1.12%	See note 3
8	2.06	4.99	2.08	5.01	0.88%	0.36%
9	1.60	2.97	1.54	2.87	-3.33%	-3.35%
10/10A	Meter measured backwater during wet weather events. Combine with Meter 6 for wet weather calibration.					
11	1941.33	25.92	1852.92	25.48	-4.55%	-1.68%

Notes:
1. System is significantly surcharged. Calibrate volume and match temporal distribution.
2. System is significantly surcharged. Calibrate to 1st peak and match temporal distribution.
3. Use additional rainfall data from City Hall. Match 1st peak. Calibrate volume.

5.5.1 Hydraulic Model Calibration Findings and Conclusions

In summary, the results from dry and wet weather calibration provide reasonable results, considering the surcharge and backflow conditions that were measured in the system during the 2009/10 flow monitoring period. The model is considered sufficiently calibrated to existing flow conditions to be used as a predictive tool for capacity studies.



LEGEND

Modeled Pipes

- 4" - 8"
- 10" - 12"
- 15" - 21"
- 24" - 30"
- > 30"

PS Modeled Pump Station

Force Main

Unmodeled Sewer Pipes

Service Area

N

0 0.5 1

Miles

FIGURE 5-1

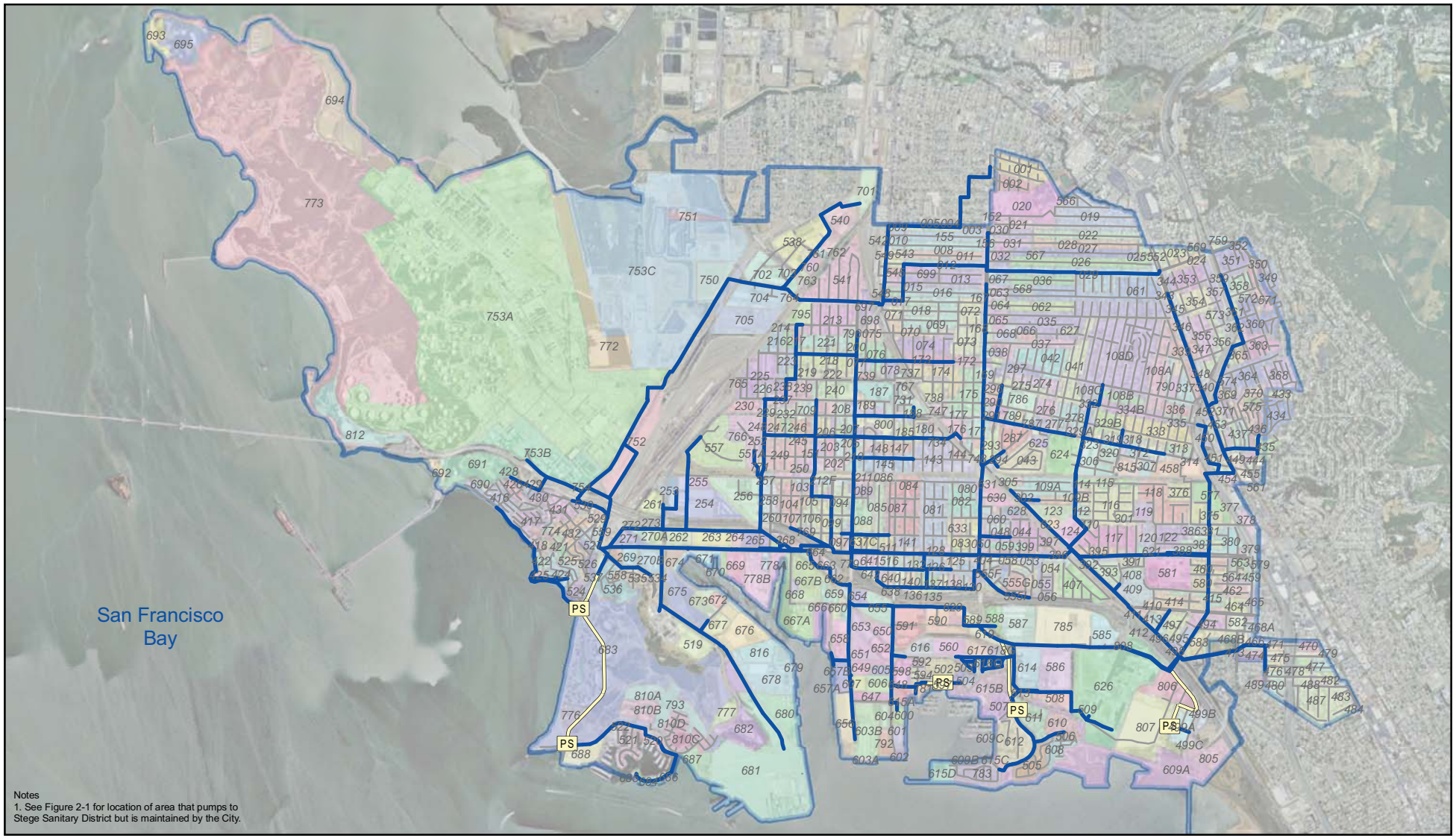
City of Richmond
Sewer Collection System Master Plan

MODELED SEWER COLLECTION SYSTEM FACILITIES

VEOLIA WATER

WEST YOST ASSOCIATES Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 5-1 (Modeled Collection System).mxd 3/18/2011



Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

- Modeled Pipes
- Sewer Pipes
- Force Main
- PS Modeled Pump Station
- Subcatchment
- Service Area

N

0 0.5 1

Miles

FIGURE 5-2

City of Richmond
Sewer Collection System Master Plan

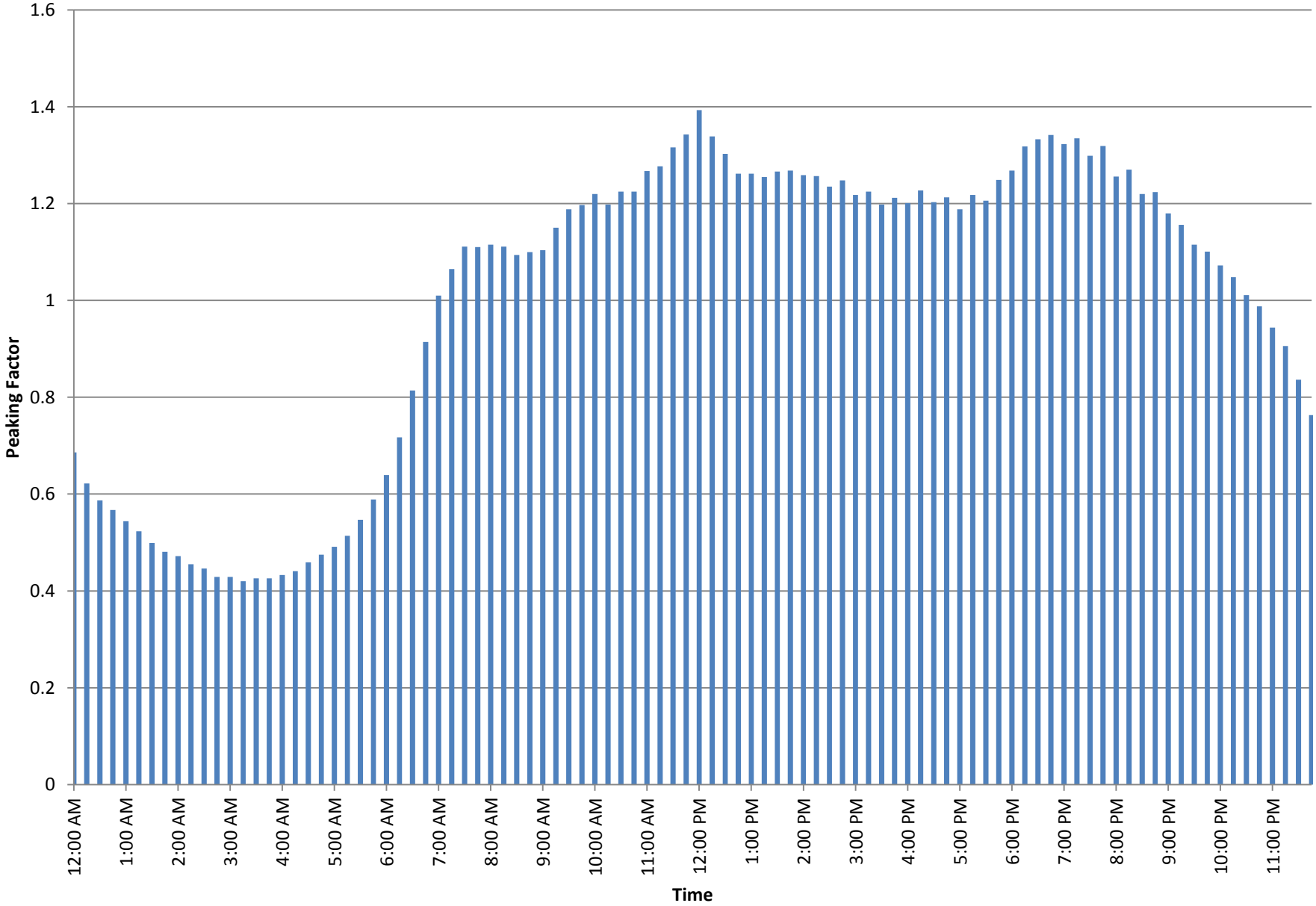
MODELED SEWER SUBCATCHMENTS

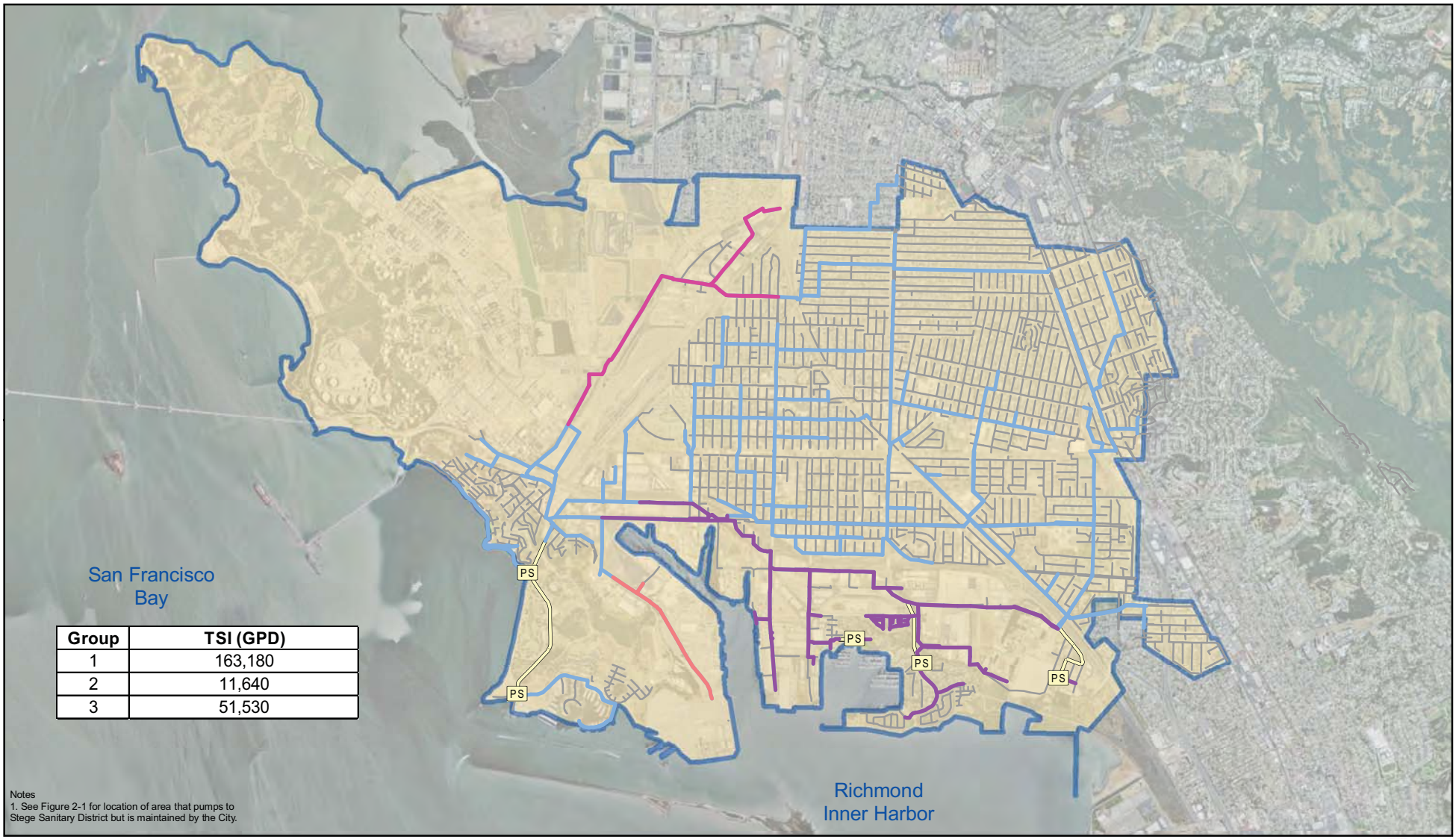
VEOLIA WATER

WEST YOST ASSOCIATES Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 5-2 (Sewershed Map).mxd 3/18/2011

Figure 5-3: Representative Diurnal Flow Pattern (Meter Site 2)





Group	TSI (GPD)
1	163,180
2	11,640
3	51,530

Notes
1. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

Pipes With TSI By Group
- Group 1
- Group 2
- Group 3

- Modeled Pipes (no TSI included)
- Sewer Pipes
- Force Main
- PS Modeled Pump Station
- Service Area

N

0 0.5 1
Miles

FIGURE 5-4

City of Richmond
Sewer Collection System Master Plan

TIDAL SATURATION INFILTRATION

VEOLIA WATER

WEST YOST ASSOCIATES Consulting Engineers

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 5-4 (Tidal Saturation Infiltration).mxd 3/18/2011

Figure 5-5. Tidal Inflow for Meter 1

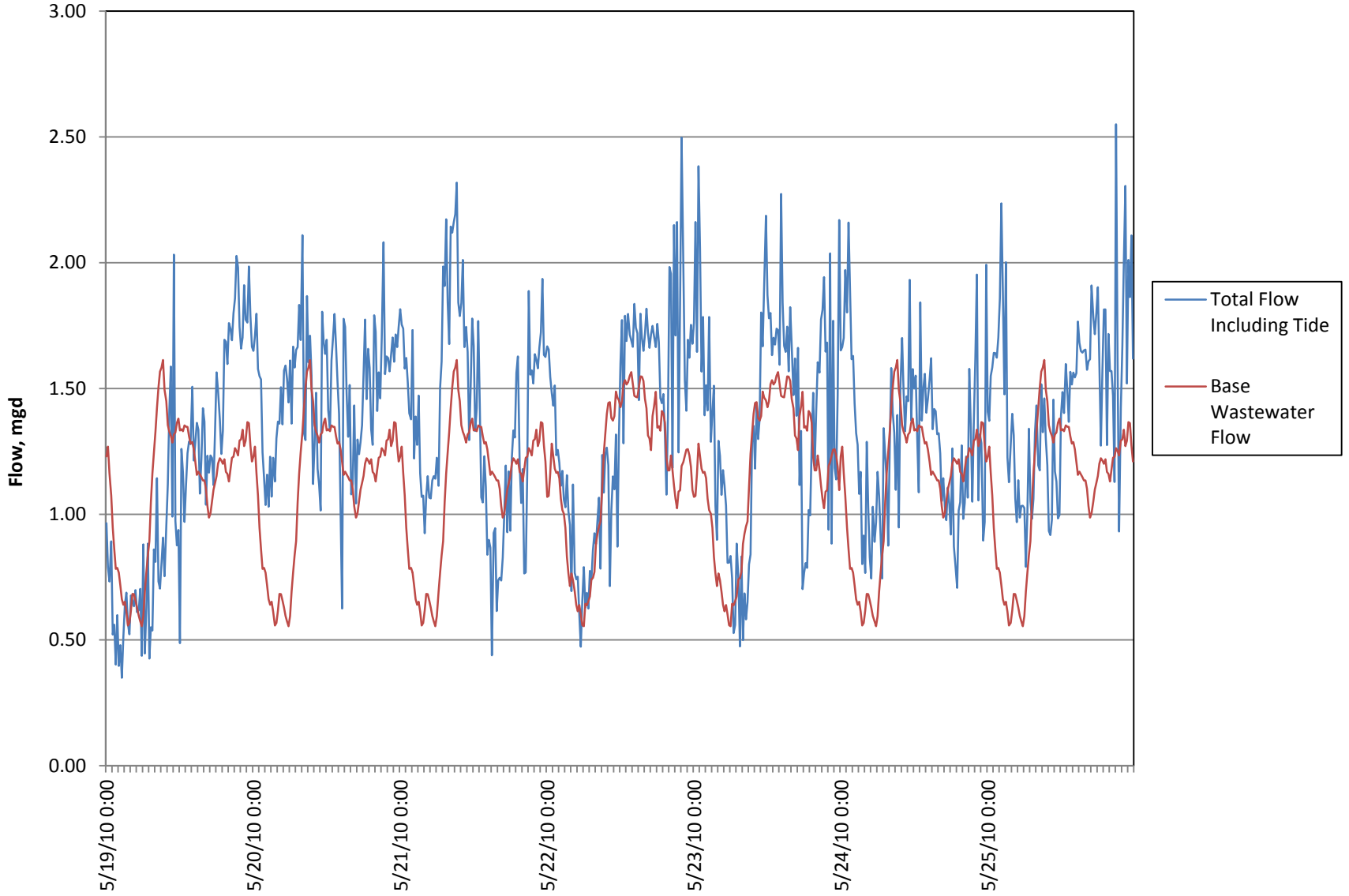


Figure 5-7. Representative DWF Calibration Results (Meter 2)

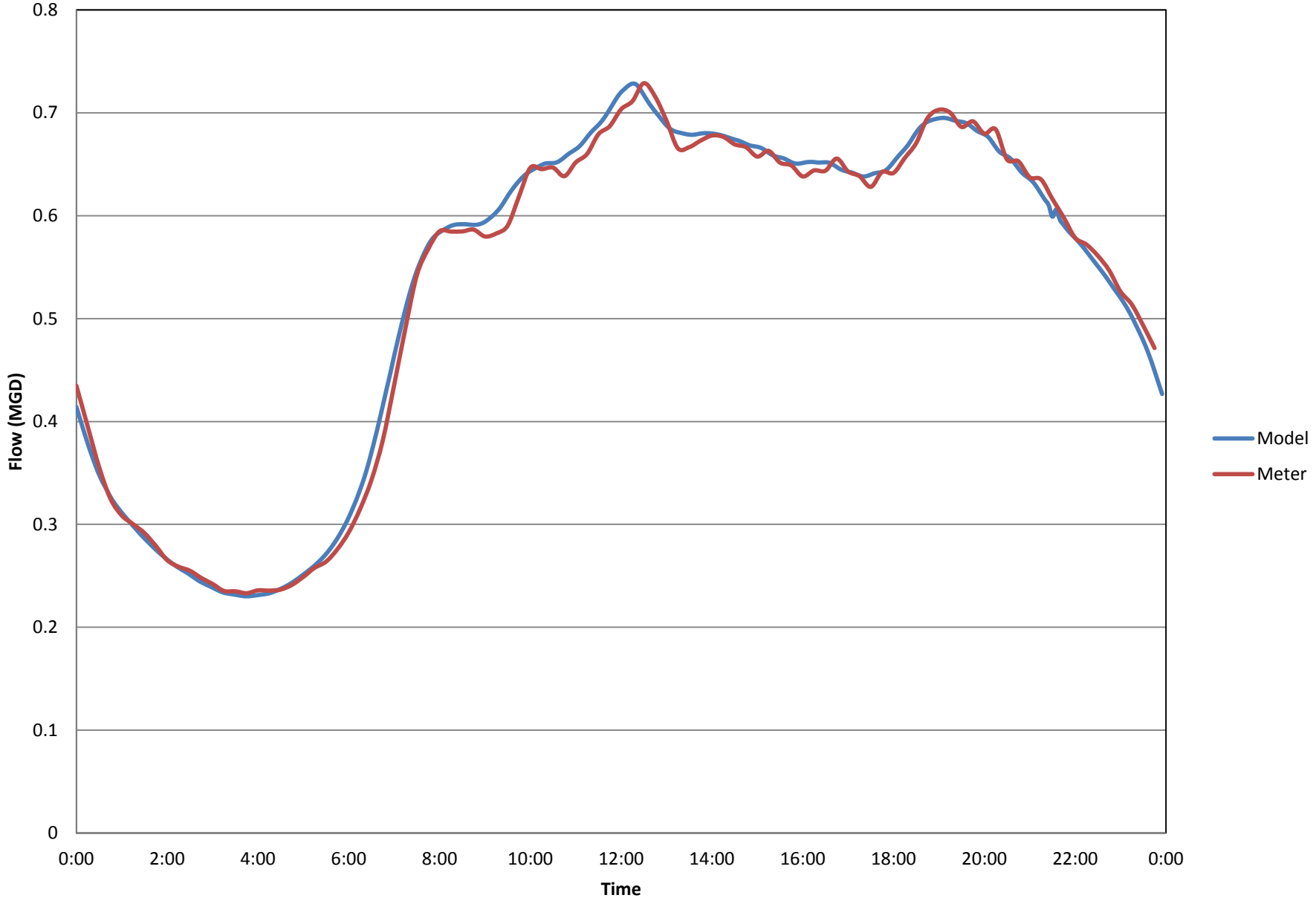
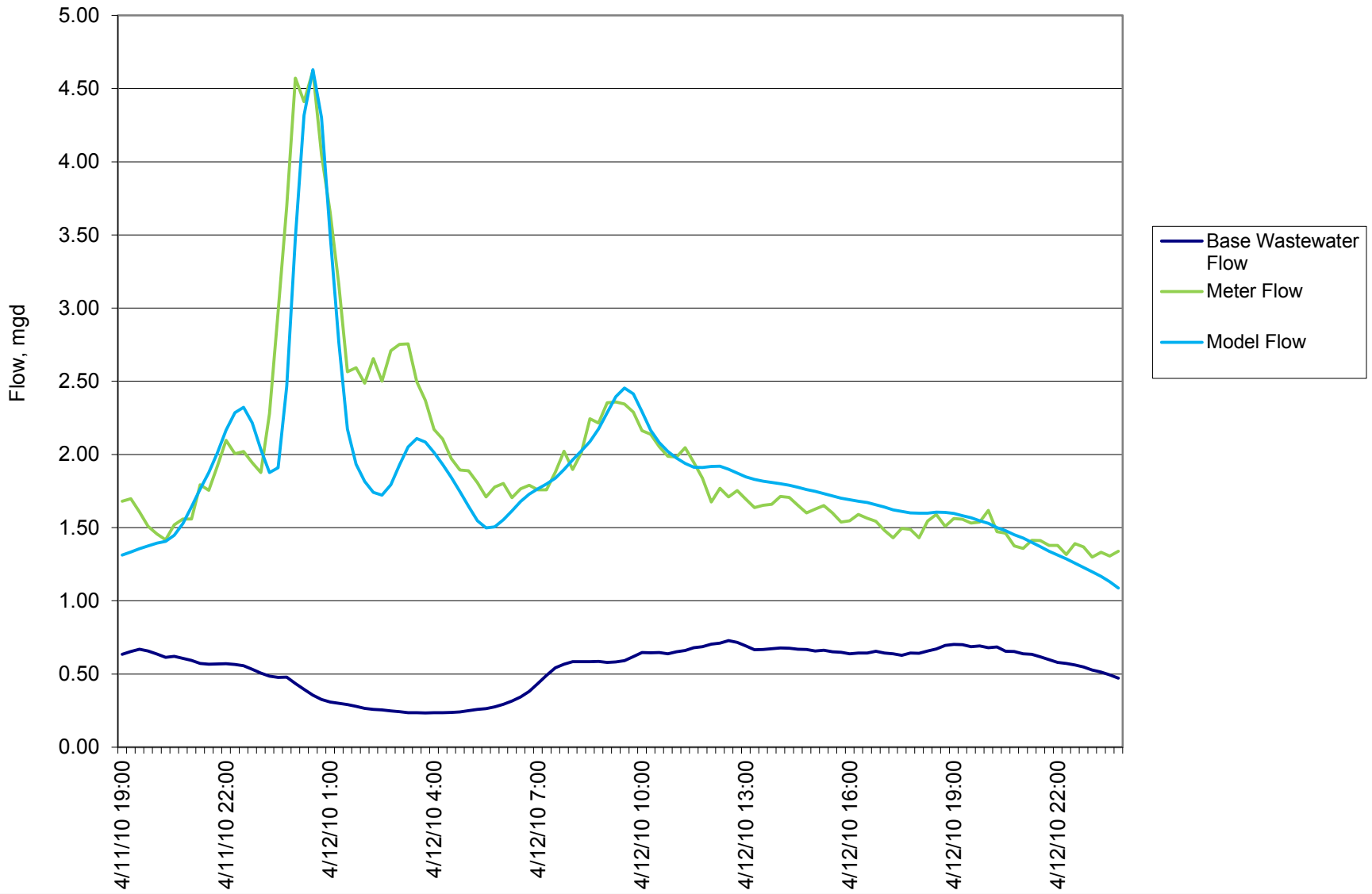


Figure 5-8. Meter 2 Wet Weather Calibration using M1 Rainfall Data



The purpose of this chapter is to present planning criteria used to evaluate existing system capacity and size new replacement facilities. The criteria include generally accepted industry standard criteria, and have been reviewed by Veolia for confirmation with the City's criteria. Planning criteria address items such as collection system capacity, gravity sewer slopes, and maximum depth of flow. The major elements of this chapter include:

- Design Storm,
- Hydraulic Deficiency Criteria, and
- New Pipeline Design Criteria.

6.1 DESIGN STORM

Design storms are synthetic rainfall events that are used to evaluate collection system capacity under wet weather flow conditions. A design storm has a specific recurrence interval and rainfall duration. Under the existing settlement agreement between the City and Baykeeper, the City is required to provide sufficient capacity to convey, without overflows, anticipated flows from a design storm with a recurrence interval of 10 years (*i.e.*, 10 percent probability of occurring in any given year) and duration of 24 hours. This requirement allows some storage within the existing manhole structures throughout the system, provided that adequate freeboard in the manhole is available.

For the City's hydraulic model, data for the 10-year, 24-hour design storm was derived from data that is maintained by the Contra Costa County Flood Control District. Using the County's depth-frequency-duration curves shown in Figure 6-1, in conjunction with the Mean Seasonal Isohyet Map provided in Figure 6-2, the total rainfall depth for a 10-year, 24-hour design storm in the City is 4.2 inches. Following Contra Costa County Flood Control District protocol, this rainfall depth was then distributed using the Natural Resource Conservation Service SCS Type 1 rainfall distribution curve.

6.2 HYDRAULIC DEFICIENCY CRITERIA

Hydraulic deficiency or capacity criteria are presented for gravity mains, force mains and lift stations. These criteria are intended to be used as planning tools to determine when flows are considered to have exceeded surcharge capacity during a specific storm event. Under these criteria, a facility may exceed surcharge capacity yet not overflow. This criteria is different than, and may be more conservative than the criteria that was established in the Baykeeper agreement. Hydraulic deficiency criteria are provided to facilitate and prioritize the need for future pipeline replacements after the City has satisfied its requirements under the Baykeeper settlement agreement.

The purpose of this master plan is to recommend improvements that are required to meet the City's obligations under the Baykeeper settlement agreement. The Baykeeper requirement prohibits SSOs under the design storm scenario. Due to the schedule constraints that were applied to this master plan, the improvements that are recommended in Chapter 7, Capacity Analysis, were sized solely to eliminate predicted SSOs. These improvements were not reviewed in the context of these proposed hydraulic deficiency criteria (if more conservative than the

Baykeeper criteria). Therefore, during specific project designs, it is recommended that the City review the facilities that are described in Chapter 7 for compliance with these hydraulic deficiency criteria. Hydraulic deficiency criteria provide triggers only, and are different than the more conservative criteria that are applied to determine the size of a new facility.

For existing pipelines, the pipe is considered to have a capacity deficiency (surcharge) when it is under peak wet weather flow conditions for a 5-year recurrence interval, 24-hour duration storm, and the water level or hydraulic grade line (HGL) is located as follows:

- For pipes 15-inches in diameter and smaller, the water level or HGL is greater than the crown of the pipe;
- For pipes greater than 15-inches in diameter, the HGL is within five feet of ground surface. In some cases, the HGL may exceed the crown of the pipe;
- For force Mains, a force main shall be considered capacity deficient if maximum velocity exceeds 8 feet per second (fps) during peak hourly flows; and
- For lift stations, a lift station shall be considered capacity deficient if the station does not have sufficient firm capacity, *i.e.* capacity with the largest pump out of service, to convey peak hourly flows during the selected storm.

6.3 NEW PIPELINE DESIGN CRITERIA

New or replacement pipelines will be designed to meet the following criteria using the 10-year, 24-hour design storm:

- Under peak dry weather flow (PDWF) conditions, velocity shall remain above 2 fps to facilitate self-cleaning;
- Under peak wet weather flow (PWWF) conditions, maximum depth of flow divided by diameter (d/D) shall strive to be equal to or less than 0.80; and
- Under all conditions, maximum allowable velocity is 10 fps.

Figure 6-1. Contra Costa County Mean Seasonal Isohyet Map

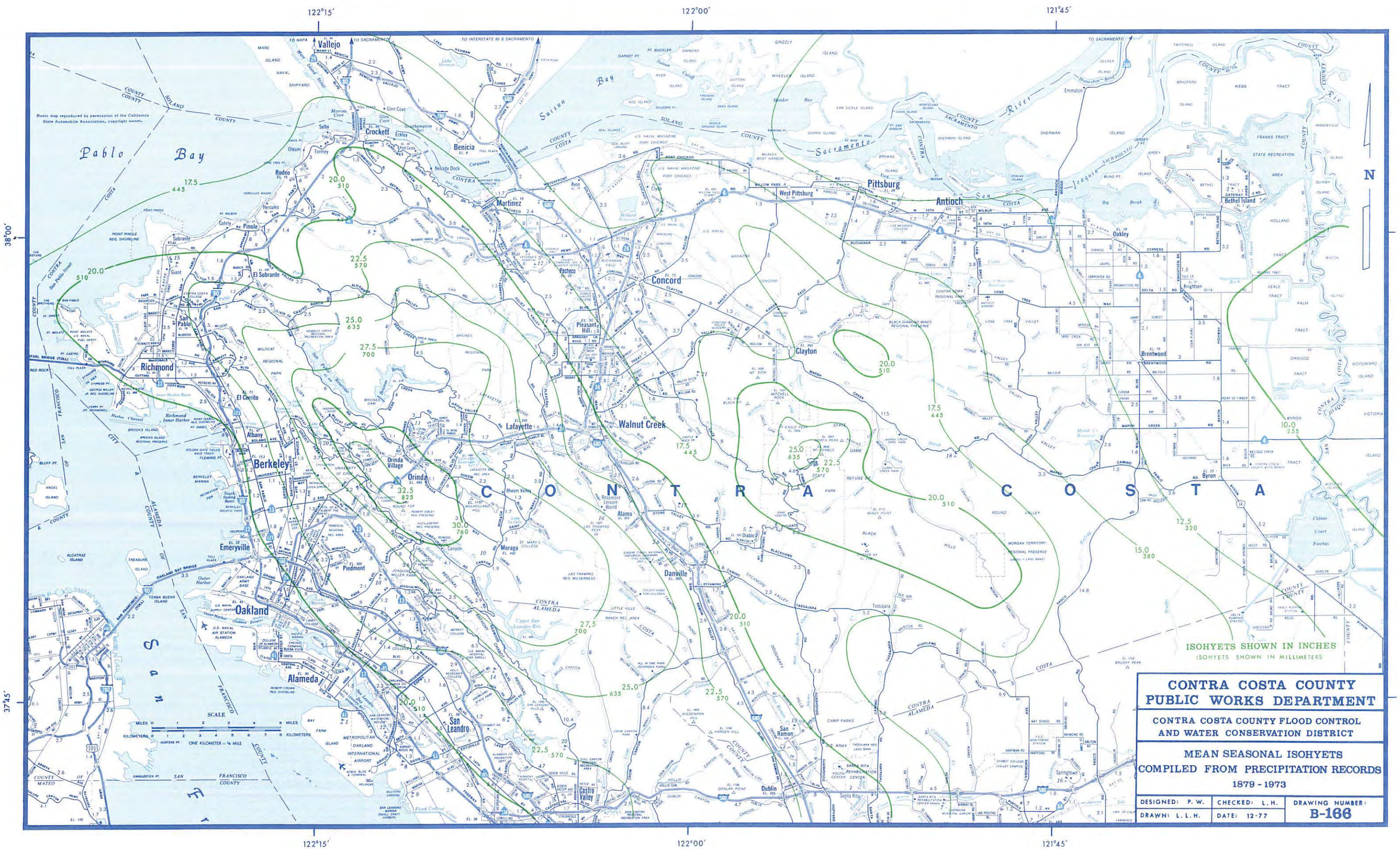
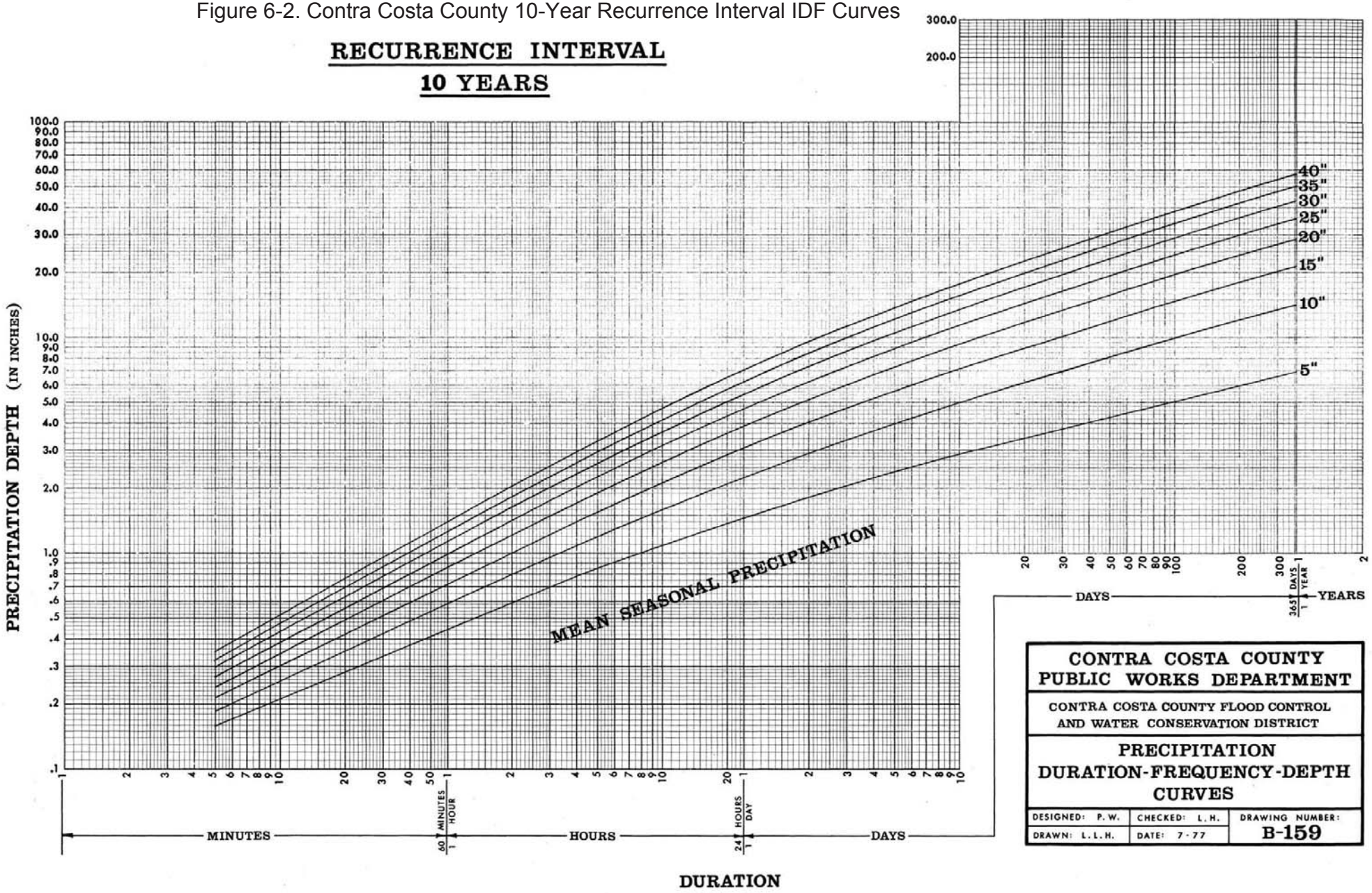


Figure 6-2. Contra Costa County 10-Year Recurrence Interval IDF Curves



Chapter 7 presents the results of the analysis of available hydraulic capacity within the City's collection system. The analysis reviews the system under wet weather capacity criteria, as needed to meet the requirements of the settlement agreement between the City and San Francisco Baykeeper. The Baykeeper agreement prohibits SSOs resulting from a 10-year, 24-hour design storm. This chapter also presents the capital improvements that are needed to provide sufficient sewer capacity and storage to meet this requirement, and provides planning level cost estimates for these improvements.

This chapter is organized as follows:

- Hydraulic Capacity Analysis Results,
- Recommended Projects, and
- Conceptual Costs.

During the time that the draft Master Plan was nearing completion, the City began discussing the need to accelerate a flow management solution for the South Harbour basin. This discussion was placed on hold, and any recommended solutions may be addressed in a future Master Plan update.

7.1 HYDRAULIC CAPACITY ANALYSIS RESULTS

The City's modeled collection system network was evaluated for its capacity to convey flows that are predicted to occur during a design storm event. The analysis was completed using a design storm with a published recurrence interval of 10 years and duration of 24 hours (10-year, 24-hour design storm).

The system was evaluated for its ability to convey all flows from the design storm without overflows. Due to the relatively flat topography of the lower third of the service area, wet weather flows are significantly impacted by the operating level at the wastewater treatment plant influent pump station. As shown in Figure 7-1, the operating level at the influent pump station establishes a hydraulic gradeline that is carried upstream through all of the trunk sewers that are located at approximately sea level. The influent pump station wet well level is defined by available pumping capacity of 42 mgd[1].

The predicted flows from the 10-year design storm is 66.6 mgd. Therefore, during the design storm, system capacity will be severely constrained by the hydraulic gradeline or water level established at the treatment plant influent pump station.

The proposed capacity improvements shown in Figure 7-2 reduce flows to the wastewater treatment plant to the extent that all predicted flows remain within the system when the influent pump station is pumping at its full capacity of 42 mgd. Flows are controlled through the addition of a new relief sewer that crosses the service area from east to west, and a new wet weather storage facility that is located in the western portion of the service area. Following the wet

[1] Maximum wet weather treatment plant influent pump station capacity provided by Veolia.

weather event, stored flows would be conveyed through existing pipelines to the WWTP. The improvements also include larger pipelines and relief sewers to provide additional capacity within the RMSD trunk sewers Wet Weather Storage

The hydraulic model identified the need to store flows of approximately 7.5 million gallons during the design storm event. By storing these flows during the peak wet weather event, the flow that is conveyed to the treatment plant will be controlled, thereby avoiding excess system surcharging and SSOs.

The desired location for wet weather storage is on the western boundary of the service area, near West Gertrude Avenue and Richmond Parkway. This location is near an existing Chevron storage pond site that may be available for use by the City. In the past, Chevron has indicated that they are interested in discussing the potential to use up to 20 million gallons of their available capacity for the City's wet weather storage, in order to secure a beneficial use for the Chevron facility.

7.1.1 Pipelines

The hydraulic model identified eight project areas where the water surface or hydraulic gradeline exceeded the ground surface elevation. These locations were identified as having sewer system overflows during the design storm event. In many areas, overflows occurred at multiple manholes along the existing sewer alignment. The eight project areas are described beginning in Section 7.2, below.

Capacity issues within the trunk sewers could be alleviated through the upsizing of existing sewers, the addition of new, parallel (relief) trunk sewers, or diversion of flows to a less impacted sewer. Generally, as the diameter of relief sewers increases, the challenges of pipeline construction also increase. The replacement pipeline must avoid existing underground utilities, cross existing railways and freeways, and maintain sufficient grade to create scouring velocity within the pipeline. The City's capacity-constrained pipelines have sufficient flow to warrant the use of parallel relief sewers. In some areas, the relief sewers may be larger than the existing pipeline.

To remove excess conservatism from the project cost estimates, the cost of the proposed capacity improvements assumed the installation of parallel relief sewers along the same alignment and to the same grade as the existing pipeline. However, a short timeline was provided between the formulation of the updated project solutions and the completion of this Master Plan. Therefore, the confirmation run included pipes that were upsized to an equivalent single larger pipe diameter. During the project design phase, it is recommended that the City and Veolia confirm the sizing of relief sewers using the hydraulic model, as a final step in project planning.

7.1.2 Pump Station Firm Capacity

Model-generated flows from the design storm event were compared to firm pump station capacity as confirmed by Veolia and listed in the 2006 master plan report (Boyle). All of the modeled pump stations had sufficient capacity to convey flows from the 10-year, 24-hour design storm, as shown in Table 7-1.

Table 7-1. Pump Station Capacities		
Pump Station	Firm Capacity from 2006 Master Plan, gpm	Design Storm Flow, gpm
Keller Beach	780	174
Ferry Point	450	331
ICI	440	245
Marina Bay Cove	440	46
Marina Bay Parkway	4200	2646

In addition to the five modeled pump stations, the City operates nine smaller stations within the sewer collection system. This Master Plan did not assess the capacity of these smaller stations to convey design flows. As trunk sewers and associated infrastructure are replaced over time, the City should review the firm capacity of these unmodeled collection system pump stations.

7.2 RECOMMENDED PROJECTS

Based on the hydraulic analyses and results, ten projects within the City's RMSD service area are recommended to address sewer system overflows and surcharge conditions resulting from the design storm event. These projects include eight capacity improvement projects, one new relief sewer, and one wet weather storage project. In order to meet the requirements of the City-Baykeeper settlement agreement, these projects must be completed within the City's required compliance timeframe in order to sufficiently address sewer system overflows.

The eight pipeline capacity improvement projects that are required to address hydraulic capacity constraints leading to SSOs from the design storm event are summarized in Table 7-2, and are also described below. The project priorities listed below are ranked with downstream sewer improvement projects listed first.

Table 7-2. Recommended Capacity Improvement Projects			
Priority	Project Name	Approximate Length	Project Description
1	Hensley Street Wet Weather Storage Project	3.8 miles of pipe plus wet weather storage	Comprises the Barrett Avenue Relief Sewer and 13th Street Capacity Improvement projects. 8- to 32-inch relief sewer and 18- to 38-inch replacement sewer.
2	Cutting Boulevard Sewer Capacity Improvements	1.2 miles	21- to 24-inch parallel relief sewer
3	Hoffman Blvd Capacity Improvements	1.2 miles	15- to 18-inch parallel relief sewer. Recommend combining with the Cutting Boulevard project.
4	1st Street Sewer Capacity Improvements	1.4 miles	24- to 27-inch parallel relief sewer
5	Virginia Ave @ Harbour Way Capacity Improvements	0.2 miles	12-inch replacement sewer. Recommend combining with the 1st Street project.
6	MacDonald at 23rd Sewer Capacity Improvements	0.4 miles	12-to 15-inch replacement sewer. Recommend combining with the 1st Street project
7	San Pablo Sewer Capacity Improvements	1.2 miles	10- to 21-inch parallel relief sewer
8	Carlson Blvd Capacity Improvements	0.5 miles	15-inch replacement sewer. Recommend combining with the San Pablo project

7.2.1 Hensley Street Wet Weather Storage Project

This project has three components: Barrett Avenue Relief Sewer, 13th Street Capacity Improvement project, and Hensley Street Wet Weather Storage Facility. Although the projects are described separately, they are recommended for implementation as a single capital improvement project.

The Barrett Avenue Relief Sewer includes a new pipeline that begins near I12MH1061, in the vicinity of 36th Street and Barrett Avenue, and continues west on Barrett Avenue, intercepting flows at 23rd Street and Harbour Way. The new pipe turns north onto Harbour Way, which becomes 10th Street. The sewer intercepts the existing 13th Street Capacity Improvement project at 10th Street and Lucas Avenue. The pipeline will be approximately 1.7 miles long, and will range in diameter from 24- to 36-inches. The alignment includes heavy traffic and several railway crossings. Additional flow monitoring is recommended to confirm the distribution of

flows and I&I upstream and downstream of Barrett Avenue. Pipe diameters would then be confirmed or adjusted based on findings from program.

The 13th Street Capacity Improvement project installs a relief sewer following the 2.1 mile long existing sewer alignment beginning at the intersection of Pine Avenue and 23rd Street, and continuing south within 23rd street, west within Emeric Avenue, south within 21st Street, west within Alfred Boulevard, south within 20th Street, west within Costa Avenue, south within 13th Street, west within Lucas Avenue, and west within Hensley Street to N. Castro Street. This relief sewer varies in diameter from 8 to 32 inches.

The alignment begins at Manhole L11MH1630 and will continue along the described alignment south and westerly to N. Castro Street to terminate at Manhole J8MH2880. The project requires a crossing of railway tracks at Portola Avenue and again at Garrard Boulevard, and crossing of Richmond Parkway at Garrard Boulevard. This project will also likely include installation of pipe through easements in the western portion of the pipeline.

The pipeline projects will convey flow to a new wet weather storage facility with a minimum capacity of 8 million gallons and desired capacity of 10 to 15 million gallons. The preferred location for storage is near the existing Chevron facility located at West Gertrude Avenue and Richmond Parkway. Chevron has discussed an interest in using the Chevron property to store the City's peak wet flows. Chevron believes that they have approximately 20 million gallons of storage available, and have expressed that they could complete the site upgrades needed to render this existing storage facility suitable for the storage of wastewater flows. Other locations may be identified through additional planning studies and conceptual designs.

The storage location would require a pumping facility to return flows back to the system after the rainfall event. The storage facility would include pre-screening, and should be designed to maximize scouring velocities and minimize odors. Storage may require the acquisition of easements and/or property, as well as community endorsement. The addition of storage will require environmental clearance under the California Environmental Quality Act. Storage projects are long-lead solutions that require experienced and early planning to ensure successful implementation in the required timeline of the City-Baykeeper settlement agreement.

7.2.2 Cutting Boulevard Sewer Capacity Improvements

This project relieves capacity issues within the existing trunk sewer through the installation of a 21- to 24-inch relief sewer that follows the existing alignment within Cutting Boulevard between Carlson Boulevard and Harbour Way South. The total project length is approximately 1.2 miles. Pipeline installation will need to consider heavy traffic patterns on Cutting Boulevard, and requires a crossing of railway tracks at Carlson Boulevard and Espee Avenue. The alignment begins at Manhole G11MH877, and continues west on Cutting Boulevard to terminate at Manhole G9MH1286.

7.2.3 Hoffman Boulevard Capacity Improvements

This project addresses capacity issues within the existing trunk sewer by installing a 15- to 18-inch diameter relief sewer following the existing alignment. The 1.2 mile-long pipeline begins at Manhole F11MH1238 at the end of Foothill Avenue and parallels Hinkley Avenue to the intersection of 23rd Street and Potrero Avenue. The pipe turns south to Hoffman Boulevard, then proceeds west on Hoffman Boulevard, turns north onto 13th Street, west on Potrero, and north on 11th Street to Cutting Boulevard. The pipe reconnects with the Cutting Boulevard trunk sewer at manhole G9MH190. It is recommended that this project is combined with the Cutting Boulevard capacity improvement project.

7.2.4 First Street Sewer Capacity Improvements

This project relieves flow within the existing trunk sewer through the installation of a 1.4-mile relief sewer ranging in diameter from 24- to 27-inches. The pipe will begin at the intersection of Pennsylvania and 5th Street, and continue west within Pennsylvania Avenue, then south within 4th street, west within Barrett Avenue, south within 3rd street, west within Nevin Avenue, and south within 1st Street to W. Cutting Boulevard.

The alignment begins at Manhole J9MH1684 and will continue along the described alignment south to W. Cutting Boulevard to terminate at Manhole G9MH1312. The project requires a crossing of Highway 580

.

7.2.5 Virginia Avenue at Harbour Way, MacDonald Avenue at 23rd Street and Carlson Boulevard Capacity Improvements

These projects address capacity issues within relatively short sections of existing trunk sewer by upsizing the respective pipelines. The Virginia Avenue project upsizes 0.2 miles of 10-inch diameter pipe to 12-inch pipe from Manhole G10MH1523 to G10MH1517. Similarly, the MacDonald Avenue project upsizes approximately 0.4 miles of 10-inch diameter pipe to 12-inch pipe from Manhole H11MH1175 to I11MH1470. The Carlson Boulevard project upsizes approximately 0.5 miles of 12-inch diameter pipe to 15-inch diameter from Manhole G11MH838 to G11MH880.

7.2.6 San Pablo Sewer Capacity Improvements

This project relieves flow within the existing trunk sewer through the installation of a new 1.2-mile long relief sewer ranging from 10- to 21-inches in diameter. The new sewer will follow the existing alignment from the intersection of Amador Street and Esmond Avenue, and then south within Amador street, west within Clinton Avenue, southwesterly within McLaughlin Street, west within Roosevelt Avenue, south within San Pablo Avenue, west within Bissell Avenue under Hwy 80, then south to the intersection of the Richmond Greenway Trail and S. 47th Street.

The alignment begins at Manhole J13MH728 and continues along the described alignment south and westerly to the Richmond Greenway, to terminate at Manhole H13MH236. The project requires a crossing of Hwy 80, and will include installation of pipe through easements adjacent to the freeway. This project includes several additional minor capacity improvements in the vicinity of the described alignment.

7.3 CONCEPTUAL COSTS

This section discusses the basis for cost estimates prepared for the capacity improvement projects that are described in Section 7.3.

7.3.1 Cost Estimating Basis

For the purposes of estimating cost for the pipeline capacity improvement projects, open cut or open trench construction was assumed, with the exception of crossings at the railway right of way, and Highways 80 and 580. Open cut construction has historically been the most widely used approach for sewer pipe installation especially with the need to install manholes and interconnections, and to provide safe crossing of existing utilities within existing streets.

The unit cost of open cut construction varies depending on site conditions and construction access limitations. However, in paved roadways underlain by generally cohesive soils above the groundwater table, and in areas without significant utility or traffic issues, open cut pipeline installation costs range from $10 to $14 per inch diameter per foot of pipe installed. These base pipeline installation costs include excavation, shoring, pipe installation, backfill, and

compaction. The City's projects anticipate normal to difficult construction conditions for all the projects.

For all of the projects that increase capacity by removing and replacing the existing pipe with a new pipe, a base pipeline installation cost of $12 per inch diameter foot of pipe was doubled to account for the additional costs of manhole installations, interconnections, utility crossings, railway or freeway crossing (required in some form for each project), and other construction needs. The cost for relief sewers, which will not require lateral connections, was increased by 75 percent to account for the remaining construction items.

Storage cost estimates applied a unit cost of $2 per gallon of flow to account for storage, pumping, and conveyance facilities, and the contingencies described below.

A 30 percent contingency for construction unknowns was added, and then an 18 percent allowance was included to account for standard design and project administration costs. Costs were based on the December 2010 Engineering News Record Construction Cost Index (ENR CCI), San Francisco, 10,120.29. Costs do not include any additional programmatic costs related to Veolia operations.

7.3.2 Estimated Project Costs

Table 7-3 summarizes the capacity improvement projects and associated costs. Construction costs include the total construction cost estimate including contingency. Total costs add project design and construction administration to the total construction cost. Detailed cost estimates are provided as part of Chapter 9, Capital Improvement Plan, and Appendix G.

Table 7-3. Capacity Improvement Project Estimated Costs

Project Name	Project	Estimated Construction Cost	Estimated Total Cost
Hensley Street Pipelines	Parallel Relief Sewer and New Trunk Sewer	$13.7M	$16.1M
Cutting & Hoffman Boulevards	Parallel Relief Sewers	$6.5M	$7.6M
First Street, MacDonald Avenue, Virginia Avenue	Parallel Relief and Trunk Sewers	$6.5M	$7.7M
San Pablo & Carlson Boulevards	Parallel Relief and Trunk Sewers	$3.6M	$4.2M
Total Estimate for Pipeline Projects		$30.3M	$35.6M
Total Estimate for Storage (8MG)		$20.8M	$24.4M

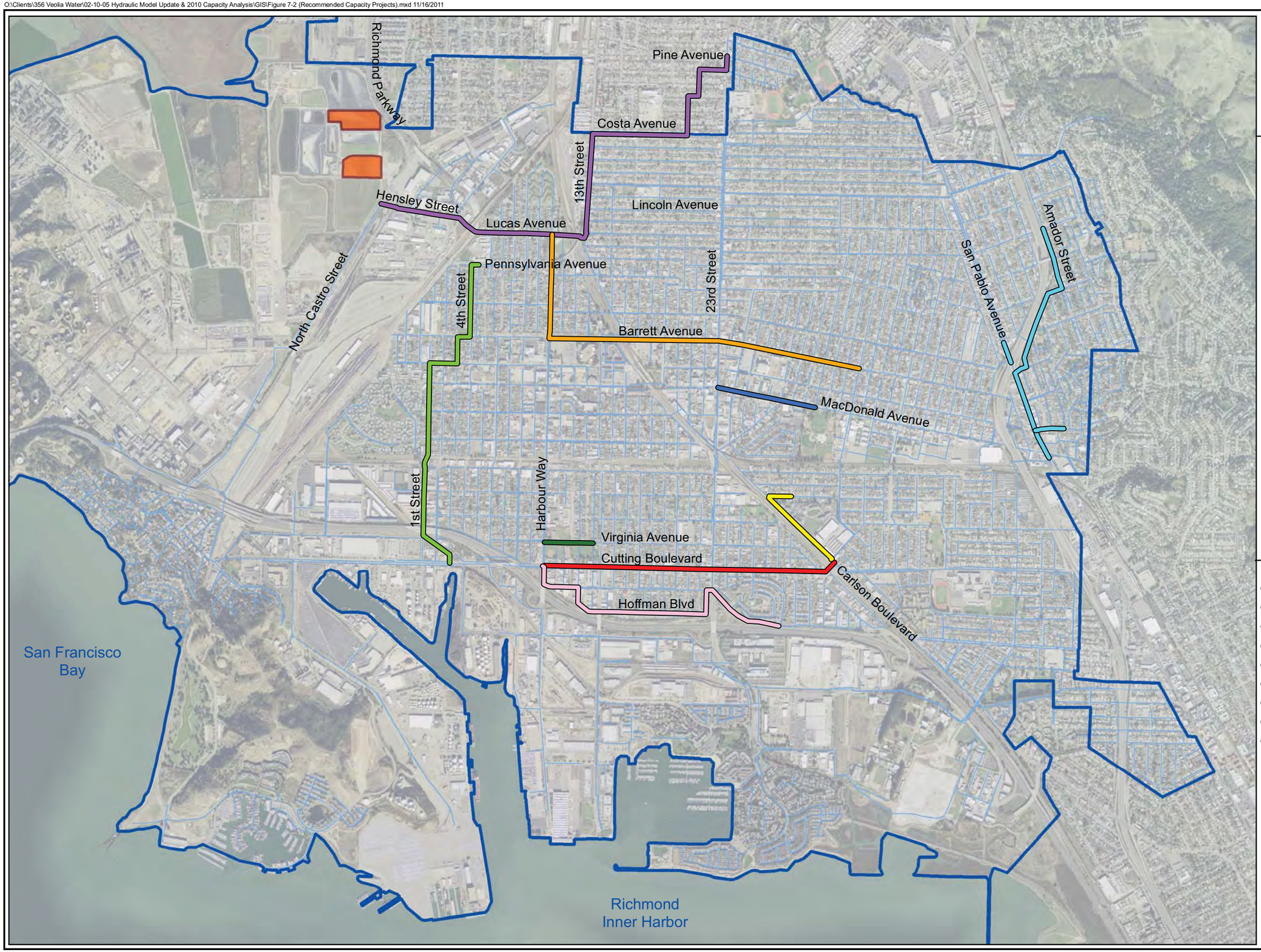
Please note Figures 7-1 and 7-3 through 7-7 will be provided separately.

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure 7-2 (Recommended Capacity Projects).mxd 11/16/2011

FIGURE 7-2

City of Richmond
Sewer Collection System
Master Plan

RECOMMENDED CAPACITY PROJECTS



N

0 0.2 0.4

Miles

Notes
1. See Figure 2-1 for location of the area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

Sewer Capacity Improvements
- 13th Street
- Barrett Avenue Relief Sewer
- Cutting Boulevard
- Hoffman Boulevard
- 1st Street
- MacDonald at 23rd Street
- Virginia Avenue at Harbour Way
- San Pablo
- Carlson Boulevard

Potential Wet Weather Storage Location
- Storage Location

Other
- Sewer Pipe Segment
- Service Area

VEOLIA WATER

WEST YOST ASSOCIATES
Consulting Engineers

In March 2010, West Yost and Veolia developed an interim capital improvement plan that provided an integrated, prioritized replacement program to address wastewater treatment plant and collection system needs. Since this time, the City has received additional collection system information through the 2010 flow monitoring program. This information adds more context to the issues facing the City related to sewer system capacity and I&I reduction needs. This chapter reviews and revises the interim plan with regard to recommended collection system improvements. The scope of work for this Master Plan was limited to a re-evaluation of prior recommendations, and did not include any additional assessments of pipeline replacement needs.

The resulting projects and priorities will more effectively address the City's most critical issues related to system-wide I&I and flow control. As with the prior rehabilitation and replacement studies, this Master Plan reviews requirements for pipelines and storage facilities only. Pump station rehabilitation and replacement needs are assessed and prioritized by Veolia Water. Pump station capacity upgrades needed to convey flows from the 10-year, 24-hour storm are discussed in Chapter 7, Capacity Analysis.

This chapter is organized as follows:

- Summary of Recommendations from Prior Studies,
- Critical Projects and Updated Priorities, and
- Long-Term Replacement Strategy.

8.1 SUMMARY OF RECOMMENDATIONS FROM PRIOR STUDIES

The City has identified a number of projects that are required to reduce I&I in the collection system. Project requirements were developed based on data collected through various field investigations, including the following:

1. Smoke testing (SFE, 2006 and 2008),
2. Closed Circuit Television (CCTV) inspections (Veolia, ongoing),
3. Flow monitoring (V&A, 2010), and
4. Sewer system overflows (RWQCB California Integrated Water Quality System (CIWQS) database, ongoing).

In addition, the City has completed a conceptual design study for replacement of the Keller Beach interceptor (Kennedy/Jenks, 2000), and has studied options for a potential regional storage facility located on property owned and operated by Chevron.

The resulting projects and project groupings are listed below in the order of priority that was established in the prior studies, with the highest priority projects listed first:

- Pipeline emergency repairs and San Pablo Avenue project: These projects included the Sunset Generator and Pennsylvania emergency repair projects, and replacement of failing pipelines along San Pablo Avenue and in the surrounding neighborhoods. These projects have been completed.
- Keller Beach interceptor replacement project: The Keller Beach interceptor is located several feet off the coast of Point Richmond, and is submerged beneath the San Francisco Bay. The condition of the pipeline is unknown, and manhole lids are corroded, generally prohibiting access for inspection. Sewers upstream of the submerged interceptor have known structural defects and have contributed to SSOs. This project replaces the interceptor and tributary pipelines, in order to avoid potential failure and discharge of raw sewage into the San Francisco Bay. The Cypress Point sewer replacement project is a critical subset of the Keller Beach project.
- Wet weather storage: Storage facilities are required to retain diluted wastewater flows during wet weather events. After the storm event subsides, the stored flows are returned to the collection system for treatment at the treatment plant. The cost of storage is expected to be significantly lower than increasing wastewater treatment plant capacity to handle excess wet weather flows. Required wet weather storage volume and peak flow rates are discussed in Chapter 7, Capacity Analysis.
- Elimination of stormwater inflow: Tidal inflow in the southern portion of the service area adds significant flows to the collection system. This project eliminates direct connections between the City's stormwater system and collection system in tidal areas. Reduction of stormwater inflow, and more specifically, tidal inflow, will reduce conveyance and treatment needs and create immediate cost savings in the overall CIP.
- Other Capacity Improvements: A placeholder was included for near-term capacity improvement projects that are required to eliminate wet weather overflows. This list has been further defined in Chapter 7, Capacity Analysis.
- Pipeline Repairs and Replacements: Point repairs and pipeline replacements were identified to eliminate the City's most significant pipeline structural defects, including pipe failures and significant offsets.

8.2 CRITICAL PROJECTS AND UPDATED PRIORITIES

The projects listed above were prioritized based on the following criteria. A ranking of 1 denotes the highest priority and 5 denotes a project that has a high priority, but is less critical than those with higher rankings.

Rank 1: Address life safety issues at the wastewater treatment plant.

Rank 2: Meet NPDES permit numerical limits for pollutant discharge.

Rank 3: Meet Baykeeper settlement agreement mandates.

Rank 4: Meet SSMP and Statewide WDR collection system requirements.

Rank 5: Prepare the City for potential NPDES permit requirements.

As a component of this Master Plan, collection system project needs were re-evaluated with regard to these rankings, using the added information that was provided through the 2010 flow monitoring program.

After removing from consideration the emergency projects that were completed in 2010, the remaining top three priority projects have not changed. However, the importance of these projects relative to one another has shifted. Also, the criticality of all of these projects has increased substantially.

The flow monitoring results revealed that the existing trunk sewers and interceptors throughout most of the service area have capacity issues in a storm with recurrence interval of less than 2 years (greater than 50 percent chance of occurring in any given year). The 2010 rainfall events resulted in surcharging but not overflows, due to the depths of pipe and available freeboard throughout the system. However, a 10-year, 24-hour storm will quickly utilize the remaining available in-system storage. It is critical that the City initiate projects that will quickly reduce system flows, in both dry and wet weather, in order to avoid the system-wide SSOs that are anticipated during the design storm event.

The revised top three projects for implementation in the near-term CIP include the following, in order of priority. Appendix F provides a map, fact sheet, and additional relevant planning details for each project. Appendix G provides a conceptual cost estimate breakdown for each project.

- Elimination of stormwater inflow. This project, in conjunction with the development of wet weather storage, has been elevated to the highest priority for near-term collection system improvements. The flow monitoring program identified substantial groundwater inflow in the portions of the service area that are adjacent to the San Francisco and San Pablo Bay. A more focused flow monitoring effort identified the lower harbor area, between Canal Boulevard and Marina Way south of I-580, as having a significant tidal flow response.

  In 2010, Veolia completed several projects to reduce the volume of tidal inflow into the sewer system. Project include separation of storm drain pipelines (conveying tidal flows) from the sewer system, and the installation of duck-bill check valves on the existing overflow structures to the Richmond Harbour. Flow monitoring conducted in July 2011 confirmed that these projects reduced the volume of tidal inflow into the sewer system. This information was incorporated into this Master Plan update.

- Wet weather storage: Wet weather storage is critical to meeting the City's objectives for safety and compliance. The 2010 flow monitoring season generated a peak hourly flow of 33 mgd. The hydraulic model predicts that peak flows will exceed 70 mgd if all system flows are conveyed to the wastewater treatment plant without diversion during the design storm. This volume of flow cannot be accommodated by the treatment plant.

- Cypress Point sewer replacement project: This project maintains its high level of criticality because the pipe has had multiple SSOs that flowed directly to the San Francisco Bay and is known to have heavy root intrusion.

- Keller Beach interceptor replacement project: This project maintains its high level of criticality because 1) the Keller Beach area produces the highest levels of rainfall dependent I&I in the collection system, and 2) failure of the Keller Beach interceptor would immediately violate the City's obligations to meet pollutant discharge requirements.

The next tier of projects undertakes an aggressive, systematic, long-term program of pipeline repairs and replacements to maintain the state of the system that is achieved through these top tier projects. These projects will systematically eliminate wet weather overflows throughout the system, including overflows from the City's two overflow structures in Richmond Harbor.

8.3 LONG-TERM REPLACEMENT STRATEGY

The City has completed CCTV inspection of all accessible pipelines within the service area, and previously identified a number of pipeline replacement projects that are needed to address structural defects. These pipeline replacement projects have been documented in earlier West Yost technical memoranda that is included in Appendix F. The proposed replacement projects should be reviewed and, where cost effective and appropriate, integrated into the design of the capacity improvement projects that are discussed in Chapter 7, Capacity Analysis.

CHAPTER 9
Capital Improvement Program

Chapter 9 presents the recommended Capital Improvement Program (CIP) for the City's RMSD gravity sewer collection system. The project requirements, configurations, and conceptual costs that are presented in this chapter are described in additional detail in Chapters 7 (Capacity Improvements) and 8 (Pipeline Repair and Replacement). This chapter summarizes, consolidates and prioritizes the proposed projects, and includes a cost-loaded implementation timeline.

The recommended CIP identifies the needed improvements at a master planning level, and does not constitute conceptual or preliminary design of these improvements. Subsequent alignment studies and preliminary designs are required to finalize pipeline configuration and alignment, to refine storage needs, and to determine the final sizes, locations, and details of the proposed improvements.

This chapter is organized as follows:

- Basis for Capital Improvement Program Development, and
- Proposed CIP.

9.1 BASIS FOR CAPITAL IMPROVEMENT PROGRAM DEVELOPMENT

The CIP was developed to create a fundable program that addresses the City's competing needs for capacity improvement and reliability. The following criteria were used to prioritize the various projects and develop a timeline for implementation.

1. Projects to Eliminate SSOs. The City is required to meet the terms of the City- Baykeeper settlement agreement. This agreement requires the City to eliminate, by 2014, capacity-related SSOs that result from a 10-year, 24-hour design storm. The CIP prioritizes the most critical capacity-related projects during this timeframe.
2. Projects to Reduce Maintenance-Related SSOs. The CIP includes the implementation of the most critical condition-related rehabilitation projects, as well as projects that render the collection system pipes inaccessible to CCTV inspection equipment, as determined through prior studies that have been completed by Veolia for the City.
3. Distribution of Capital Costs. In addition to meeting the above requirements, an implementation schedule for the recommended projects was developed that strives to manage expenditures through June 2013 to the City's available funding level of $30 million. This program maximizes the opportunity for success in project implementation by using previously-issued and/or approved bond funds.

9.2 PROPOSED CIP

Table 9-1 presents the proposed CIP, which begins implementation in Fiscal Year 2011/12 and extends into Fiscal Year 2020/2021. The CIP is intended to be a living document that is adjusted as needed to address future issues and priorities that may arise after completion of the Master Plan. The most critical components of the CIP are summarized below. Additional information on the individual projects, including detailed cost estimates, can be found in Chapters 7 and 8 of this report.

Table 9-1. City of Richmond Sewer Collection System Capital Improvement Program

	Project Name	Estimated Cost	Fiscal Year 2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
R&R Priority												
1	Stormwater Inflow Abatement	$10,600,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000
2	Cypress Point Sewer Replacement	$ 300,000	300,000									
3	Keller Beach Interceptor Replacement	$ 5,670,000	567,000	1,000,000	1,367,667	1,367,667	1,367,667					
4	Ongoing R&R Projects	$ 7,000,000				1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
5	Inaccessible R&R Projects	$ 4,750,000	2,375,000	1,187,500	1,187,500							
	Subtotal R&R	$ 28,320,000	$ 4,302,000	$ 3,247,500	$ 3,615,167	$ 3,427,667	$ 3,427,667	$ 2,060,000	$ 2,060,000	$ 2,060,000	$ 2,060,000	$ 2,060,000
Capacity Project												
1	Hensley Street Pipelines	$16,117,000	1,611,700	7,252,650	7,252,650							
2	Hensley Street Storage	$24,544,000	2,454,400	11,044,800	11,044,800							
3	Cutting and Hoffman Boulevard Capacity Improvements	$7,639,000	763,900	3,437,550	3,437,550							
4	First Street, MacDonald and Virginia Avenue Capacity Improvements	$7,691,000			769,100	6,921,900						
5	San Pablo and Carlson Capacity Improvements	$4,236,000				423,600	3,812,400					
n/a	Emergency Projects[(a)]	$10,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
	Subtotal Capacity	$70,227,000	5,830,000	22,735,000	23,504,100	8,345,500	4,812,400	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
	Total CIP	**$ 98,547,000**	**10,132,000**	**25,982,500**	**27,119,267**	**11,773,167**	**8,240,067**	**3,060,000**	**3,060,000**	**3,060,000**	**3,060,000**	**3,060,000**

[(a)] Includes South Harbour Overflow Mitigation Project

The total estimated 10-year CIP cost is $98.5 million. Of this amount, $60.2 million is needed to meet the capacity requirements that are included in the City-Baykeeper settlement agreement. Implementation of the capacity-related projects is recommended for completion within the Baykeeper settlement agreement timeframe. If this schedule is not achievable, these improvements are recommended within the 10-year CIP timeframe. The remaining costs were spread through the 10-year timeframe of this CIP, but can be further distributed into future programs.

Although the City-Baykeeper settlement agreement requires completion of the proposed capacity improvements by September 1, 2014, the CIP schedule for the Baykeeper-related capacity improvements may be constrained by anticipated permitting needs in addition to available funds. To maximize the success of the capacity improvement aspect of the CIP, the CIP prioritizes projects that are needed to provide in-system storage. By limiting the volume of flow that reaches the WWTP during peak wet weather events, the City will also have the greatest control over the management of system issues that could result in wet weather SSOs, including SSOs that would be released through the two combined sewer/stormwater discharges to the Richmond Inner Harbor.

The highest priority projects related to wet weather diversion, storage, and management are the Hensley Street pipelines, Hensley Street storage, and Cutting Boulevard / Hoffman Boulevard capacity improvement projects. These projects are planned for completion by 2013/14. The remaining pipeline capacity improvements will eliminate more localized predicted sewer system overflow issues over time. If the City is able to accelerate the remaining proposed capacity improvement projects, then this schedule will be updated accordingly.

9.2.1 Capacity Improvement Projects

The CIP includes ten capacity improvement projects as described in Chapter 7, which are grouped into five capital improvement projects. The projects provide sufficient capacity for the system to convey or store flows from the design storm event through the installation of larger diameter pipelines, parallel relief sewers, and wet weather storage.

The projects were originally planned for implementation starting in Fiscal Year 2010/2011. Preliminary design work for the Barrett Avenue Relief Sewer project, which is a component of the Hensley Street pipelines, is currently underway.

The total projected cost of capacity improvement projects is $60.2 million. In addition, the CIP includes a $10 million contingency for emergency projects that are needed to address capacity-related SSOs.

9.2.2 Rehabilitation and Replacement Projects

The CIP presents needed rehabilitation and replacement projects on a parallel track with the proposed capacity improvements. The following projects are considered a priority for the City and Veolia with regard to ongoing system rehabilitation:

- Elimination of stormwater inflow. This project is a placeholder for efforts to identify and eliminate sources of significant stormwater and tidal inflow into the southern portion of the sewer system. The cost to complete this work is expected to be

recovered through the resulting reductions in storage and conveyance requirements. This project assumes 10 projects at $1.06 million per project, including all contingencies.

The City is implementing these projects, including the installation of duck-bill check valves and other improvements to prevent tidal inflow from entering the sewer system through the City's stormwater system. 2011 flow monitoring has confirmed that these projects have measurably reduced tidal contributions to I&I.

- Cypress Point sewer replacement project. This project replaced an existing pipeline that has had multiple SSOs that flowed directly to the San Francisco Bay. The pipeline is known to have heavy root intrusion and other maintenance and structural issues. This project replaces 750 linear feet of 12-inch diameter pipe at $430/foot, including all costs and contingencies ($300,500).
- Keller Beach interceptor replacement project. This project replaces the existing submerged gravity interceptor that services the Point Richmond community. The Keller Beach area has the highest levels of rainfall dependent I&I in the collection system. Because the pipe is submerged, failure of this interceptor would directly impact the San Francisco Bay.
- Miscellaneous projects to correct areas of the system that are currently inaccessible to CCTV equipment. The City is currently replacing approximately eight miles of pipelines that have structural defects (with NASSCO PACP structural defect grade 5) that are not severe enough to be considered an emergency condition, but render the pipeline inaccessible to CCTV inspection. This project will be completed by early 2012.

The total estimated combined cost of these priority rehabilitation and replacement projects as reported in the two technical memoranda that are included as Appendix F is $28.3 million.

Master Plan Appendices are available in a separate document.

APPENDIX A

Exceptions to the 50% Rule for Land Use Unit Flow Factor Assignments

Table A-1. Exception Descriptions

Area ID[(a)]	Exception Description
1	Number of parcels not within service area. Assumed that they do contribute waste water to the sewer system. Gave the parcels without houses a vacant designation.
2	Number of schools and churches near Sonoma St. and Garvin Ave. reassigned as Public and Institutional.
3	Pipe network reaches a little beyond the service area. This includes the other half of West Contra Costa Adult Ed, and residential parcels. Residential parcels were designated as Low Density Residential, consistent with the county data which shows 5-7 DU/acre.
4	Pipe network reaches beyond the service area, into San Pablo. According to the San Pablo General Plan, this area is medium density, 13-24 DU/acre.
5	Open space area encompassing three parcels reassigned to be Low Density Residential, according to aerial photography.
6	Pipe network goes outside the service area boundaries. Neighboring parcels are all Low Density Residential.
7	The Mixed Residential area was reassigned as Medium Density Residential because the area has an average DU/acre that falls into the Medium Density Residential range.
8	Much of the region assigned to City Center was reassigned according to aerial photography. Mostly Low Density Residential.
9	Row of parcels neighboring John F. Kennedy Park was designated as Low Density Residential.
10	Few parcels east of highway not given land use designations because no neighboring sewer mains.
11	All circular developments in this region not included. Most developments primarily outside service area boundary and likely all served by same agency.
12	Another area where pipe network goes outside the service area boundaries. All are High Density Residential.
13	Land use designations manually removed from few parcels because no neighboring sewer mains.
14	Land use designations manually removed from few parcels because no neighboring sewer mains.
15	Land use designations manually removed from few parcels because no neighboring sewer mains.
16	Few parcels reassigned to be vacant according to aerial photography.
General	All parcels in areas with a Mixed Uses land use designation were assigned land uses according to aerial photography.
General	For occupied parcels with large fields, parking lots, open space, or non-wastewater generating areas, the parcel was designated as non-wastewater generating, and only the occupied areas of the parcel were isolated and designated as wastewater generating.

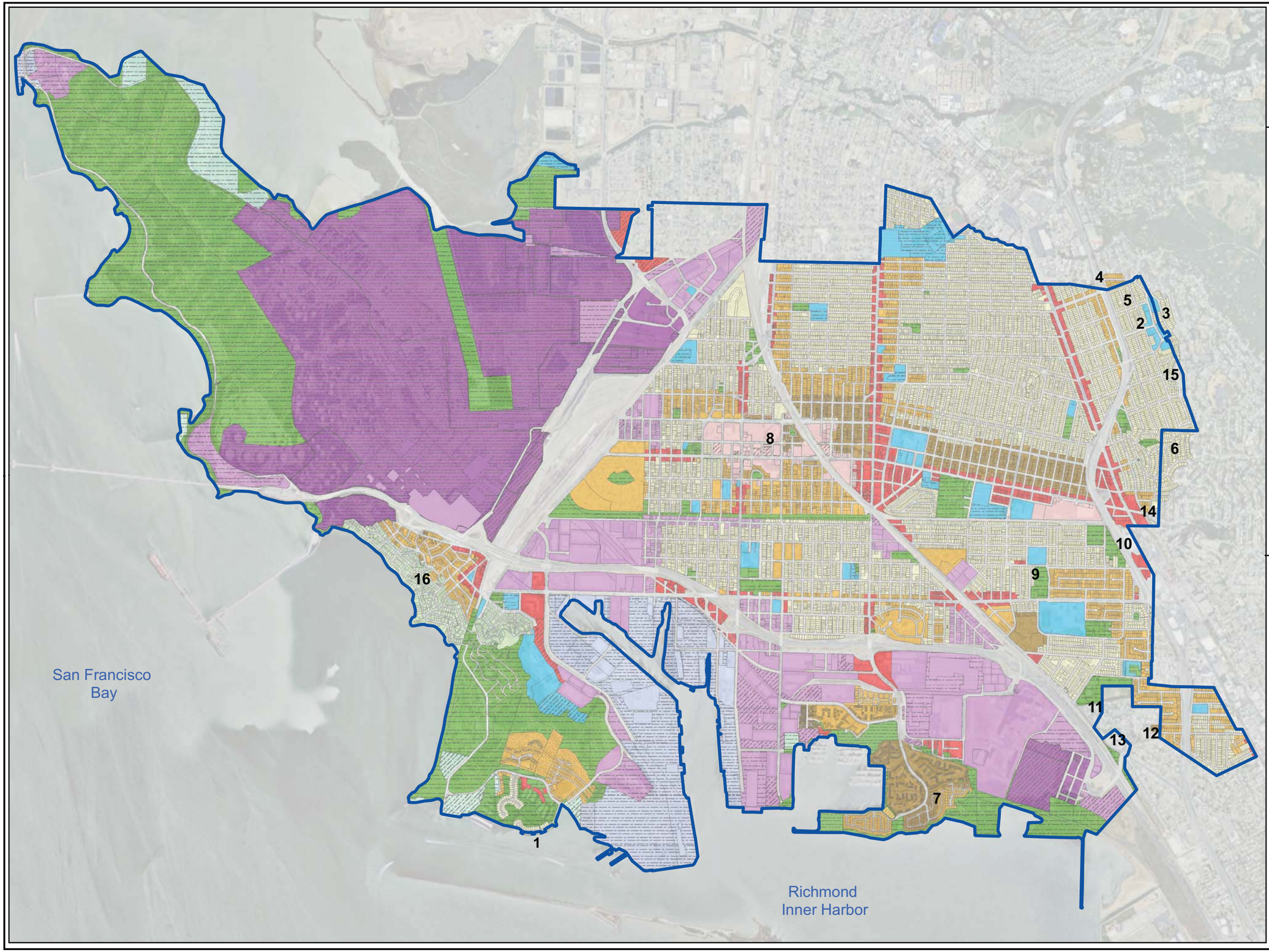
(a) Areas can be located on Figure A-1 according to their corresponding ID.

O:\Clients\356 Veolia Water\02-10-05 Hydraulic Model Update & 2010 Capacity Analysis\GIS\Figure A-1.mxd 3/18/2011

FIGURE A-1

City of Richmond
Sewer Collection System
Master Plan

EXCEPTION LOCATIONS



N

0 0.5 1

Miles

Notes
1. Numbers represent areas of exception. Descriptions of each area can be found on Table A-1.
2. See Figure 2-1 for location of area that pumps to Stege Sanitary District but is maintained by the City.

LEGEND

- Very Low Density Residential
- Low Density Residential
- Medium Density Residential
- High Density Residential
- Neighborhood Retail / General Commercial
- Regional Office / Shopping / City Center
- Industrial / Office Flex / Light Industry
- Heavy Industry
- Port / Marine Terminal / Ship Repair
- Public and Institutional
- Water Related Commerce and Commercial Recreation
- Open Space
- Service Area
- Non-WW Generating
- Vacant

VEOLIA WATER

WEST YOST ASSOCIATES
Consulting Engineers

APPENDIX B

V&A Flow Monitoring Reports

FLOW MONITORING AND INFLOW / INFILTRATION STUDY

Veolia City of Richmond

December 2010

V&A

FLOW MONITORING AND INFLOW / INFILTRATION STUDY

Veolia City of Richmond

Prepared for

Prepared by

December 2010

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
INTRODUCTION 9
Site Notes 11
METHODS AND PROCEDURES 12
Confined Space Entry 12
Flow Meter Installation 13
RAINFALL RESULTS 14
Rain Gauge Triangulation 16
Storm Event Classification 18
FLOW MONITORING RESULTS SUMMARY 21
Average Dry Weather Flows 21
Inflow / Infiltration: Methods 23
Graphical Identification of I&I Components 25
Analysis Techniques 25
Inflow Analysis 28
RDI (Rain Dependent Infiltration) Analysis 32
GWI (Groundwater Infiltration) Analysis 36
Combined I&I Results Summary 41
Pipeline Capacity Analysis 45
RECOMMENDATIONS 48

TABLES

Table 1. Flow Monitoring and I&I Results Summary 1
Table 2. List of Flow Monitoring and Rainfall Monitoring Sites 9
Table 3. Rainfall Events used for I&I Analyis 14
Table 4. IDW Method (Sample) 17
Table 5. Rain Gauge Distribution by Basin 17
Table 6. Peak Measured Rainfall Densities per Hourly Period 20
Table 7. Dry Weather Flow Summary 21
Table 8. Inflow Analysis Summary 28
Table 9. RDI Analysis Summary 32
Table 10. Excess Groundwater Infiltration Rates above Typical Rate 38
Table 11. Combined I&I Analysis Summary 41
Table 12. Capacity Analysis Summary 45

FIGURES

Figure 1. Average Dry Weather Flow (Flow Schematic) 3
Figure 2. Peak Measured Flow (Flow Schematic) 3
Figure 3. General Overview Map 4
Figure 4. Inflow Temperature Map: Overall Rankings 5
Figure 5. RDI Temperature Map: Overall Rankings 6
Figure 6. GWI Temperature Map: Overall Rankings 7
Figure 7. Combined I&I Temperature Map: Overall Rankings 8
Figure 8. Flow Sites, Basins and Rain Gauge Locations 10
Figure 9. Flow Monitoring Sites Flow Schematic 10
Figure 10. Typical Flow Meter Installation 13
Figure 11. Rainfall Activity over Flow Monitoring Period (RG1 Data shown) 14
Figure 12. Rainfall Accumulation Plots 15
Figure 13. Rainfall Inverse Distance Weighting Method 16
Figure 14. NOAA Northern California Rainfall Frequency Map 18
Figure 15. Rain Event Frequency Plots 19
Figure 16. Storm Event Classifications 20
Figure 17. Average Dry Weather Flow (Flow Schematic) 22
Figure 18. Typical Sources of Infiltration and Inflow 24
Figure 19. Inflow / Infiltration Graphical Response Patterns 25
Figure 20. I&I Flow Graph for Site 2, Event 6 27
Figure 21. Inflow Indicators by Site 29
Figure 22. Inflow Temperature Map: Peak I&I per Acre 30
Figure 23. Inflow Temperature Map: Peak I&I per ADWF 31
Figure 24. RDI Indicators by Site 33
Figure 25. RDI Temperature Map: Infiltration per Acre 34
Figure 26. RDI Temperature Map: Infiltration per ADWF 35
Figure 27. Groundwater Infiltration Sample Figure 36
Figure 28. Minimum Flow Ratios vs. ADWF 37
Figure 29. GWI Temperature Map: Infiltration per Acre 39
Figure 30. GWI Temperature Map: Infiltration per ADWF 40
Figure 31. Combined I&I Indicator by Site 42
Figure 32. Combined I&I Temperature Map: R-Value (per Acre) 43
Figure 33. Combined I&I Temperature Map: Total I&I per ADWF 44
Figure 34. Peak Measured Flow (Flow Schematic) 46
Figure 35. d/D Ratios (Flow Schematic) 46
Figure 36. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site 47

APPENDIX

Appendix A: Flow Monitoring Sites: Data, Graphs, Information

EXECUTIVE SUMMARY

Flow Monitoring Results

V&A has completed sanitary sewer flow monitoring, rainfall monitoring and inflow/infiltration (I&I) analysis within the City of Richmond, California (City). Flow and rainfall monitoring occurred over a 4-month period from February 3, 2010 to June 4, 2010 at 12 open channel flow monitoring sites. One of the sites, Site 10, was moved on March 18, 2010; data after March 18 is shown as Site 10A. Table 1 summarizes the flow monitoring and inflow/infiltration results for the flow monitoring sites.

Table 1.
Flow Monitoring and I&I Results Summary

Site[A]	ADWF (mgd)	Peak Flow (mgd)	Total Infiltration and Inflow (gallons)[B]	Overall Inflow Ranking	Overall Infiltration Ranking		Overall Combined I&I Ranking	Peaking Factor	d/D Ratio
					RDI	GWI			
Site 1	1.13	5.88	59,592,000	9	1	8	2	5.22	2.52
Site 2	0.54	4.62	16,064,000	6	11	9	8	8.59	0.84
Site 3	4.70	23.81	209,186,000	10	2	3	3	5.07	2.55
Site 4	0.12	1.23	7,868,000	8	6	4	6	10.39	5.08
Site 5A	0.037	1.06	2,130,000	1	3	2	1	29.02	3.82
Site 5B	1.97	17.70	77,884,000	4	7	10	4	8.99	2.87
Site 6	1.85	7.70	34,273,000	11	9	5	11	4.17	3.74
Site 7	0.68	5.19	19,031,000	5	10	7	7	7.64	0.60
Site 8	0.46	5.66	20,923,000	2	4	11	5	12.18	1.31
Site 9	0.41	5.55	16,854,000	3	8	6	9	13.50	4.45
Site 10/10A	1.69/ 1.46	11.01	38,154,000	7	5	1	10	6.53	2.61

[A] Site 11 monitored flow on the main interceptor line on Canal Boulevard; therefore, was excluded from this analysis.

[B] Over monitoring period: 2/3/2010 – 6/4/2010.

The following results from this project are noted:

- **Inflow:** The northeast quadrant of the City appears to have the highest inflow quantities.
- **Rain Dependent Infiltration (RDI):** The western region of the City appears to have the highest RDI rates.
- **Groundwater Infiltration (GWI):** The southeast quadrant of the City appears to have the highest GWI rates.
- **Combined I&I:** The west and central regions of the City contribute the most totalized inflow and infiltration over the course of a full wet weather season.

- **Peaking Factor:** All locations exceeded typical design threshold limits for peak flow to average dry weather flow ratio. Site 5A had the largest peaking factor.
- **d/D Ratio:** All of the site locations except for Sites 2 and 7 reached a surcharged pipe condition.

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. The highest inflow occurs within Basins 2, 5, 7, 8 and 9.
    b. If total 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. The highest groundwater infiltration (including tidal infiltration) is occurring in Basin 10. The highest rain dependent infiltration is occurring in Basins 1 and 3.
2. **I&I Investigation Methods:** Potential I&I investigation methods include the following:
    a. smoke testing
    b. mini-basin flow monitoring
    c. night-time reconnaissance work to (1) investigate and determine direct point sources of inflow, and (2) determine the areas and/or pipe reaches responsible for high levels of infiltration contribution.
    d. CCTV inspection
3. **I&I Reduction Cost Effective Analysis:** The City should conduct a study to determine which is more cost-effective: (1) locating the sources of inflow/infiltration and systematically rehabilitating or replacing the faulty pipelines; or (2) continued treatment of the additional rainfall dependent I&I flow.

Figure 1 and Figure 2 show flow schematics demonstrating the pipe conditions during average dry weather flow and peak measured flow conditions, respectively. Figure 3 through Figure 7 show temperature maps summarizing the results of this project.

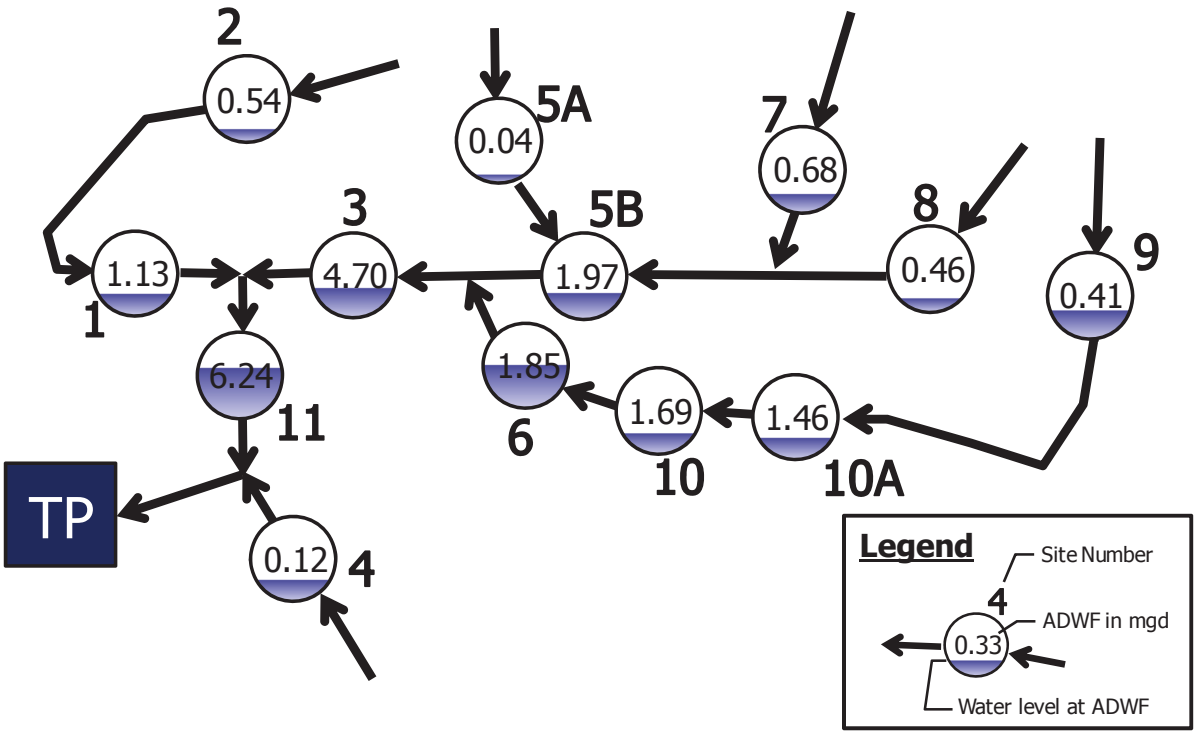


Figure 1. Average Dry Weather Flow (Flow Schematic)

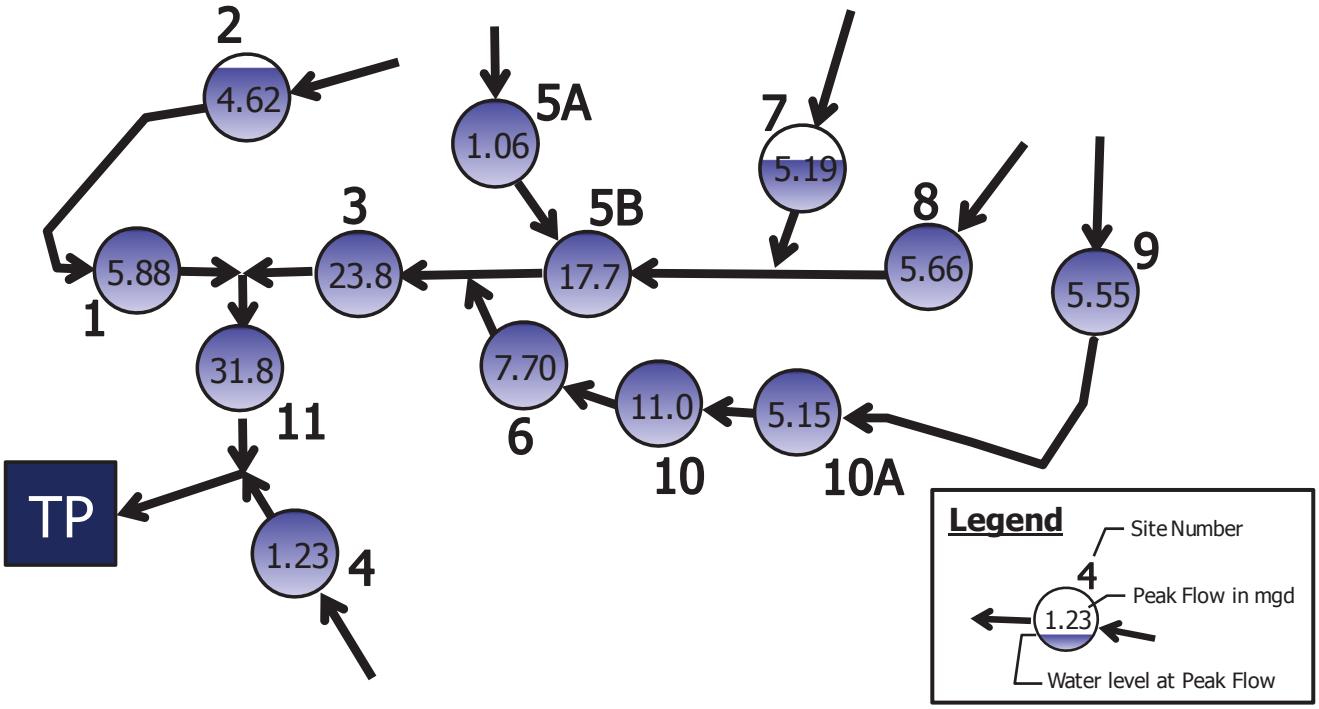


Figure 2. Peak Measured Flow (Flow Schematic)

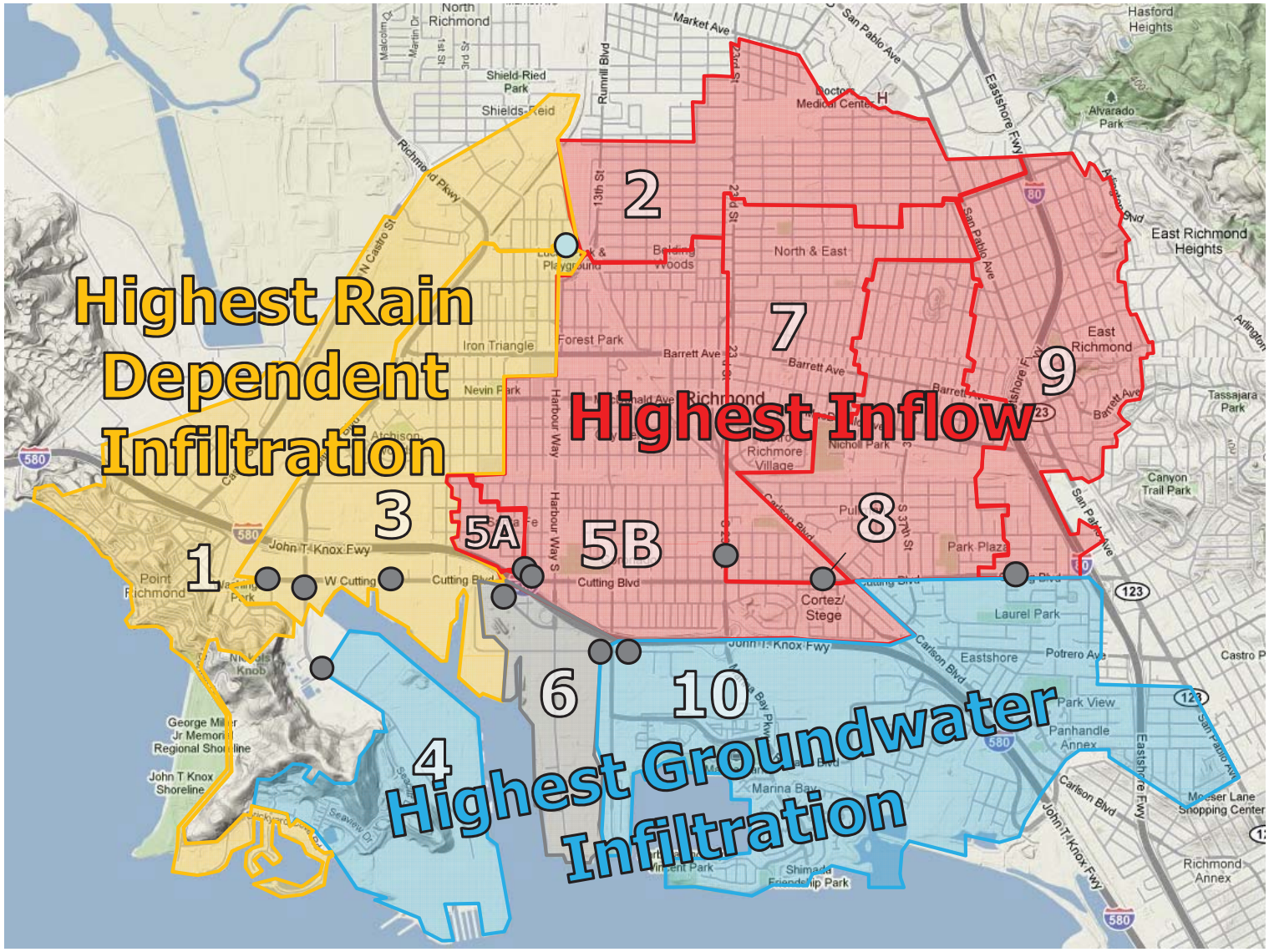


Figure 3. General Overview Map

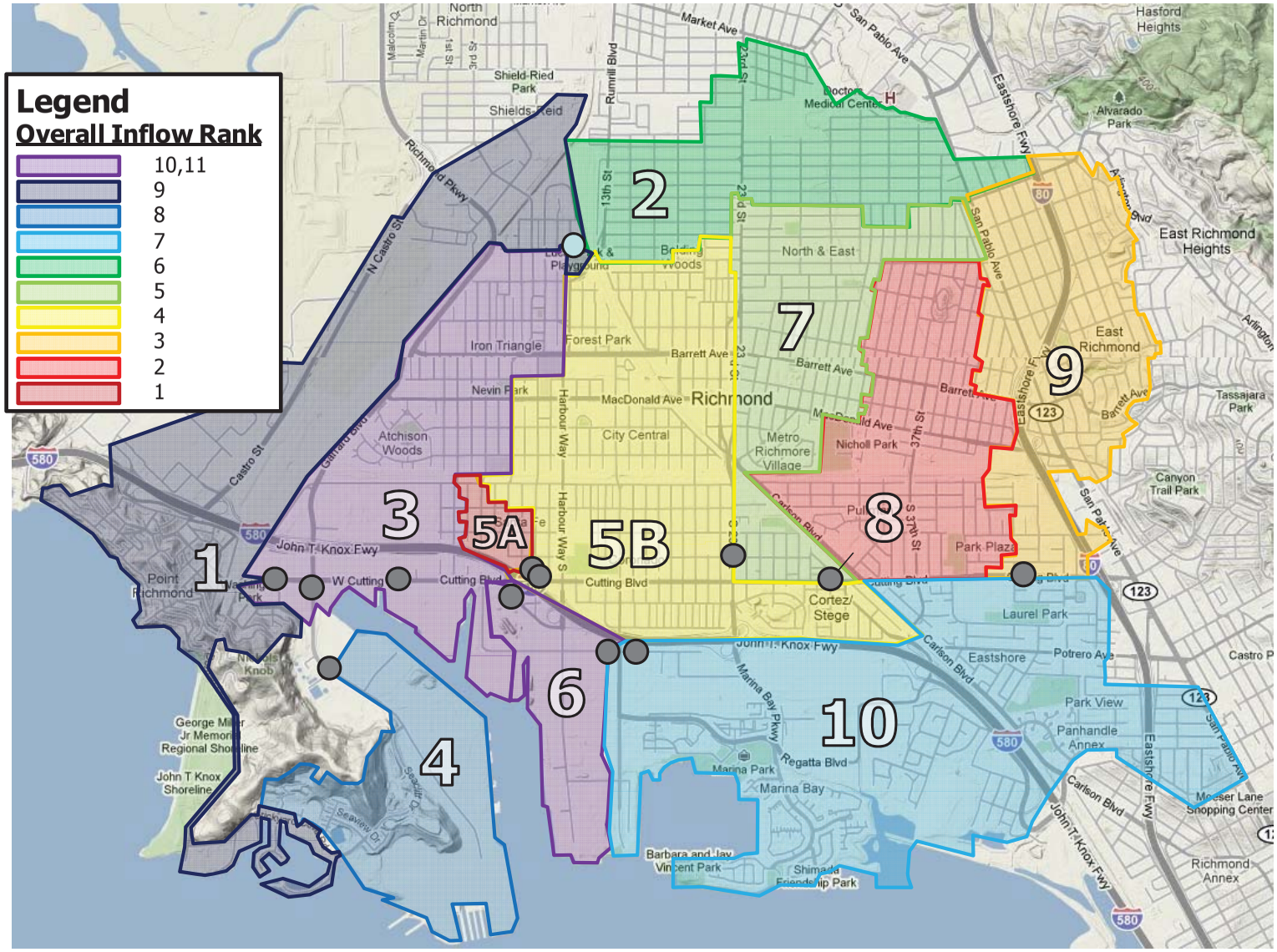


Figure 4. Inflow Temperature Map: Overall Rankings

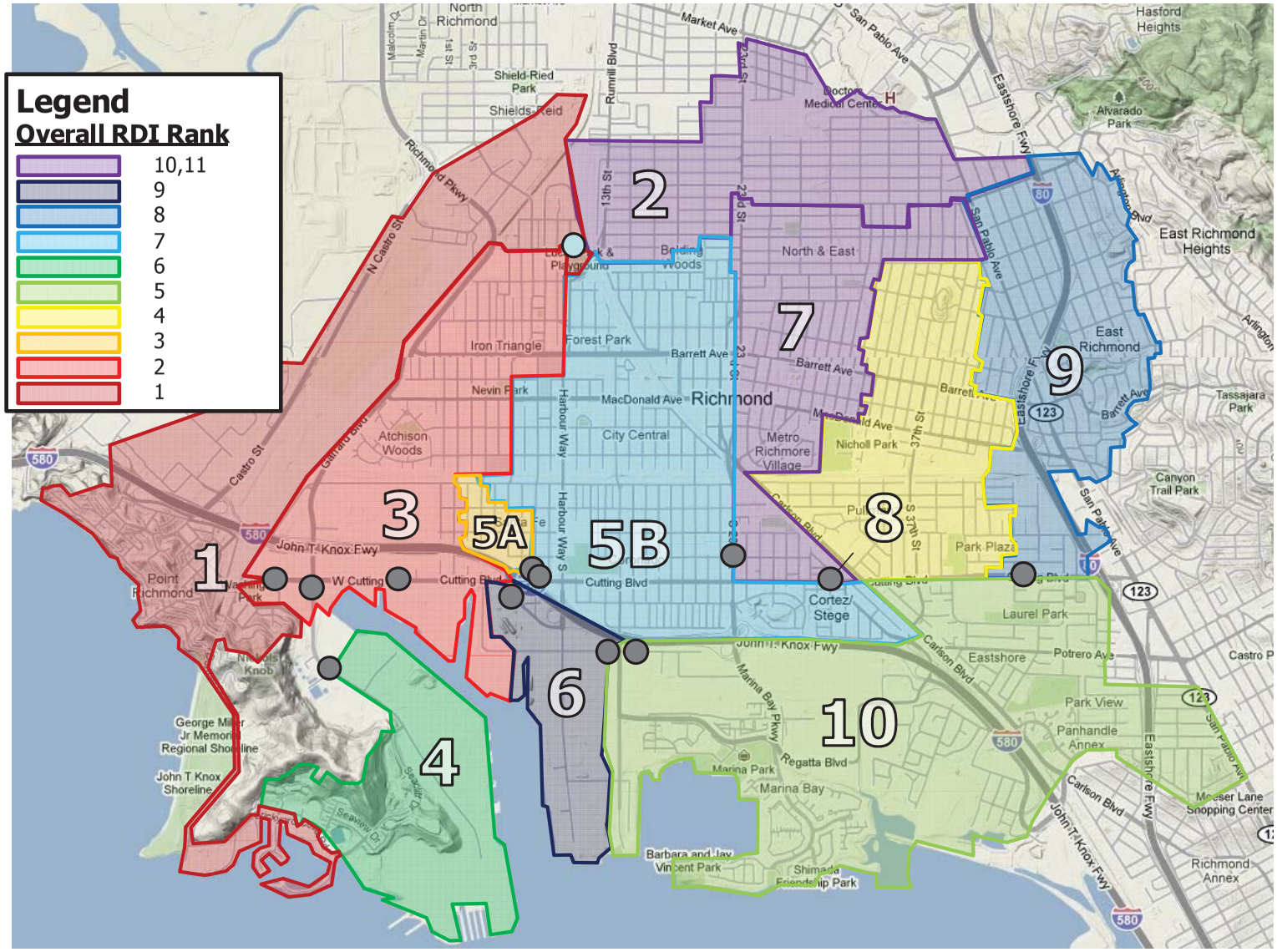


Figure 5. RDI Temperature Map: Overall Rankings

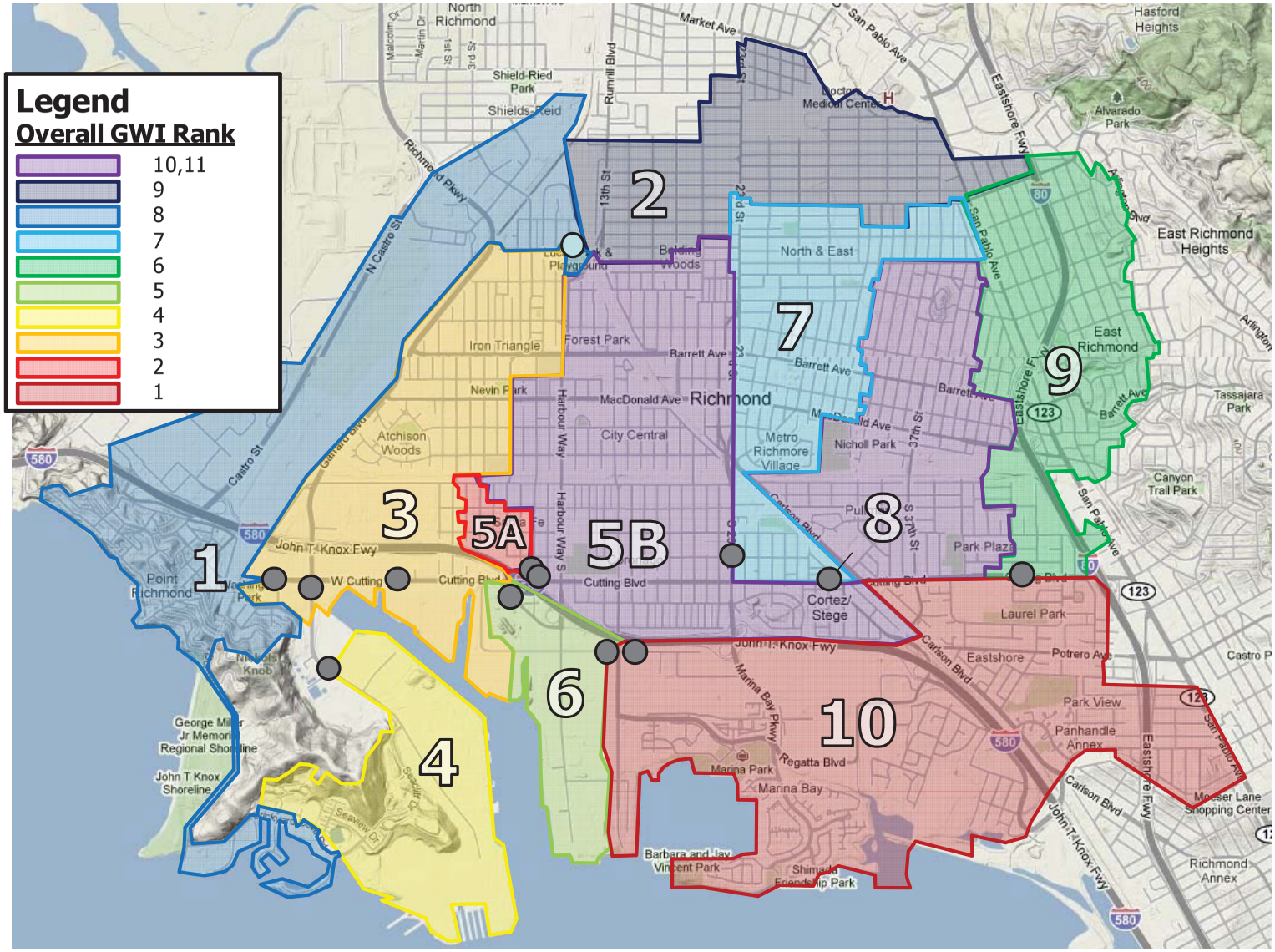


Figure 6. GWI Temperature Map: Overall Rankings

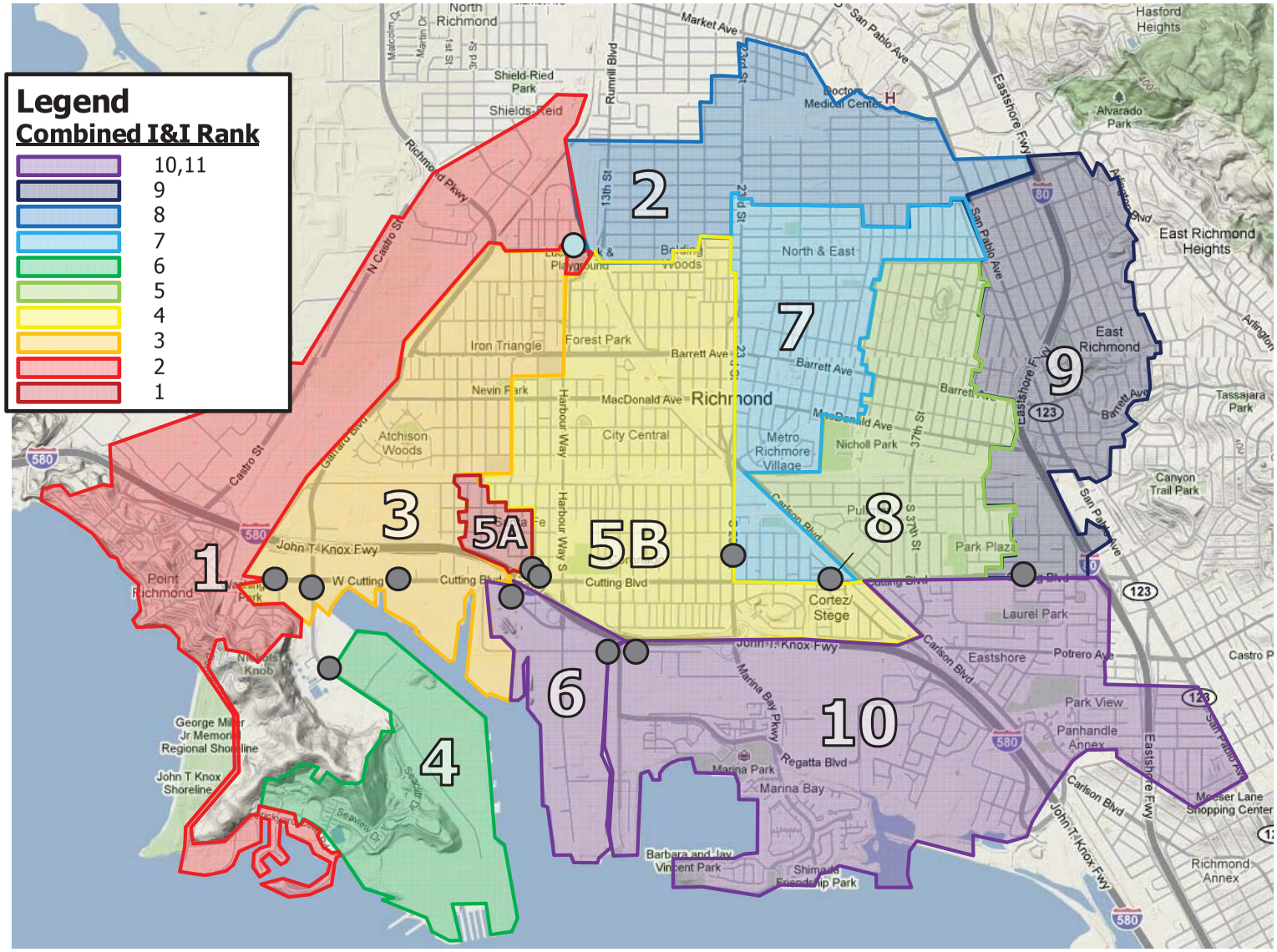


Figure 7. Combined I&I Temperature Map: Overall Rankings

INTRODUCTION

V&A has completed sanitary sewer flow monitoring, rainfall monitoring and inflow/infiltration (I&I) analysis within the City of Richmond sanitary sewer collection system. Flow monitoring occurred over the 4-month period from February 3, 2010 to June 4, 2010 at 12 open channel flow monitoring sites. One of the sites, Site 10, was moved on March 18, 2010; data after March 18 is shown as Site 10A. Rainfall data was used from two locations within the City. The flow monitoring sites with associated drainage basins and rain gauge sites are listed in Table 2 and illustrated in Figure 8. Figure 9 shows the flow schematic for the flow monitoring sites. Detailed descriptions of the individual flow monitoring sites, including photographs, are included in *Appendix A*.

Table 2.
List of Flow Monitoring and Rainfall Monitoring Sites

Monitoring Site	Diameter (in)	Acres Upstream from Site	Location
Site 1	54”	1,326	Cutting Boulevard and Wine Street
Site 2	21”	487	Lucas Avenue @ 10th Street
Site 3	54”	4,418	Cutting Boulevard west of Chesson Street
Site 4	18”	381	Canal Boulevard, across from City of Richmond Treatment Plant
Site 5A	18”	47	S. 8th Street South of Virginia Avenue
Site 5B	48”	1,790	S. 8th Street South of Virginia Avenue
Site 6	36”	1,942	Hoffman Boulevard @ South 7th Street
Site 7	21”	460	Virginia Avenue and South 23rd Street
Site 8	24”	489	On median of Cutting Boulevard @ S. 30th Street
Site 9	21”	533	Cutting Circle, west of S. 49th Street
Site 10	36”	1,202	Wright Avenue and Marina Way
Site 10A	36”	1,084	Wright Avenue, east of Marina Way
Site 11	66”	5,744	Cutting Boulevard and Canal Boulevard
RG 1	City of Richmond Treatment Facility		
RG 2	Poinsett Avenue, east of Jordan Avenue		

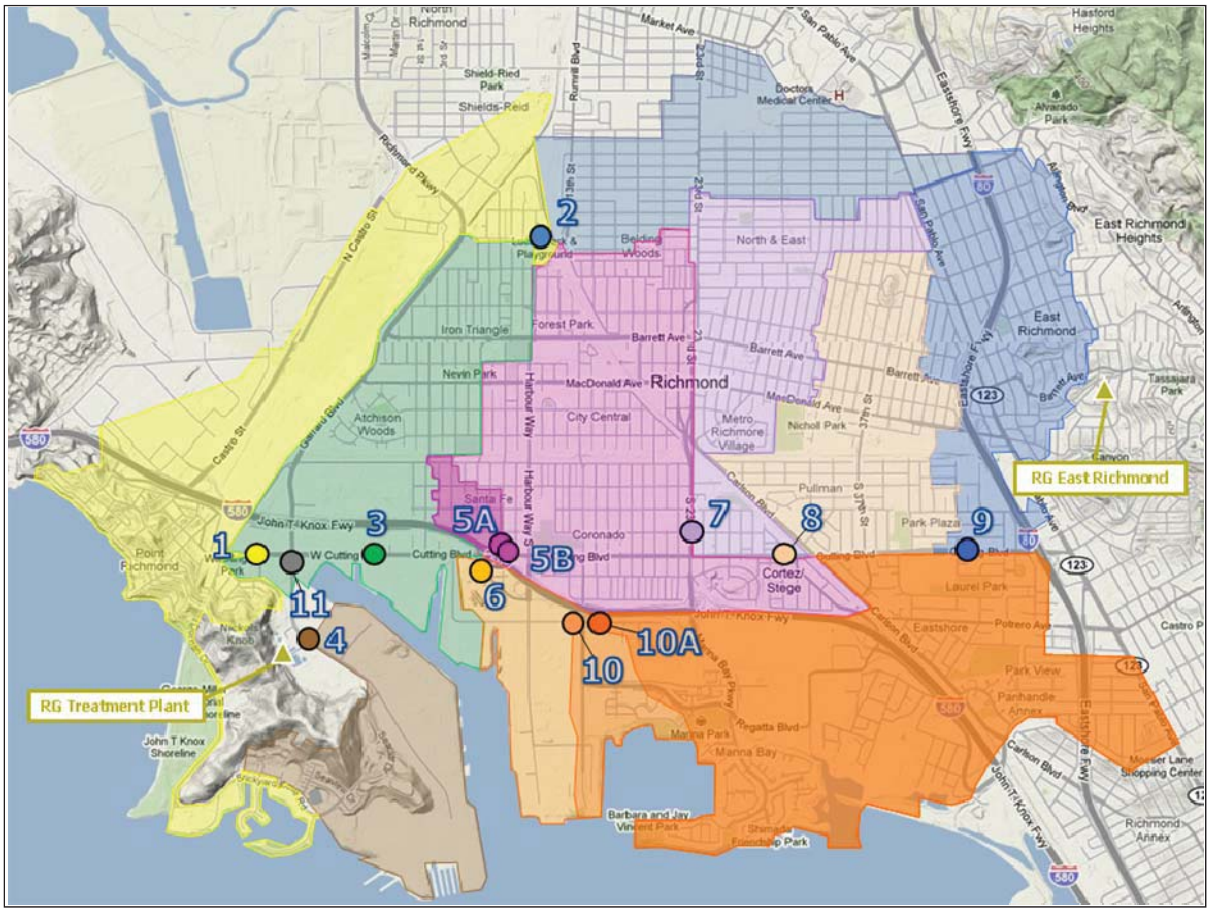


Figure 8. Flow Sites, Basins and Rain Gauge Locations

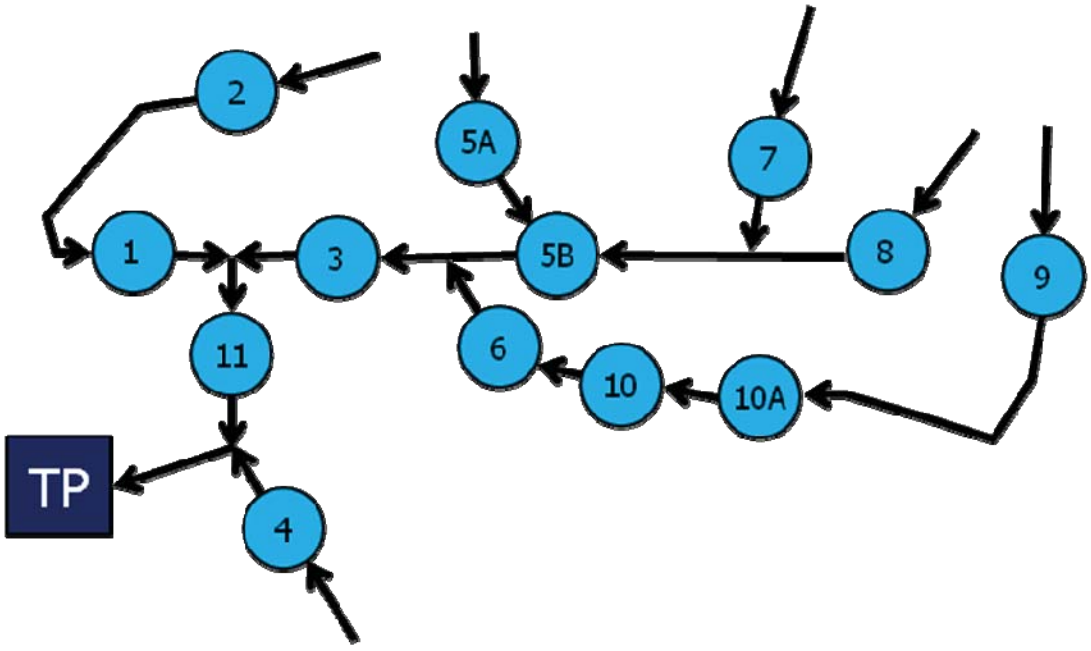


Figure 9. Flow Monitoring Sites Flow Schematic

Site Notes

Site 4: The basin upstream from Site 4 has the *lowest density* compared to the other basins that were monitored. There is a large service area in terms of acreage, but the actual contributing flows from this basin are relatively small. Our ranking system for normalizing infiltration and inflow results uses two methods: (1) normalize by acreage, and (2) normalize by average dry weather flow. For Site 4 (more than any other site), the overall ranking would vary considerably depending on the type of normalization method used. The master plan consultant may wish to determine which method of normalization is more appropriate for this project, specifically when considering the I&I analysis results presented for Site 4.

Sites 10 and 10A: Site 10 was moved upstream three manholes (named Site 10A) to try to capture and differentiate tidal infiltration within this basin. For the purposes of I&I analysis later in this study, Sites 10 and 10A will be grouped together.

Site 11: The intent of Site 11 was to monitor flow on the main interceptor line on Canal Boulevard, feeding the influent wet well. This would serve a means to capture nearly all flow entering the treatment facility. The intended manhole in a field west of Canal Boulevard could not be found. Site 11 was placed instead on the downstream side of a large "Tee" junction box where the two large trunk lines on Cutting Boulevard intersect. This was not an ideal location for a flow meter (turbulent intersecting flows), but it was the only location available at the time of installation. The flow data appears to be generally solid, but the level of confidence in this data is less than with other sites. Additionally, it is noted that there is no basin associated with Site 11. The data for Site 11 is included in the baseline flow presentation and also shown in Appendix A; however, it is not included in the I&I analysis section of this report for the aforementioned reasons.

METHODS AND PROCEDURES

Confined Space Entry

A confined space (Photo 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. Title 8, Section 5158 of the California Code of Regulations provides the guidelines and rules for working in these environments. In general, the atmosphere must be constantly monitored for sufficient levels of oxygen (19.5 to 23.0%), and the absence of Hydrogen Sulfide (H_2S) gas, Carbon Monoxide (CO) gas and 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/she is equipped with the necessary personal protective equipment needed to perform the job safely, including a personal 4-gas monitor (Photo 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 entrant(s) to monitor the atmosphere on another 4-gas monitor and maintaining records of all Entrants, if there is more than one. The Supervisor develops the safe work plan for the job at hand prior to entering.

Photo 1. Confined Space Entry

Photo 2. Typical Personal 4-Gas Monitor

Flow Meter Installation

Five Isco 2150 and seven Sigma 910 flow meters were installed by V&A in the sewer lines shown in Figure 8. Isco and Sigma meters use a pressure transducer to collect depth readings and ultrasonic Doppler sensors on the probe to determine the average fluid velocity. Figure 10 shows a sketch of a typical flow meter installation.

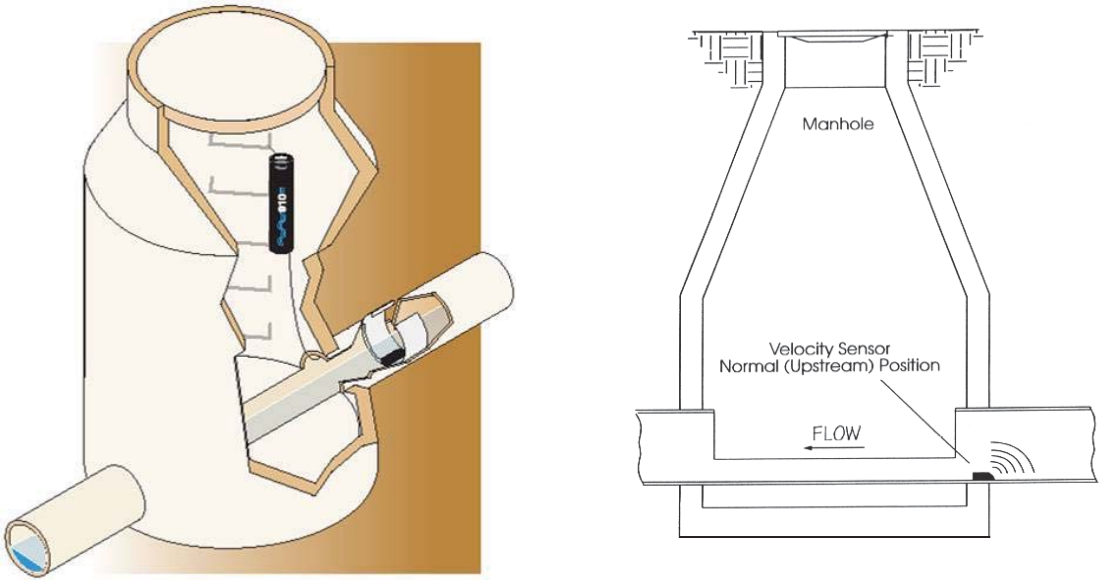


Figure 10. Typical Flow Meter Installation

Continuous depth and velocity readings were recorded by the flow meters in 5-minute increments and downloaded into a computer spreadsheet program where the data could be analyzed and made report ready. Manual level and velocity readings were taken in the field during the flow meter installation and again when the flow meters were removed. These readings were compared to the readings of the flow meters to ensure proper calibration and accuracy.

RAINFALL RESULTS

For the purposes of infiltration and inflow analysis, the rainfall over the flow monitoring period was distinguished into six rainfall events, summarized in Table 3. Figure 11 graphically displays the rainfall events recorded over the flow monitoring period (RG1 data illustrated). Figure 12 shows the rain accumulation plot of the rain gauges, as well as the historical average rainfall[1] in the City during this project duration. Rainfall totals for Rain Gauges 1 and 2 were at approximately 94% and 143%, respectively, of historical normal levels (as measured from central Richmond) during this time period[2].

Table 3.
Rainfall Events used for I&I Analyis

Rainfall Event	RG1 (in)	RG2 (in)	Dates of Event
Event 1	1.14	1.66	2/21/2010 – 2/24/2010
Event 2	0.70	1.17	2/26/2010 – 3/1/2010
Event 3	1.19	1.18	3/2/2010 – 3/4/2010
Event 4	0.58	0.91	3/12/2010 – 3/14/2010
Event 5	0.93	1.44	4/4/2010 – 4/8/2010
Event 6	1.52	2.32	4/11/2010 – 4/13/2010
Total over Period	10.19	15.20	2/3/2010 – 6/4/2010

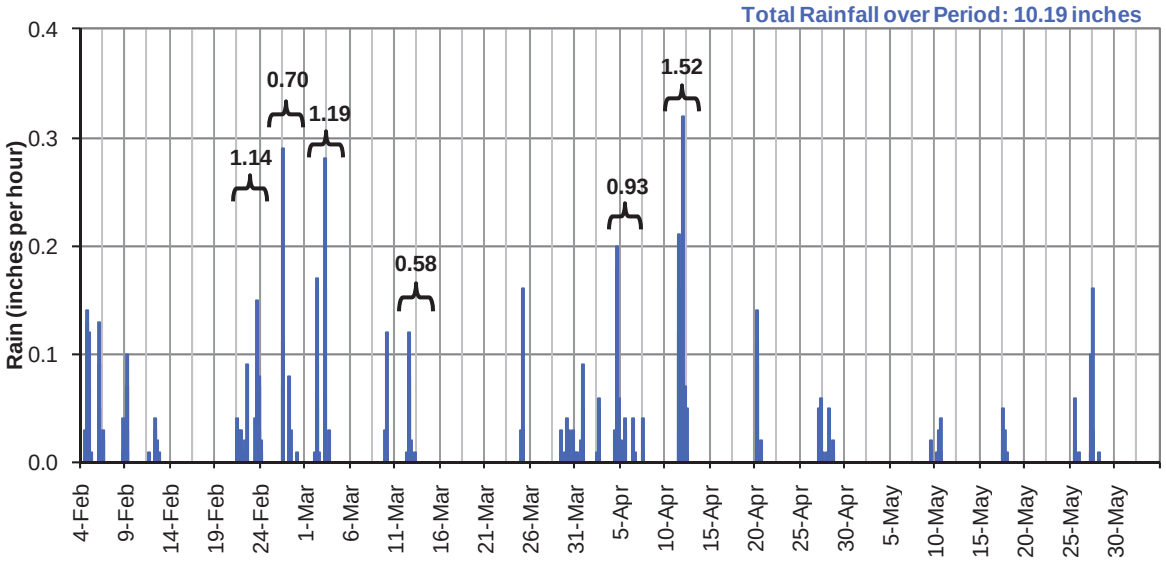


Figure 11. Rainfall Activity over Flow Monitoring Period (RG1 Data shown)

[1] Historical data taken from the WRCC: http://www.wrcc.dri.edu/summary/climsmnca.html

[2] The historical data gauge is located approximately 1.64 miles due northeast of RG1, and 1.75 due west of RG2. RG2 is located in the Richmond Hills; it is typical that this topography would have higher rainfall totals than closer to the Bay.

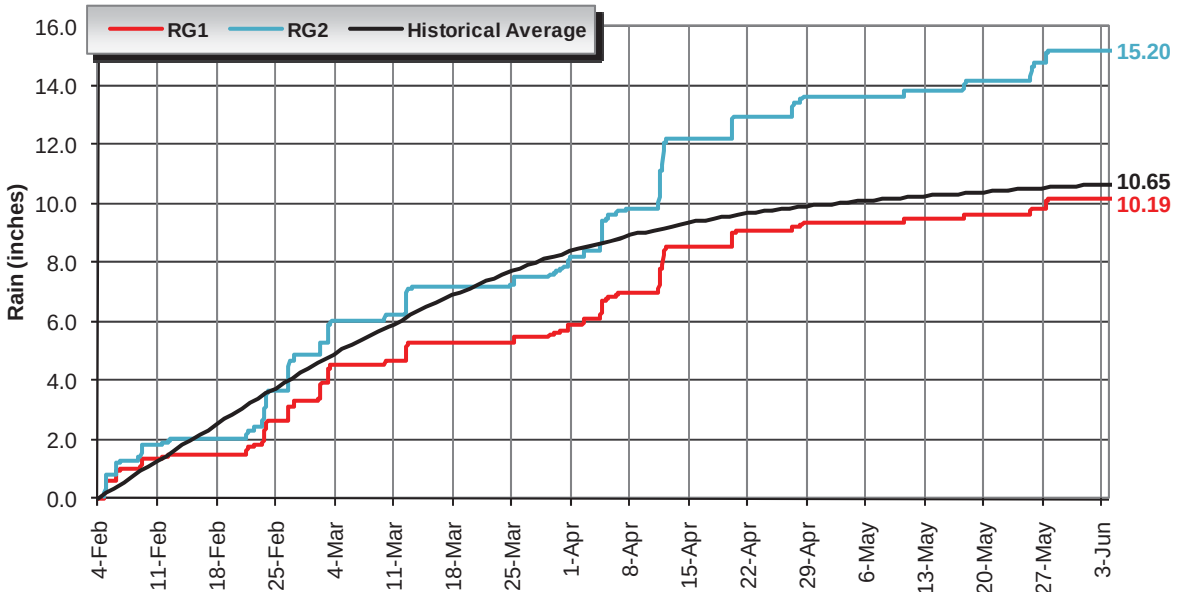


Figure 12. Rainfall Accumulation Plots

Rain Gauge Triangulation

The rainfall affecting the sanitary sewer collection system basins must be calculated based on the proximity to the rain gauge locations. The mean precipitation for the sanitary sewer collection system was calculated by taking data from seven local rain gauges and using the Inverse Distance Weighting (IDW) method. The IDW is an interpolation method that assumes the influence of each rain gauge location diminishes with distance. The center of a sanitary sewer collection system was identified and a weighted average was taken of the precipitation data from nearby rain gauge locations. The IDW function is as follows:

$$weight(d) = \frac{1/d^{p}}{\sum 1/d^{p}}, \quad \text{where:} \quad d = \text{distance} \quad p = \text{power } (p > 0)$$

The value of p is user defined. The most common choice for hydrological studies of watershed areas is $p = 2$. Figure 13 and Table 4 illustrate the IDW method (sample data). The rain gauge distribution as calculated for each flow monitoring site is shown in Table 5.

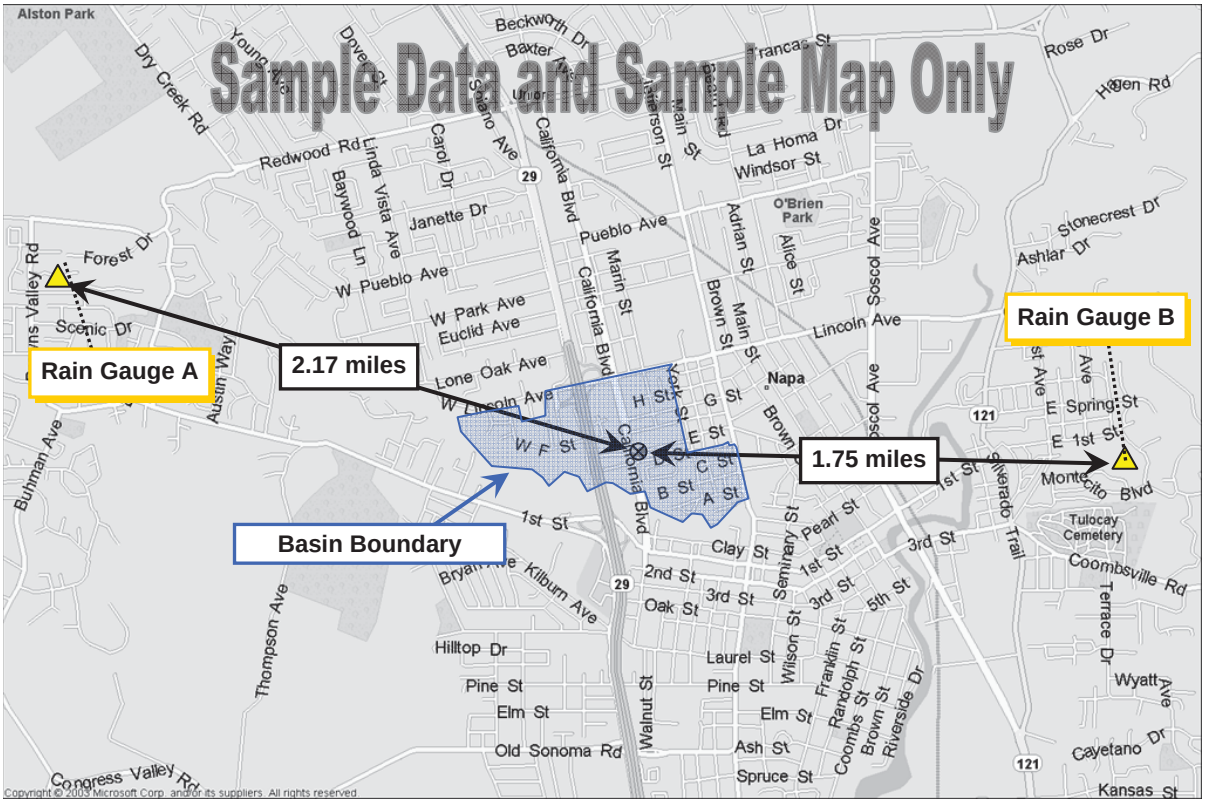


Figure 13. Rainfall Inverse Distance Weighting Method

Table 4.
IDW Method (Sample)

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%**

Table 5.
Rain Gauge Distribution by Basin

Monitoring Site	RG 1	RG 2
Site 1	70.1%	29.9%
Site 2	28.1%	71.9%
Site 3	41.5%	58.5%
Site 4	95.7%	4.3%
Site 5A	85.0%	15.0%
Site 5B	41.8%	58.2%
Site 6	35.0%	65.0%
Site 7	21.1%	78.9%
Site 8	12.1%	87.9%
Site 9	1.8%	98.2%
Site 10/10A	33.0%	67.0%
Site 11	61.3%	38.7%

Storm Event Classification

It is important to classify the relative size of the major storm event that occurs over the course of a flow monitoring period[3]. Storm events are classified by intensity and duration. Based on historical data, frequency contour maps for given intensity and duration storm events have been developed by the National Oceanic and Atmospheric Administration (NOAA) for all areas within the continental United States. For example, the NOAA Rainfall Frequency Atlas[4] classifies a 10-year, 24-hour storm event in Richmond as 3.5 inches (Figure 14). This means that in any given year, there is a 10% chance that 3.5 inches of rain will fall in any 24-hour period.

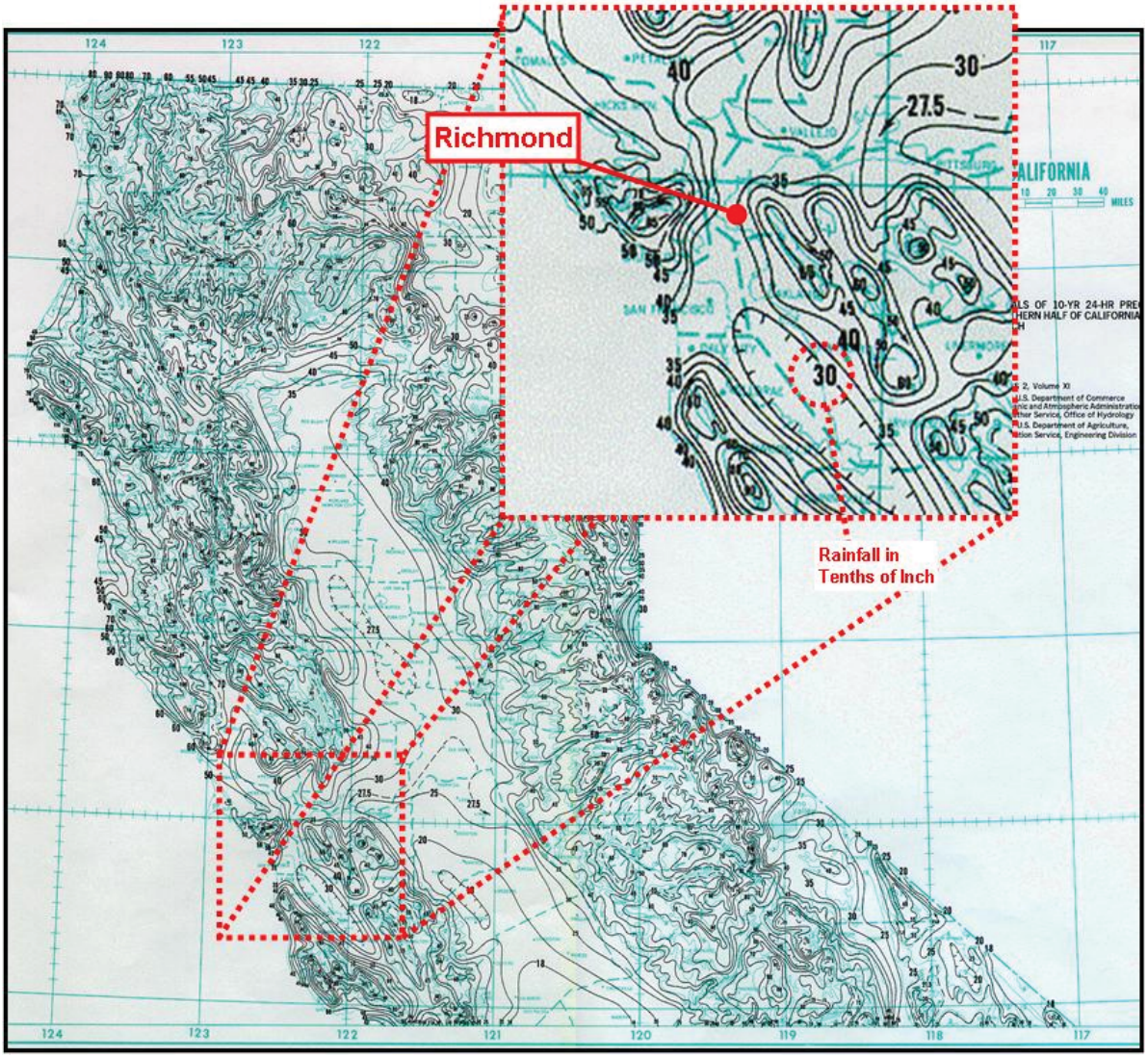


Figure 14. NOAA Northern California Rainfall Frequency Map

[3] Sanitary sewers are often designed to withstand I&I contribution to sanitary flows for specific sized "design" storm events.

[4] NOAA Western U.S. Precipitation Frequency Maps Atlas 2, 1973 <http://www.wrcc.dri.edu/pcpnfreq.html>.

From the NOAA frequency maps, the rainfall totals for 1-hour, 6-hour and 24-hour period durations, and 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year period intensities, were plotted to develop a rain event frequency map specific to each rainfall monitoring site, shown in Figure 15.

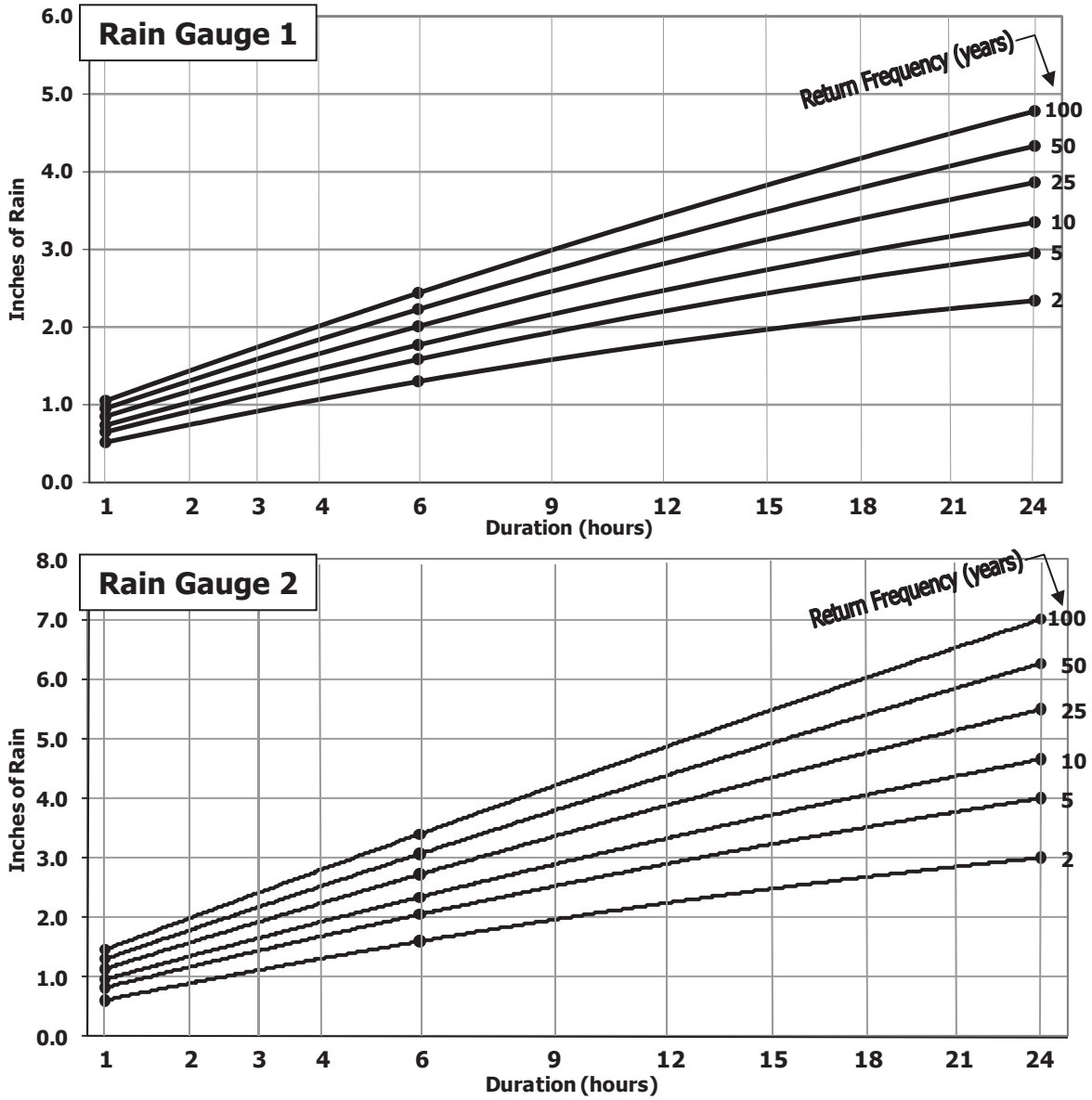


Figure 15. Rain Event Frequency Plots

Peak measured densities per hourly periods were calculated for each rain gauge location for the largest rainfall event of the season (Event 6), summarized in Table 6[5]. Superimposing the peak measured densities for the storm events on the Rainfall Storm Event Classification Chart determines the classification of each storm event, shown in Figure 16.

[5] For example, for RG1 the highest rainfall in a 1-hour period was 0.32 and in any 24-hour period was 1.52 inches.

Table 6.
Peak Measured Rainfall Densities per Hourly Period

Rainfall Duration	Rain Gauge 1 Peak Densities (inches)	Rain Gauge 2 Peak Densities (inches)
1 hr	0.32	0.49
3 hr	0.53	0.99
6 hr	0.79	1.22
12 hr	1.13	1.74
18 hr	1.43	2.19
24 hr	1.52	2.32

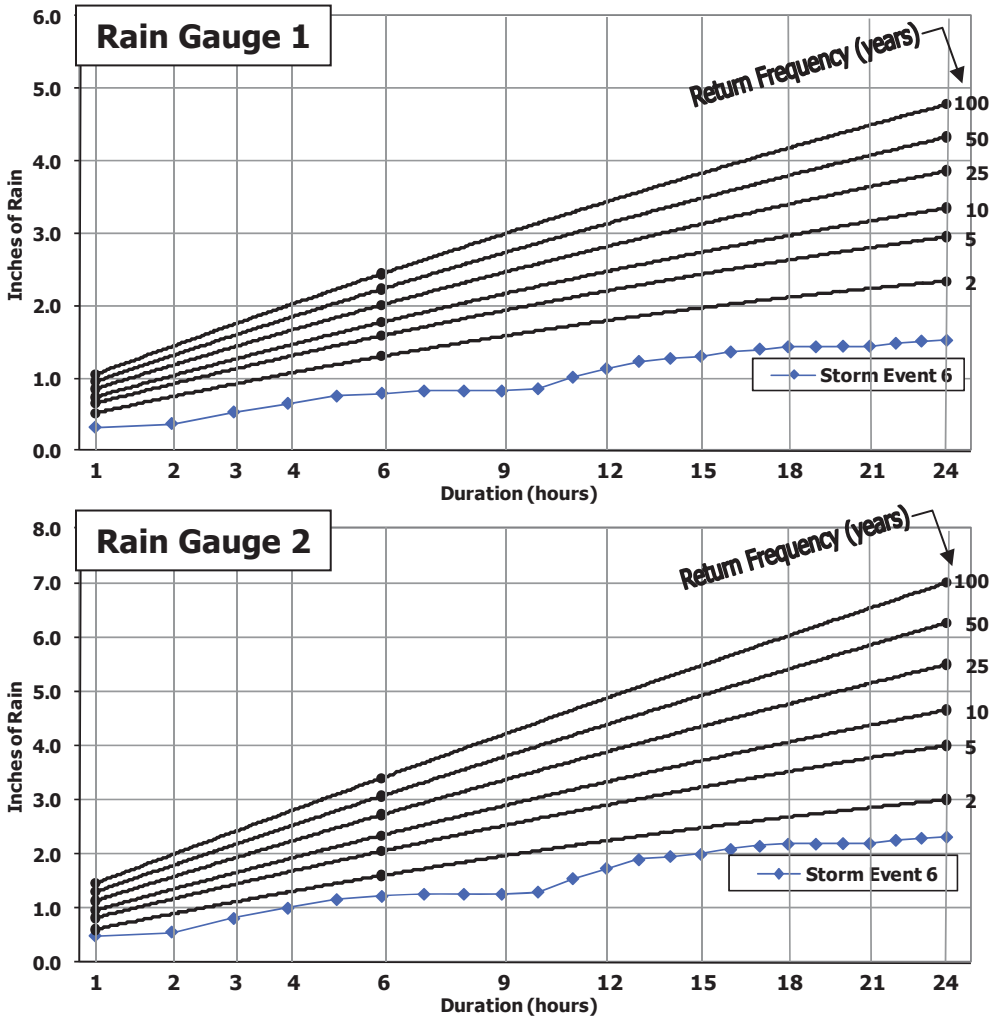


Figure 16. Storm Event Classifications

For both rain gauges, all the events during the flow monitoring period were classified as less than a 2-year events.

FLOW MONITORING RESULTS SUMMARY

Average Dry Weather Flows

Weekday and weekend flow patterns vary and must be separated when determining average dry weather flows. Days least affected by rainfall were used to estimate weekend and weekday average flows[6].

Table 7 lists the average dry weather flow (ADWF) recorded during this study for the flow monitoring sites. Figure 17 shows flow schematics demonstrating the pipe conditions during average dry weather flow. Detailed graphs of the flow monitoring data on a site-by-site basis are included in *Appendix A*.

Table 7.
Dry Weather Flow Summary

Monitoring Site	Weekday ADWF	Weekend ADWF	Overall ADWF	Weekend/ Weekday Ratio
Site 1	1.11	1.17	1.13	1.05
Site 2	0.53	0.56	0.54	1.05
Site 3	4.67	4.76	4.70	1.02
Site 4	0.12	0.12	0.12	1.01
Site 5A	0.036	0.038	0.037	1.05
Site 5B	1.96	1.99	1.97	1.02
Site 6	1.84	1.86	1.85	1.01
Site 7	0.68	0.69	0.68	1.02
Site 8	0.46	0.48	0.46	1.03
Site 9	0.40	0.43	0.41	1.06
Site 10	1.66	1.74	1.69	1.04
Site 10A	1.46	1.45	1.46	0.99
Site 11	6.18	6.40	6.24	1.03
System[7]	6.30	6.51	6.36	1.03

[6] Average days taken from the first two weeks in May, 2010.
[7] System taken as Site 4 + Site 11

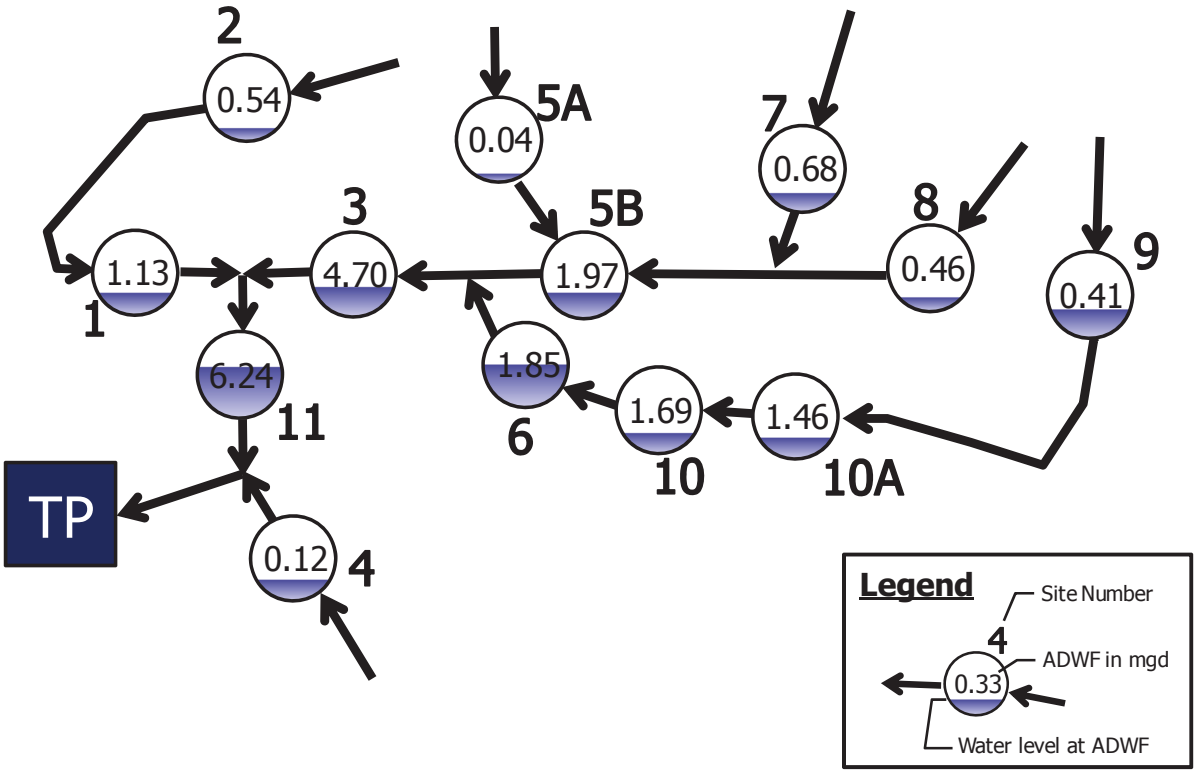


Figure 17. Average Dry Weather Flow (Flow Schematic)

Inflow / Infiltration: Methods

Inflow / Infiltration (I&I) consists of storm water and groundwater which enters the sewer system through pipe defects and improper storm drainage connections, defined as follows:

Inflow

- **Definition:** 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.
- **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.
- **Graphical Identification:** Inflow is usually recognized graphically by large magnitude, short duration spikes immediately following a rain event.

Infiltration

- **Definition:** Infiltration is defined as water entering the sanitary sewer system through defective pipes, pipe joints, and manhole walls, and may include cracks, offset joints, root intrusion points, and broken pipes.
- **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 and/or manholes, and may include cracks, offset joints, root intrusion points, and broken pipes. The sources may be wide-spread throughout a sanitary sewer system.
- **Graphical Identification:** 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.

Infiltration Components

Infiltration can be further subdivided into components as follows:

- **Groundwater Infiltration** – Groundwater infiltration depends on the depth of the groundwater table above the pipelines as well as the percentage of the system submerged. The variation on groundwater levels and subsequent groundwater infiltration rates are

seasonal by nature. On a day-to-day basis, groundwater infiltration rates are relatively steady and will not fluctuate greatly.

- **Rainfall Dependent Infiltration –** This component occurs as a result of storm water and enters the sewer system through pipe defects similar to 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 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. Note: this type of infiltration can have a quick response and graphically can look very similar to inflow.

Figure 18 illustrates the possible locations and components of I&I.

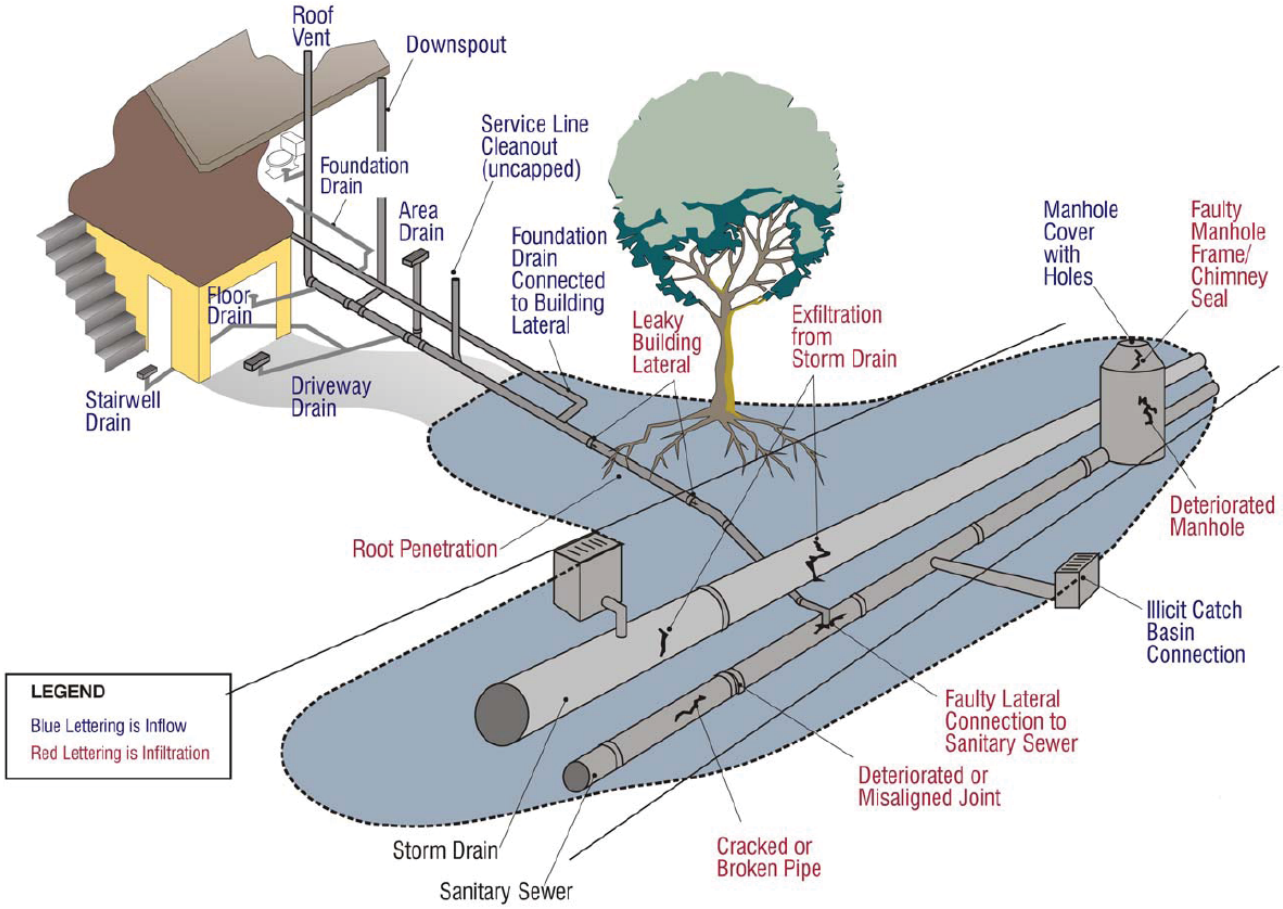


Figure 18. Typical Sources of Infiltration and Inflow

Graphical Identification of I&I Components

Figure 19 shows sample graphs indicating the typical graphical response patterns for inflow/infiltration.

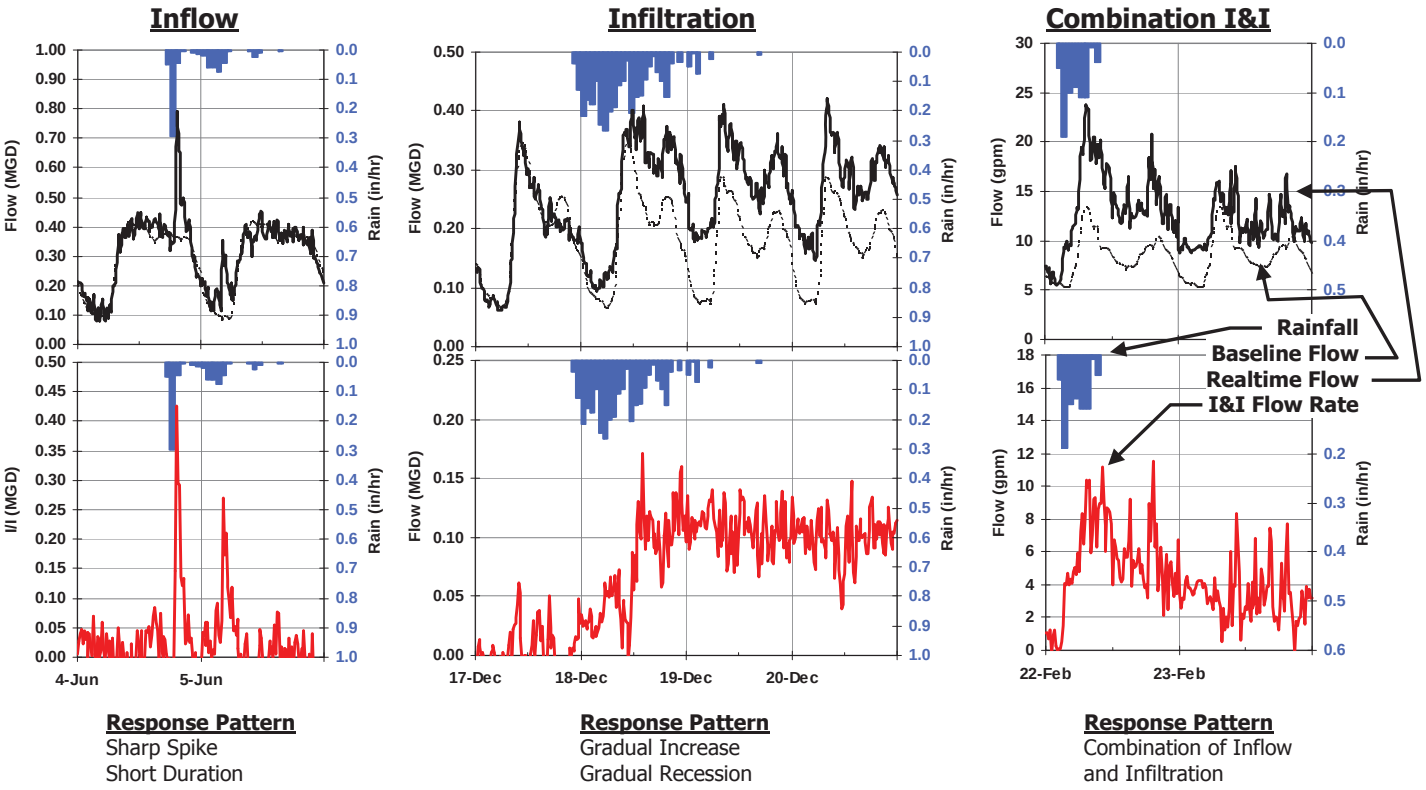


Figure 19. Inflow / Infiltration Graphical Response Patterns

Analysis Techniques

After differentiating I&I flows from baseline flows, various calculations can be made to determine which I&I component is more prevalent at a particular site, and to compare the relative magnitude of the I&I components between drainage basins and between storm events, summarized as follows:

Inflow Indicators

Peak I&I Flow Rate: It is preferable for I&I analysis to look strictly at I&I flow rates rather than peak flow rates; peak flow rates can be skewed higher or lower depending on whether the storm event I&I response occurs during low flow or high flow hours. After determining the peak I&I flow rate for a given site, and for a given storm event, there are three ways to *normalize* the peak I&I rates for an "apples-to-apples" comparison amongst the different drainage basins:

- **Peak I&I Flow Rate per IDM:** Peak measured I&I rate divided by length of pipe within the drainage basin, expressed in units of inch-diameter-mile (IDM) (miles of pipeline multiplied by the diameter of the pipeline in inches). Final units are gallons per day (gpd) per IDM.
- **Peak I&I Flow Rate per Acre:** Peak measured I&I rate divided by the basin size of the drainage basin, basin units expressed in acres. Units are gpd per acre.
- **Peak I&I Flow Rate to ADWF Ratio:** Peak measured I&I rate divided by average dry weather flow (ADWF). This is a ratio and is expressed without units.

The Peak I&I Rate per Acre and Peak I&I to ADWF Ratio methods are used in this report. A final ranking of inflow is based on averaging the individual rankings for each method. For the purposes of this report, each method is given equal weighting towards the final ranking.

Infiltration Indicators

Dry Weather 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, which may result in quantifying the rate of excess ground water infiltration. Similar to the discussion on inflow, GWI infiltration rates can be normalized by means of pipe length (IDM), basin area (acres) and/or dry weather flow rates (ADWF). These methods are discussed in further detail in the *Groundwater Analysis* section later in this report.

Rainfall Dependent Infiltration: Infiltration occurring 24 hours or more after the conclusion of a storm event is classified as rainfall dependent infiltration. Analysis is conducted by looking at the infiltration rates at set periods after the conclusion of a storm event. Depending on the system and the time required for flows to return to ADWF levels, different set periods may be examined to determine the basins with the greatest or most sustained rainfall dependent infiltration rates.

For this project, the infiltration rates were taken between 24 and 48 hours after the conclusion of the storm event.

Combined I&I Indicators

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/infiltration and is used to identify the overall volumetric influence of I&I within the monitoring basin. Similar to Inflow, pipe length, basin area and dry weather flow are used to normalize combined I&I for basin comparison:

- **Combined I&I Flow Rate per IDM:** Total infiltration (gallons) divided by length of pipe (IDM) and divided by storm event rainfall (inches of rain). Final units are gallons per day (gpd) per IDM per inch-rain.
- **R-Value:** Total infiltration (gallons) divided by the total rainfall that fell within the acreage of that basin (gallons of rainfall). This is expressed as a percentage and is explained as "the percent of rain that falls that enters the sanitary sewer collection system." Systems with R-Values less than 5%[8] are often considered to be performing well.

[8] Keefe, P.N. "Test Basins for I&I Reduction and SSO Elimination", 1998, WEF Wet Weather Specialty Conference, Cleveland.

- **Combined I&I Flow Rate per ADWF:** Total infiltration (gallons) divided by the ADWF (gpd) and divided by storm event rainfall (inches of rain). Final units are gallons (x 10^6) per MGD of ADWF per inch-rain.

Figure 20 below shows a sample I&I graph that illustrates and summarizes the I&I response and I&I calculations made per site per storm event. Similar graphs for each site and storm event are located in *Appendix A*.

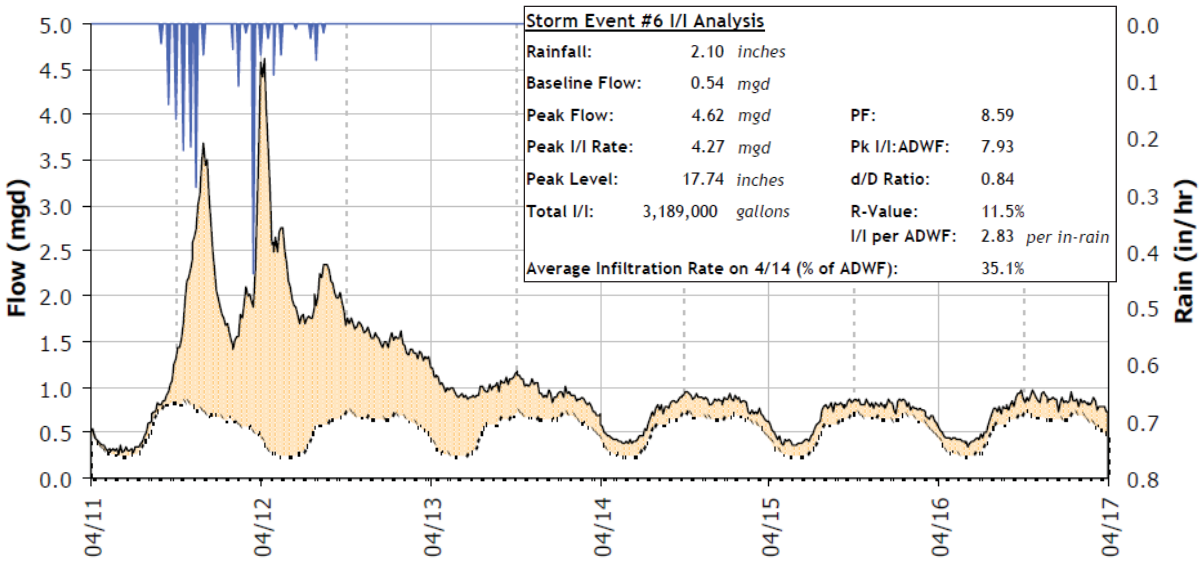


Figure 20. I&I Flow Graph for Site 2, Event 6

Inflow Analysis

Table 8 summarizes the peak measured I&I flows and inflow analysis results for the flow monitoring locations. Figure 21 shows bar graphs of the inflow indicators. Figure 22 and Figure 23 illustrate temperature maps showing inflow analysis results of the basins within the Richmond collection system.

Note: Treatment plant operation procedures will back flow into the collection system during storm events, so as not to overwhelm the treatment facility. This backflow into the system was observed at Sites 1, 3, 4, 5A, 5B, 6, 10, 10A and 11. It is strongly noted that the measured peak I&I values at these sites may be skewed either lower (due to the backflow condition dampening the flows through the pipeline) or higher (due to "flushing" when the flow is released through the system).

Table 8.
Inflow Analysis Summary

Site	ADWF (mgd)	Peak I&I Rate[A] (mgd)	Peak I&I per Acre (gpd/acre)	Peak I&I to ADWF Ratio	Per Acre Ranking	Per ADWF Ranking	Overall[B] Inflow Ranking
Site 1	1.13	5.05	3,806	4.48	10	9	9
Site 2	0.54	4.27	8,758	7.93	6	6	6
Site 3	4.70	20.19	4,569	4.30	9	11	10
Site 4	0.12	1.11	2,912	9.40	12	4	8
Site 5A	0.037	1.03	21,879	28.03	1	1	1
Site 5B	1.97	16.04	8,958	8.15	5	5	4
Site 6	1.85	6.63	3,416	3.60	11	12	11
Site 7	0.68	4.64	10,078	6.82	3	7	5
Site 8	0.46	5.36	10,960	11.54	2	3	2
Site 9	0.41	5.13	9,622	12.47	4	2	3
Site 10/ 10A	1.69/ 1.46	9.27	7,713	5.50	7	8	7

[A] Over monitoring period: 2/3/2010 – 6/4/2010

[B] Overall rankings determined by equal weighting between the "per Acre" and the "per ADWF" ranking methods. In the event of a tie ranking, the site with highest average daily flow rate was given the lower rank.

The following inflow analysis results are noted:

- Site 5A ranked 1 in Inflow. It is noted that Site 5A was a smaller line discharging into the much larger trunk sewer on Cutting Boulevard. When the system is used for storage (per treatment plant operations) Site 5A is the most likely of the sites to have a skewed higher peak due to a "flushing" effect when flows are released back towards the influent wet well.
- The northeast quadrant of the City appears to have the highest inflow quantities.

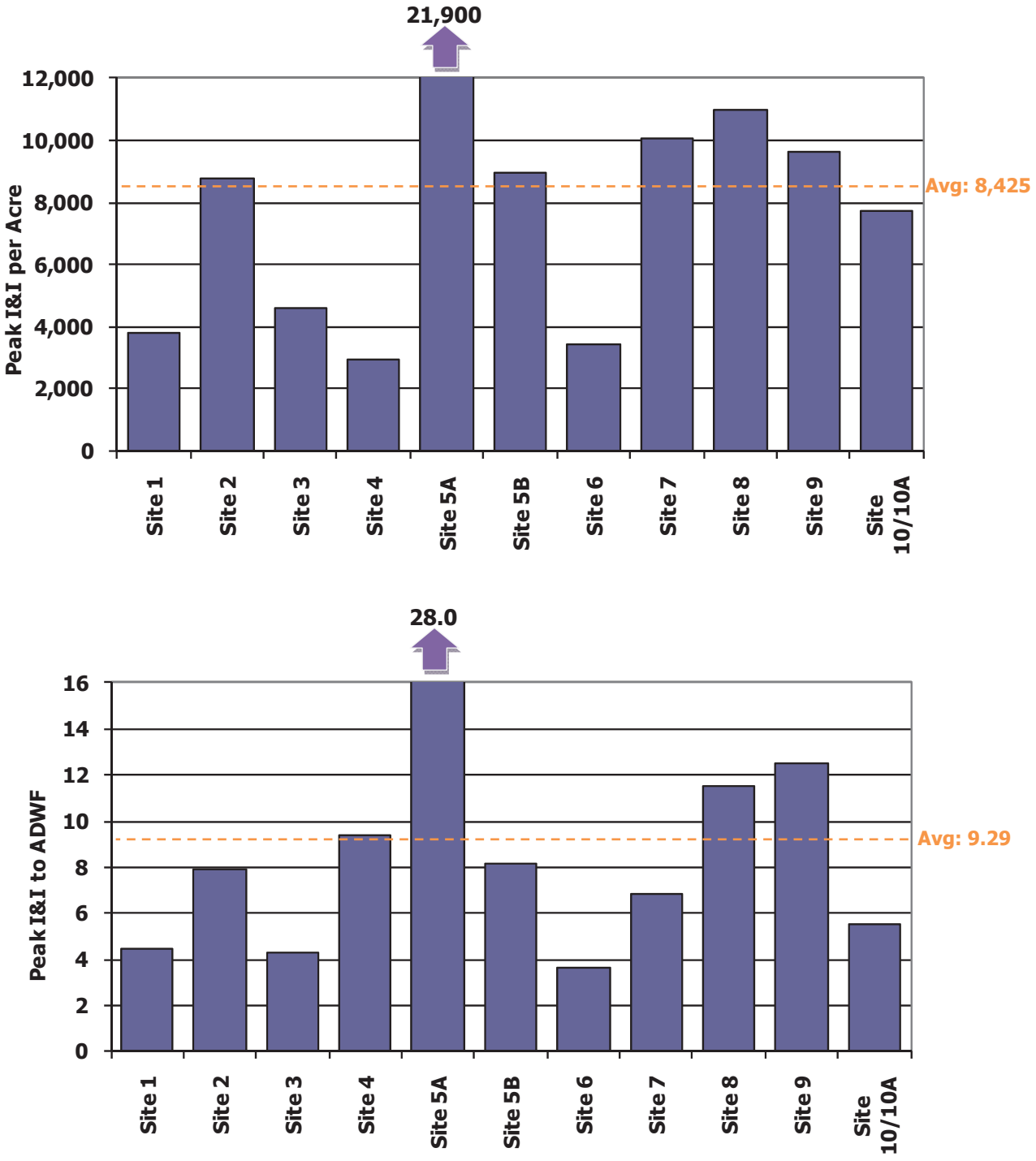


Figure 21. Inflow Indicators by Site

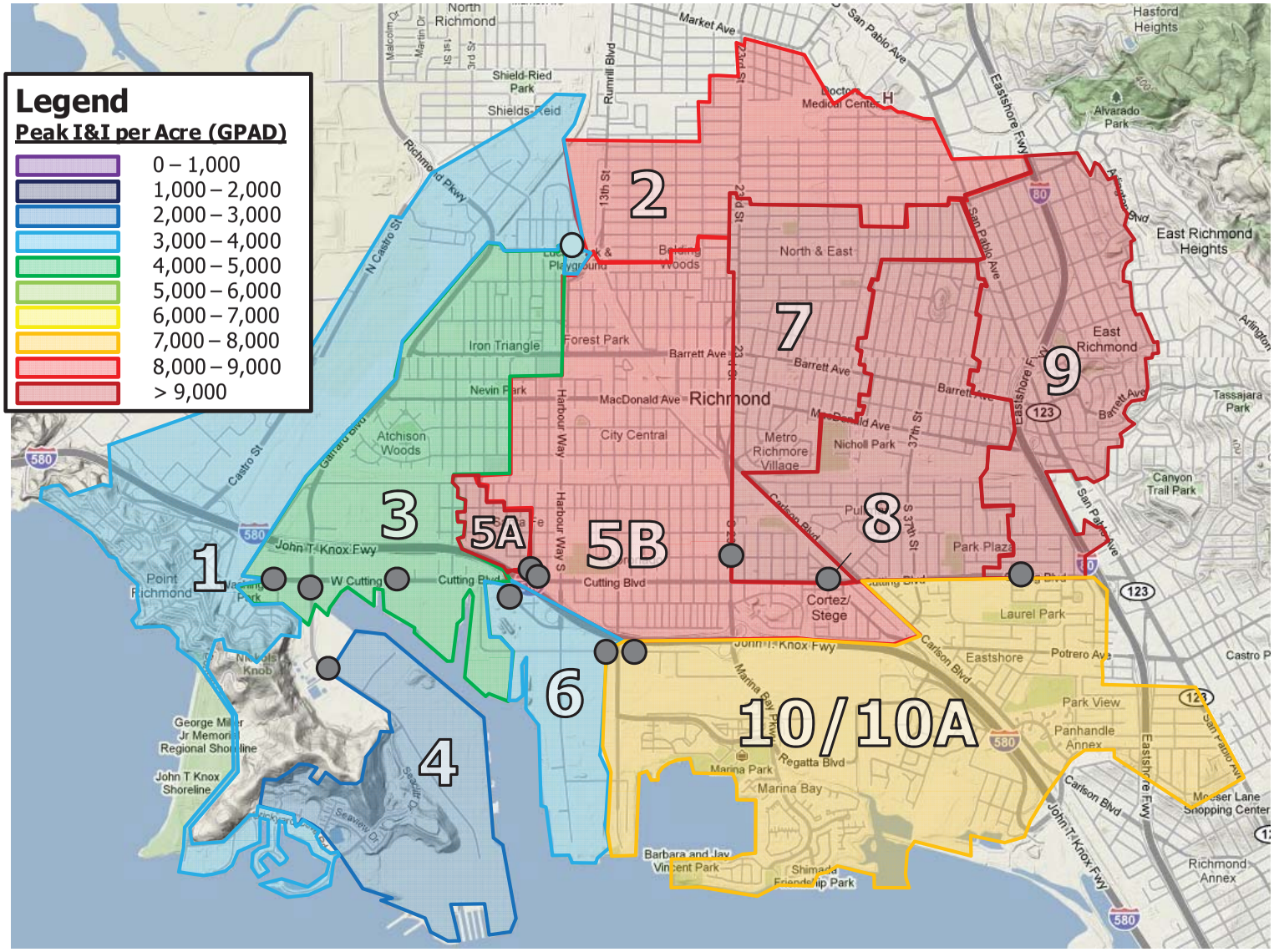


Figure 22. Inflow Temperature Map: Peak I&I per Acre

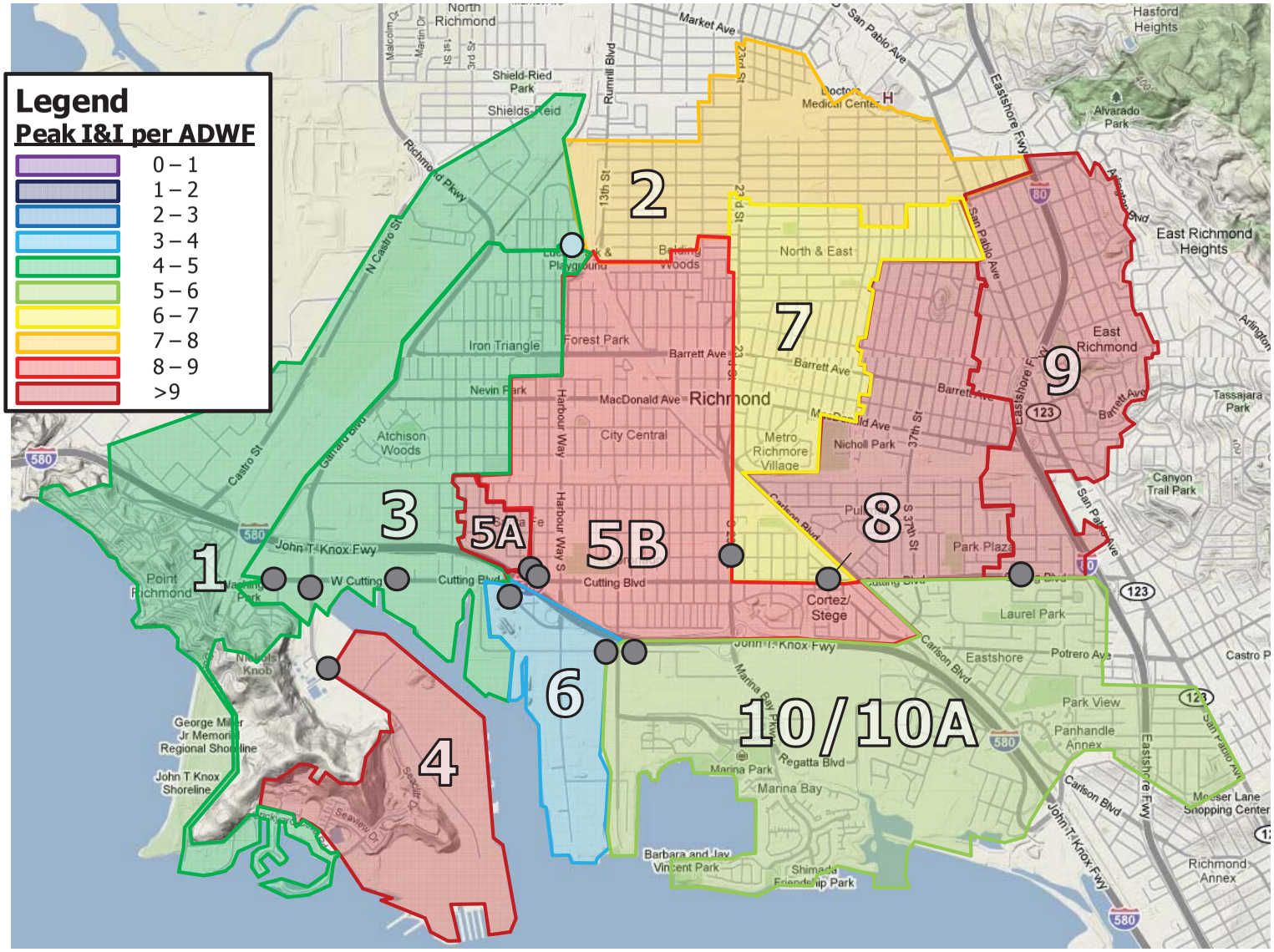


Figure 23. Inflow Temperature Map: Peak I&I per ADWF

RDI (Rain Dependent Infiltration) Analysis

Table 89 summarizes the RDI flows and infiltration component analysis results for the flow monitoring locations. To try to obtain the most consistent RDI value across the flow monitoring period, the infiltration rates (measured from 24 hours to 48 hours after the storm event) for the six storm events were averaged.

Figure 24 shows bar graphs of the RDI indicators. Figure 25 and Figure 26 illustrate temperature maps showing RDI analysis results of the basins within the Richmond collection system.

Table 9.
RDI Analysis Summary

Site	ADWF (mgd)	Infiltration Rate 24-48 hrs post Event (mgd)							Infiltration Rate per Acre (GPAD)	Infiltration Rate (% of ADWF)
		#1	#2	#3	#4	#5	#6	Avg. of Rain Events #1 - #6		
Site 1	1.13	1.77	1.02	1.36	1.01	0.43	1.18	1.13	850 *(1)*	100% *(2)*
Site 2	0.54	0.19	0.17	0.29	0.13	0.13	0.19	0.18	377 *(10)*	34% *(10)*
Site 3	4.70	5.47	4.30	4.19	2.70	1.28	3.52	3.58	809 *(2)*	76% *(4)*
Site 4	0.12	0.16	0.10	0.16	0.19	0.10	0.15	0.14	376 *(11)*	121% *(1)*
Site 5A	0.037	0.06	0.04	0.04	0.02	0.00	0.04	0.03	718 *(3)*	92% *(3)*
Site 5B	1.97	1.34	1.15	1.28	0.90	0.32	0.88	0.98	548 *(6)*	50% *(7)*
Site 6	1.85	1.76	1.70	0.88	0.00	0.12	0.17	0.77	397 *(9)*	42% *(9)*
Site 7	0.68	0.19	0.17	0.28	0.20	0.17	0.32	0.22	479 *(7)*	32% *(11)*
Site 8	0.46	0.36	0.33	0.47	0.23	0.06	0.21	0.28	564 *(5)*	59% *(5)*
Site 9	0.41	0.35	0.23	0.19	0.15	0.16	0.25	0.22	416 *(8)*	54% *(6)*
Site 10/10A	1.69/ 1.46	1.28	1.10	0.84	0.25	0.25	0.75	0.75	620 *(4)*	44% *(8)*

Ranking within Category

The following RDI analysis results are noted:

- The western region of the City appears to have the highest RDI rates.

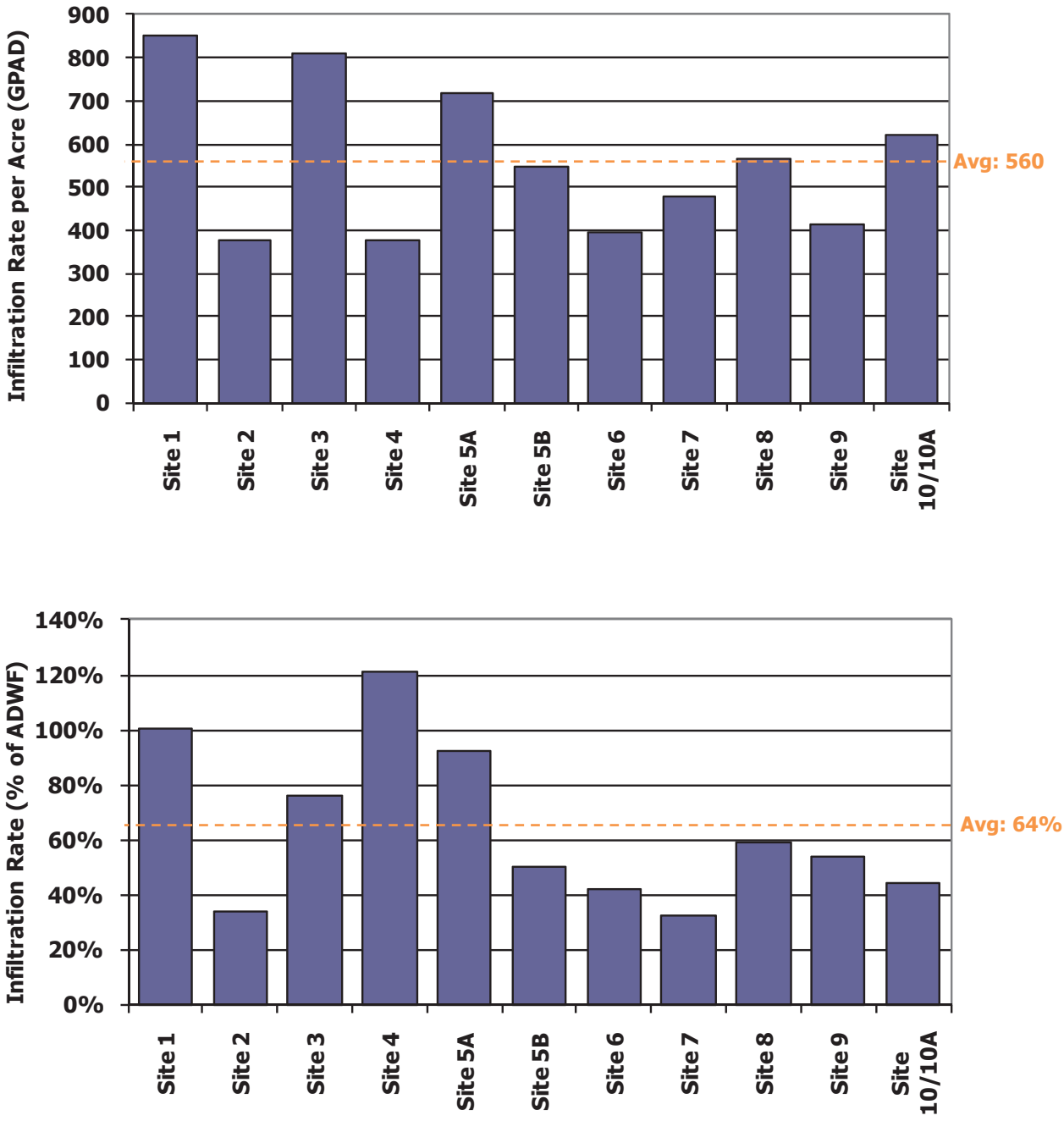


Figure 24. RDI Indicators by Site

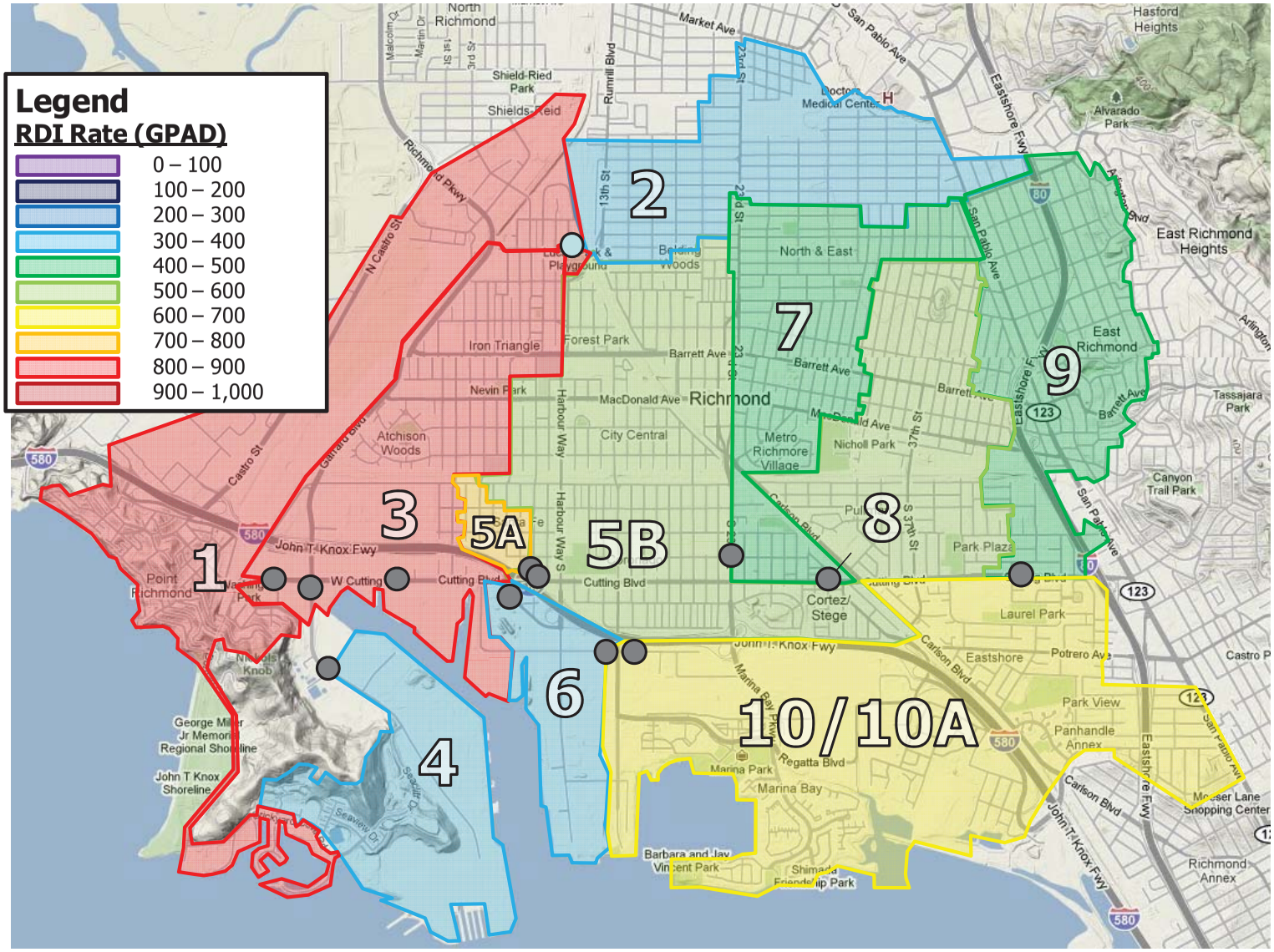


Figure 25. RDI Temperature Map: Infiltration per Acre

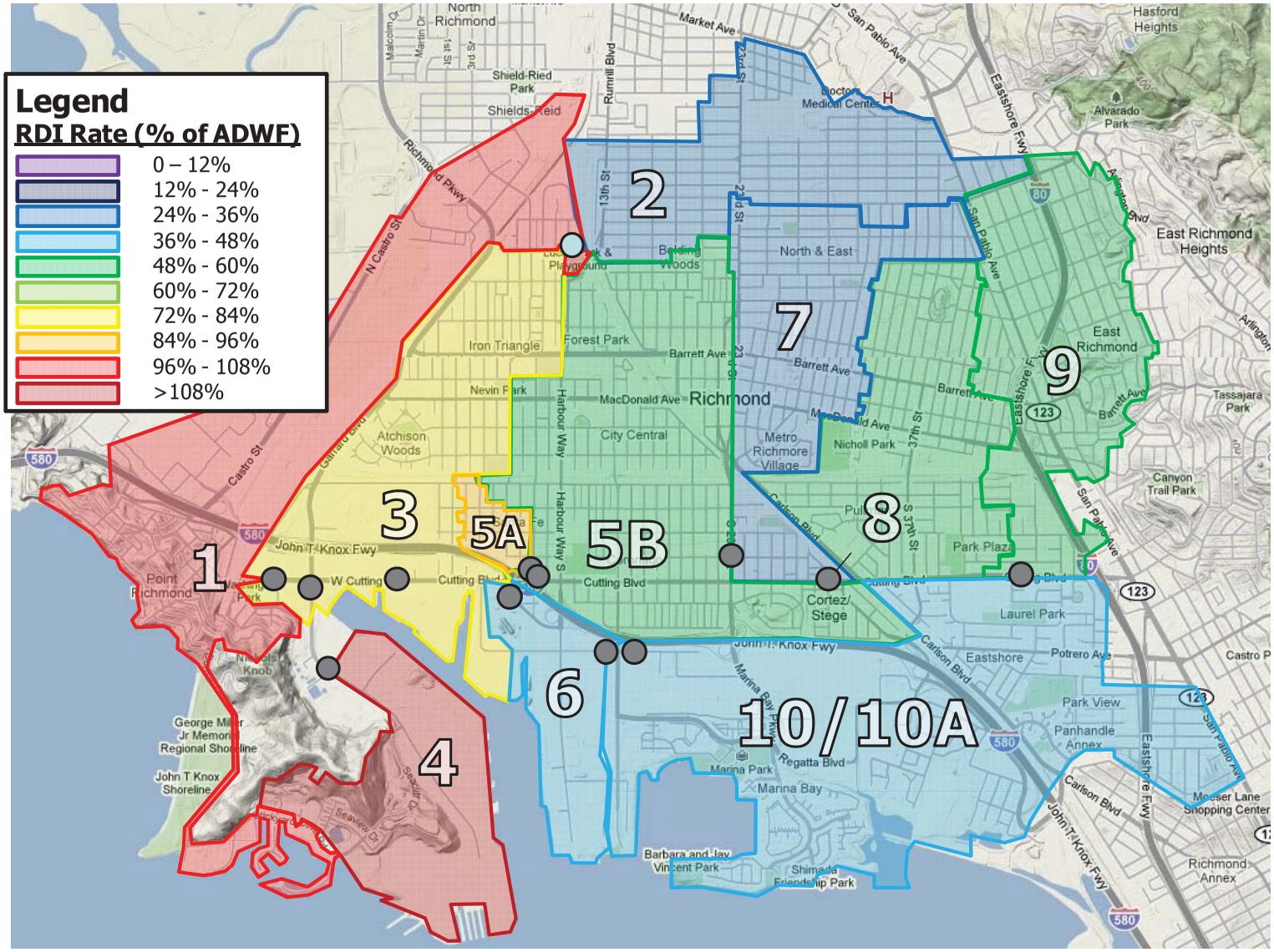


Figure 26. RDI Temperature Map: Infiltration per ADWF

GWI (Groundwater Infiltration) Analysis

Dry weather (baseline) 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 lows 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[9]. Figure 27 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.

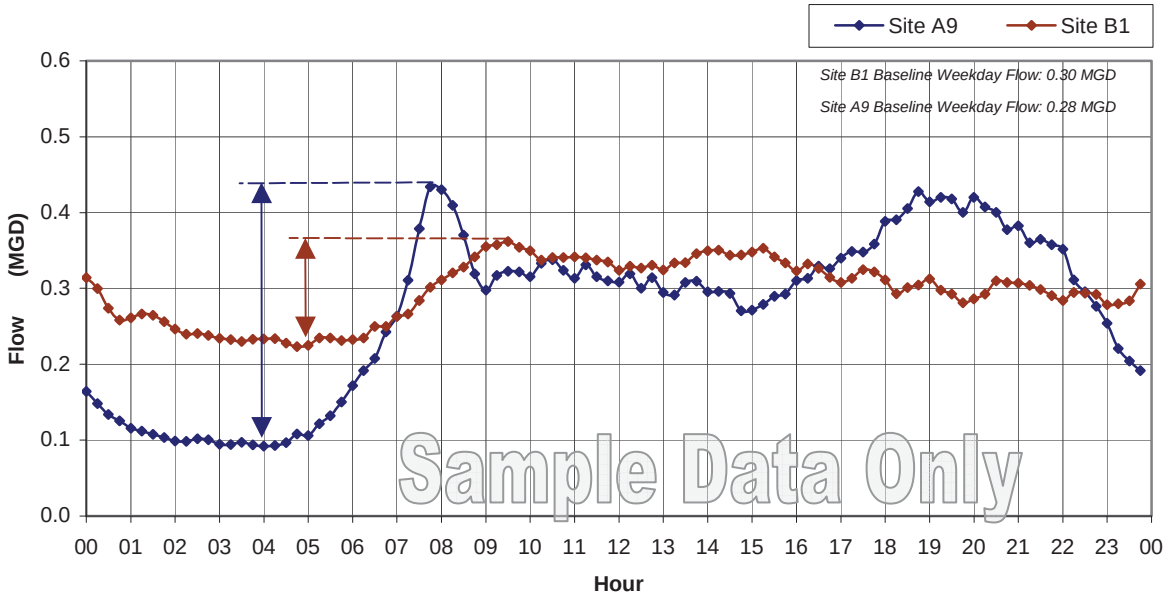


Figure 27. Groundwater Infiltration Sample Figure

It can be useful to compare the peak-to-baseline and low-to-baseline flow ratios for all flow metering sites. A site with abnormal ratios, and with no other reasons to suspect abnormal flow patterns (such as proximity to pump station, treatment facilities, etc.), has a distinct possibility of higher levels of groundwater infiltration in comparison to the rest of the collection system. Figure 28 plots the min-to-baseline flow ratios against the baseline flows for all sites monitored during this study. The dotted line shows "typical" min-to-baseline flow ratios per the Water Environment Federation (WEF)[10].

[9] Theoretically imagining an extreme case, if there were 0.2 MGD of baseline flow and 2.0 MGD of groundwater infiltration, the peaks and lows would be barely recognizable; the baseline flow would be nearly a straight line.

[10] WEF Manual of Practice No. 9 "Design and Construction of Sanitary and Storm Sewers".

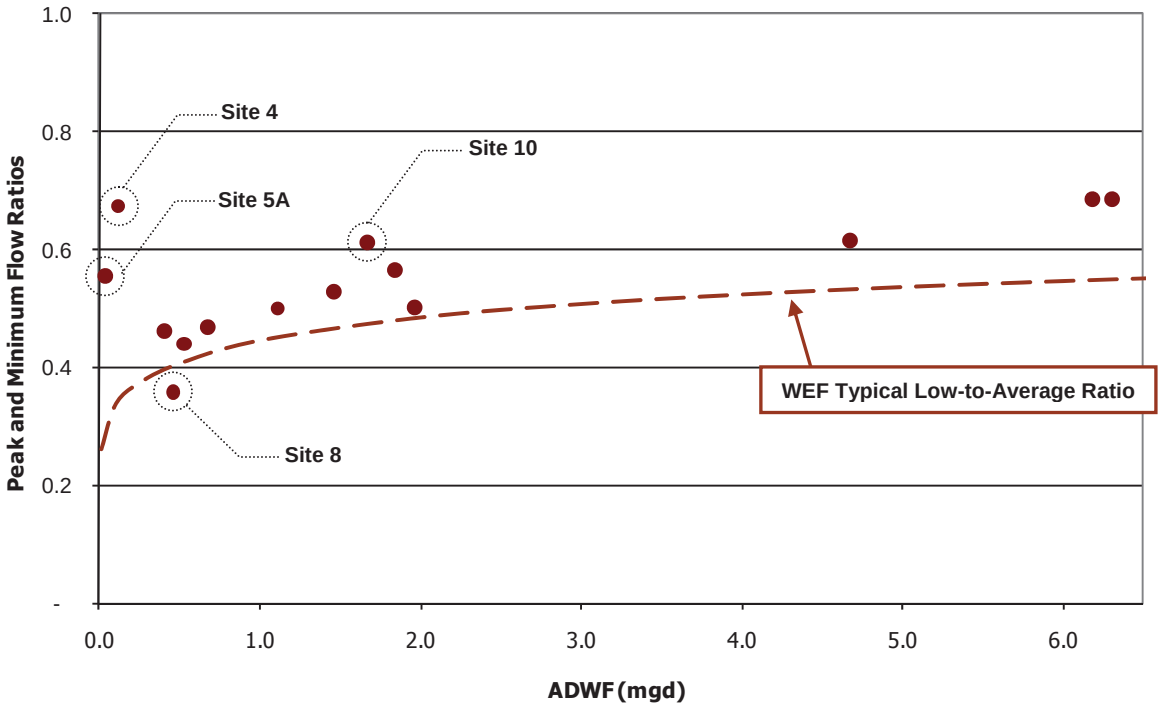


Figure 28. Minimum Flow Ratios vs. ADWF[11]

All of the monitoring sites except Site 8 had minimum flow to ADWF ratios that were **above** the WEF typical Low-to-Average Ratio, indicating excessive groundwater infiltration. The rates of groundwater infiltration above typical groundwater infiltration standards (as set forth by WEF) for each site were calculated and are shown in Table 10. Please note: The stated groundwater rates are not **total** groundwater infiltration rates, but groundwater rates above typical rates.

Figure 29 and Figure 30 illustrate temperature maps showing GWI analysis results of the basins within the Richmond collection system.

Note 1: There was tidal infiltration observed through many of the flow monitoring locations, often in significant quantities. Much of the quantified GWI may be due to tidal infiltration into the sanitary sewer collection system.

Note 2: Due to treatment plant operation procedures wherein flow is backed up into the system, sites near the treatment facility (Sites 1, 3, 4 and 11) may have GWI numbers skewed higher or lower than would be actually recorded were there no backflow condition.

[11] 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.

Table 10.
Excess Groundwater Infiltration Rates above Typical Rate

Location	WkDay ADWF[12] (mgd)	Excess GWI Rate (mgd)	GWI Rate per Acre (GPAD)	GWI Rate per Revised ADWF[13] (%)	Per Acre Ranking	Per ADWF Ranking	Overall[A] GWI Ranking
Site 1	1.11	0.11	83	11%	9	8	9
Site 2	0.53	0.030	62	6%	10	10	9
Site 3	4.67	0.92	209	25%	3	4	3
Site 4	0.12	0.062	161	110%	6	1	4
Site 5A	0.036	0.014	296	61%	2	2	2
Site 5B	1.96	0.079	44	4%	11	11	10
Site 6	1.84	0.34	174	22%	4	5	5
Site 7	0.68	0.057	124	9%	7	9	7
Site 8	0.46	n/a	n/a	n/a	12	12	11
Site 9	0.40	0.049	92	14%	8	7	6
Site 10	1.66	0.48	398	40%	1	3	1
Site 10A	1.46	0.19	174	15%	4	6	8

[A] Overall rankings determined by equal weighting between the "per Acre" and the "per ADWF" ranking methods. In the event of a tie ranking, the site with highest average daily flow rate was given the lower rank.

The following RDI analysis results are noted:

- The southeast quadrant of the City appears to have the highest GWI rates.

[12] Weekday ADWF is used for this calculation to avoid atypical results during weekend flows which may exist in basins with a large commercial/business service area.

[13] Revised ADWF is calculated as the ADWF after subtracting out the excess GWI. For Site 1, the revised ADWF = 1.11 – 0.11 = 1.00 mgd. Note: the revised ADWF is only used in this analysis. For other analyses and calculations in this study, the measured ADWF (not revised) is used.

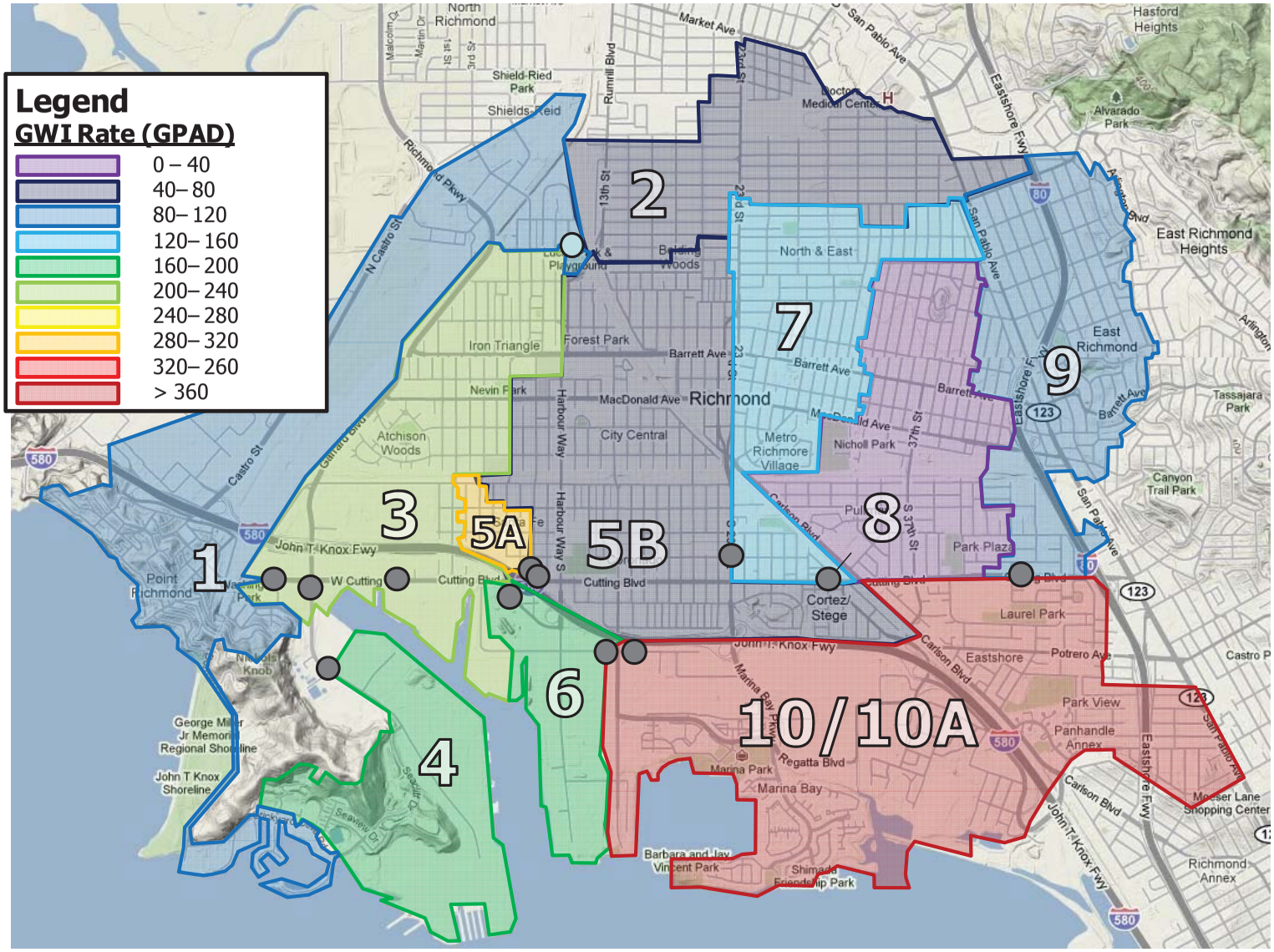


Figure 29. GWI Temperature Map: Infiltration per Acre

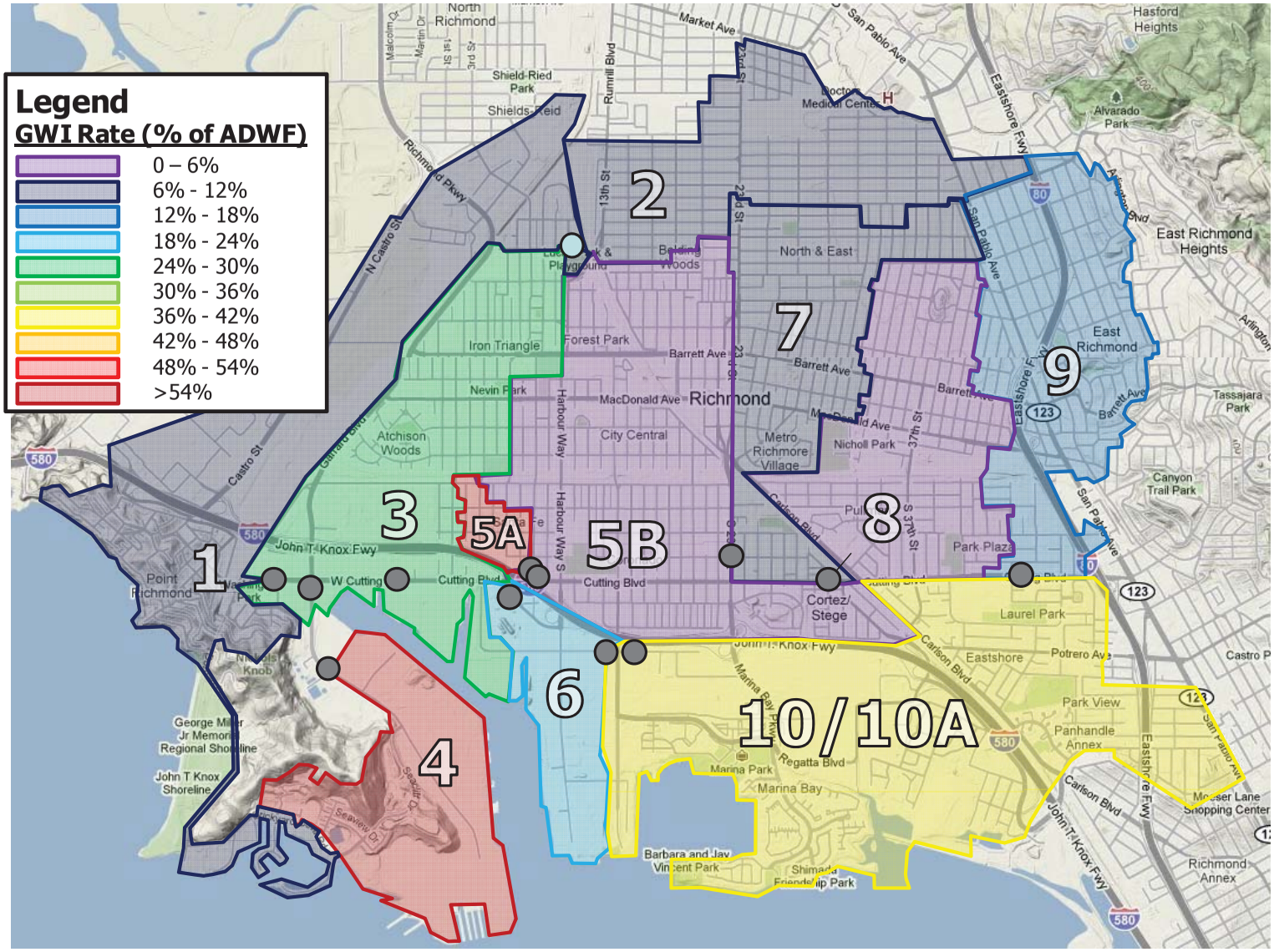


Figure 30. GWI Temperature Map: Infiltration per ADWF

Combined I&I Results Summary

Table 11 summarizes the combined I&I analysis results for the flow monitoring locations. Combined I&I was analyzed across this entirety of the flow monitoring period. This type of analysis was necessary due to the stacked nature of the rainfall events and the long infiltration recession times of the Richmond collection system; generally real-time flows did not have time to return to baseline flow rates.

Figure 31 shows bar graphs of the inflow indicators. Figure 32 and Figure 33 illustrate temperature maps showing inflow analysis results of the basins within the Richmond collection system.

Table 11.
Combined I&I Analysis Summary

Site	ADWF (mgd)	Total Infiltration[A] (gallons)	R-Value[A] (%)	I&I per ADWF per In-Rain[A]	R-Value (per acre) Ranking	Per ADWF Ranking	Overall Combined I&I Ranking
Site 1	1.13	59,592,000	19.3%	6.17	2	3	2
Site 2	0.54	16,064,000	12.1%	2.98	7	8	8
Site 3	4.70	209,186,000	18.3%	4.67	3	4	3
Site 4	0.12	7,868,000	9.9%	8.66	10	1	6
Site 5A	0.037	2,130,000	20.9%	7.20	1	2	1
Site 5B	1.97	77,884,000	16.8%	4.15	4	6	4
Site 6	1.85	34,273,000	6.7%	1.90	11	11	11
Site 7	0.68	19,031,000	14.9%	2.73	6	9	7
Site 8	0.46	20,923,000	14.9%	4.27	5	5	5
Site 9	0.41	16,854,000	10.7%	3.76	9	7	9
Site 10/10A	1.69/ 1.46	38,154,000	11.9%	2.66	8	10	10

[A] Over monitoring period: 2/3/2010 – 6/4/2010

[B] Overall rankings determined by equal weighting between the “per Acre” and the “per ADWF” ranking methods. In the event of a tie ranking, the site with highest average daily flow rate was given the lower rank.

The following combined I&I analysis results are noted:

- The west and central regions of the City contribute the most totalized inflow and infiltration over the course of a full wet weather season.

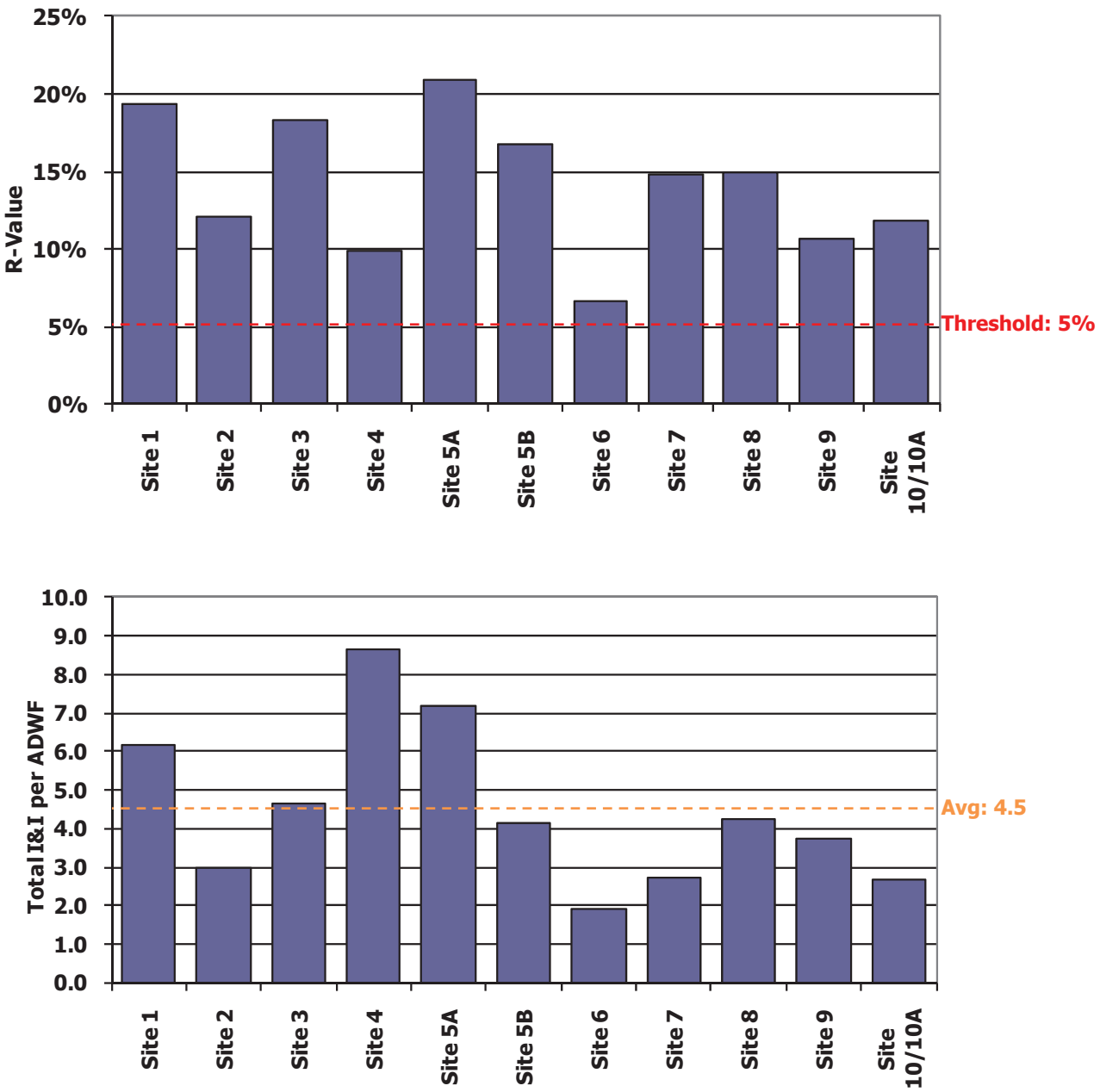


Figure 31. Combined I&I Indicator by Site

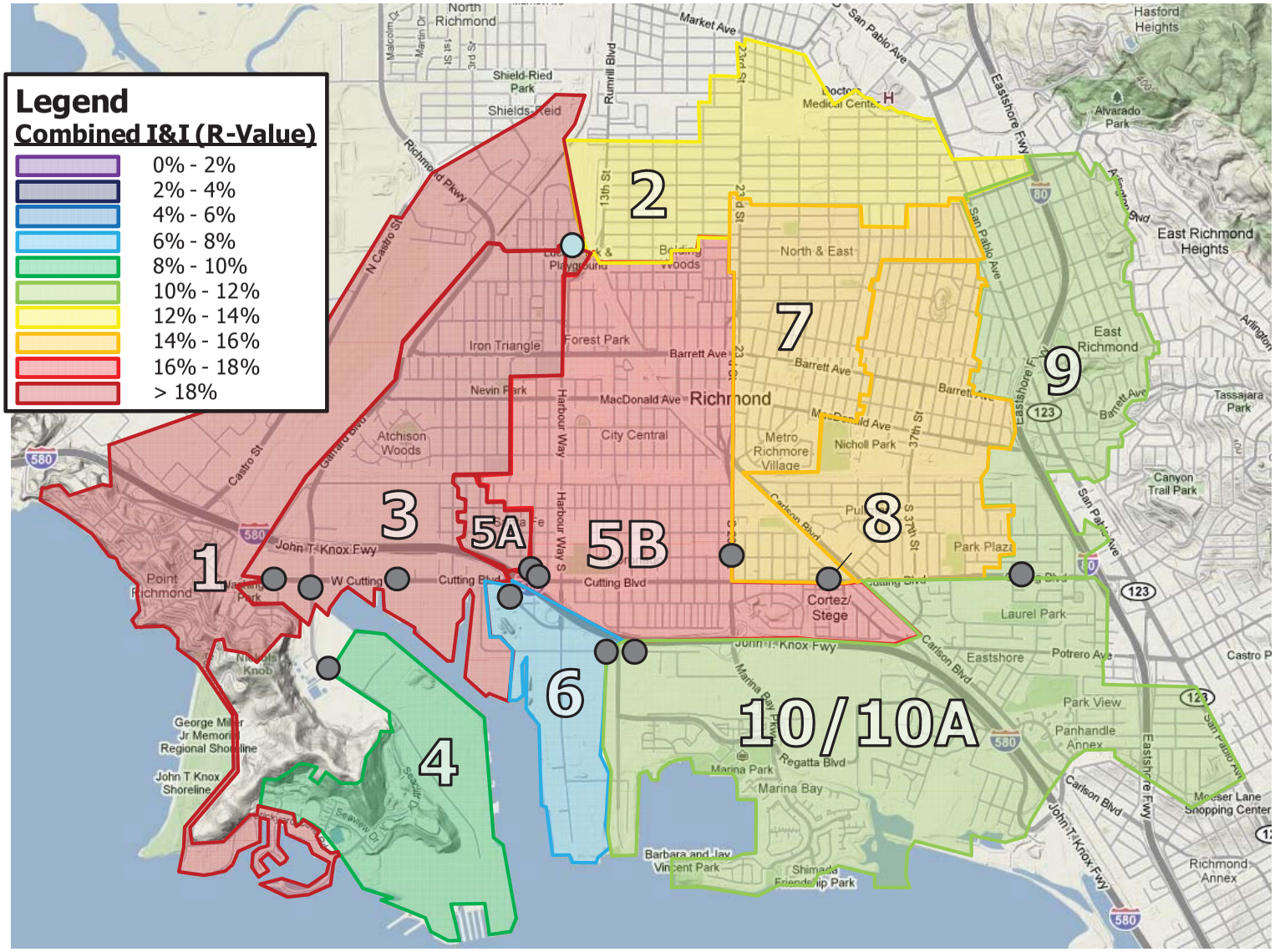


Figure 32. Combined I&I Temperature Map: R-Value (per Acre)

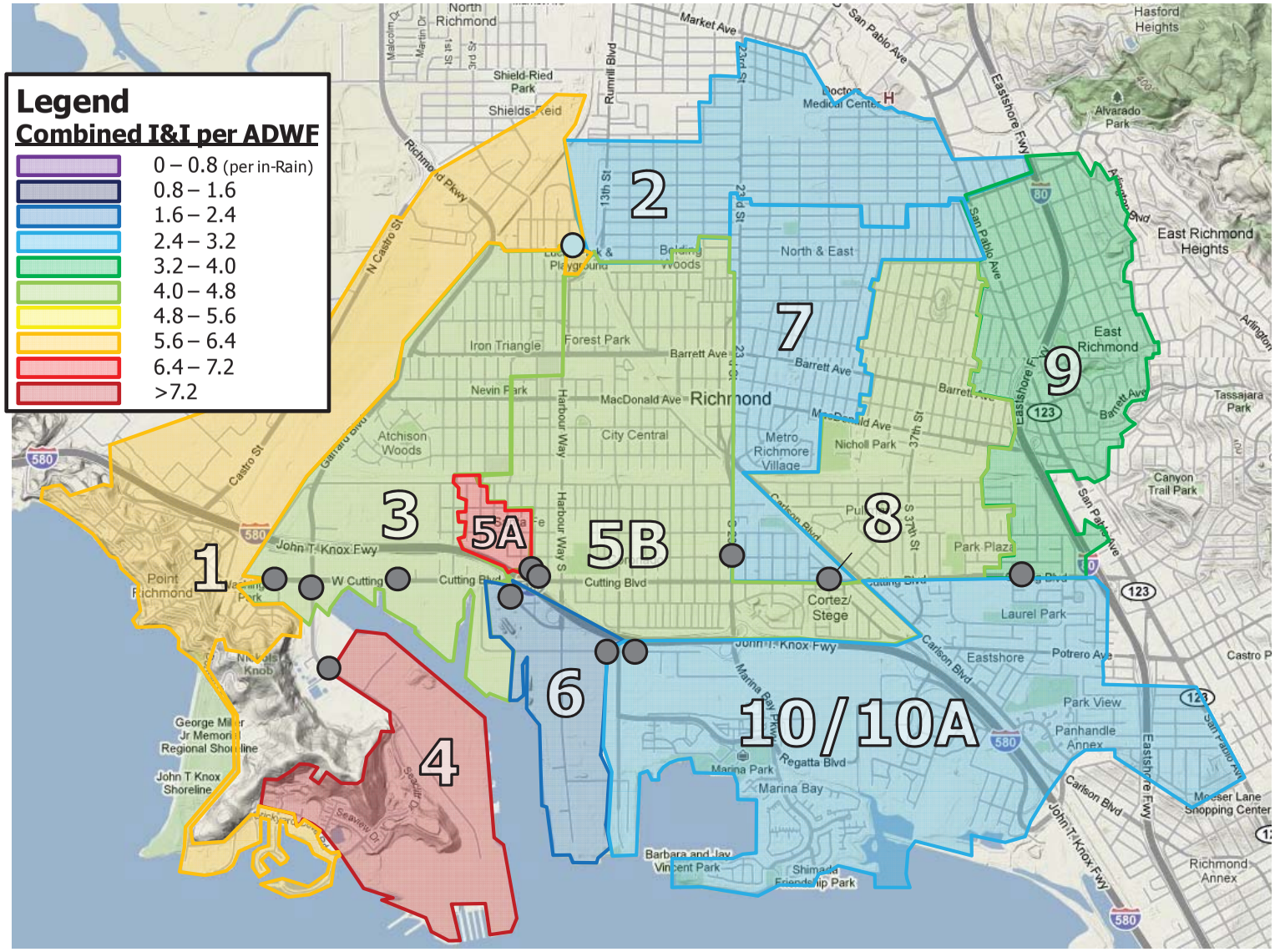


Figure 33. Combined I&I Temperature Map: Total I&I per ADWF

Pipeline Capacity Analysis

Peaking Factor: Peaking Factor is defined as the Peak Measured Flow divided by the Average Dry Weather Flow. A peaking factor threshold value of 3.0 is commonly used for sanitary sewer design.

d/D Ratio: The d/D ratio is the peak measured depth of flow divided by the pipe diameter. A d/D ratio less than 0.75 is a common threshold value used for pipe design. The d/D ratio for each site was computed based on the maximum depth of flow during the rainfall events.

Table 12 summarizes the peak recorded d/D ratios and Peaking Factors per site during the flow monitoring period. Figure 34 shows a flow chart of the peak flows. Figure 35 shows a flow chart of the d/D ratios. Figure 36 shows bar graphs of the capacity results.

Table 12.
Capacity Analysis Summary

Monitoring Site	ADWF (mgd)	Peak Flow (mgd)	Peaking Factor	Diameter (in)	Peak Level (in)	d/D Ratio	Surcharged Level above Pipe Crown (ft)
Site 1	1.13	5.88	5.22	54”	136.1	2.52	6.8
Site 2	0.54	4.62	8.59	21”	17.7	0.84	n/a
Site 3	4.70	23.81	5.07	54”	137.4	2.55	7.0
Site 4	0.12	1.23	10.39	18”	91.5	5.08	6.1
Site 5A	0.037	1.06	29.02	18”	68.8	3.82	4.2
Site 5B	1.97	17.70	8.99	48”	137.8	2.87	7.5
Site 6	1.85	7.70	4.17	36”	134.7	3.74	8.2
Site 7	0.68	5.19	7.64	21”	12.7	0.60	n/a
Site 8	0.46	5.66	12.18	24”	31.5	1.31	0.6
Site 9	0.41	5.55	13.50	21”	93.5	4.45	6.0
Site 10	1.69	11.01	6.53	36”	94.1	2.61	4.8
Site 10A	1.46	5.15	3.54	36”	89.2	2.48	4.4
Site 11	6.24	31.76	5.09	66”	162.3	2.46	8.0

The following capacity analysis results are noted:

- **Peaking Factor:** All locations exceeded typical design threshold limits for peak flow to average dry weather flow ratio. Site 5A had the largest peaking factor.
- **d/D Ratio:** All of the site locations except Site 7 exceeded the common threshold value for d/D ratio. All of the site locations except for Sites 2 and 7 reached a surcharged pipe condition.

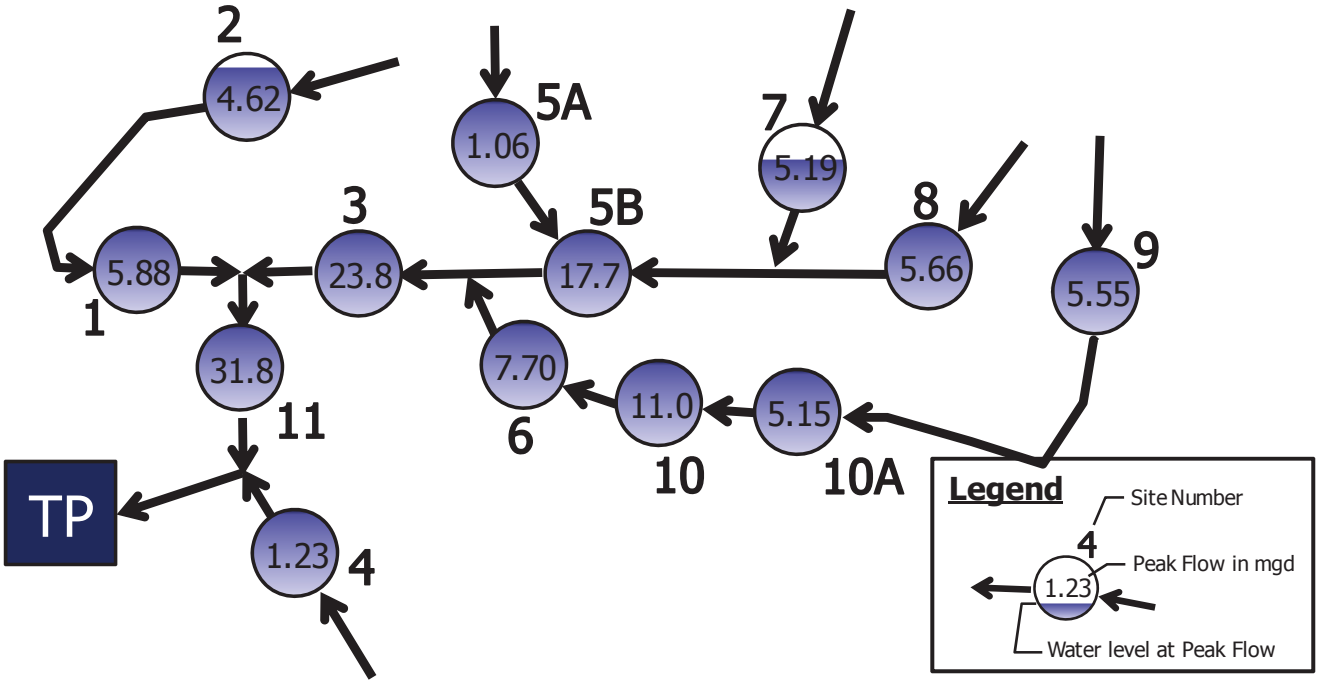


Figure 34. Peak Measured Flow (Flow Schematic)

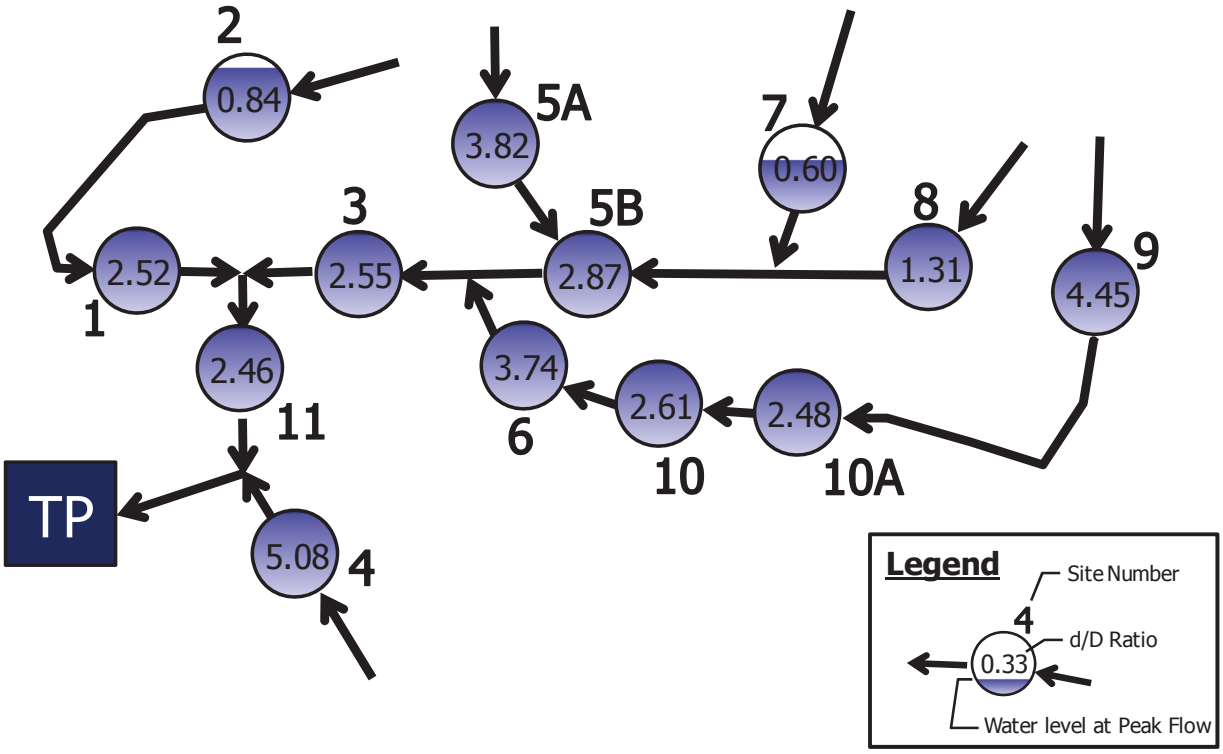


Figure 35. d/D Ratios (Flow Schematic)

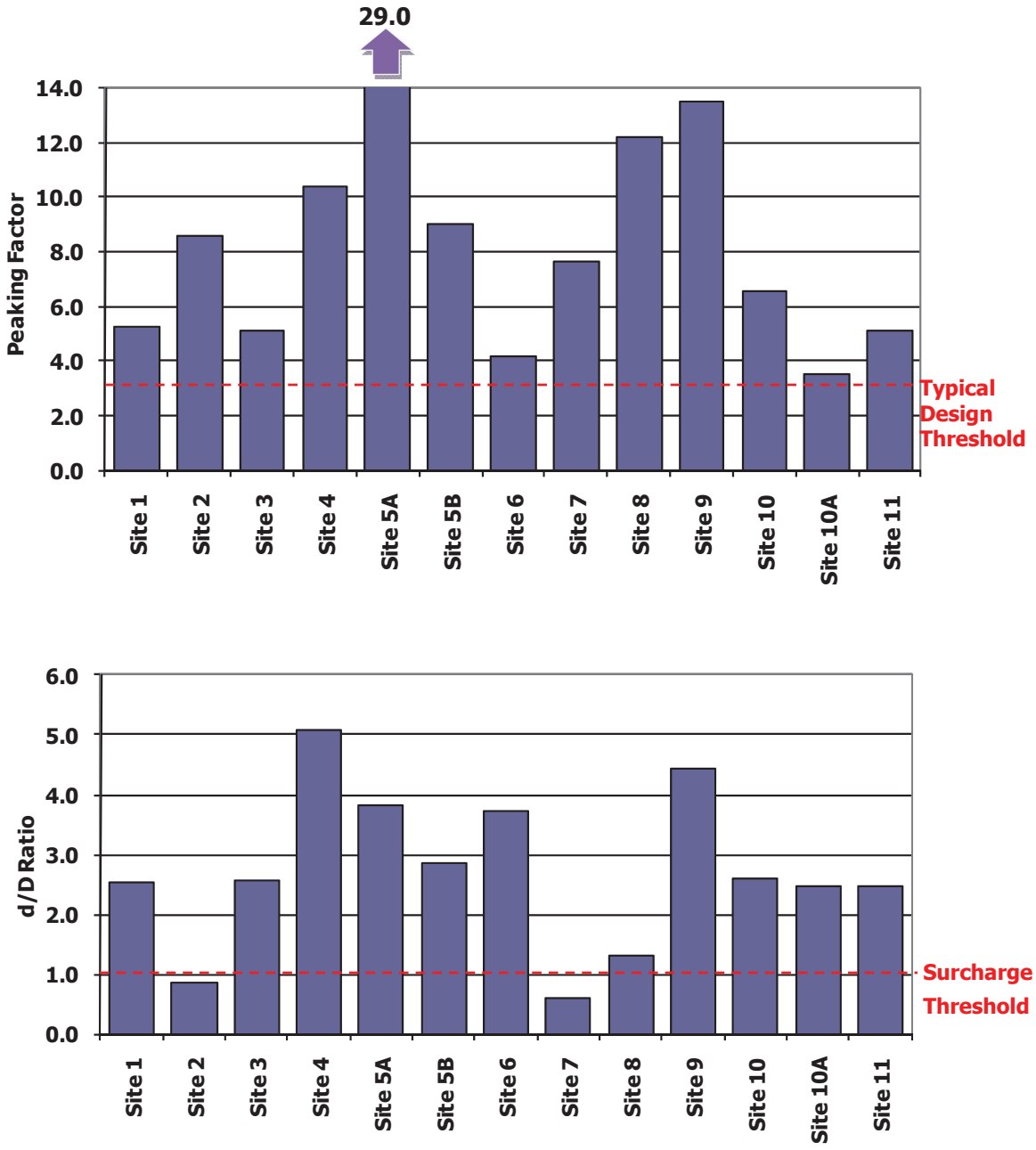


Figure 36. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site

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. The highest inflow occurs within Basins 2, 5, 7, 8 and 9.
    b. If total 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. The highest groundwater infiltration (including tidal infiltration) is occurring in Basin 10. The highest rain dependent infiltration is occurring in Basins 1 and 3.
2. **I&I Investigation Methods:** Potential I&I investigation methods include the following:
    a. smoke testing
    b. mini-basin flow monitoring
    c. night-time reconnaissance work to (1) investigate and determine direct point sources of inflow, and (2) determine the areas and/or pipe reaches responsible for high levels of infiltration contribution.
    d. CCTV inspection
3. **I&I Reduction Cost Effective Analysis:** The City should conduct a study to determine which is more cost-effective: (1) locating the sources of inflow/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 SITES: DATA, GRAPHS, INFORMATION

Temporary Flow Monitoring Study

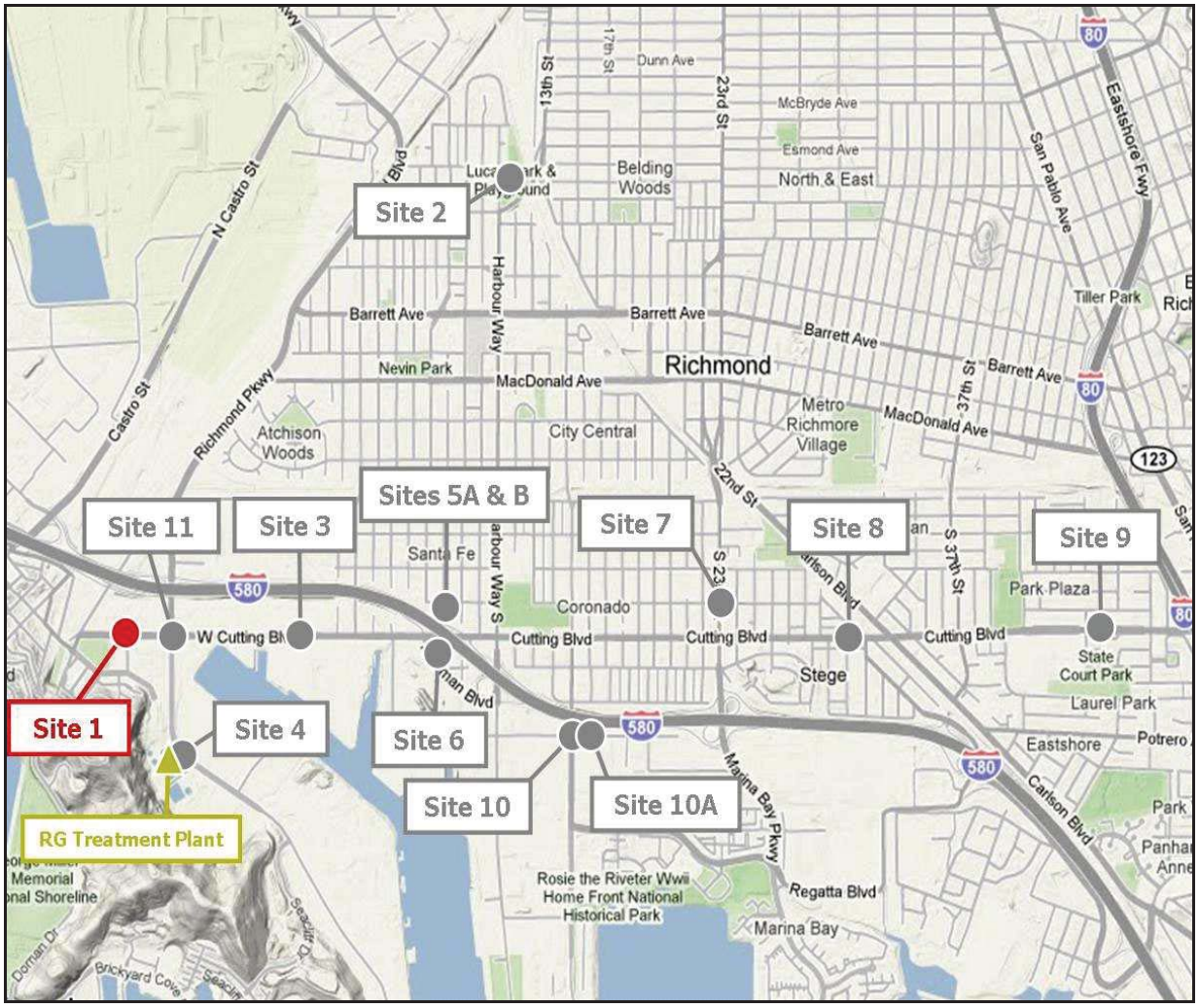
Sanitary Sewer Collection System

Monitoring Site: Site 1

Location: W Cutting Boulevard at Wine Street

Size/Type Line: 54-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 1

Location: W Cutting Boulevard at Wine Street

Latitude: 37.9253°

Longitude: -122.3806°

Rim Elevation: 8 *feet above sea level*

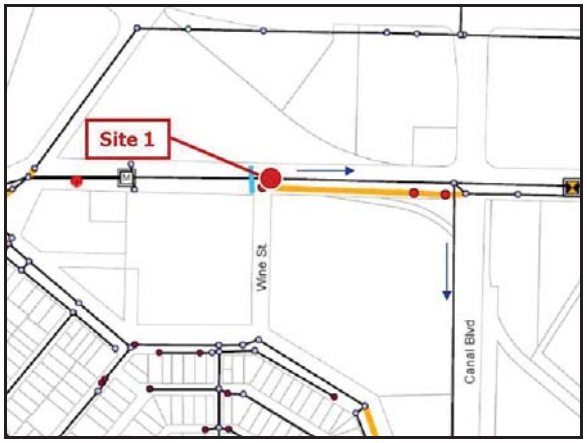
Diameter: 54 *inches*

Average Dry Weather Flow: 1.127 *mgd*

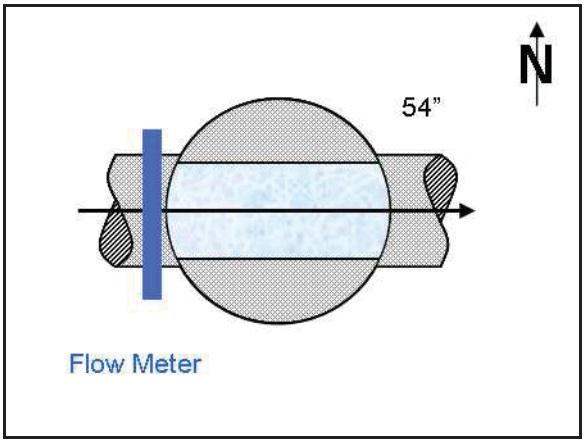
Peak Measured Flow: 5.884 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

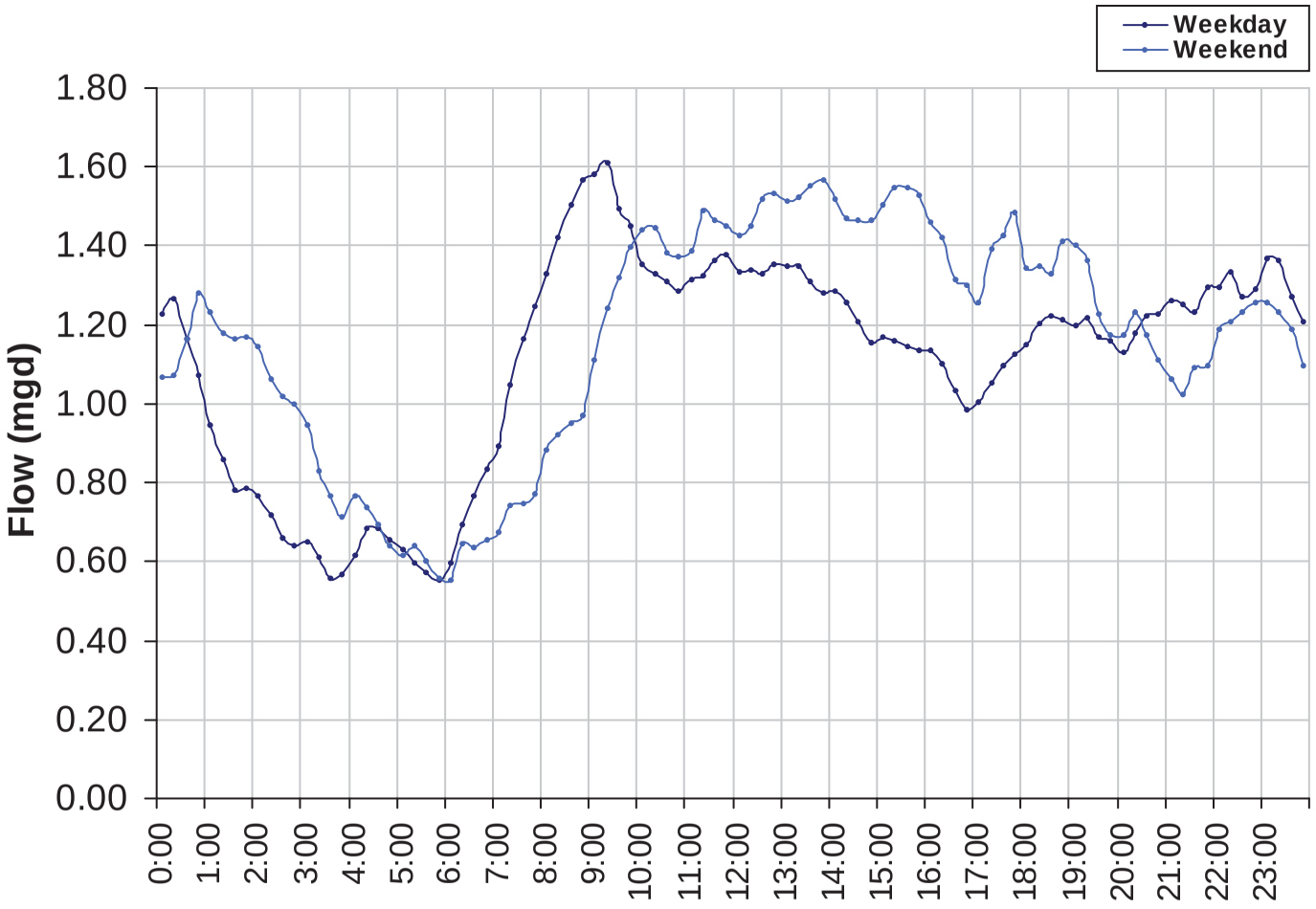


Street View Photo

Plan View Photo

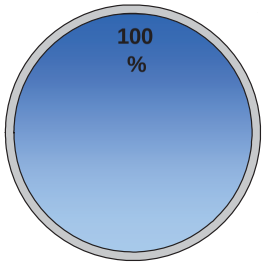
Average Dry Weather Flow

Monitoring Site:
Site 1



Peak Measured Flow:

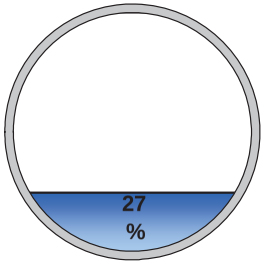
5.88 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

1.13 *mgd*

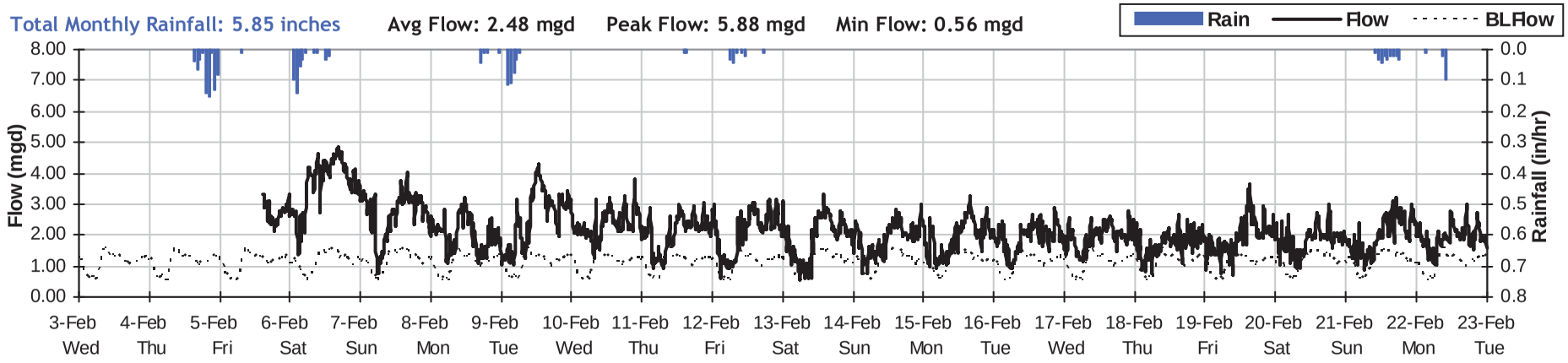


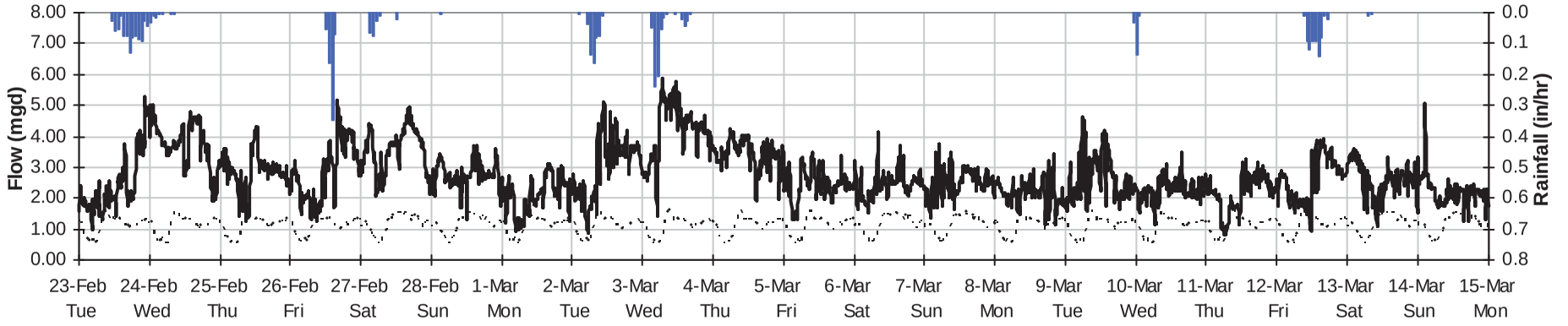
V&A

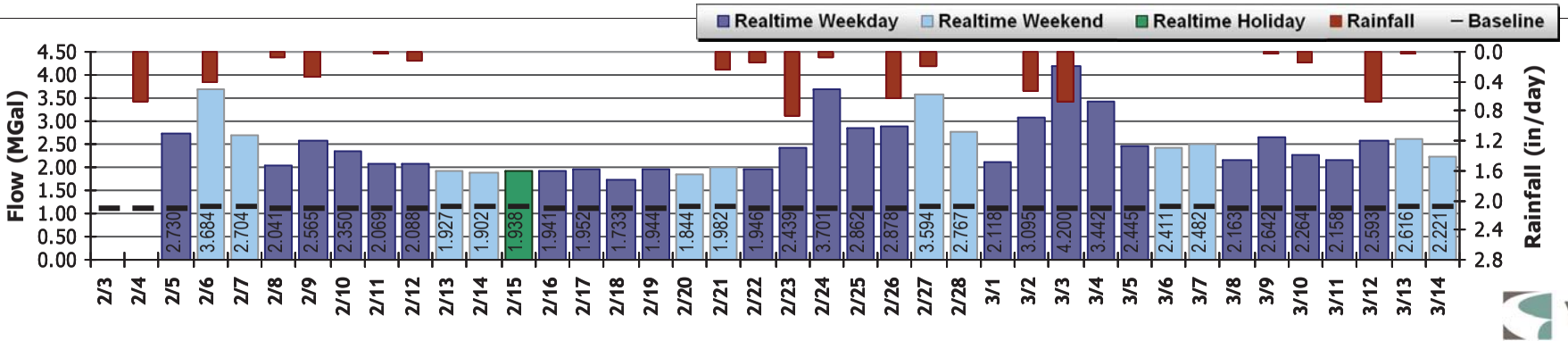
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 1

Total Monthly Rainfall: 5.85 inches Avg Flow: 2.48 mgd Peak Flow: 5.88 mgd Min Flow: 0.56 mgd





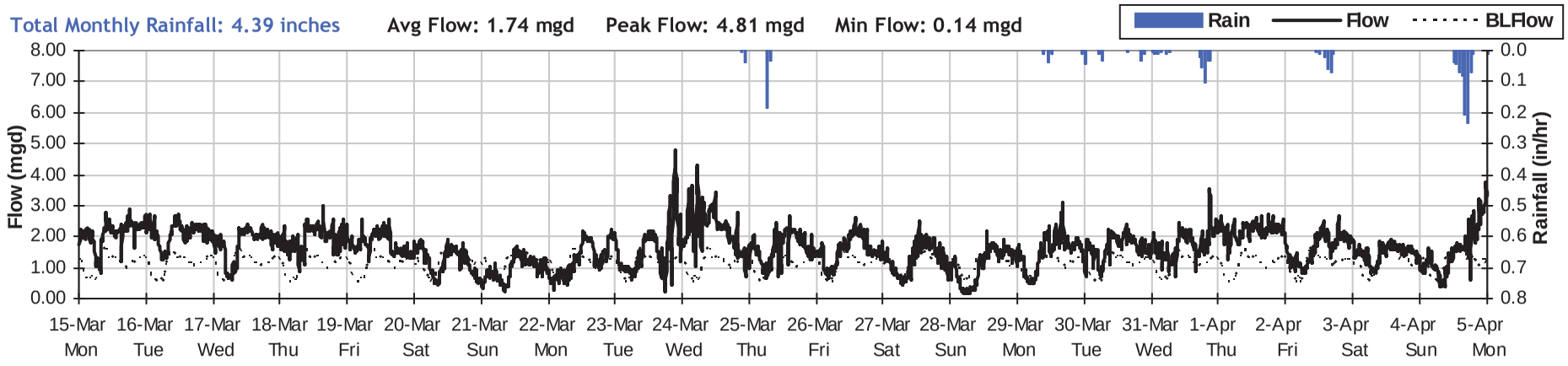


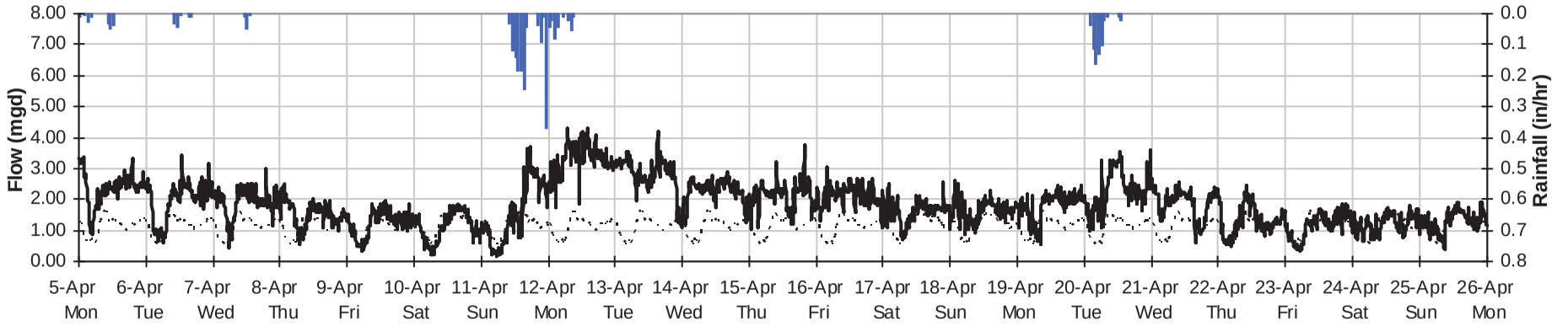
V&A

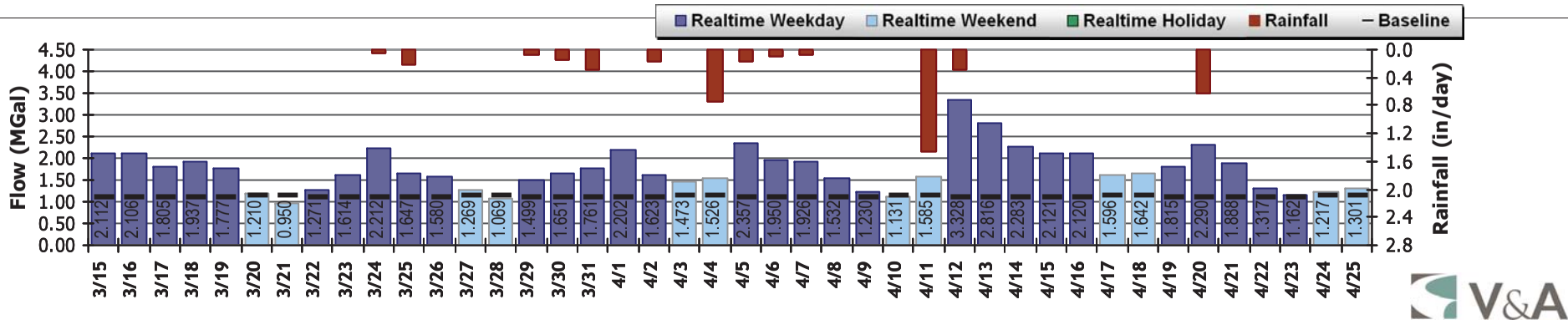
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 1

Total Monthly Rainfall: 4.39 inches Avg Flow: 1.74 mgd Peak Flow: 4.81 mgd Min Flow: 0.14 mgd



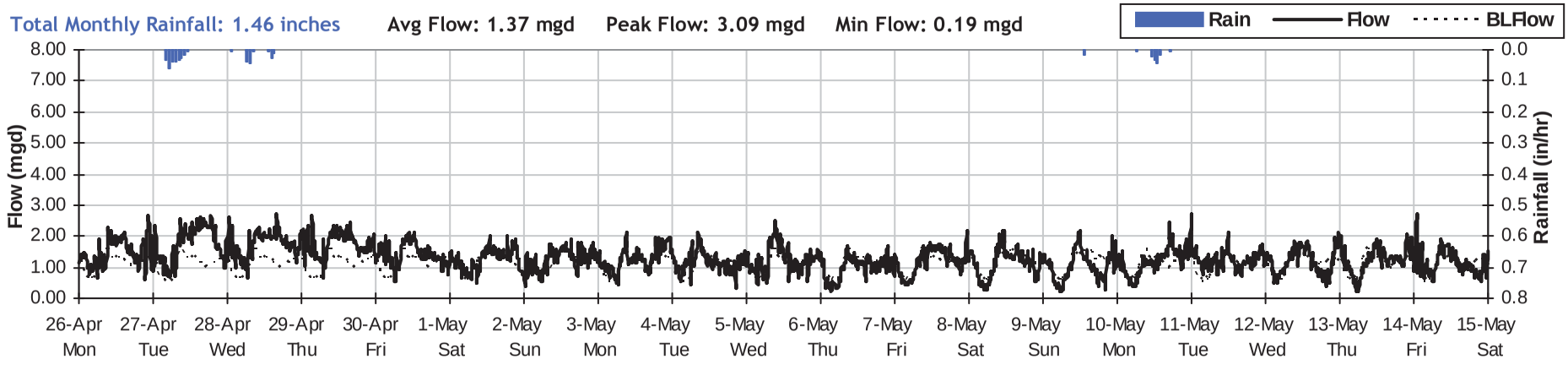


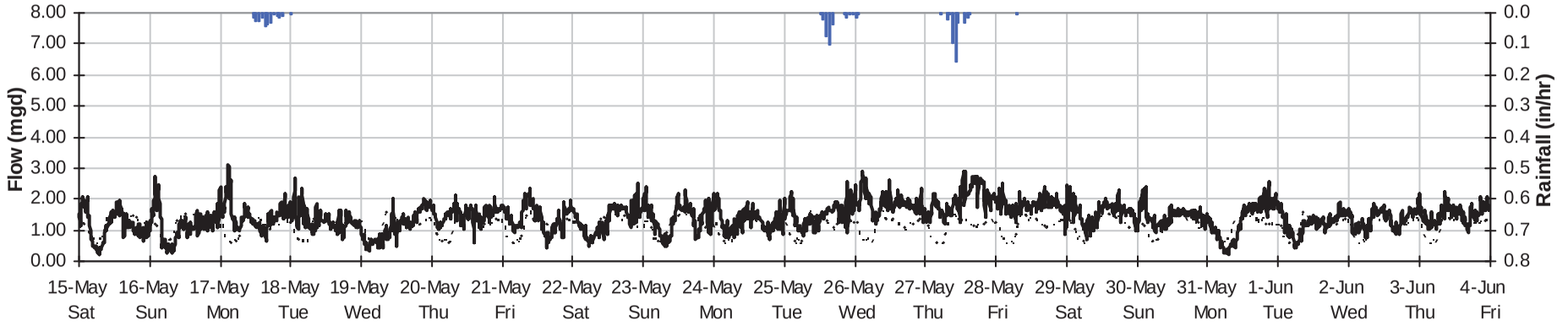


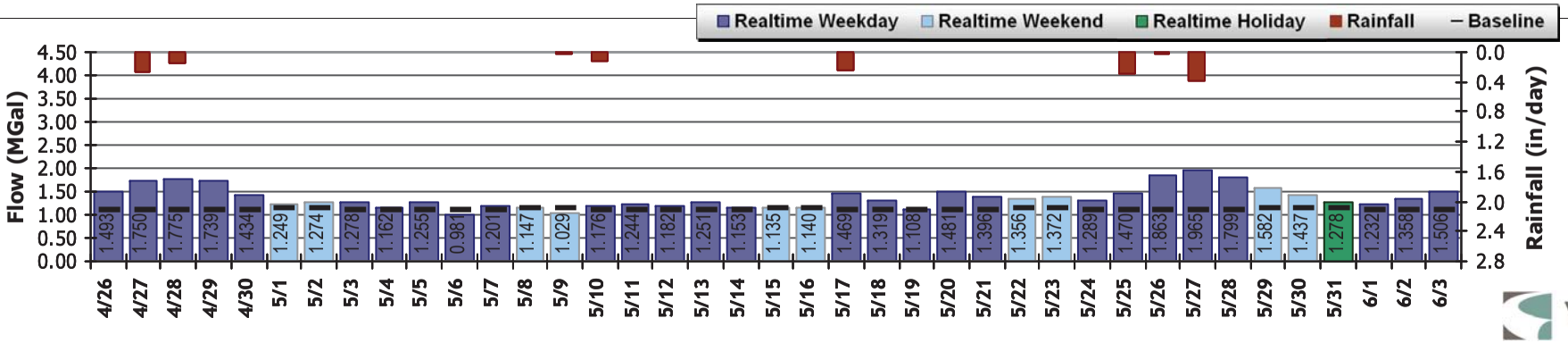
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 1

Total Monthly Rainfall: 1.46 inches Avg Flow: 1.37 mgd Peak Flow: 3.09 mgd Min Flow: 0.19 mgd





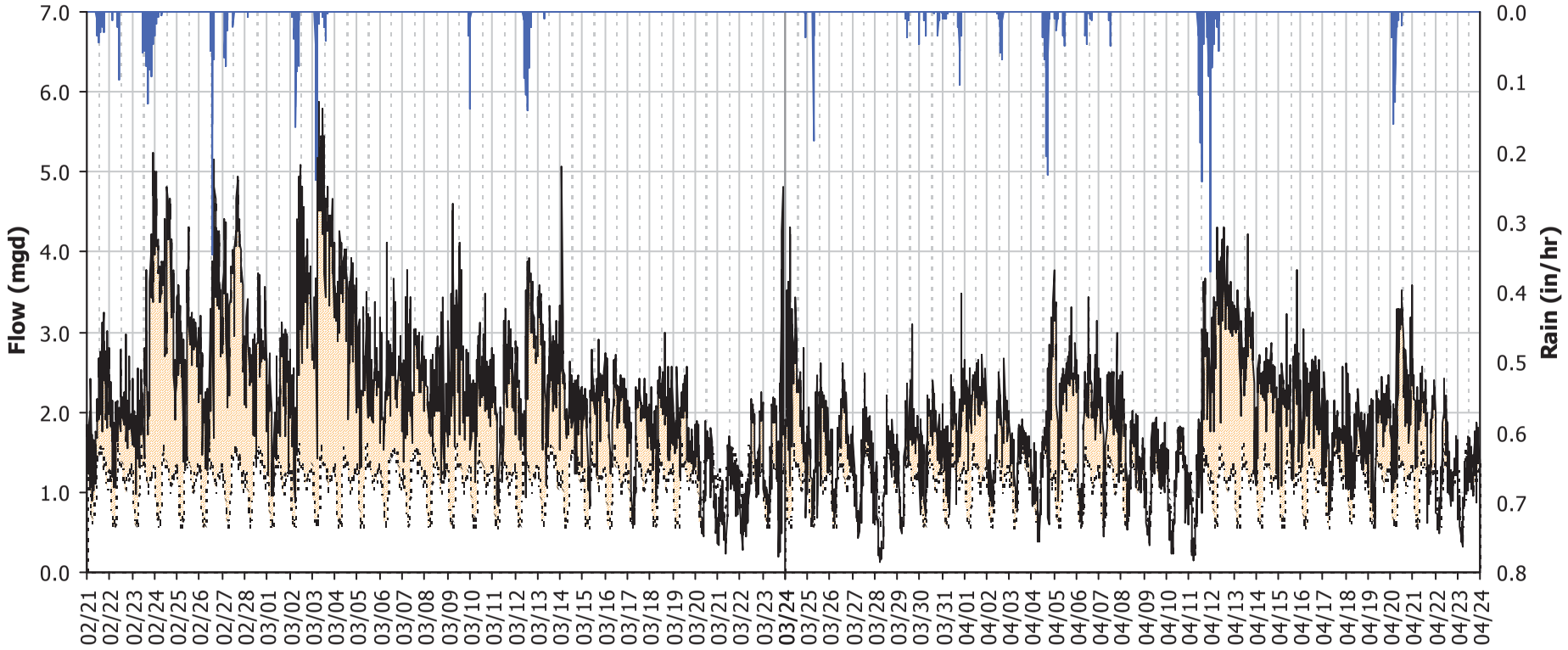


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 1

Multiple Events Detail I/I Graph

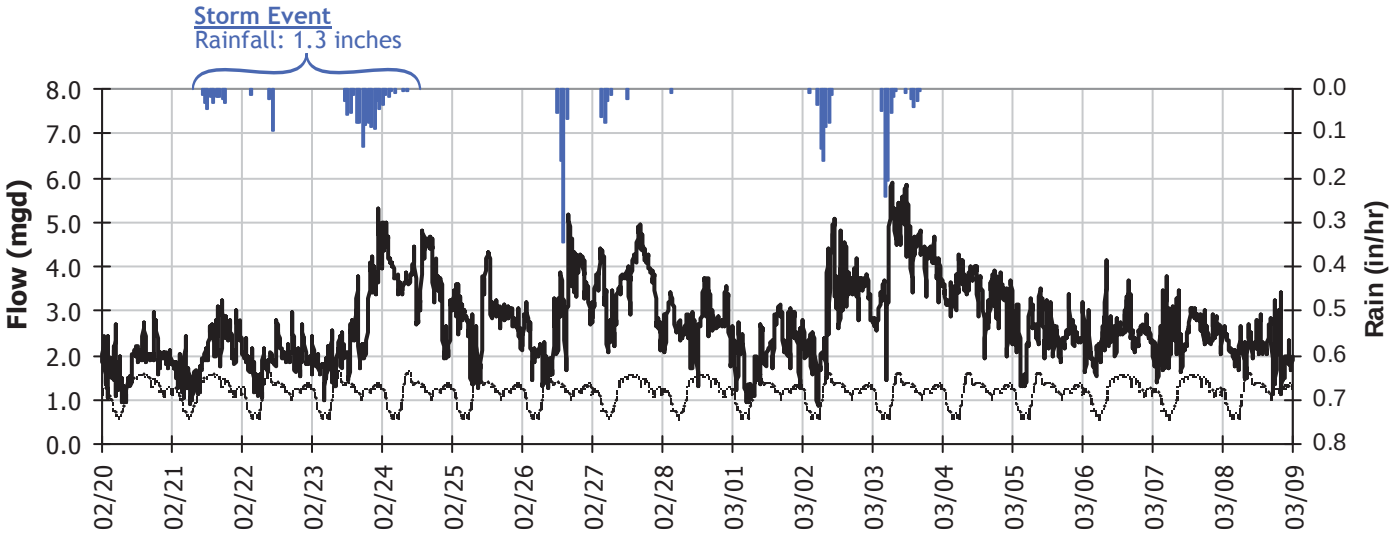


Multiple Events I/I Analysis

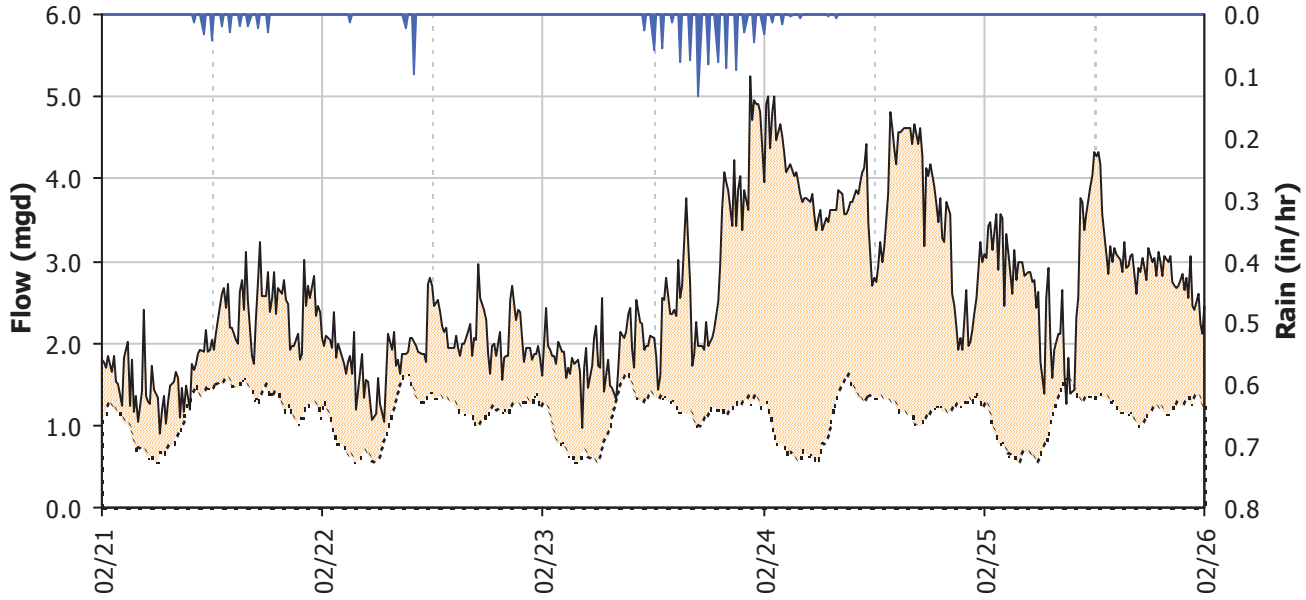
Rainfall:	8.57	*inches*	**Baseline Flow:**	1.13	*mgd*
Peak Flow:	5.88	*mgd*	**PF:**	5.22	
Peak I/I Rate:	5.05	*mgd*	**Pk I/I:ADWF:**	4.48	
Peak Level:	136.13	*inches*	**d/D Ratio:**	2.52	
Total I/I:	59,592,000	*gallons*	**R-Value:**	19.3%	
			I/I per ADWF:	6.2	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 1

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



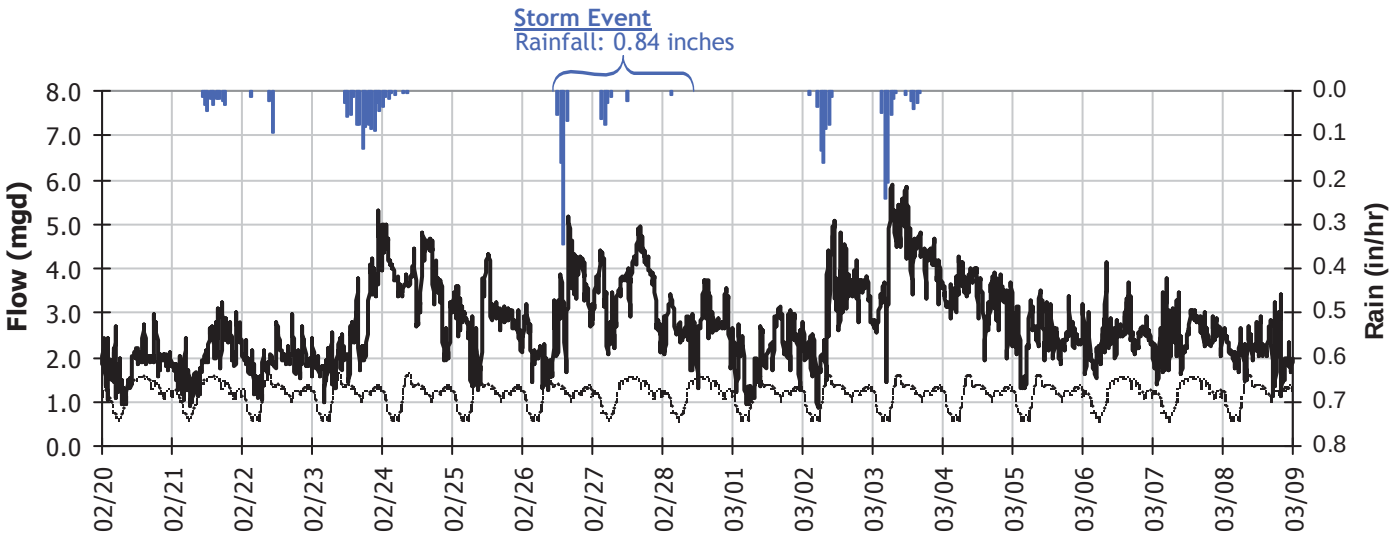
Storm Event #1 I/I Analysis

Rainfall:	1.30	*inches*		
Baseline Flow:	1.13	*mgd*		
Peak Flow:	5.25	*mgd*	**PF:**	4.66
Peak I/I Rate:	4.14	*mgd*	**Pk I/I:ADWF:**	3.68
Peak Level:	130.35	*inches*	**d/D Ratio:**	2.41
Total I/I:	7,335,000	*gallons*	**R-Value:**	15.7%
			I/I per ADWF:	5.02 *per in-rain*

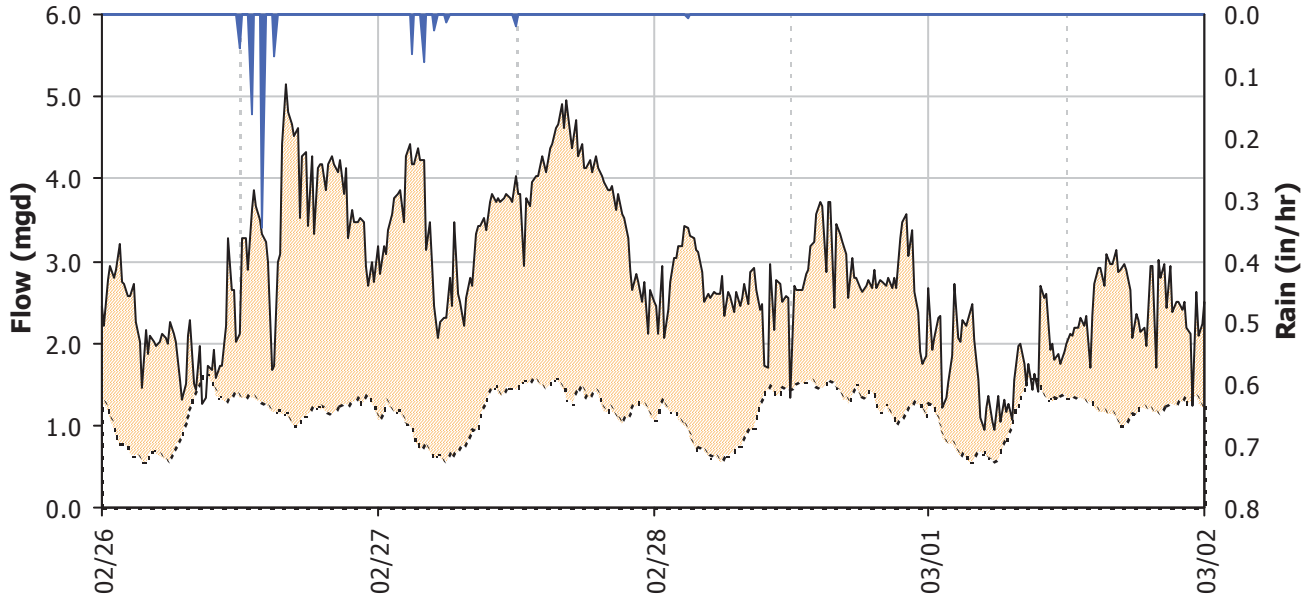
Average Infiltration Rate on 2/25 (% of ADWF): 157.1%

	I/I Summary Event 2	**Monitoring Site:** Site 1

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



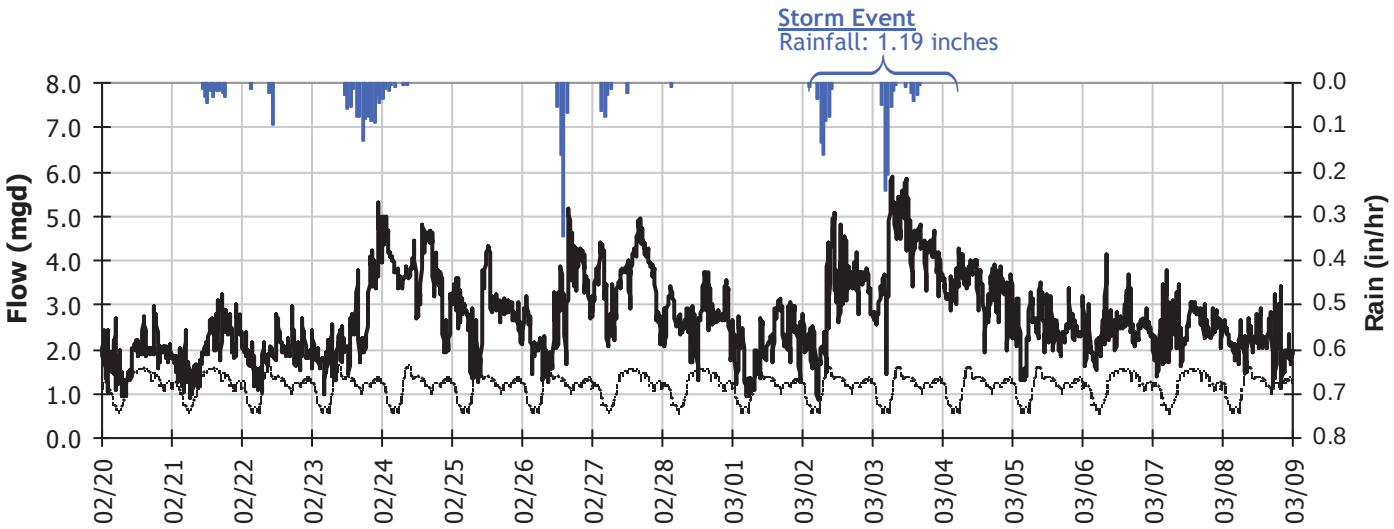
Storm Event #2 I/I Analysis

Rainfall:	0.84	*inches*		
Baseline Flow:	1.13	*mgd*		
Peak Flow:	5.15	*mgd*	**PF:**	4.57
Peak I/I Rate:	4.01	*mgd*	**Pk I/I:ADWF:**	3.56
Peak Level:	110.52	*inches*	**d/D Ratio:**	2.05
Total I/I:	6,814,000	*gallons*	**R-Value:**	22.5%
			I/I per ADWF:	7.19 *per in-rain*

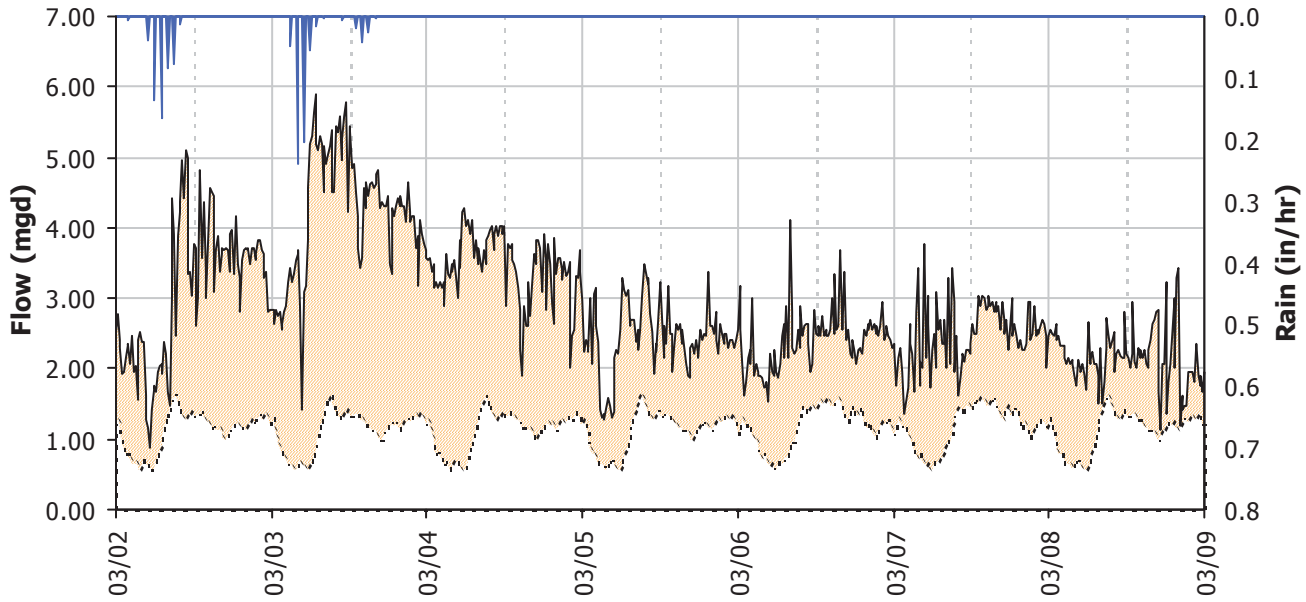
Average Infiltration Rate on 3/1 (% of ADWF): 90.9%

	I/I Summary Event 3	**Monitoring Site:** Site 1

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



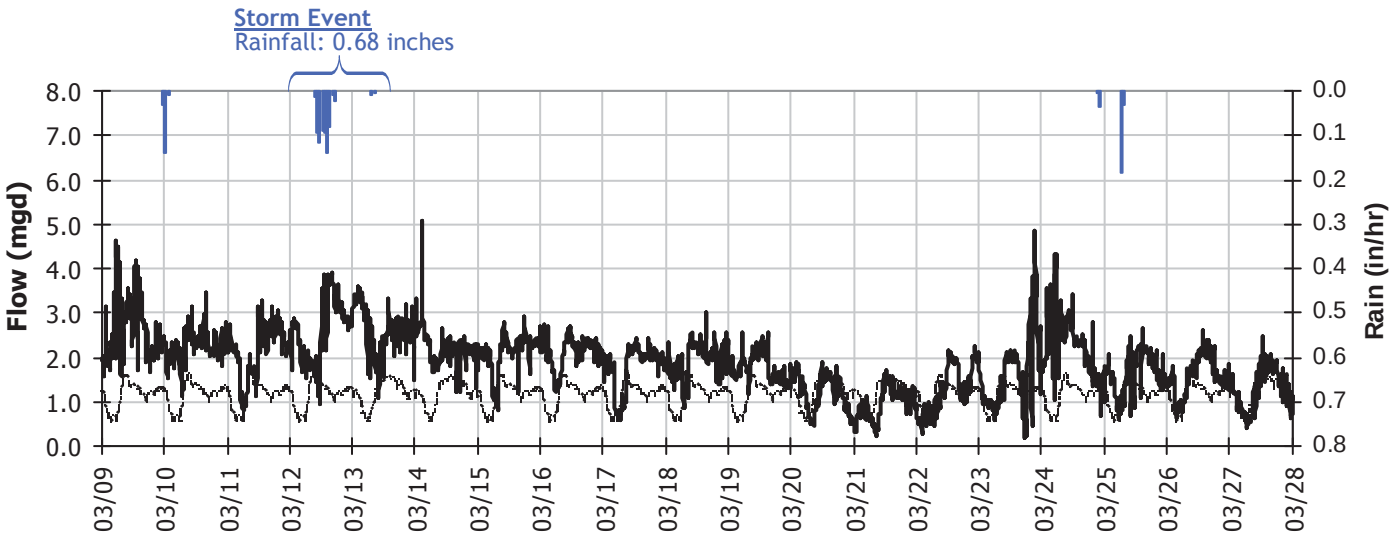
Storm Event #3 I/I Analysis

Rainfall:	1.19	*inches*		
Baseline Flow:	1.13	*mgd*		
Peak Flow:	5.88	*mgd*	**PF:**	5.22
Peak I/I Rate:	5.05	*mgd*	**Pk I/I:ADWF:**	4.48
Peak Level:	132.35	*inches*	**d/D Ratio:**	2.45
Total I/I:	12,359,000	*gallons*	**R-Value:**	28.9%
			I/I per ADWF:	9.24 *per in-rain*

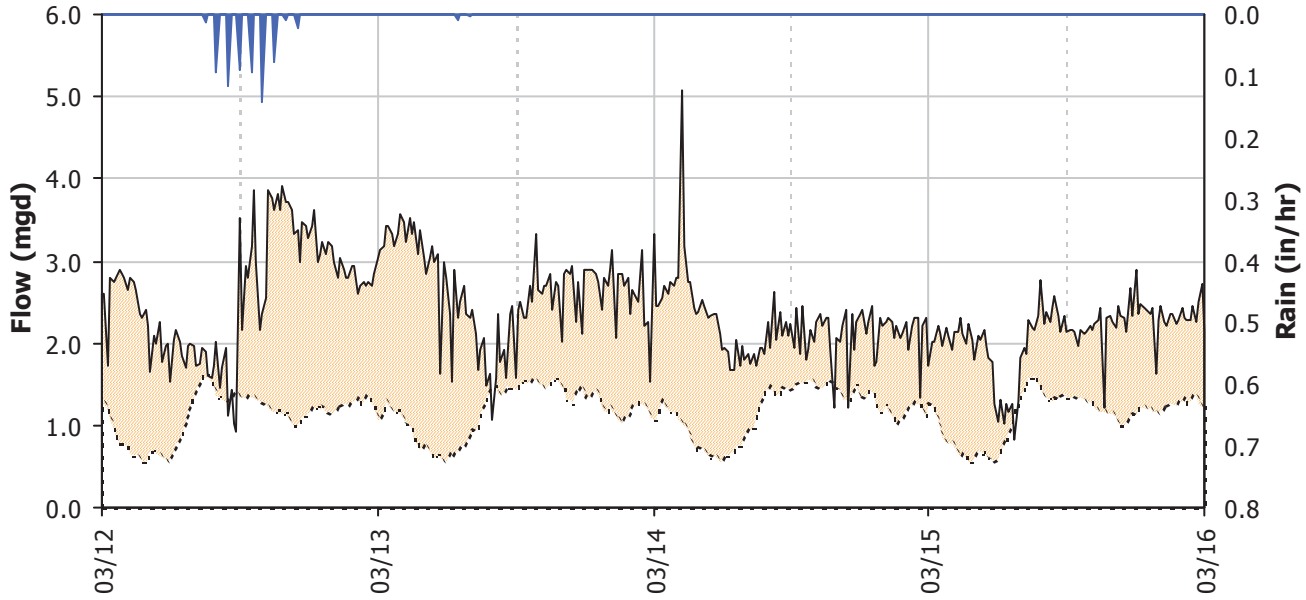
Average Infiltration Rate on 3/5 (% of ADWF): 120.4%

	I/I Summary Event 4	**Monitoring Site:** Site 1

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



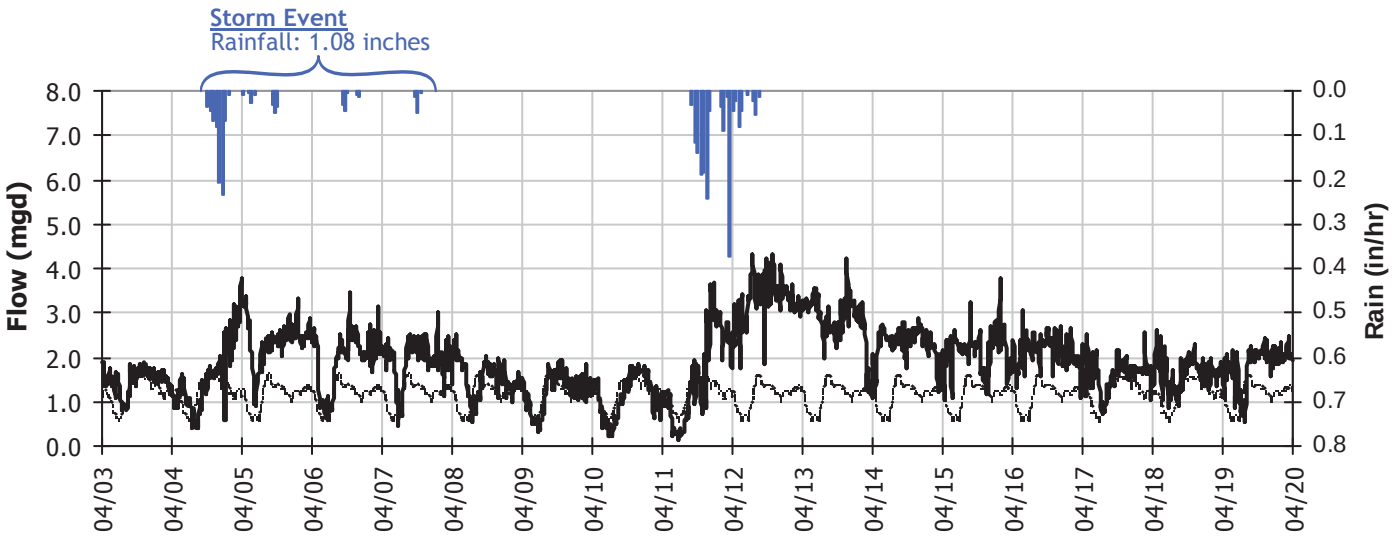
Storm Event #1 I/I Analysis

Rainfall:	0.68	*inches*		
Baseline Flow:	1.13	*mgd*		
Peak Flow:	5.07	*mgd*	**PF:**	4.50
Peak I/I Rate:	4.06	*mgd*	**Pk I/I:ADWF:**	3.60
Peak Level:	116.26	*inches*	**d/D Ratio:**	2.15
Total I/I:	4,995,000	*gallons*	**R-Value:**	20.4%
			I/I per ADWF:	6.53 *per in-rain*

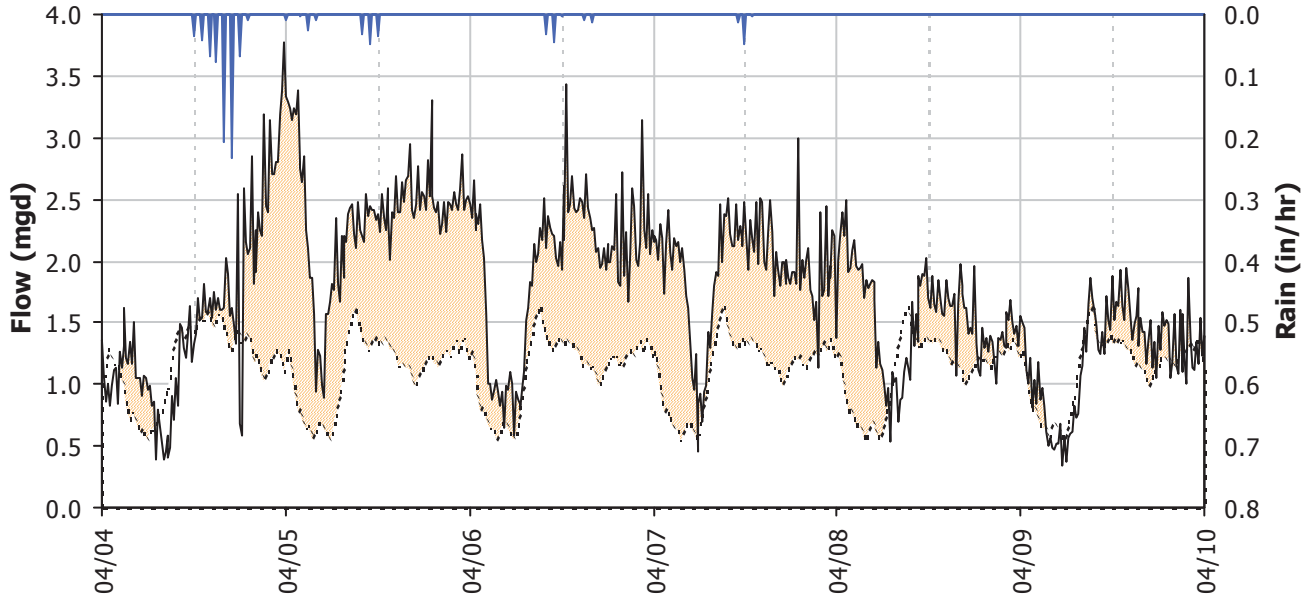
Average Infiltration Rate on 3/14 (% of ADWF): 89.6%

	I/I Summary Event 5	**Monitoring Site:** Site 1

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



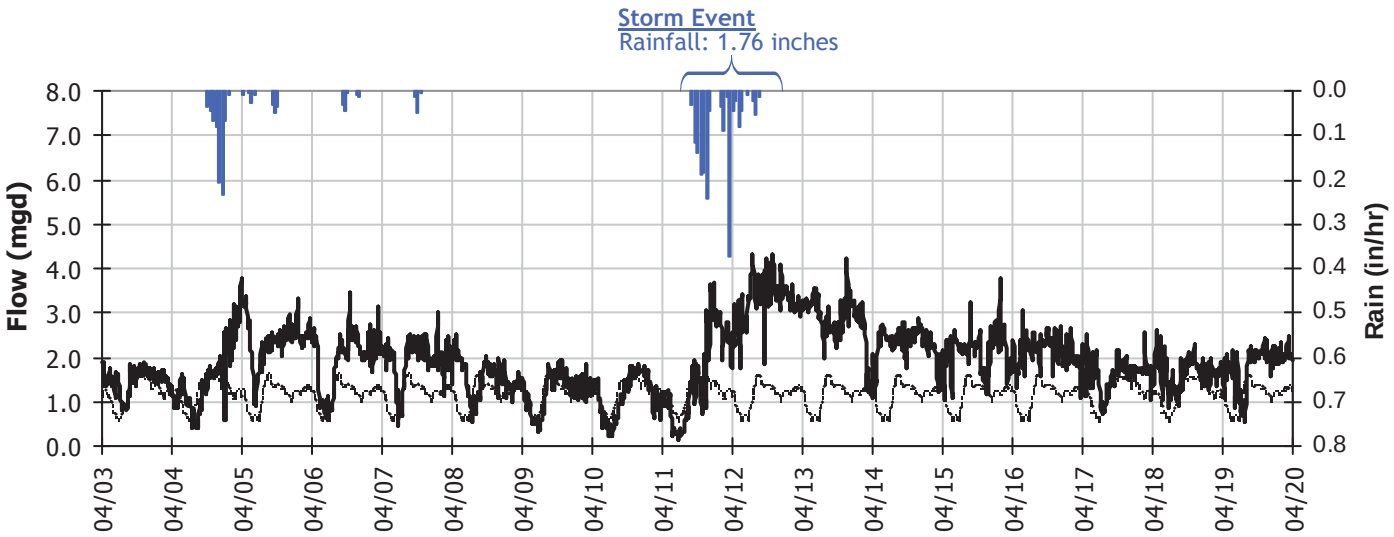
Storm Event #5 I/I Analysis

Rainfall:	1.08	*inches*		
Baseline Flow:	1.13	*mgd*		
Peak Flow:	3.78	*mgd*	**PF:**	3.35
Peak I/I Rate:	2.68	*mgd*	**Pk I/I:ADWF:**	2.38
Peak Level:	96.82	*inches*	**d/D Ratio:**	1.79
Total I/I:	3,806,000	*gallons*	**R-Value:**	9.8%
			I/I per ADWF:	3.12 *per in-rain*

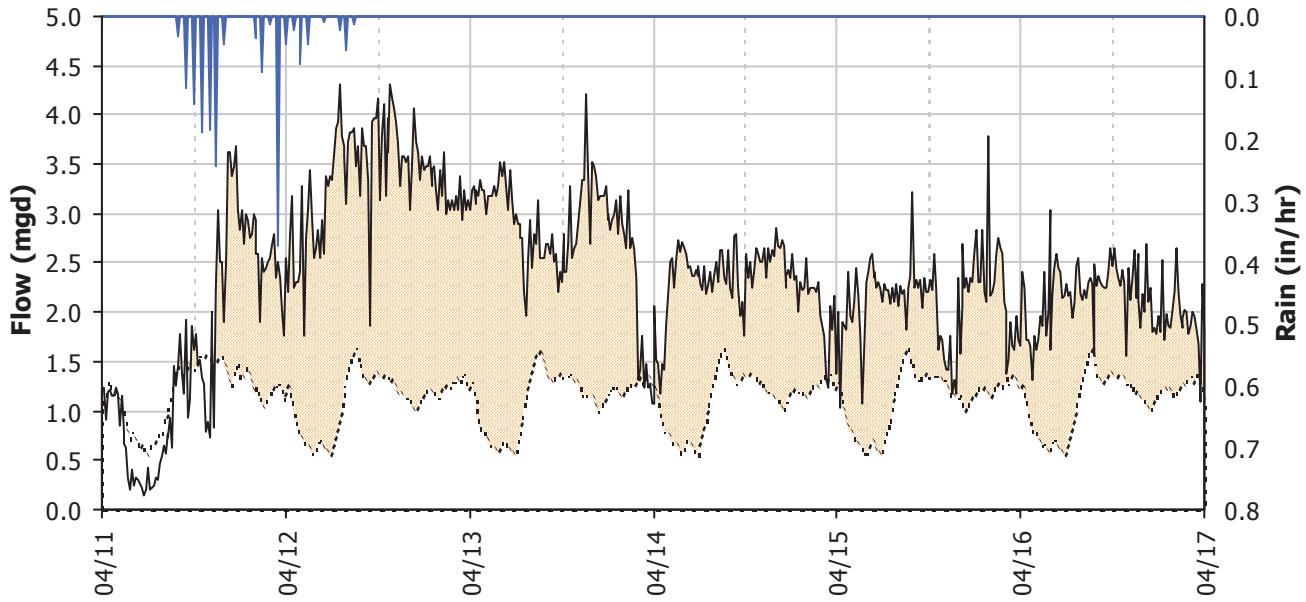
Average Infiltration Rate on 4/8 (% of ADWF): 37.9%

	I/I Summary Event 6	**Monitoring Site:** Site 1

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



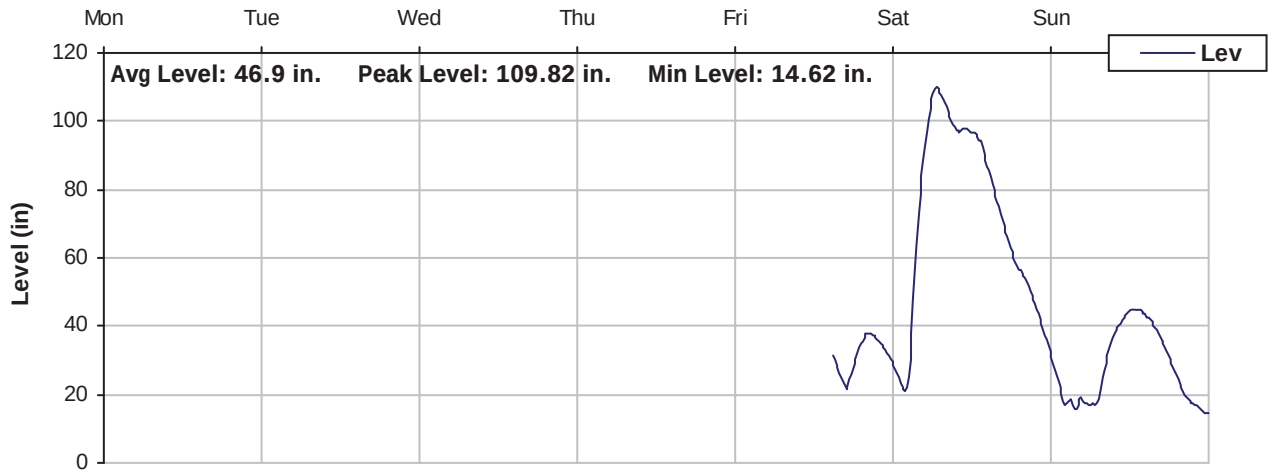
Storm Event #6 I/I Analysis

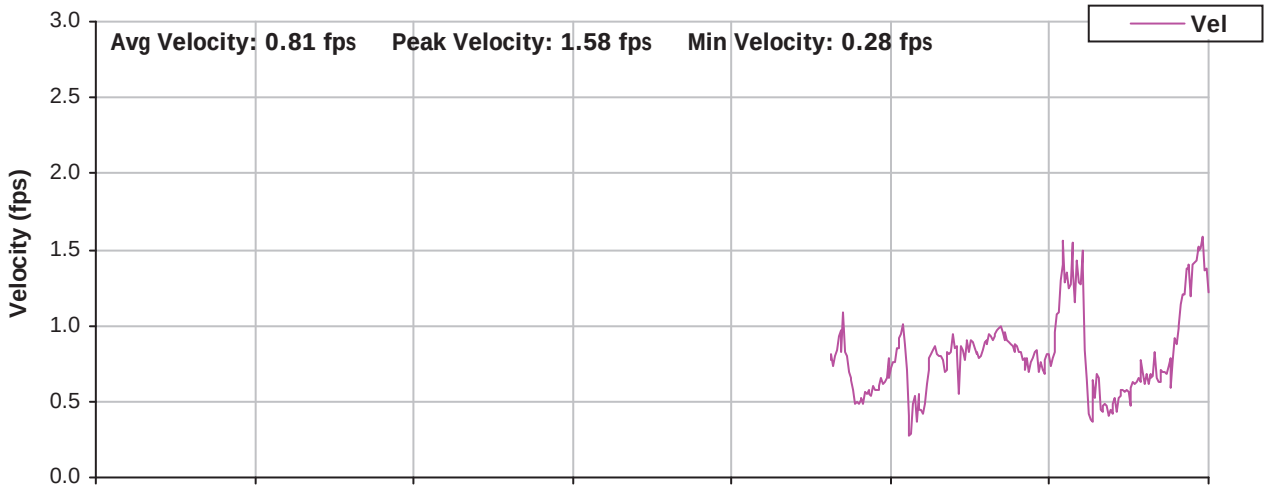
Rainfall:	1.76	*inches*		
Baseline Flow:	1.13	*mgd*		
Peak Flow:	4.31	*mgd*	**PF:**	3.83
Peak I/I Rate:	3.42	*mgd*	**Pk I/I:ADWF:**	3.04
Peak Level:	136.13	*inches*	**d/D Ratio:**	2.52
Total I/I:	7,542,000	*gallons*	**R-Value:**	11.9%
			I/I per ADWF:	3.80 *per in-rain*

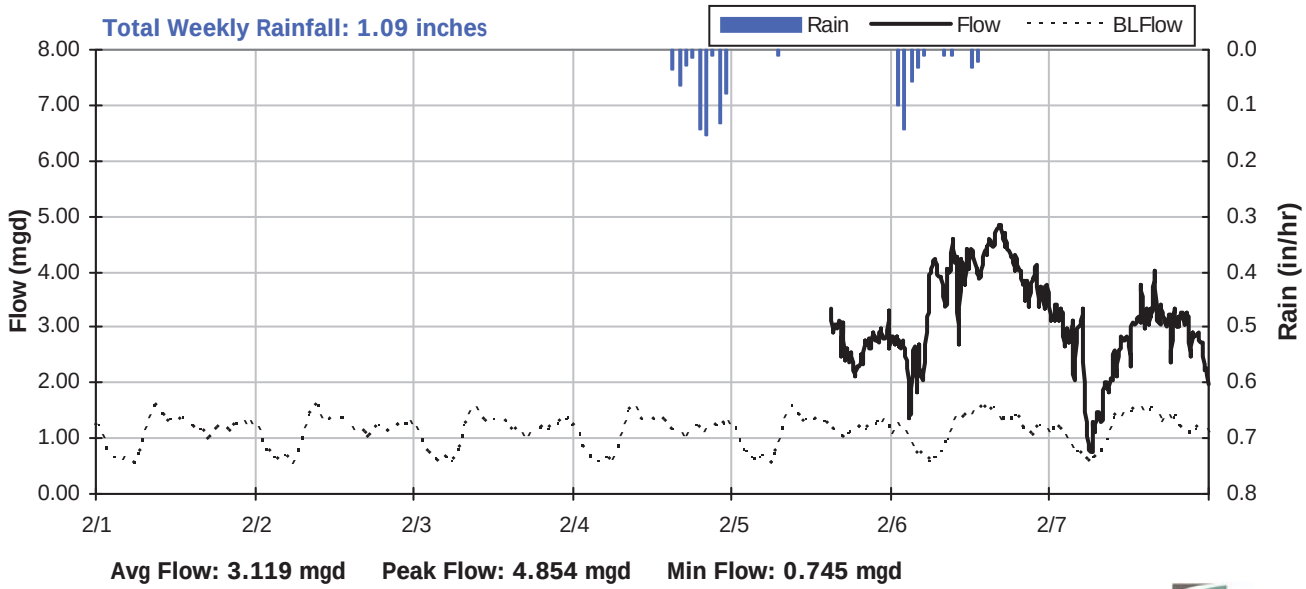
Average Infiltration Rate on 4/14 (% of ADWF): 104.6%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 1



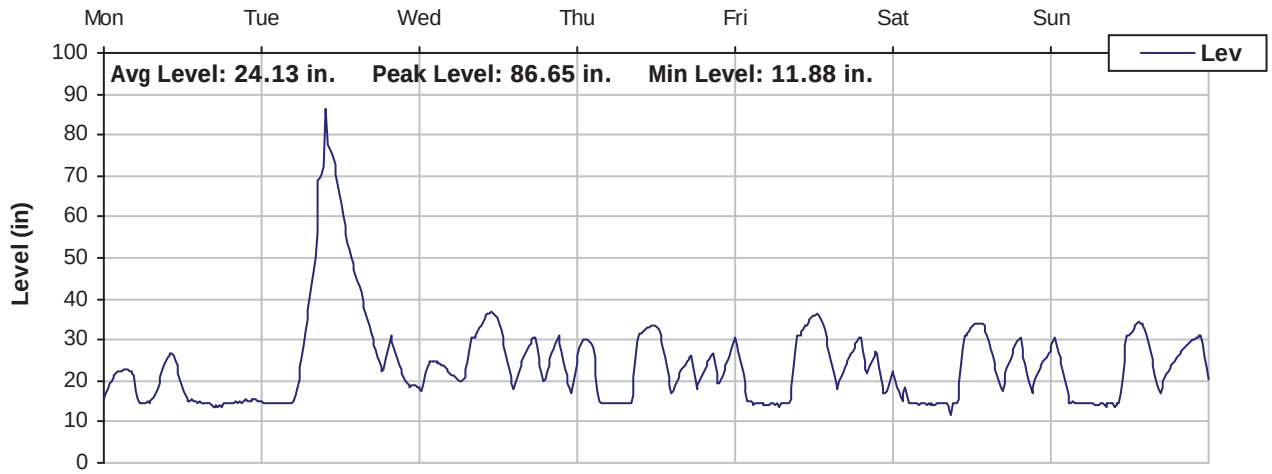


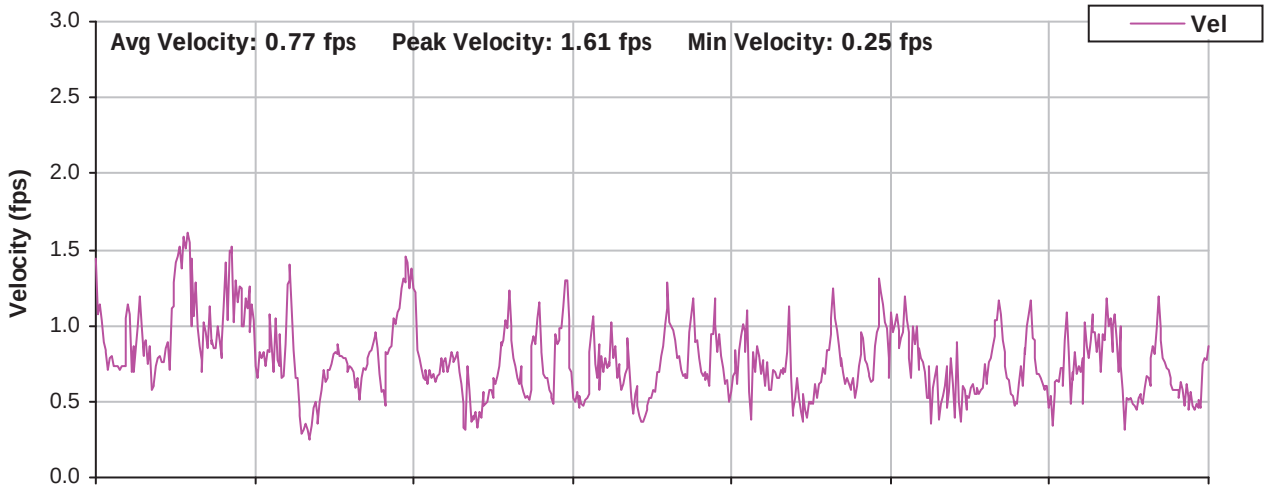


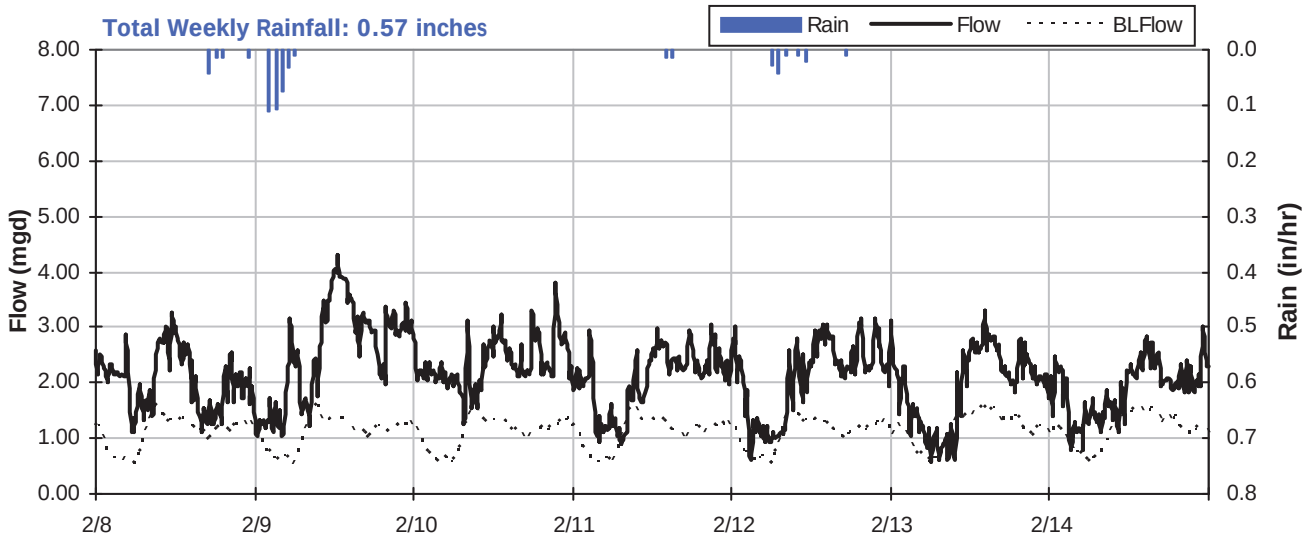
Avg Flow: 3.119 mgd **Peak Flow: 4.854 mgd** **Min Flow: 0.745 mgd**

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 1







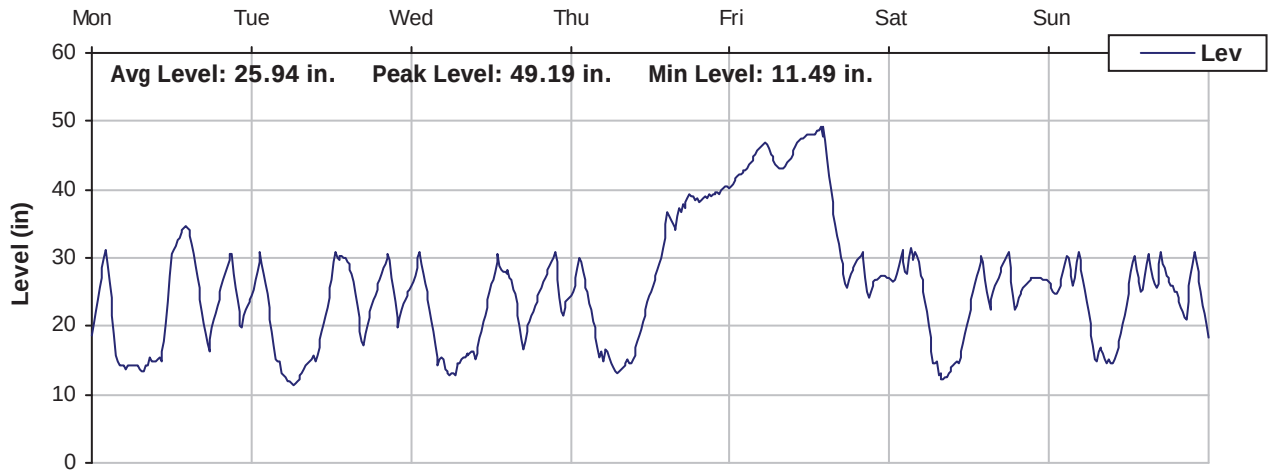
Avg Flow: 2.134 mgd **Peak Flow: 4.315 mgd** **Min Flow: 0.557 mgd**

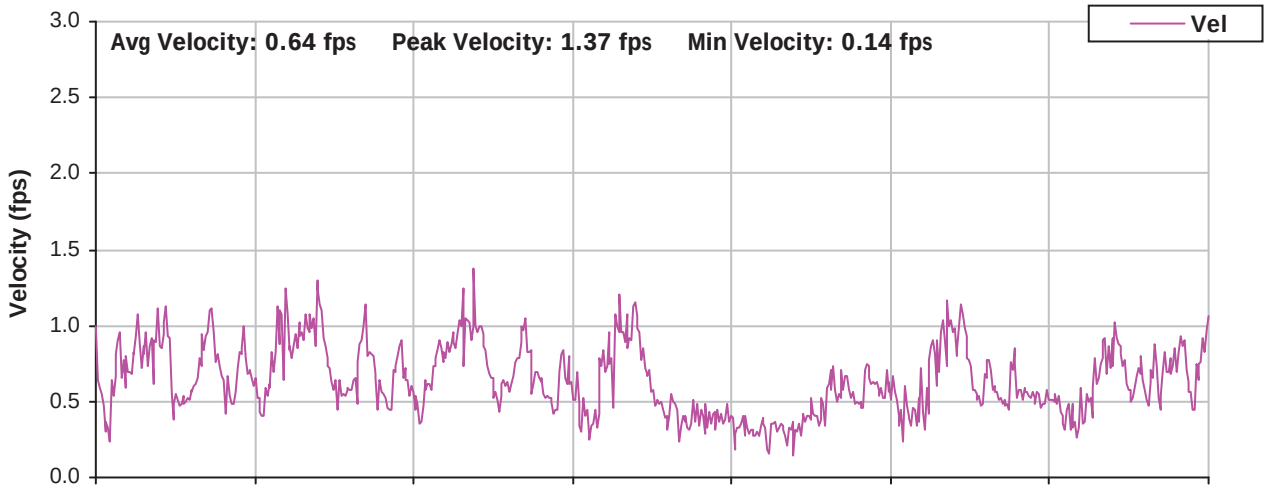
Level, Velocity and Flow

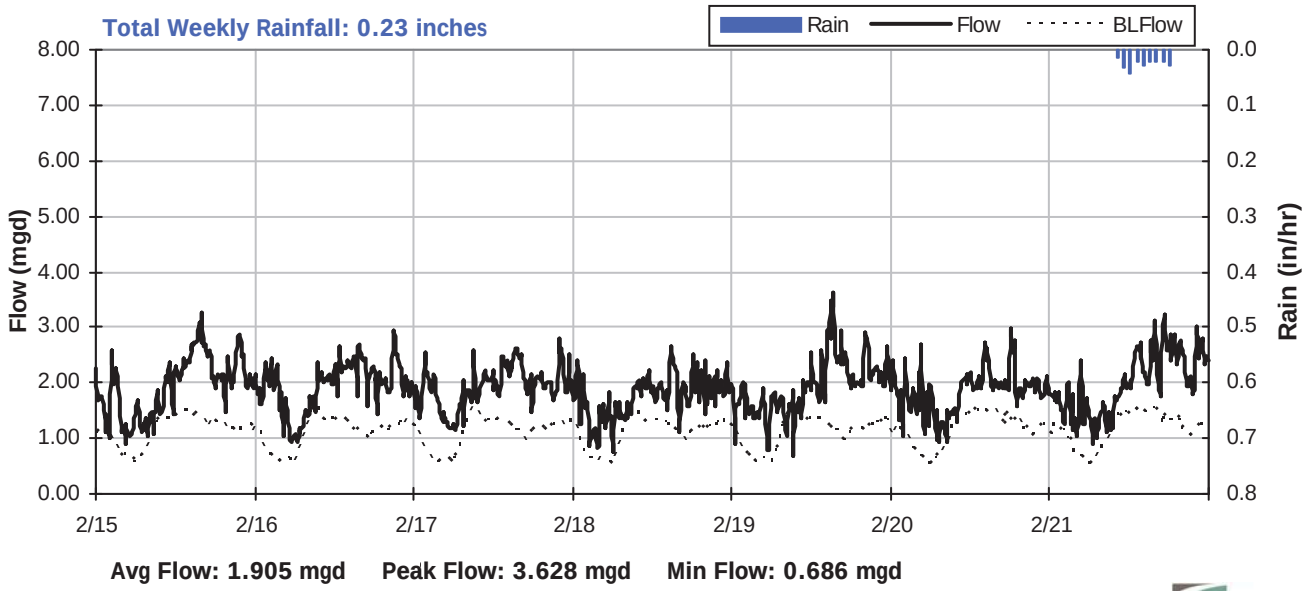
From 2/15/2010 to 2/22/2010

Monitoring Site:

Site 1



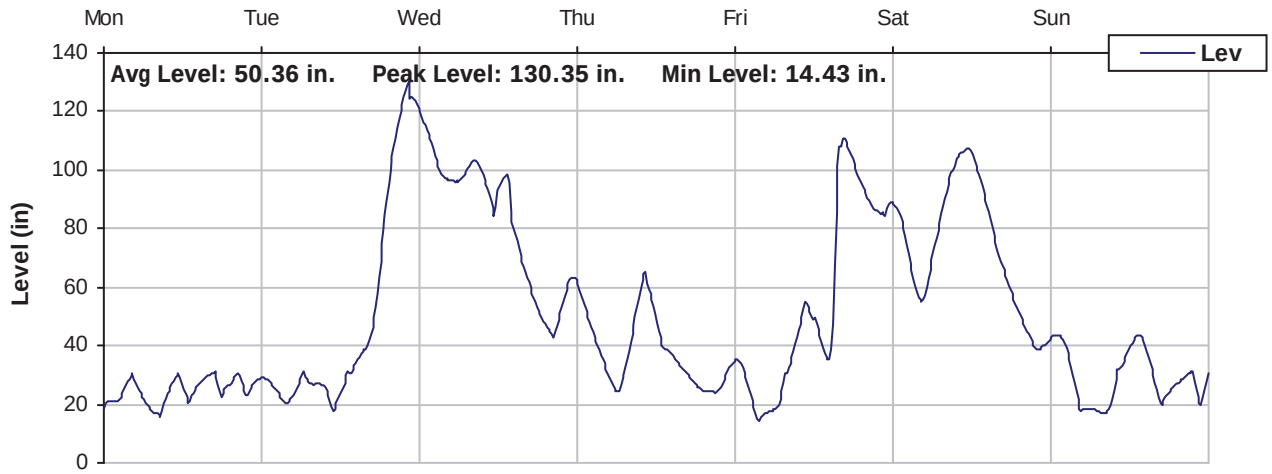


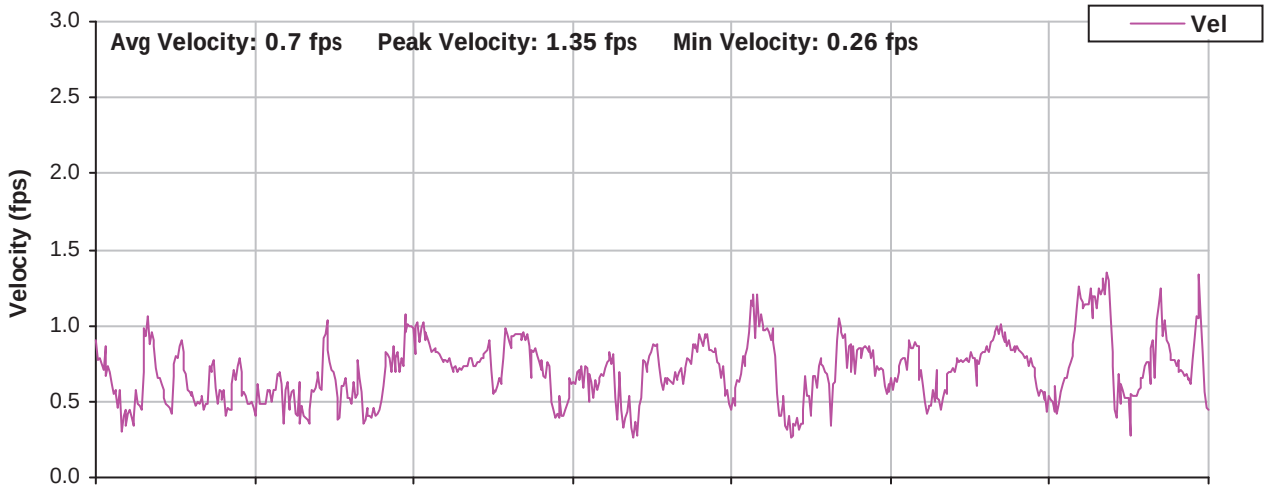


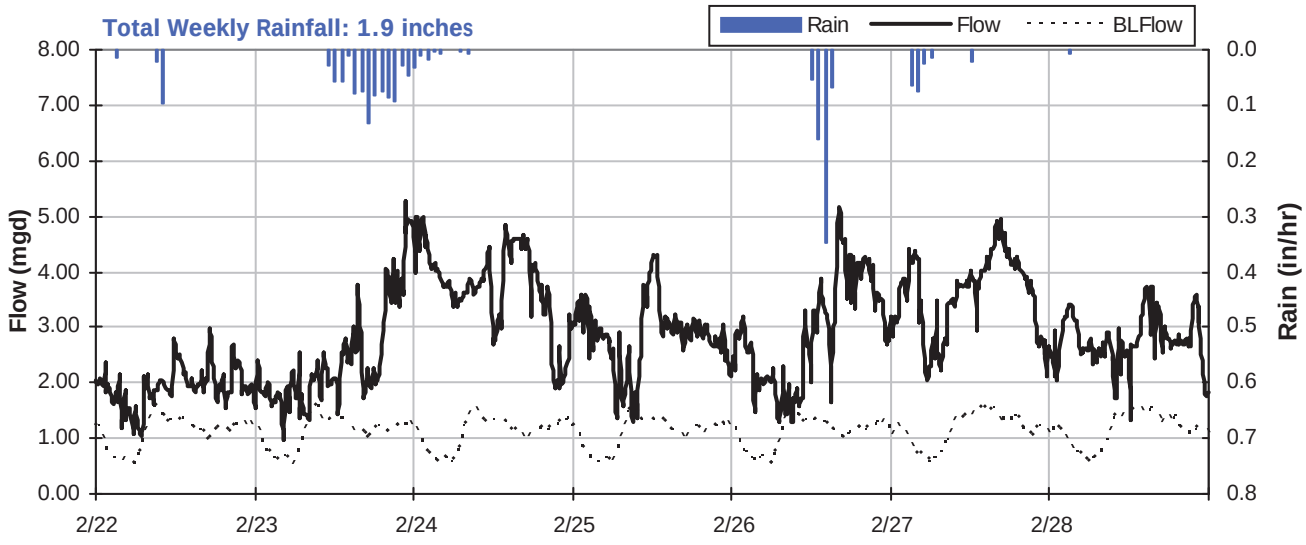
Avg Flow: 1.905 mgd **Peak Flow: 3.628 mgd** **Min Flow: 0.686 mgd**

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 1



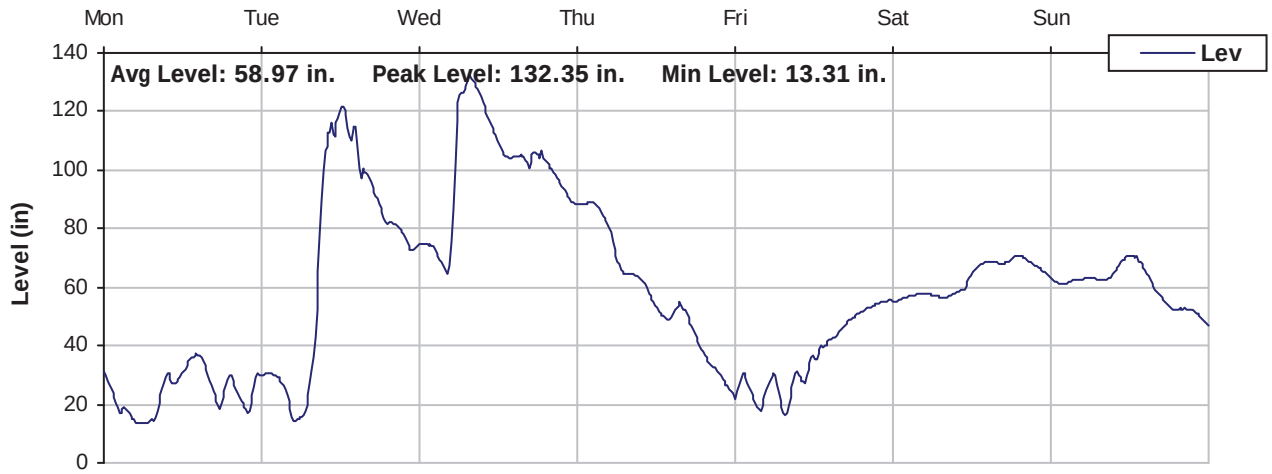


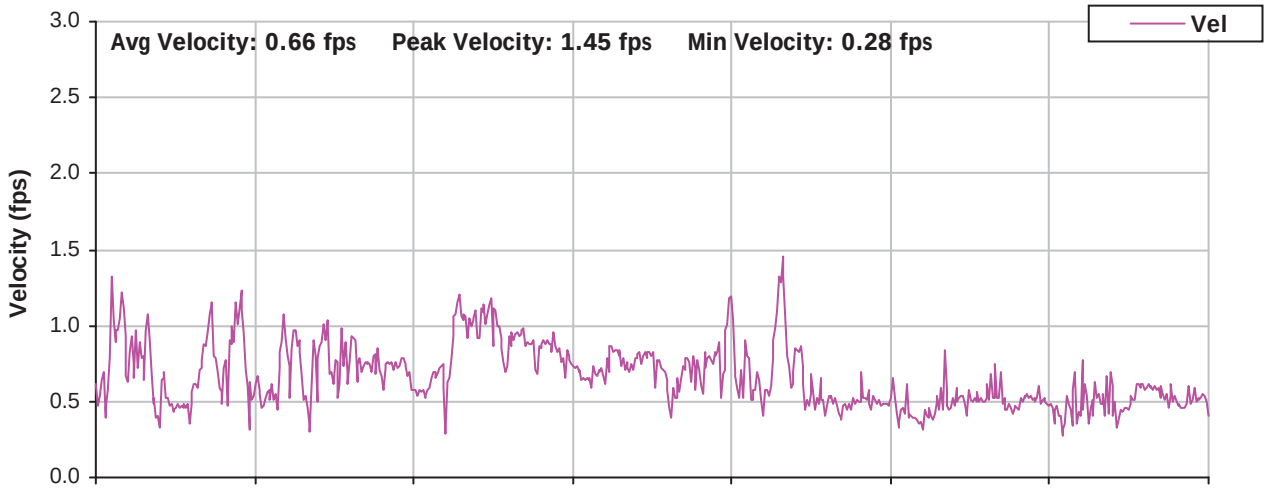


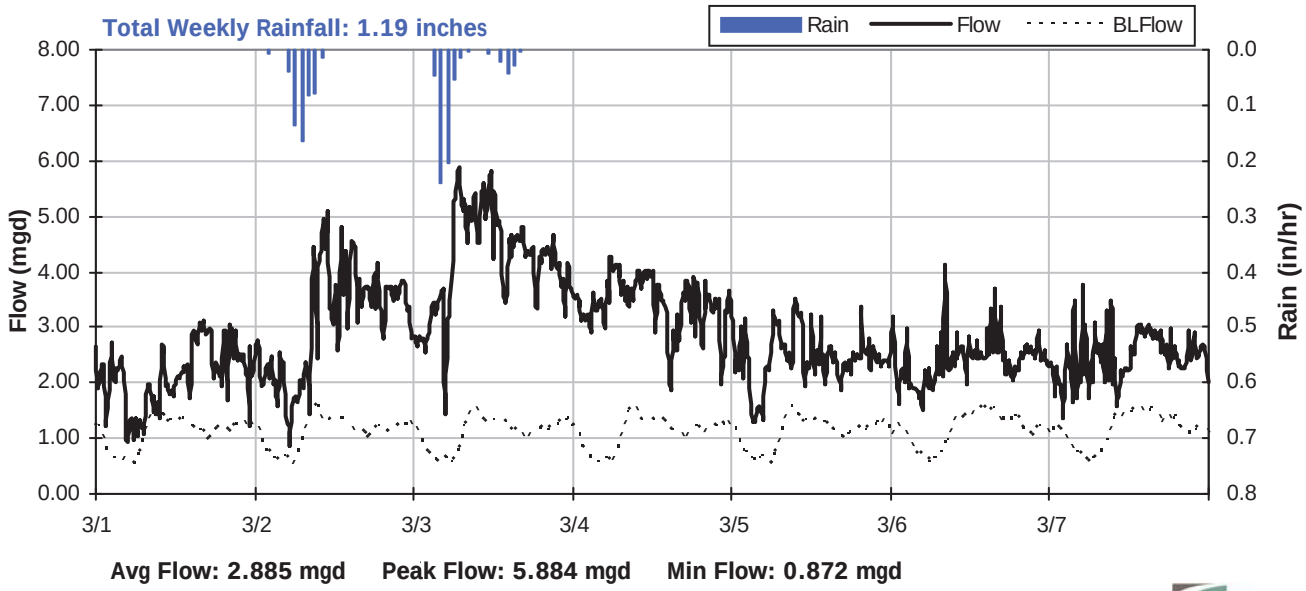
Avg Flow: 2.884 mgd **Peak Flow: 5.246 mgd** **Min Flow: 0.977 mgd**

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 1



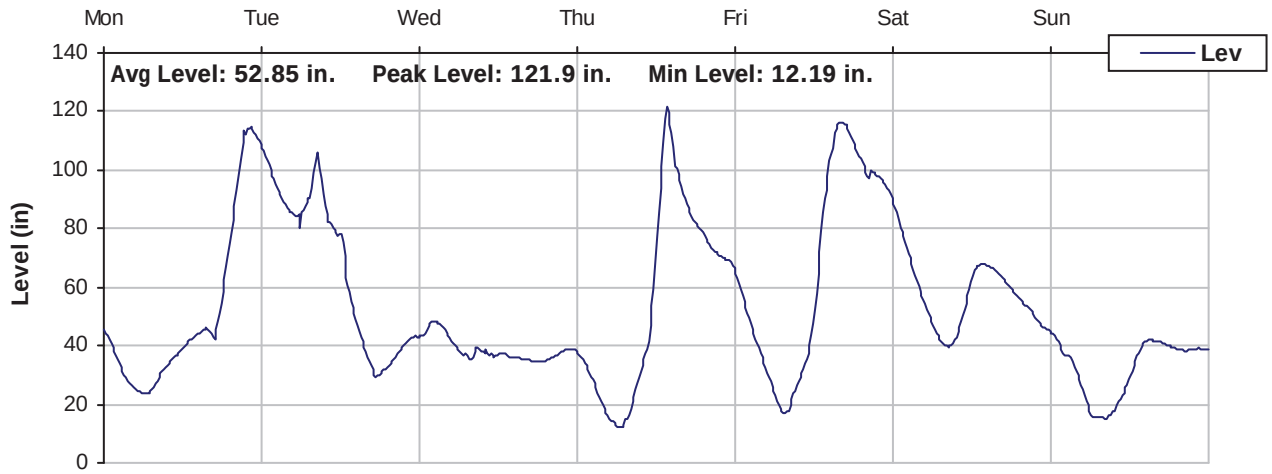


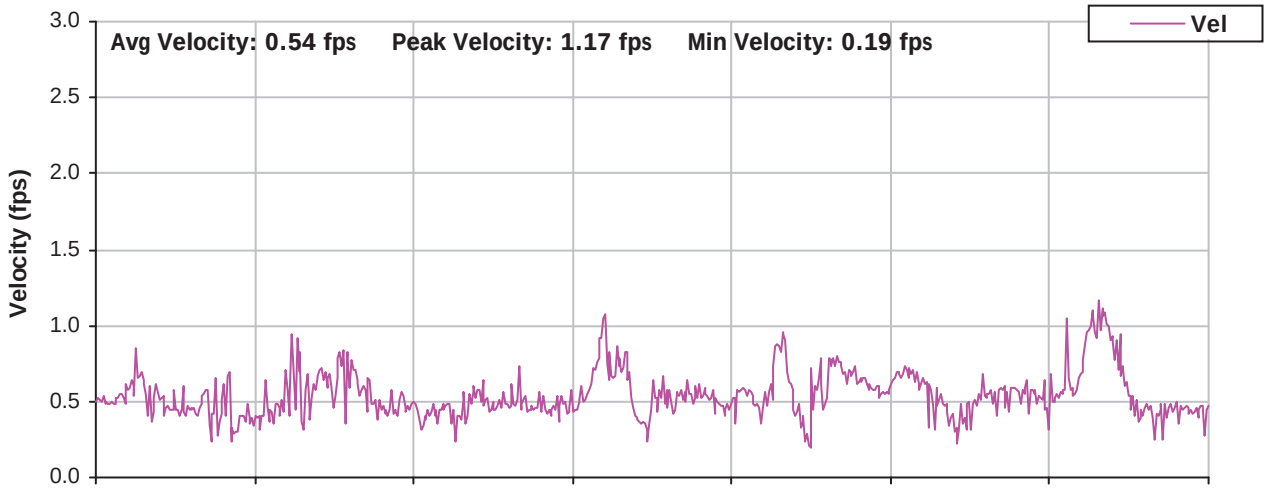


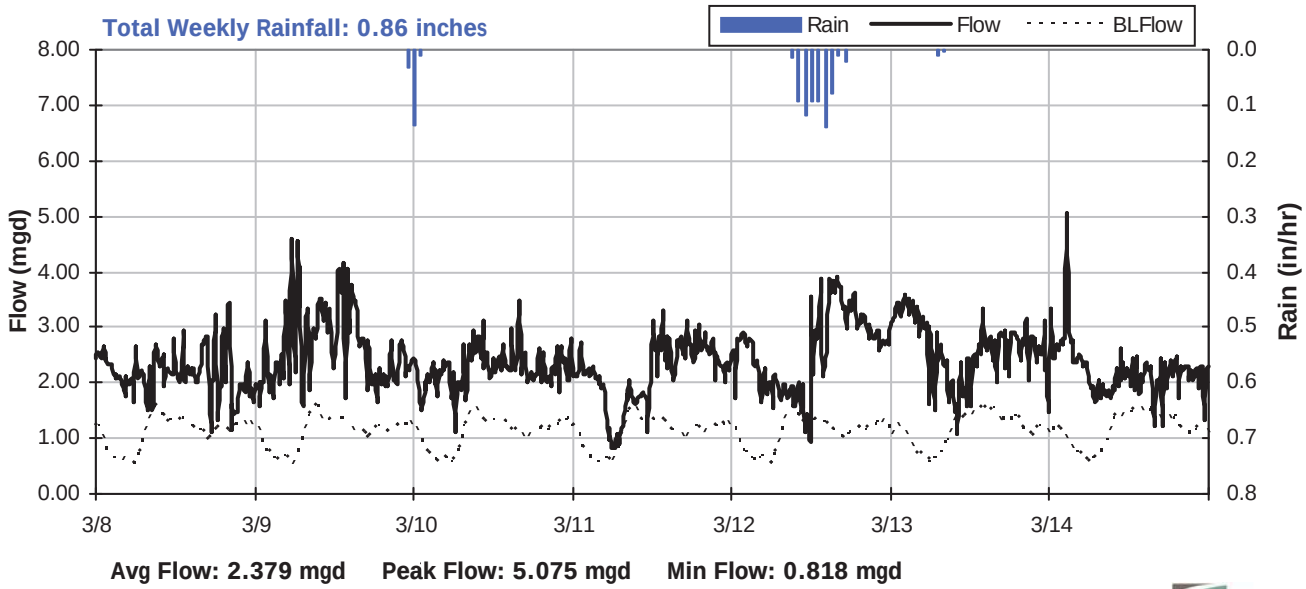
Avg Flow: 2.885 mgd **Peak Flow: 5.884 mgd** **Min Flow: 0.872 mgd**

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 1







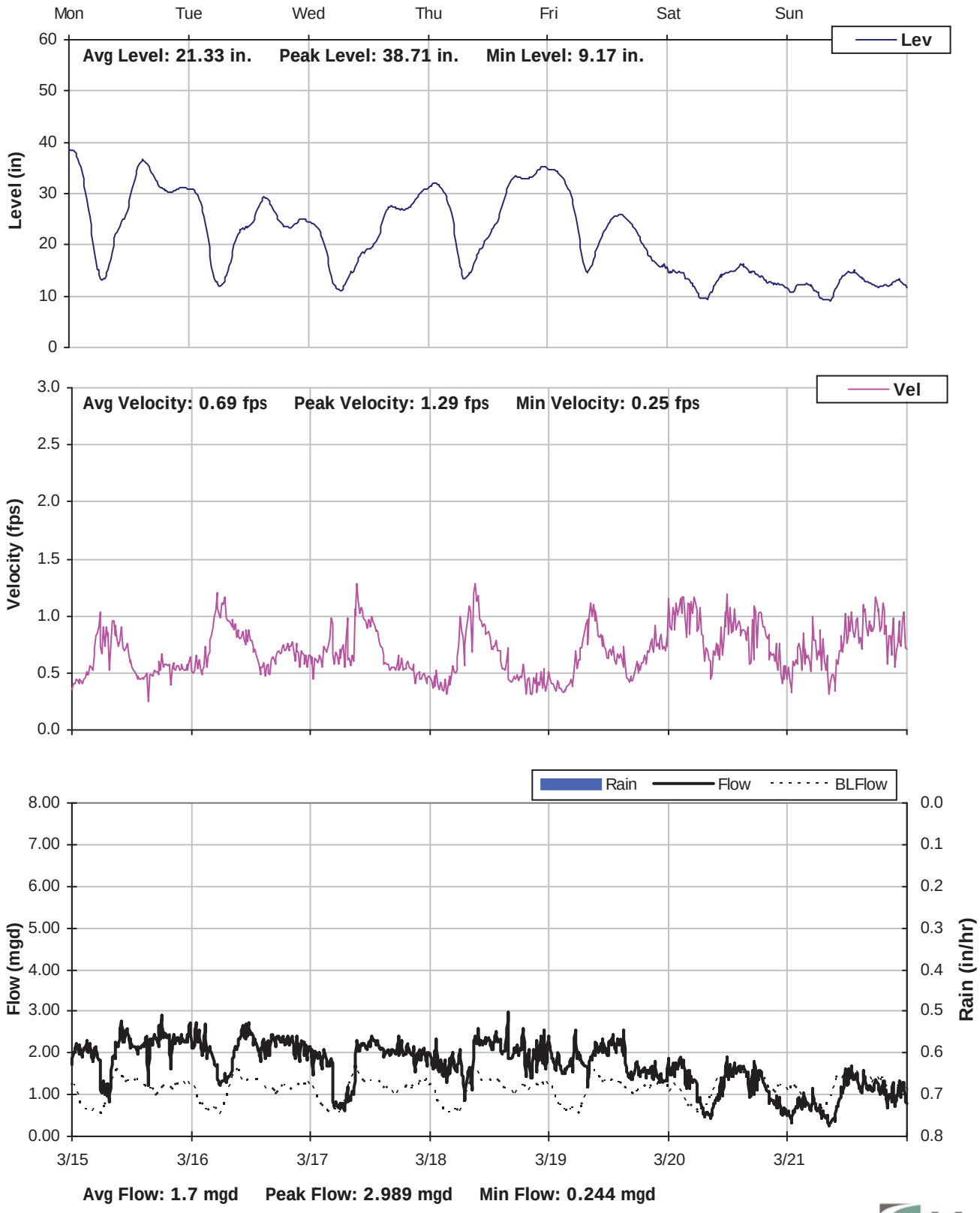
Avg Flow: 2.379 mgd **Peak Flow: 5.075 mgd** **Min Flow: 0.818 mgd**

Level, Velocity and Flow

From 3/15/2010 to 3/22/2010

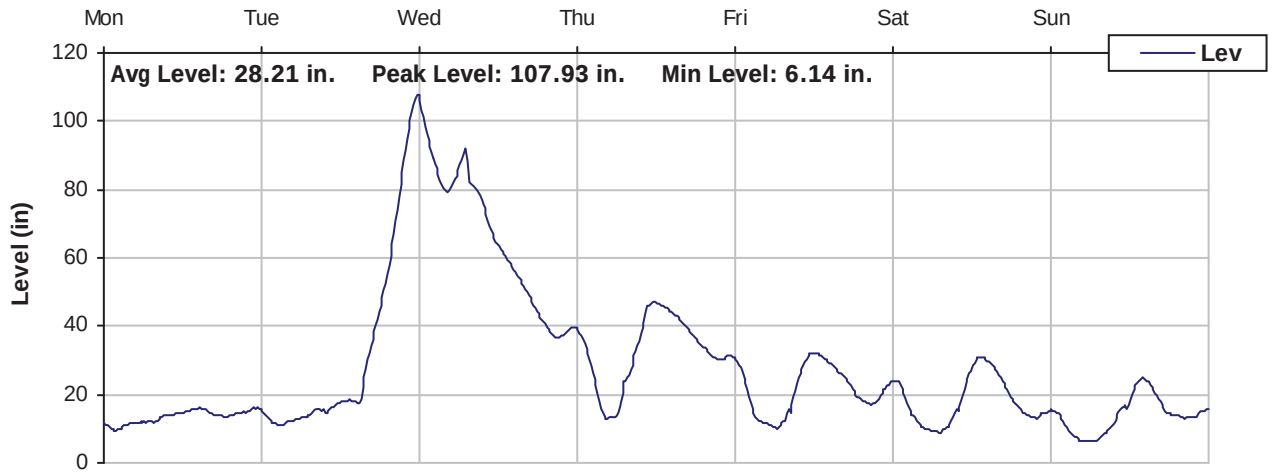
Monitoring Site:

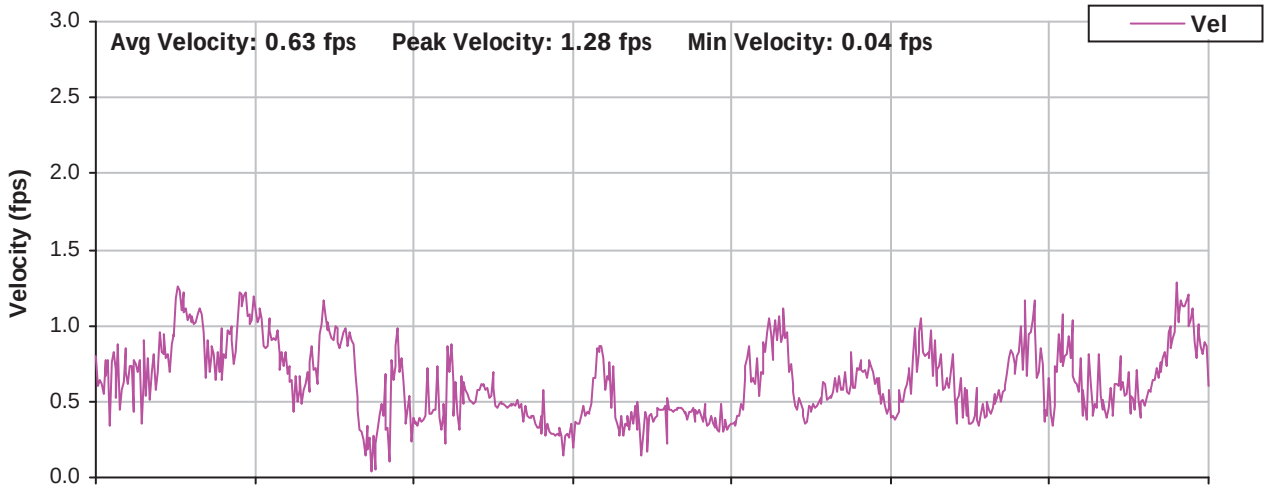
Site 1

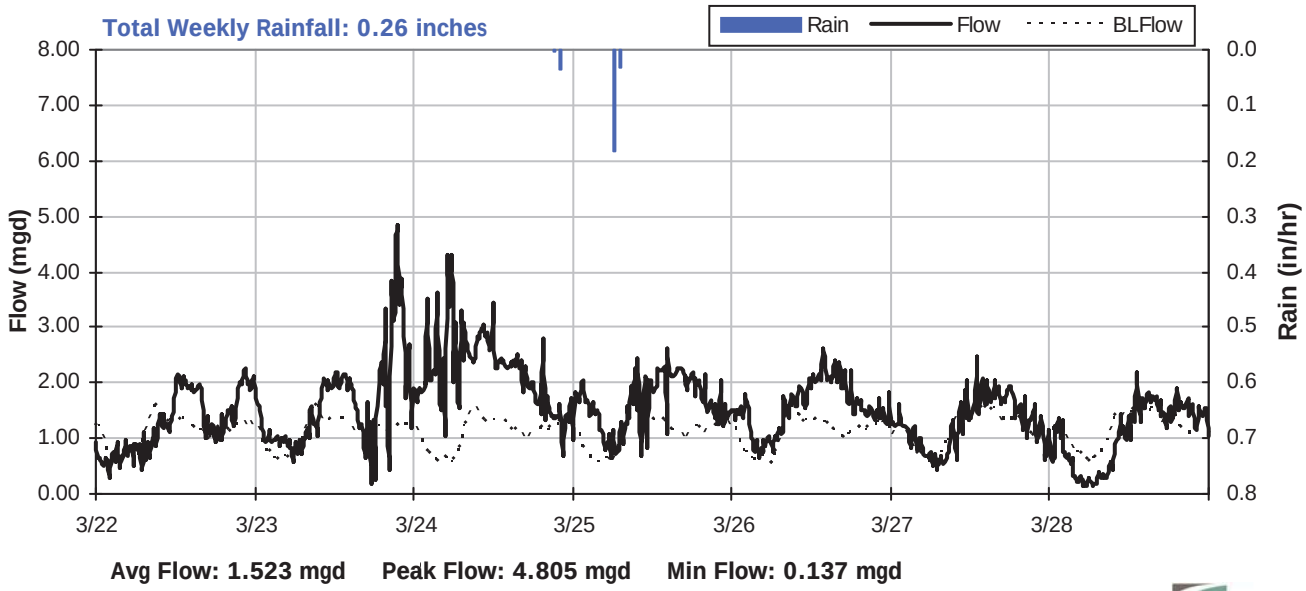


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 1



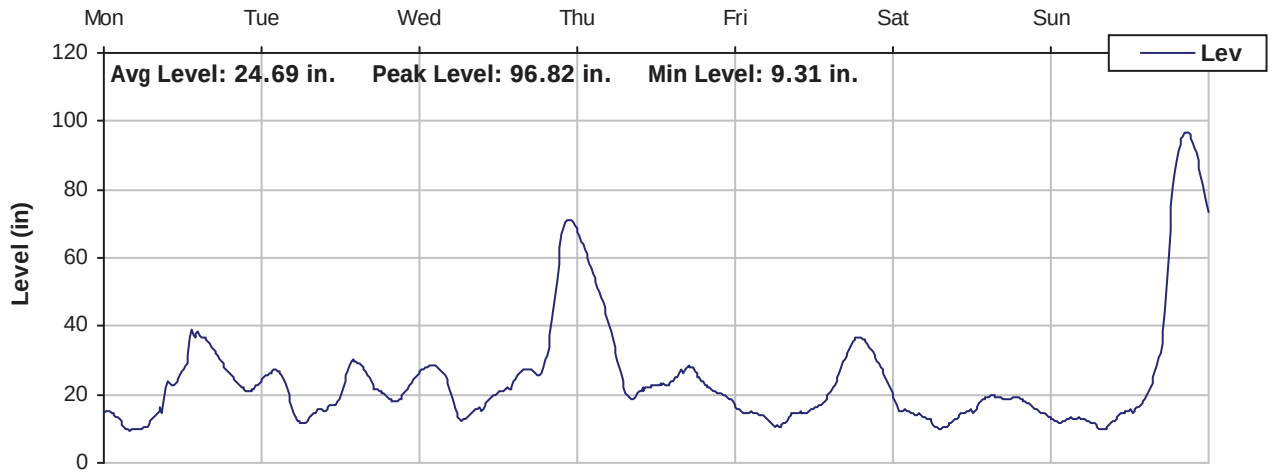


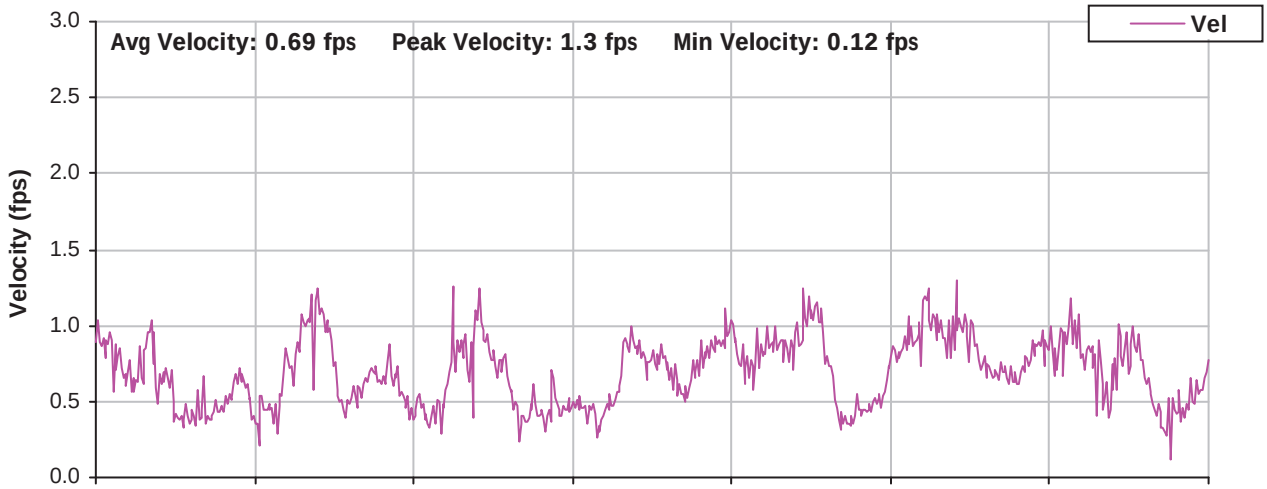


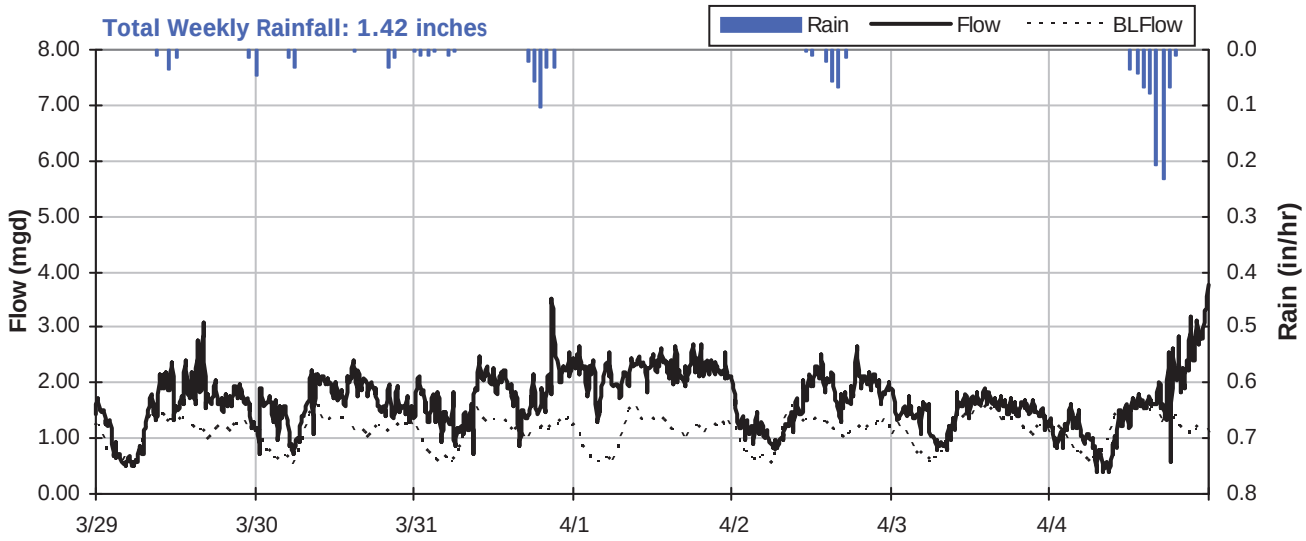
Avg Flow: 1.523 mgd Peak Flow: 4.805 mgd Min Flow: 0.137 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 1



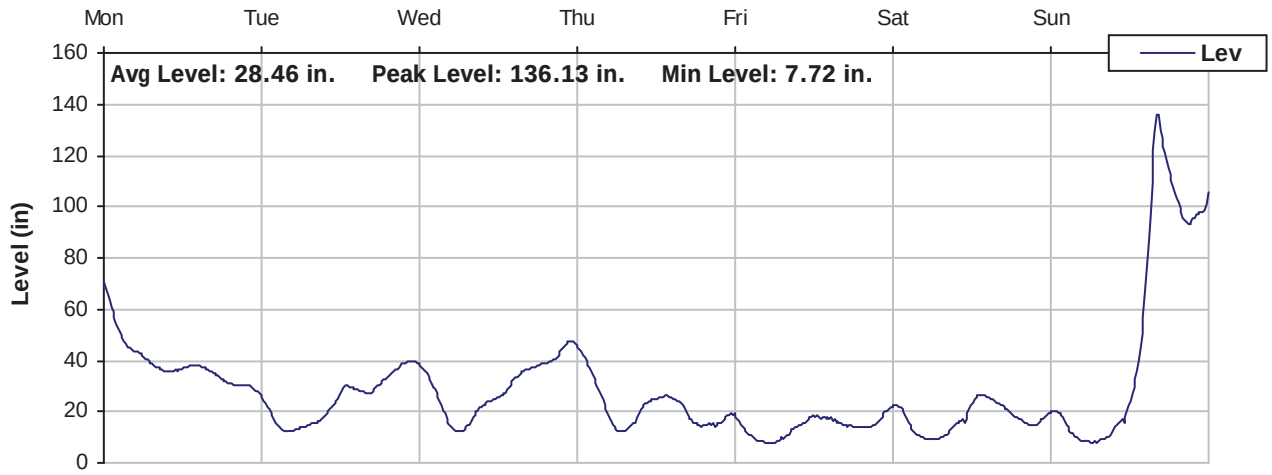


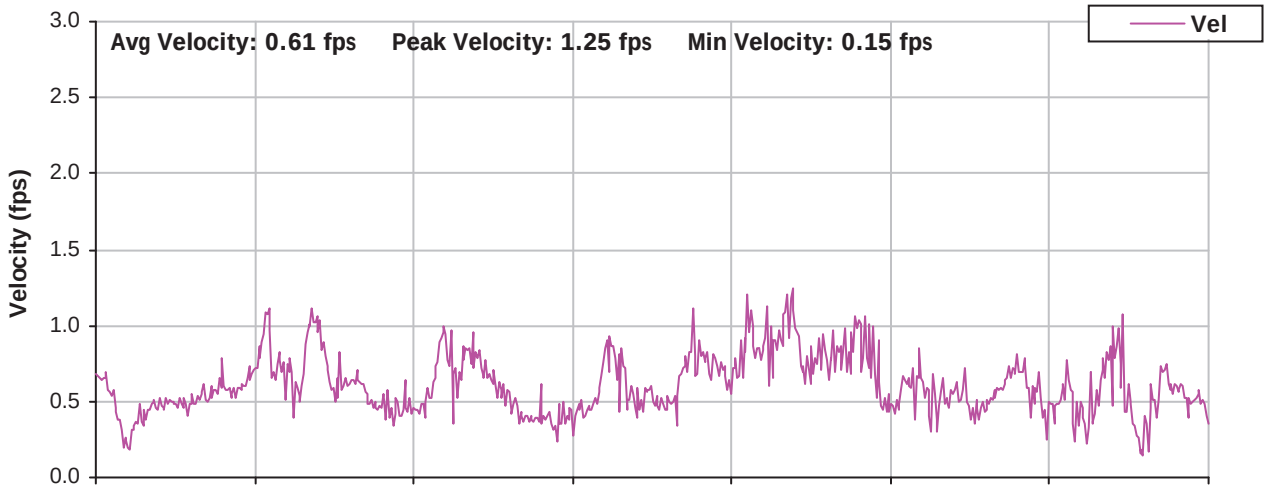


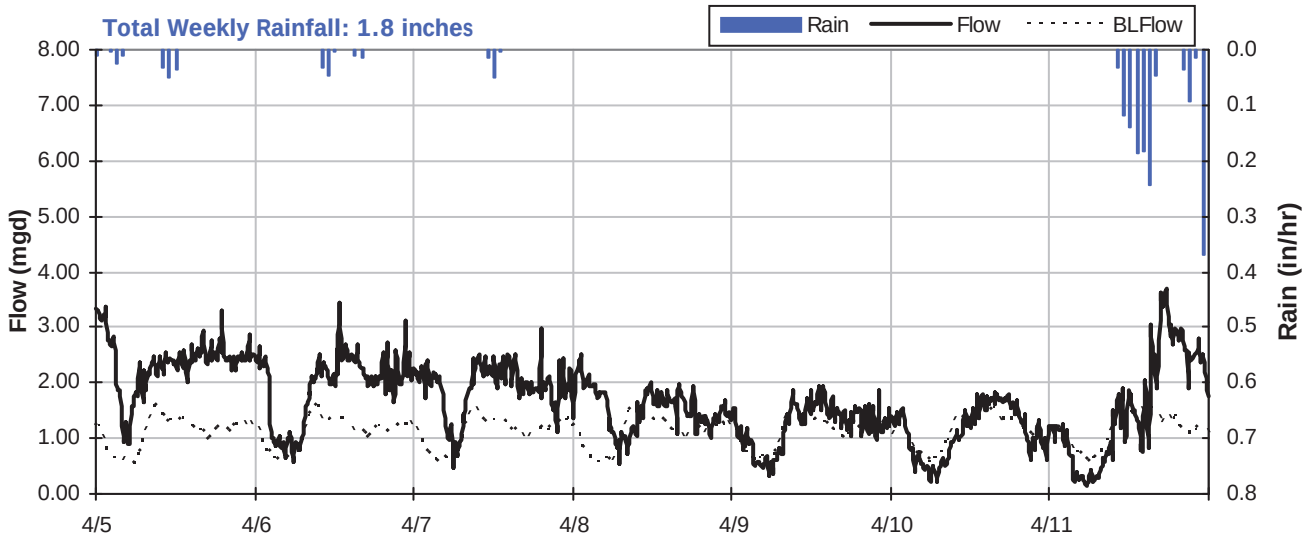
Avg Flow: 1.677 mgd **Peak Flow: 3.775 mgd** **Min Flow: 0.384 mgd**

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 1







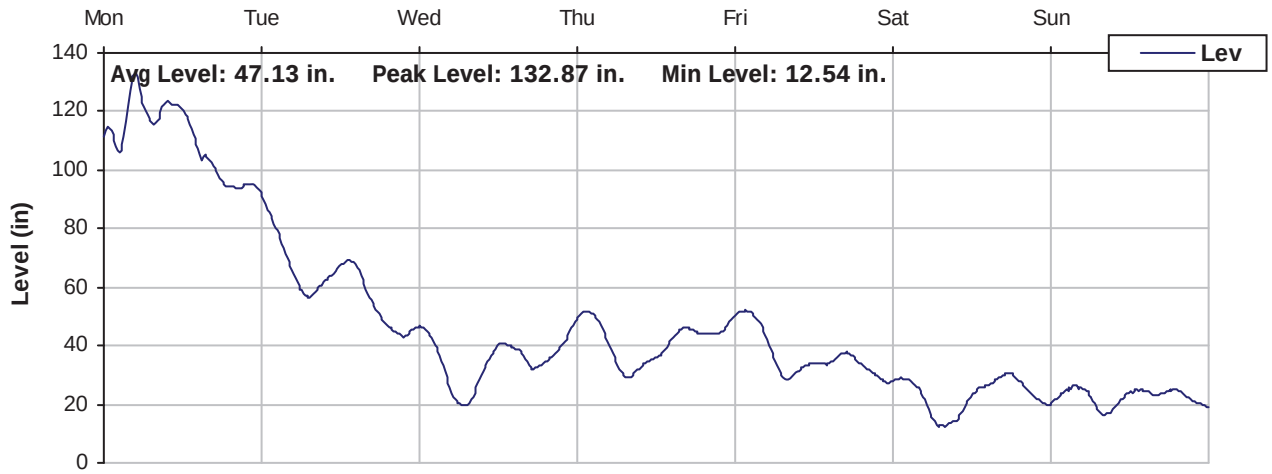
Avg Flow: 1.673 mgd **Peak Flow: 3.677 mgd** **Min Flow: 0.138 mgd**

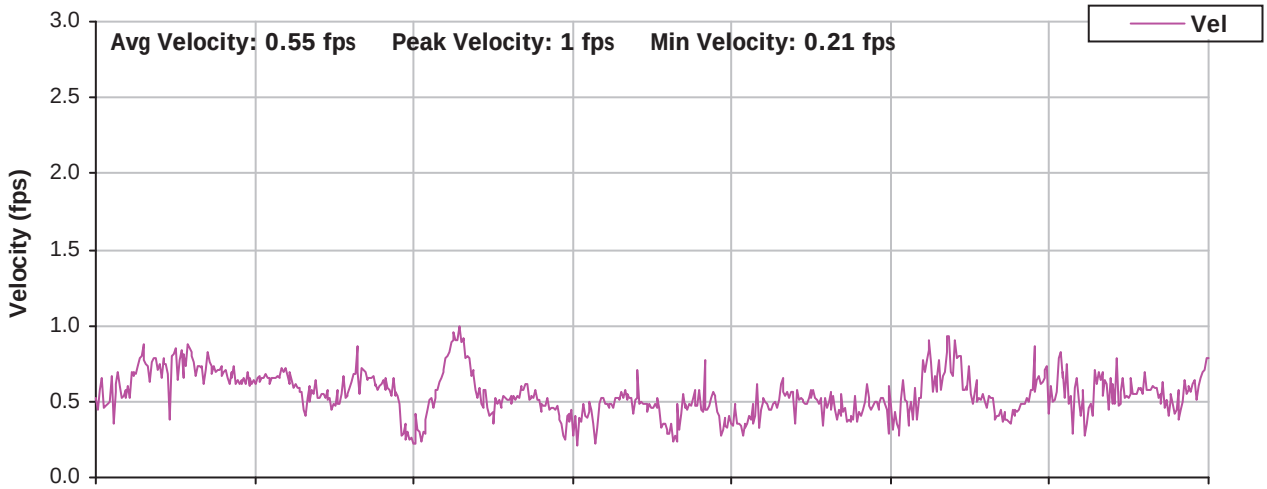
Level, Velocity and Flow

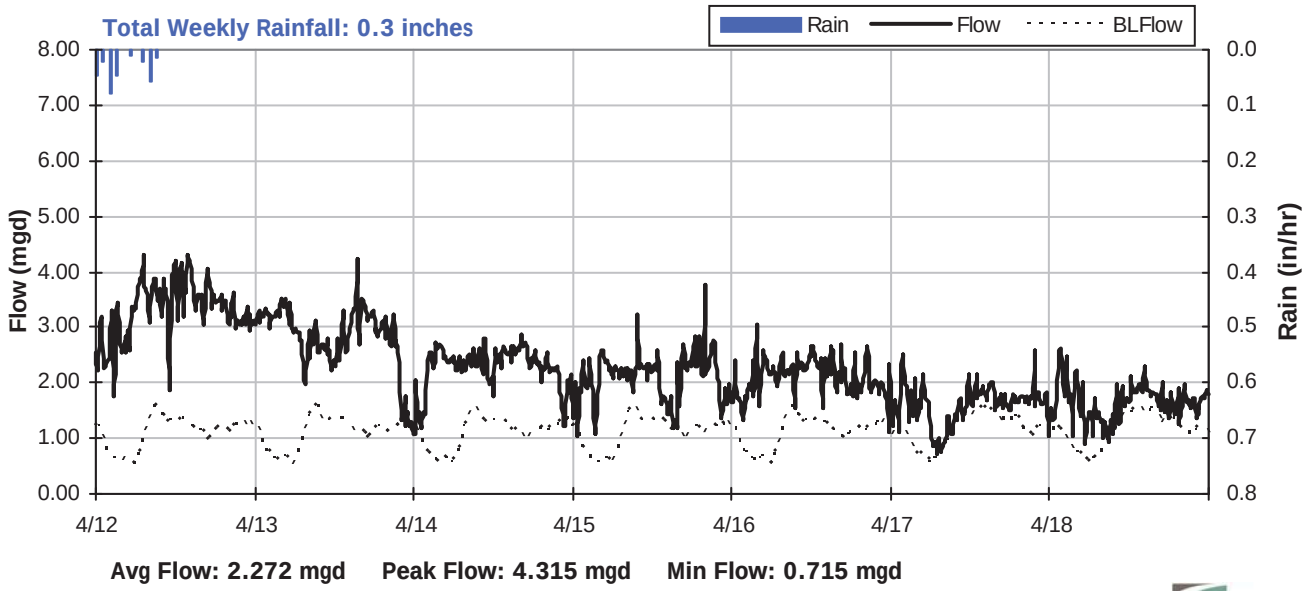
From 4/12/2010 to 4/19/2010

Monitoring Site:

Site 1



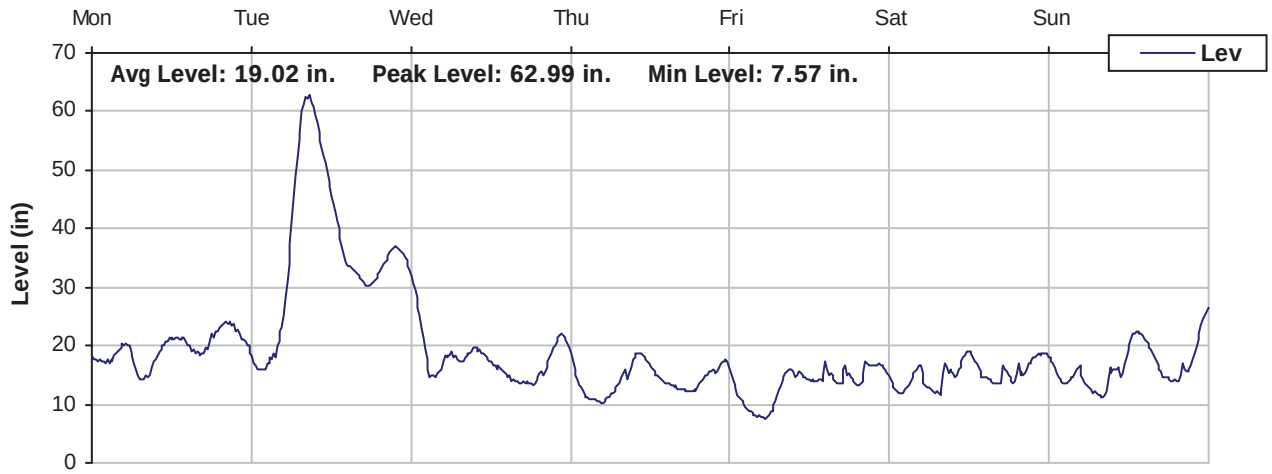


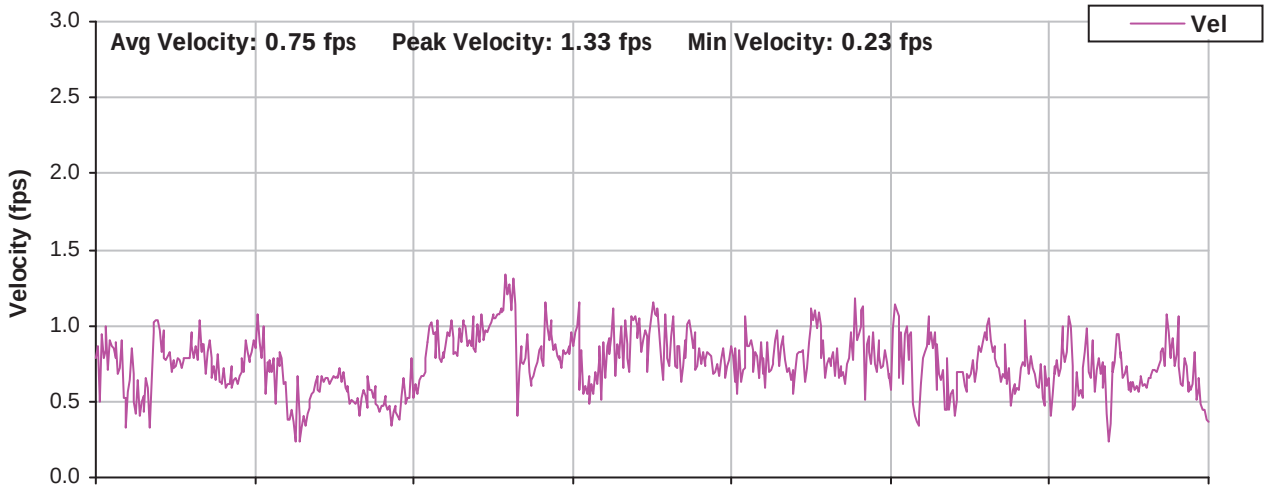


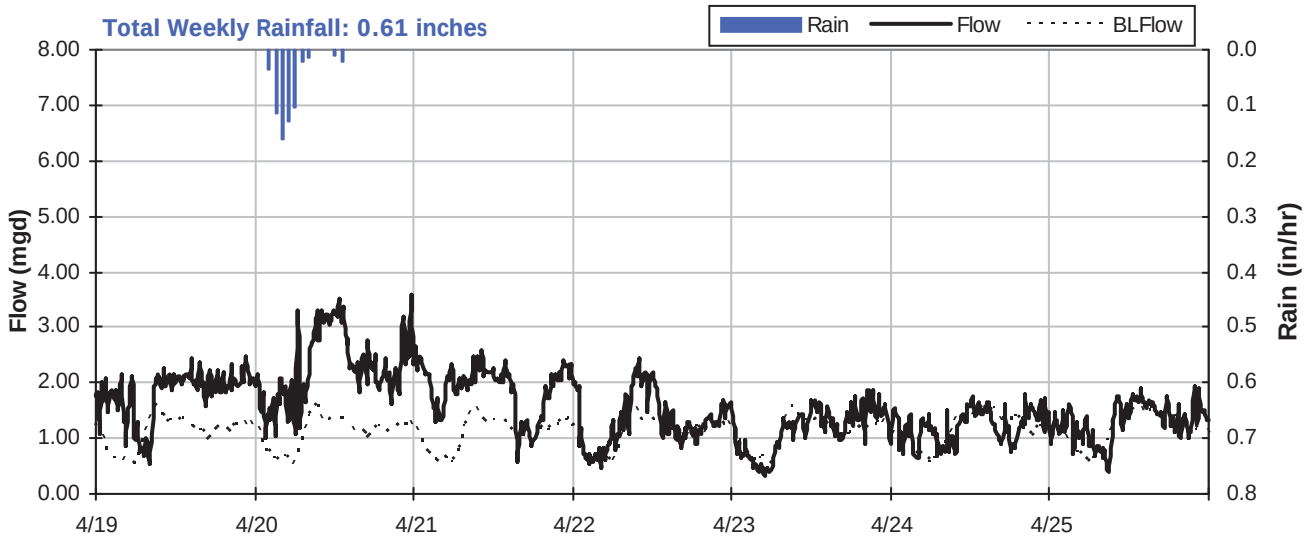
Avg Flow: 2.272 mgd **Peak Flow: 4.315 mgd** **Min Flow: 0.715 mgd**

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 1



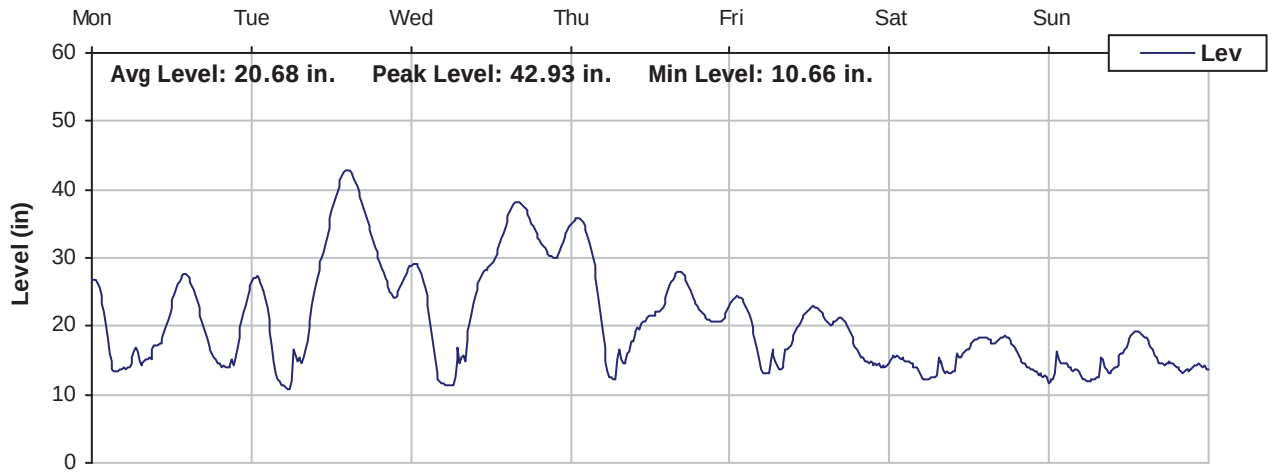


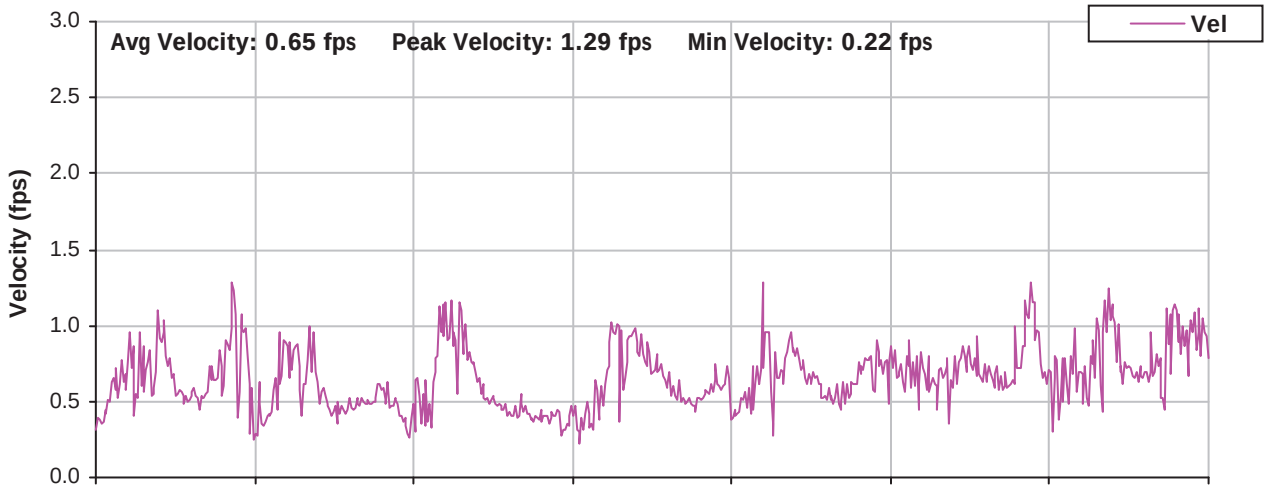


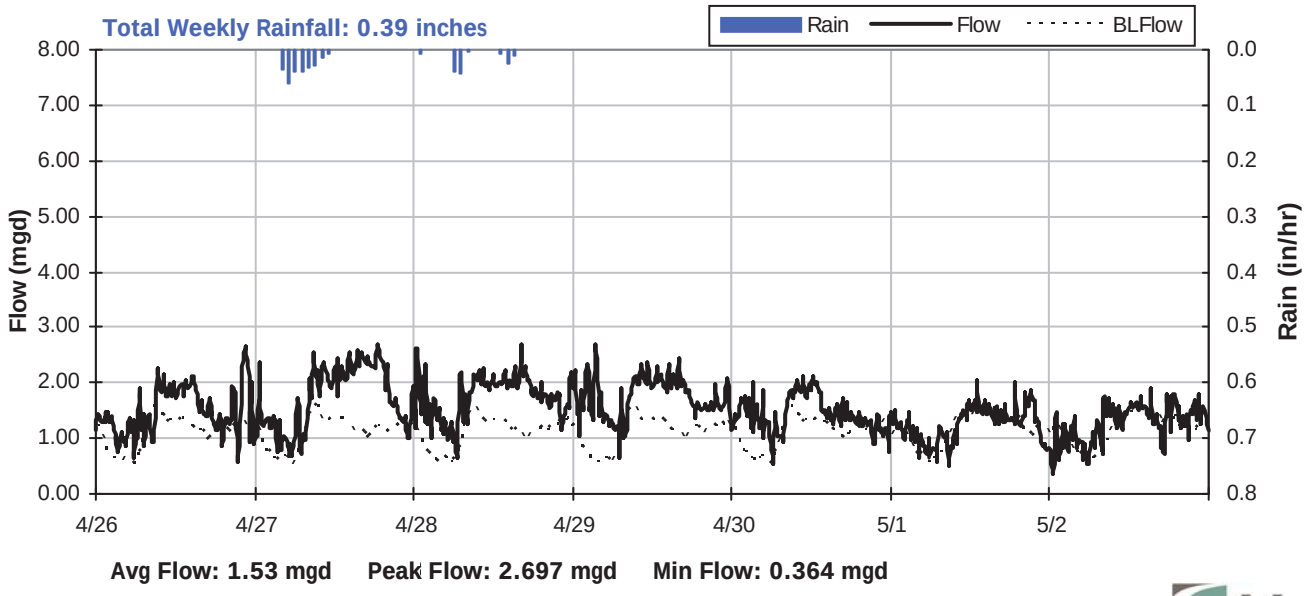
Avg Flow: 1.57 mgd **Peak Flow: 3.576 mgd** **Min Flow: 0.327 mgd**

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 1



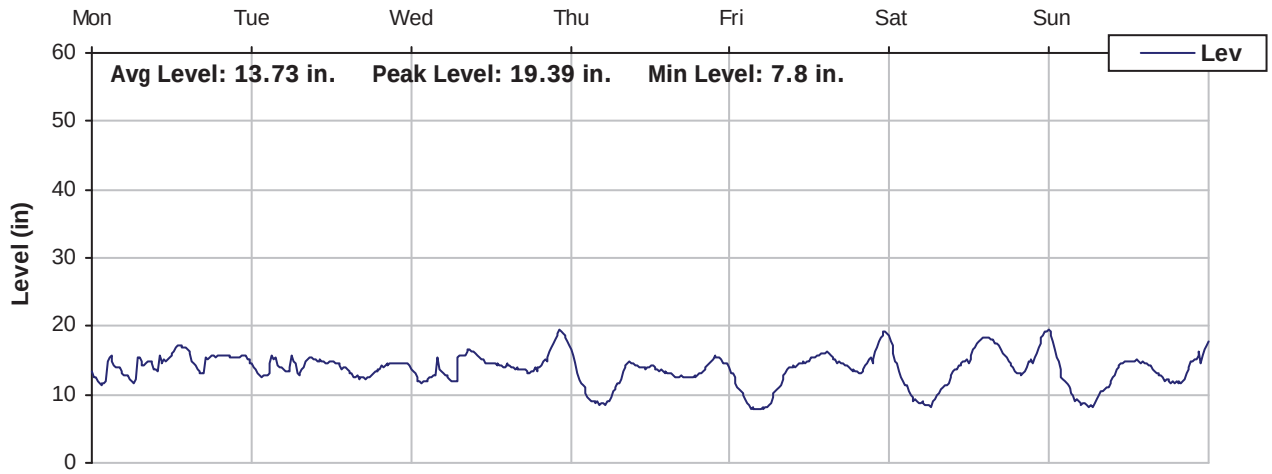


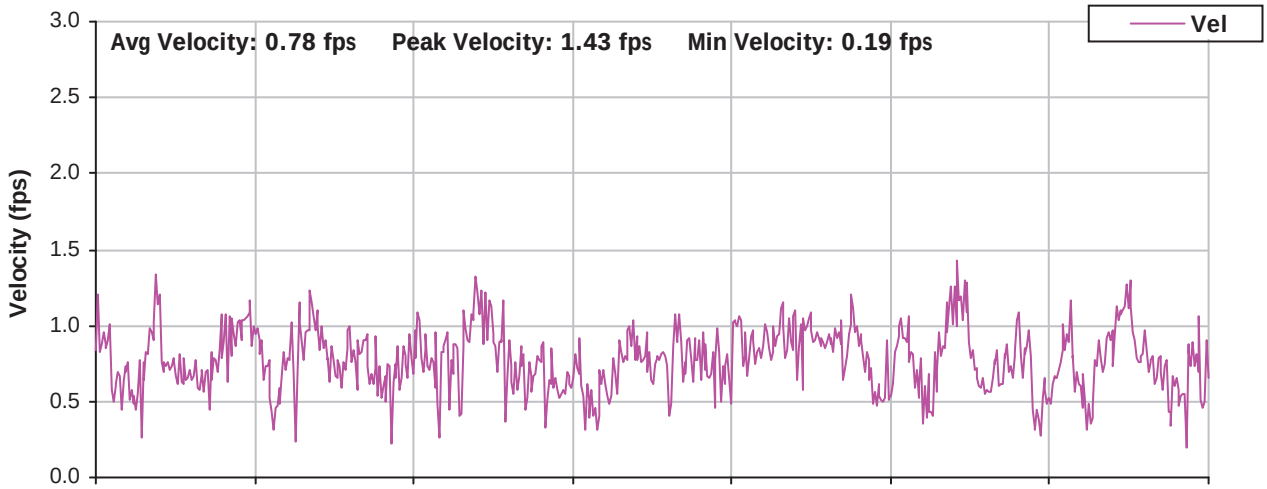


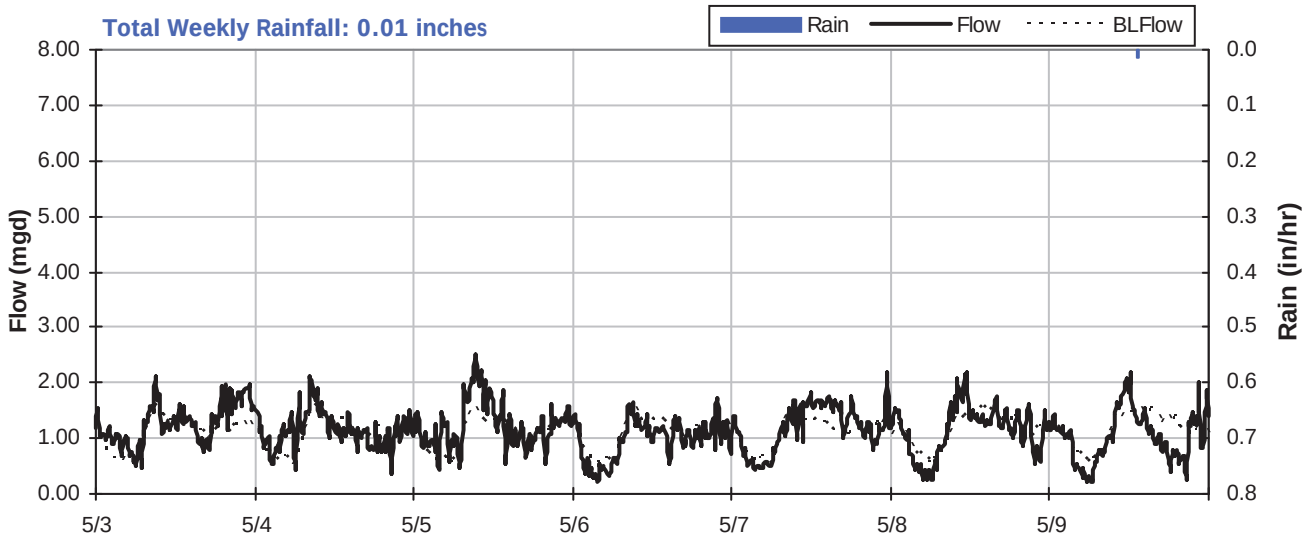
Avg Flow: 1.53 mgd **Peak Flow: 2.697 mgd** **Min Flow: 0.364 mgd**

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 1







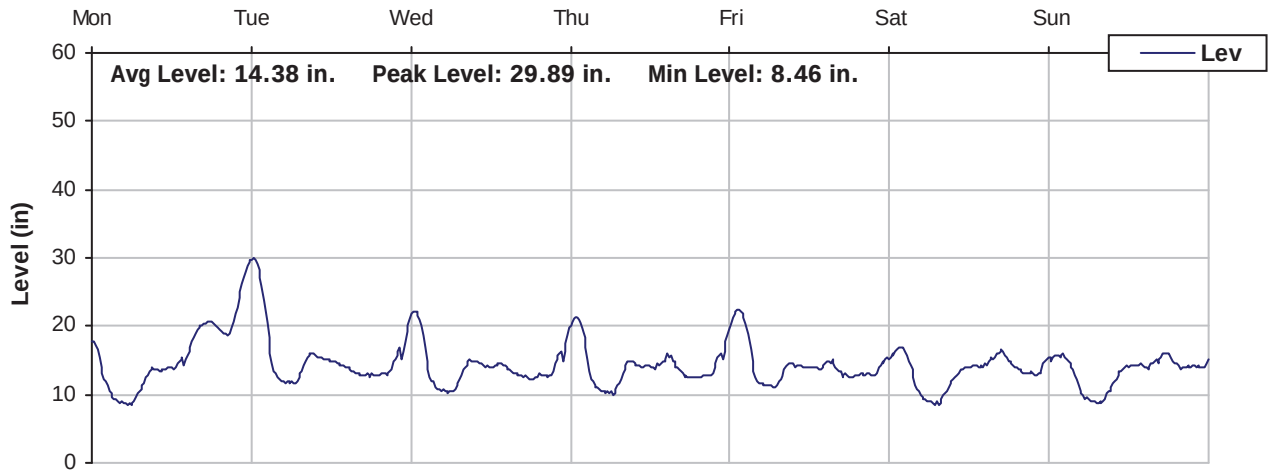
Avg Flow: 1.15 mgd **Peak Flow: 2.524 mgd** **Min Flow: 0.201 mgd**

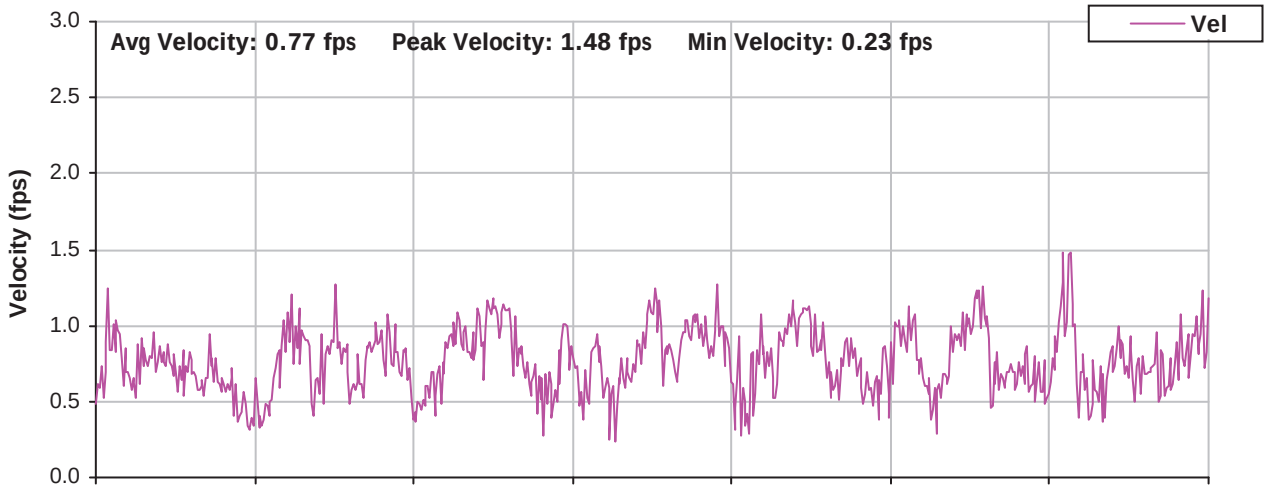
Level, Velocity and Flow

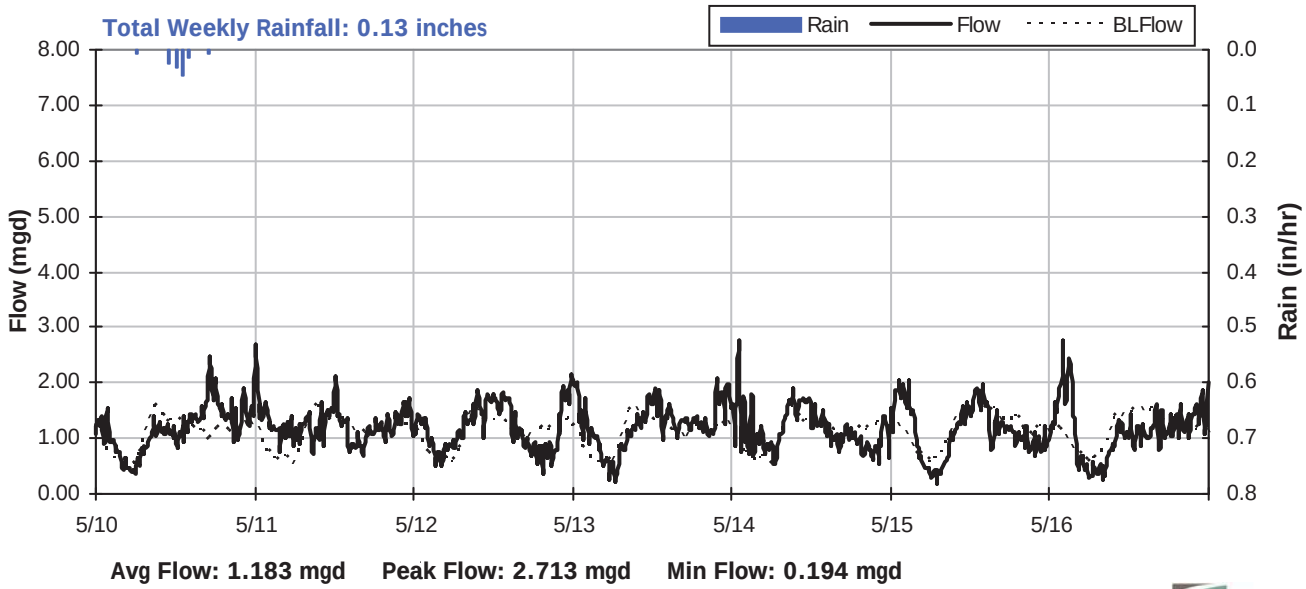
From 5/10/2010 to 5/17/2010

Monitoring Site:

Site 1







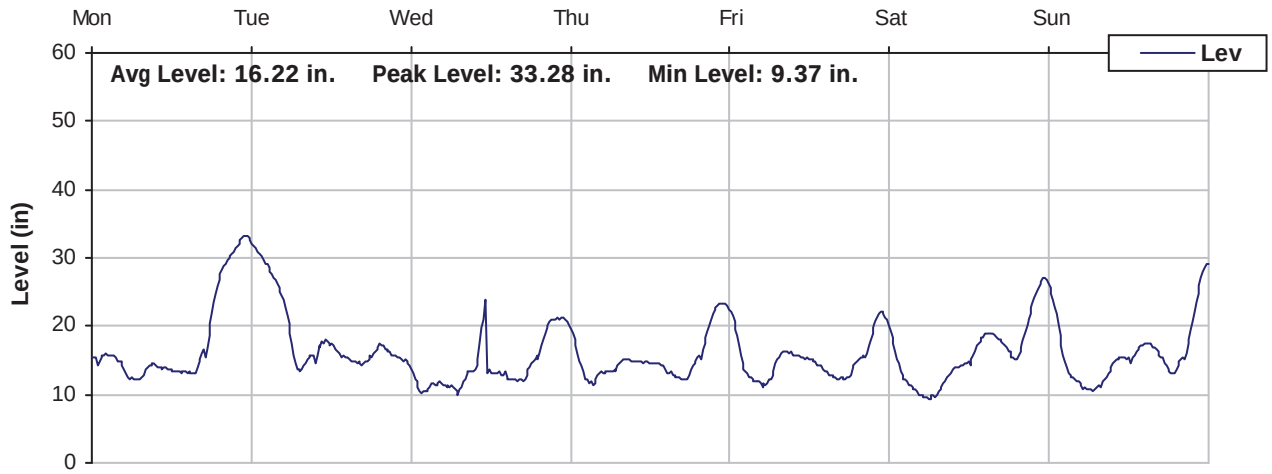
Avg Flow: 1.183 mgd **Peak Flow: 2.713 mgd** **Min Flow: 0.194 mgd**

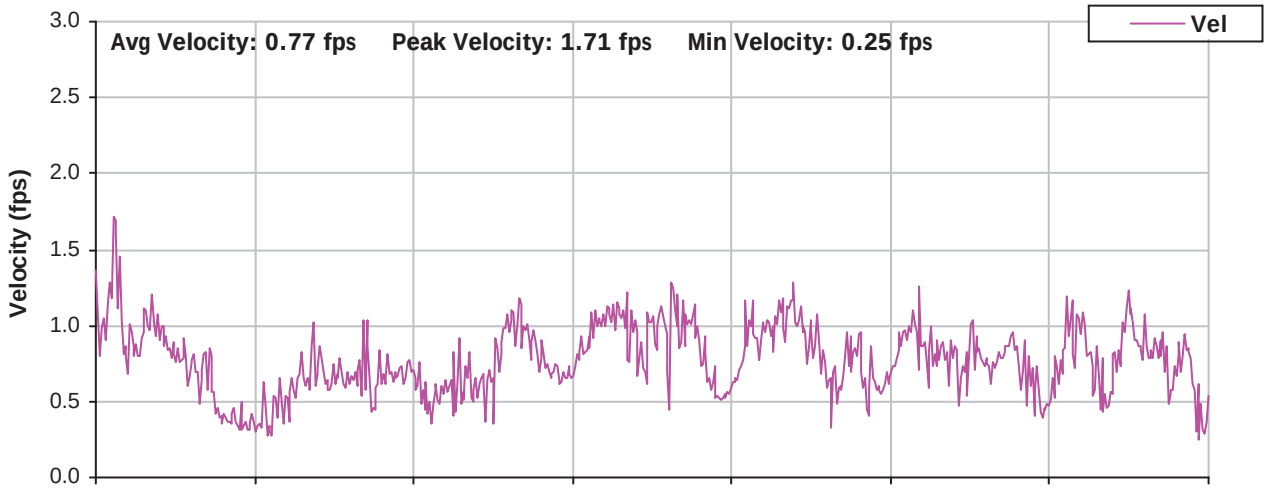
Level, Velocity and Flow

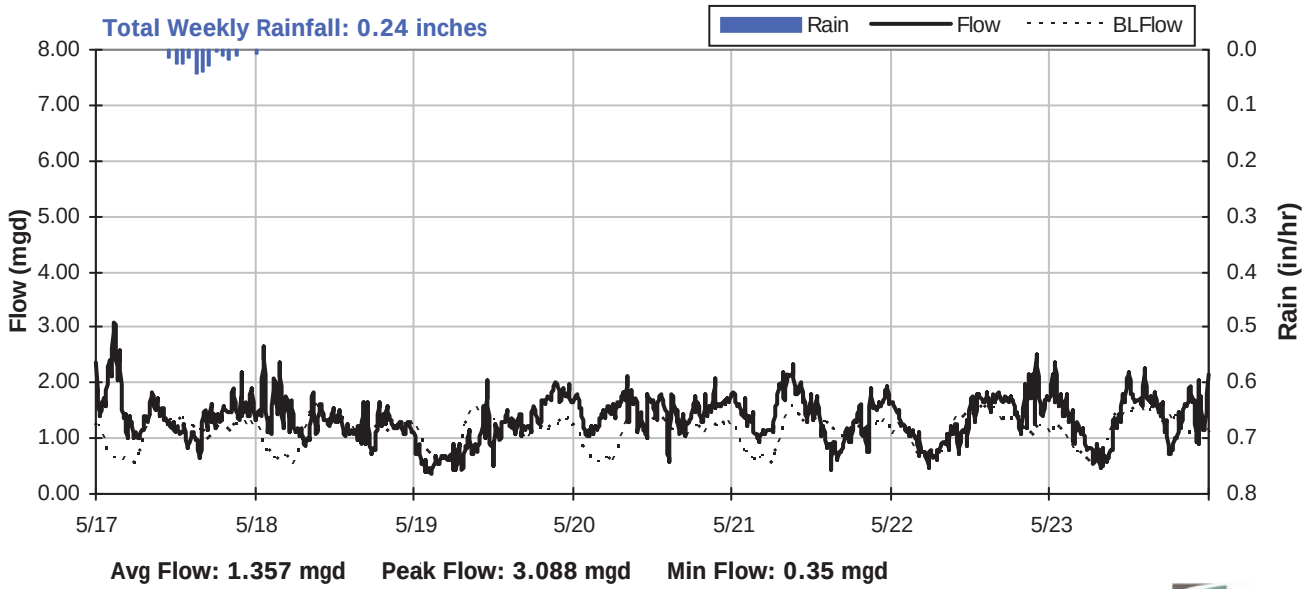
From 5/17/2010 to 5/24/2010

Monitoring Site:

Site 1







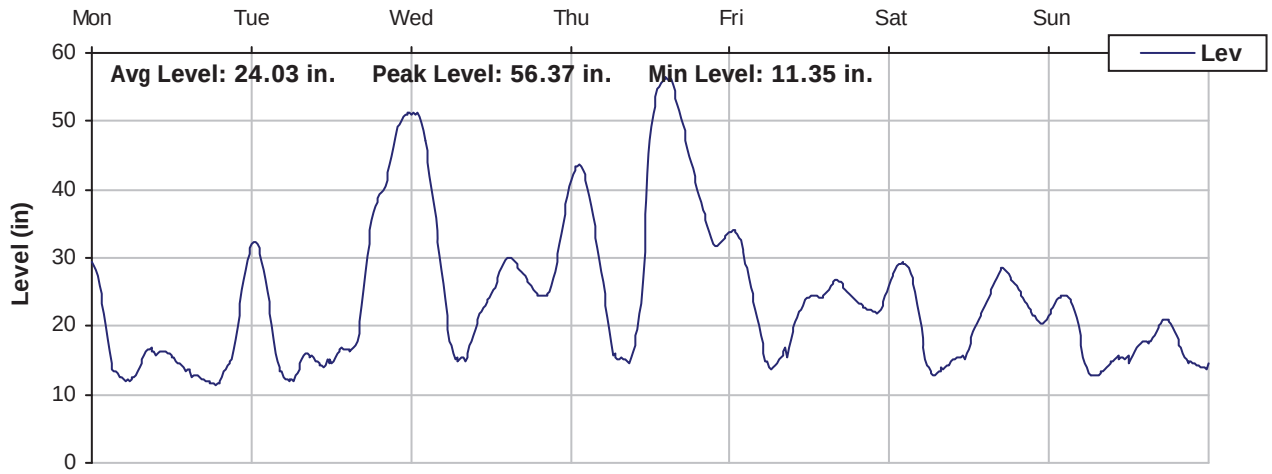
Avg Flow: 1.357 mgd **Peak Flow: 3.088 mgd** **Min Flow: 0.35 mgd**

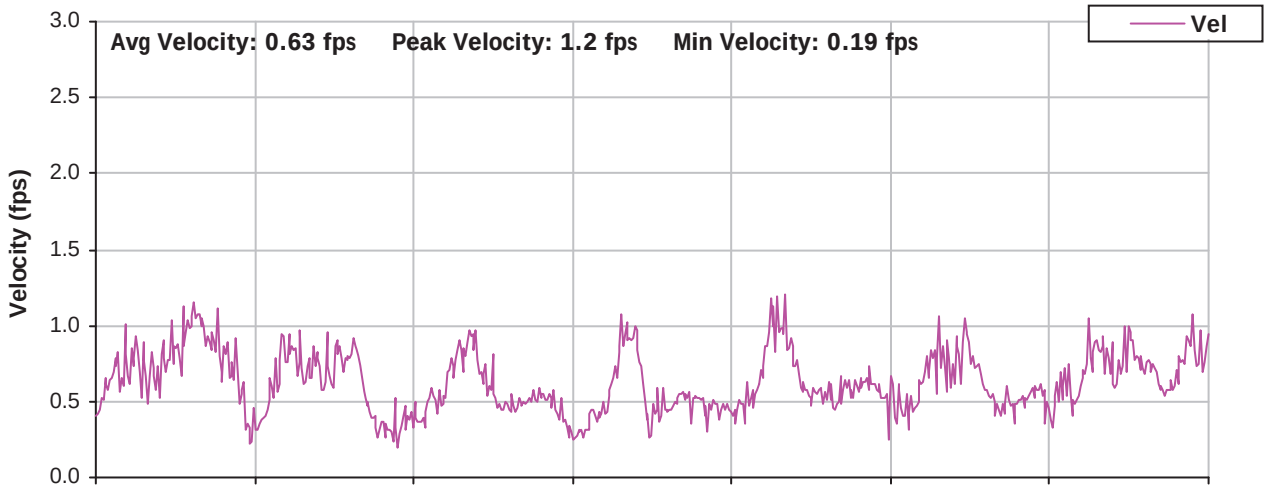
Level, Velocity and Flow

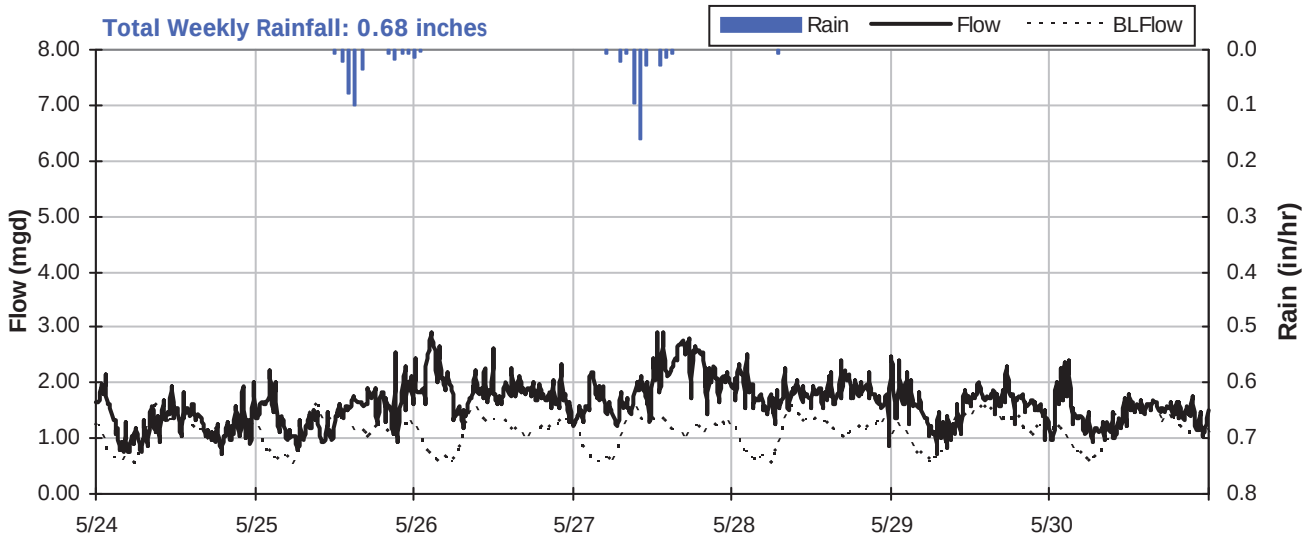
From 5/24/2010 to 5/31/2010

Monitoring Site:

Site 1







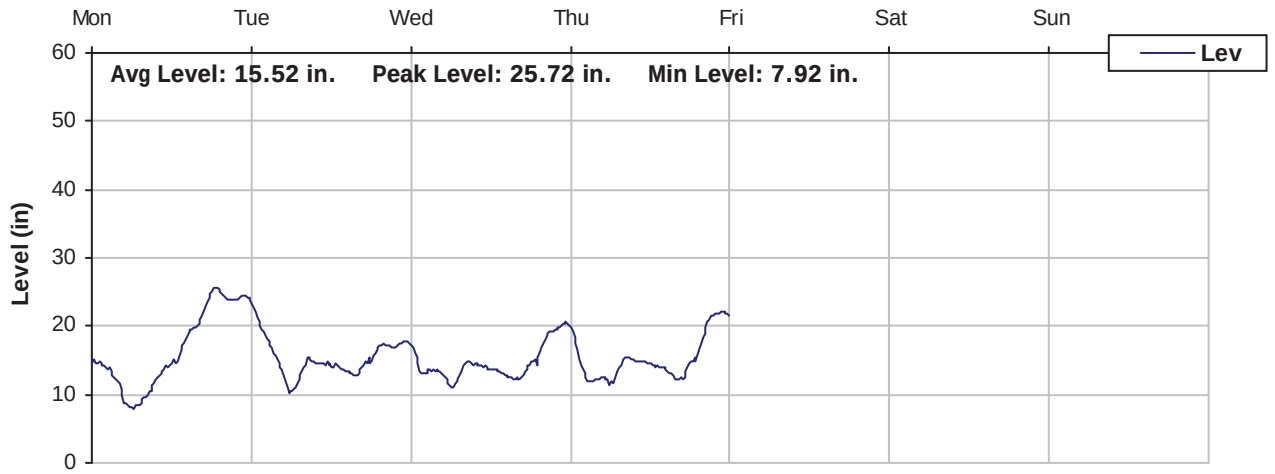
Avg Flow: 1.629 mgd **Peak Flow: 2.893 mgd** **Min Flow: 0.708 mgd**

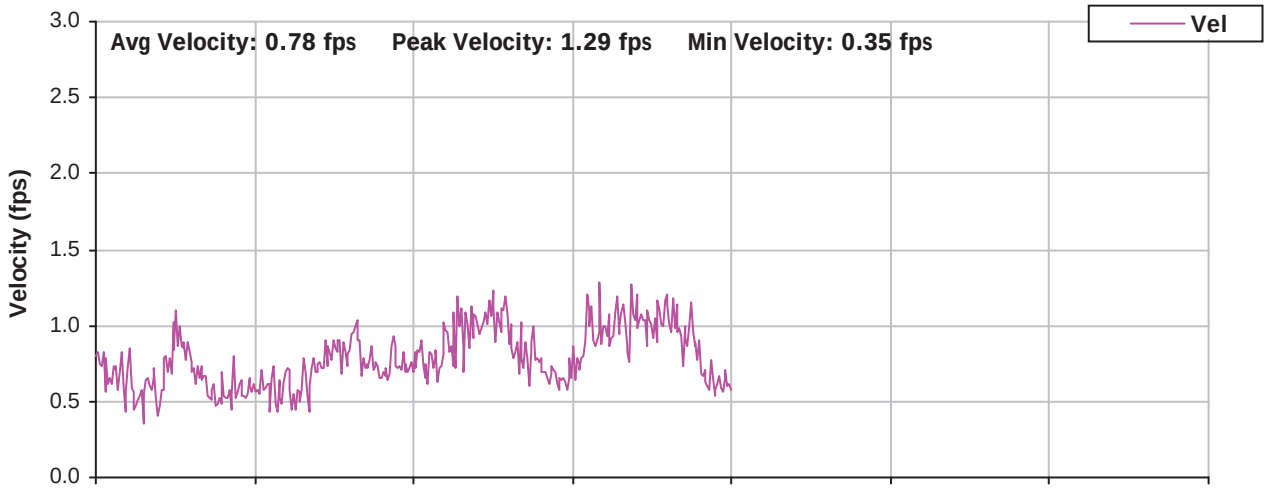
Level, Velocity and Flow

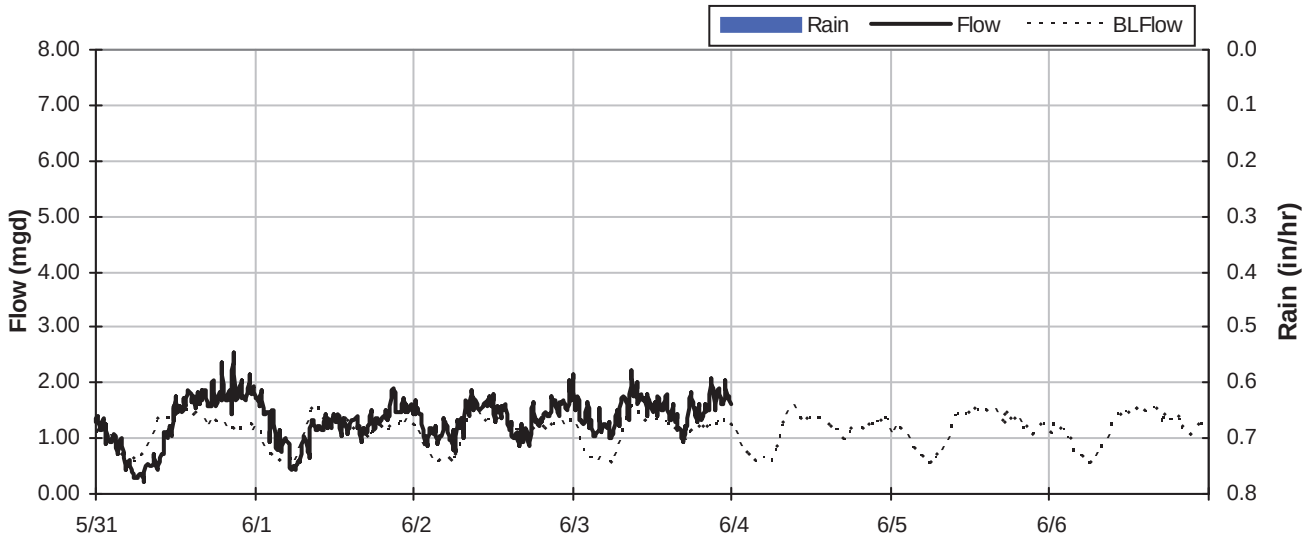
From 5/31/2010 to 6/7/2010

Monitoring Site:

Site 1







Avg Flow: 1.344 mgd **Peak Flow: 2.544 mgd** **Min Flow: 0.23 mgd**

Temporary Flow Monitoring Study

Sanitary Sewer Collection System

Monitoring Site: Site 2

Location: Lucas Avenue at 10th Street

Size/Type Line: 21-inch Sanitary Sewer Pipe

Data Summary Report

Site Information Report

Monitoring Site: Site 2

Location: Lucas Avenue at 10th Street

Latitude: 37.9444°

Longitude: -122.3599°

Rim Elevation: 31 *feet above sea level*

Diameter: 21 *inches*

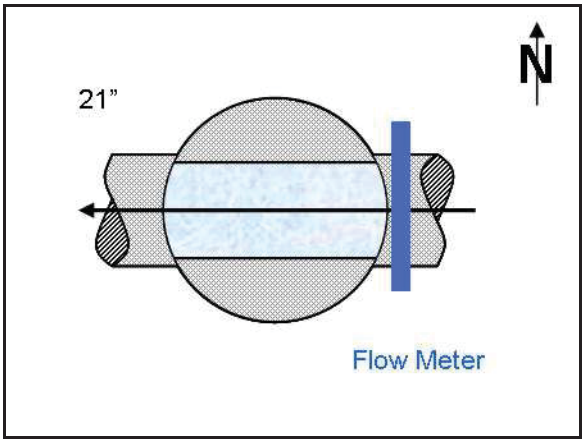
Average Dry Weather Flow: 0.538 *mgd*

Peak Measured Flow: 4.621 *mgd*

Satellite Photo

Sanitary Map

Flow Sketch

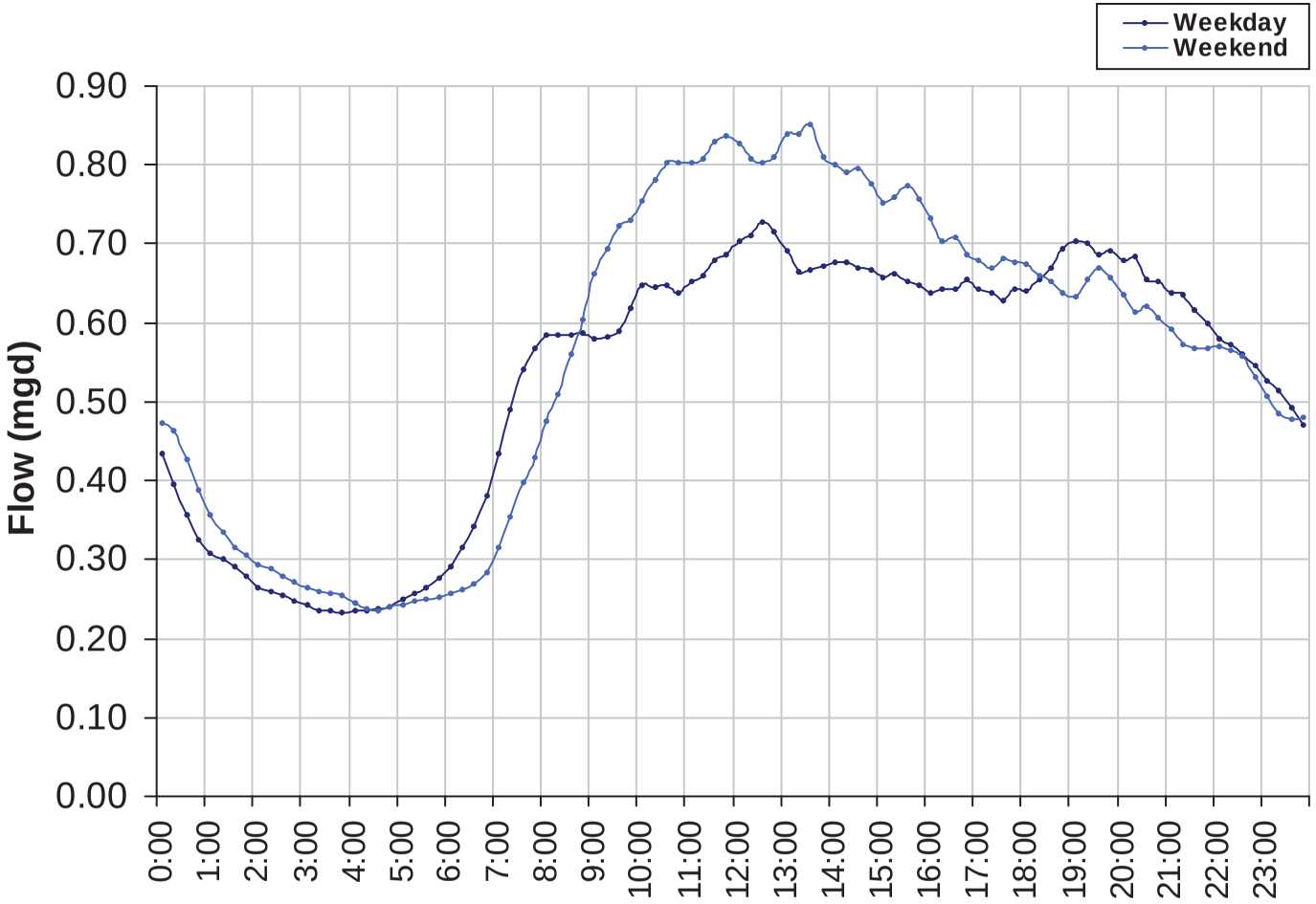


Street View Photo

Plan View Photo

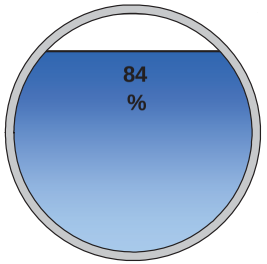
Average Dry Weather Flow

Monitoring Site:
Site 2



Peak Measured Flow:

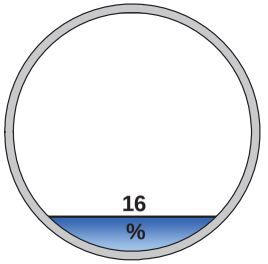
4.62 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

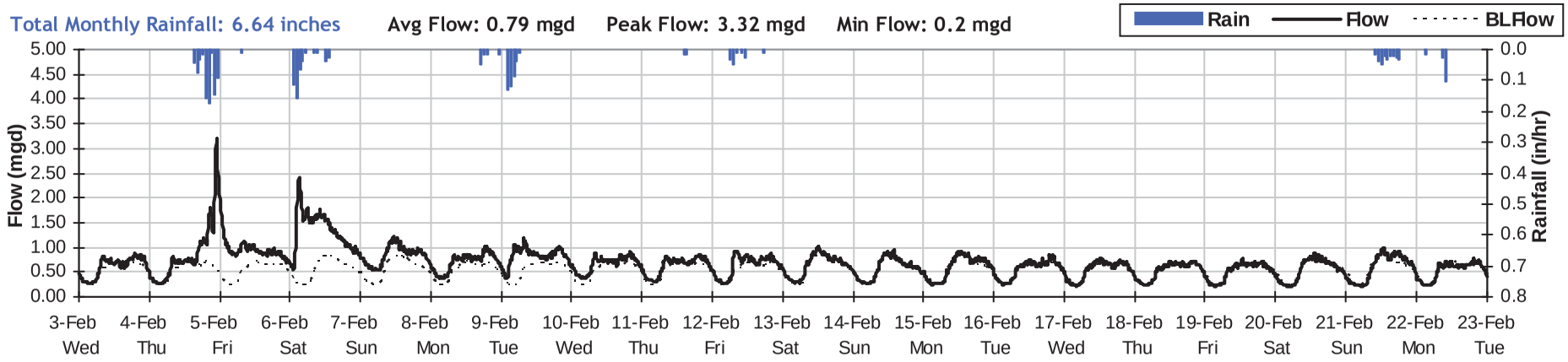
0.54 *mgd*

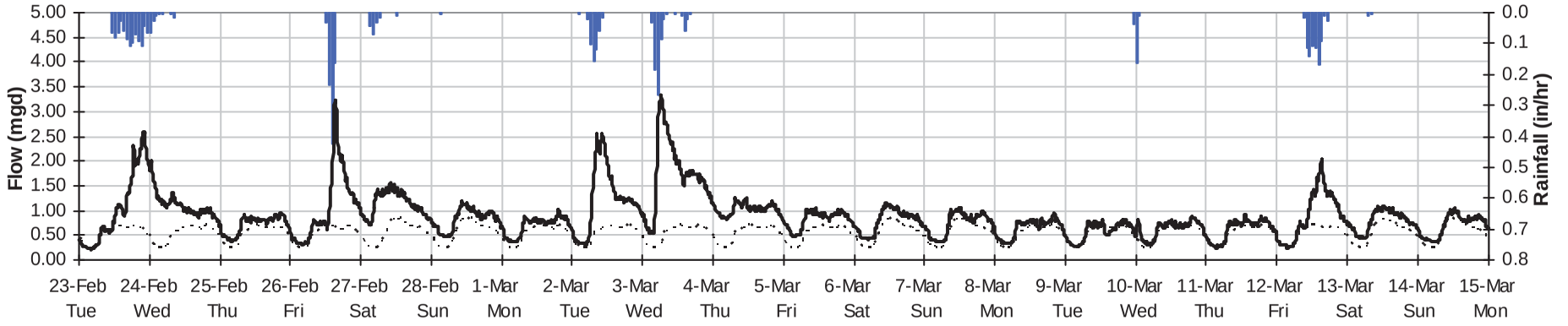


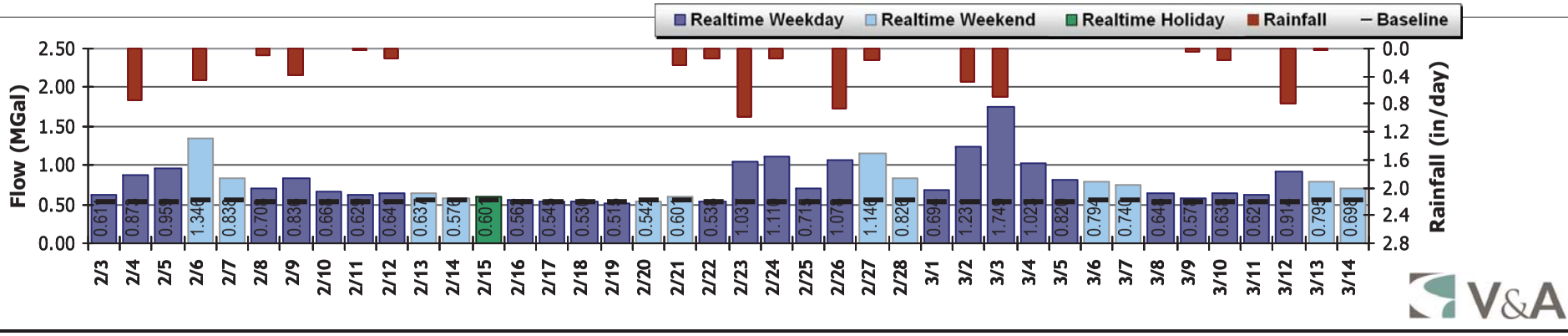
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 2

Total Monthly Rainfall: 6.64 inches Avg Flow: 0.79 mgd Peak Flow: 3.32 mgd Min Flow: 0.2 mgd





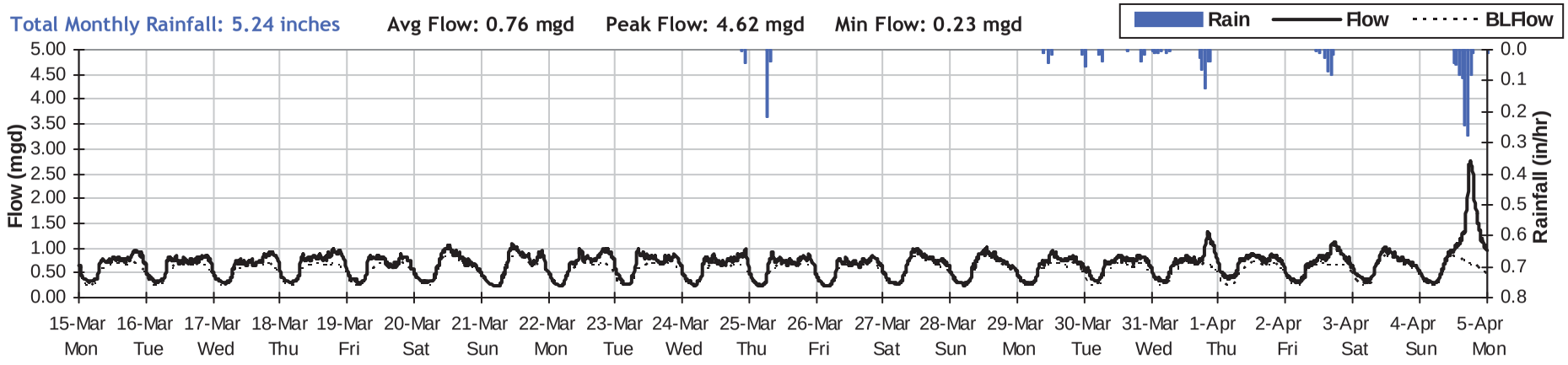


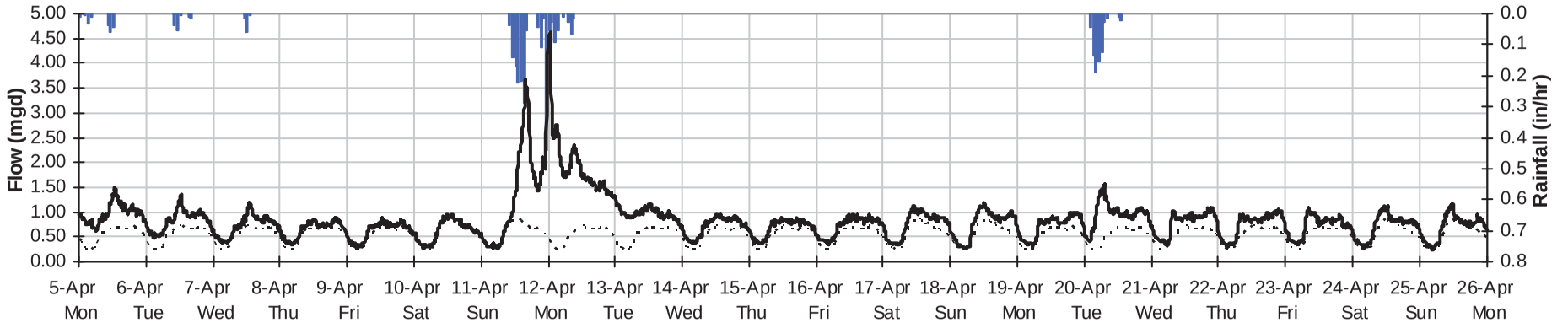
V&A

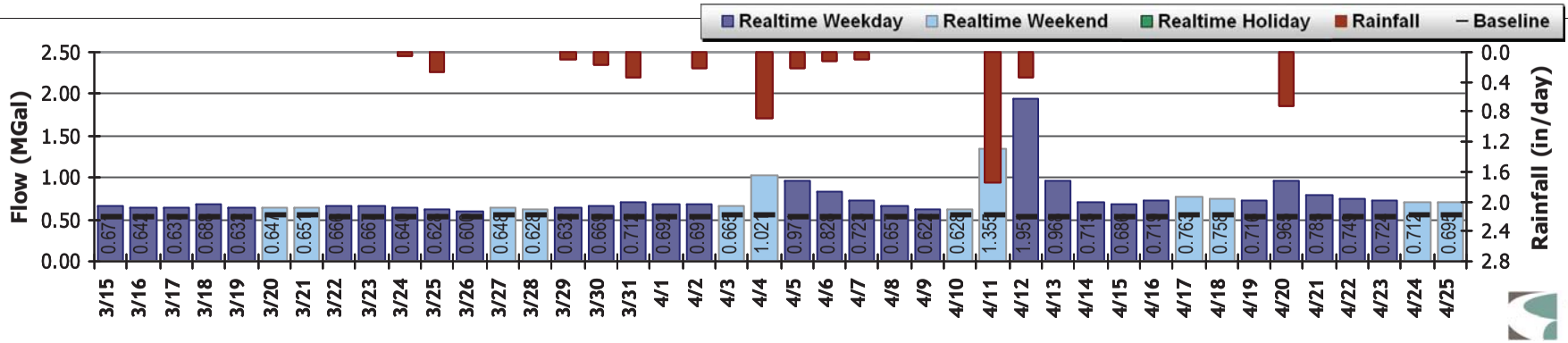
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 2

Total Monthly Rainfall: 5.24 inches Avg Flow: 0.76 mgd Peak Flow: 4.62 mgd Min Flow: 0.23 mgd





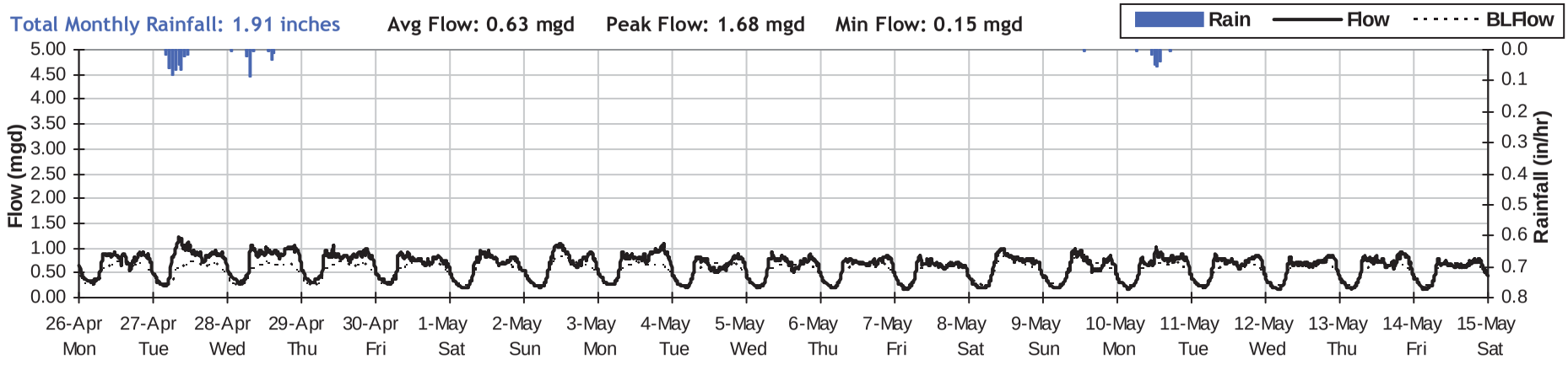


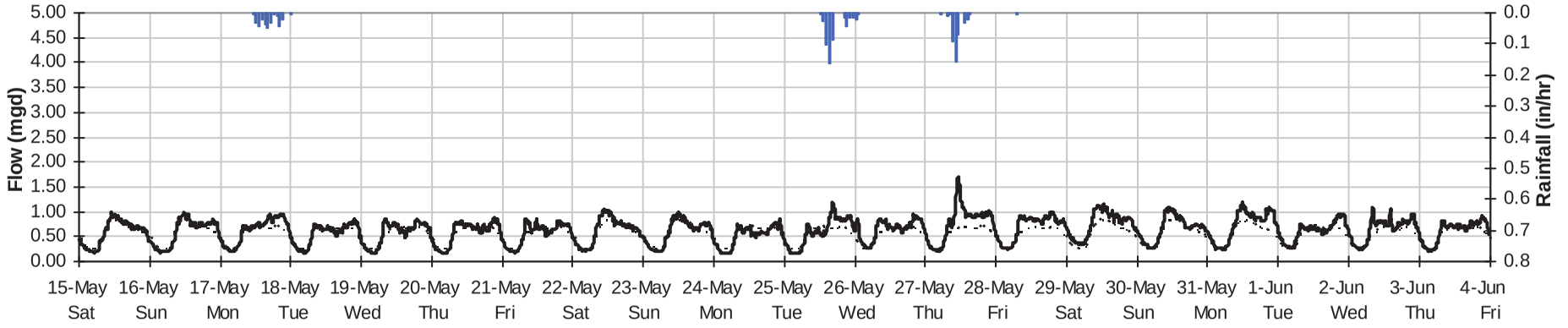
V&A

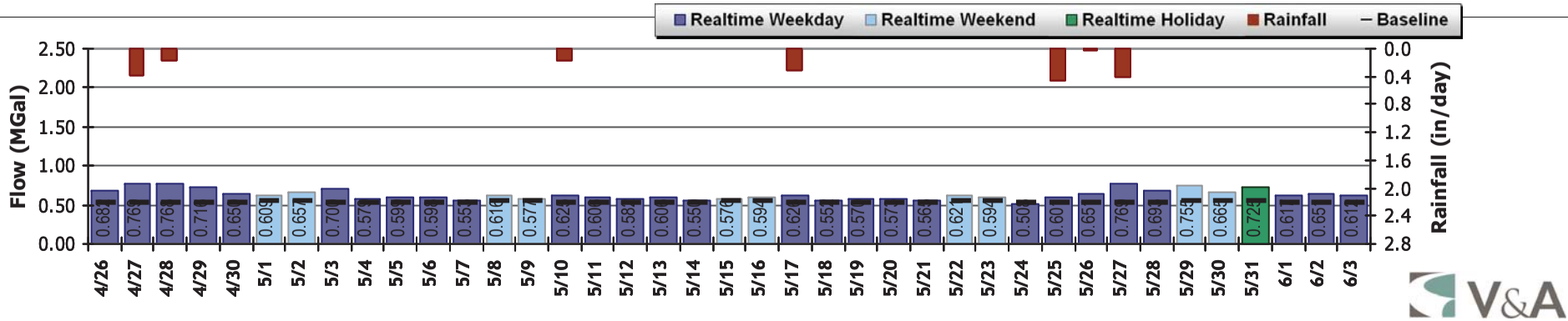
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 2

Total Monthly Rainfall: 1.91 inches Avg Flow: 0.63 mgd Peak Flow: 1.68 mgd Min Flow: 0.15 mgd





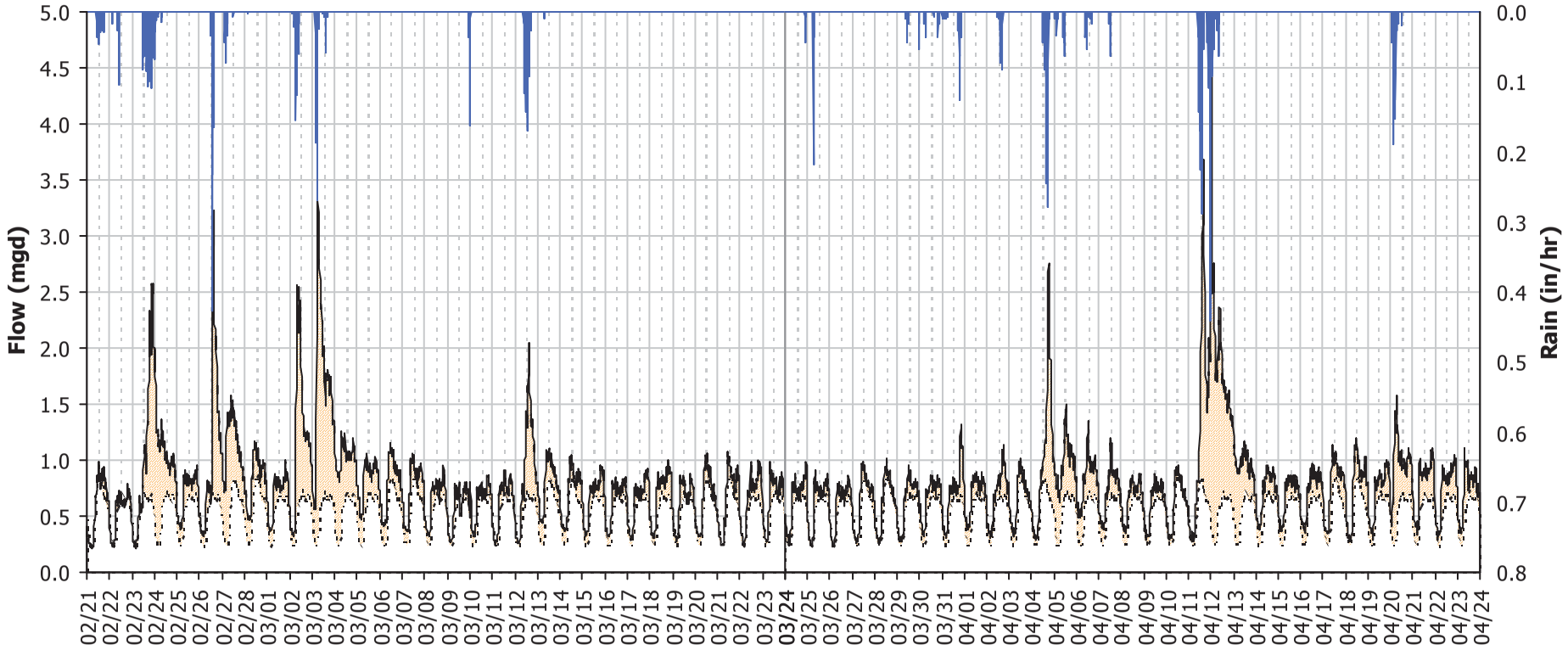


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 2

Multiple Events Detail I/I Graph

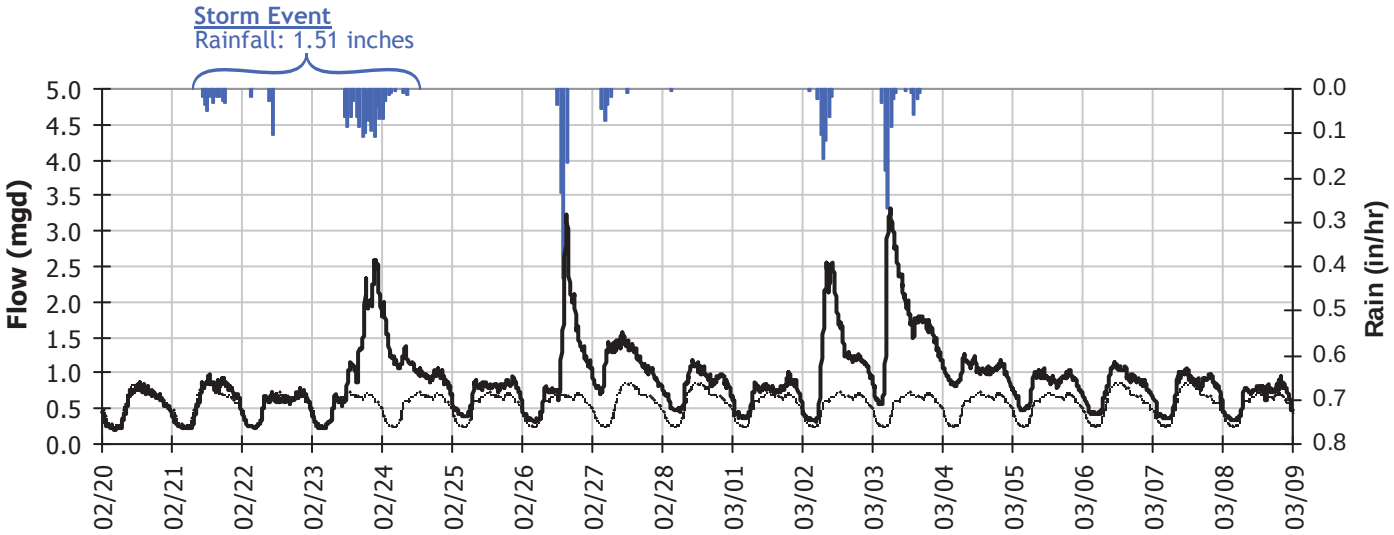


Multiple Events I/I Analysis

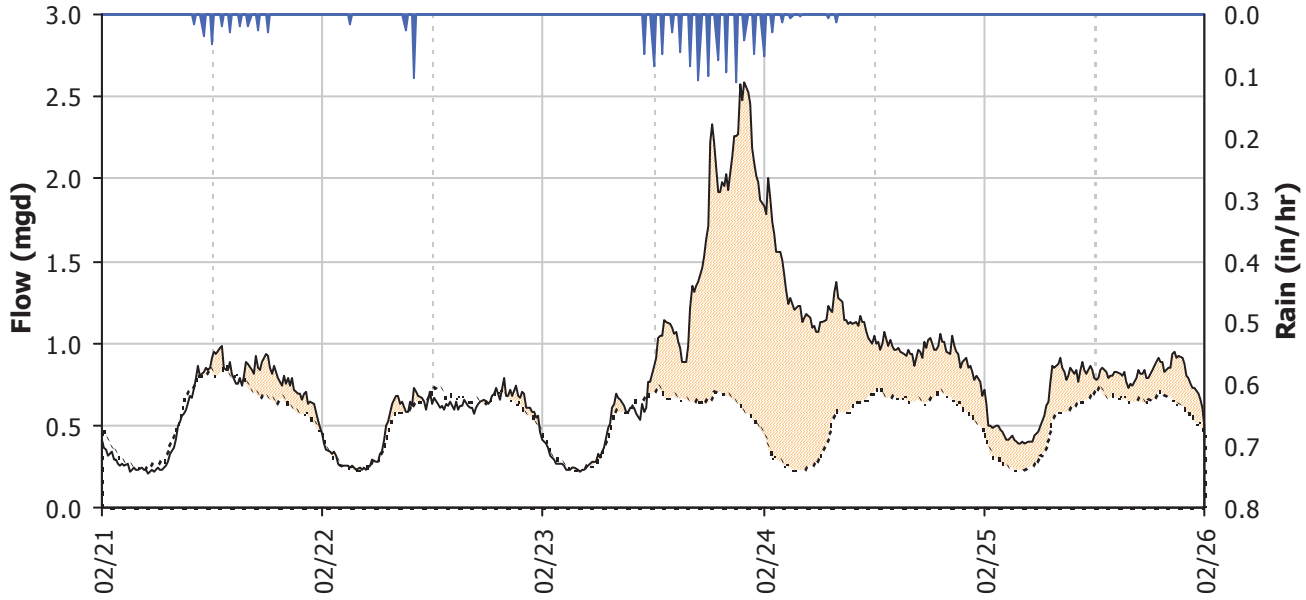
Rainfall:	10.00	*inches*	**Baseline Flow:**	0.54	*mgd*
Peak Flow:	4.62	*mgd*	**PF:**	8.59	
Peak I/I Rate:	4.27	*mgd*	**Pk I/I:ADWF:**	7.93	
Peak Level:	17.74	*inches*	**d/D Ratio:**	0.84	
Total I/I:	16,064,000	*gallons*	**R-Value:**	12.1%	
			I/I per ADWF:	3.0	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 2

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



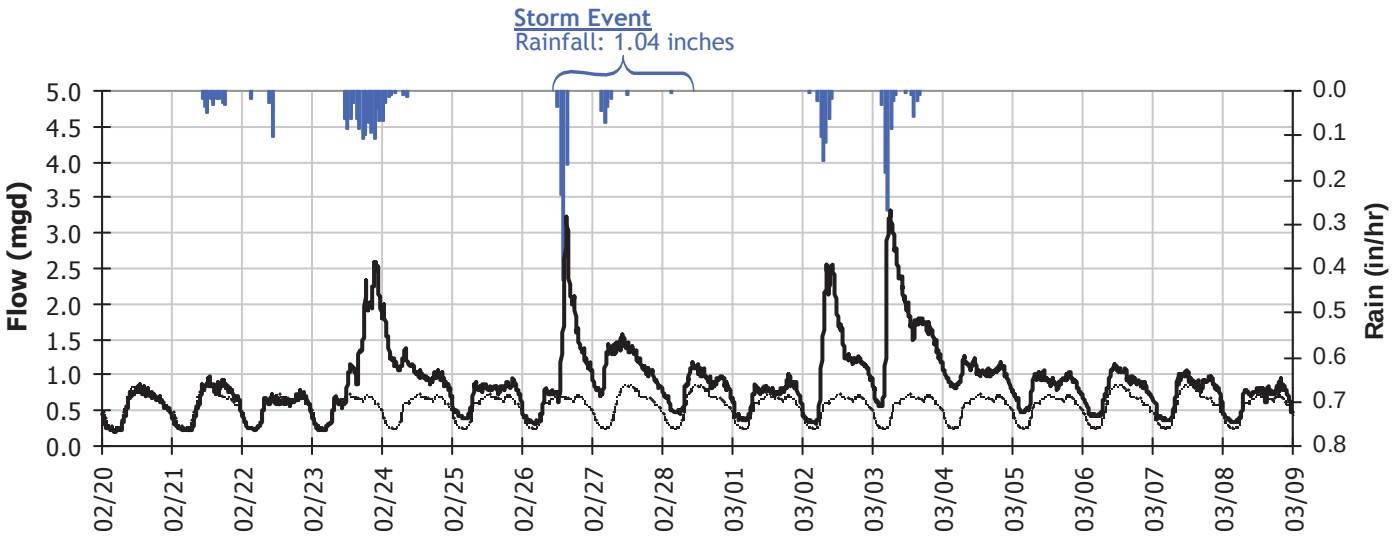
Storm Event #1 I/I Analysis

Rainfall:	1.51	*inches*		
Baseline Flow:	0.54	*mgd*		
Peak Flow:	2.58	*mgd*	**PF:**	4.80
Peak I/I Rate:	2.00	*mgd*	**Pk I/I:ADWF:**	3.72
Peak Level:	8.00	*inches*	**d/D Ratio:**	0.38
Total I/I:	1,324,000	*gallons*	**R-Value:**	6.6%
			I/I per ADWF:	1.63 *per in-rain*

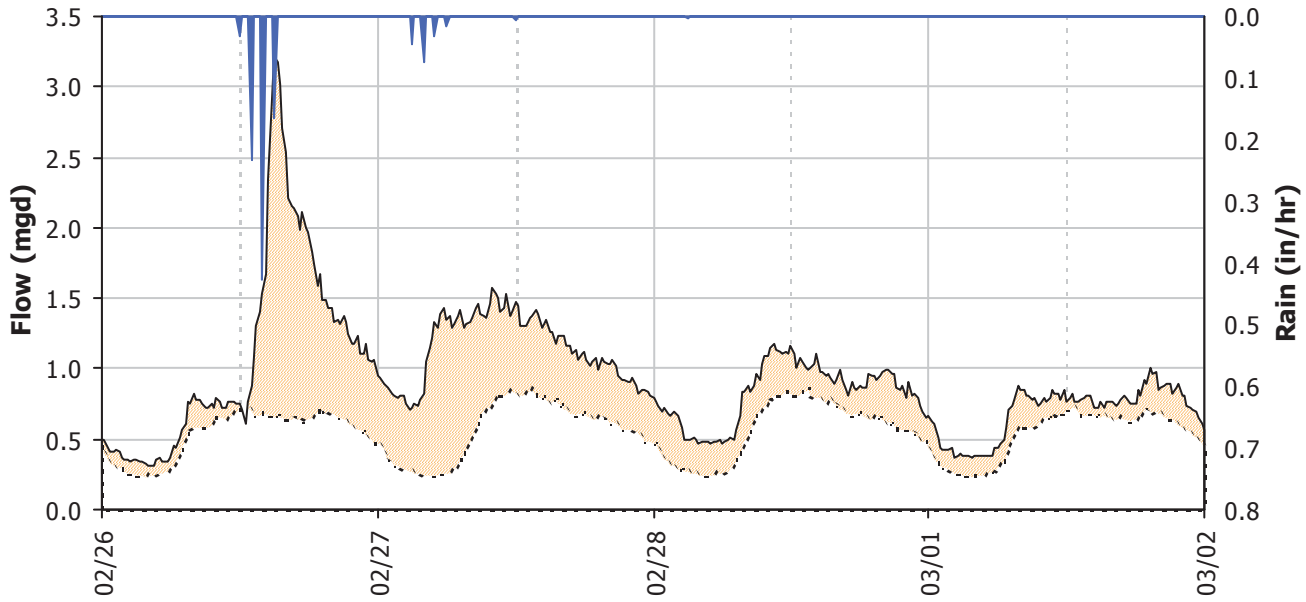
Average Infiltration Rate on 2/25 (% of ADWF): 34.8%

	I/I Summary Event 2	**Monitoring Site:** Site 2

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph

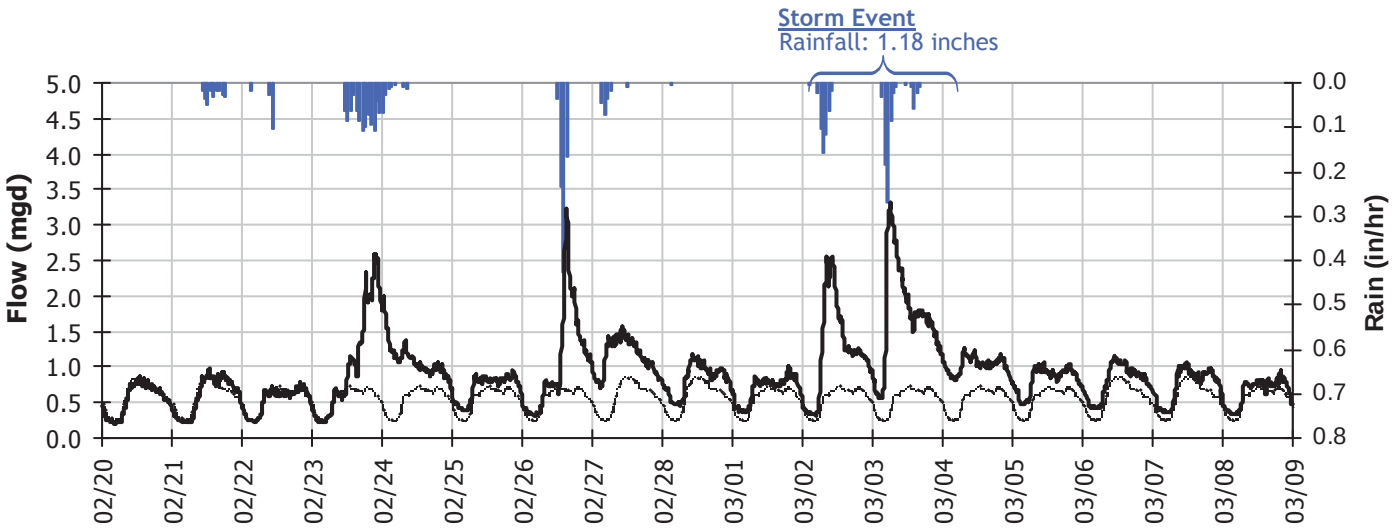


Storm Event #2 I/I Analysis

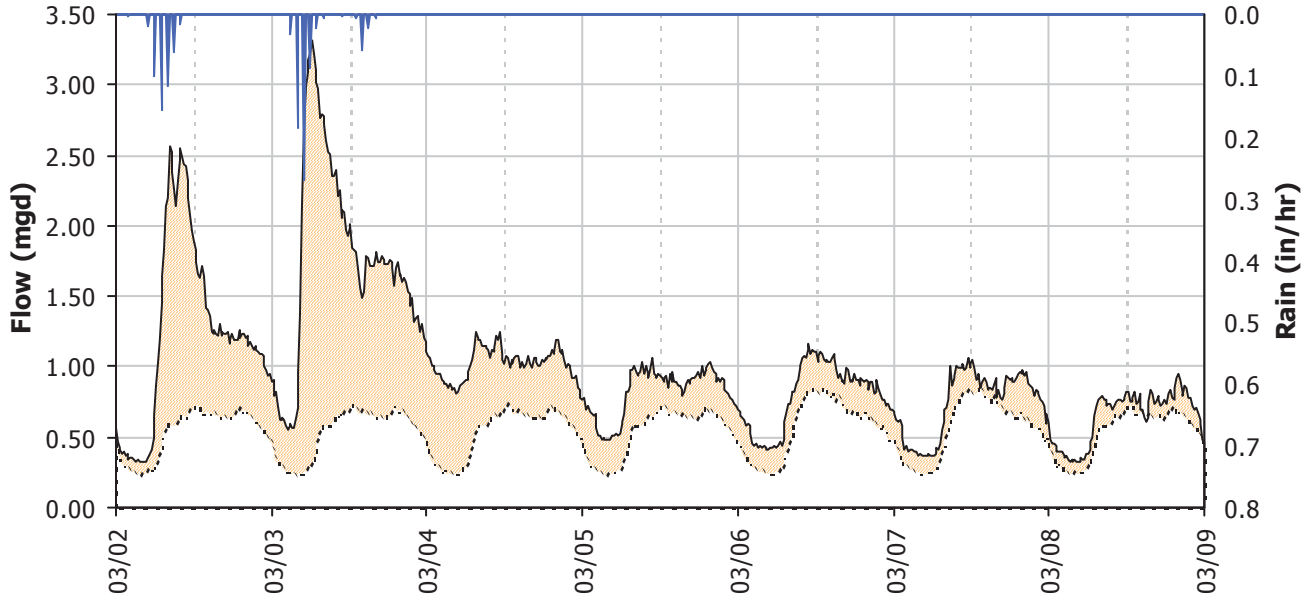
Rainfall:	1.04 *inches*			
Baseline Flow:	0.54 *mgd*			
Peak Flow:	3.22 *mgd*	**PF:**	5.98	
Peak I/I Rate:	2.56 *mgd*	**Pk I/I:ADWF:**	4.76	
Peak Level:	9.00 *inches*	**d/D Ratio:**	0.43	
Total I/I:	1,568,000 *gallons*	**R-Value:**	11.4%	
		I/I per ADWF:	2.81 *per in-rain*	
Average Infiltration Rate on 3/1 (% of ADWF):			30.9%	

	I/I Summary Event 3	**Monitoring Site:** Site 2

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



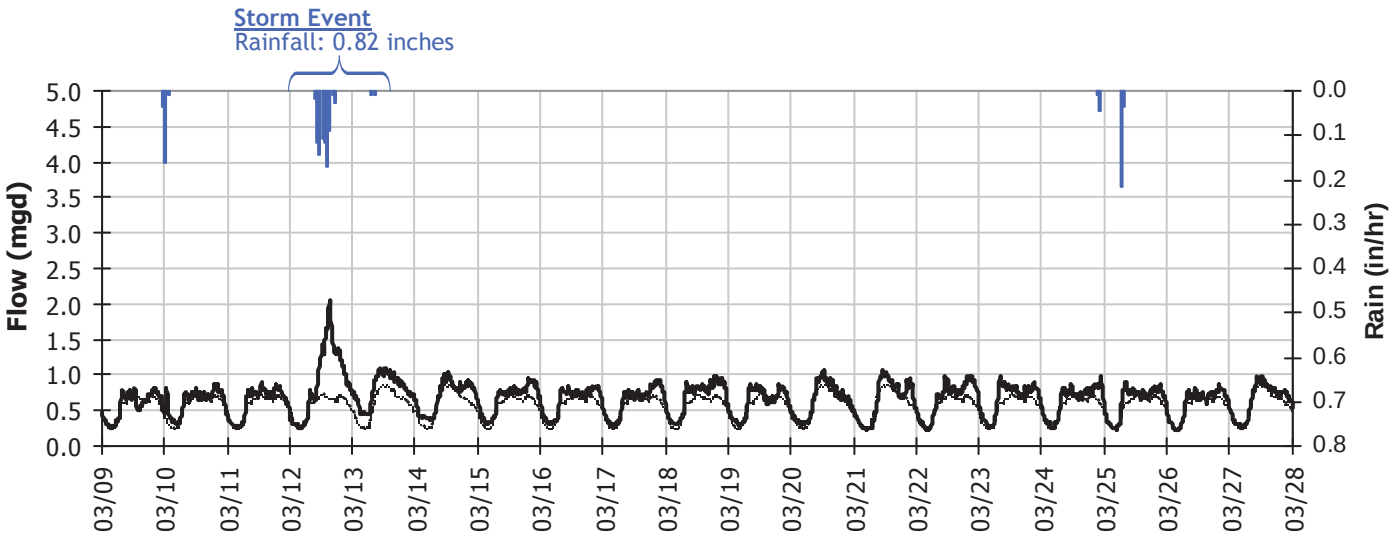
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	0.54	*mgd*		
Peak Flow:	3.32	*mgd*	**PF:**	6.17
Peak I/I Rate:	3.00	*mgd*	**Pk I/I:ADWF:**	5.58
Peak Level:	8.91	*inches*	**d/D Ratio:**	0.42
Total I/I:	3,239,000	*gallons*	**R-Value:**	20.7%
			I/I per ADWF:	5.09 *per in-rain*

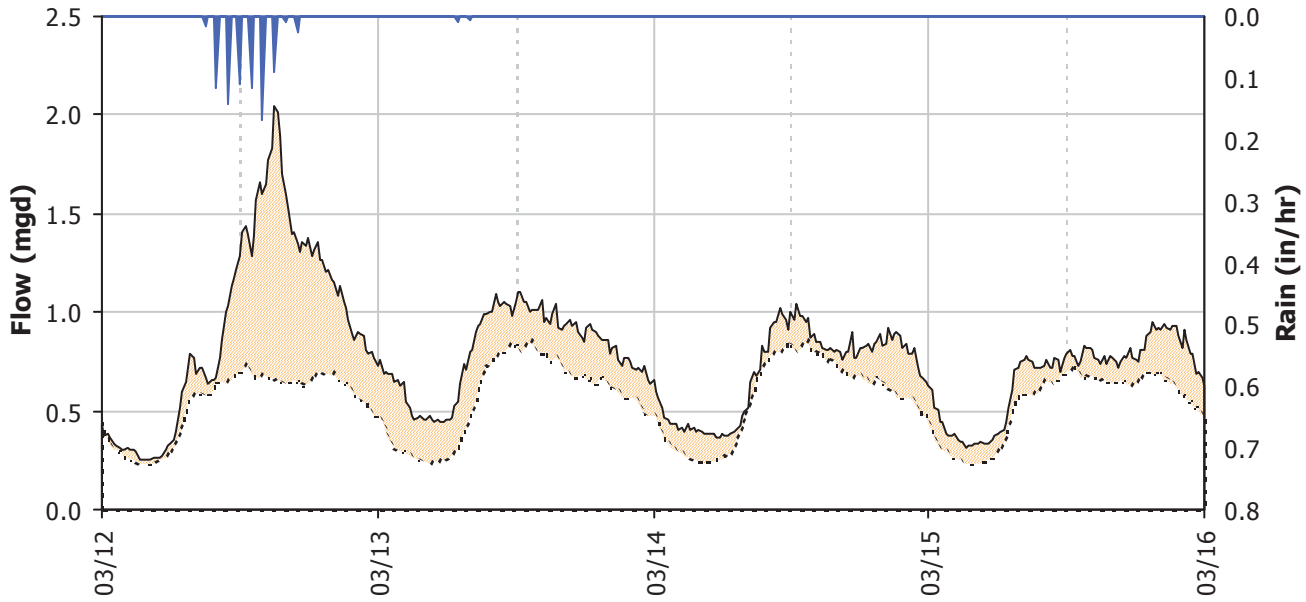
Average Infiltration Rate on 3/5 (% of ADWF): 54.8%

	I/I Summary Event 4	**Monitoring Site:** Site 2

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



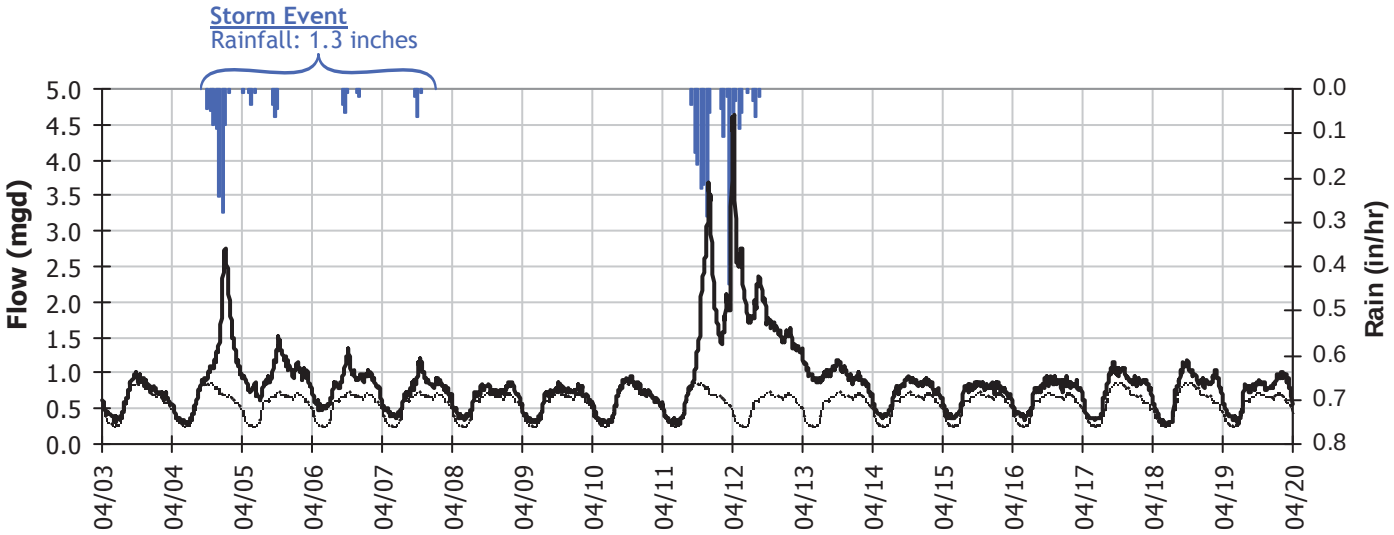
Storm Event #1 I/I Analysis

Rainfall:	0.82	*inches*		
Baseline Flow:	0.54	*mgd*		
Peak Flow:	2.05	*mgd*	**PF:**	3.81
Peak I/I Rate:	1.39	*mgd*	**Pk I/I:ADWF:**	2.59
Peak Level:	7.08	*inches*	**d/D Ratio:**	0.34
Total I/I:	902,000	*gallons*	**R-Value:**	8.3%
			I/I per ADWF:	2.05 *per in-rain*

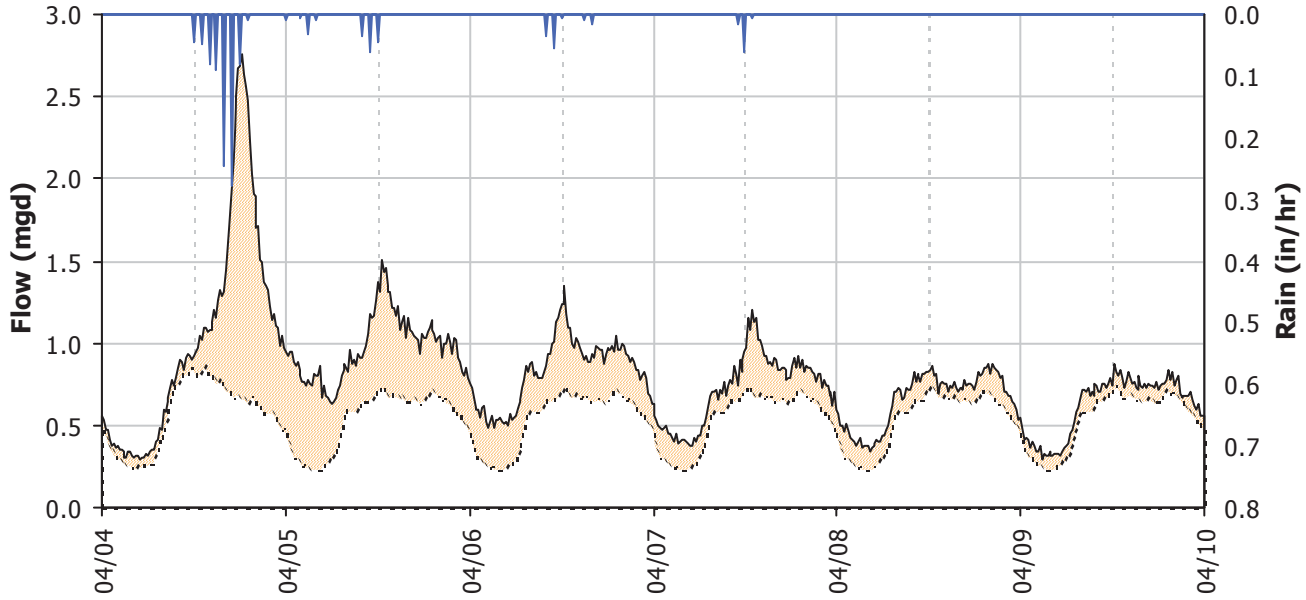
Average Infiltration Rate on 3/14 (% of ADWF): 25.1%

	I/I Summary Event 5	**Monitoring Site:** Site 2

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



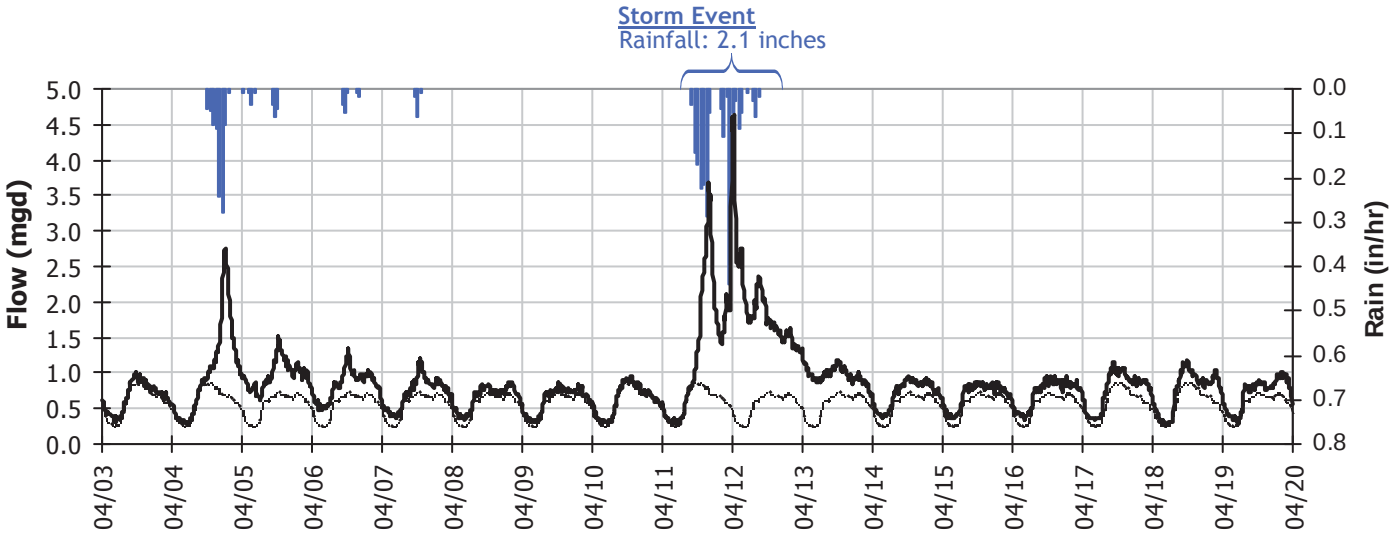
Storm Event #5 I/I Analysis

Rainfall:	1.30	*inches*		
Baseline Flow:	0.54	*mgd*		
Peak Flow:	2.75	*mgd*	**PF:**	5.12
Peak I/I Rate:	2.09	*mgd*	**Pk I/I:ADWF:**	3.89
Peak Level:	8.16	*inches*	**d/D Ratio:**	0.39
Total I/I:	1,616,000	*gallons*	**R-Value:**	9.4%
			I/I per ADWF:	2.31 *per in-rain*

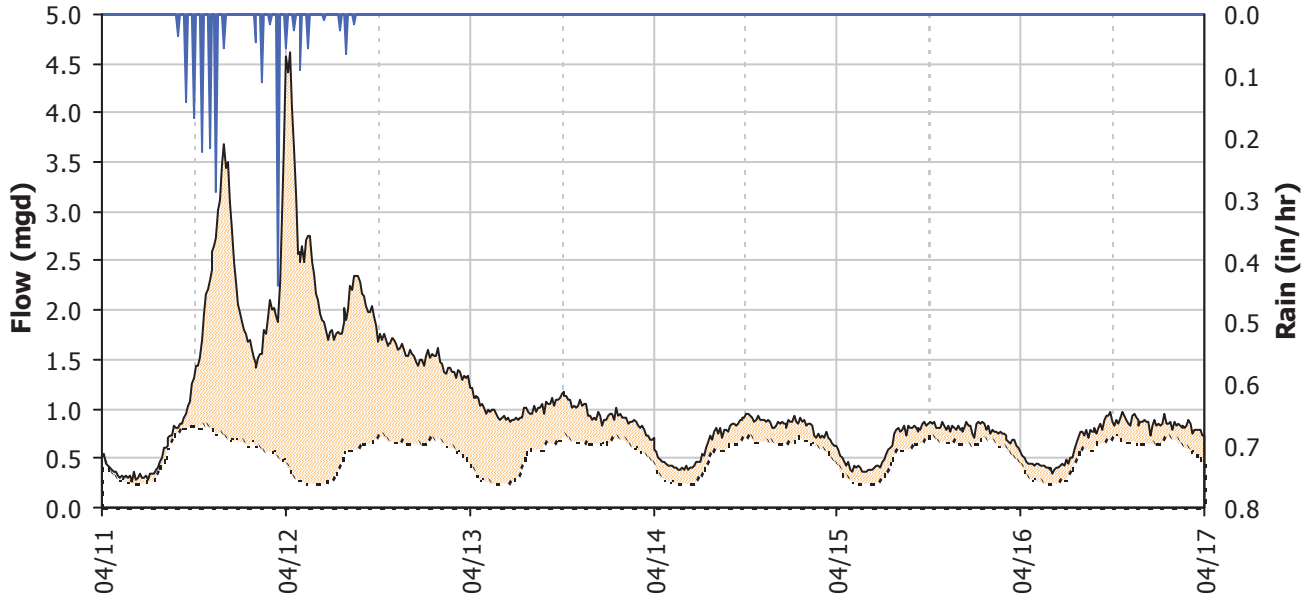
Average Infiltration Rate on 4/8 (% of ADWF): 24.1%

	I/I Summary Event 6	**Monitoring Site:** Site 2

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



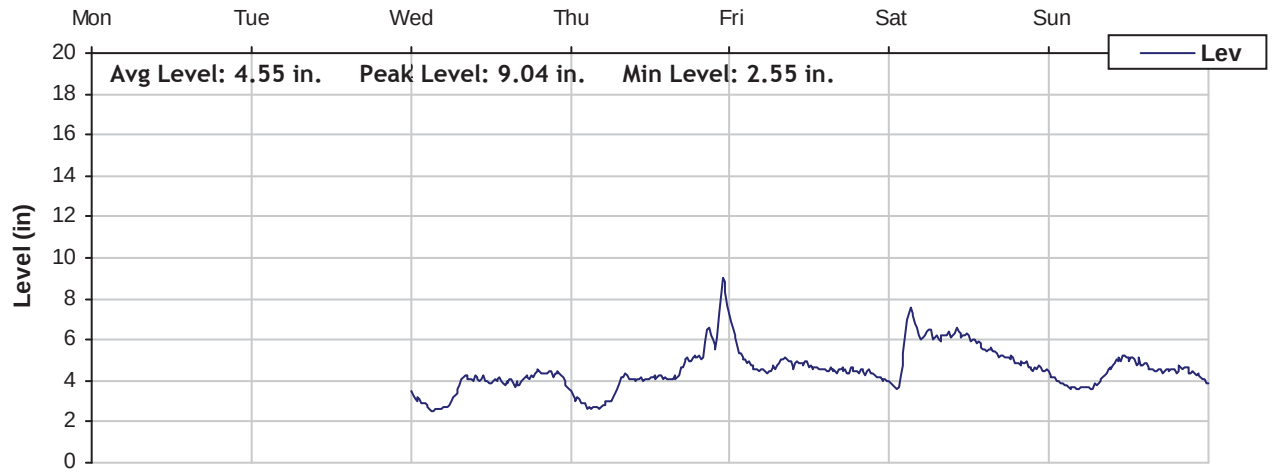
Storm Event #6 I/I Analysis

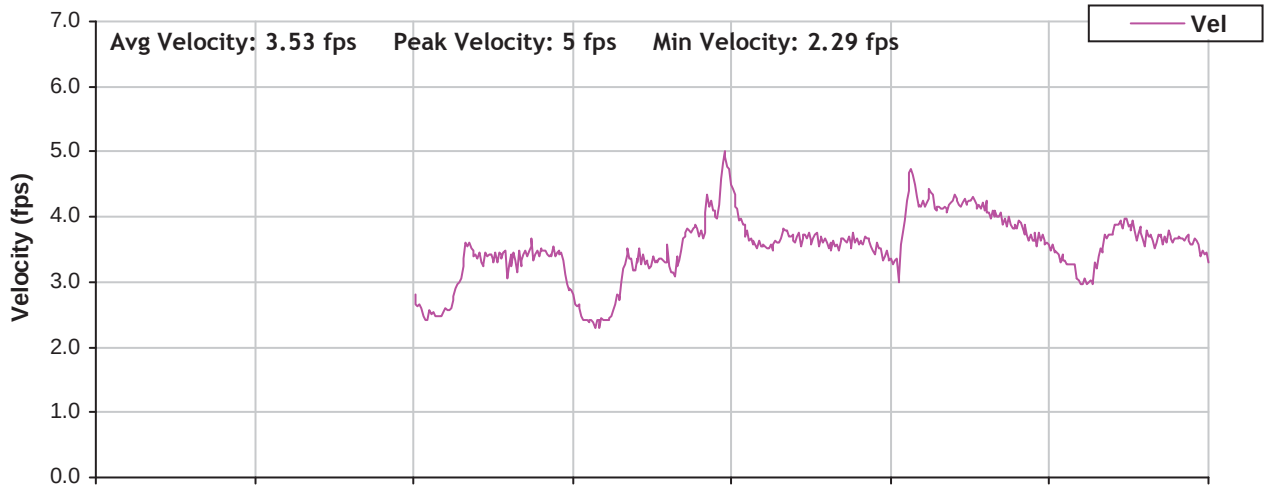
Rainfall:	2.10	*inches*		
Baseline Flow:	0.54	*mgd*		
Peak Flow:	4.62	*mgd*	**PF:**	8.59
Peak I/I Rate:	4.27	*mgd*	**Pk I/I:ADWF:**	7.93
Peak Level:	17.74	*inches*	**d/D Ratio:**	0.84
Total I/I:	3,189,000	*gallons*	**R-Value:**	11.5%
			I/I per ADWF:	2.83 *per in-rain*

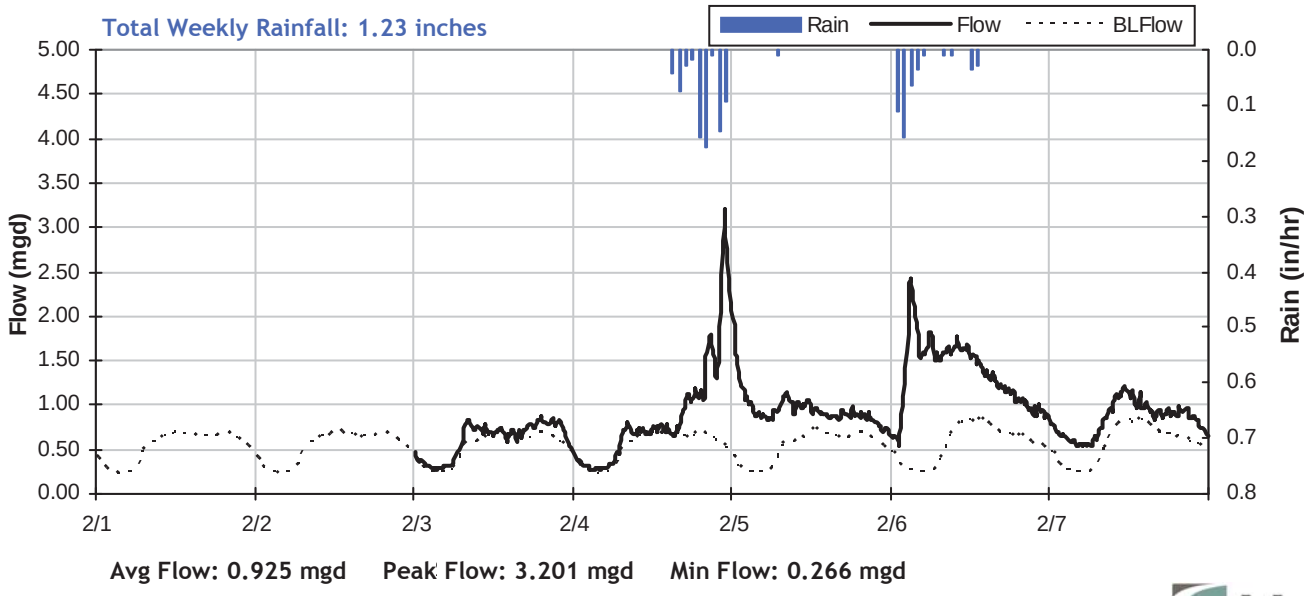
Average Infiltration Rate on 4/14 (% of ADWF): 35.1%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 2





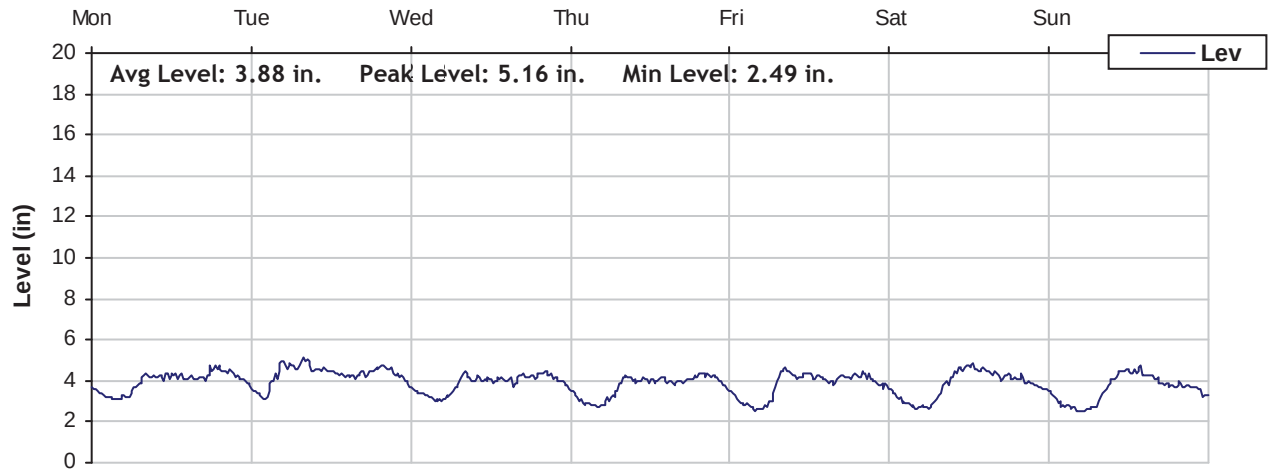


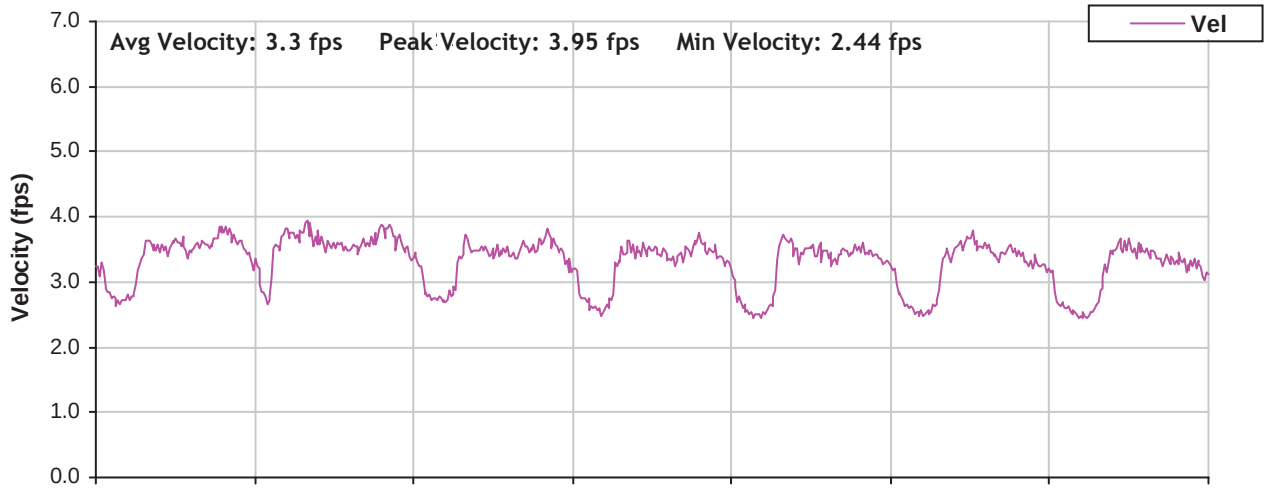
Avg Flow: 0.925 mgd Peak Flow: 3.201 mgd Min Flow: 0.266 mgd

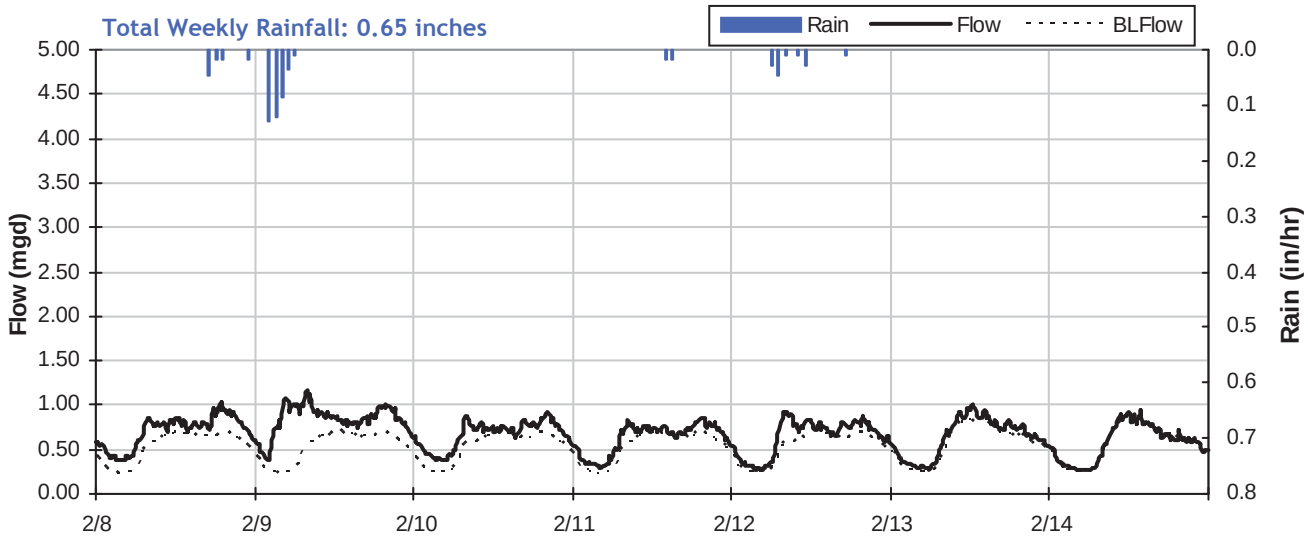
V&A

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 2



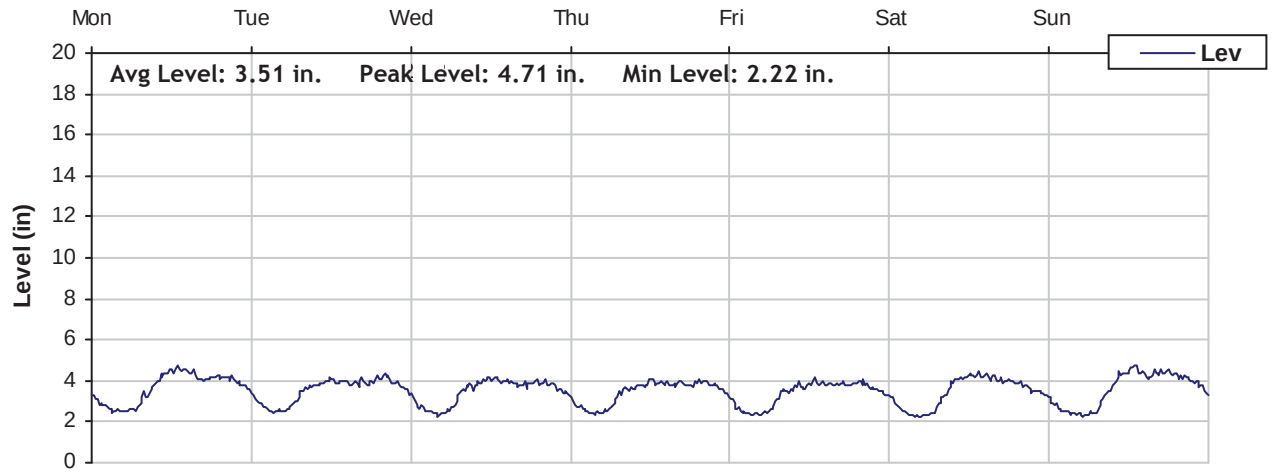


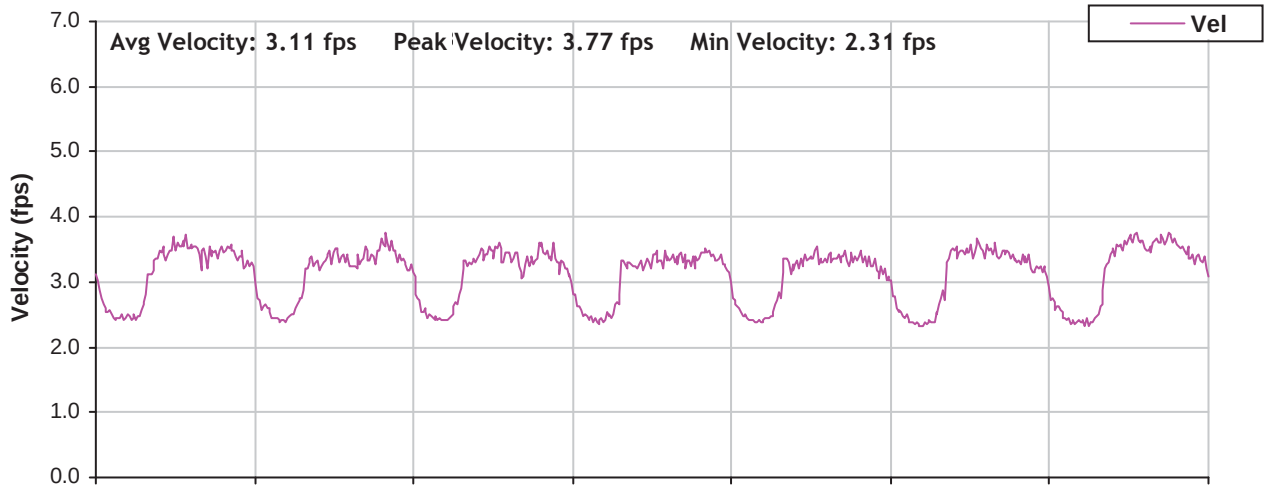


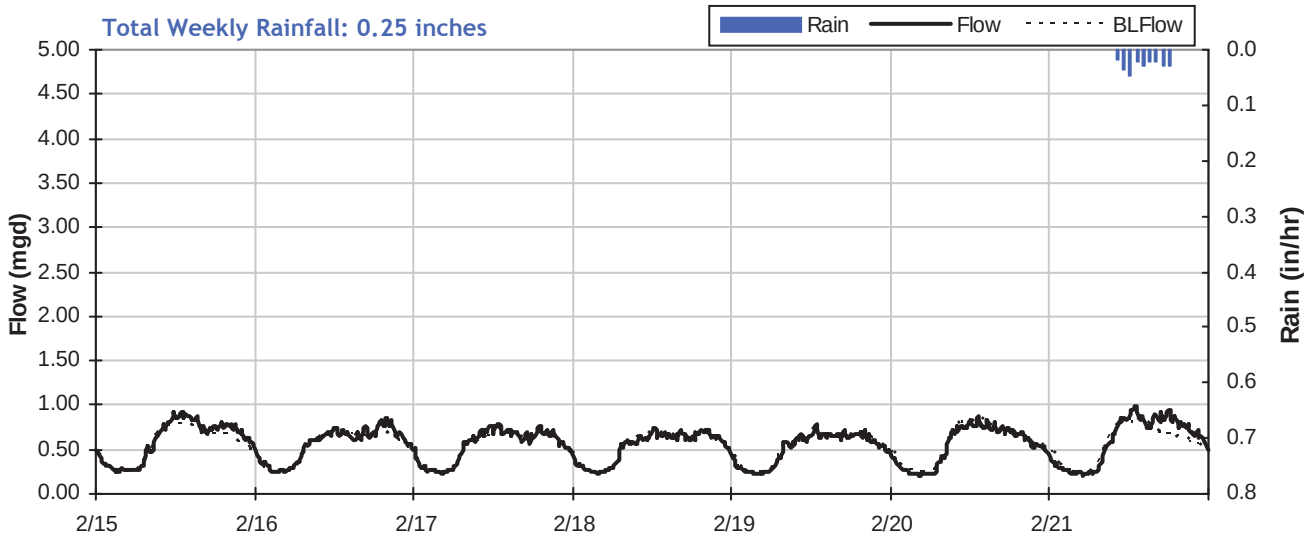
Avg Flow: 0.671 mgd Peak Flow: 1.174 mgd Min Flow: 0.26 mgd

Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 2



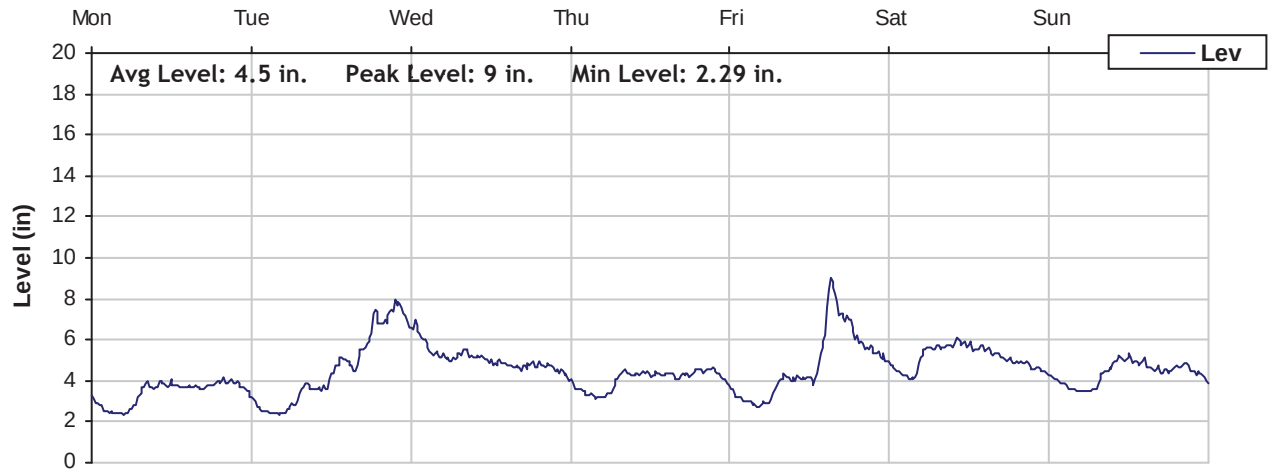


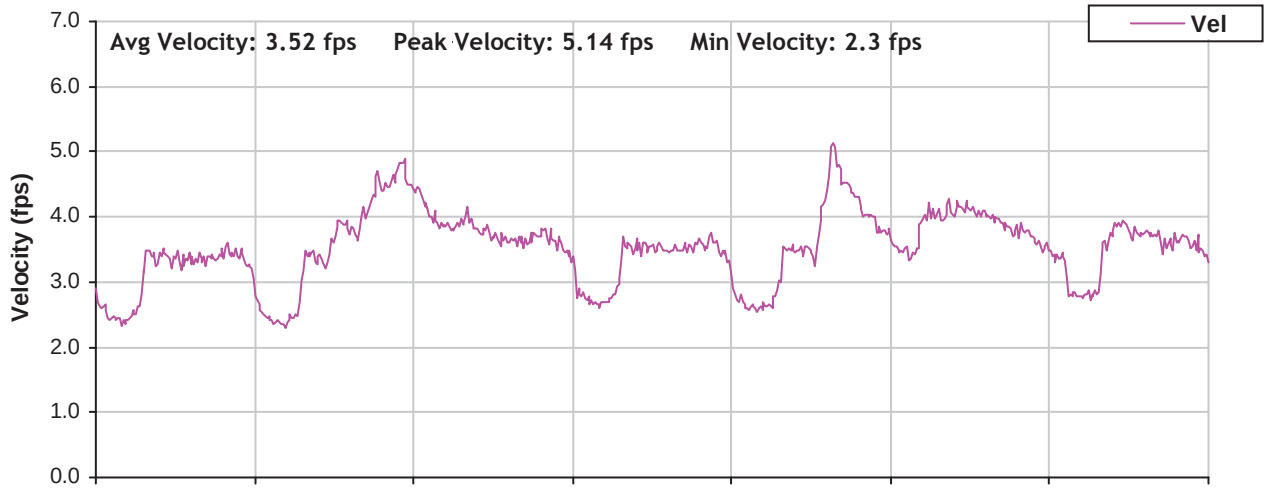


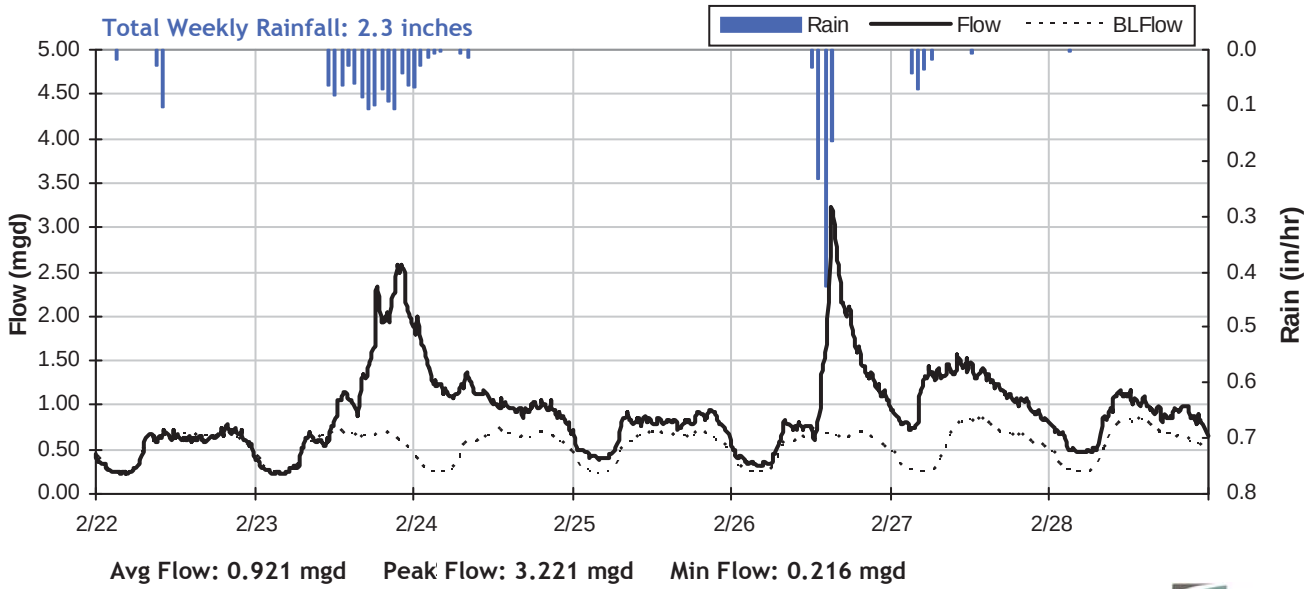
Avg Flow: 0.557 mgd Peak Flow: 0.981 mgd Min Flow: 0.202 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 2



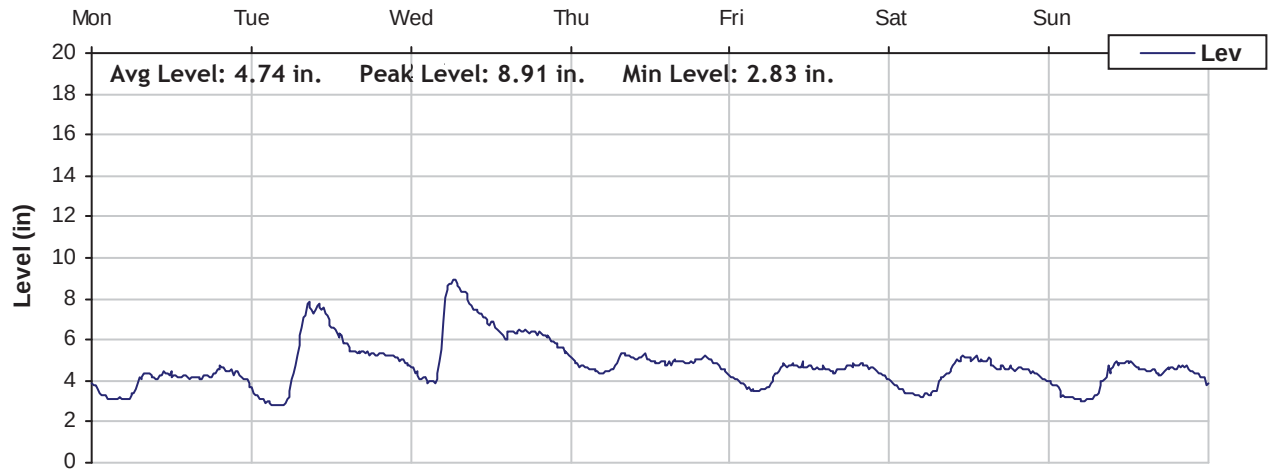


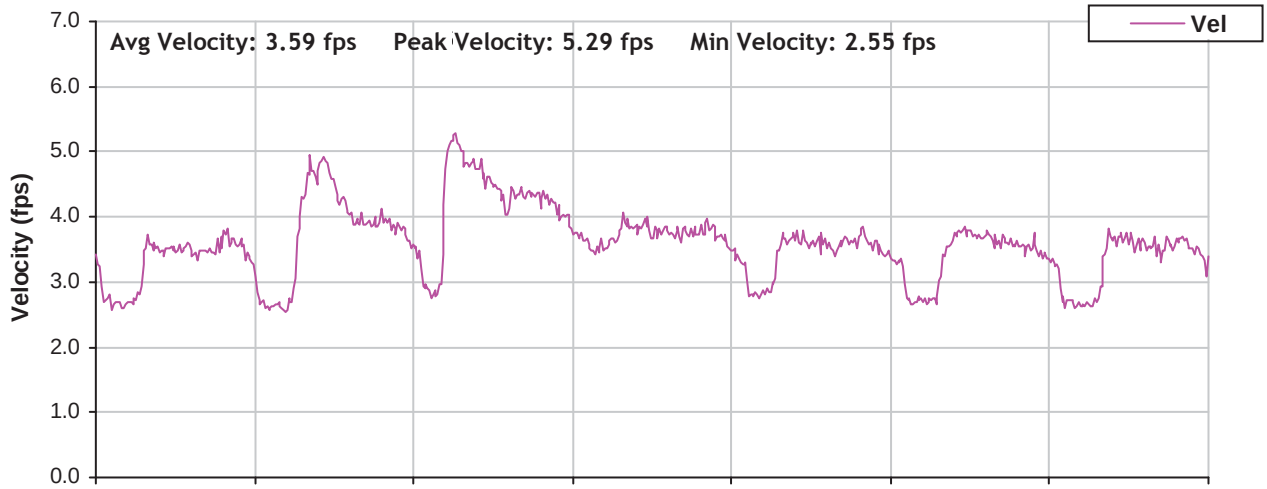


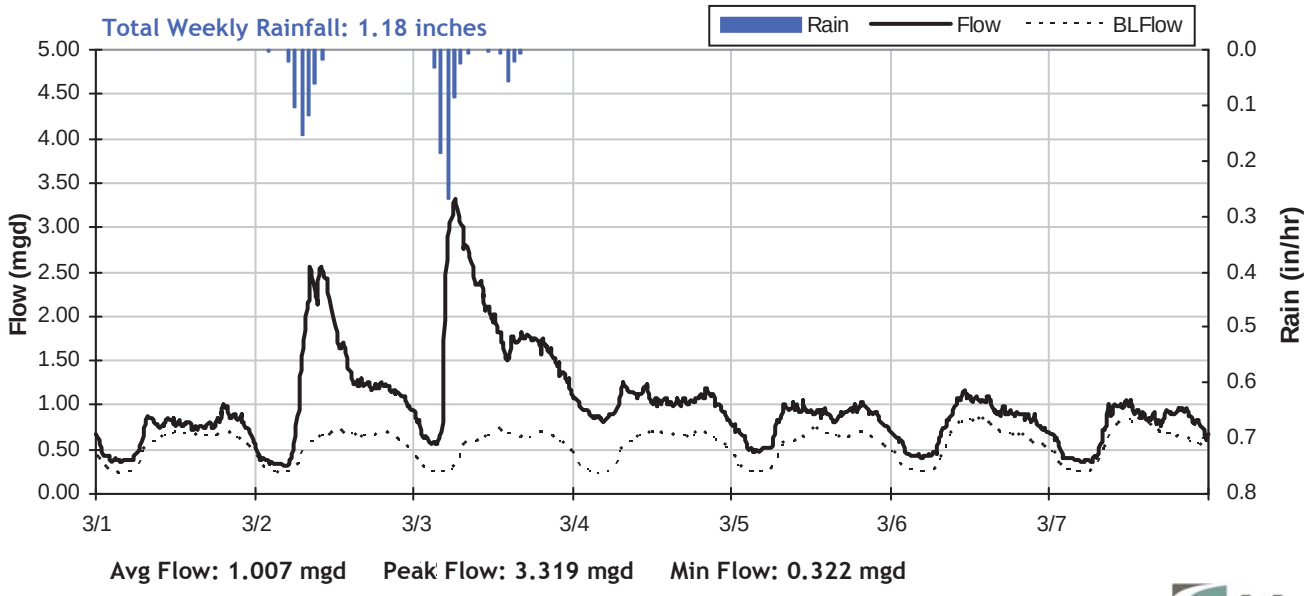
Avg Flow: 0.921 mgd Peak Flow: 3.221 mgd Min Flow: 0.216 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 2



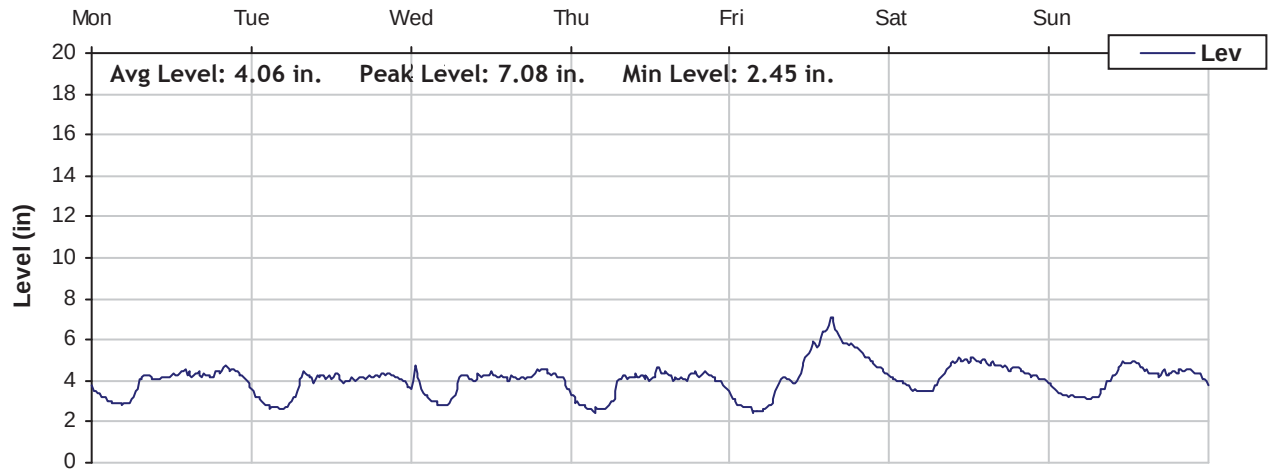


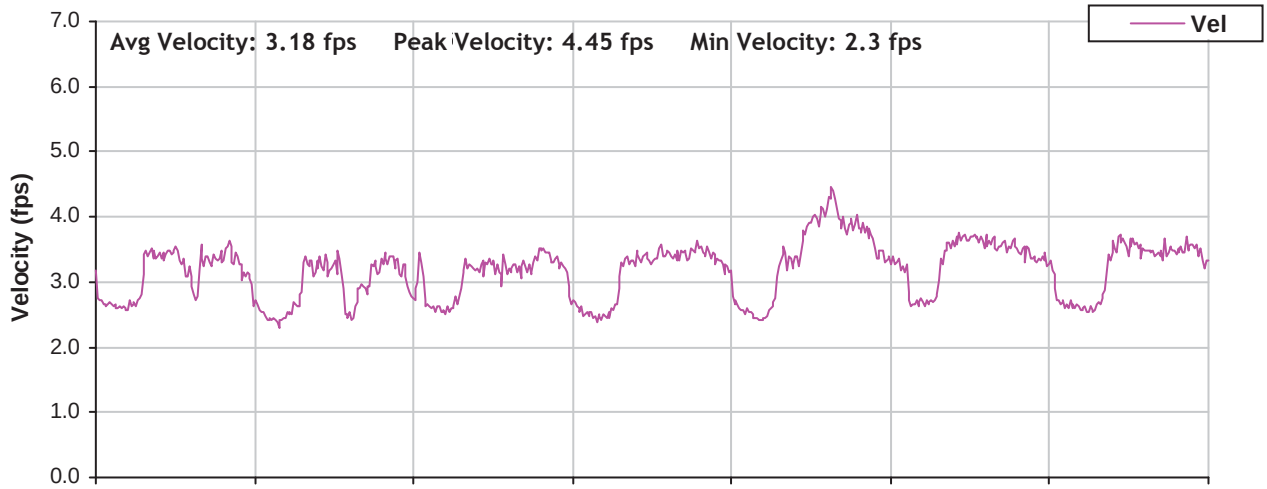


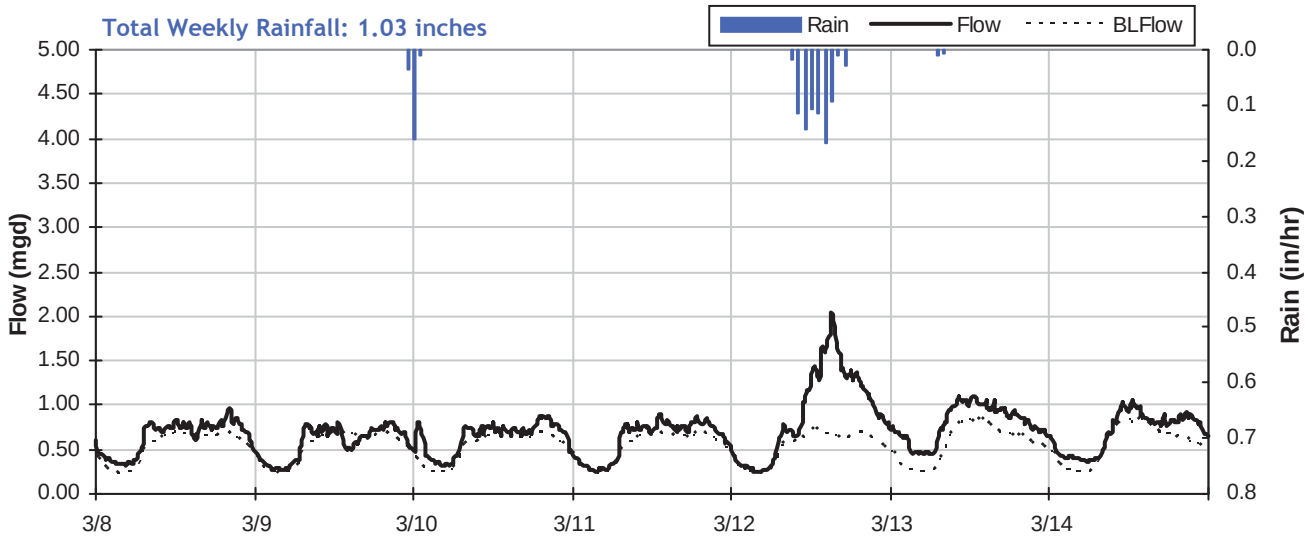
Avg Flow: 1.007 mgd Peak Flow: 3.319 mgd Min Flow: 0.322 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 2



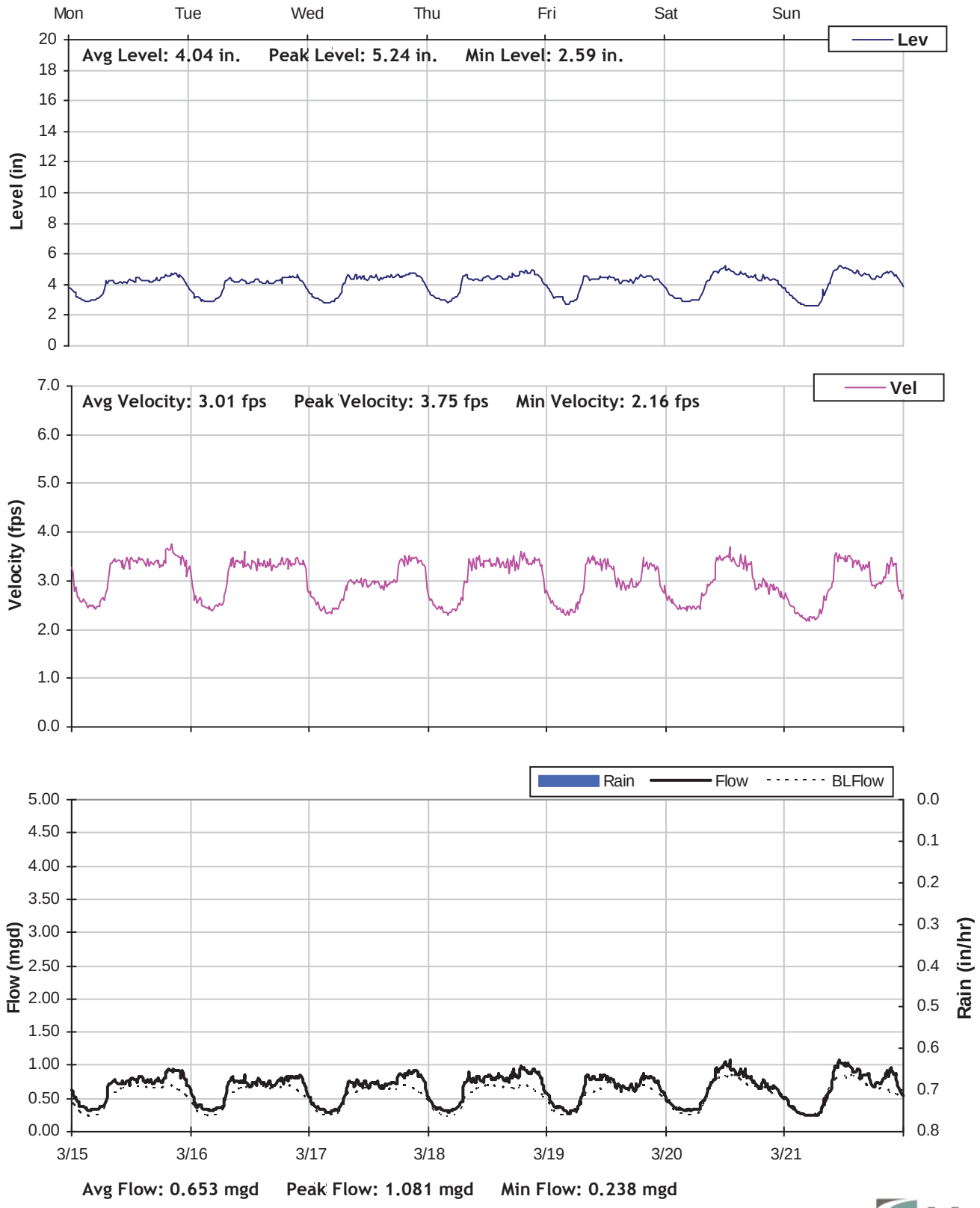




Avg Flow: 0.699 mgd Peak Flow: 2.05 mgd Min Flow: 0.242 mgd

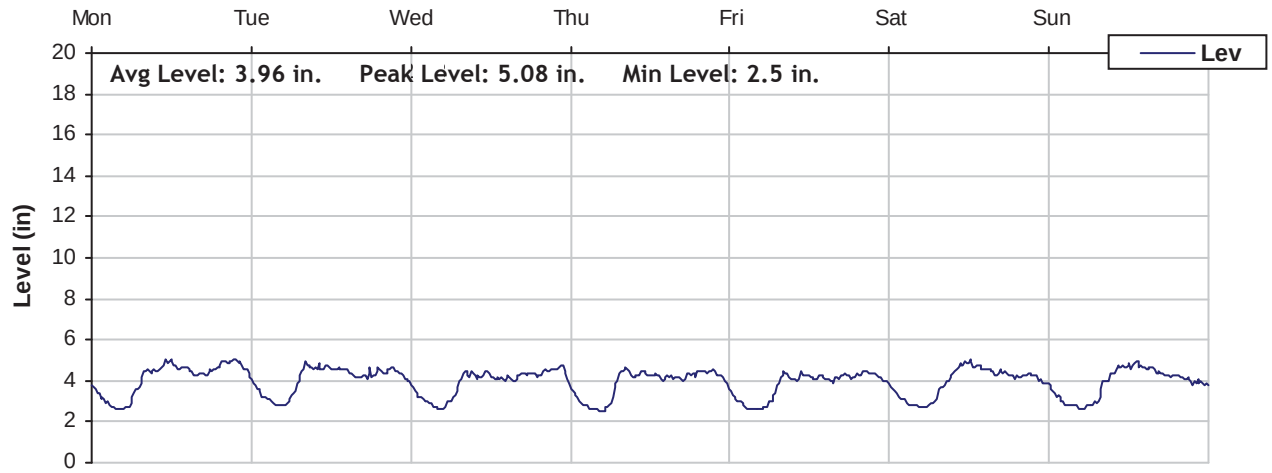
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

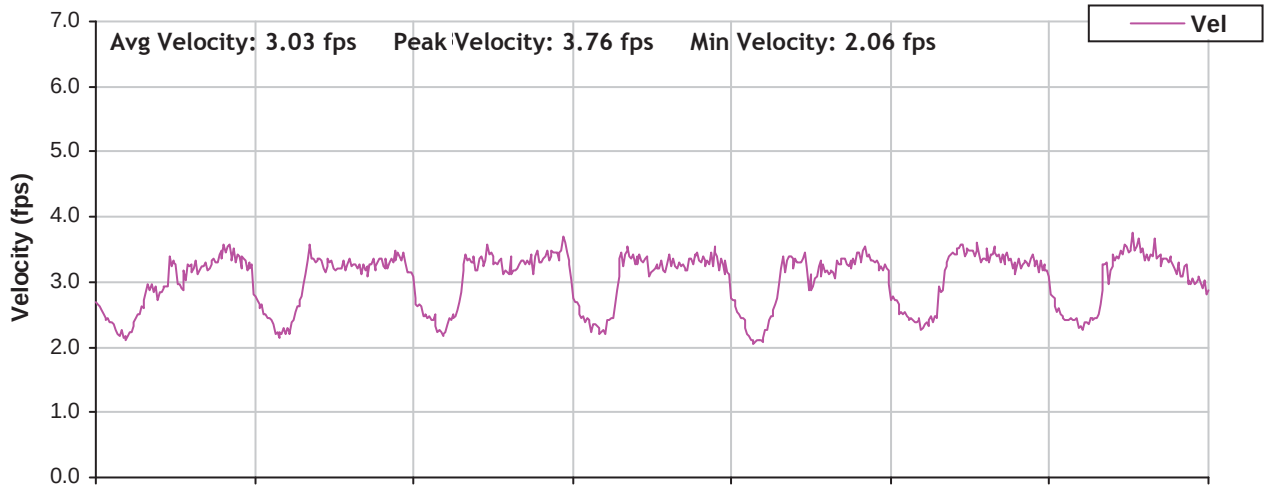
Monitoring Site:
Site 2

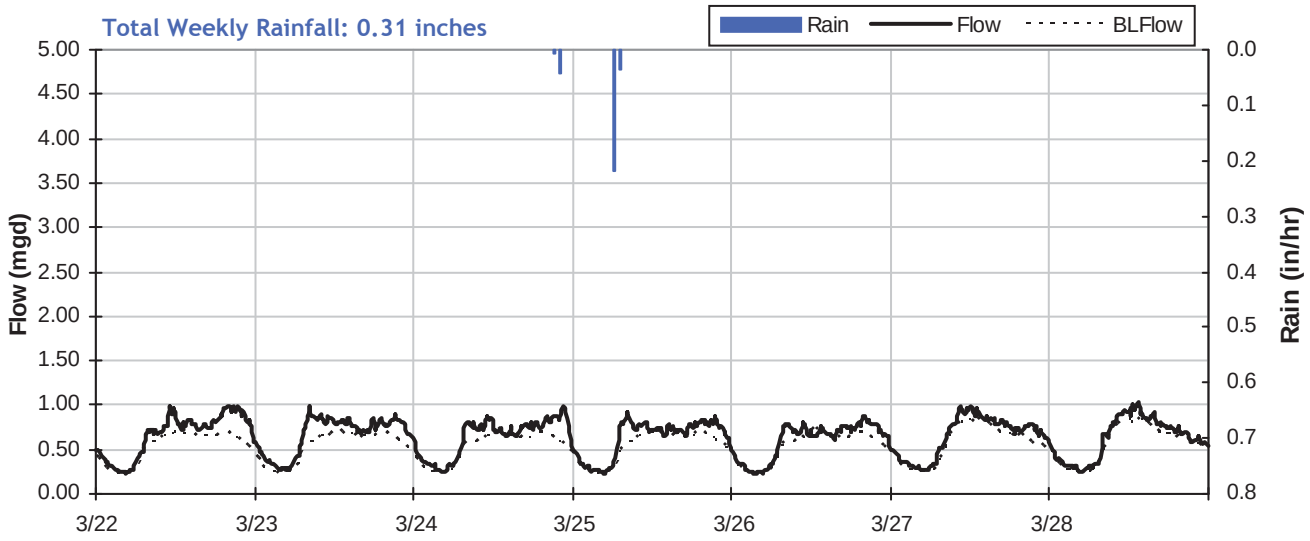


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 2



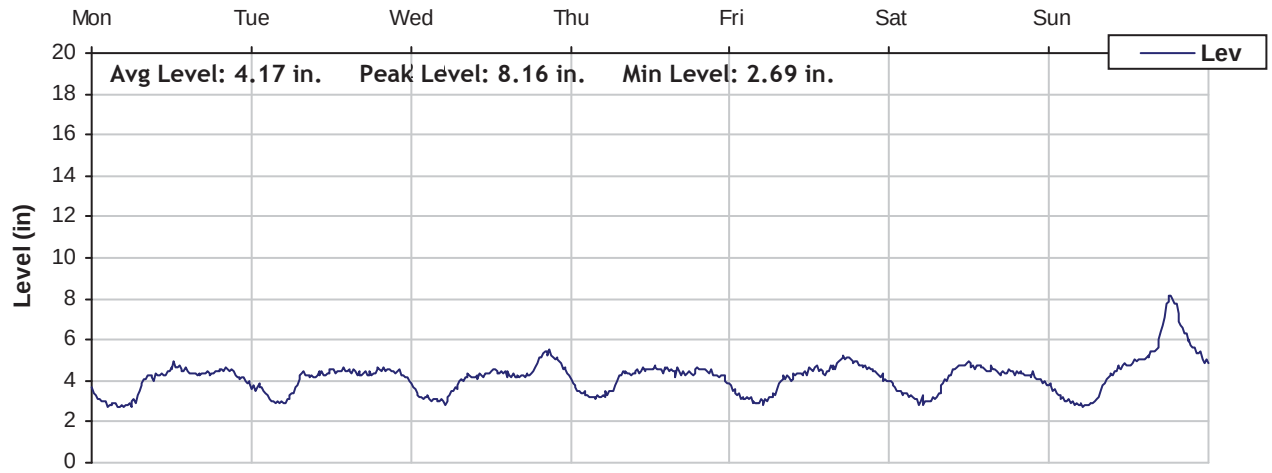


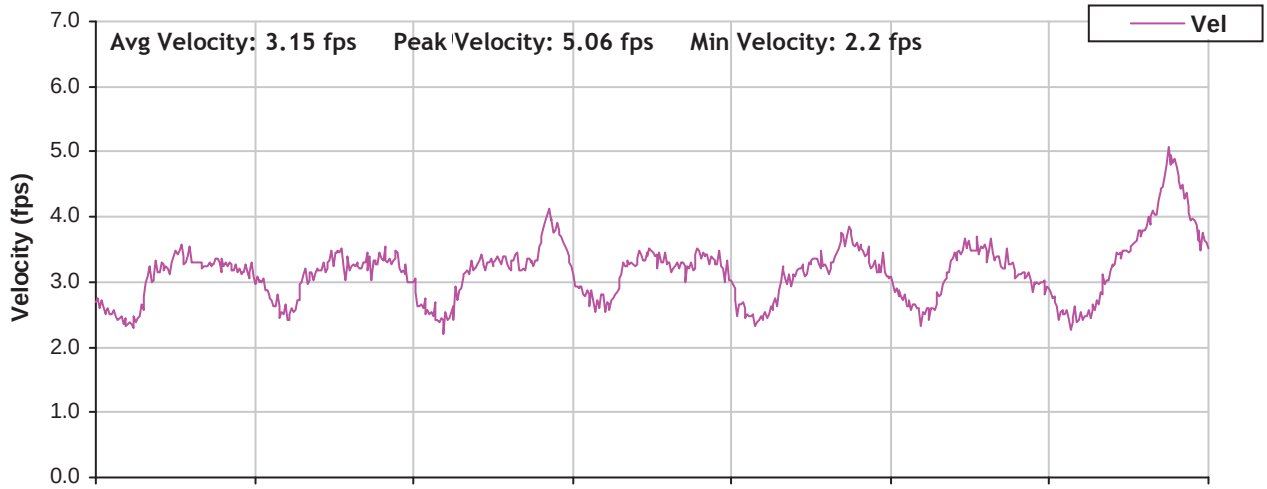


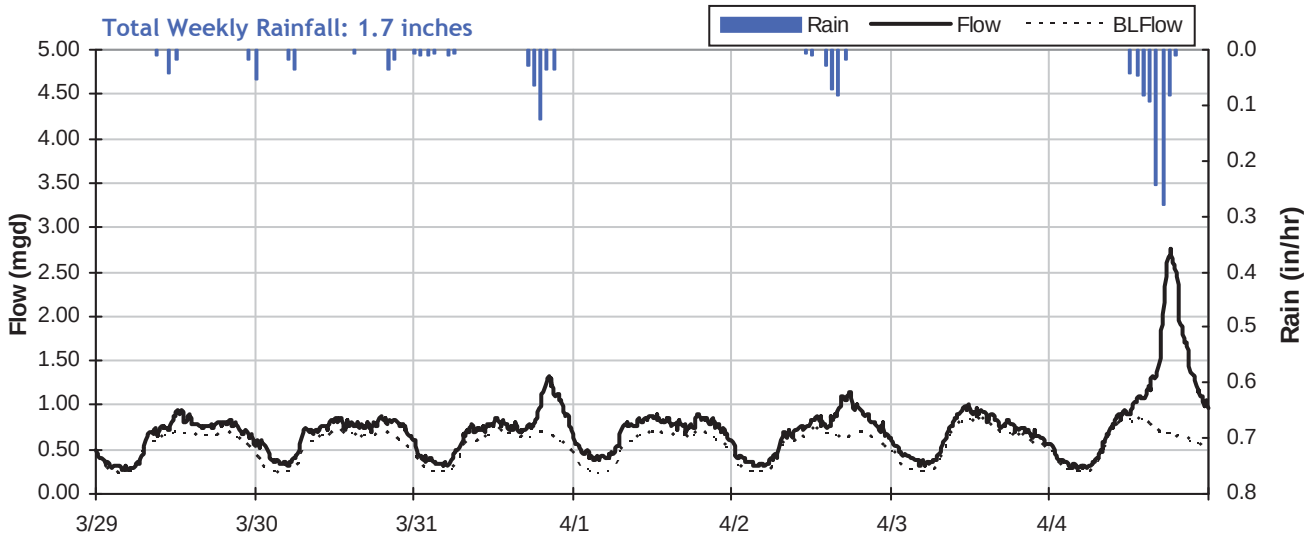
Avg Flow: 0.639 mgd Peak Flow: 1.022 mgd Min Flow: 0.23 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 2



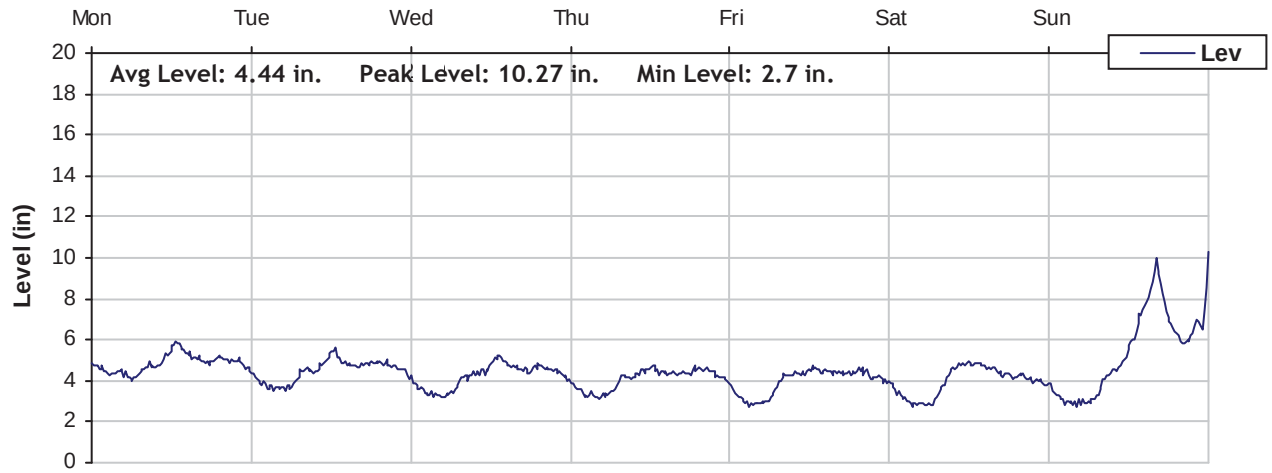


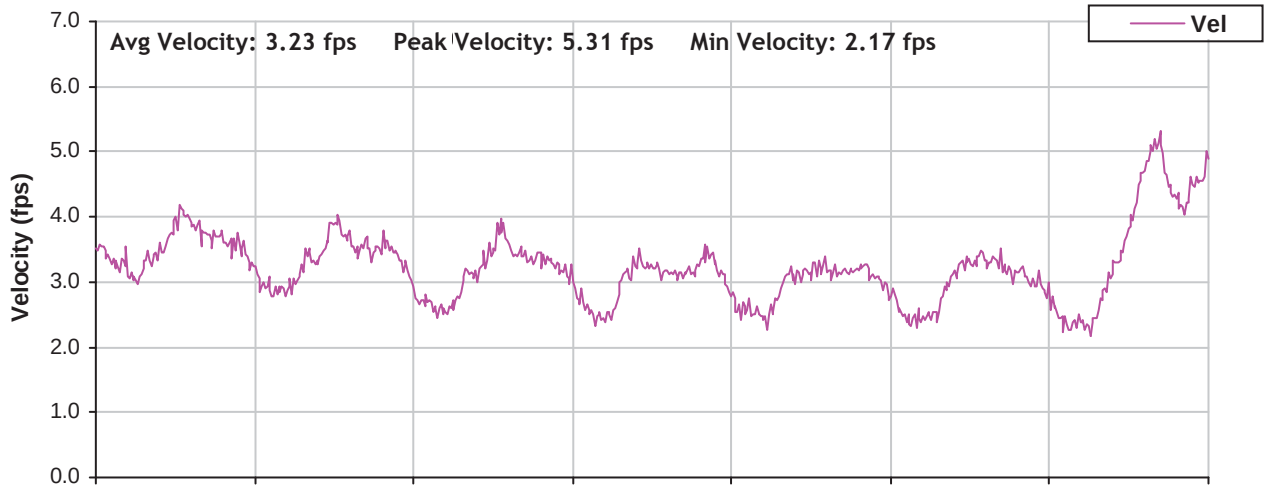


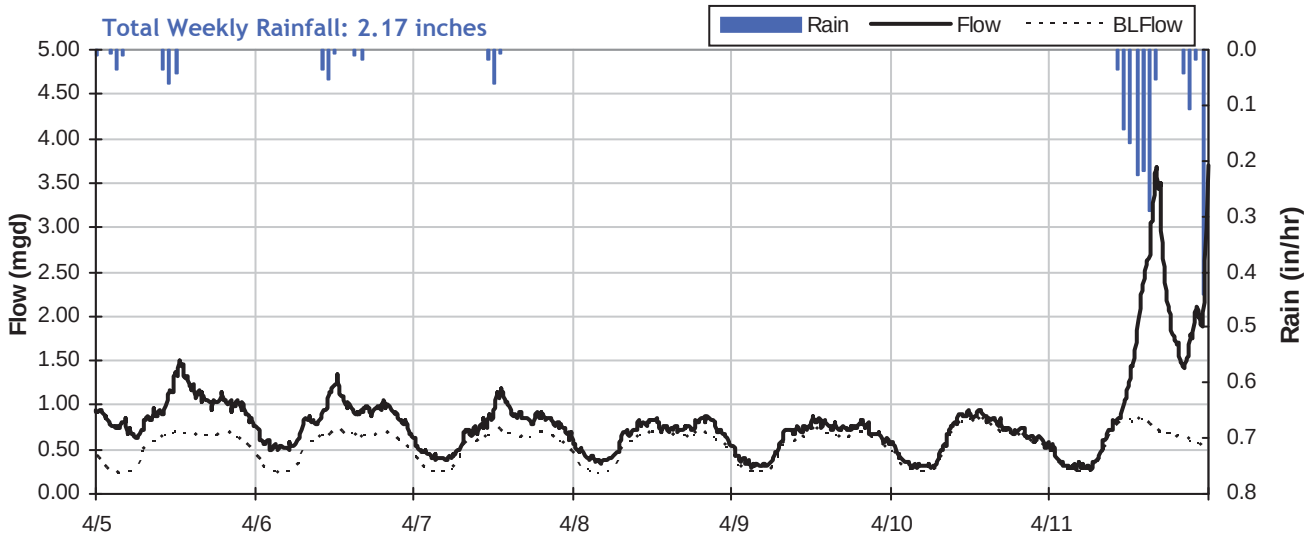
Avg Flow: 0.726 mgd Peak Flow: 2.755 mgd Min Flow: 0.274 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 2



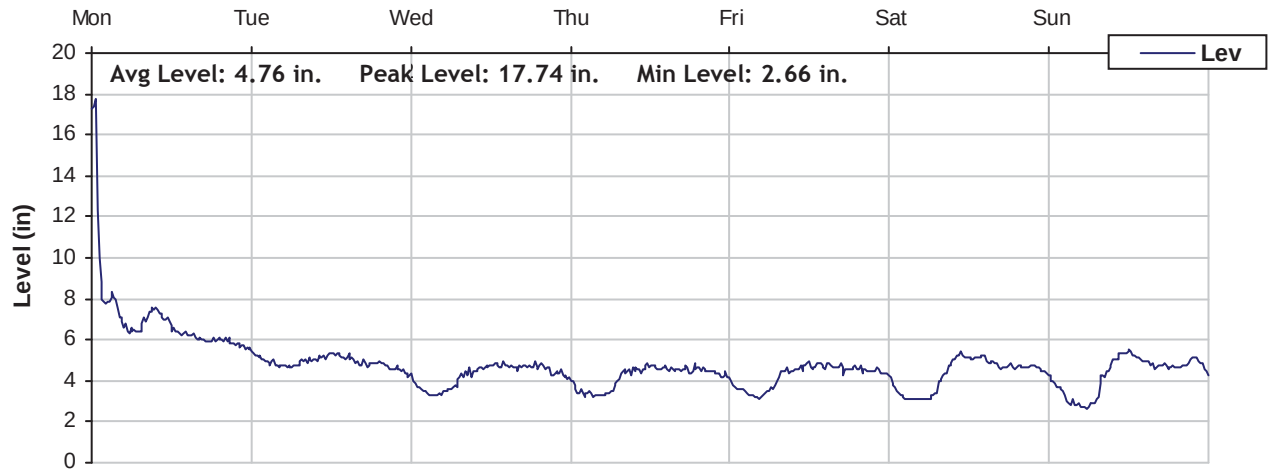


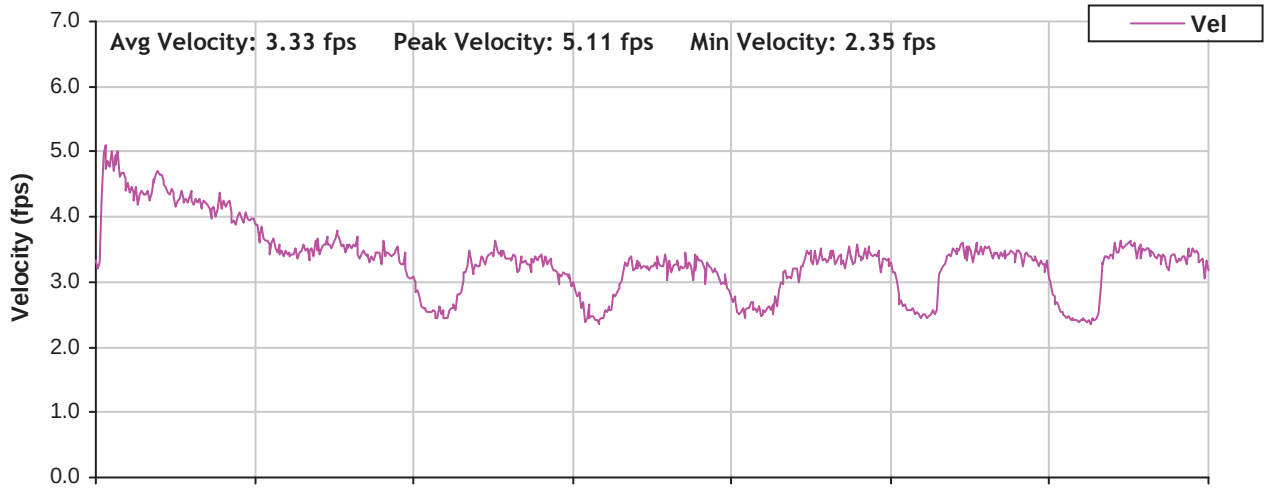


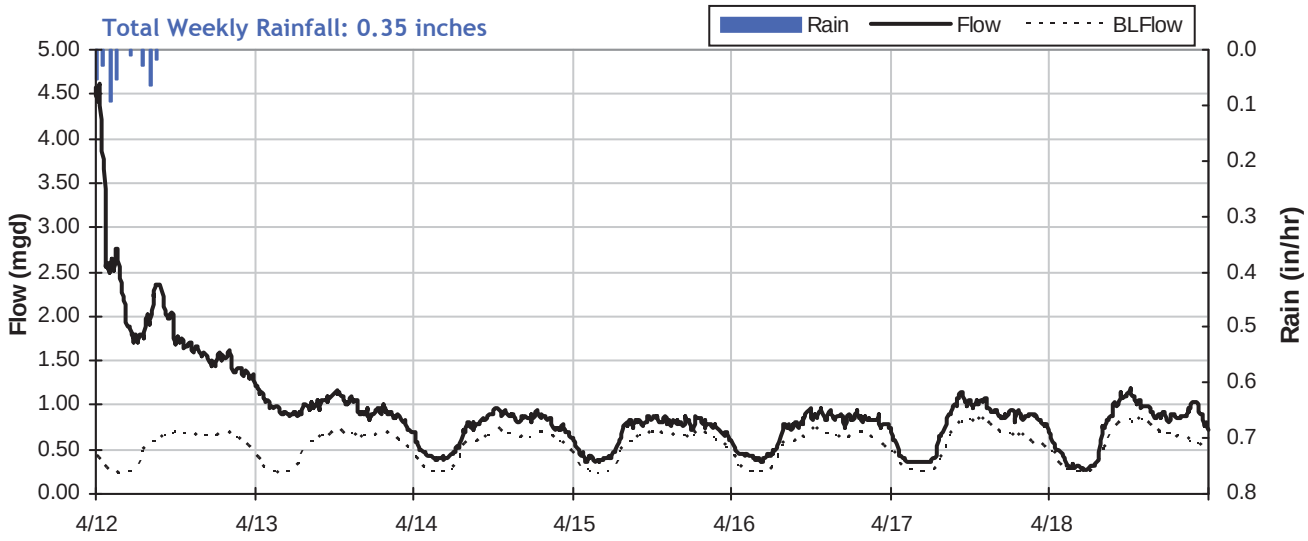
Avg Flow: 0.826 mgd Peak Flow: 3.695 mgd Min Flow: 0.27 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 2



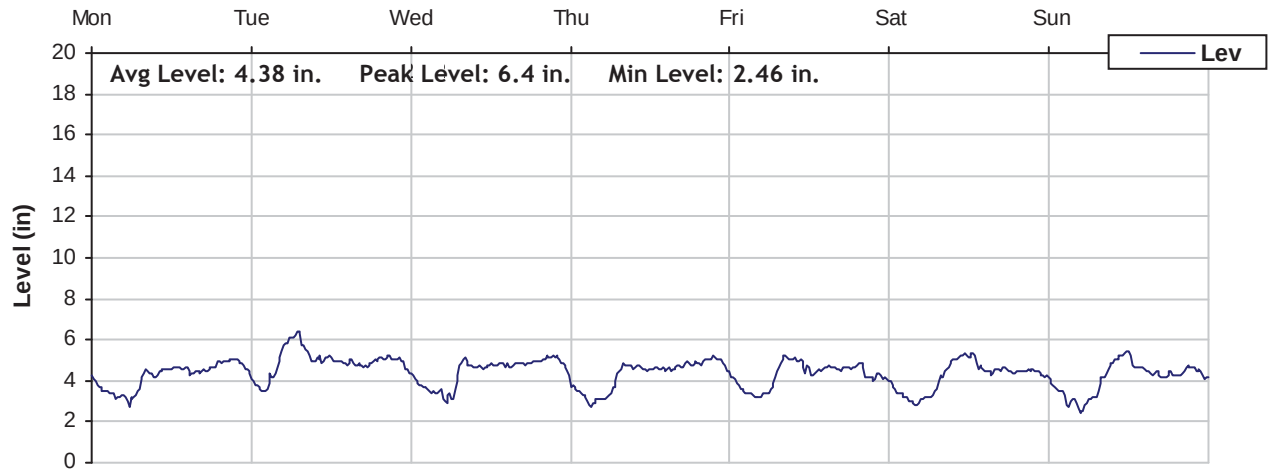


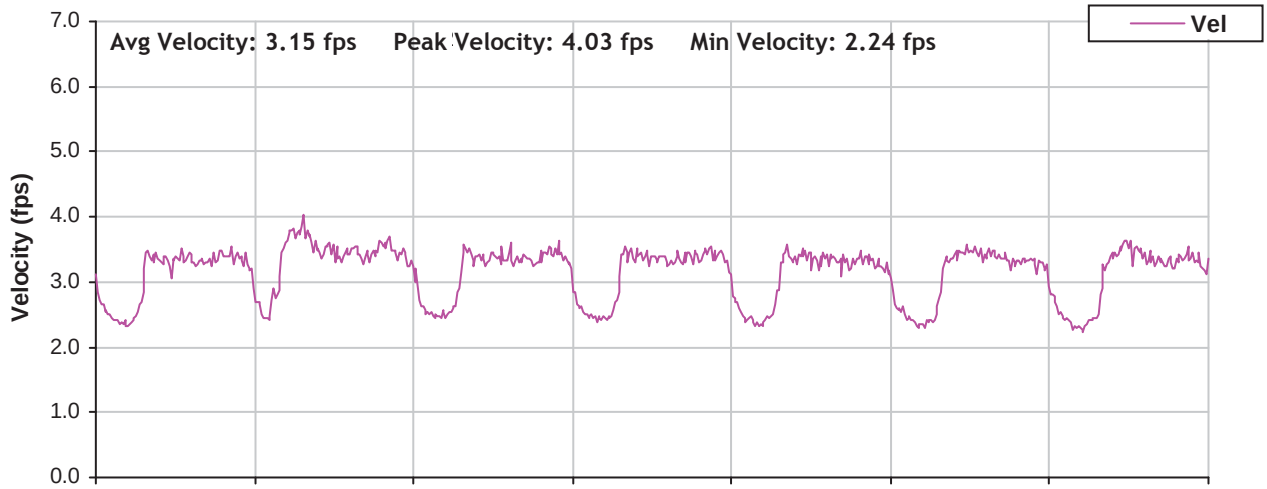


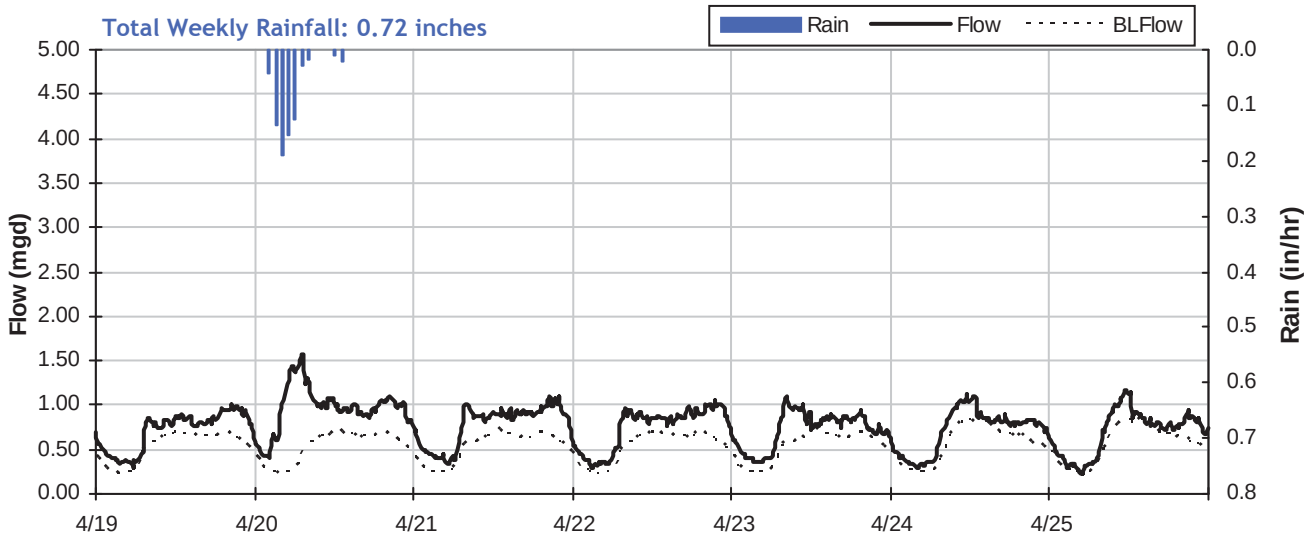
Avg Flow: 0.937 mgd Peak Flow: 4.621 mgd Min Flow: 0.272 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 2



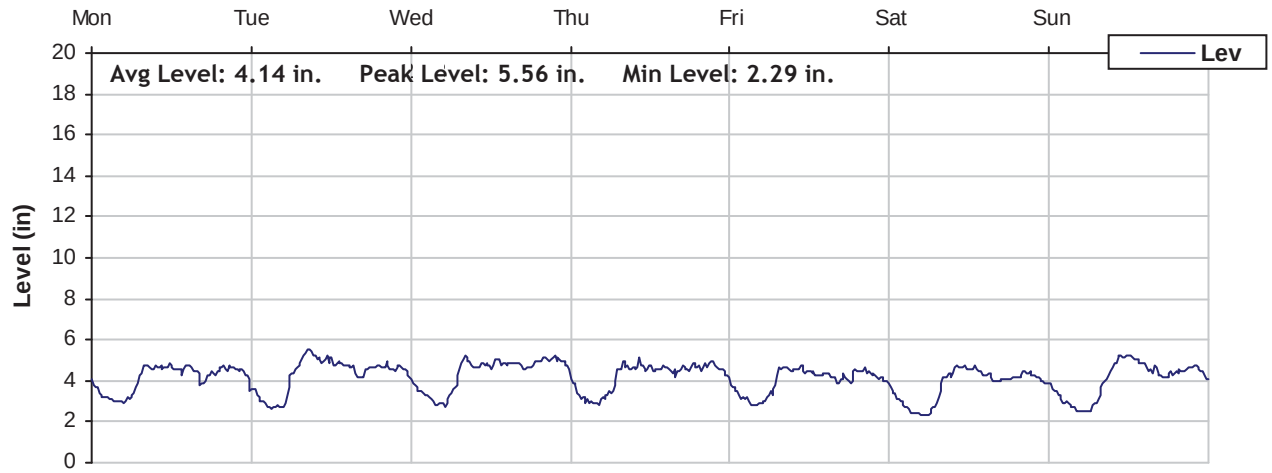


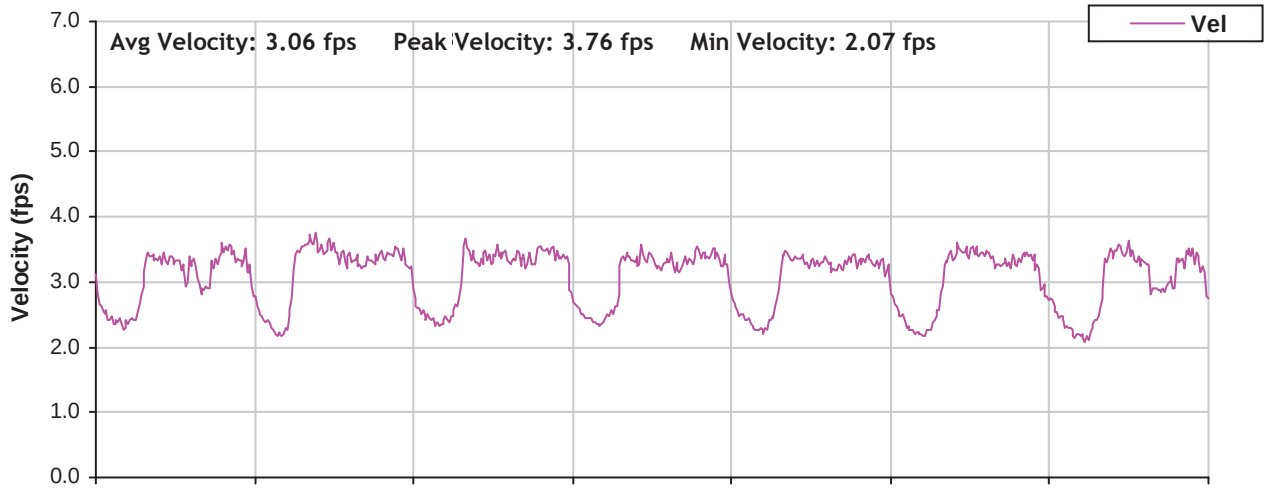


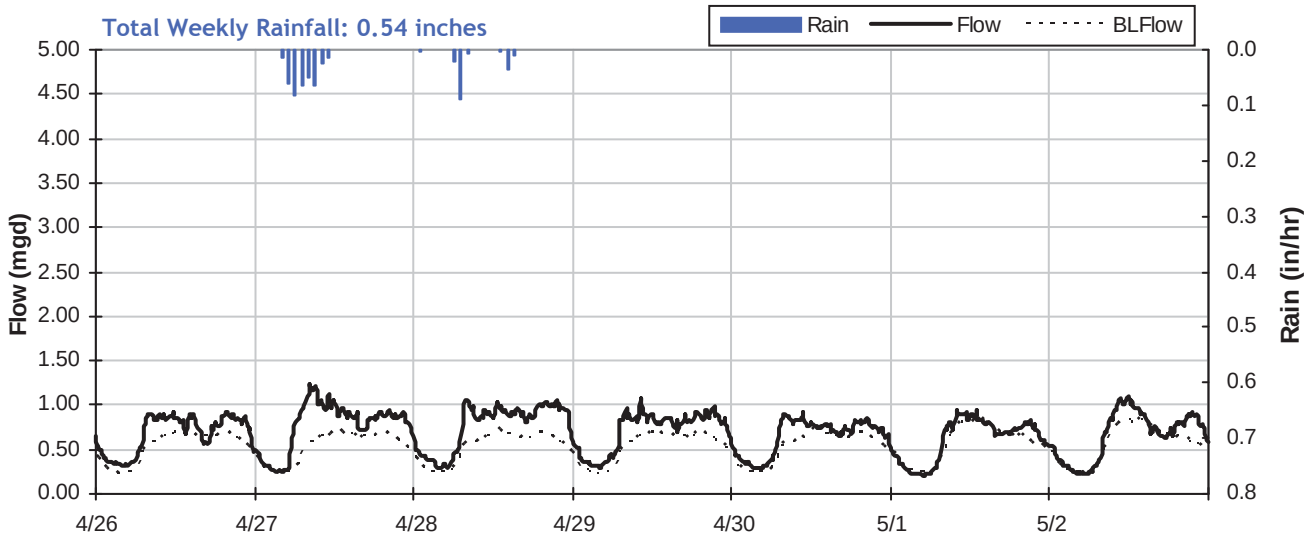
Avg Flow: 0.764 mgd Peak Flow: 1.57 mgd Min Flow: 0.231 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 2



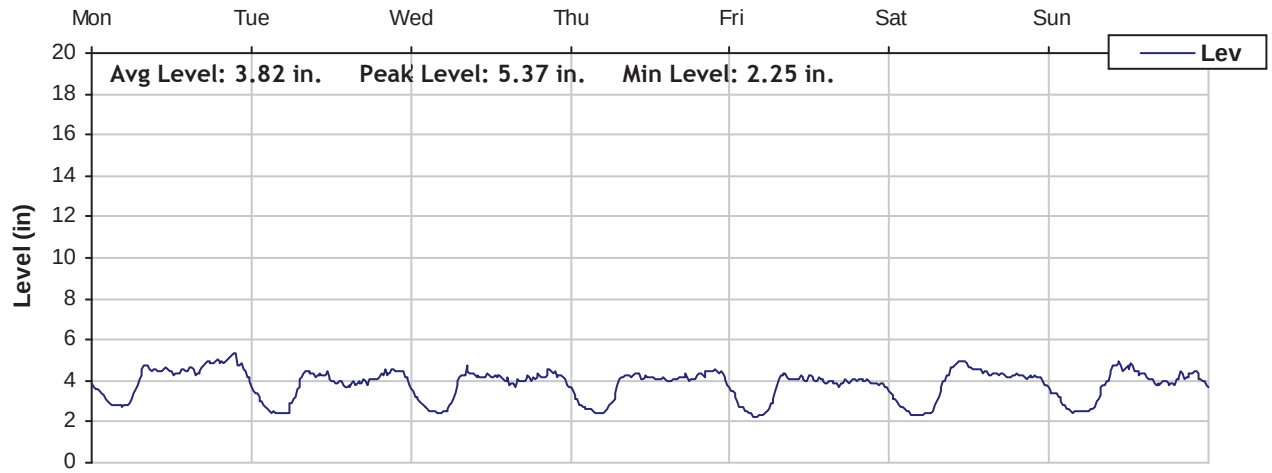


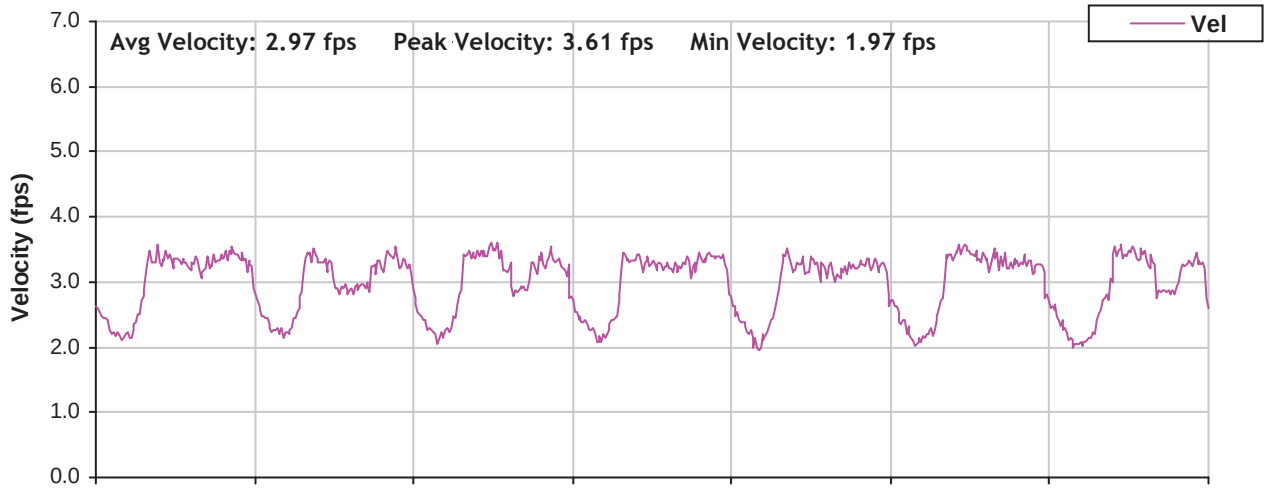


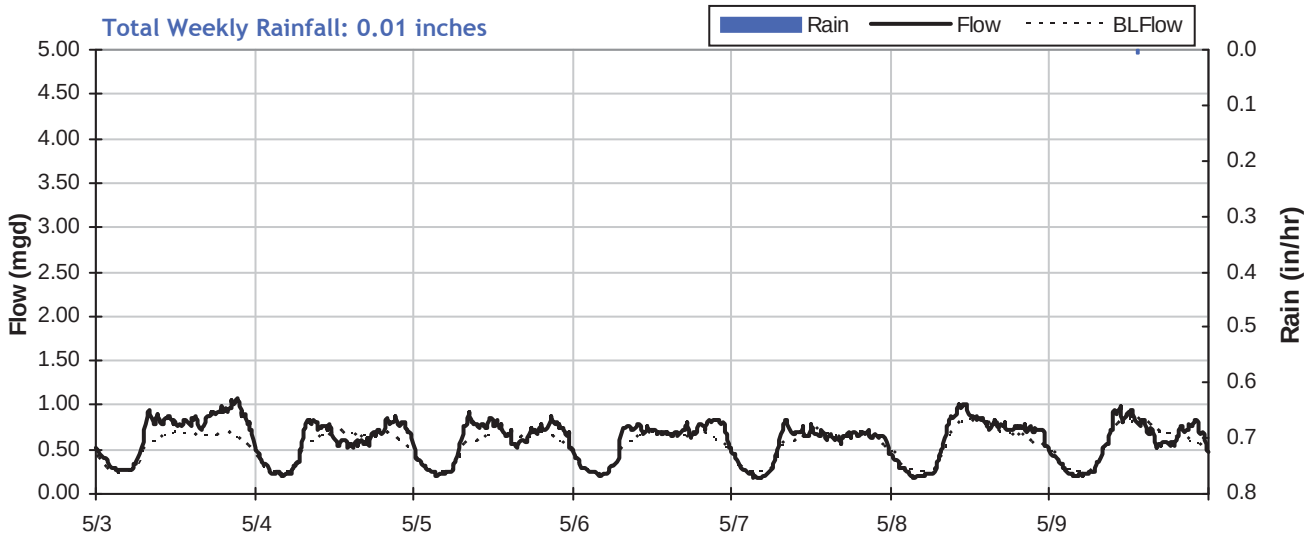
Avg Flow: 0.693 mgd Peak Flow: 1.228 mgd Min Flow: 0.2 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 2



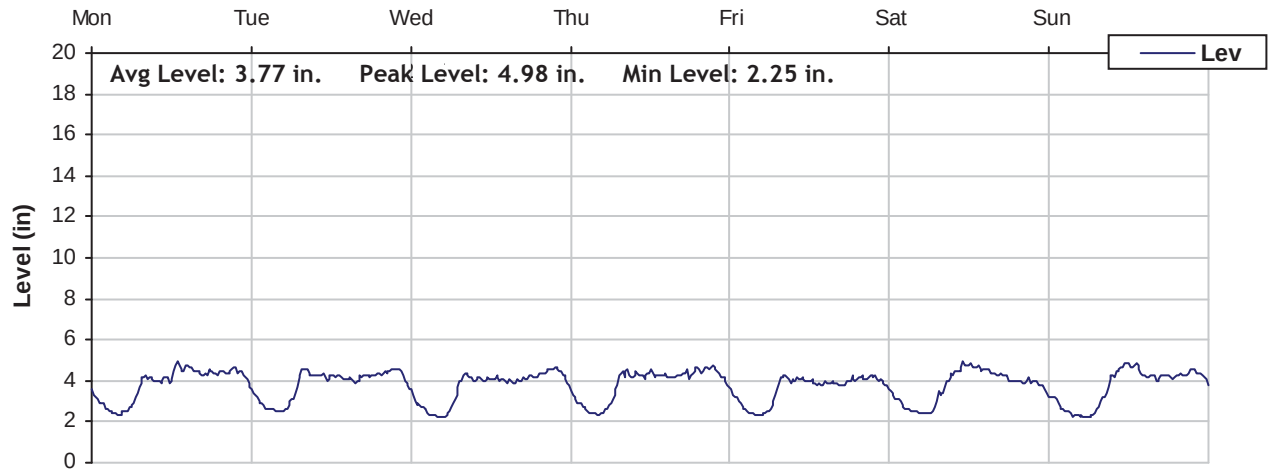


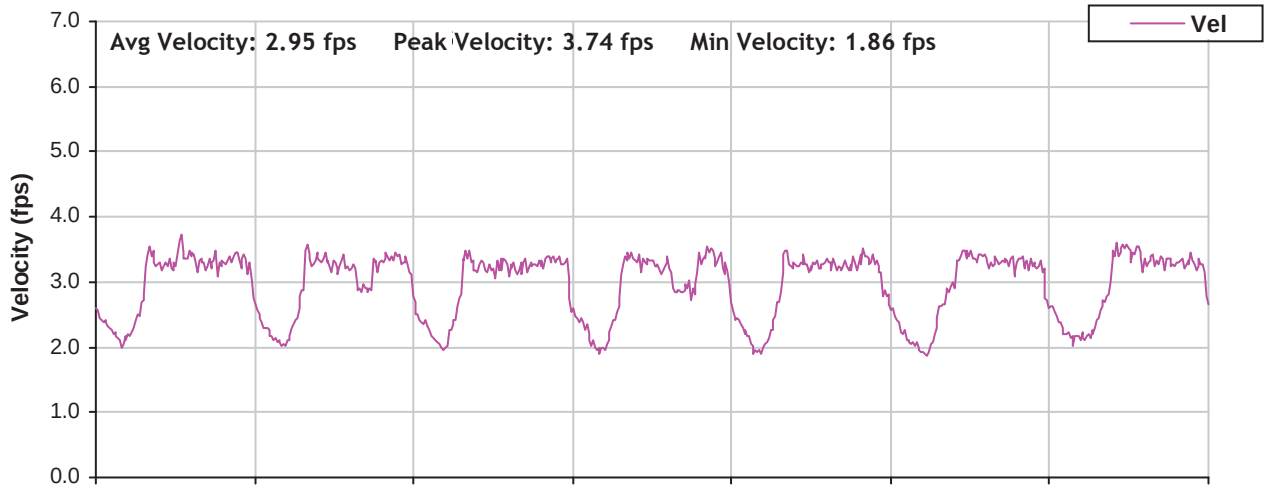


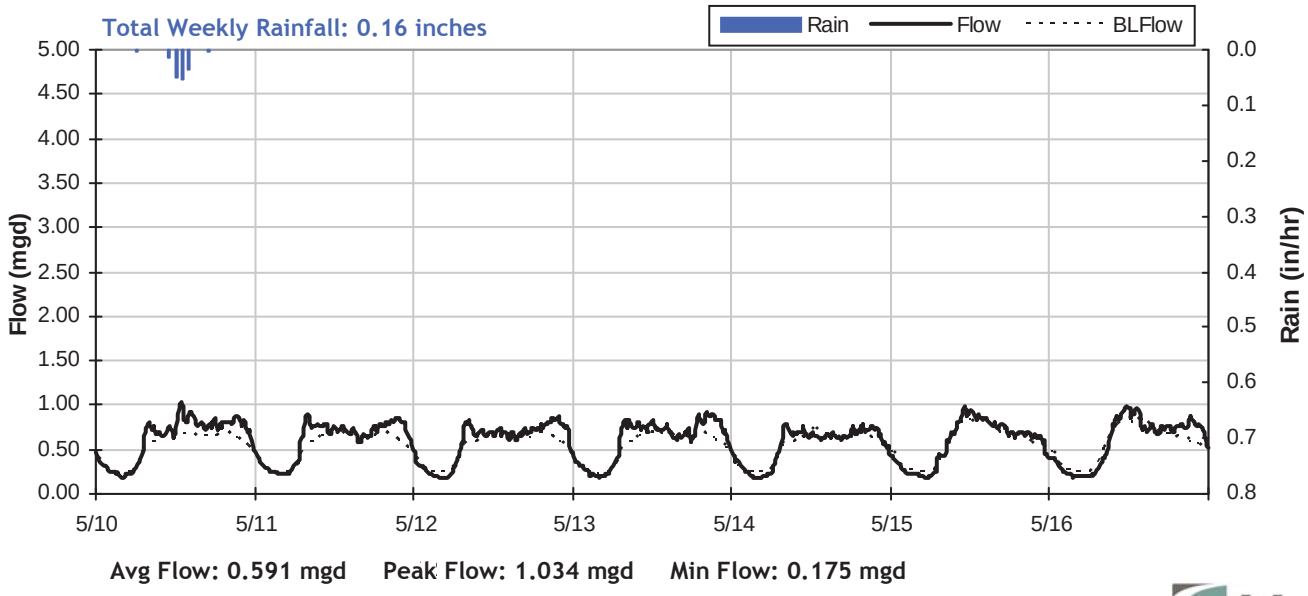
Avg Flow: 0.603 mgd Peak Flow: 1.074 mgd Min Flow: 0.18 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 2



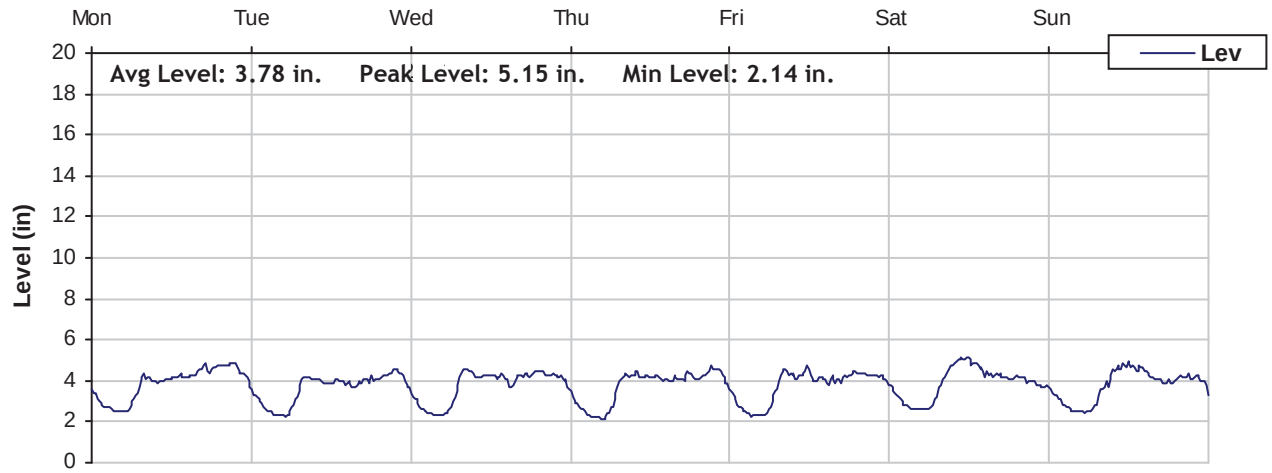


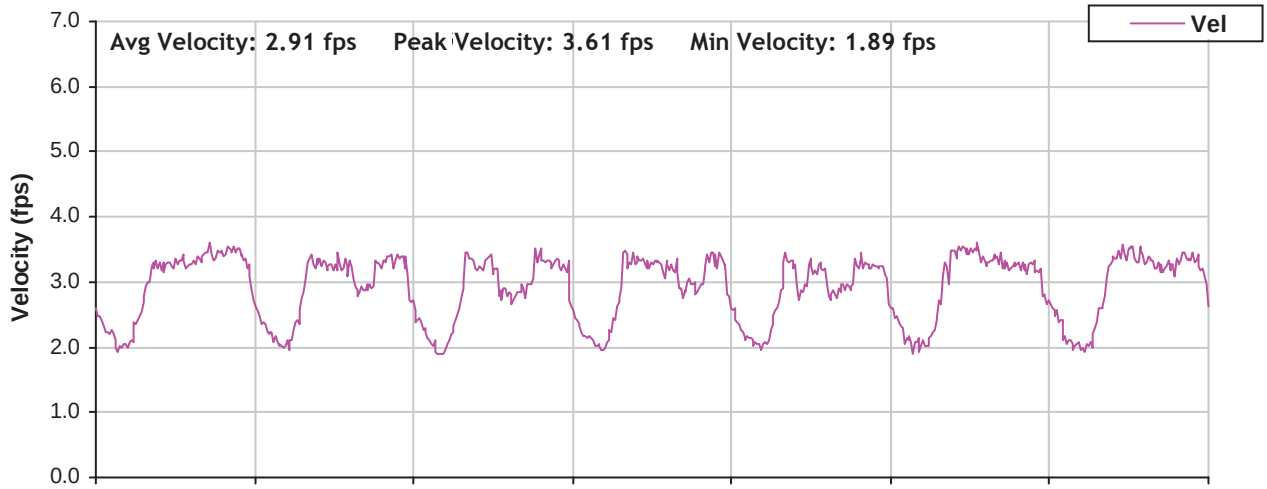


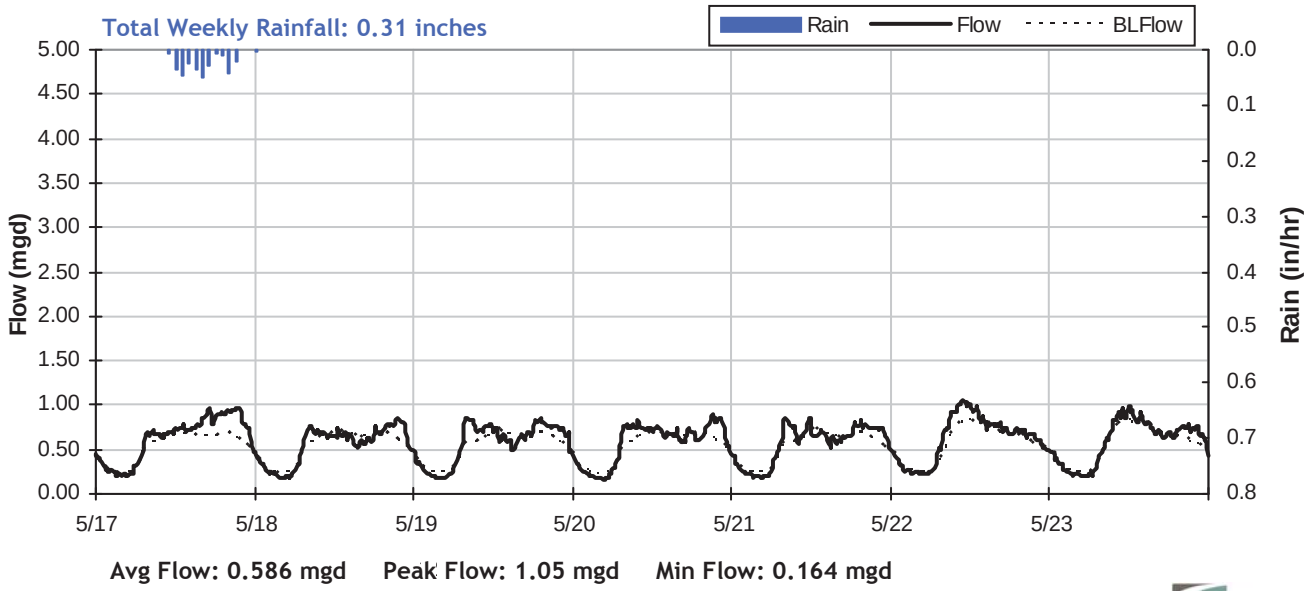
Avg Flow: 0.591 mgd Peak Flow: 1.034 mgd Min Flow: 0.175 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 2



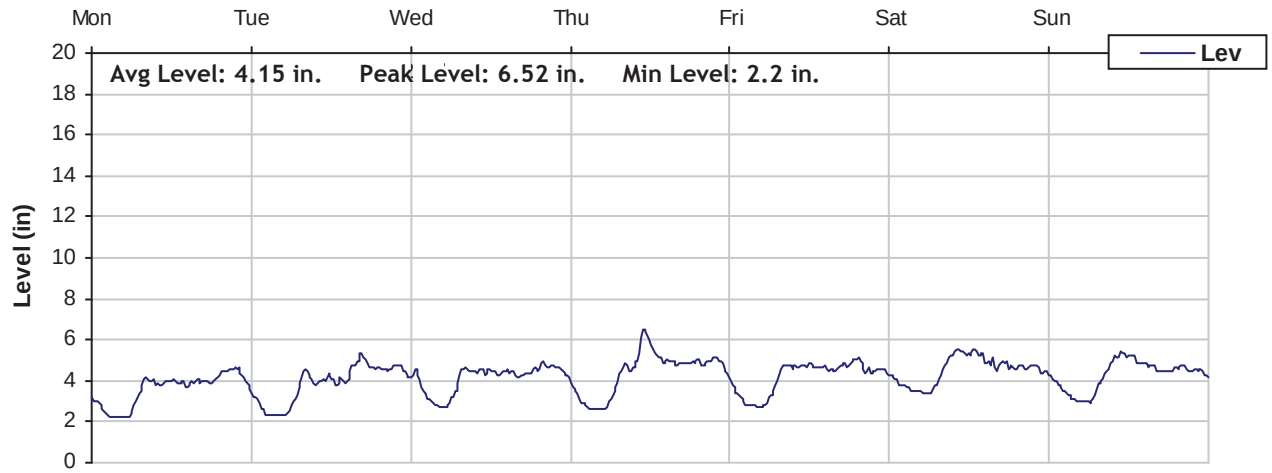


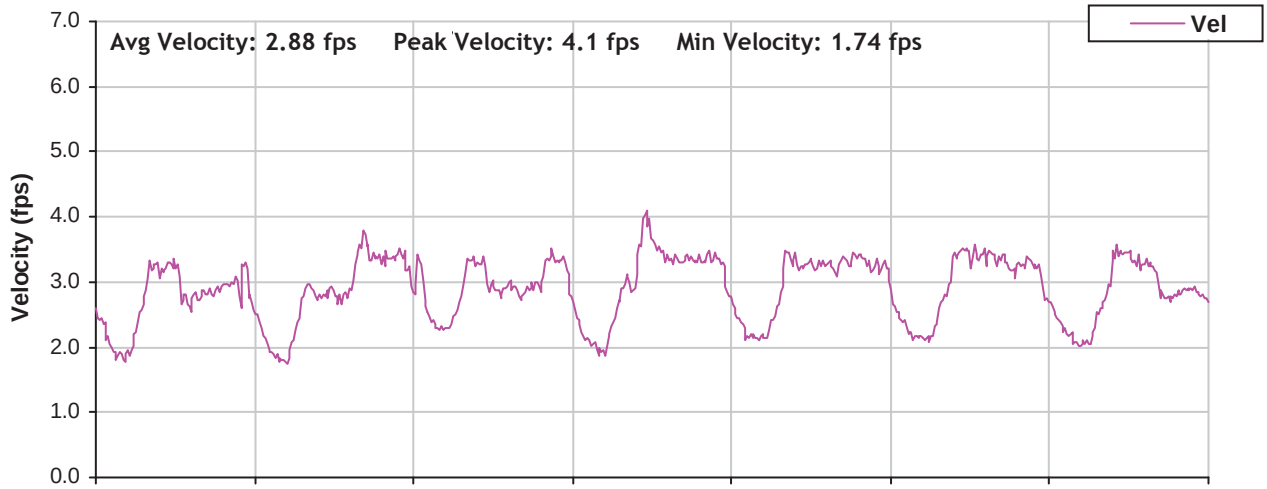


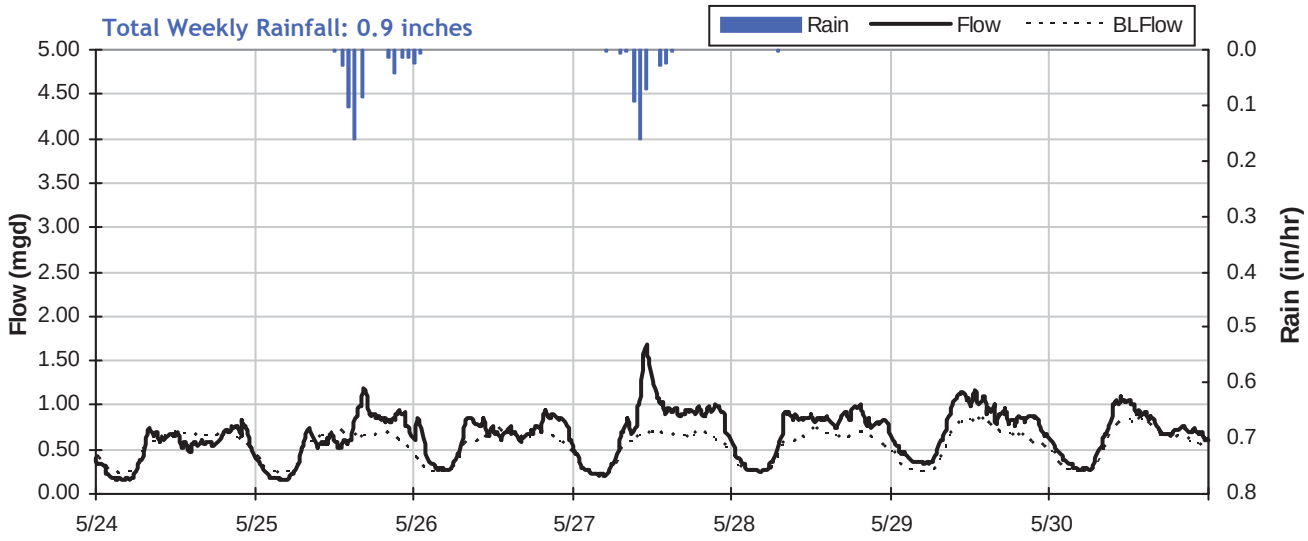
Avg Flow: 0.586 mgd Peak Flow: 1.05 mgd Min Flow: 0.164 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 2



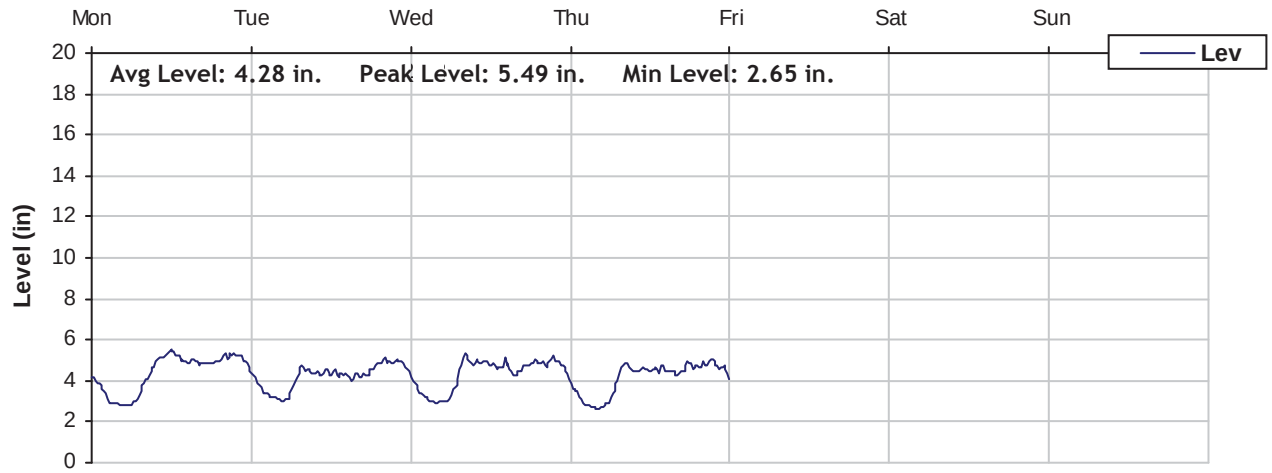


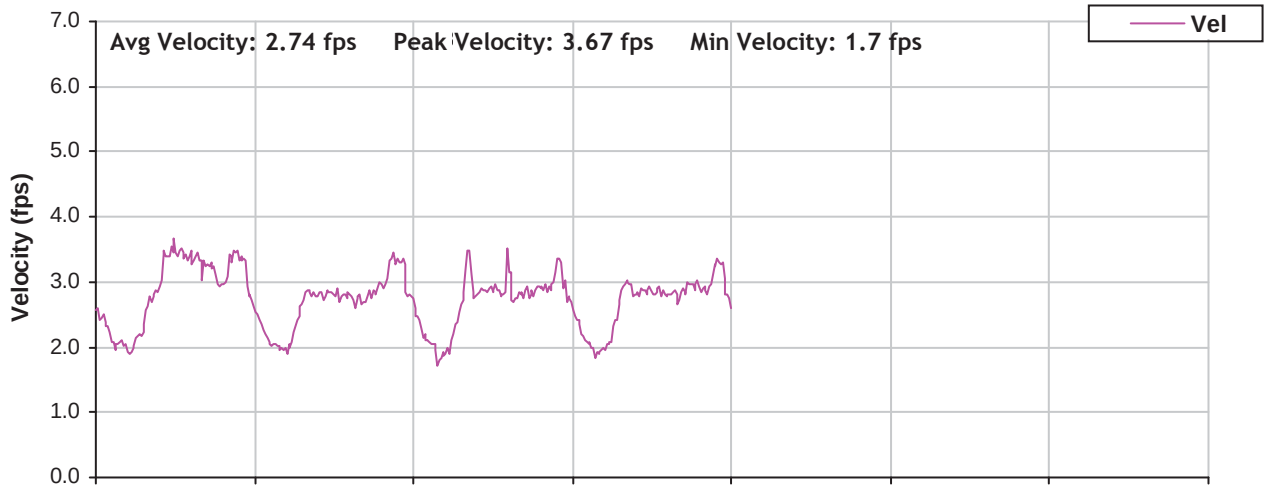


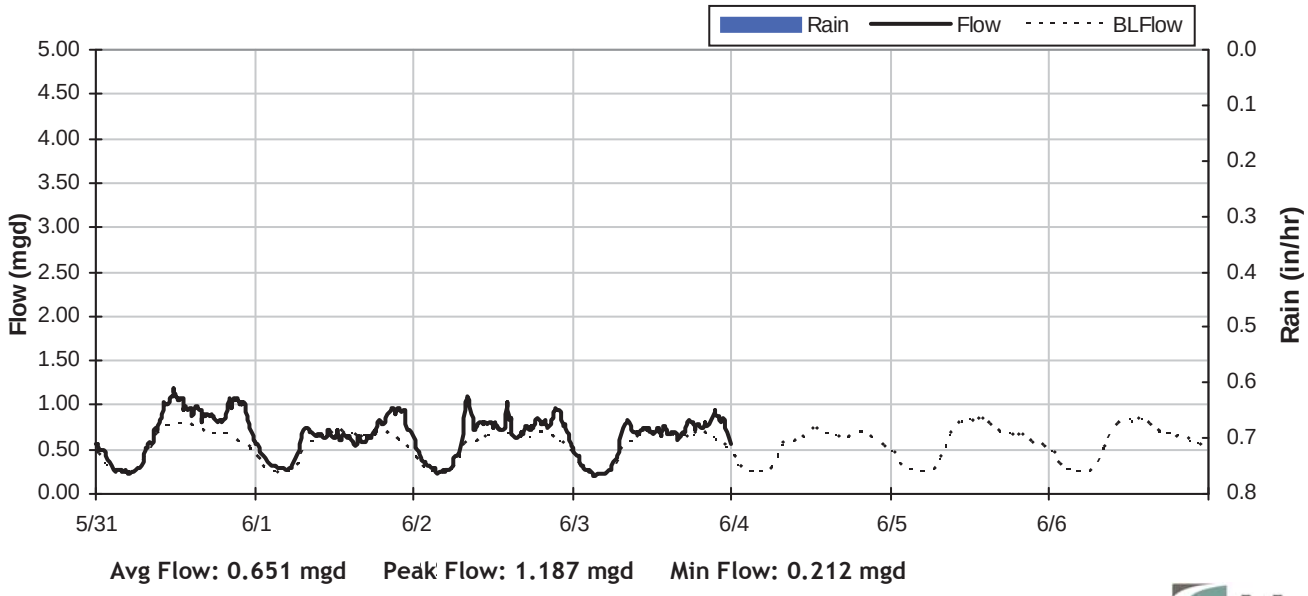
Avg Flow: 0.663 mgd Peak Flow: 1.685 mgd Min Flow: 0.154 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 2







Avg Flow: 0.651 mgd Peak Flow: 1.187 mgd Min Flow: 0.212 mgd

Temporary Flow Monitoring Study

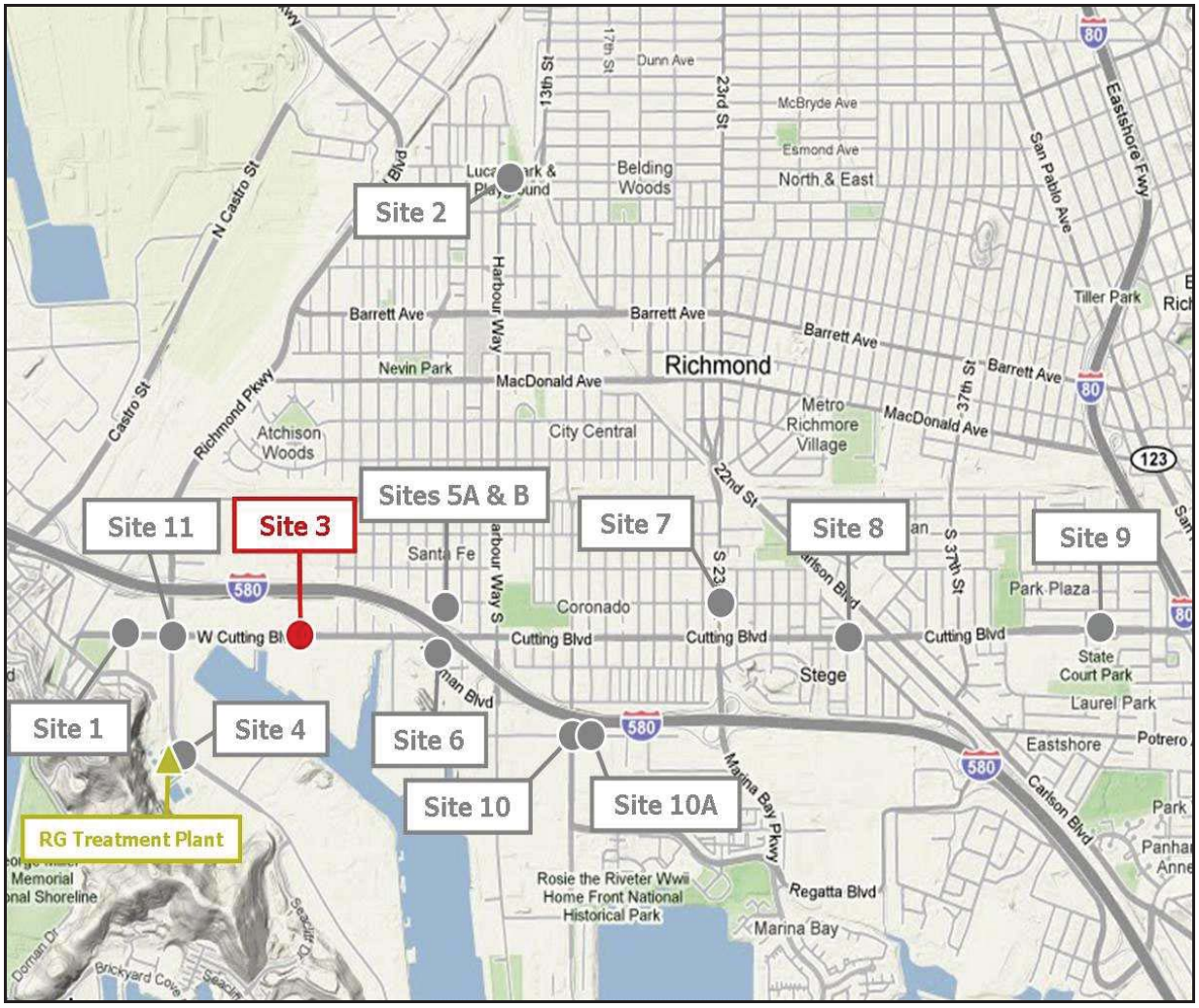
Sanitary Sewer Collection System

Monitoring Site: Site 3

Location: W Cutting Boulevard; west of Chesson Street

Size/Type Line: 54-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 3

Location: W Cutting Boulevard; west of Chesson Street

Latitude: 37.9253°

Longitude: -122.3711°

Rim Elevation: 10 *feet above sea level*

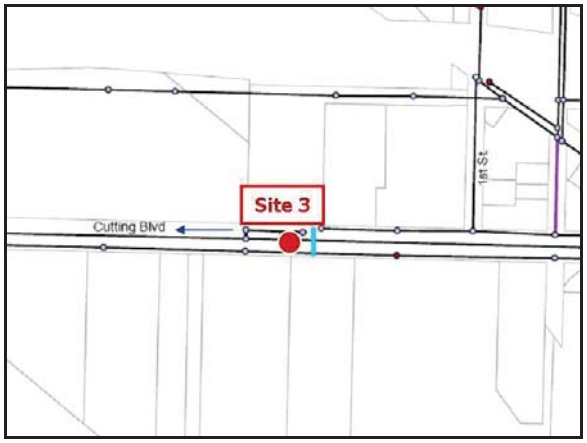
Diameter: 54 *inches*

Average Dry Weather Flow: 4.698 *mgd*

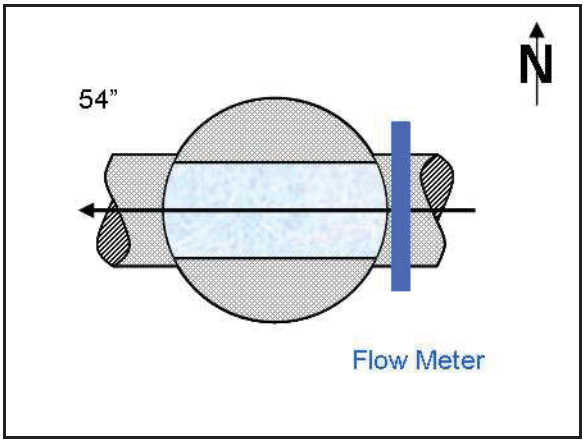
Peak Measured Flow: 23.814 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

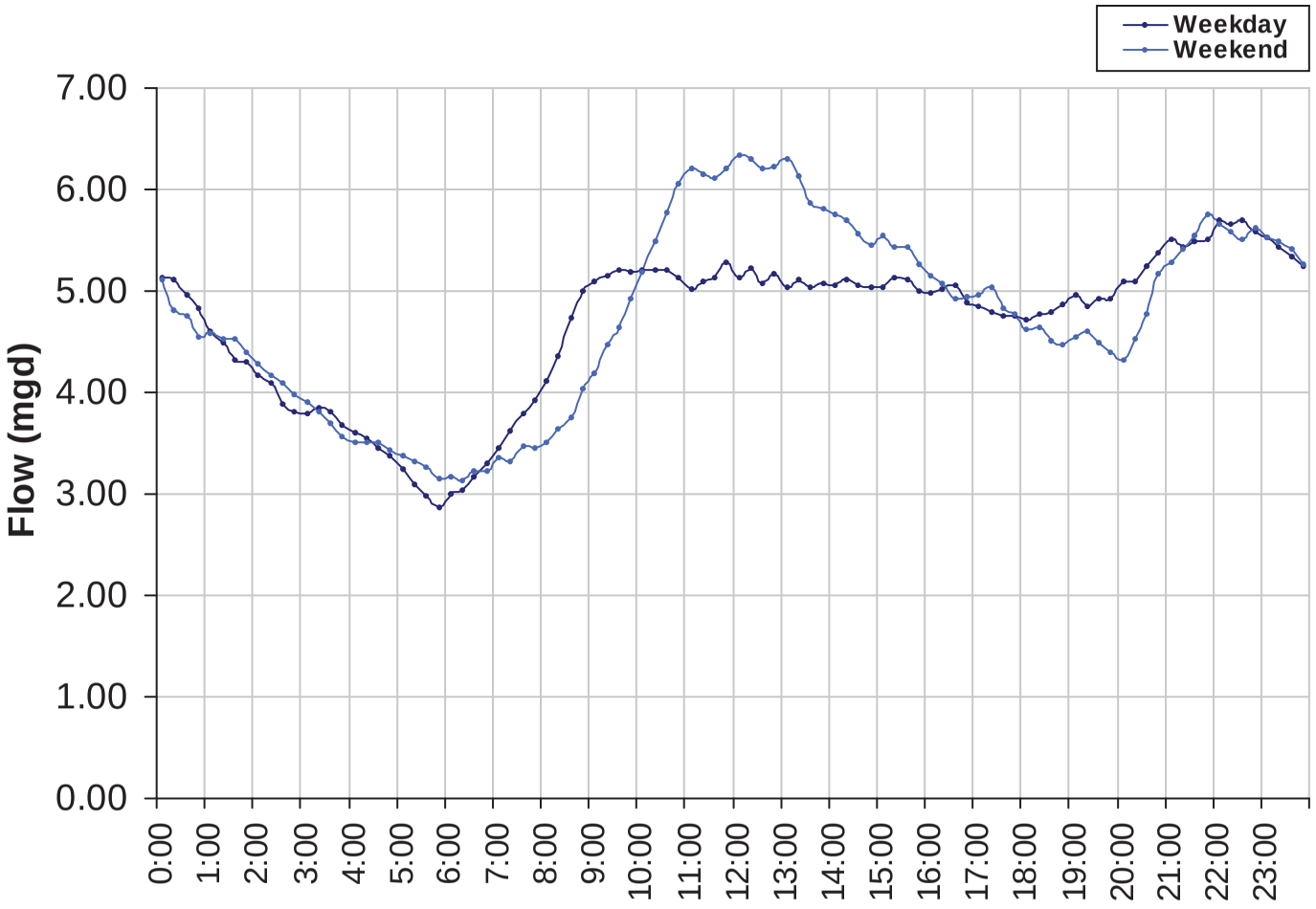


Street View Photo

Plan View Photo

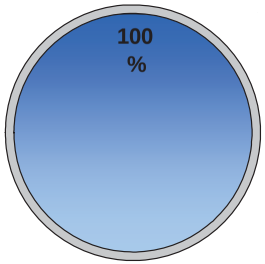
Average Dry Weather Flow

Monitoring Site:
Site 3



Peak Measured Flow:

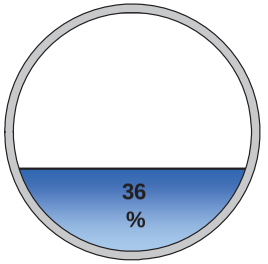
23.81 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

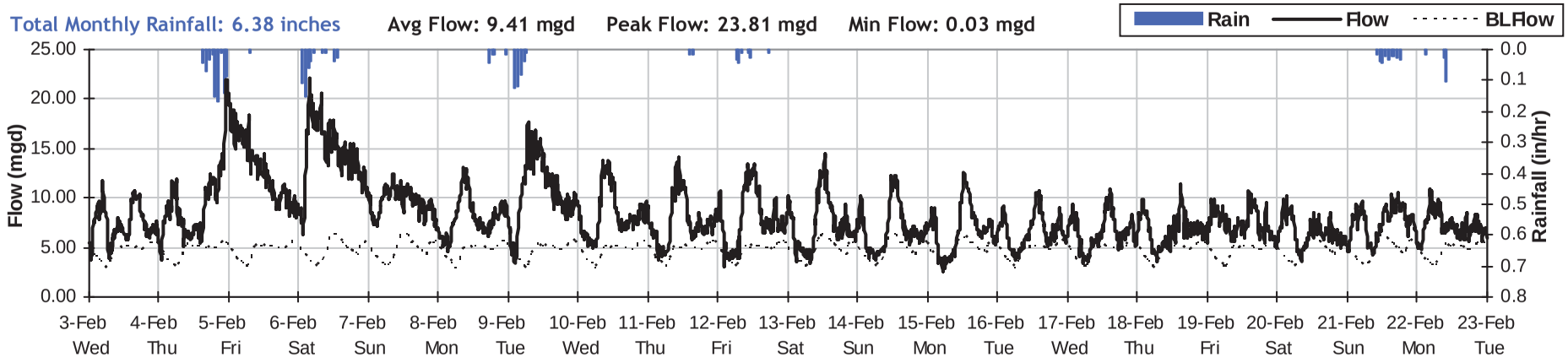
4.70 *mgd*

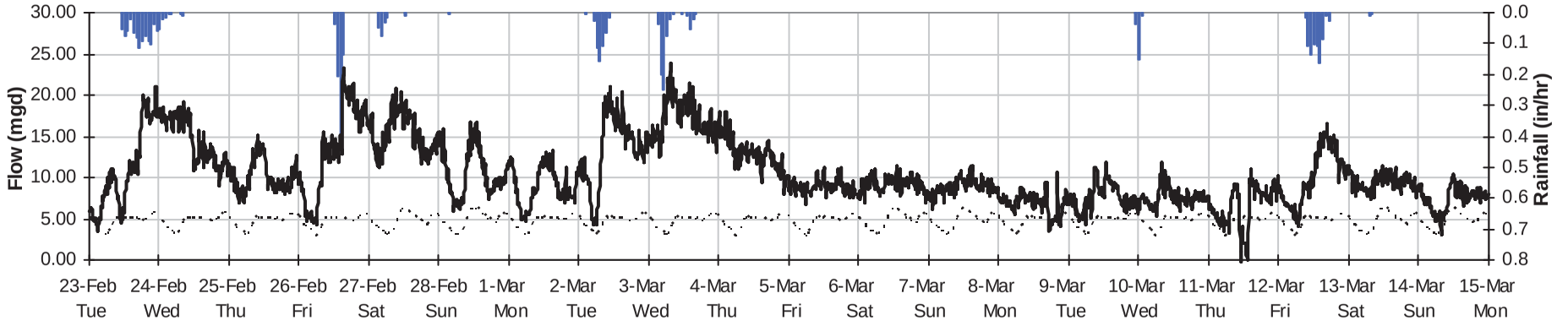


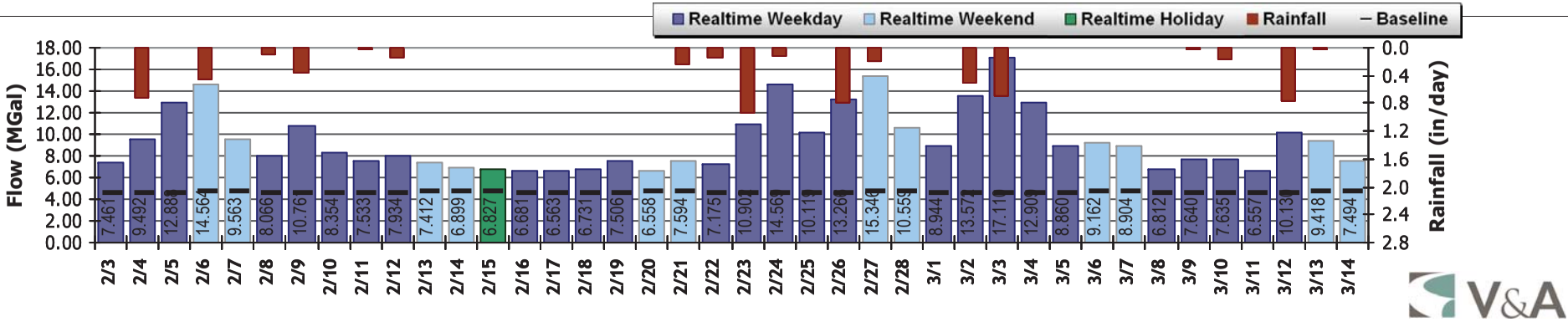
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 3

Total Monthly Rainfall: 6.38 inches Avg Flow: 9.41 mgd Peak Flow: 23.81 mgd Min Flow: 0.03 mgd





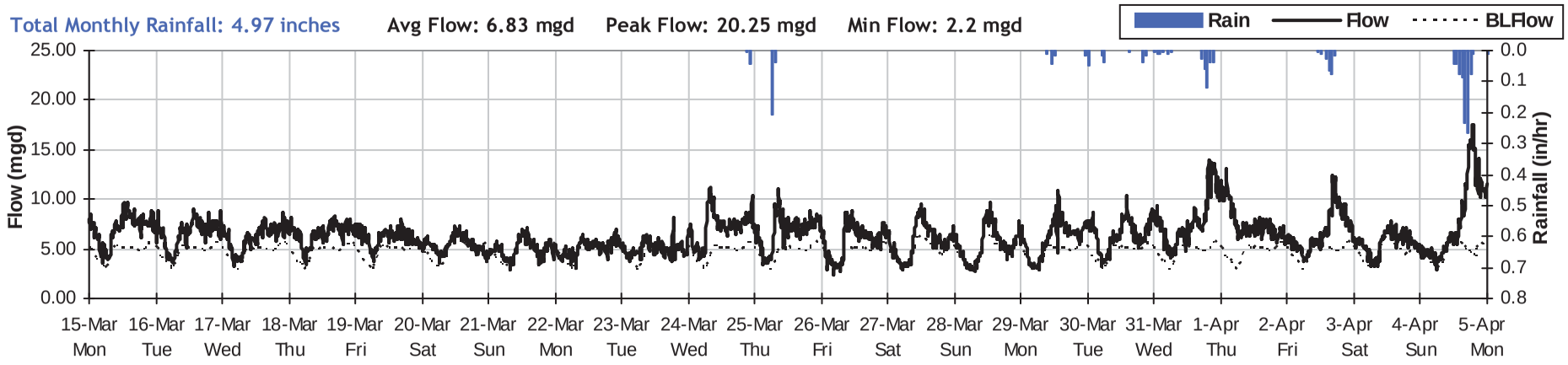


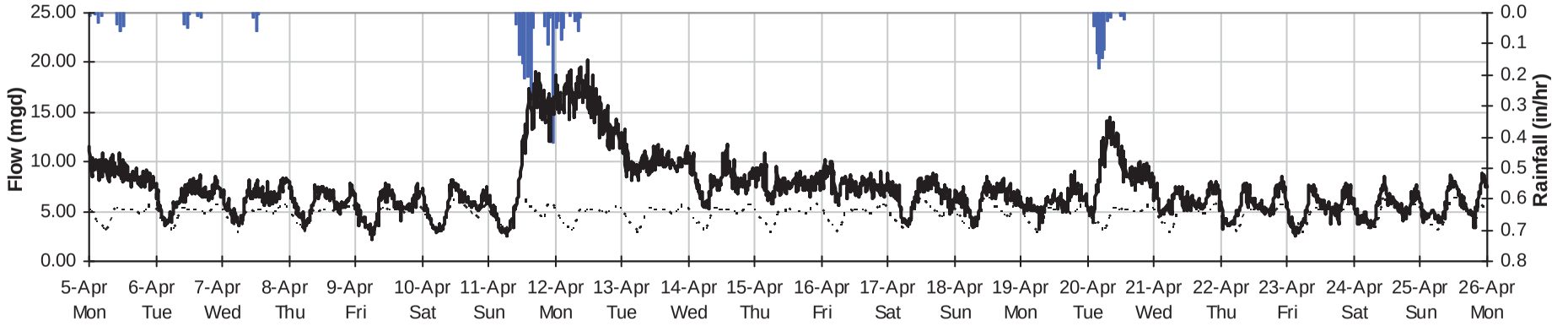
V&A

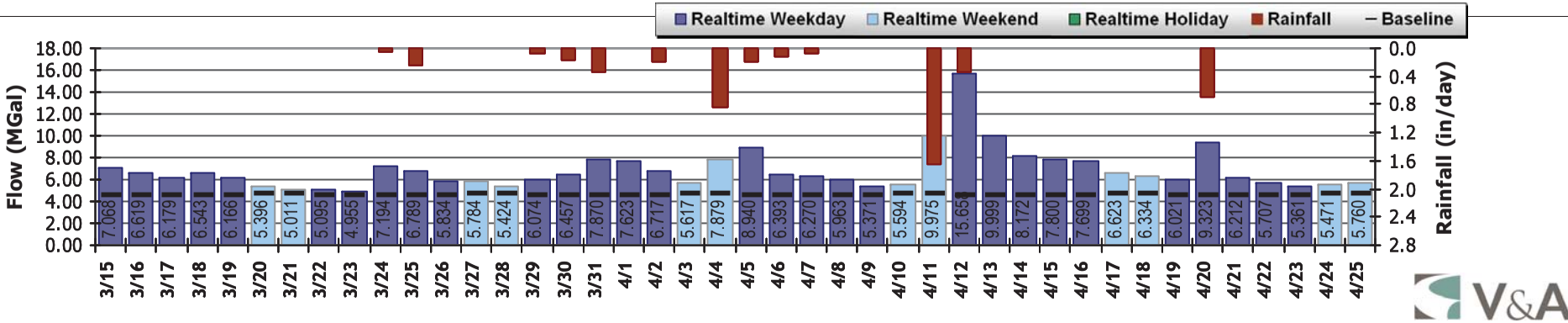
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 3

Total Monthly Rainfall: 4.97 inches Avg Flow: 6.83 mgd Peak Flow: 20.25 mgd Min Flow: 2.2 mgd





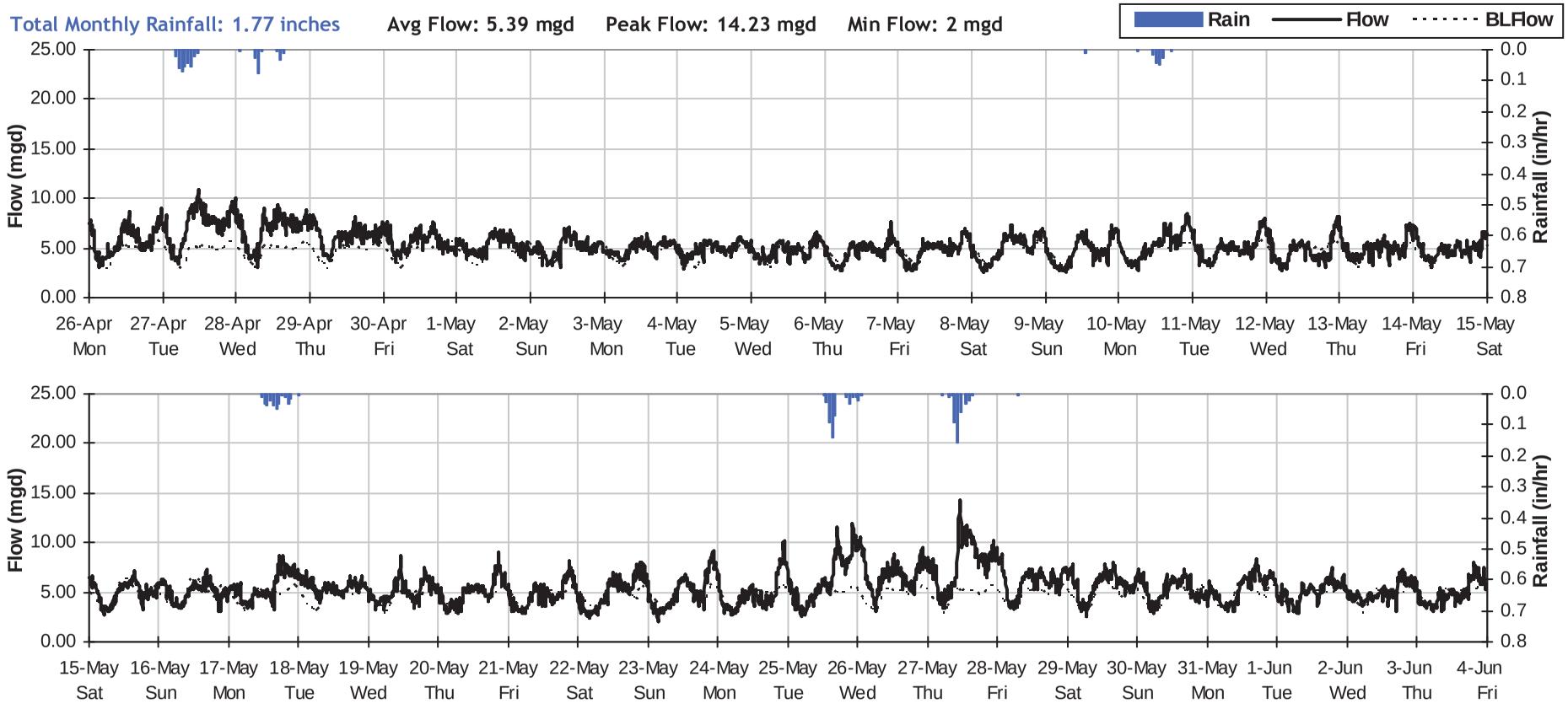


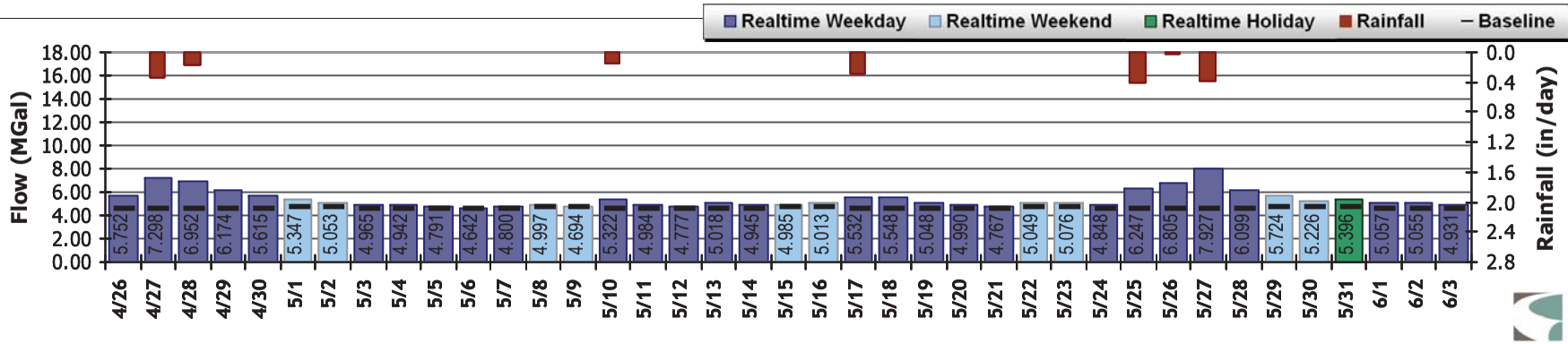
V&A

Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 3

Total Monthly Rainfall: 1.77 inches Avg Flow: 5.39 mgd Peak Flow: 14.23 mgd Min Flow: 2 mgd



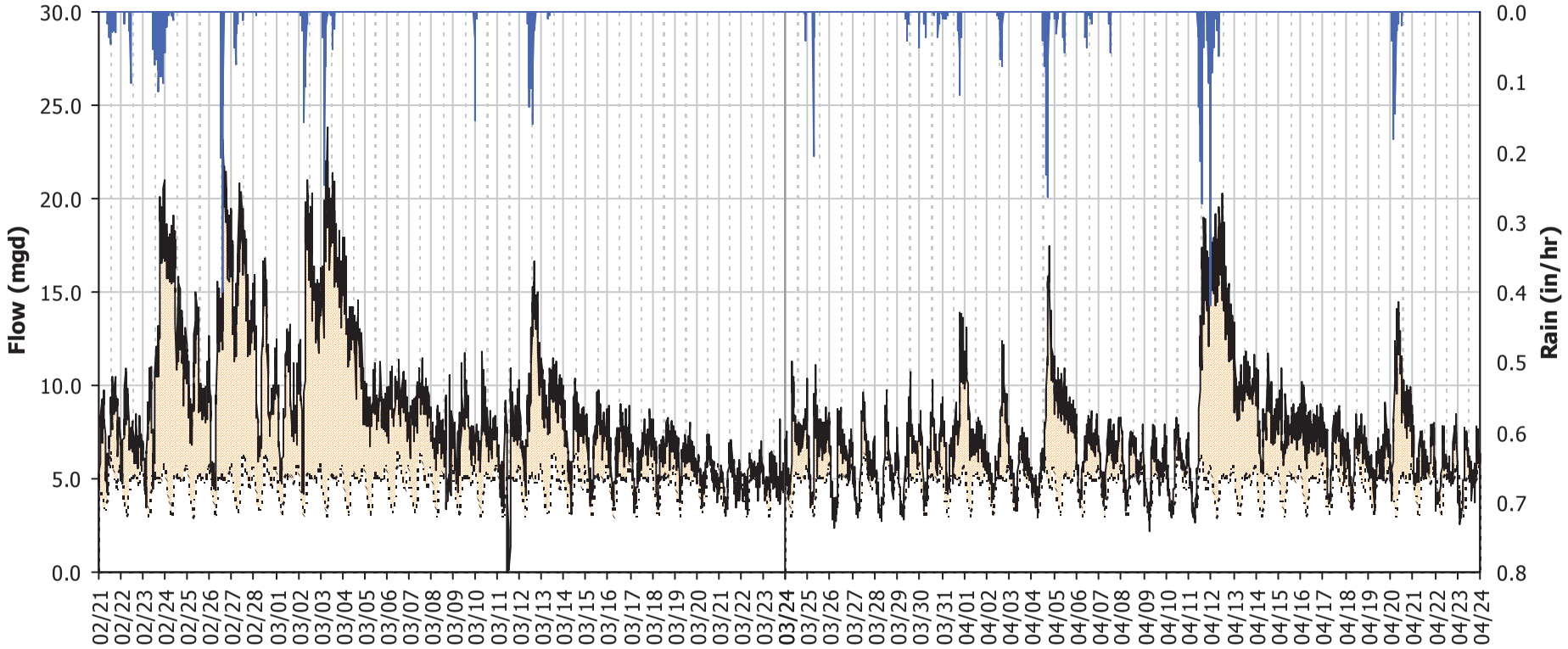


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 3

Multiple Events Detail I/I Graph



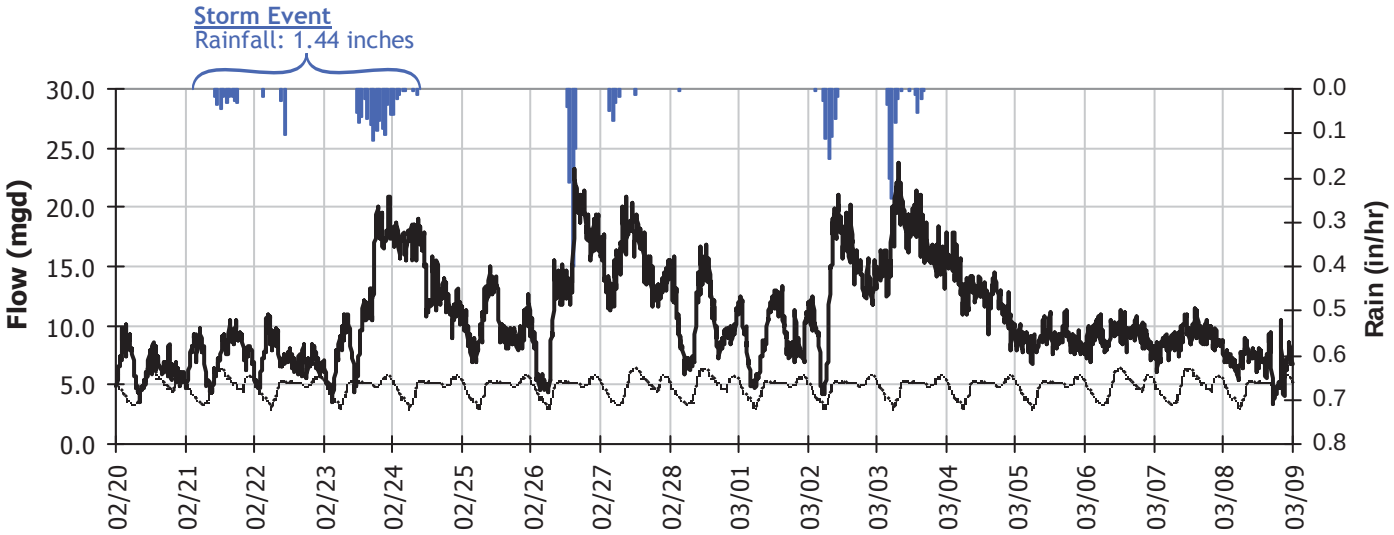
Multiple Events I/I Analysis

Rainfall:	9.54	*inches*	**Baseline Flow:**	4.70	*mgd*
Peak Flow:	23.81	*mgd*	**PF:**	5.07	
Peak I/I Rate:	20.19	*mgd*	**Pk I/I:ADWF:**	4.30	
Peak Level:	137.44	*inches*	**d/D Ratio:**	2.55	
Total I/I:	209,186,000	*gallons*	**R-Value:**	18.3%	
			I/I per ADWF:	4.7	*per in-rain*

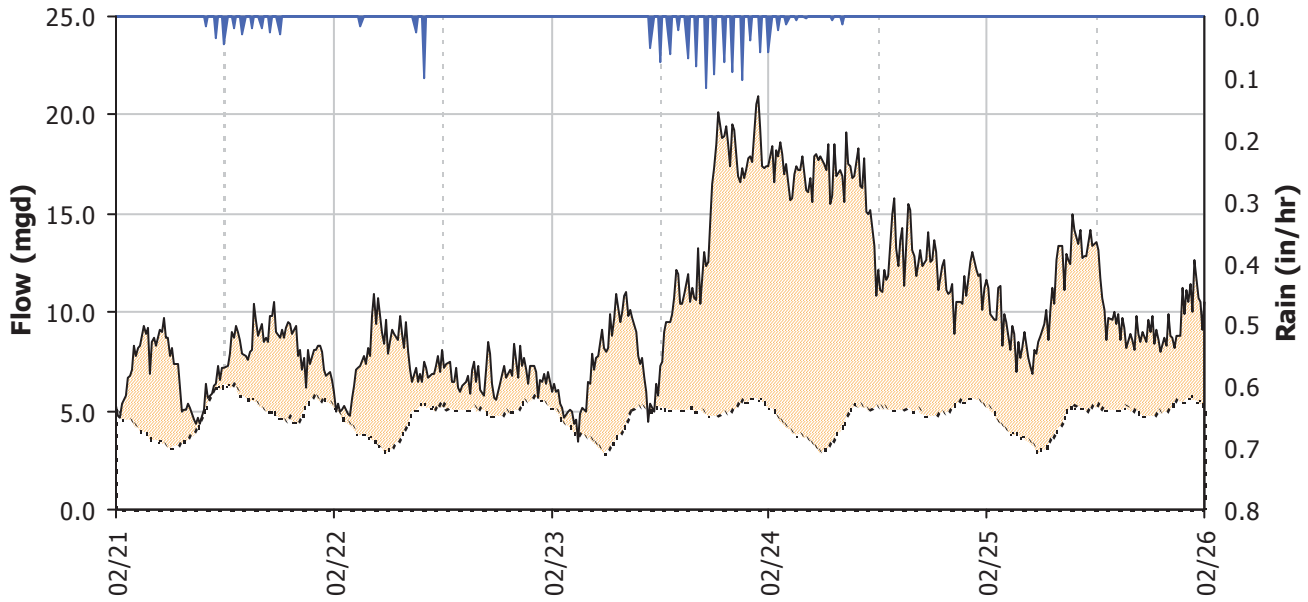
I/I Summary
Event 1

Monitoring Site:
Site 3

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

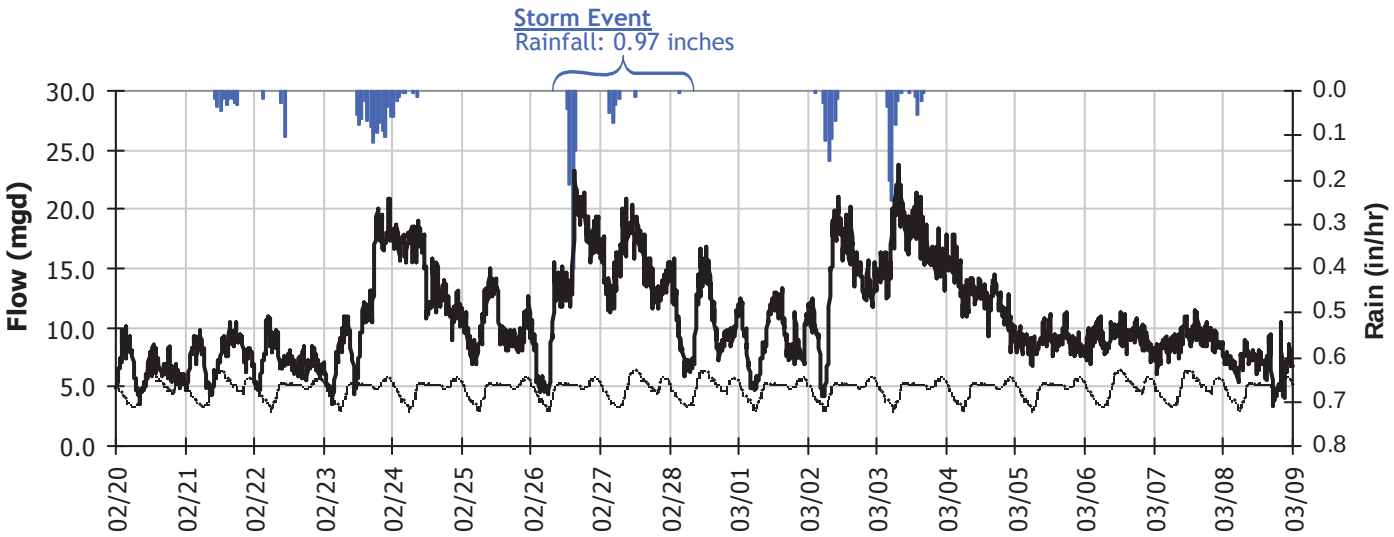
Rainfall:	1.44	*inches*		
Baseline Flow:	4.70	*mgd*		
Peak Flow:	20.98	*mgd*	**PF:**	4.47
Peak I/I Rate:	15.40	*mgd*	**Pk I/I:ADWF:**	3.28
Peak Level:	132.48	*inches*	**d/D Ratio:**	2.45
Total I/I:	26,963,000	*gallons*	**R-Value:**	15.6%
			I/I per ADWF:	3.97 *per in-rain*

Average Infiltration Rate on 2/25 (% of ADWF): 116.4%

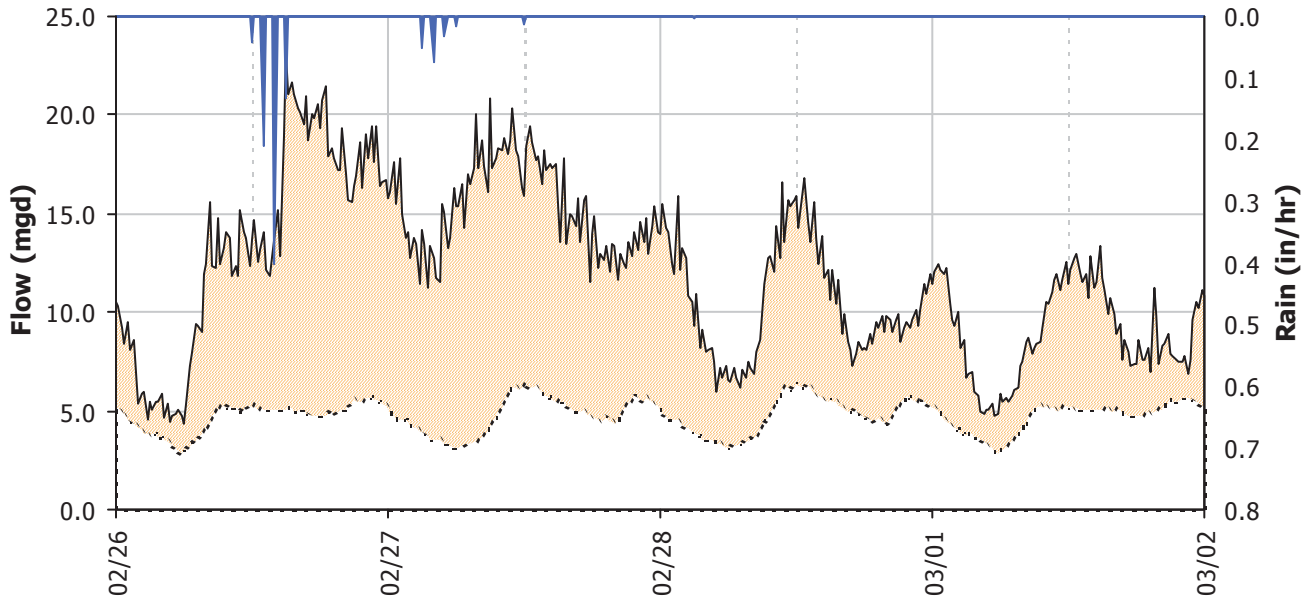
V&A

	I/I Summary Event 2	**Monitoring Site:** Site 3

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



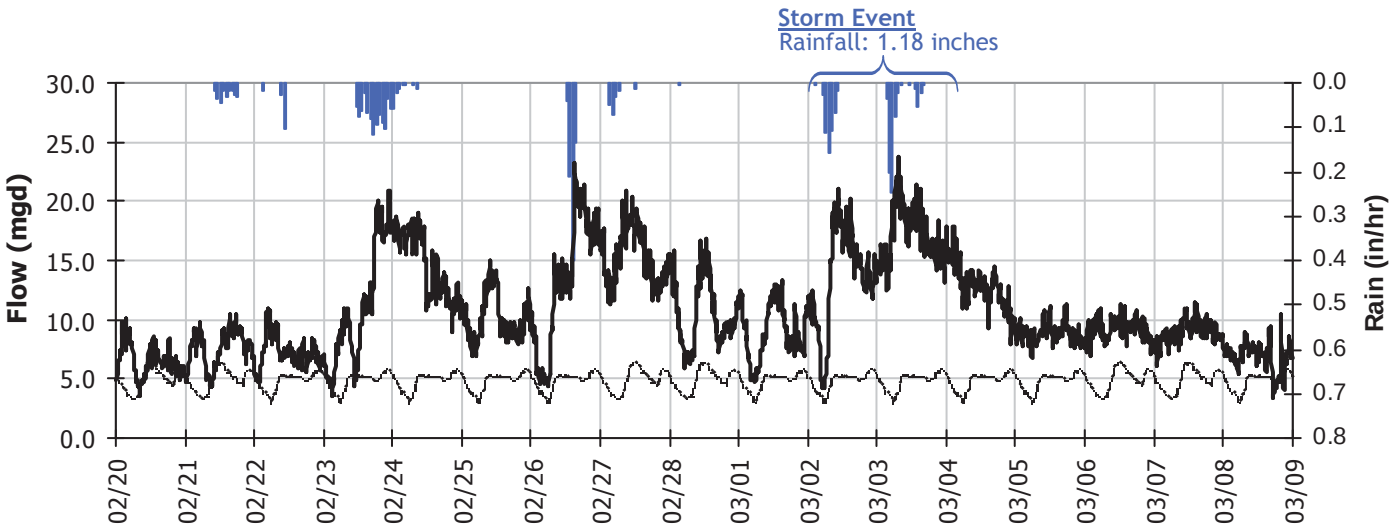
Storm Event #2 I/I Analysis

Rainfall:	0.97	*inches*		
Baseline Flow:	4.70	*mgd*		
Peak Flow:	23.20	*mgd*	**PF:**	4.94
Peak I/I Rate:	18.16	*mgd*	**Pk I/I:ADWF:**	3.87
Peak Level:	113.62	*inches*	**d/D Ratio:**	2.10
Total I/I:	29,310,000	*gallons*	**R-Value:**	25.1%
			I/I per ADWF:	6.40 *per in-rain*

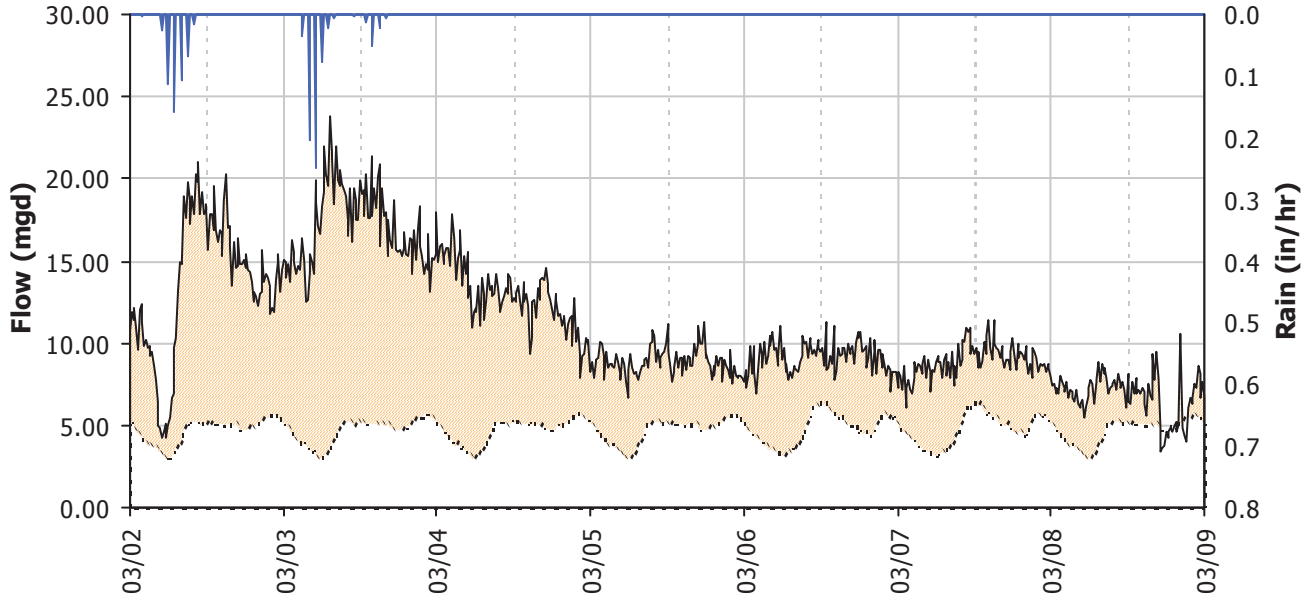
Average Infiltration Rate on 3/1 (% of ADWF): 91.6%

	I/I Summary Event 3	**Monitoring Site:** Site 3

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



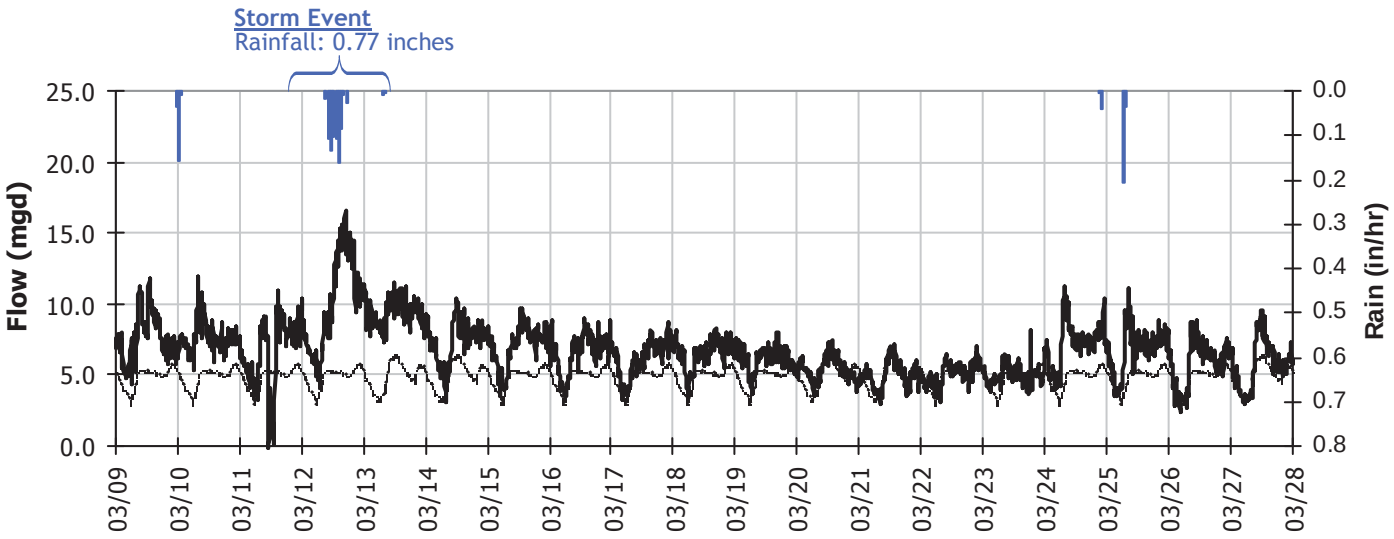
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	4.70	*mgd*		
Peak Flow:	23.81	*mgd*	**PF:**	5.07
Peak I/I Rate:	20.19	*mgd*	**Pk I/I:ADWF:**	4.30
Peak Level:	137.06	*inches*	**d/D Ratio:**	2.54
Total I/I:	44,461,000	*gallons*	**R-Value:**	31.3%
			I/I per ADWF:	7.99 *per in-rain*

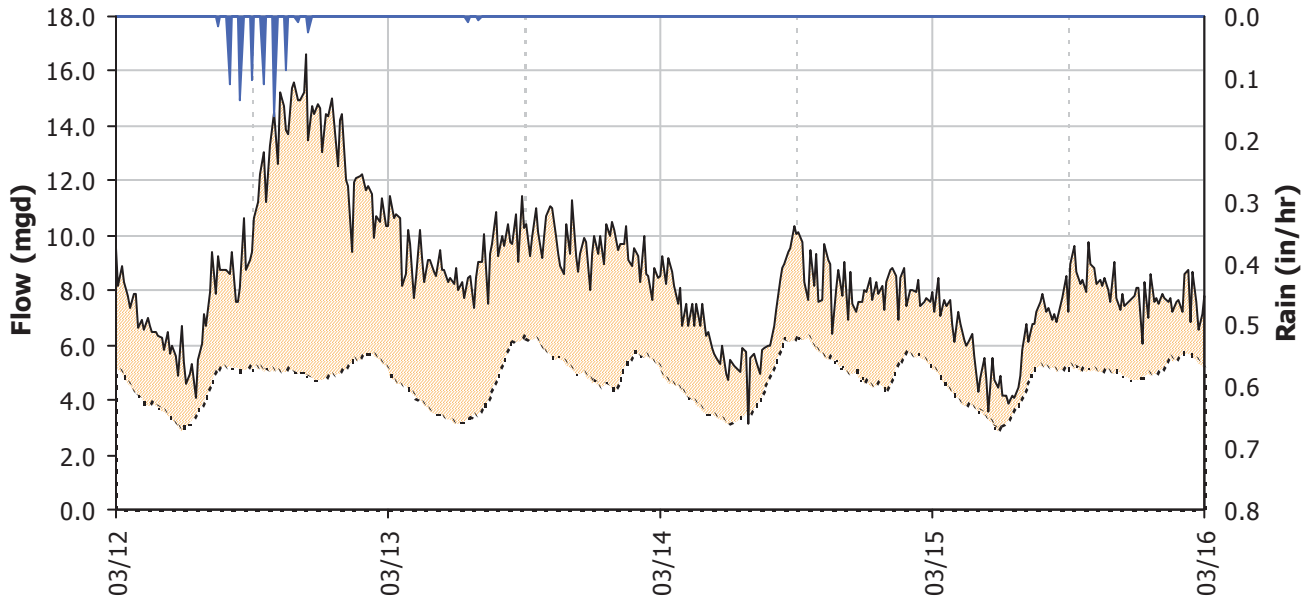
Average Infiltration Rate on 3/5 (% of ADWF): 89.1%

	I/I Summary Event 4	**Monitoring Site:** Site 3

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



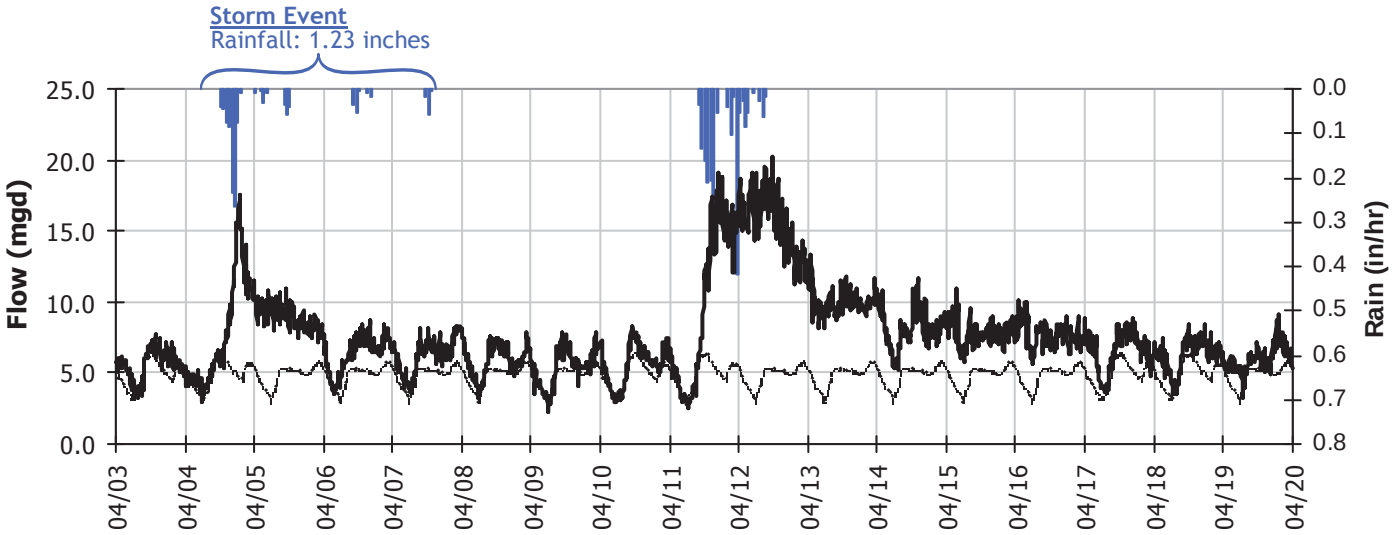
Storm Event #1 I/I Analysis

Rainfall:	0.77	*inches*		
Baseline Flow:	4.70	*mgd*		
Peak Flow:	16.62	*mgd*	**PF:**	3.54
Peak I/I Rate:	11.73	*mgd*	**Pk I/I:ADWF:**	2.50
Peak Level:	116.79	*inches*	**d/D Ratio:**	2.16
Total I/I:	15,274,000	*gallons*	**R-Value:**	16.5%
			I/I per ADWF:	4.21 *per in-rain*

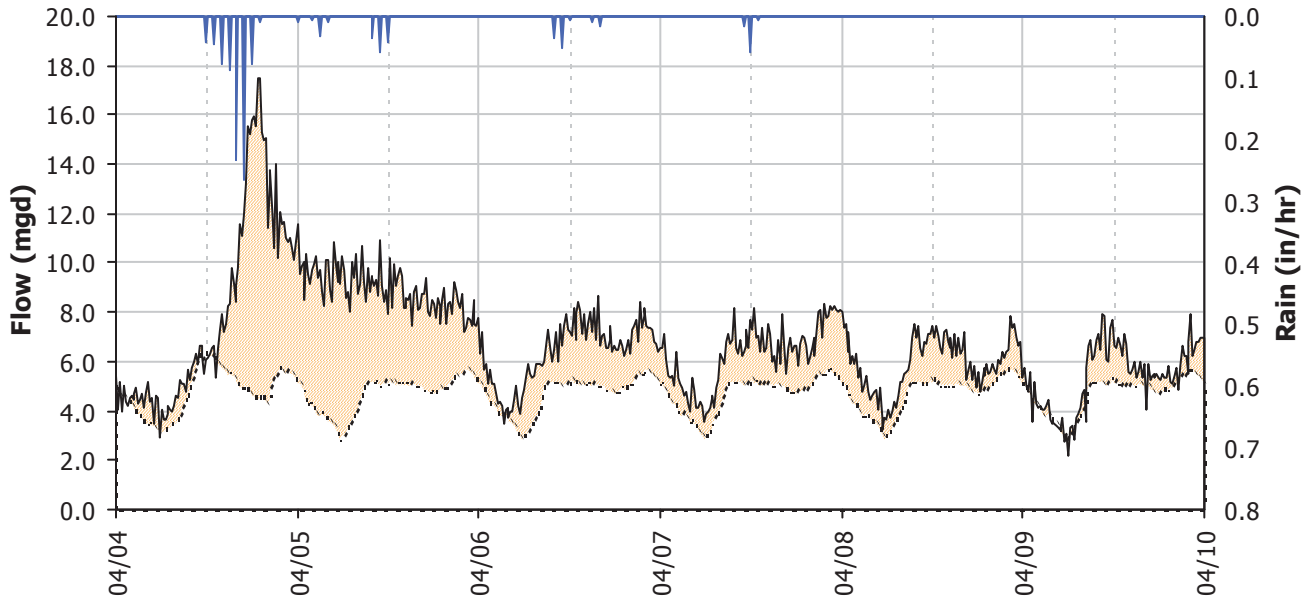
Average Infiltration Rate on 3/14 (% of ADWF): 57.5%

	I/I Summary Event 5	**Monitoring Site:** Site 3

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



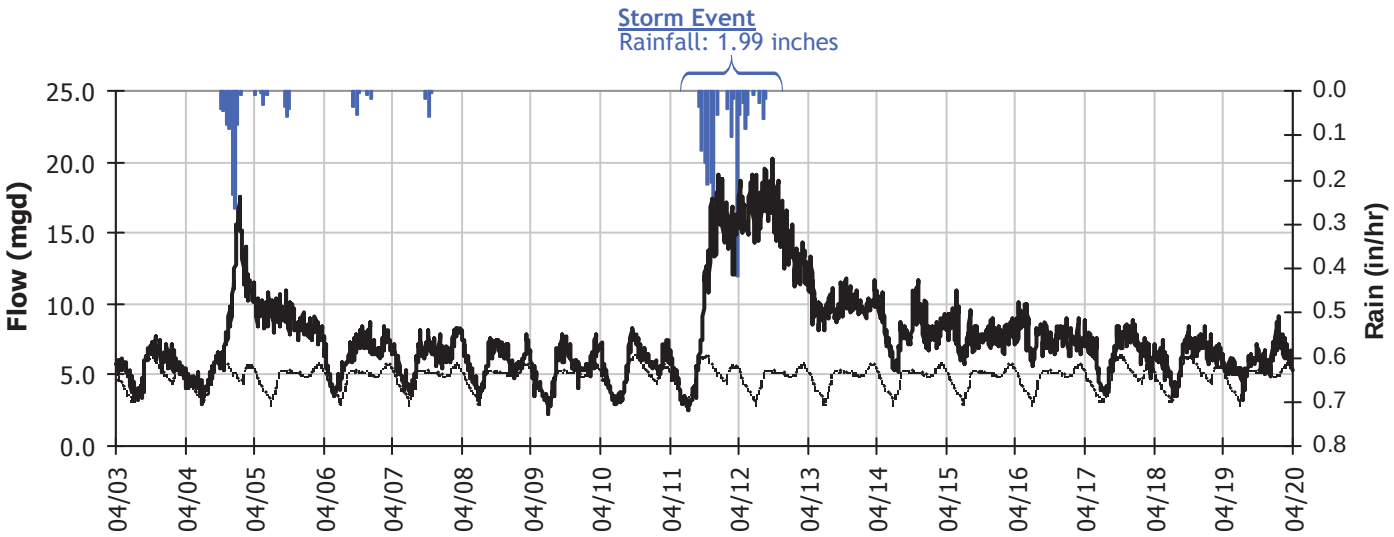
Storm Event #5 I/I Analysis

Rainfall:	1.23	*inches*		
Baseline Flow:	4.70	*mgd*		
Peak Flow:	17.49	*mgd*	**PF:**	3.72
Peak I/I Rate:	13.01	*mgd*	**Pk I/I:ADWF:**	2.77
Peak Level:	97.34	*inches*	**d/D Ratio:**	1.80
Total I/I:	12,707,000	*gallons*	**R-Value:**	8.6%
			I/I per ADWF:	2.20 *per in-rain*

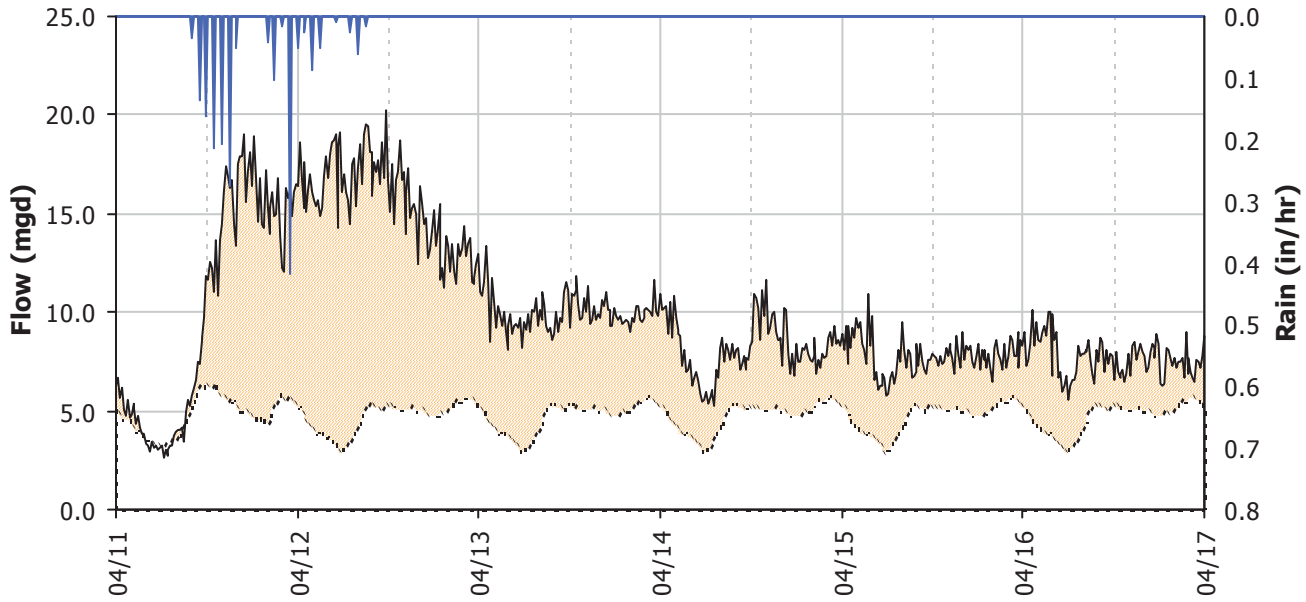
Average Infiltration Rate on 4/8 (% of ADWF): 27.3%

	I/I Summary Event 6	**Monitoring Site:** Site 3

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



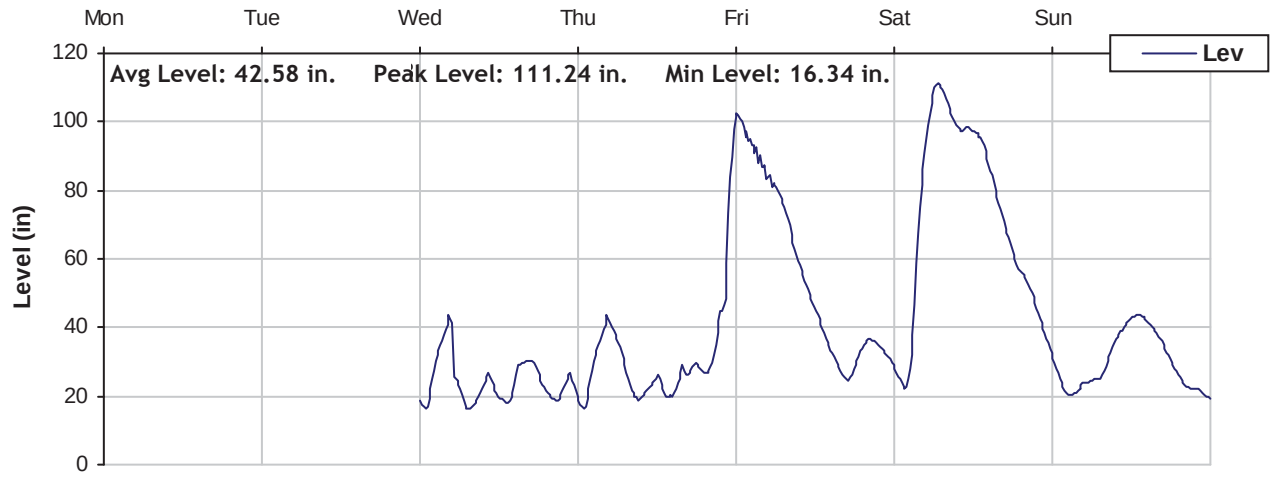
Storm Event #6 I/I Analysis

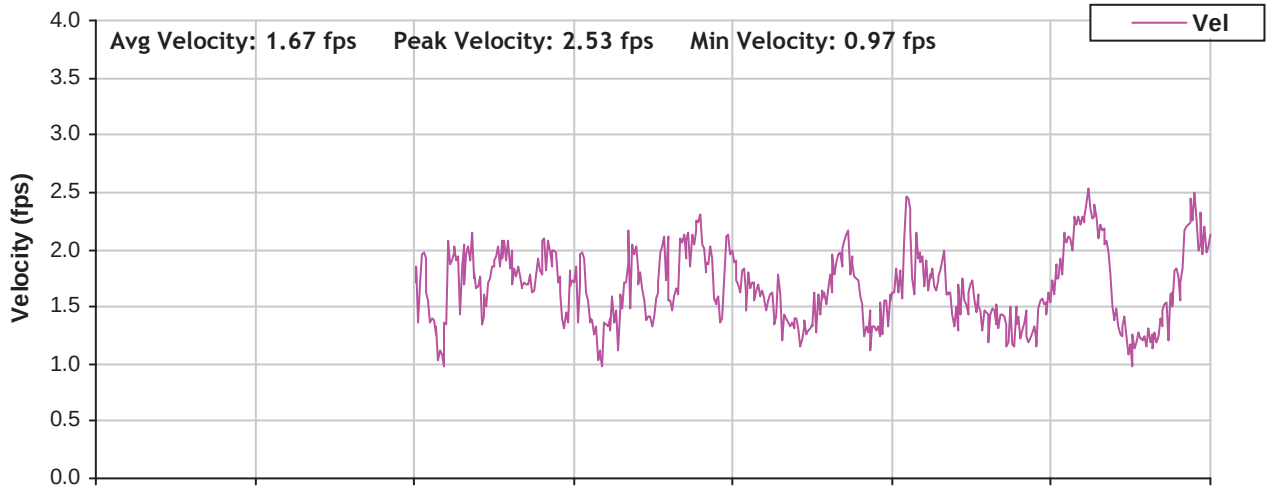
Rainfall:	1.99	*inches*		
Baseline Flow:	4.70	*mgd*		
Peak Flow:	20.25	*mgd*	**PF:**	4.31
Peak I/I Rate:	16.27	*mgd*	**Pk I/I:ADWF:**	3.46
Peak Level:	137.44	*inches*	**d/D Ratio:**	2.55
Total I/I:	31,215,000	*gallons*	**R-Value:**	13.1%
			I/I per ADWF:	3.34 *per in-rain*

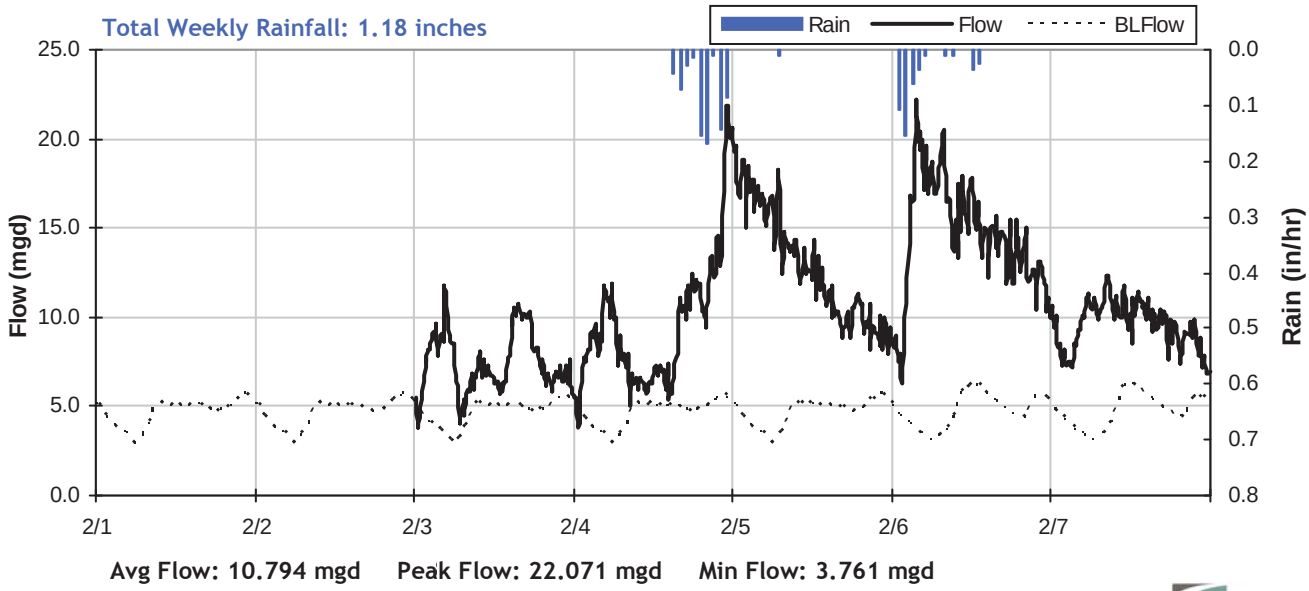
Average Infiltration Rate on 4/14 (% of ADWF): 74.8%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 3



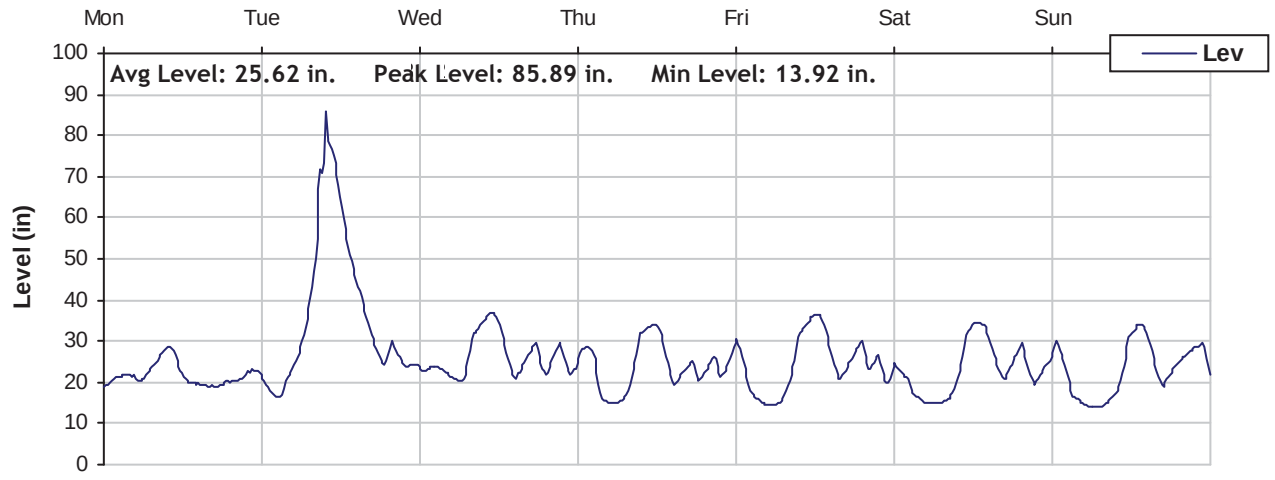


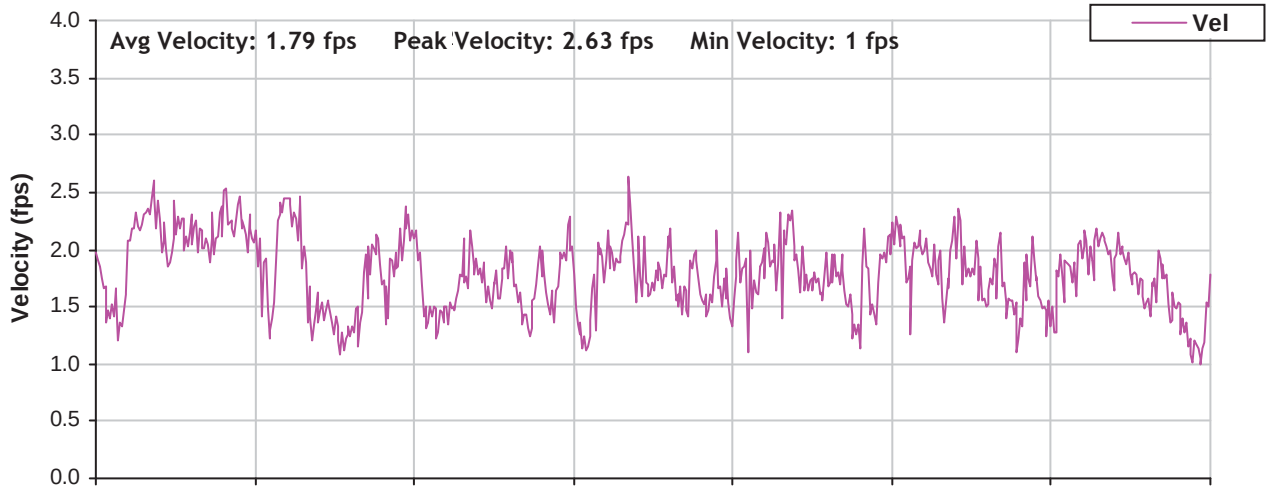


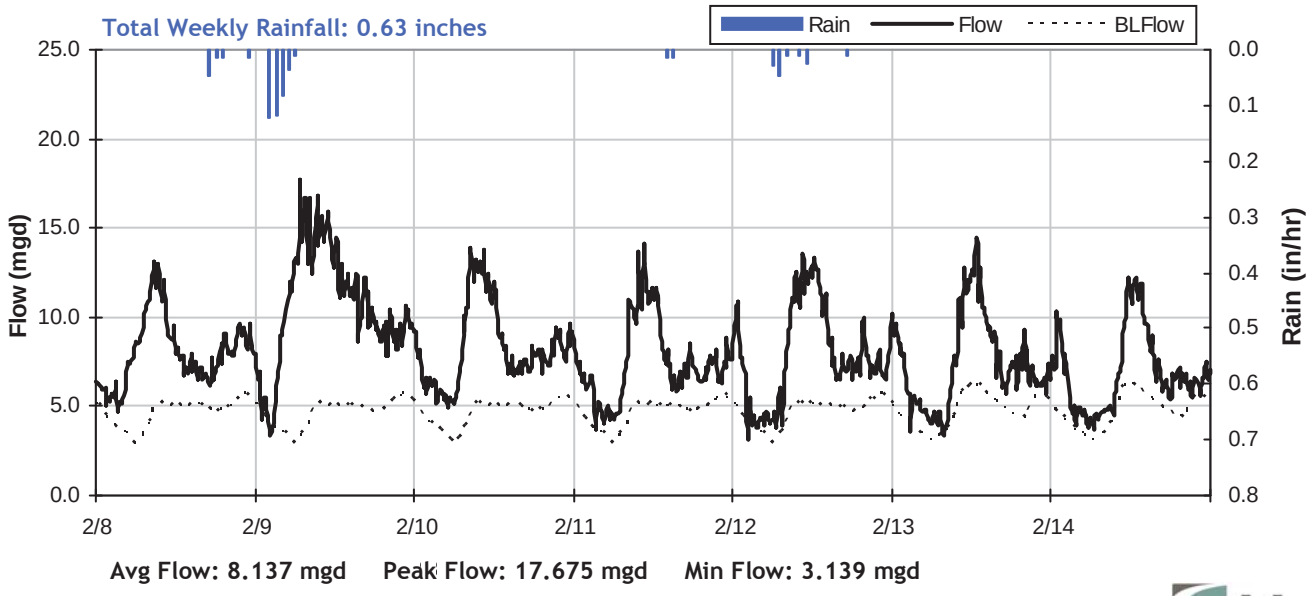
Avg Flow: 10.794 mgd Peak Flow: 22.071 mgd Min Flow: 3.761 mgd

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 3

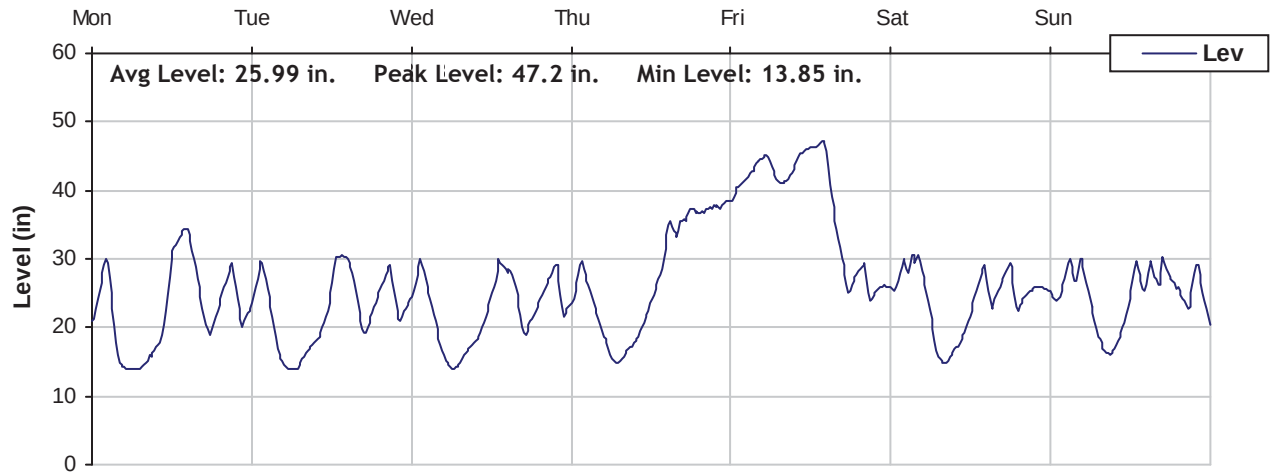


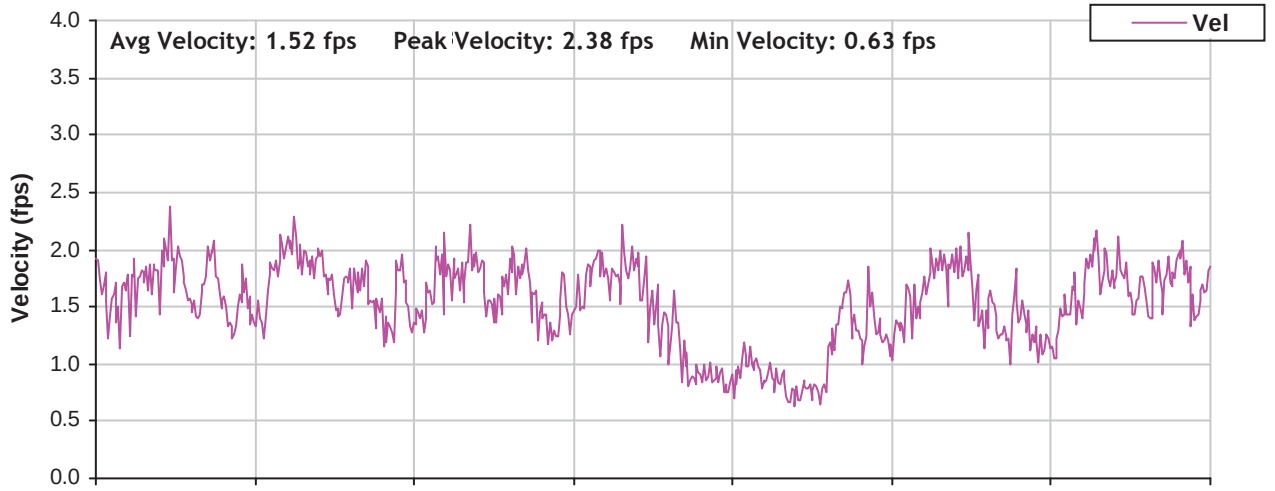


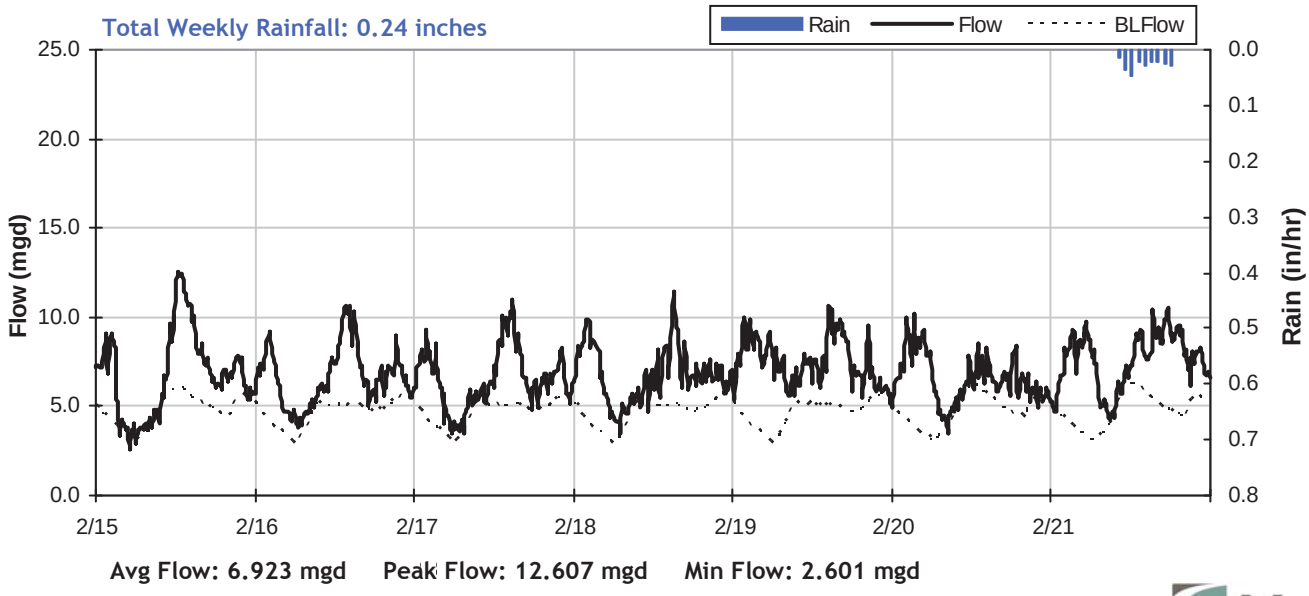


Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 3

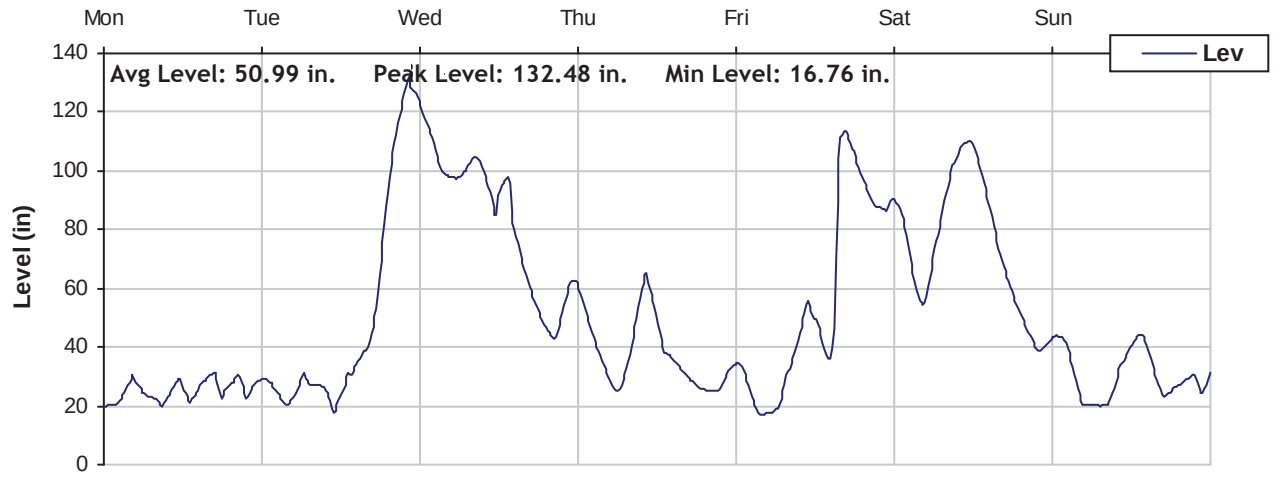


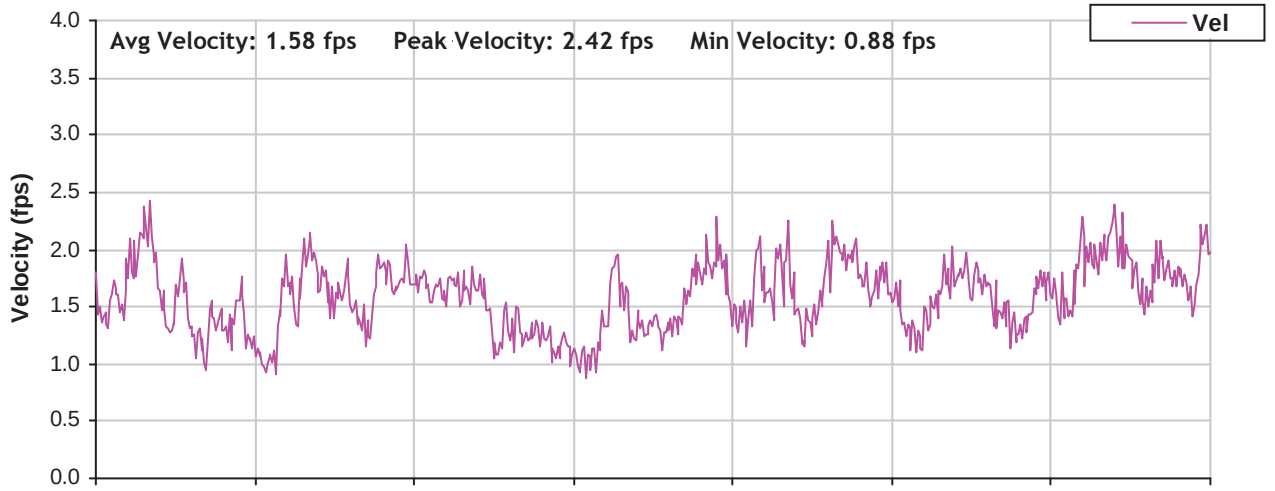


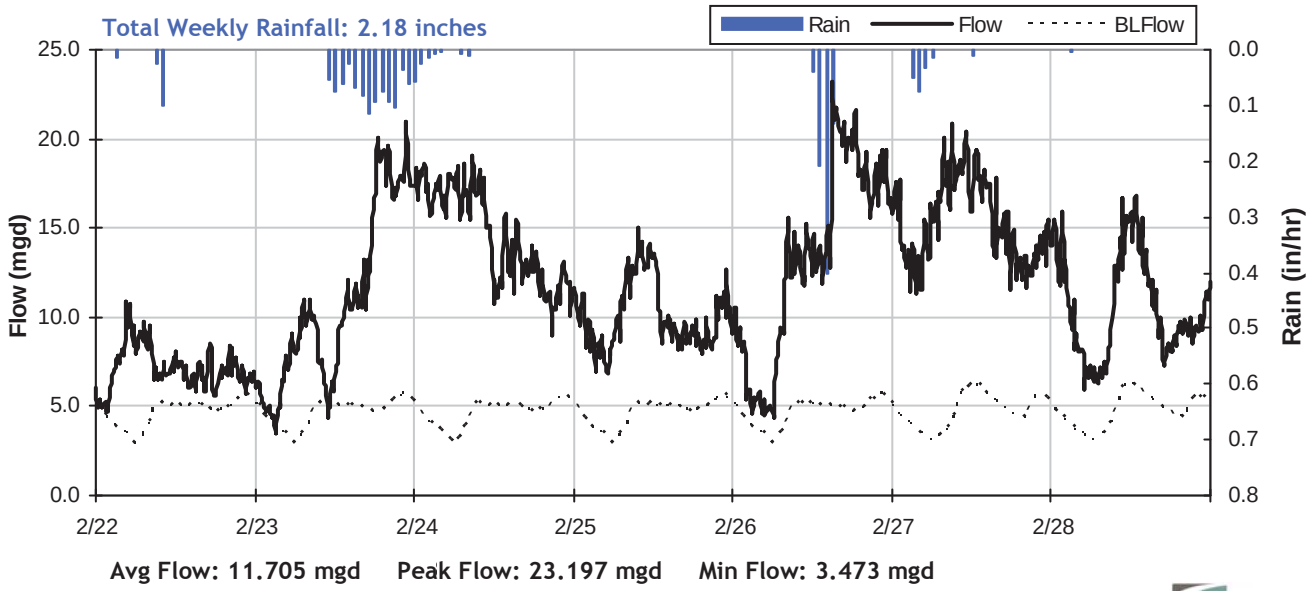


Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 3



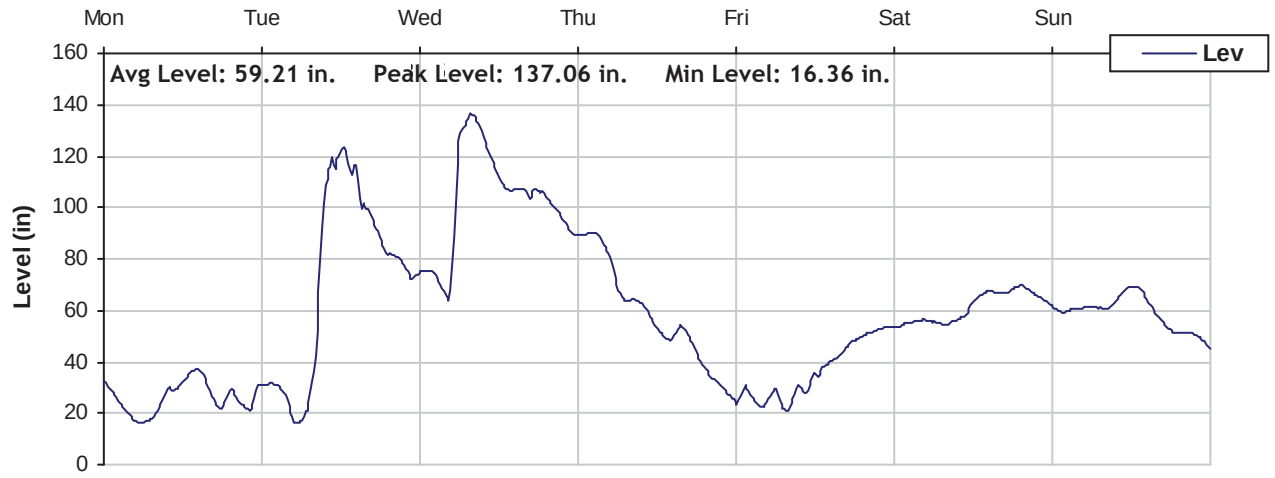


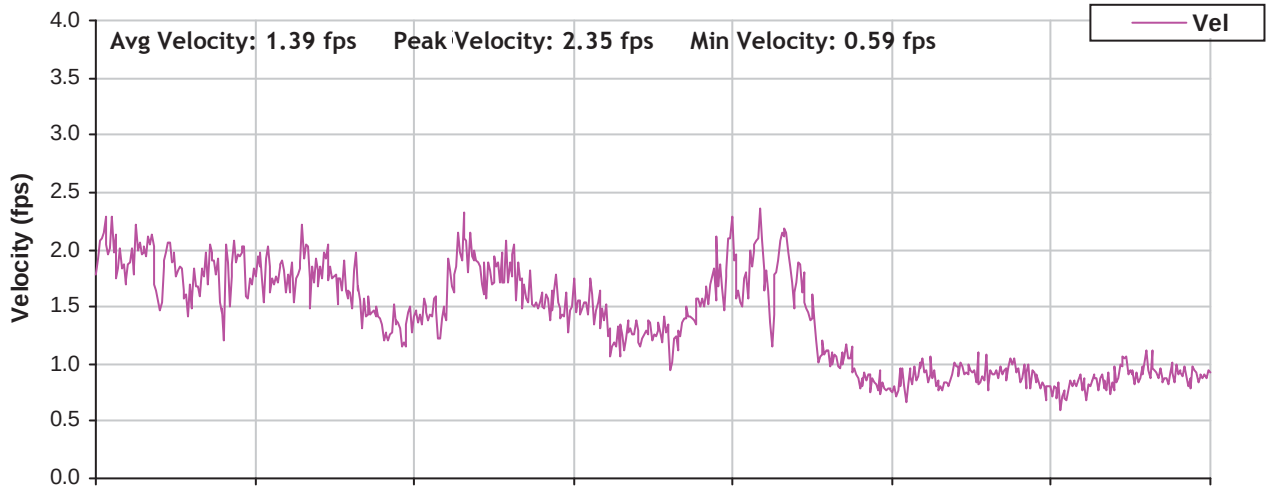


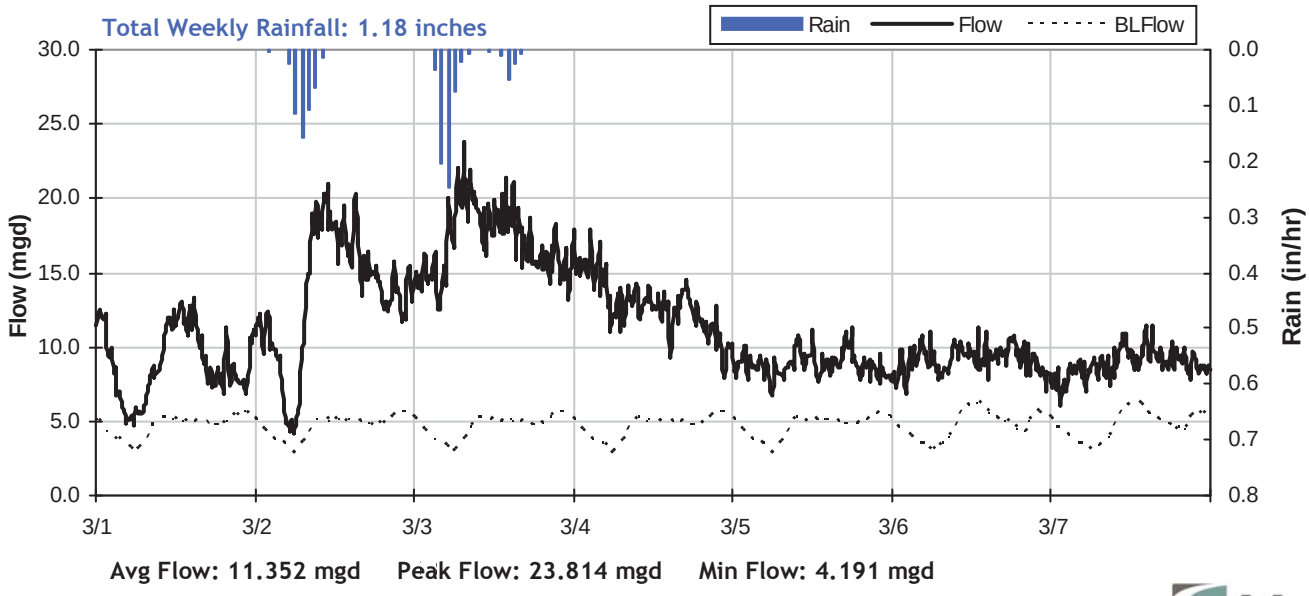
Avg Flow: 11.705 mgd Peak Flow: 23.197 mgd Min Flow: 3.473 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 3





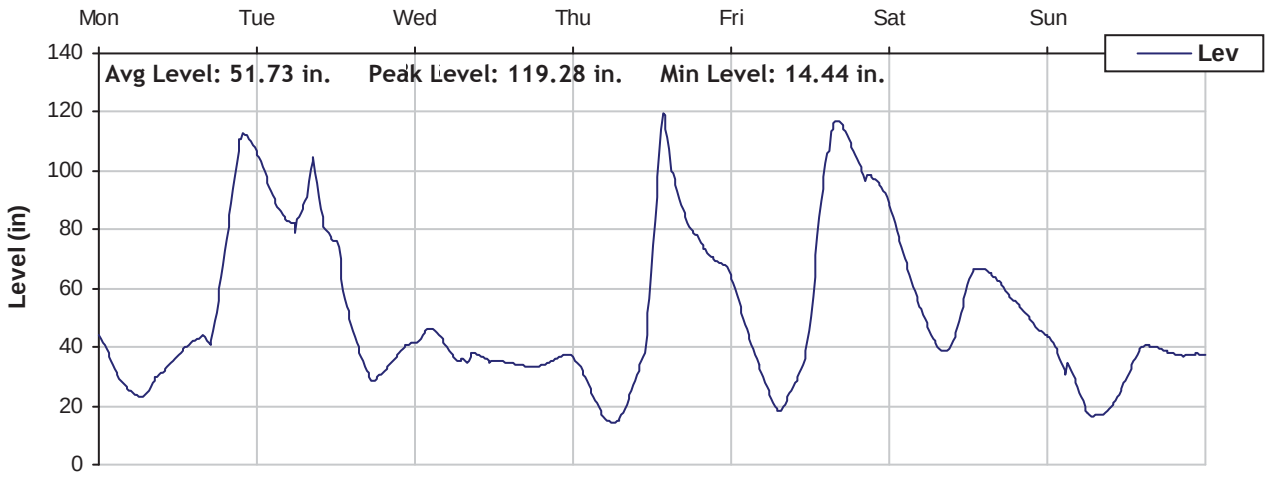


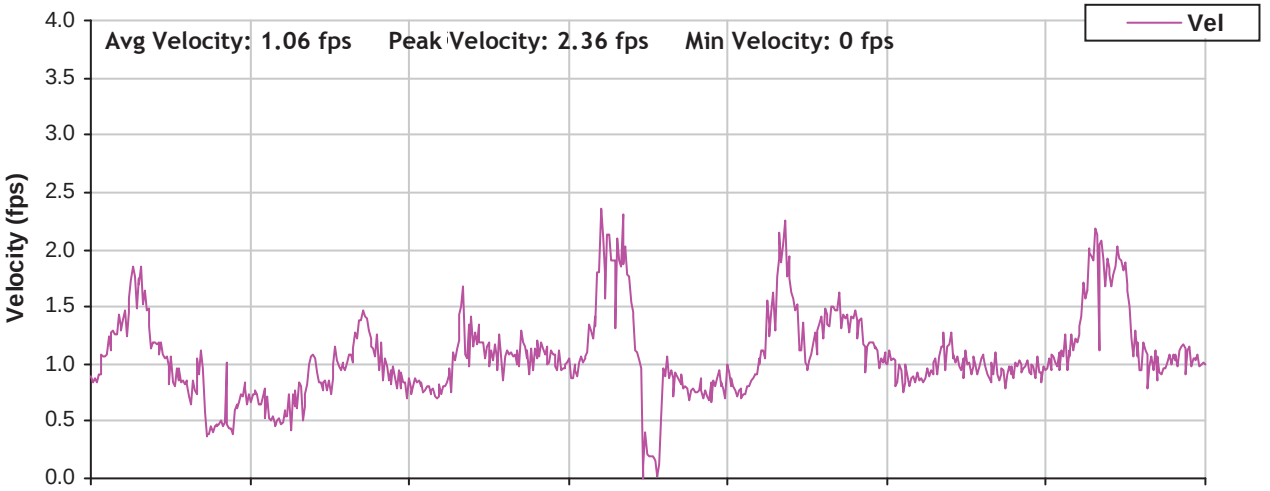
Avg Flow: 11.352 mgd Peak Flow: 23.814 mgd Min Flow: 4.191 mgd

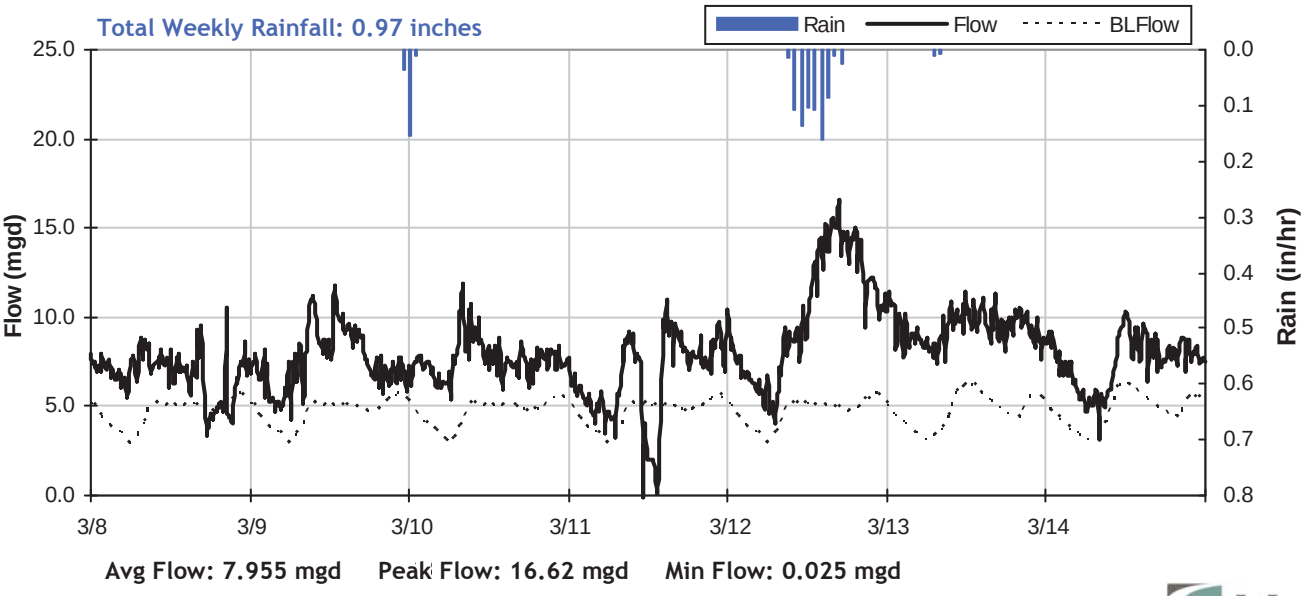
V&A

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 3

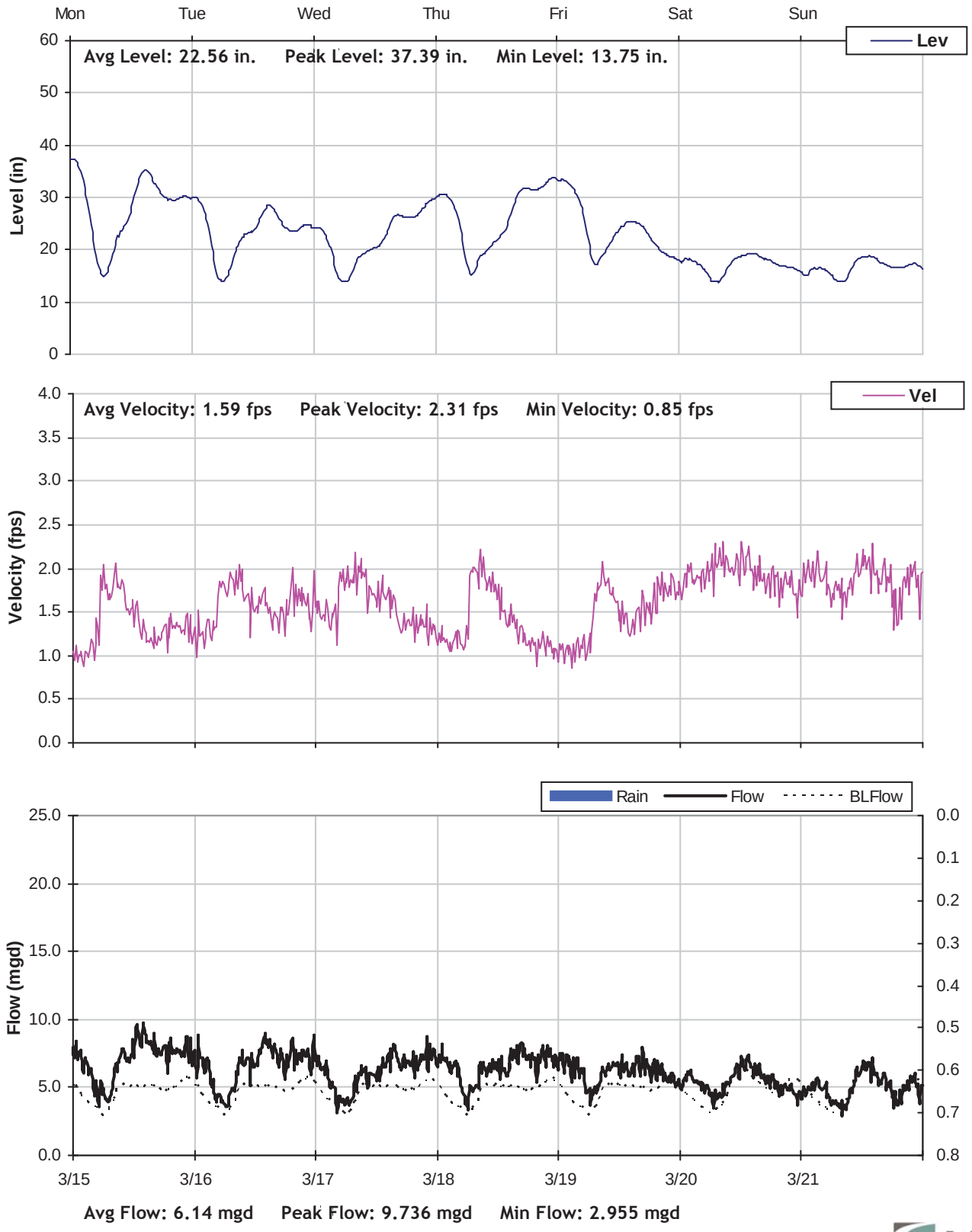






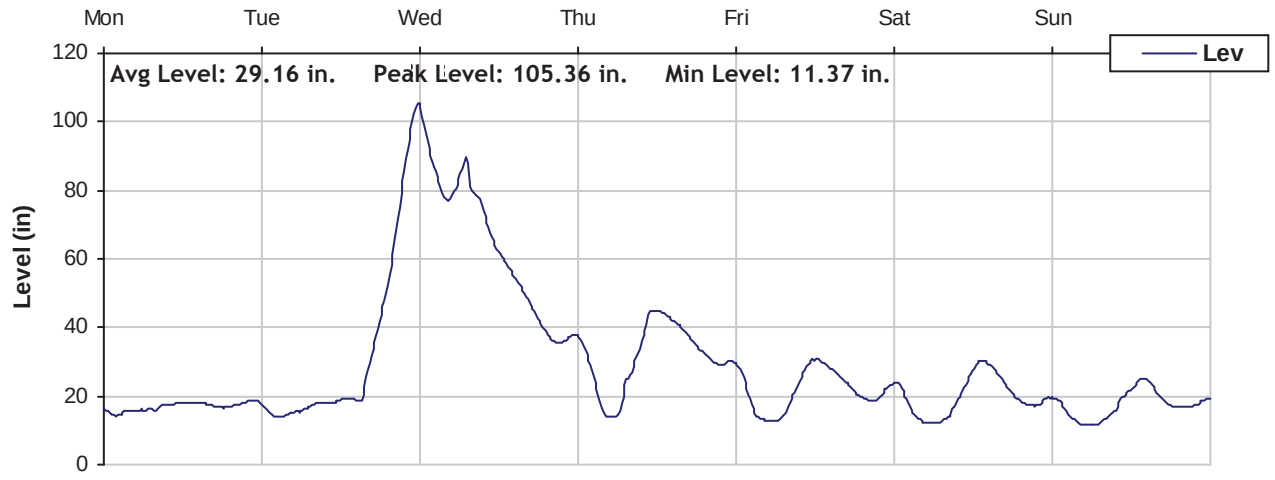
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

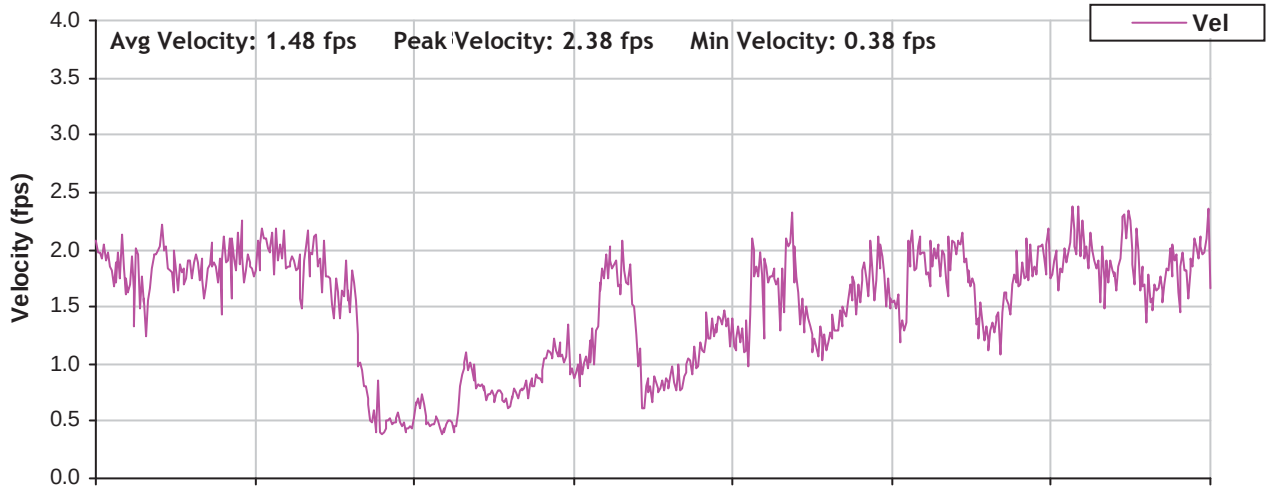
Monitoring Site:
Site 3

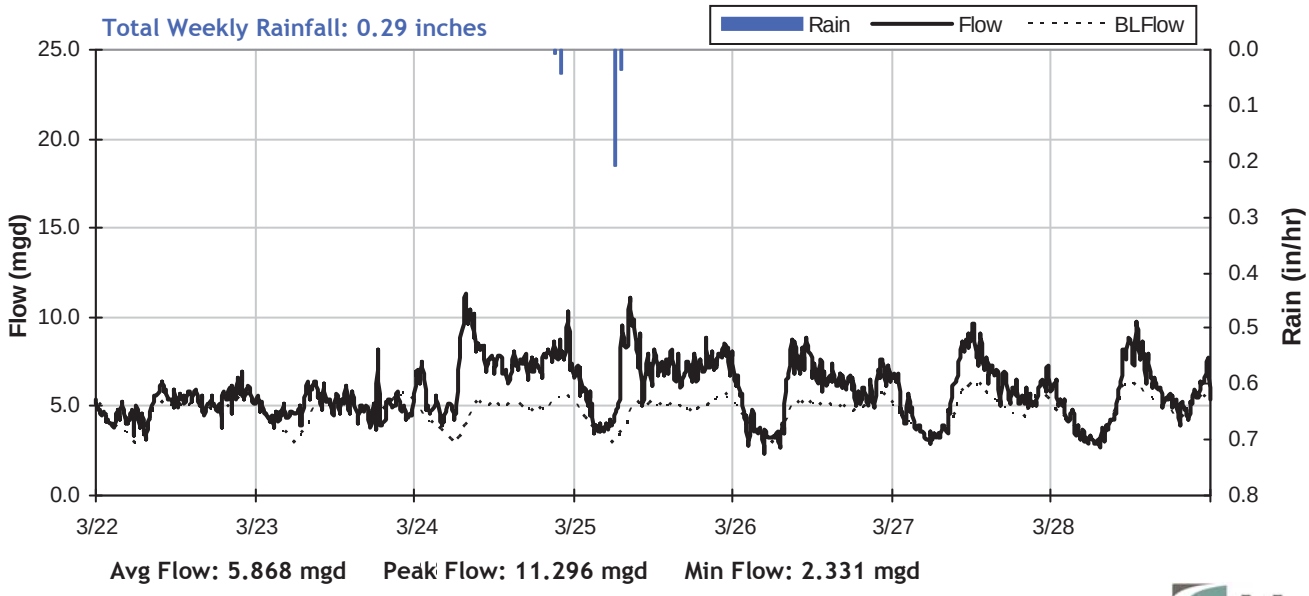


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 3

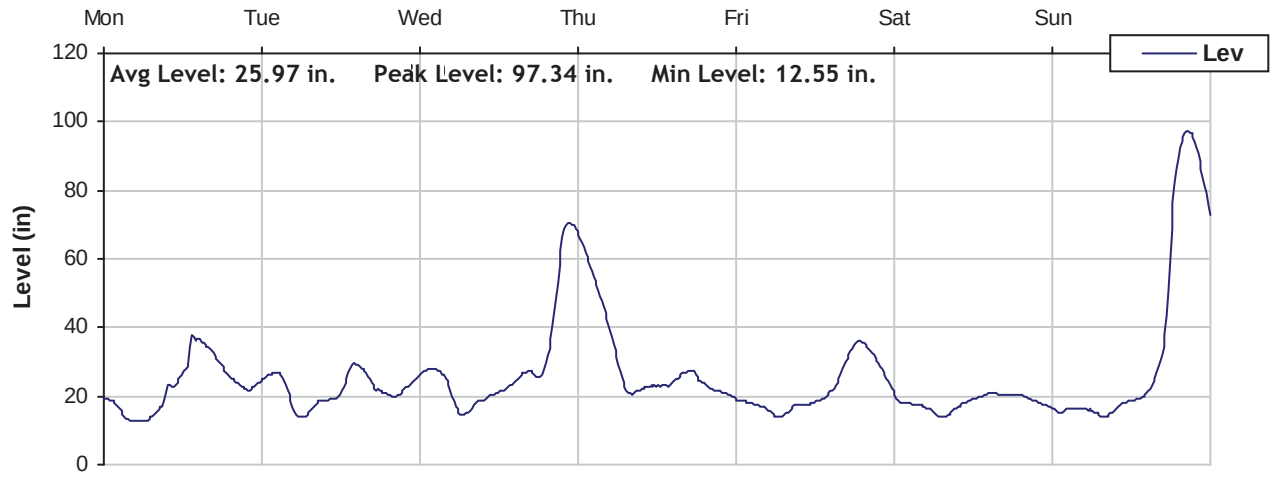


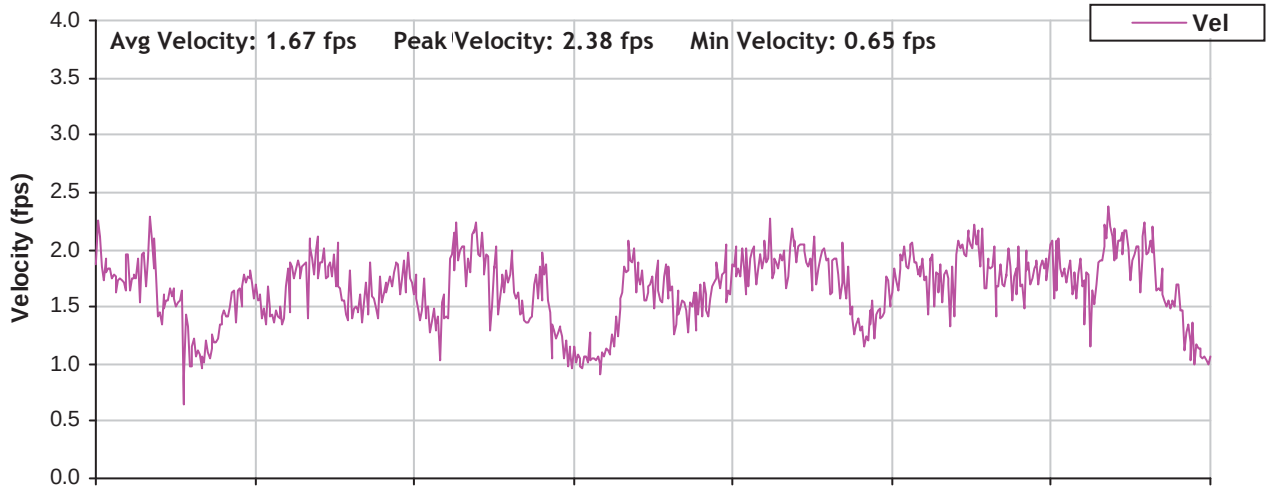


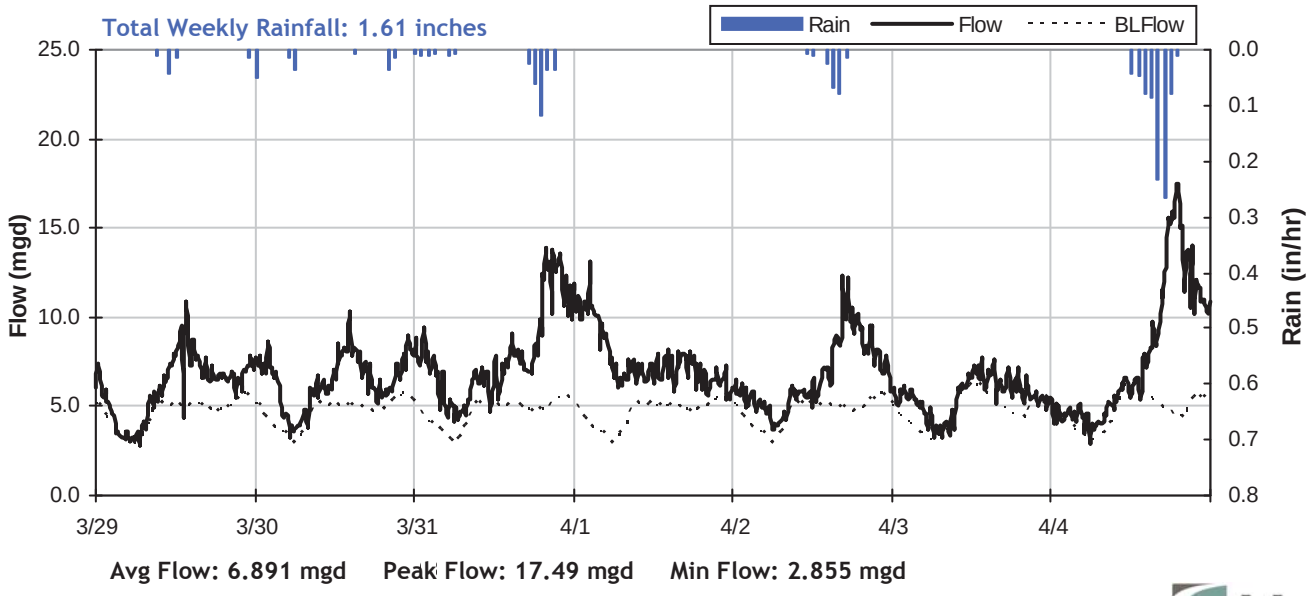


Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 3



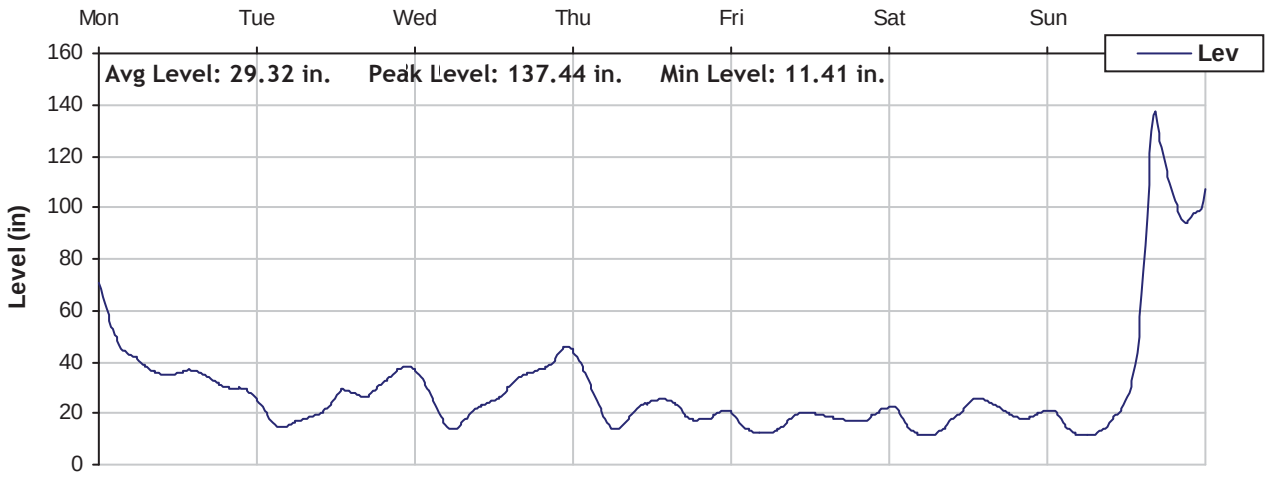


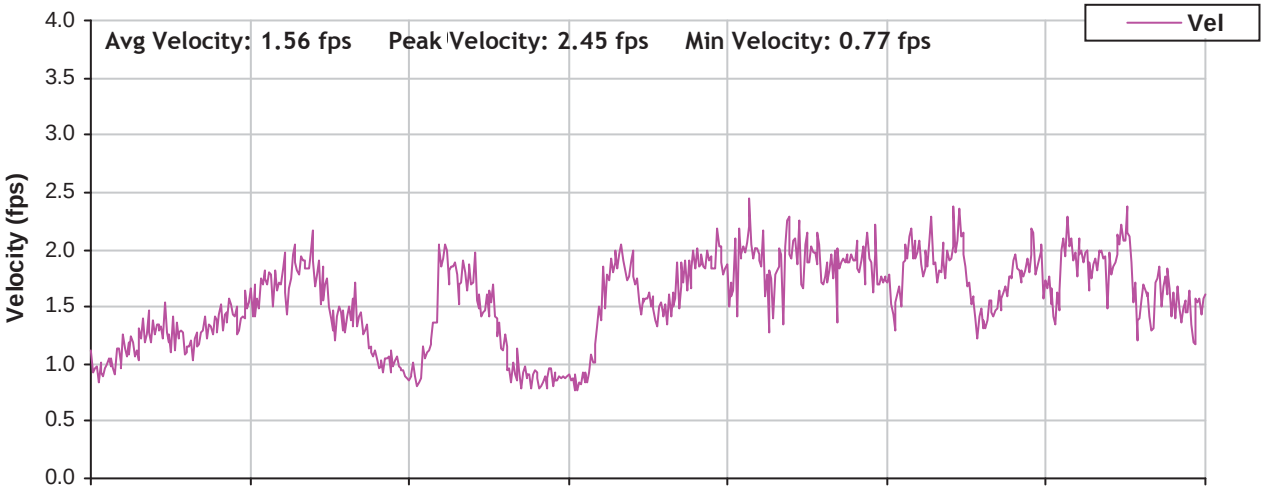


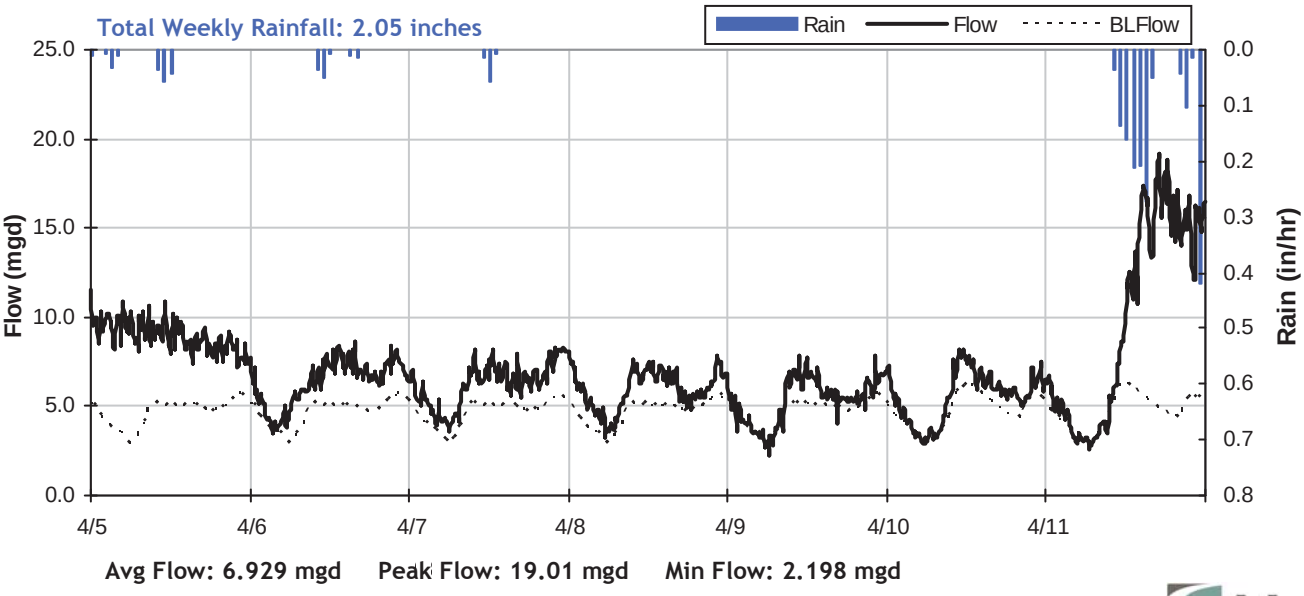
Avg Flow: 6.891 mgd Peak Flow: 17.49 mgd Min Flow: 2.855 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 3

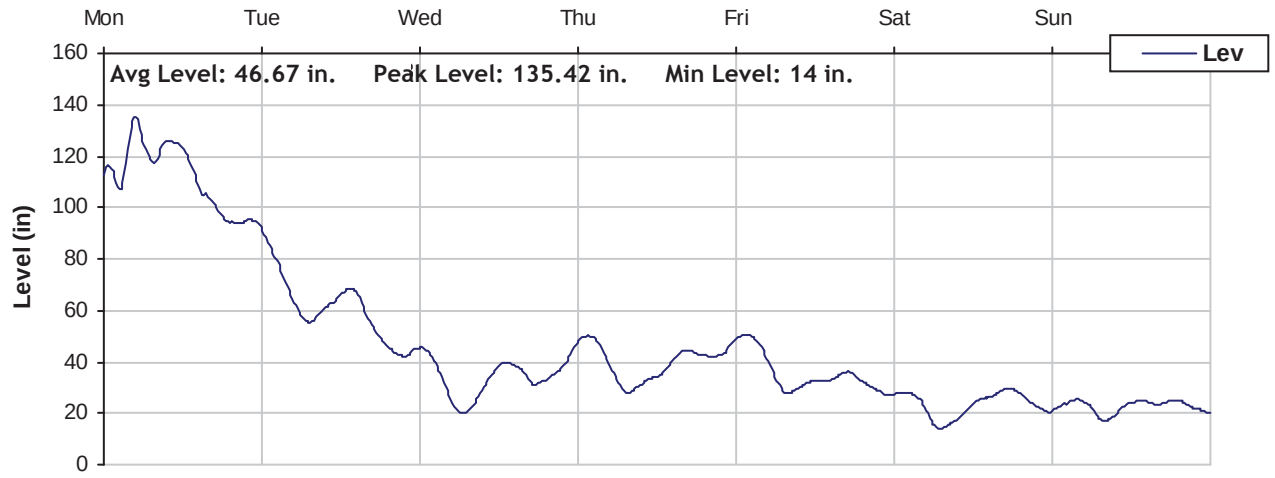


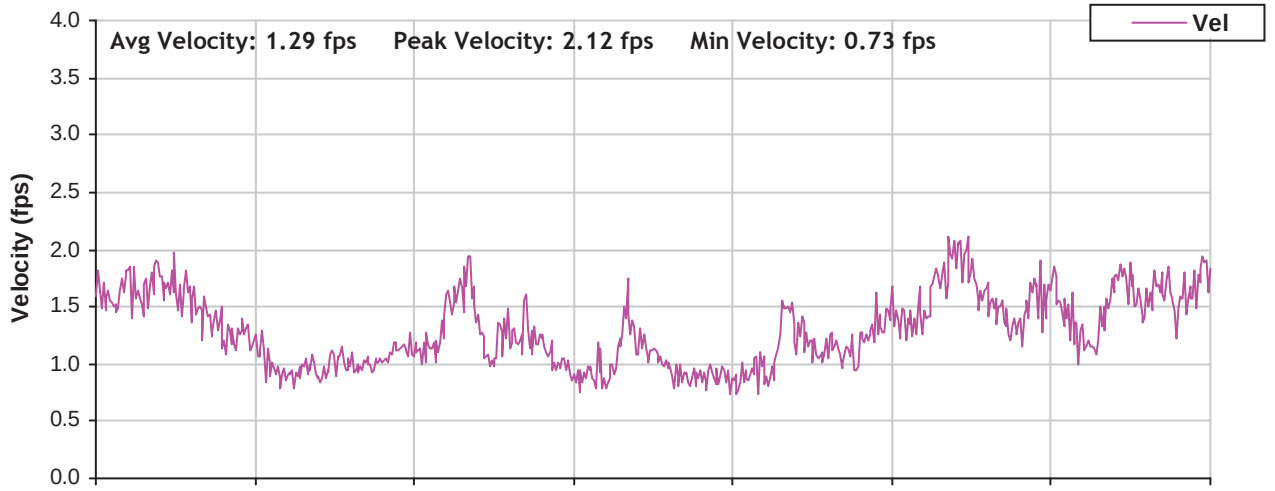


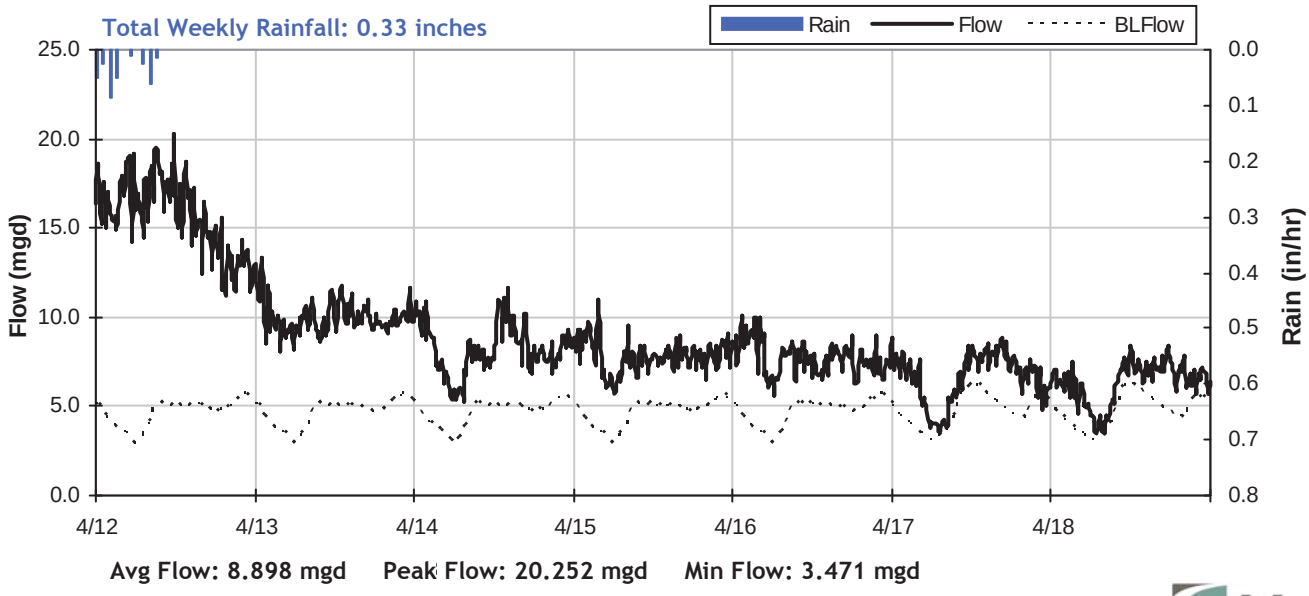


Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 3

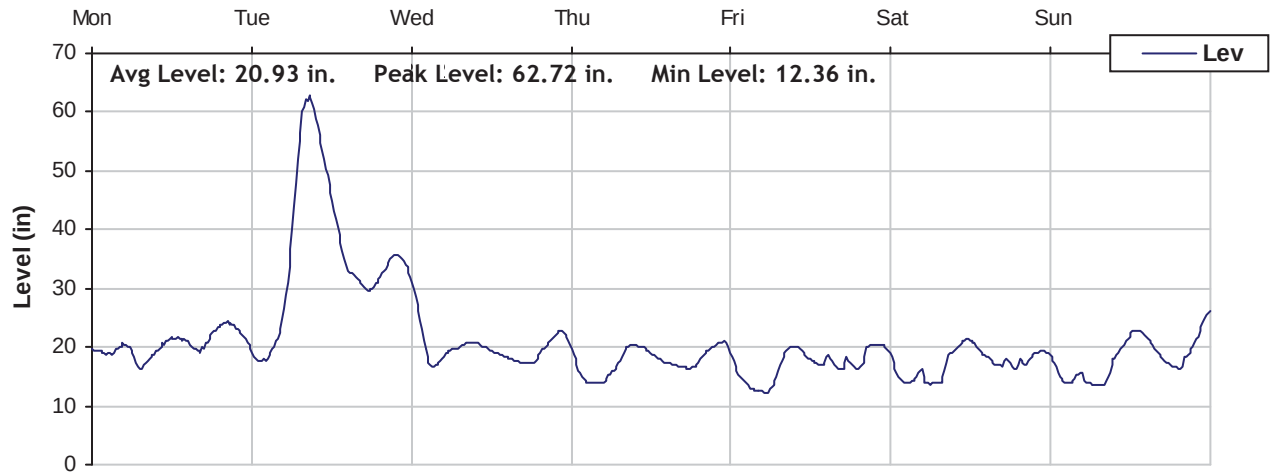


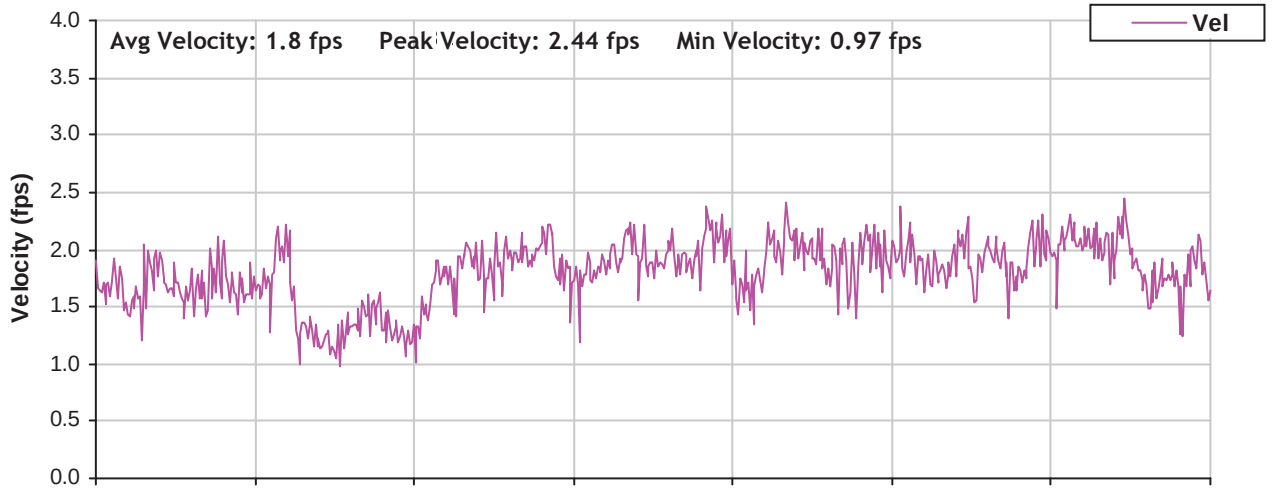


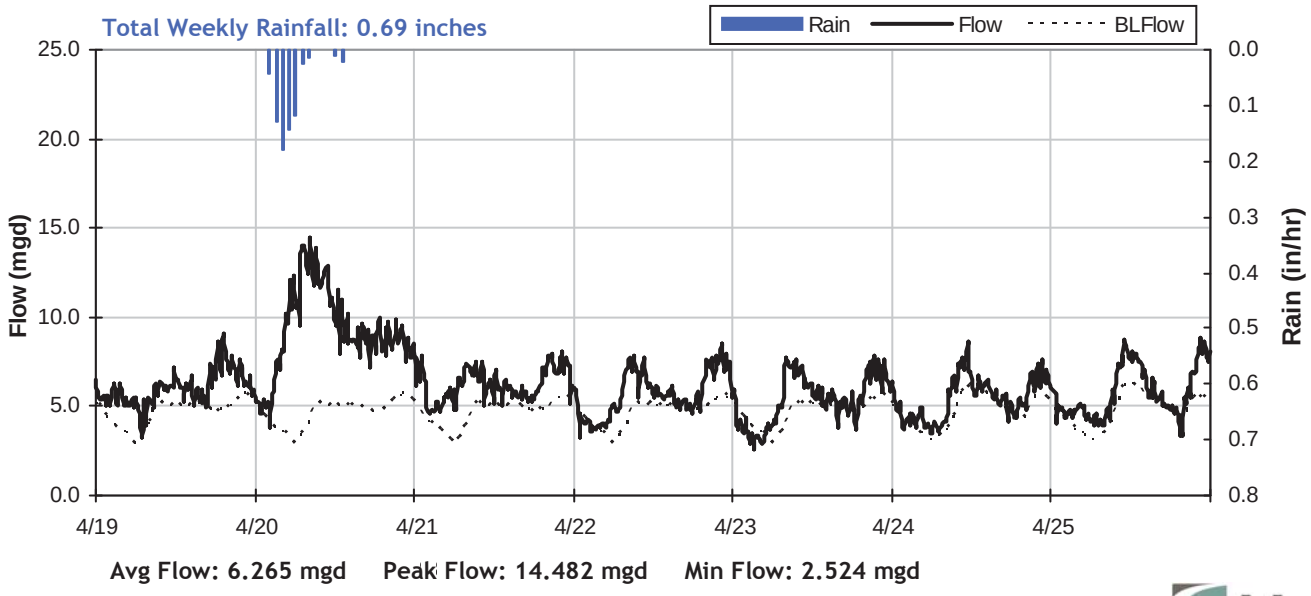


Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 3

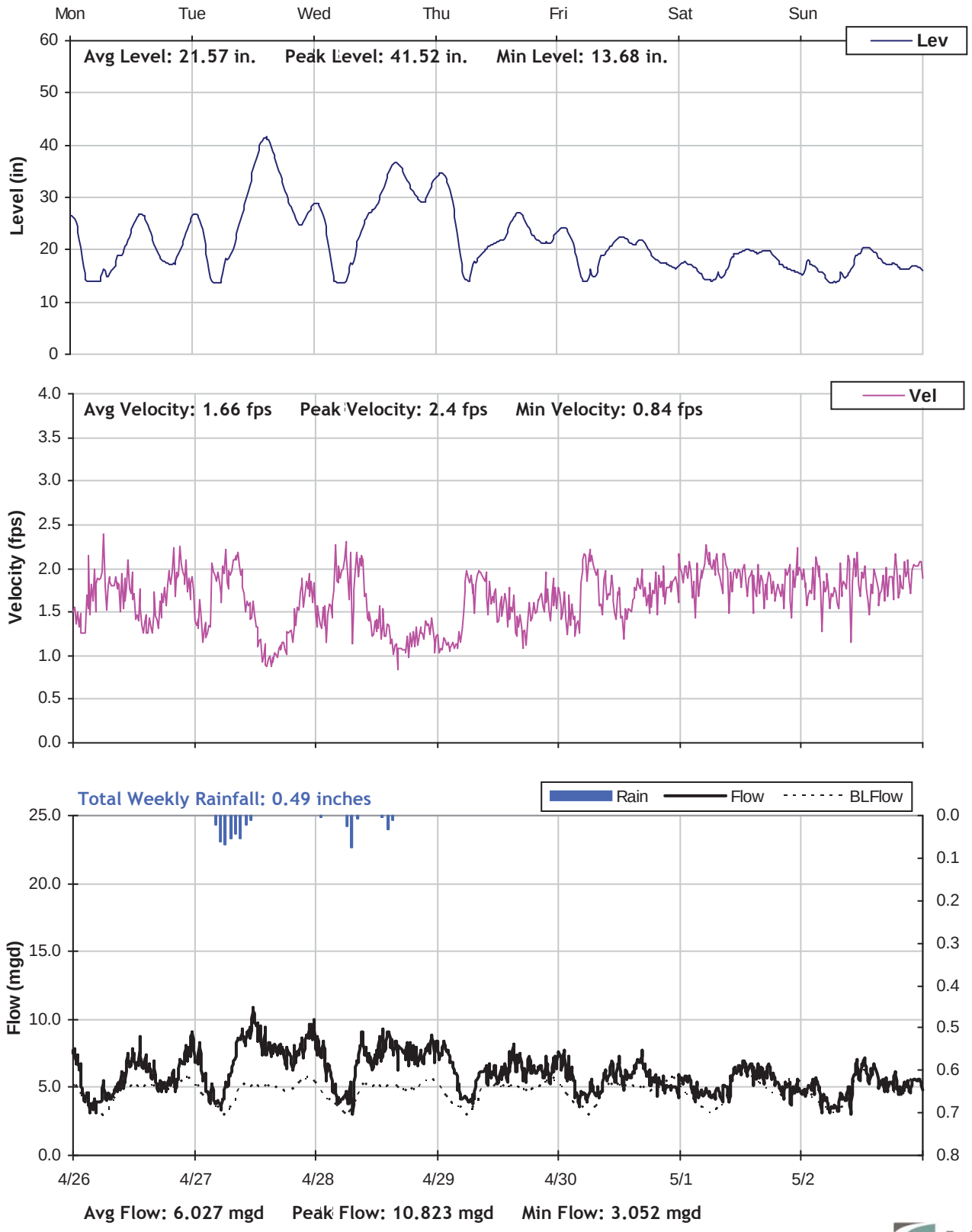






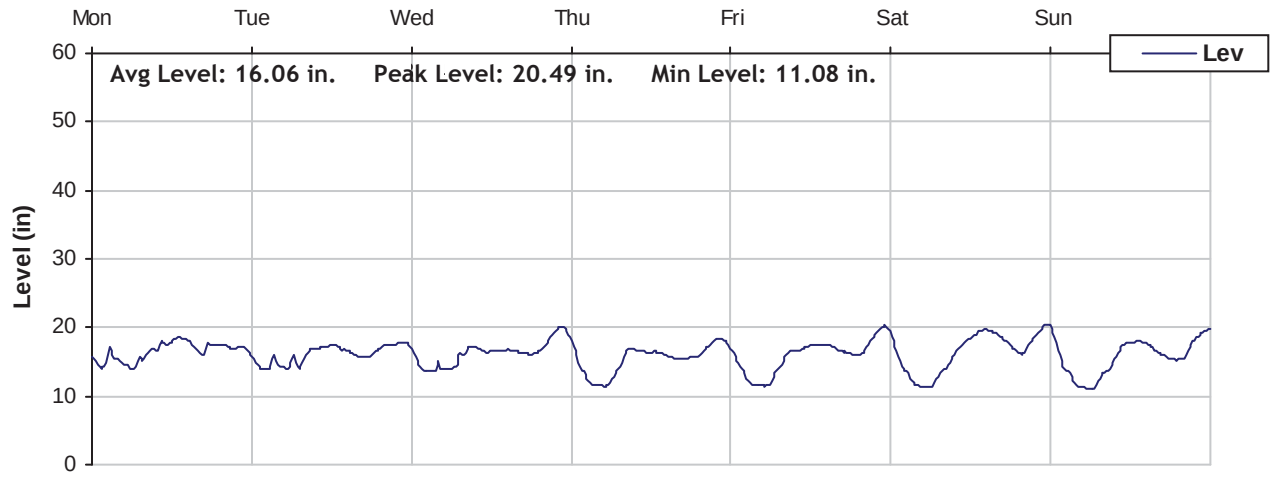
Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

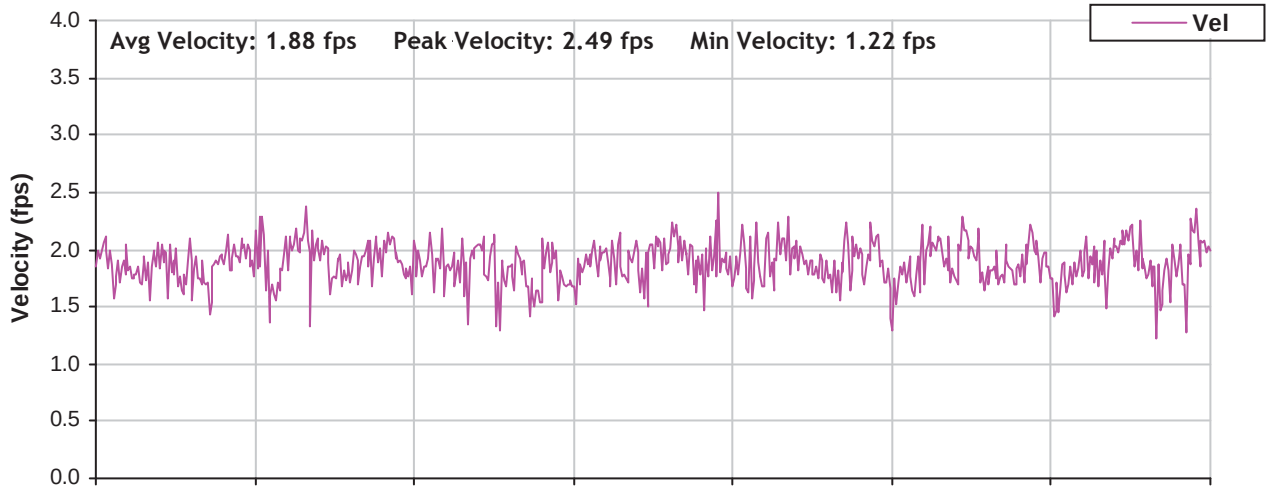
Monitoring Site:
Site 3

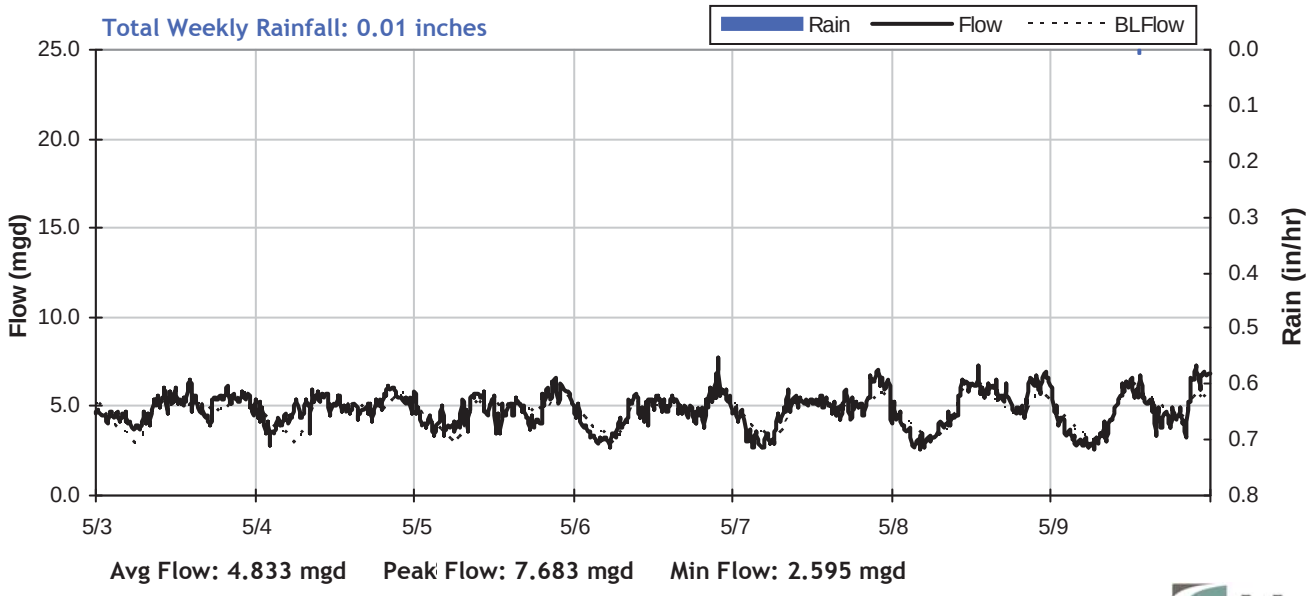


Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 3



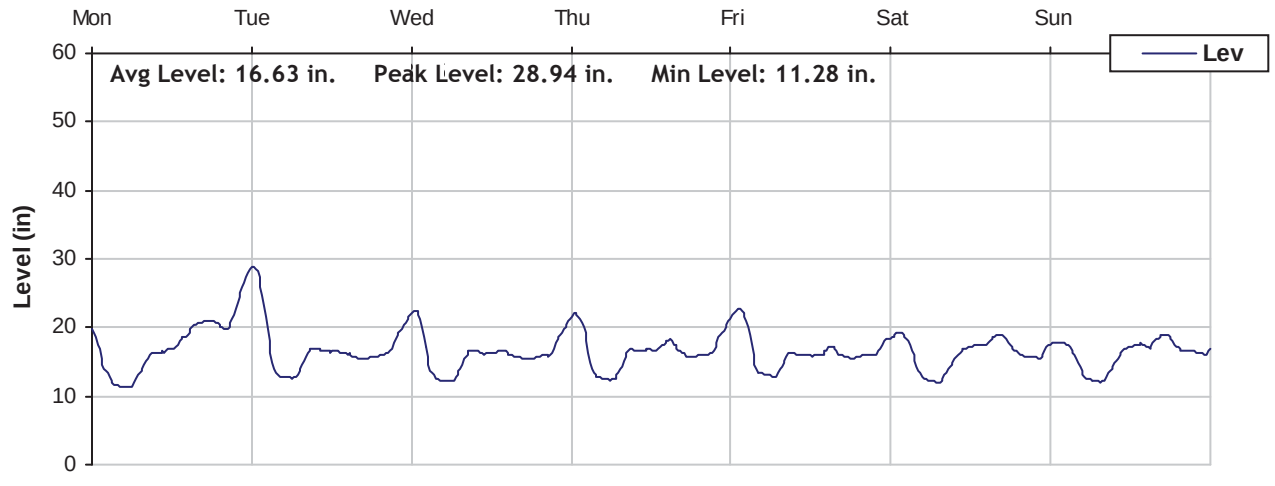


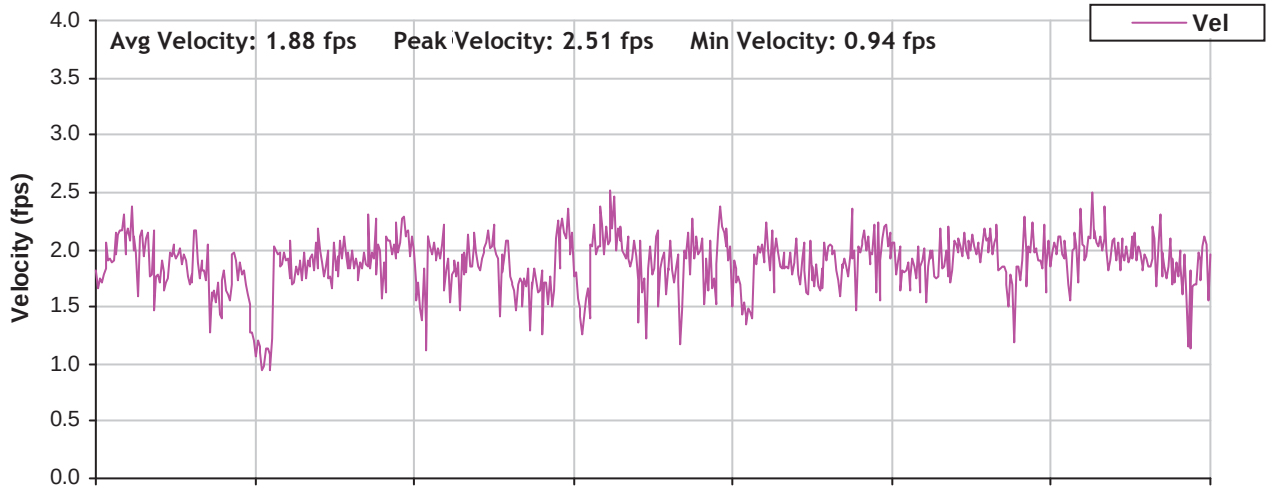


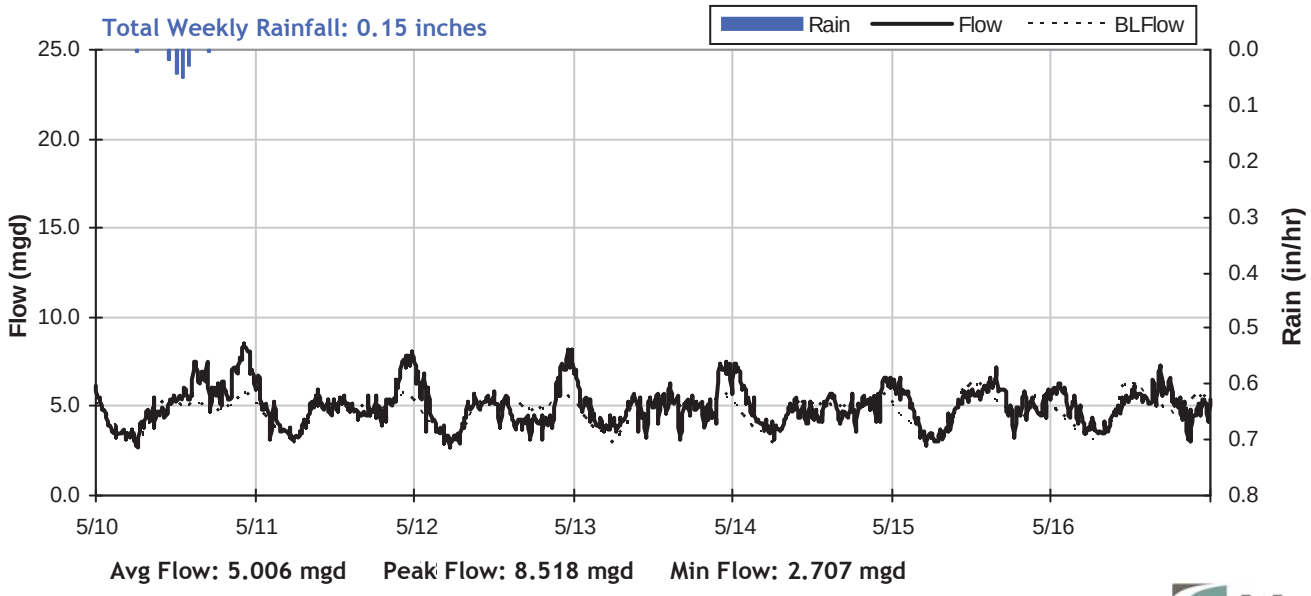
Avg Flow: 4.833 mgd Peak Flow: 7.683 mgd Min Flow: 2.595 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 3

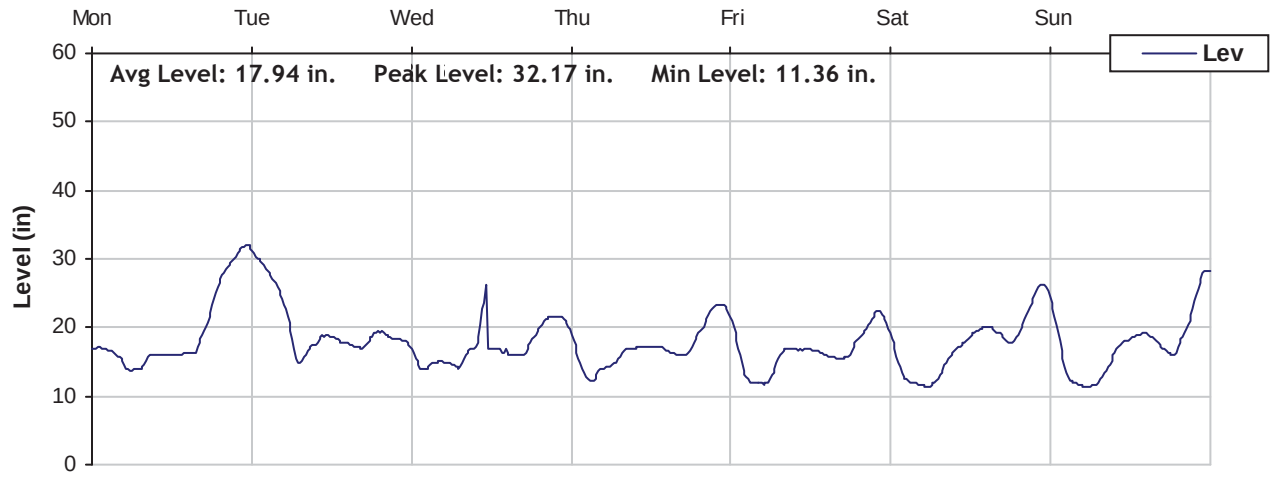


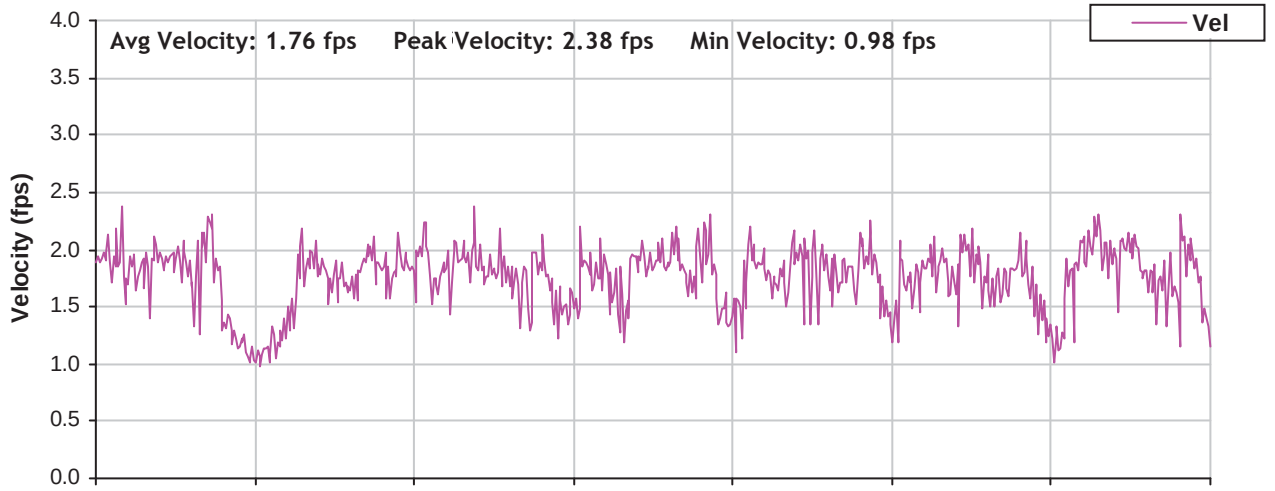


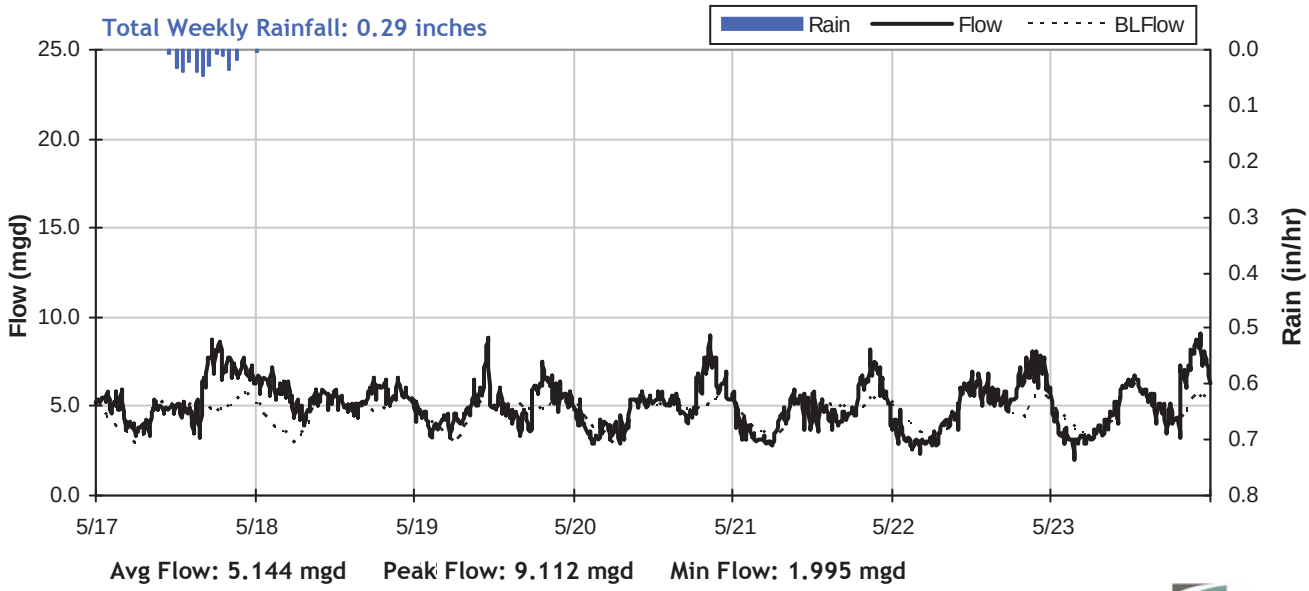


Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 3

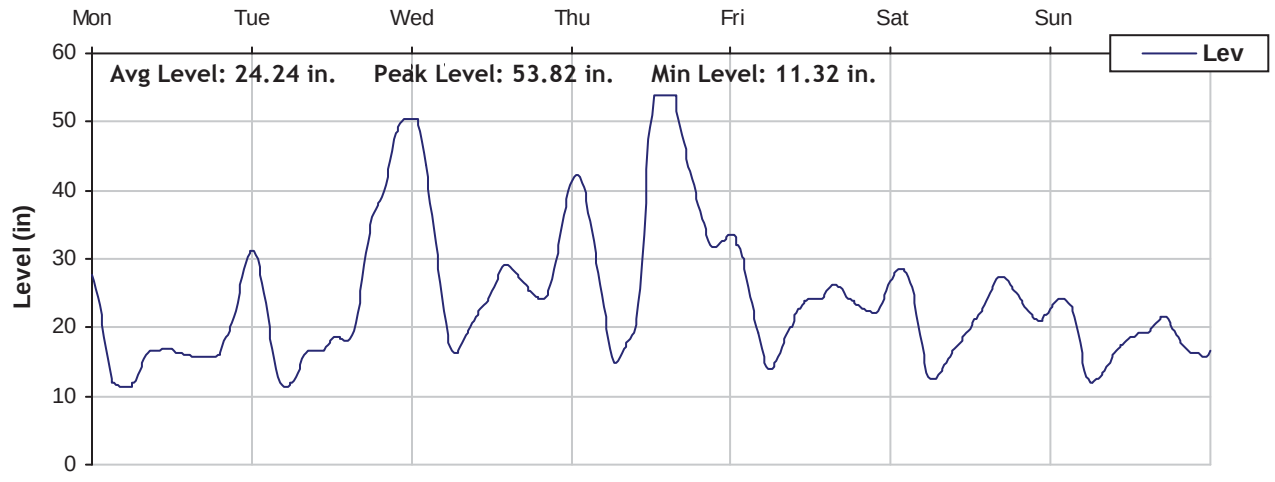


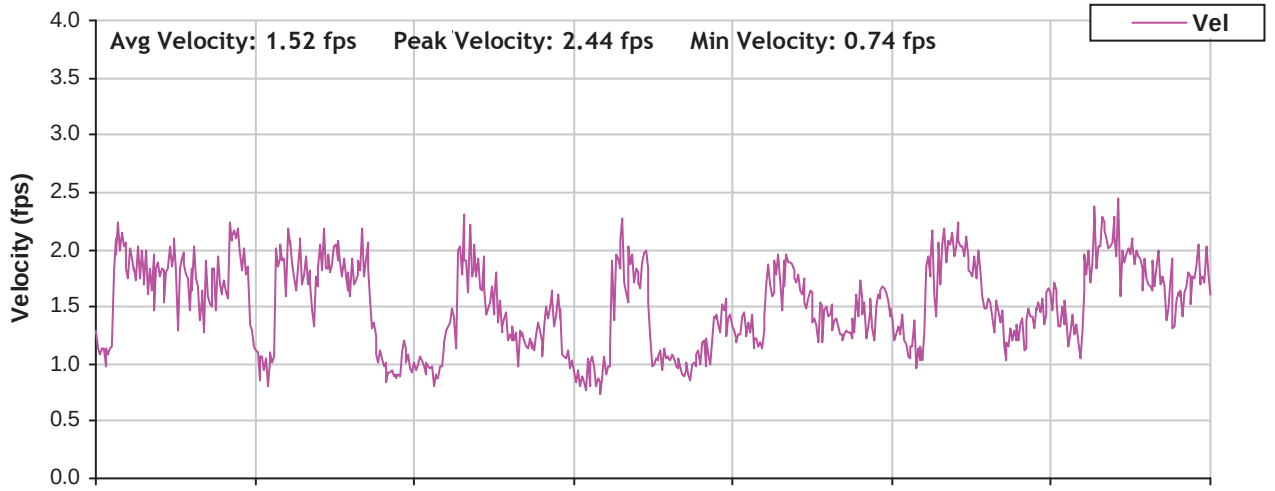


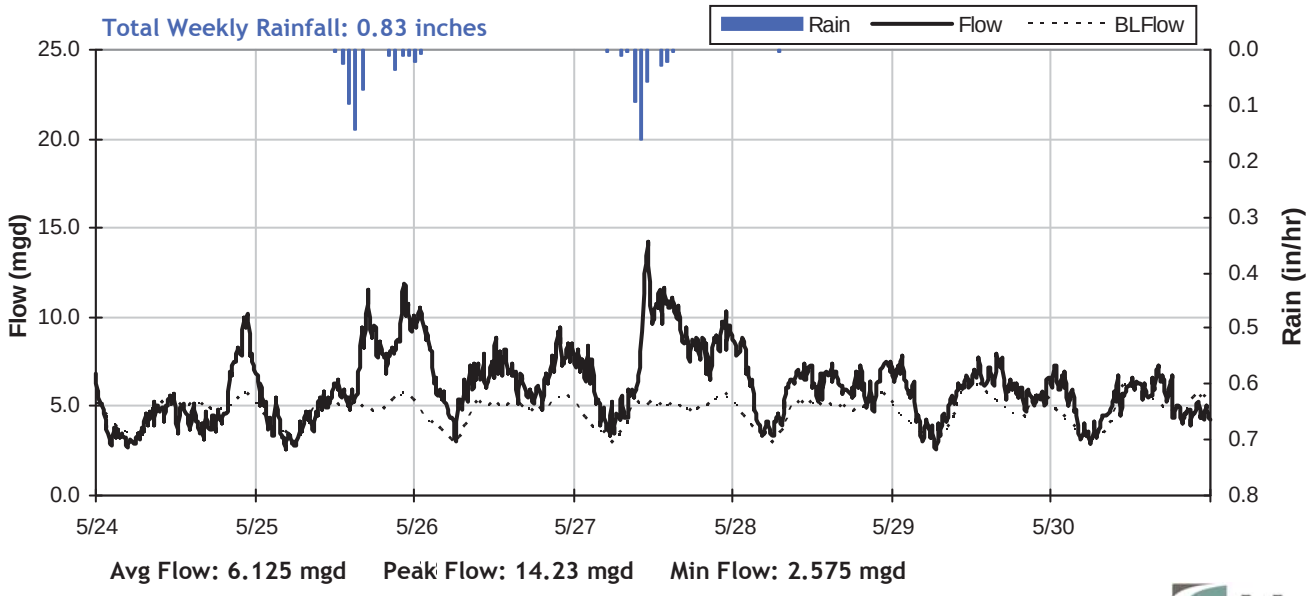


Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 3



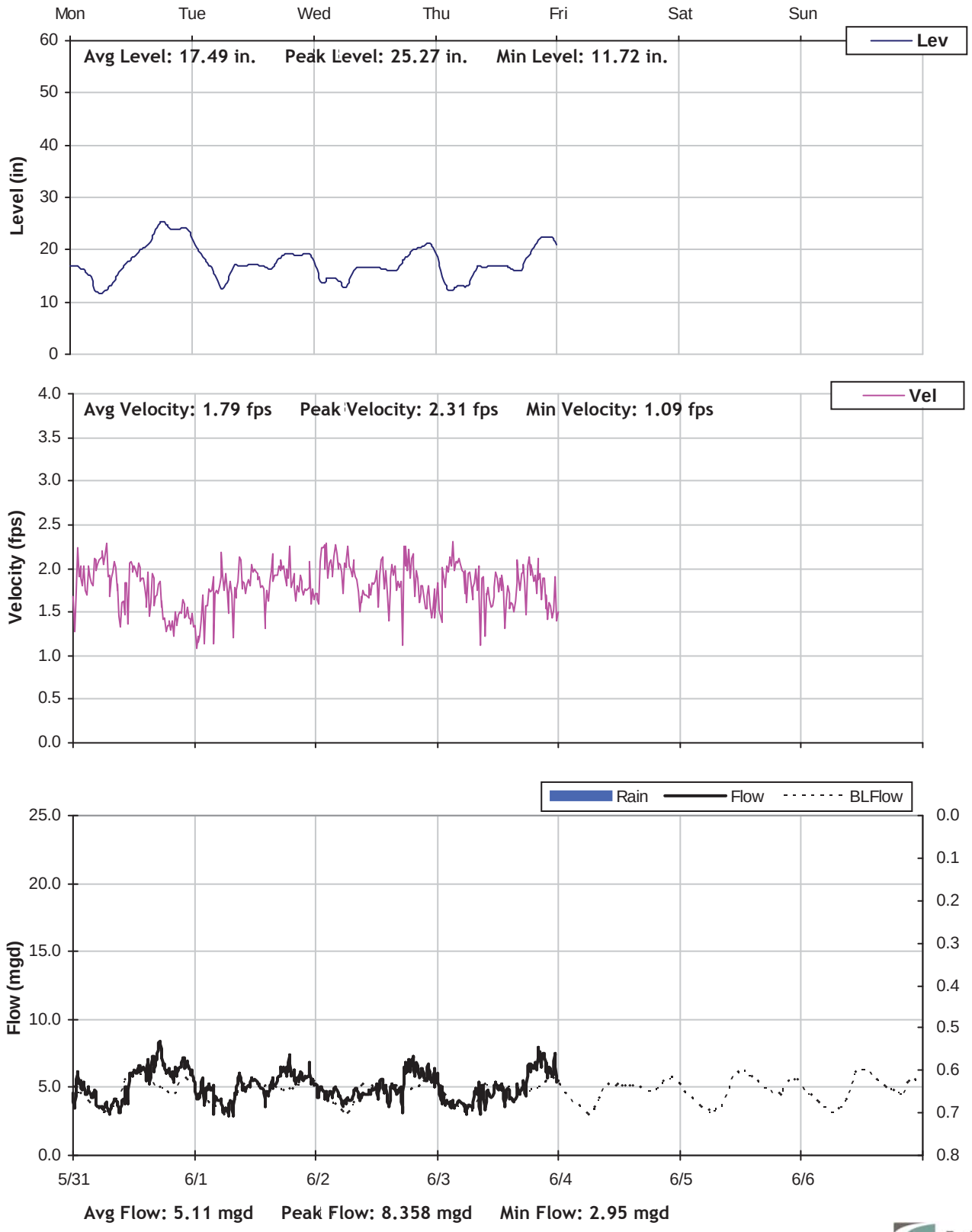




Avg Flow: 6.125 mgd Peak Flow: 14.23 mgd Min Flow: 2.575 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 3



Temporary Flow Monitoring Study

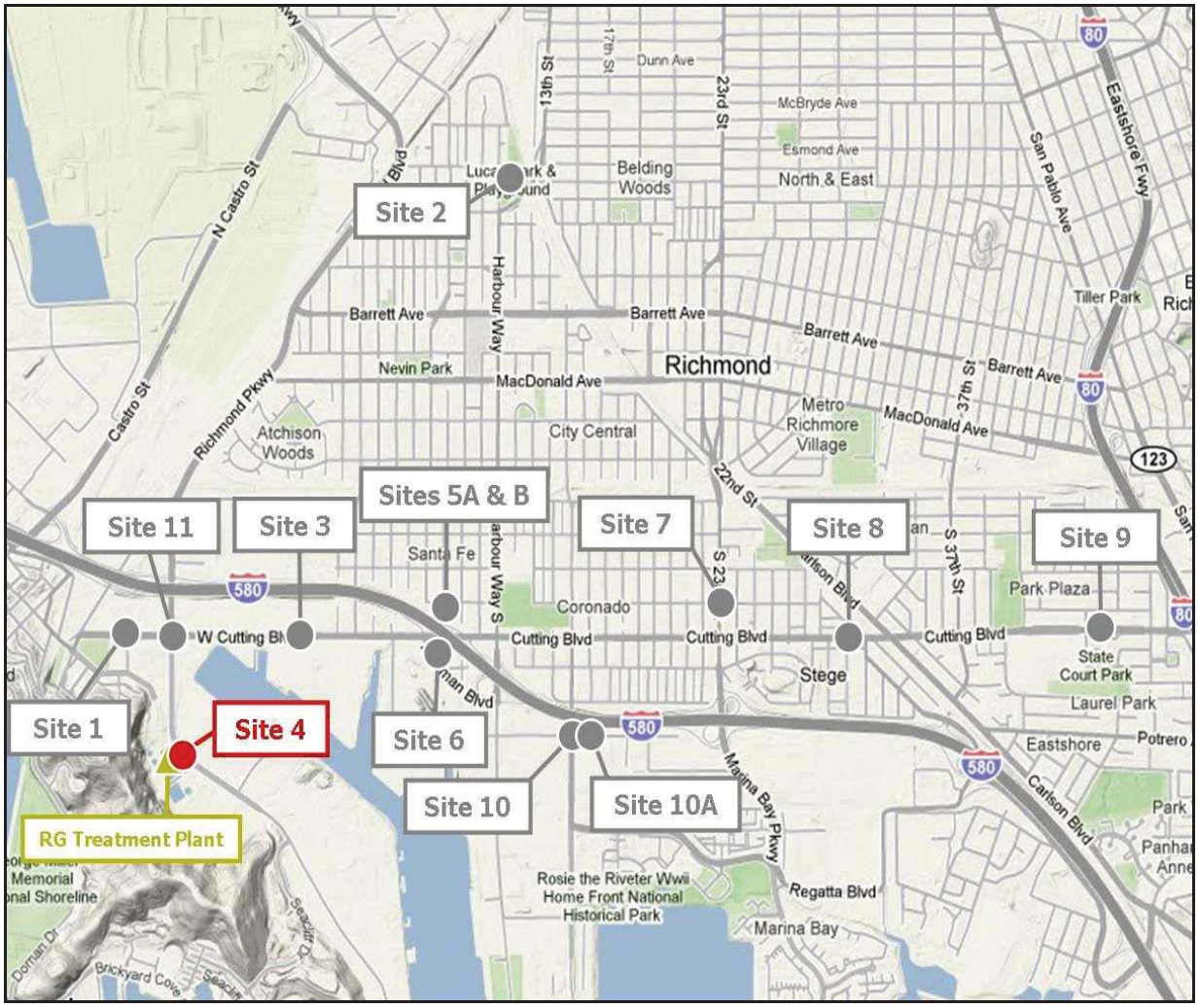
Sanitary Sewer Collection System

Monitoring Site: Site 4

Location: Canal Boulevard; across the street from the Wastewater Treatment Plant

Size/Type Line: 18-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 4

Location: Canal Boulevard; across the street from the Wastewater Treatment Plant

Latitude: 37.9203°

Longitude: -122.3772°

Rim Elevation: 15 *feet above sea level*

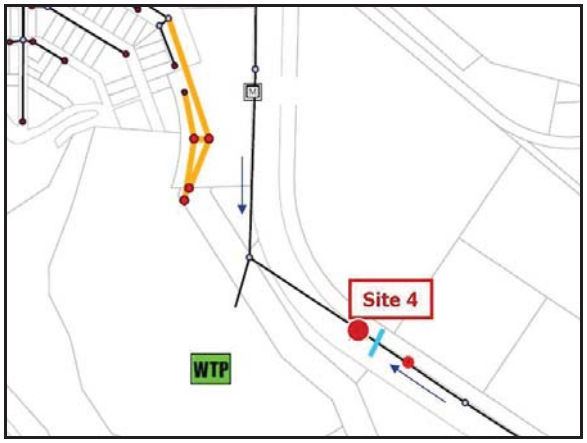
Diameter: 18 *inches*

Average Dry Weather Flow: 0.118 *mgd*

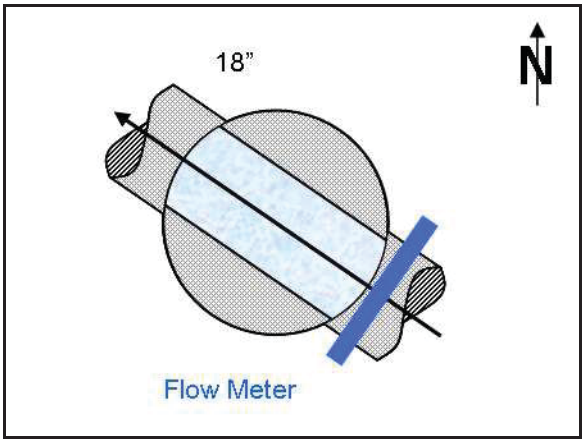
Peak Measured Flow: 1.226 *mgd*

Satellite Photo

Sanitary Map

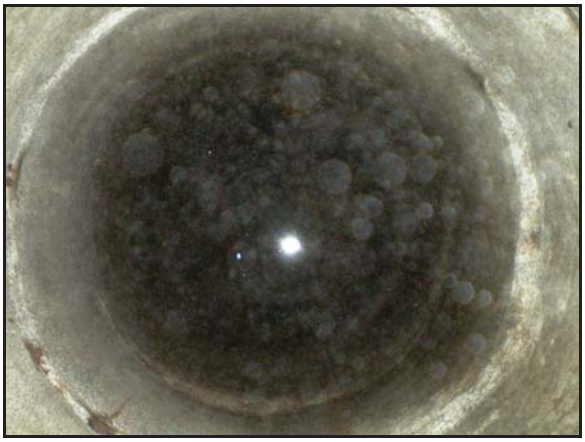


Flow Sketch



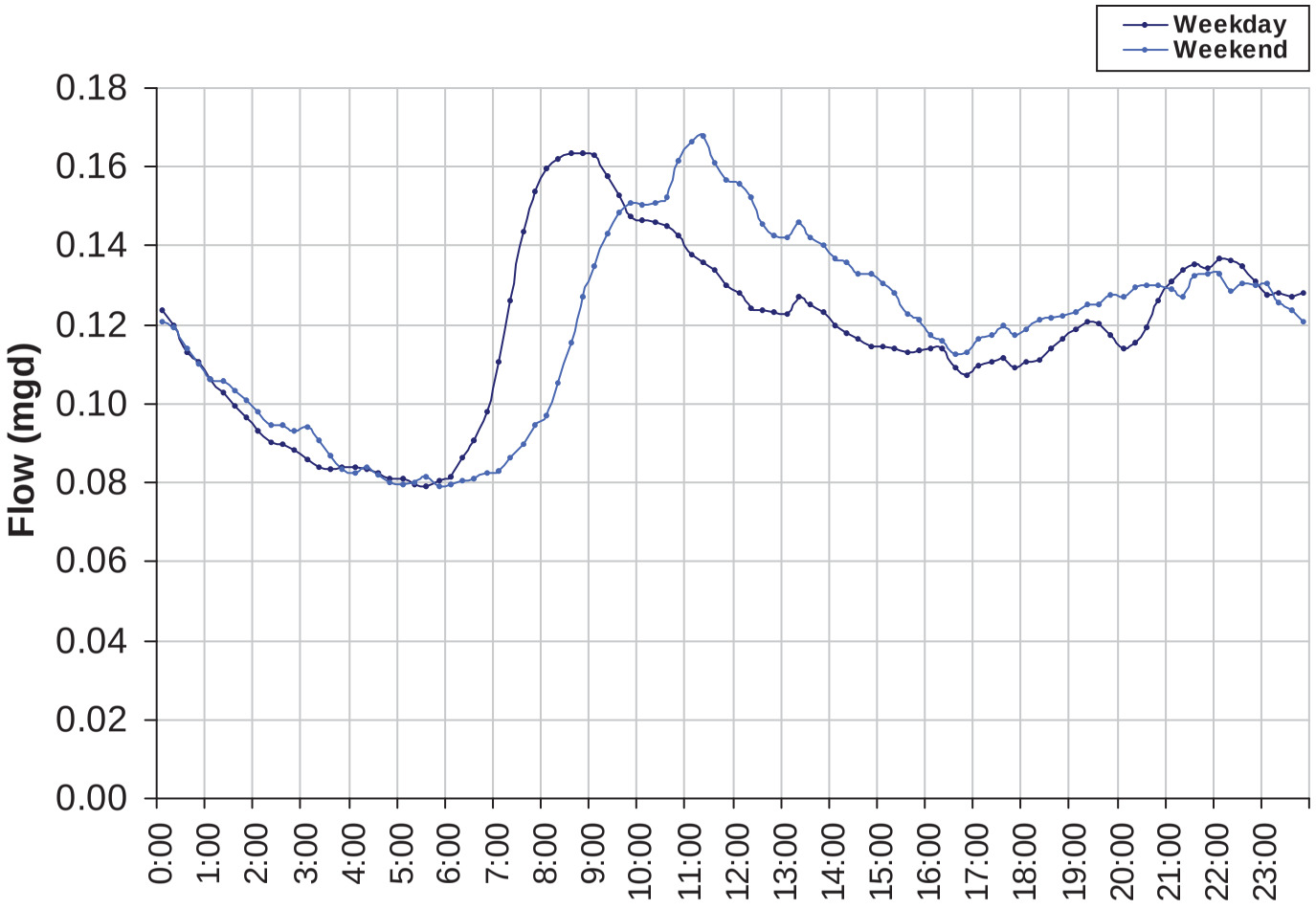
Street View Photo

Plan View Photo



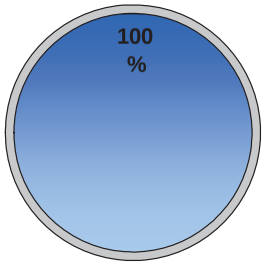
Average Dry Weather Flow

Monitoring Site:
Site 4



Peak Measured Flow:

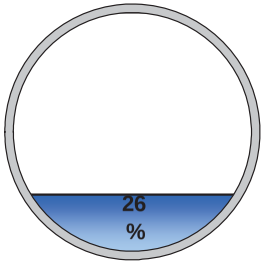
1.23 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

0.12 *mgd*

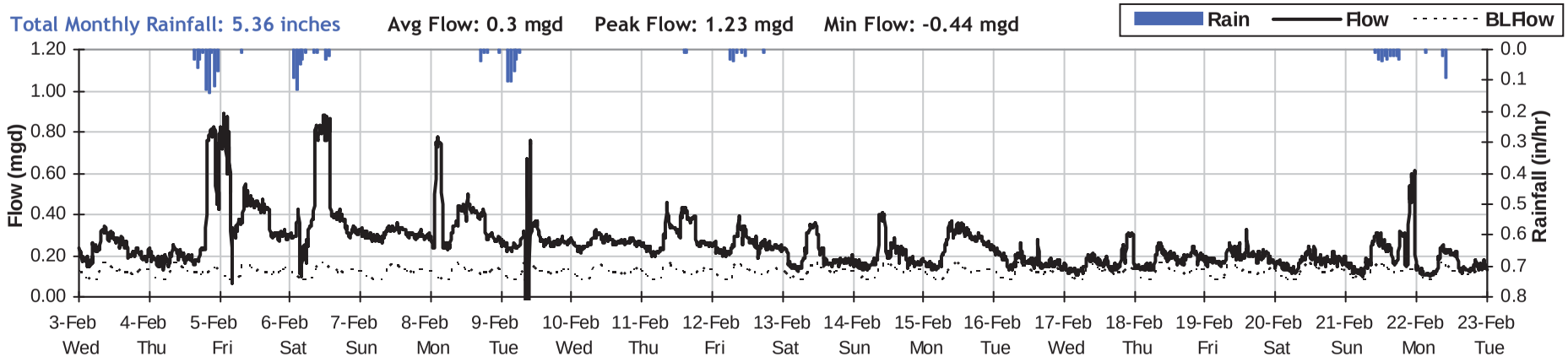


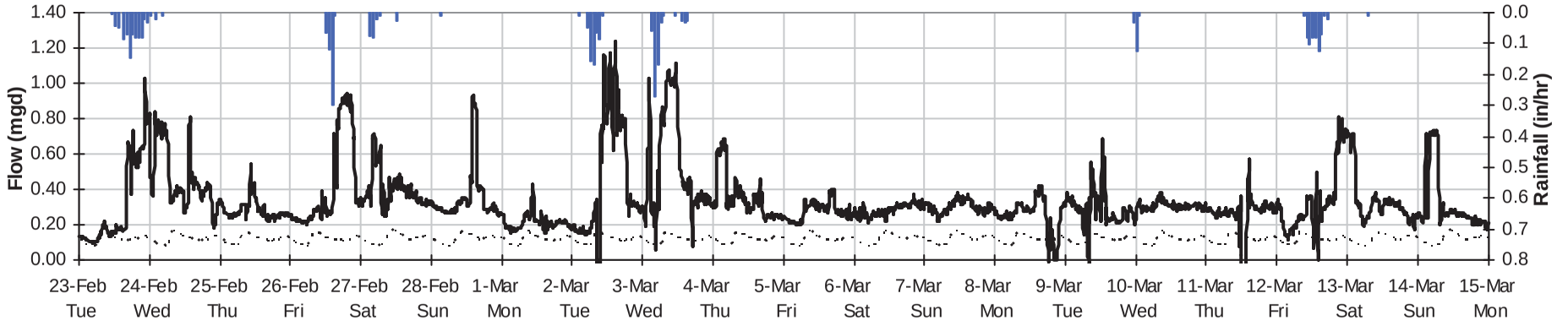
V&A

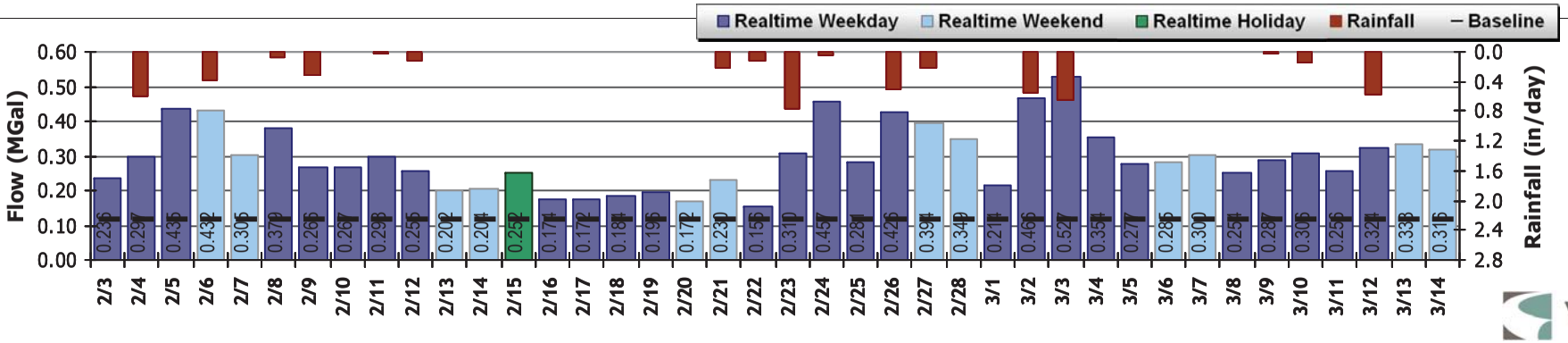
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 4

Total Monthly Rainfall: 5.36 inches Avg Flow: 0.3 mgd Peak Flow: 1.23 mgd Min Flow: -0.44 mgd



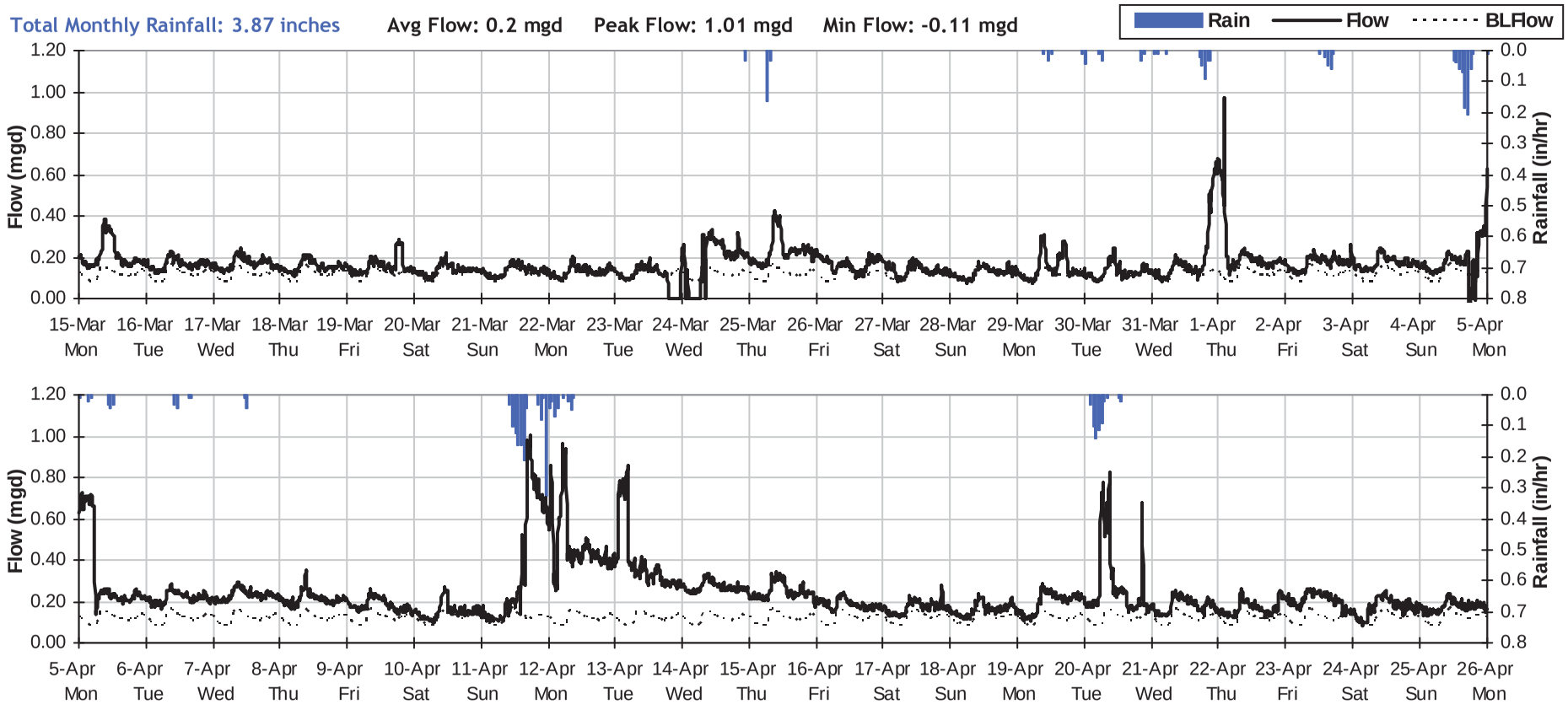


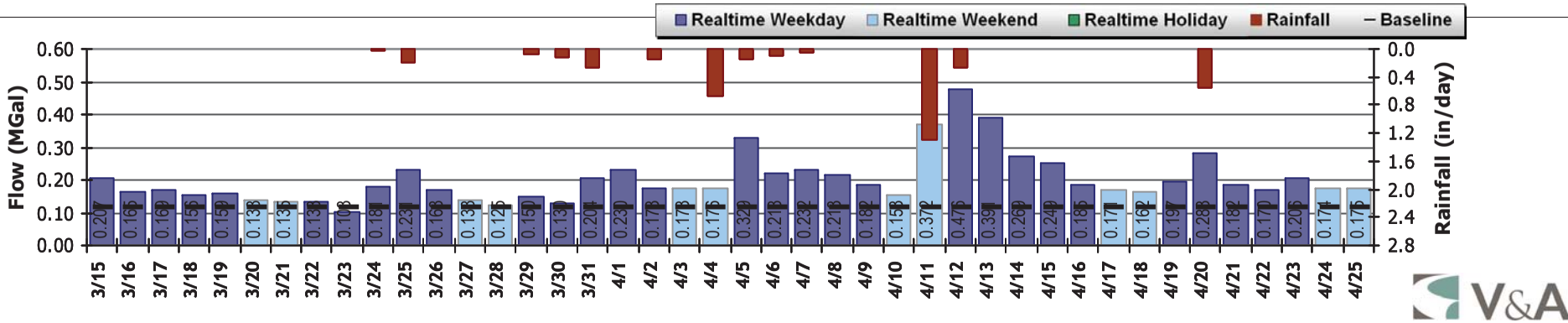


V&A

Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 4



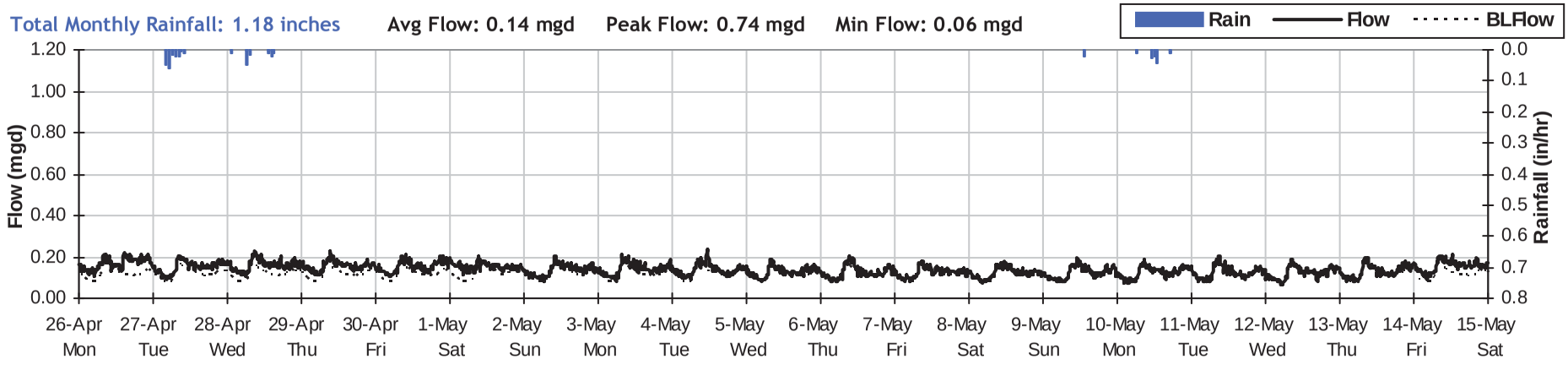


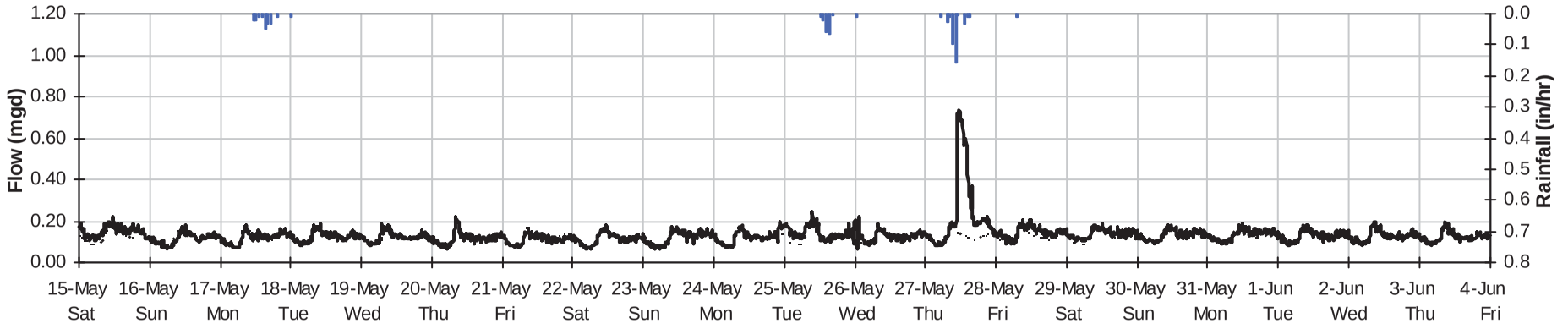
V&A

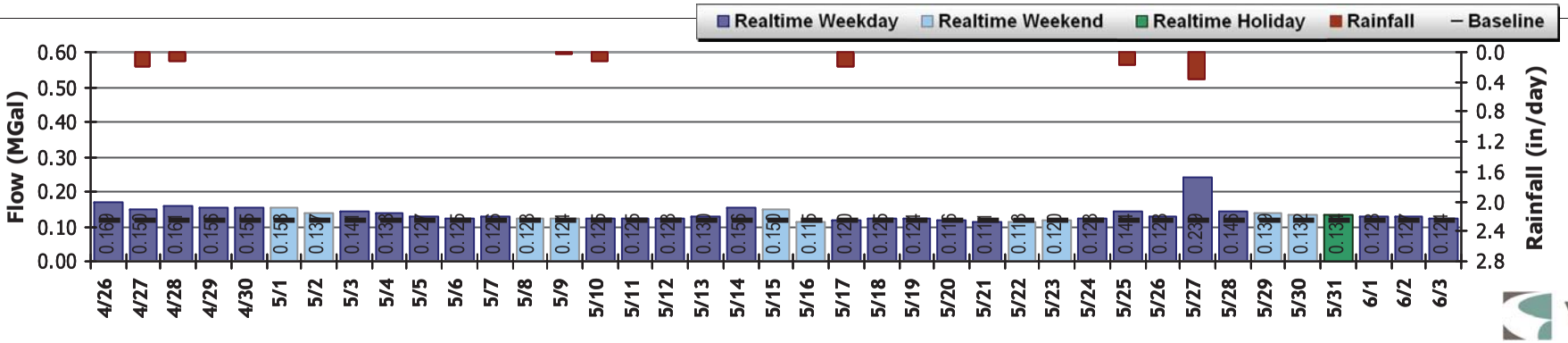
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 4

Total Monthly Rainfall: 1.18 inches Avg Flow: 0.14 mgd Peak Flow: 0.74 mgd Min Flow: 0.06 mgd





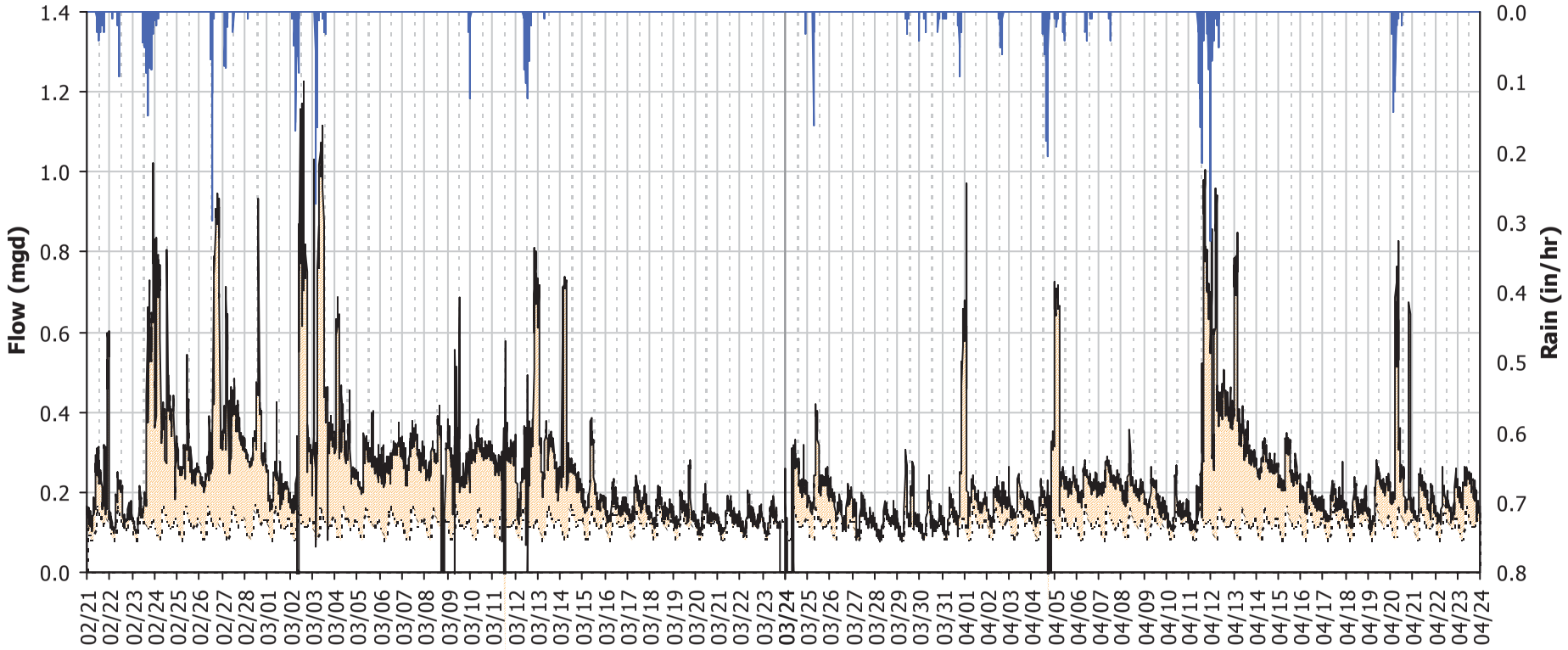


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 4

Multiple Events Detail I/I Graph

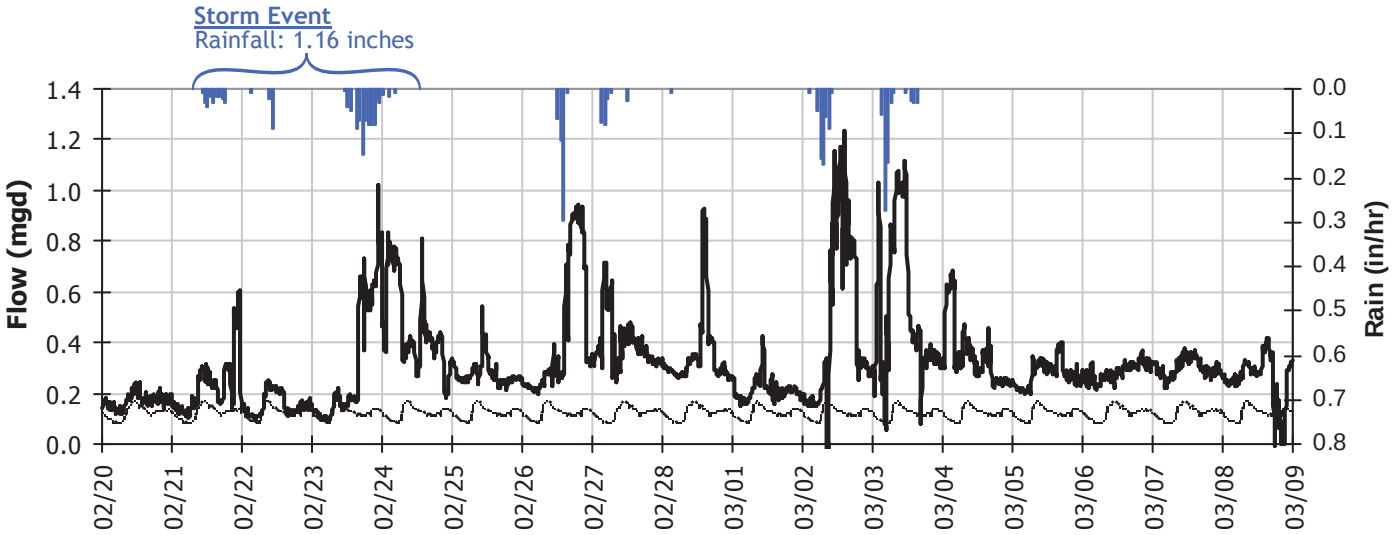


Multiple Events I/I Analysis

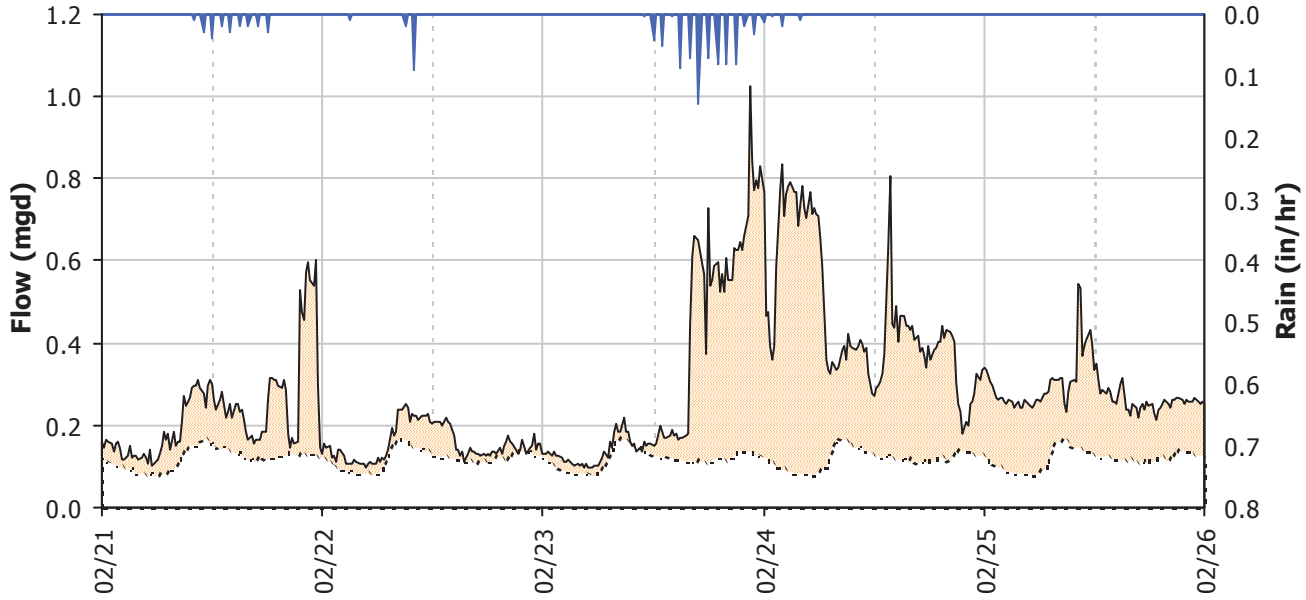
Rainfall:	7.69	*inches*	**Baseline Flow:**	0.12	*mgd*
Peak Flow:	1.23	*mgd*	**PF:**	10.39	
Peak I/I Rate:	1.11	*mgd*	**Pk I/I:ADWF:**	9.40	
Peak Level:	91.49	*inches*	**d/D Ratio:**	5.08	
Total I/I:	7,868,000	*gallons*	**R-Value:**	9.9%	
			I/I per ADWF:	8.7	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 4

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



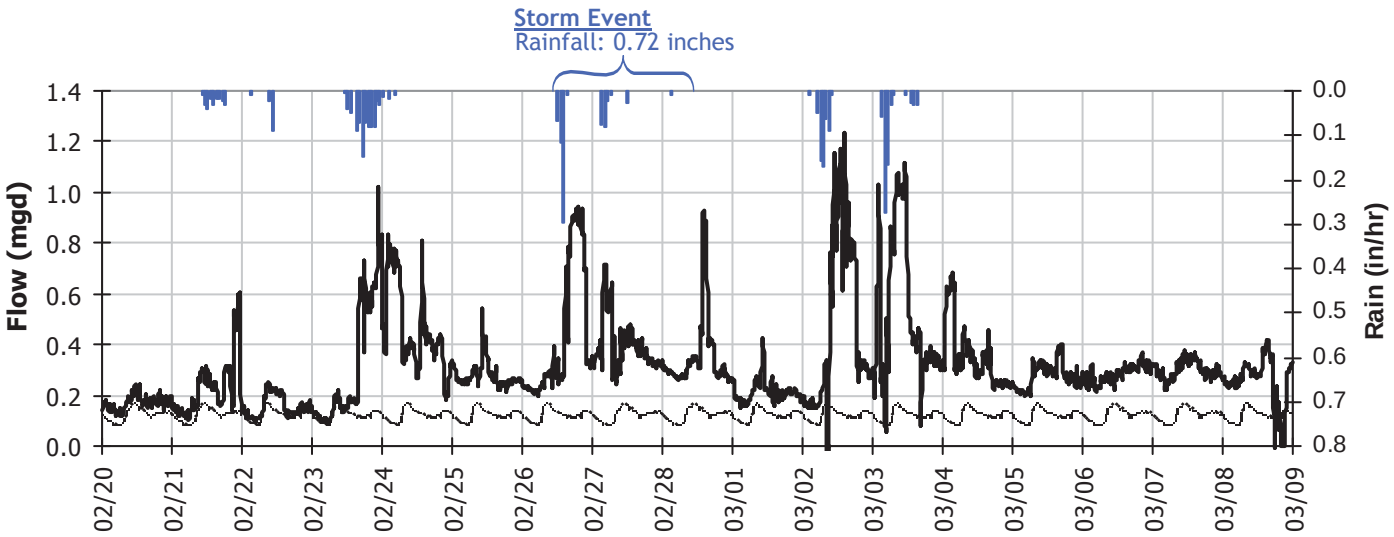
Storm Event #1 I/I Analysis

Rainfall:	1.16	*inches*		
Baseline Flow:	0.12	*mgd*		
Peak Flow:	1.02	*mgd*	**PF:**	8.68
Peak I/I Rate:	0.89	*mgd*	**Pk I/I:ADWF:**	7.54
Peak Level:	83.86	*inches*	**d/D Ratio:**	4.66
Total I/I:	846,000	*gallons*	**R-Value:**	7.0%
			I/I per ADWF:	6.17 *per in-rain*

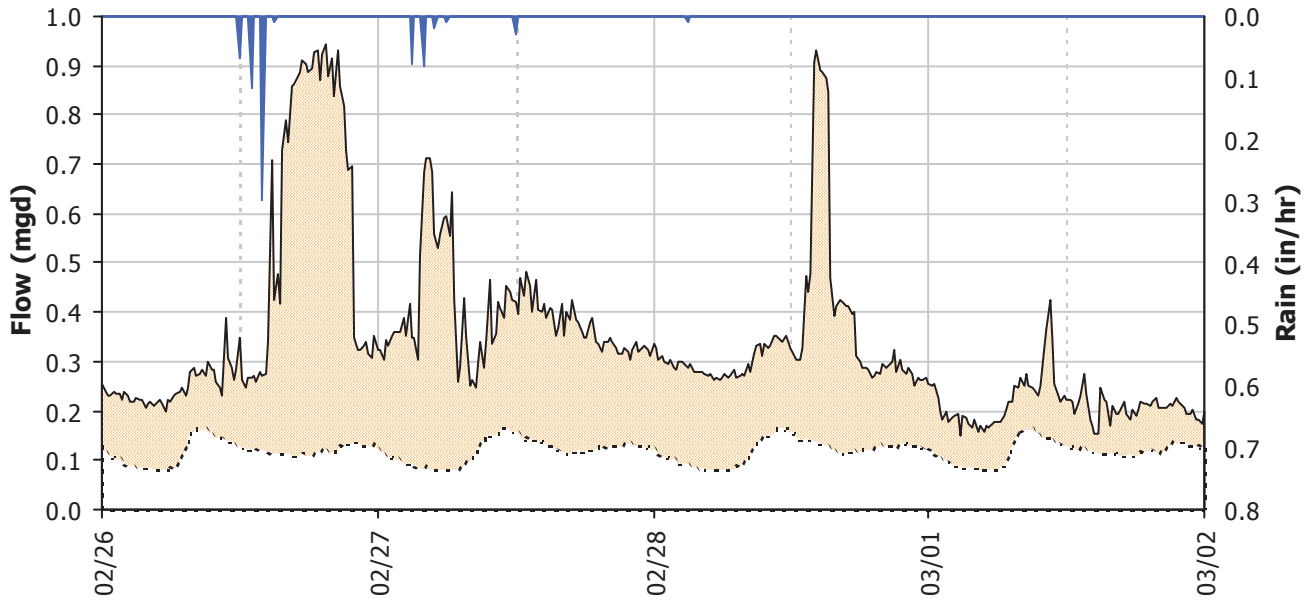
Average Infiltration Rate on 2/25 (% of ADWF): 138.5%

	I/I Summary Event 2	**Monitoring Site:** Site 4

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



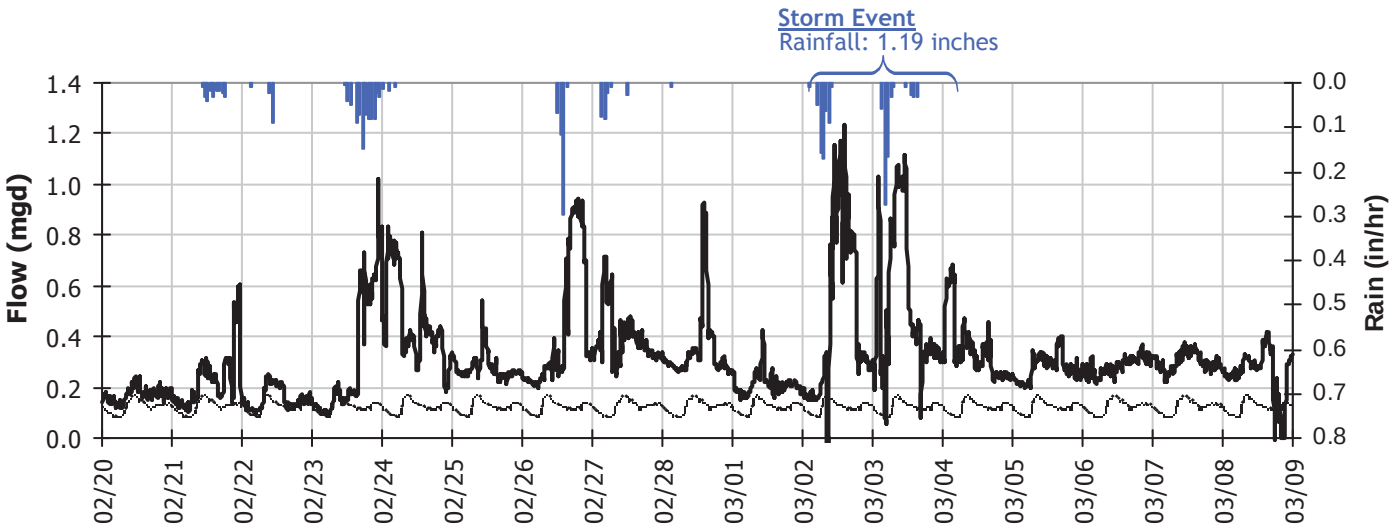
Storm Event #2 I/I Analysis

Rainfall:	0.72	*inches*		
Baseline Flow:	0.12	*mgd*		
Peak Flow:	0.94	*mgd*	**PF:**	8.00
Peak I/I Rate:	0.82	*mgd*	**Pk I/I:ADWF:**	6.98
Peak Level:	63.12	*inches*	**d/D Ratio:**	3.51
Total I/I:	910,000	*gallons*	**R-Value:**	12.2%
			I/I per ADWF:	10.71 *per in-rain*

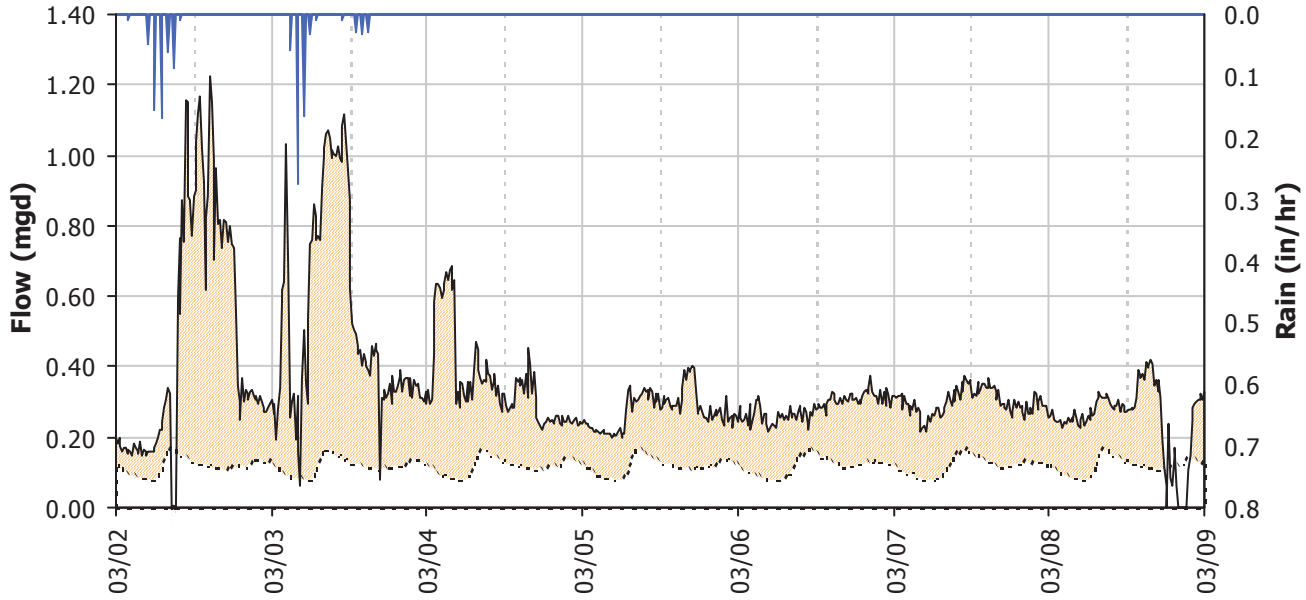
Average Infiltration Rate on 3/1 (% of ADWF): 81.3%

	I/I Summary Event 3	**Monitoring Site:** Site 4

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



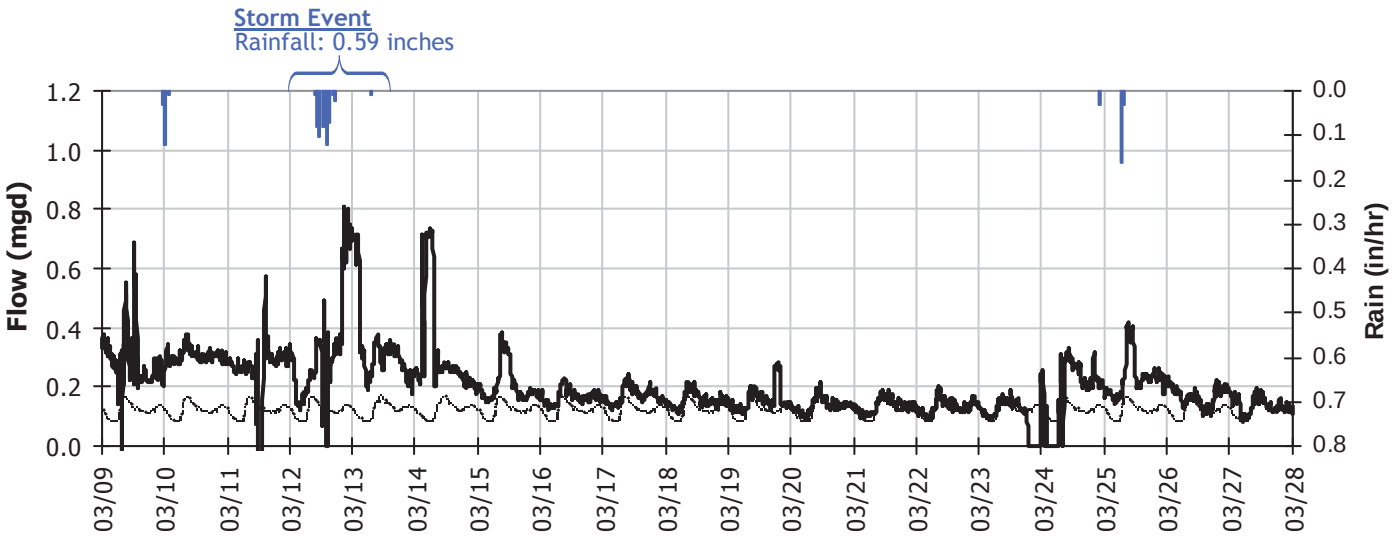
Storm Event #3 I/I Analysis

Rainfall:	1.19	*inches*		
Baseline Flow:	0.12	*mgd*		
Peak Flow:	1.23	*mgd*	**PF:**	10.39
Peak I/I Rate:	1.11	*mgd*	**Pk I/I:ADWF:**	9.40
Peak Level:	83.84	*inches*	**d/D Ratio:**	4.66
Total I/I:	1,639,000	*gallons*	**R-Value:**	13.3%
			I/I per ADWF:	11.67 *per in-rain*

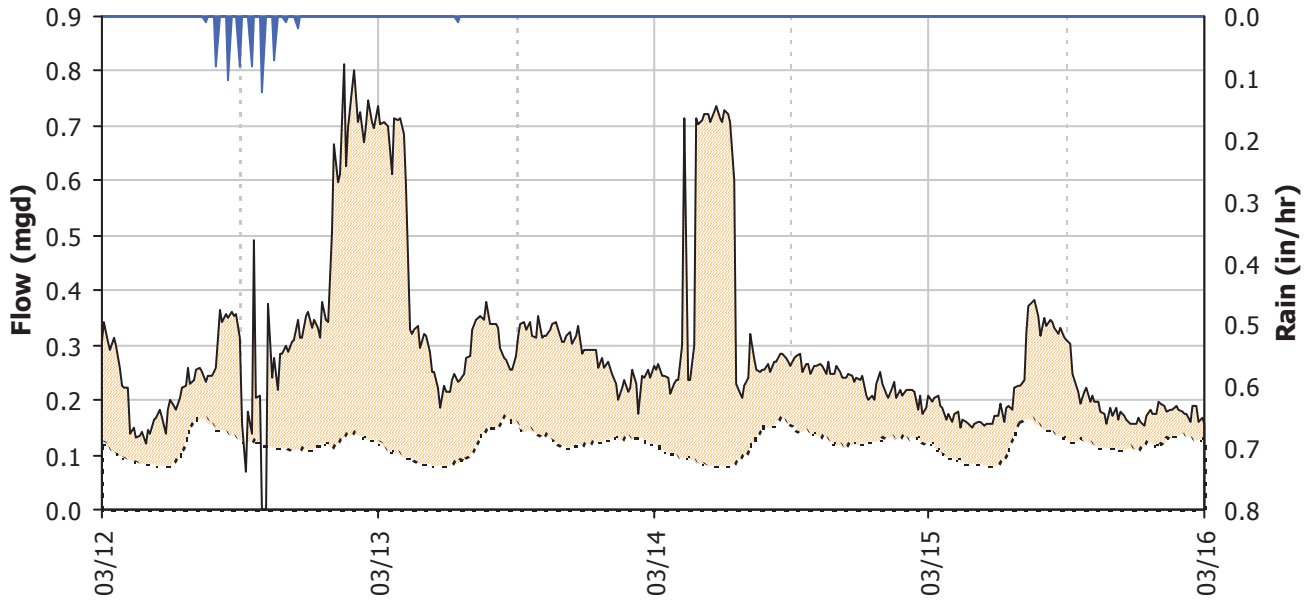
Average Infiltration Rate on 3/5 (% of ADWF): 135.0%

	I/I Summary Event 4	**Monitoring Site:** Site 4

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



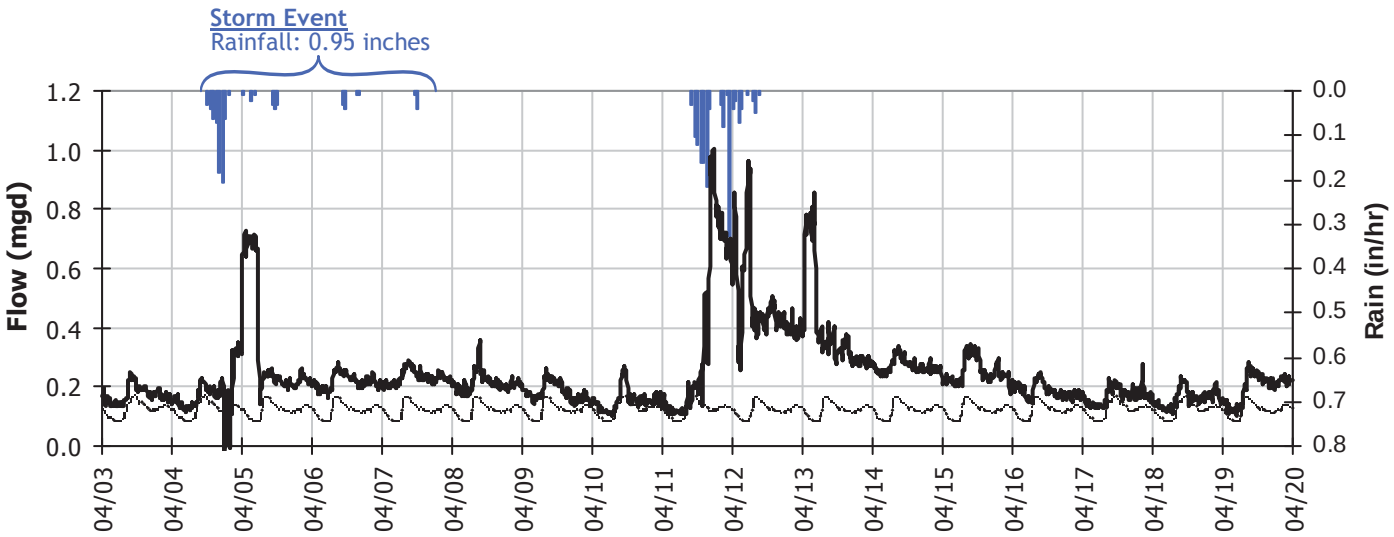
Storm Event #1 I/I Analysis

Rainfall:	0.59	*inches*		
Baseline Flow:	0.12	*mgd*		
Peak Flow:	0.81	*mgd*	**PF:**	6.87
Peak I/I Rate:	0.68	*mgd*	**Pk I/I:ADWF:**	5.76
Peak Level:	70.09	*inches*	**d/D Ratio:**	3.89
Total I/I:	707,000	*gallons*	**R-Value:**	11.5%
			I/I per ADWF:	10.08 *per in-rain*

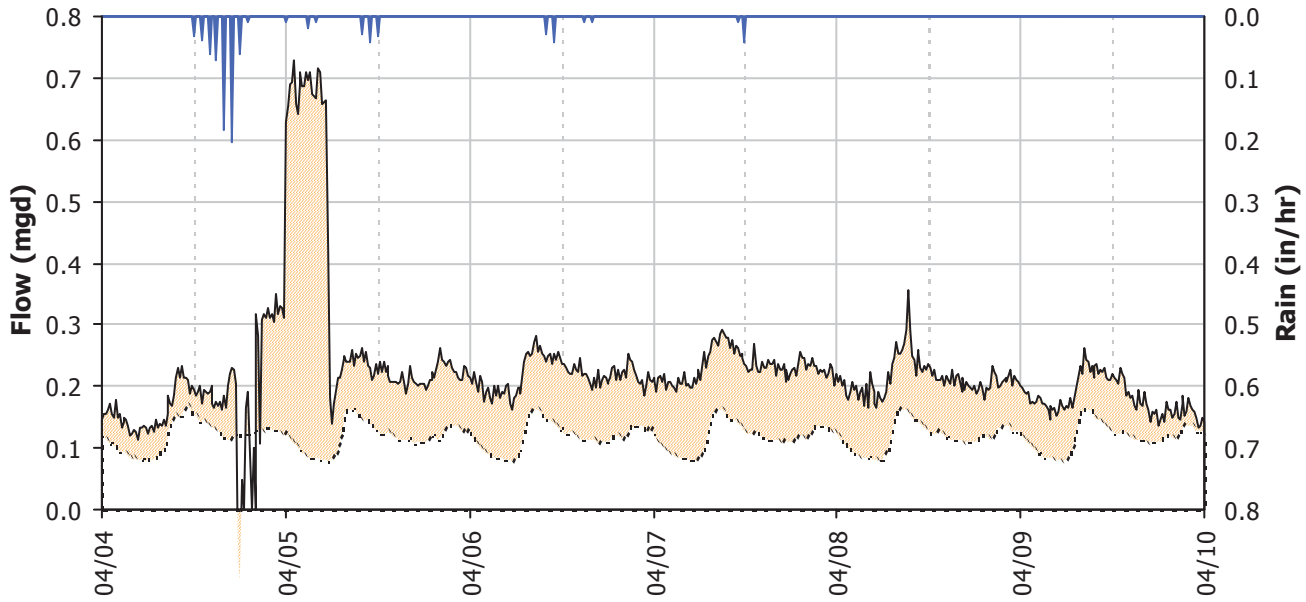
Average Infiltration Rate on 3/14 (% of ADWF): 164.5%

	I/I Summary Event 5	**Monitoring Site:** Site 4

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



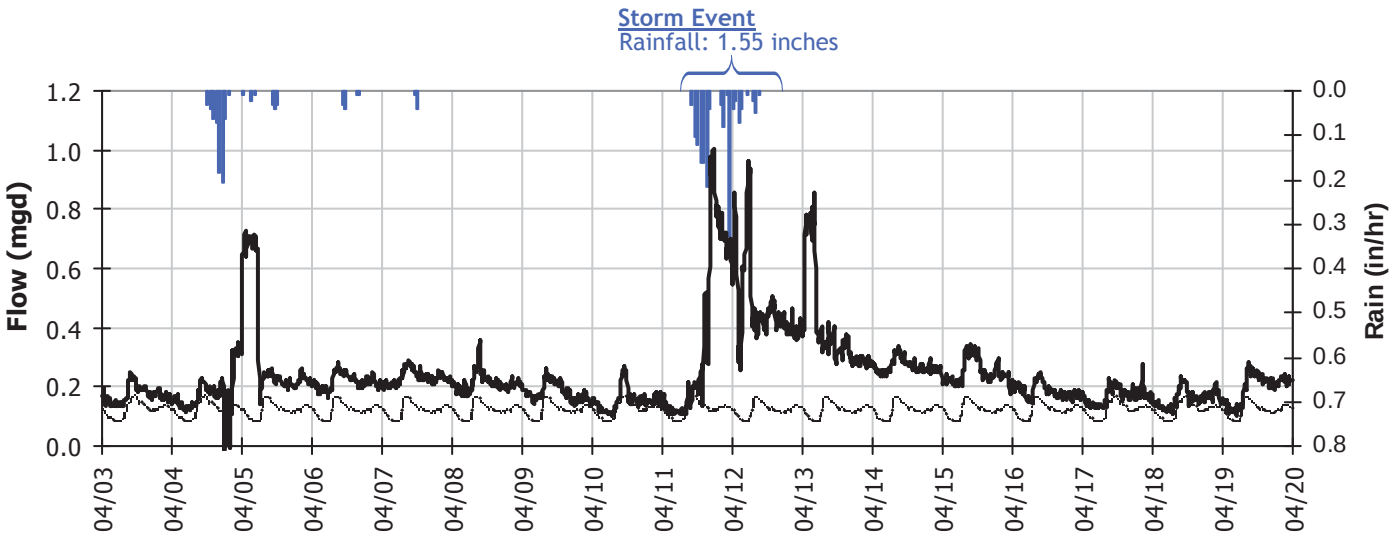
Storm Event #5 I/I Analysis

Rainfall:	0.95	*inches*		
Baseline Flow:	0.12	*mgd*		
Peak Flow:	0.73	*mgd*	**PF:**	6.16
Peak I/I Rate:	0.63	*mgd*	**Pk I/I:ADWF:**	5.35
Peak Level:	52.40	*inches*	**d/D Ratio:**	2.91
Total I/I:	644,000	*gallons*	**R-Value:**	6.5%
			I/I per ADWF:	5.73 *per in-rain*

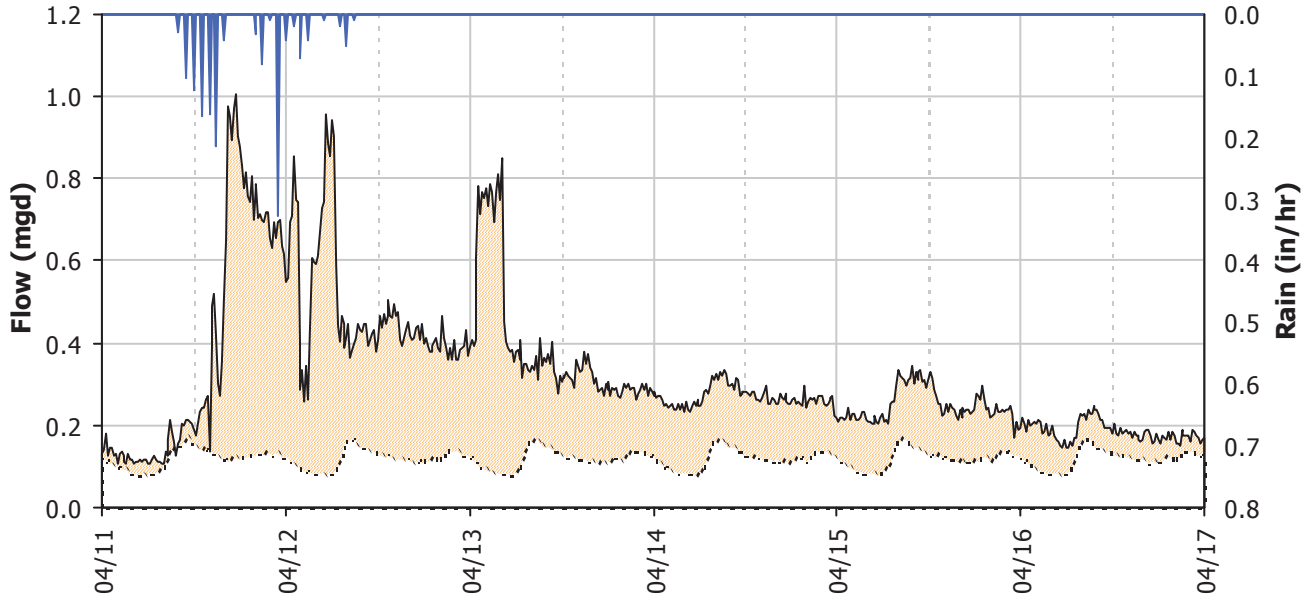
Average Infiltration Rate on 4/8 (% of ADWF): 81.2%

	I/I Summary Event 6	**Monitoring Site:** Site 4

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



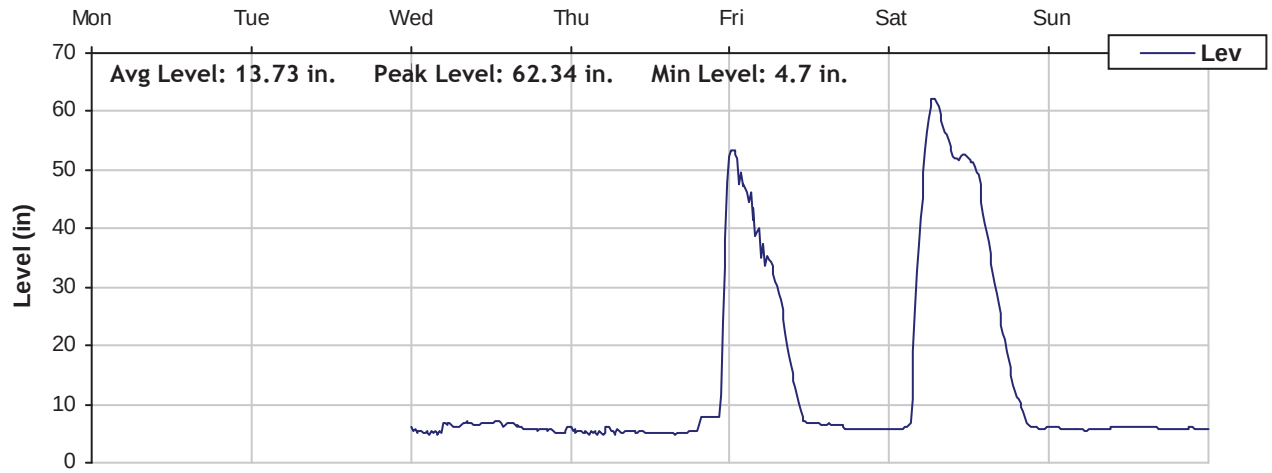
Storm Event #6 I/I Analysis

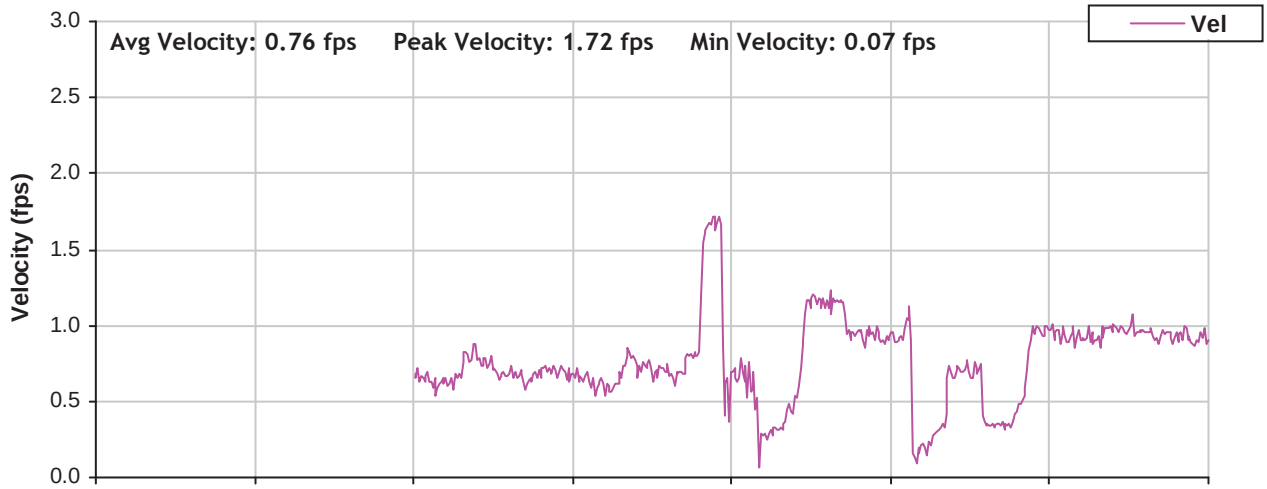
Rainfall:	1.55	*inches*		
Baseline Flow:	0.12	*mgd*		
Peak Flow:	1.01	*mgd*	**PF:**	8.52
Peak I/I Rate:	0.89	*mgd*	**Pk I/I:ADWF:**	7.50
Peak Level:	91.49	*inches*	**d/D Ratio:**	5.08
Total I/I:	1,236,000	*gallons*	**R-Value:**	7.7%
			I/I per ADWF:	6.74 *per in-rain*

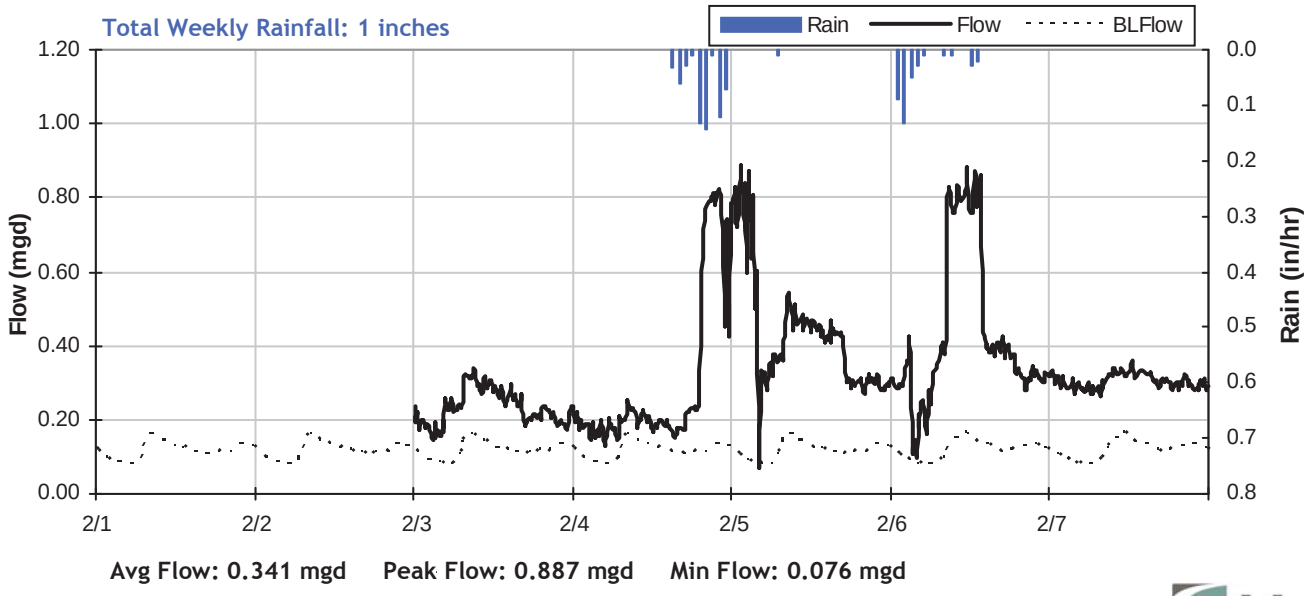
Average Infiltration Rate on 4/14 (% of ADWF): 128.3%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 4



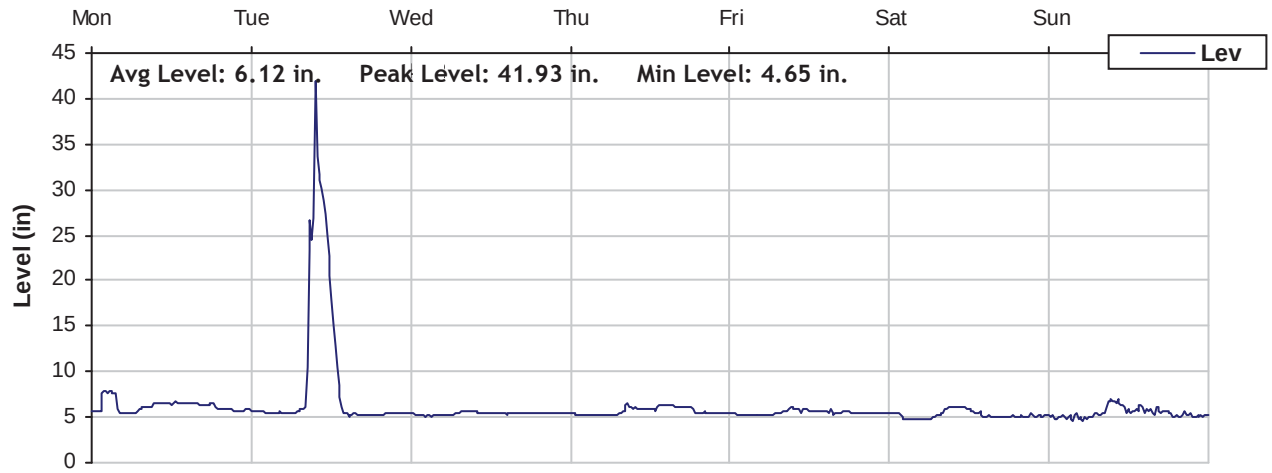


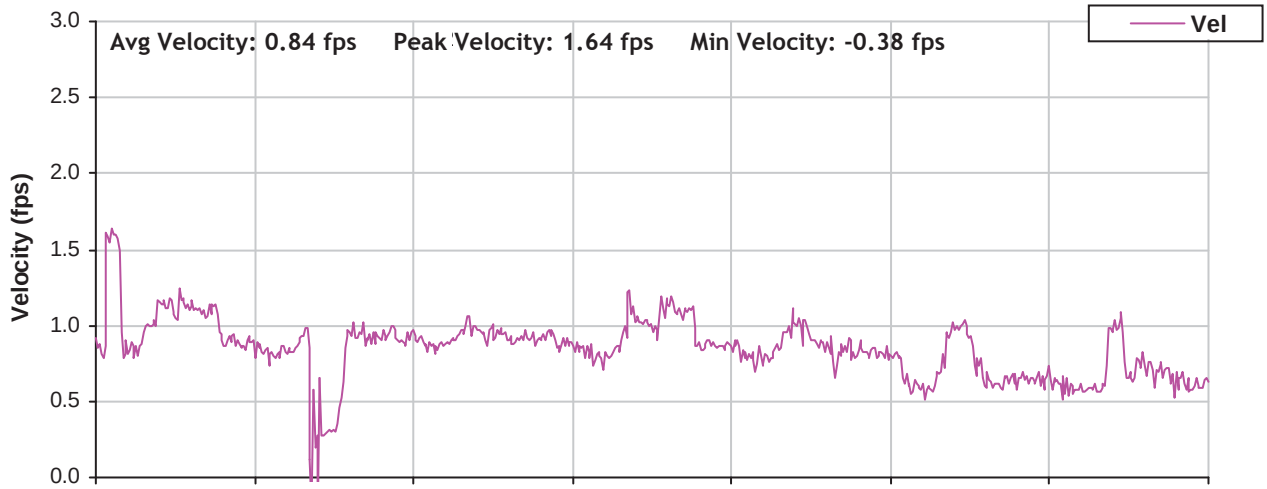


Avg Flow: 0.341 mgd Peak Flow: 0.887 mgd Min Flow: 0.076 mgd

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 4

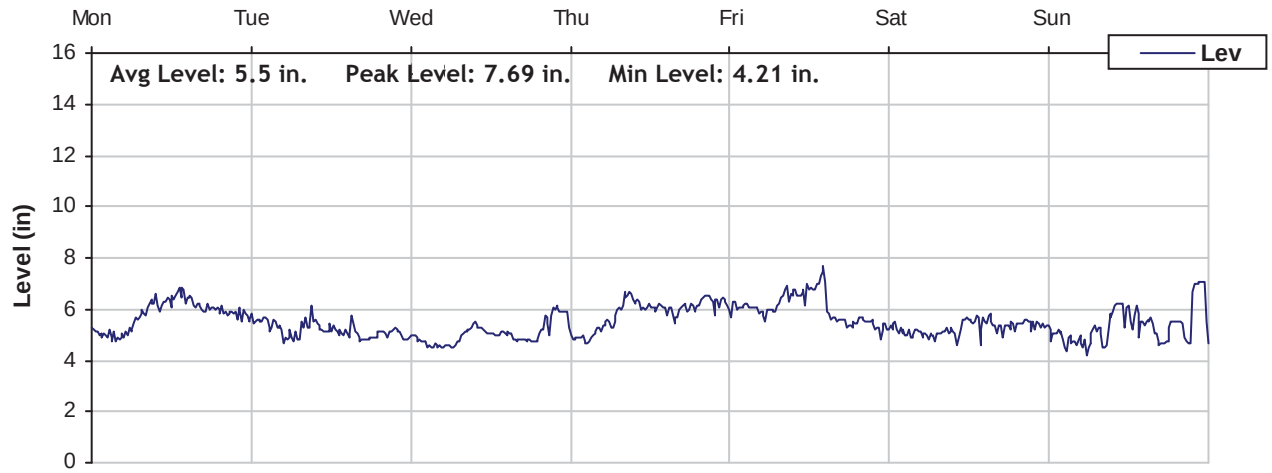


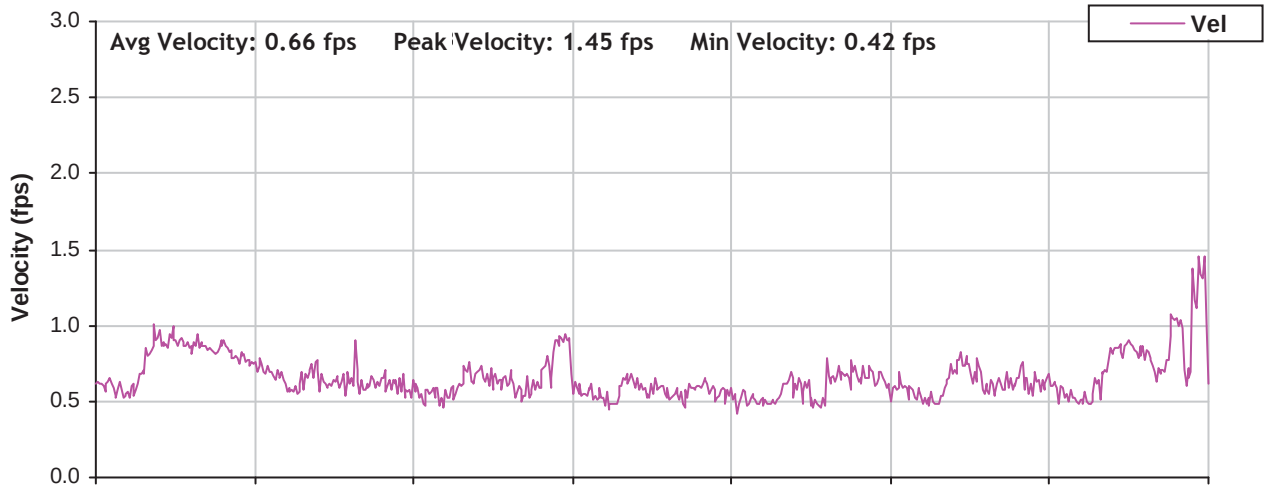


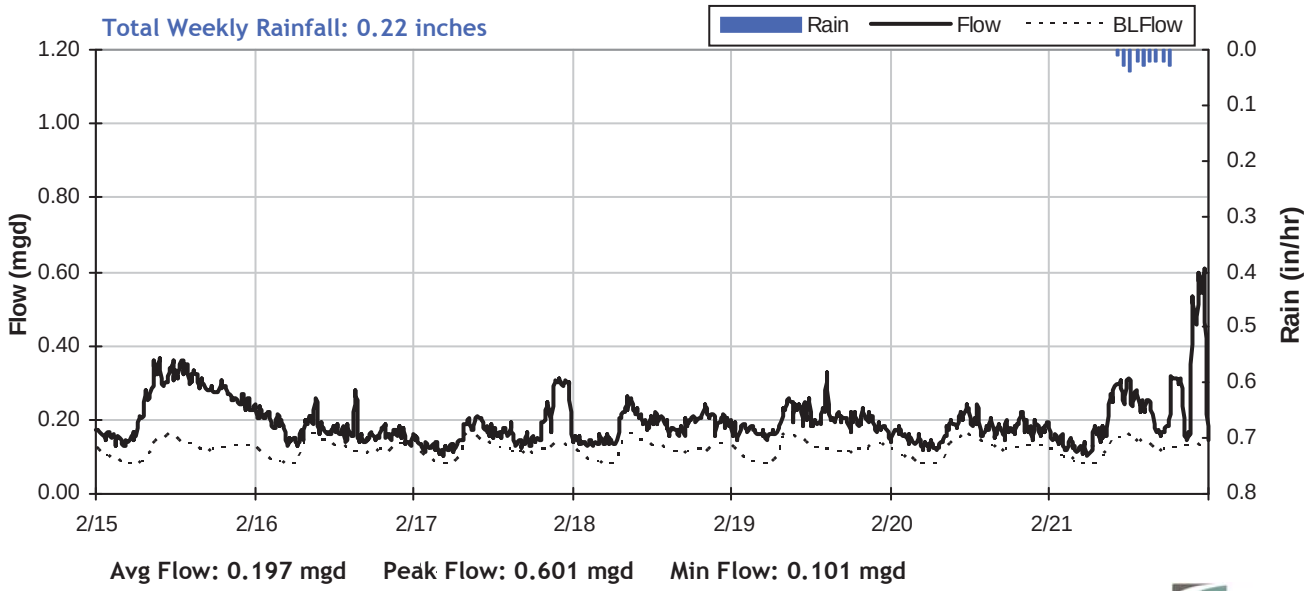
Avg Flow: 0.267 mgd Peak Flow: 0.774 mgd Min Flow: -0.438 mgd

Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 4



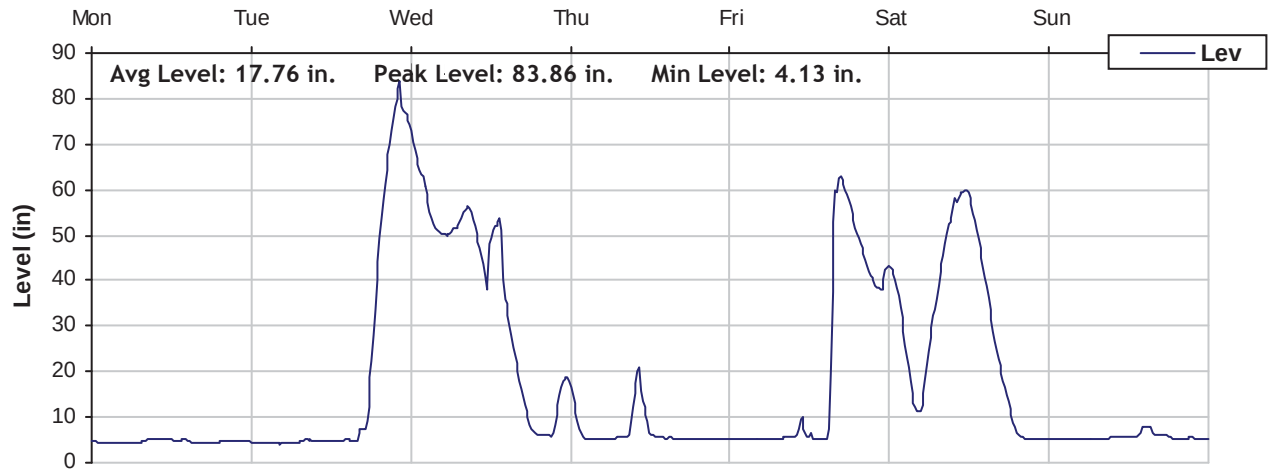


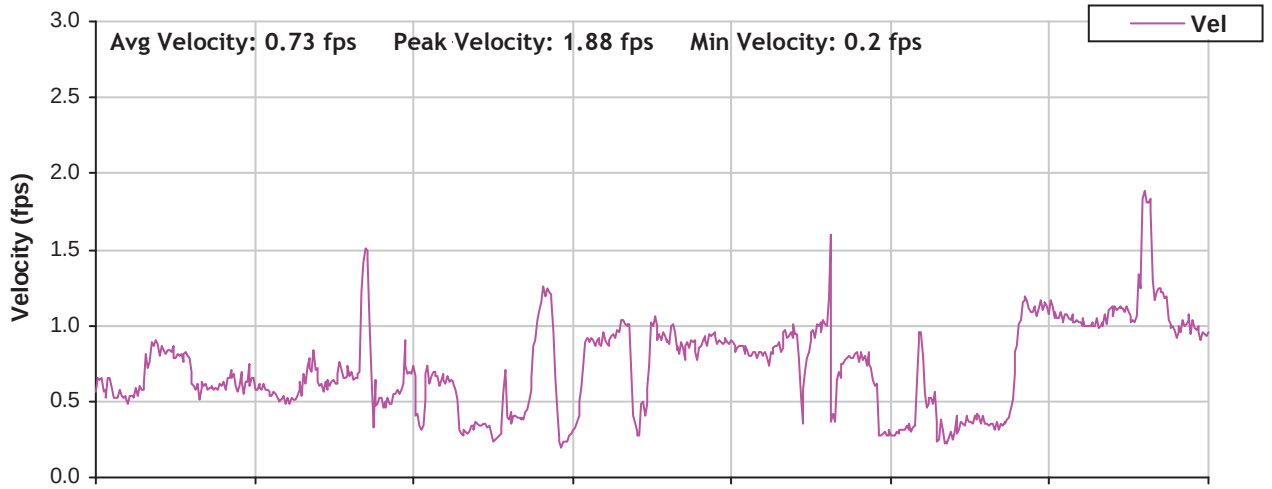


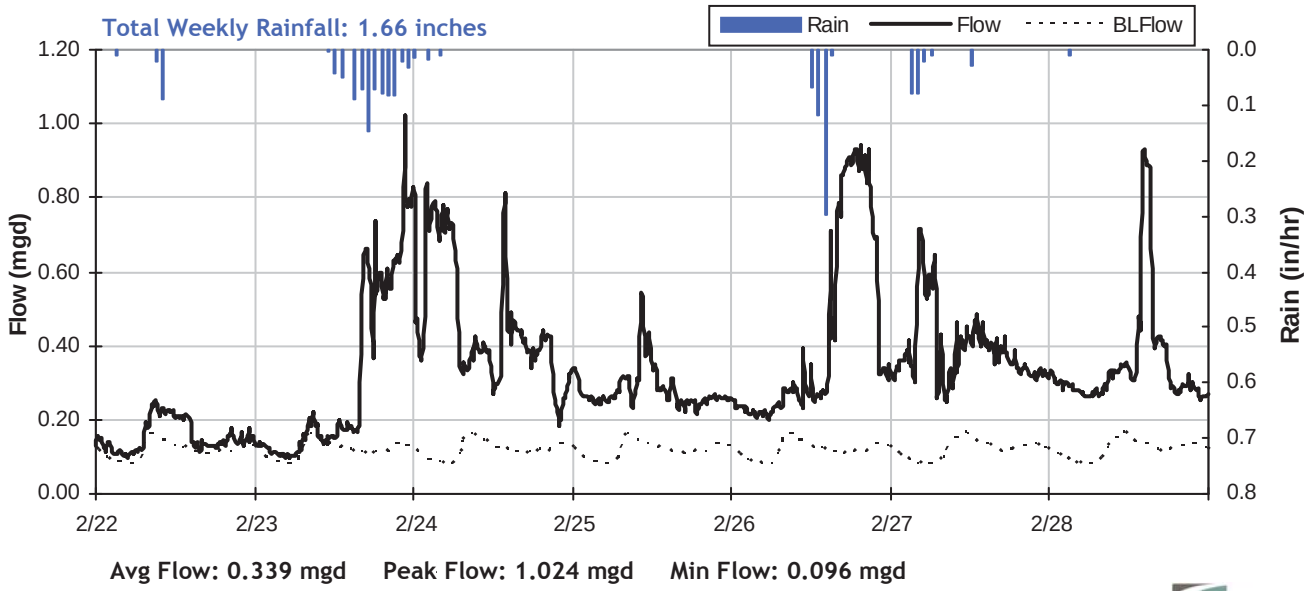
Avg Flow: 0.197 mgd Peak Flow: 0.601 mgd Min Flow: 0.101 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 4



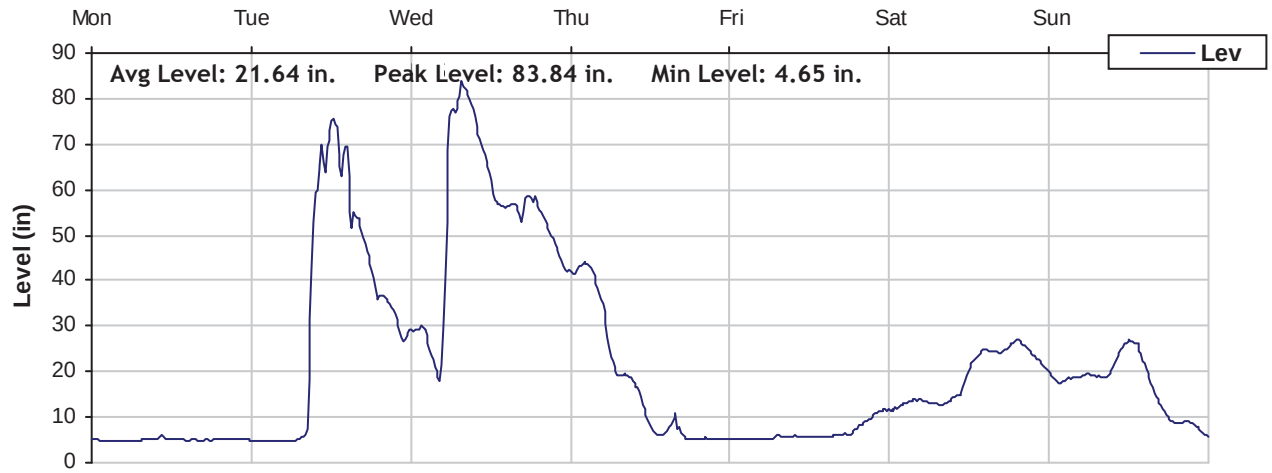


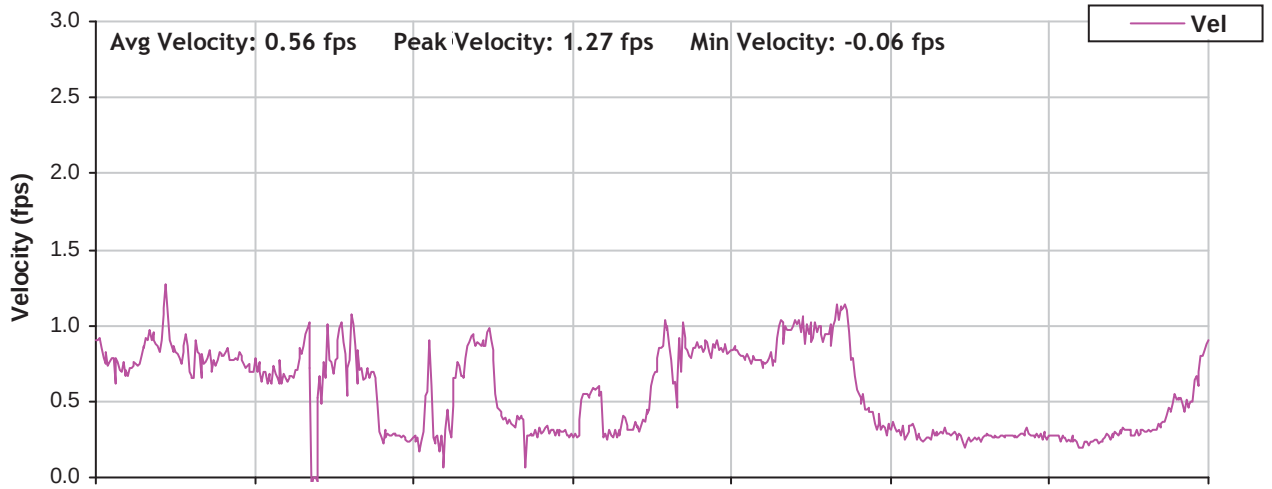


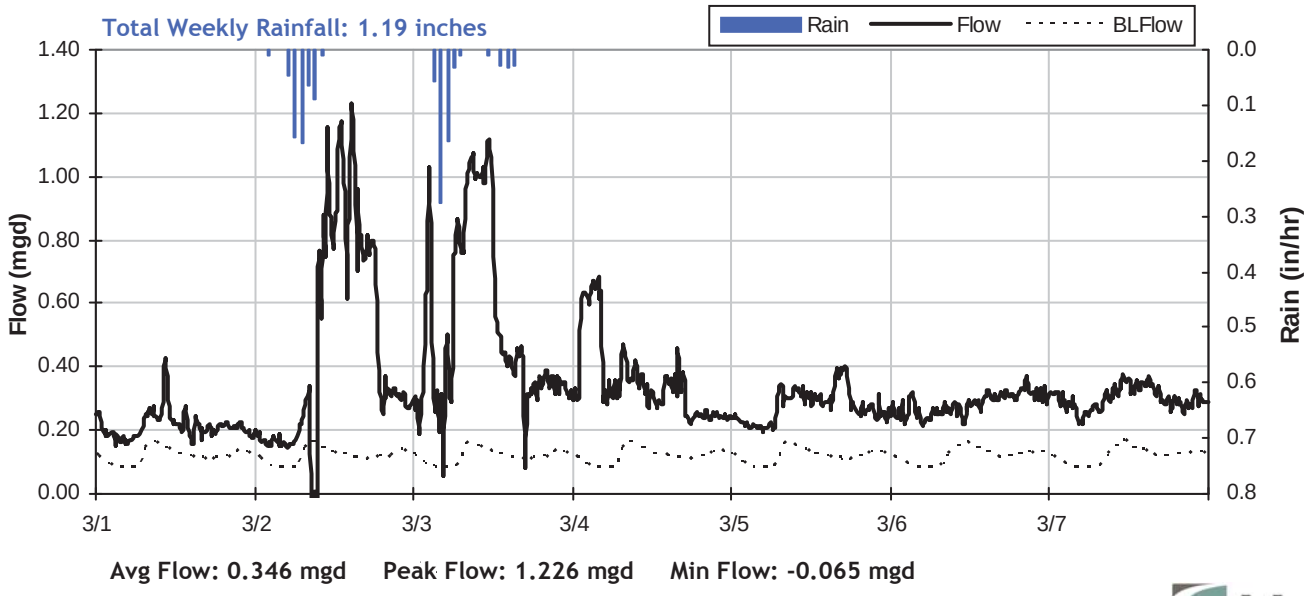
Avg Flow: 0.339 mgd Peak Flow: 1.024 mgd Min Flow: 0.096 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 4



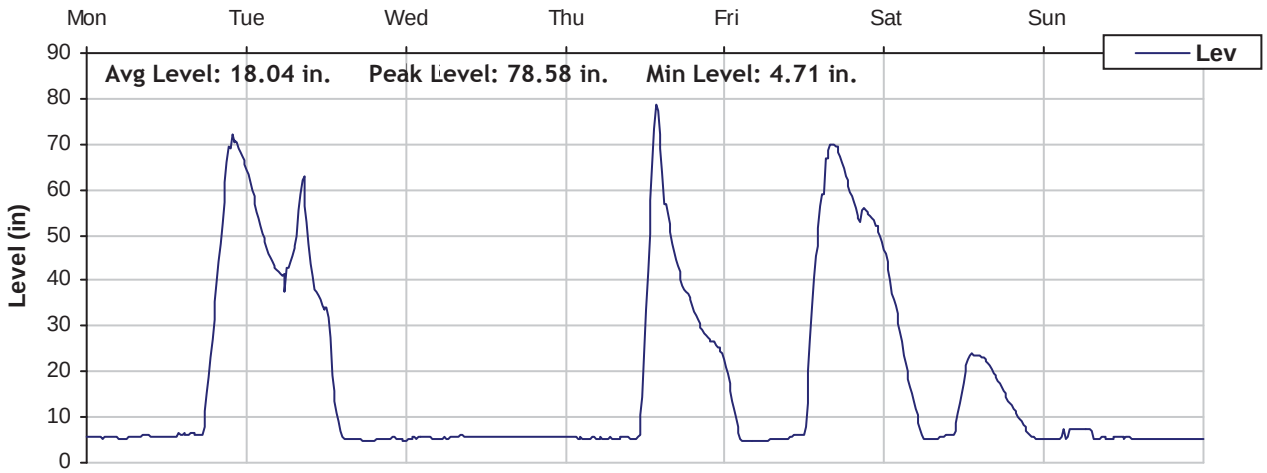


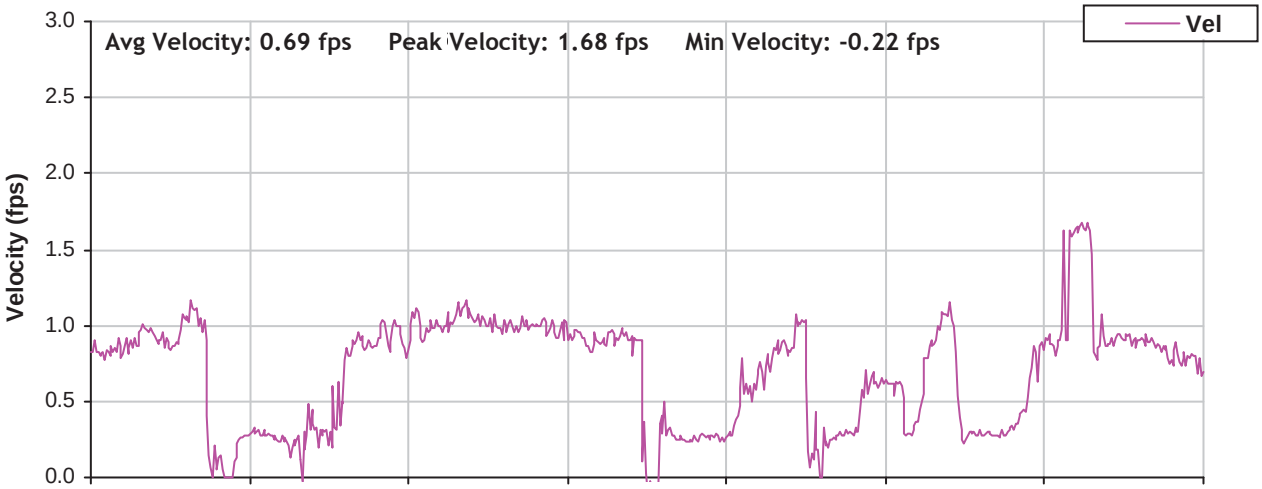


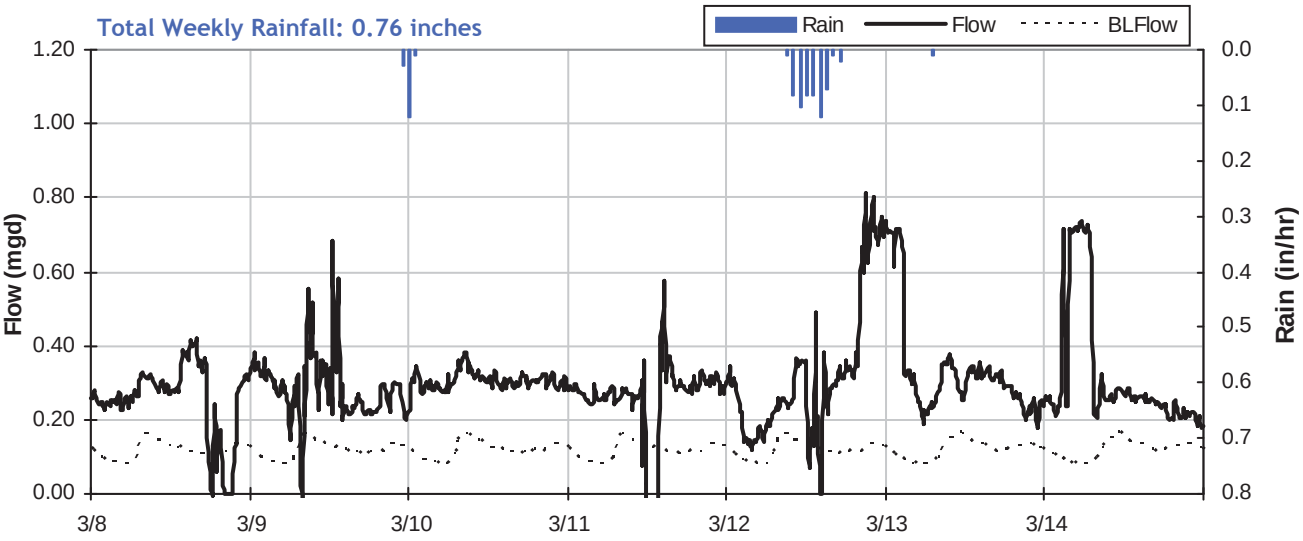
Avg Flow: 0.346 mgd Peak Flow: 1.226 mgd Min Flow: -0.065 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 4



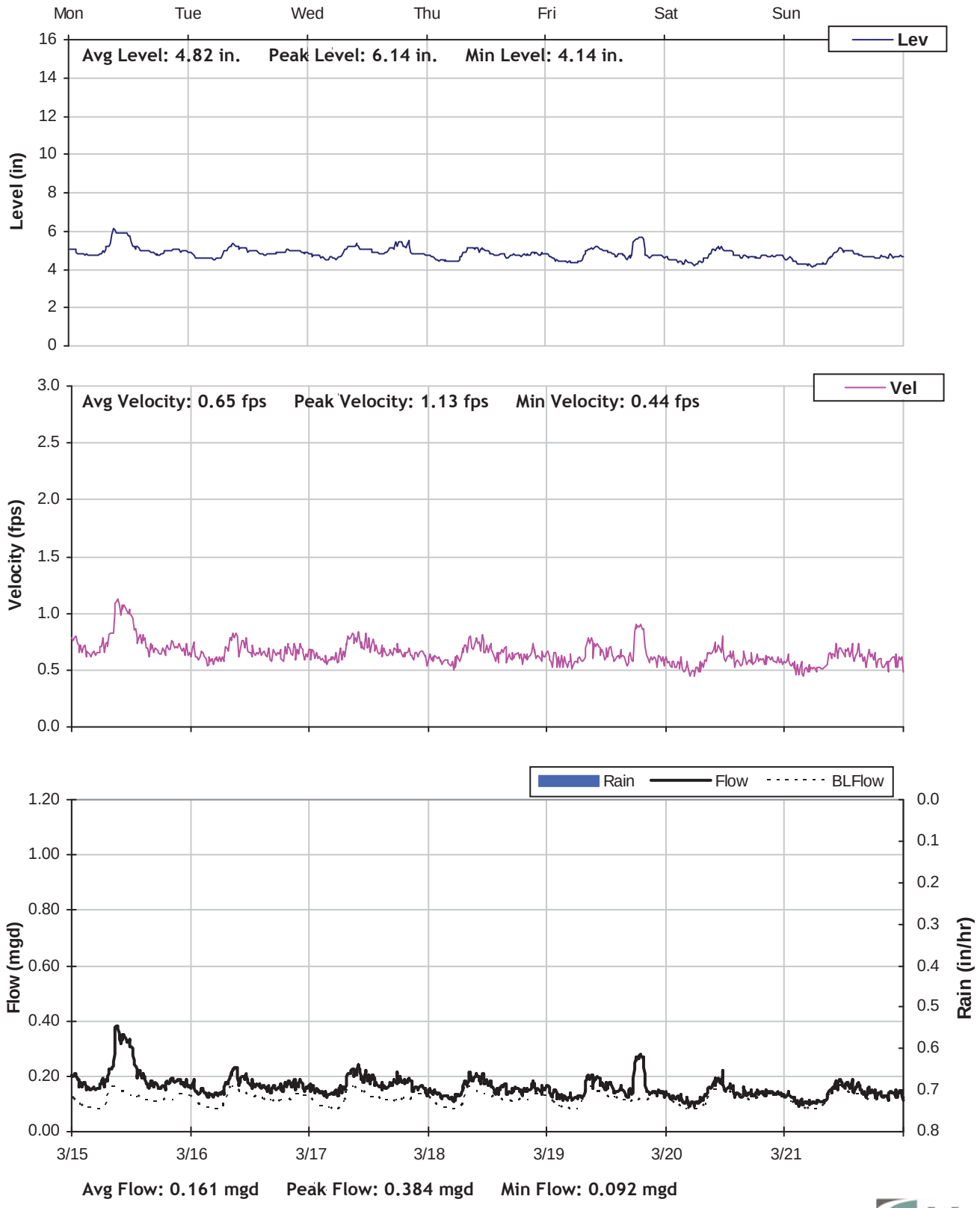




Avg Flow: 0.296 mgd Peak Flow: 0.811 mgd Min Flow: -0.251 mgd

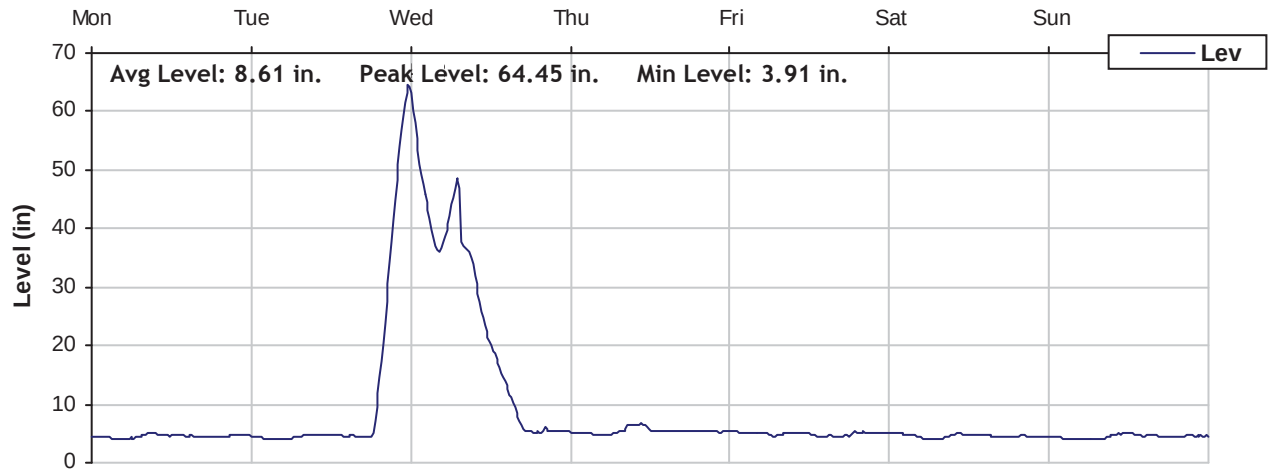
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

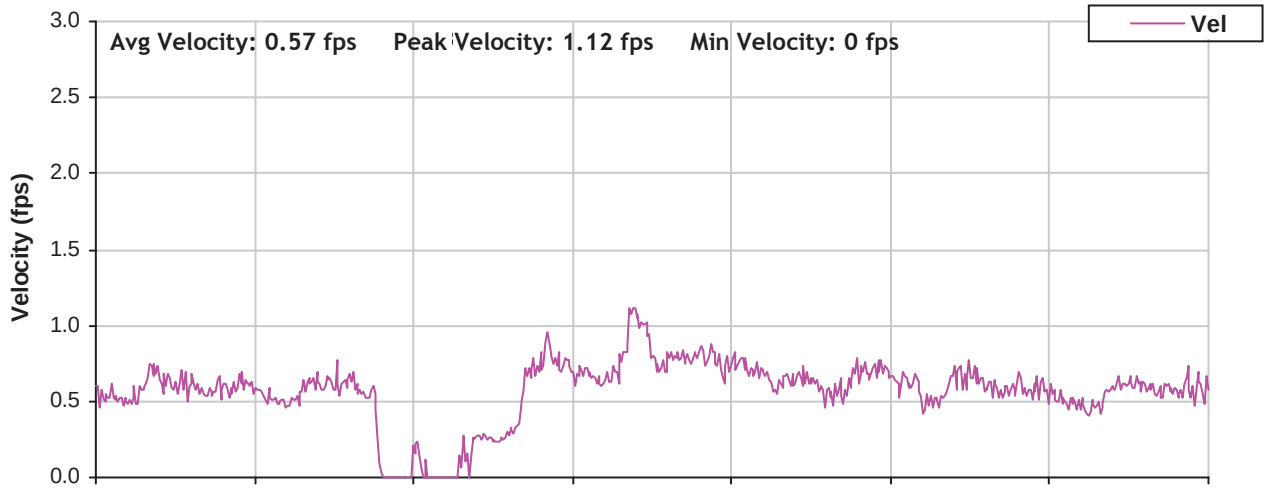
Monitoring Site:
Site 4

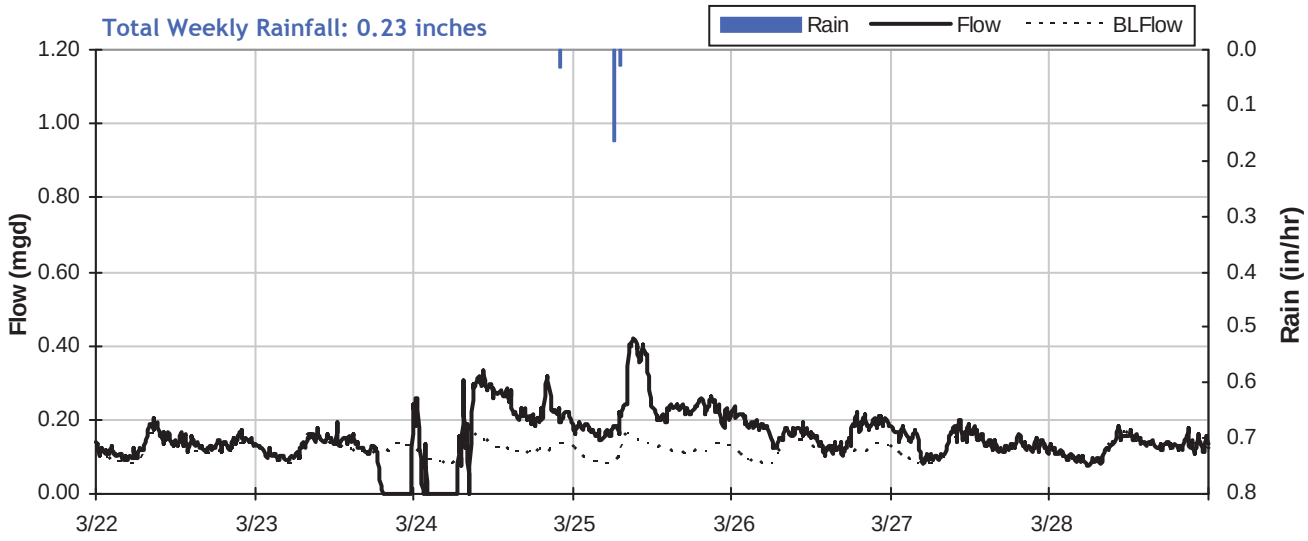


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 4



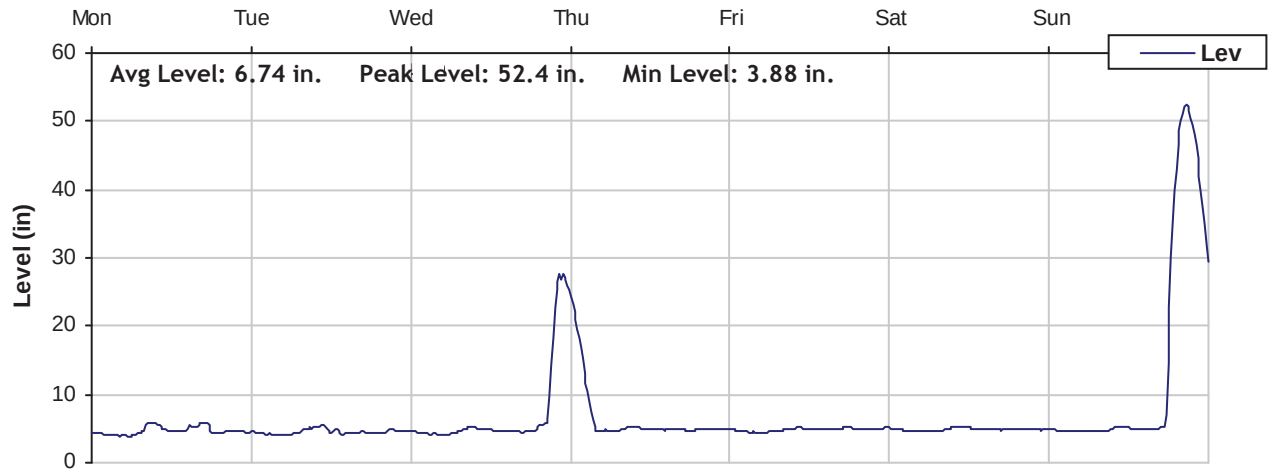


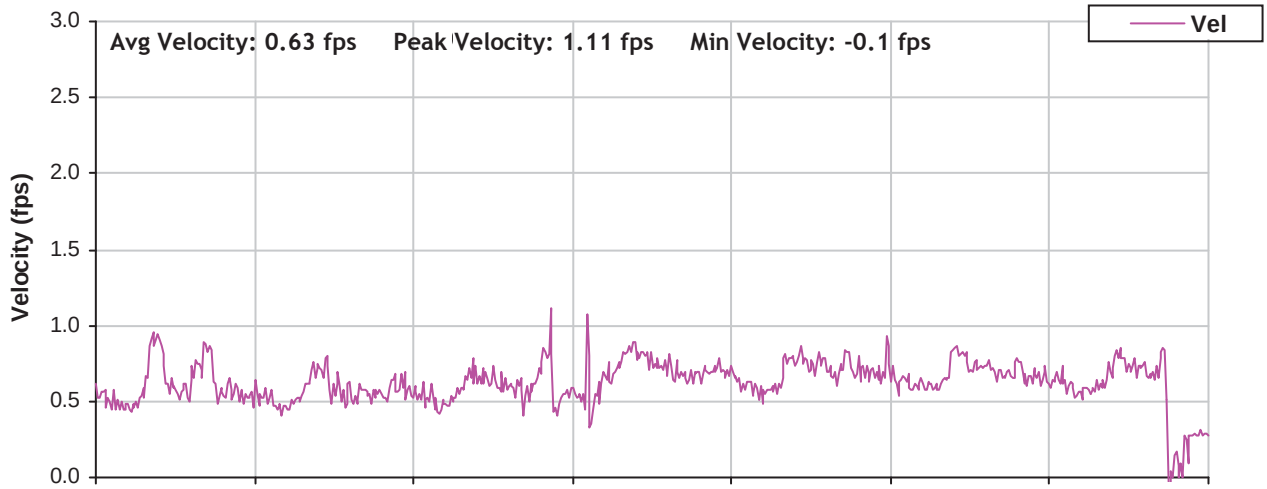


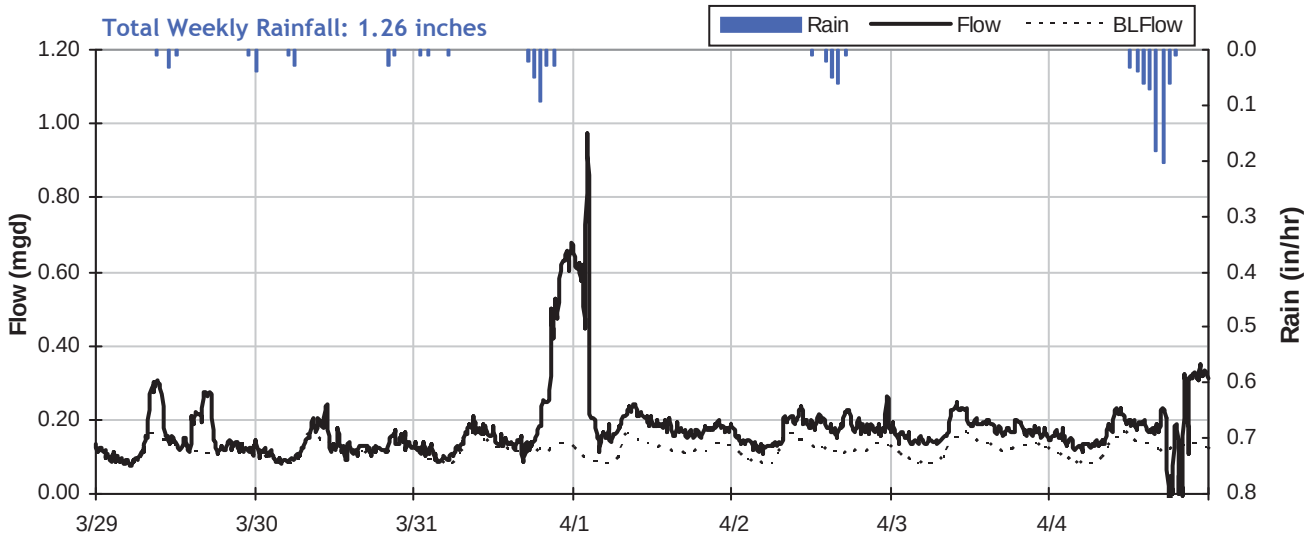
Avg Flow: 0.154 mgd Peak Flow: 0.421 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 4



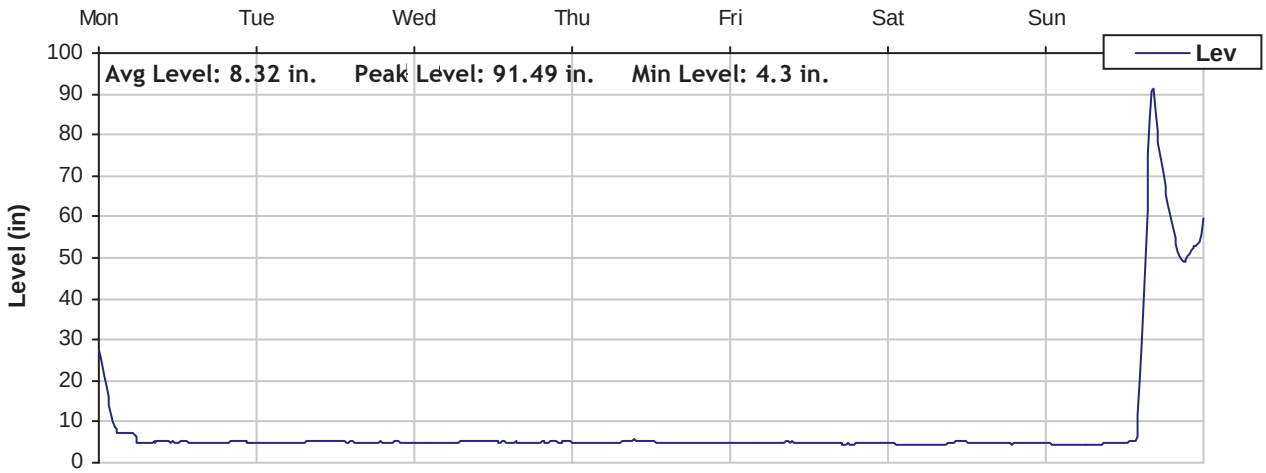


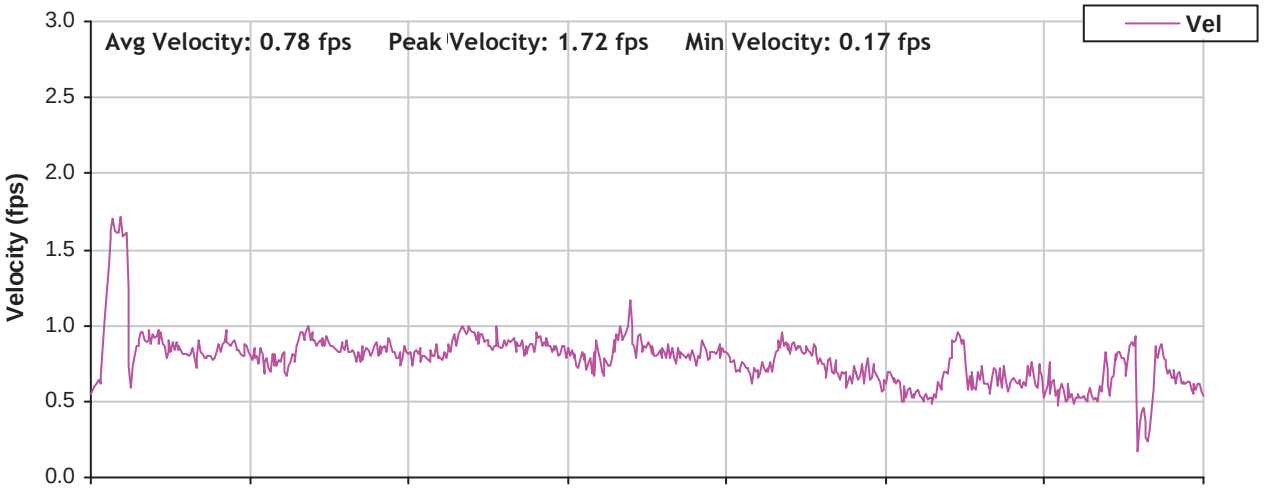


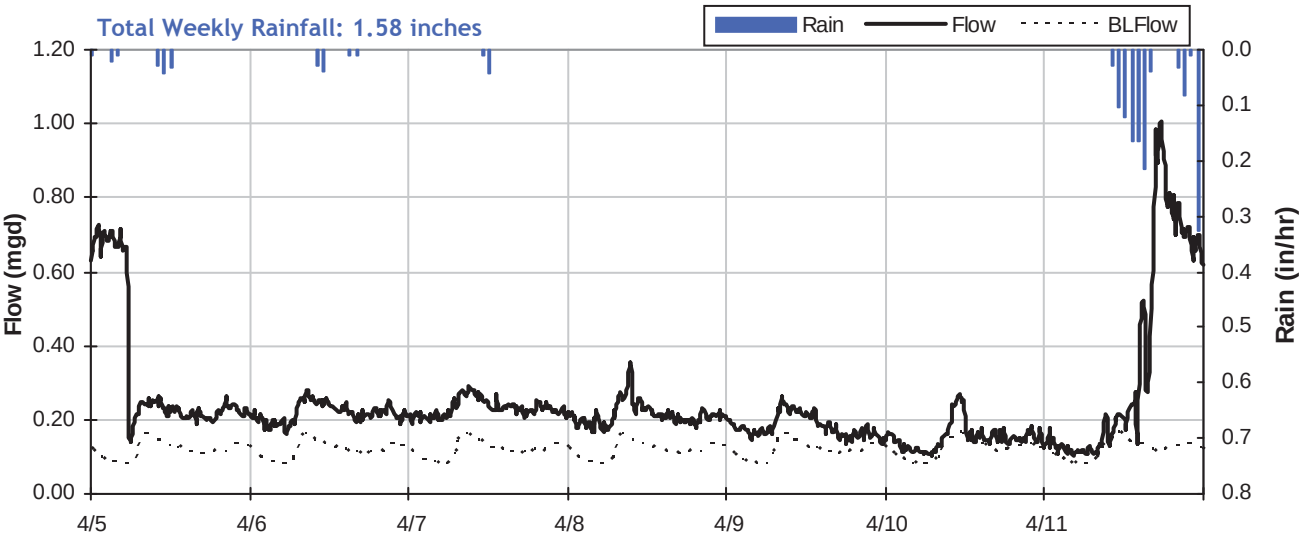
Avg Flow: 0.177 mgd Peak Flow: 0.972 mgd Min Flow: -0.114 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 4



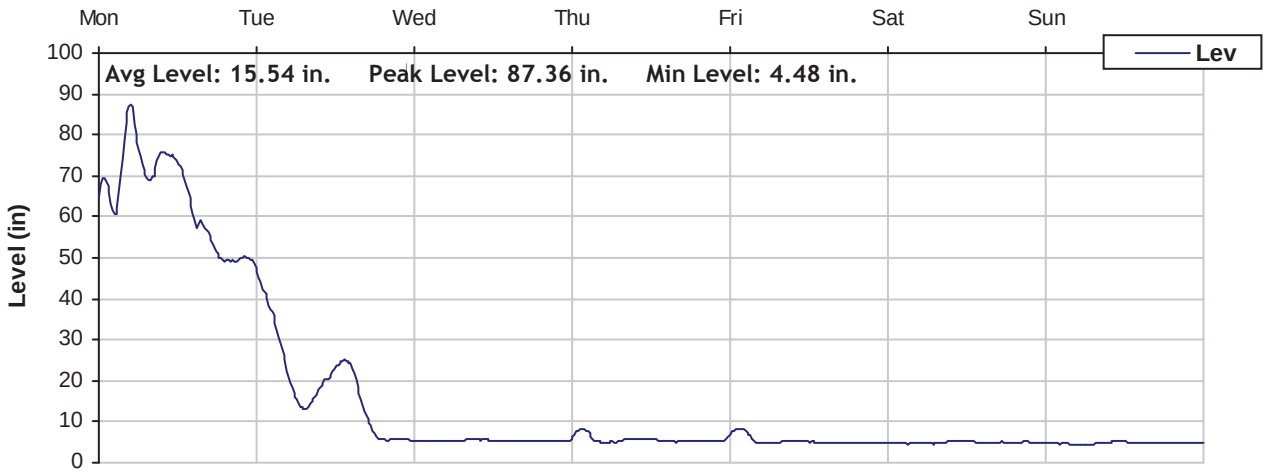


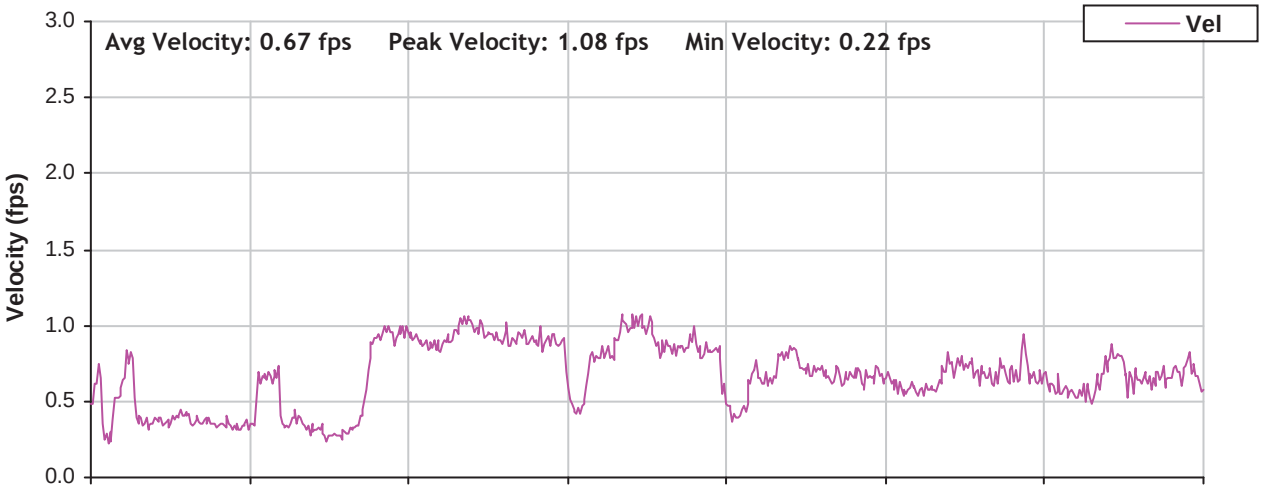


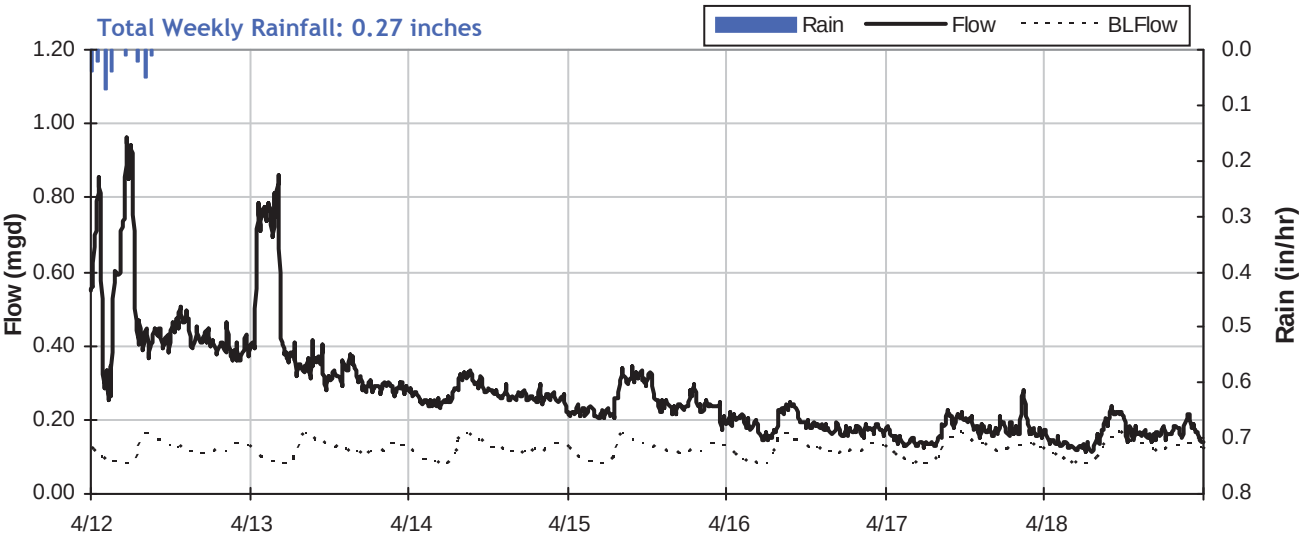
Avg Flow: 0.243 mgd Peak Flow: 1.005 mgd Min Flow: 0.102 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 4



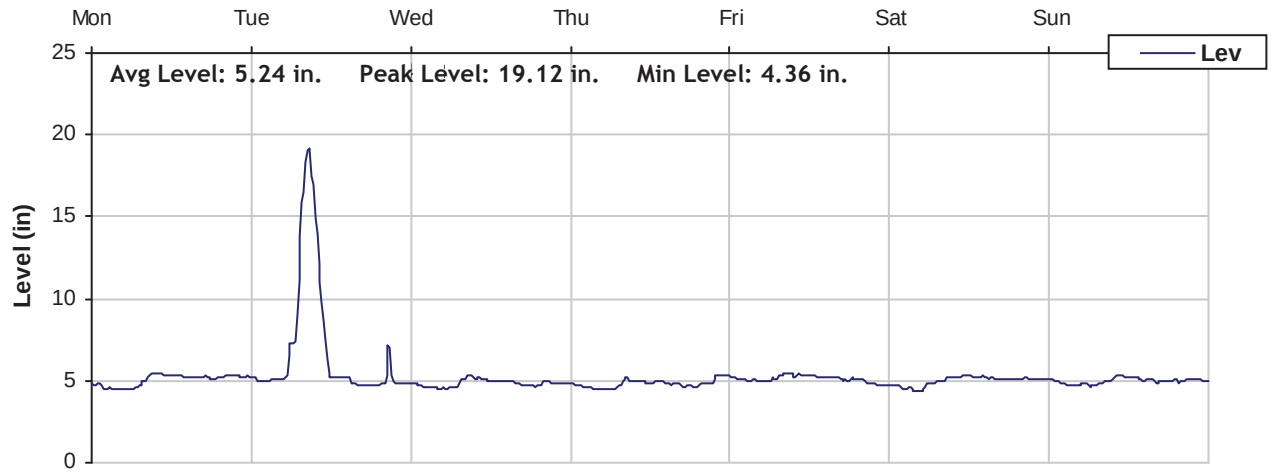


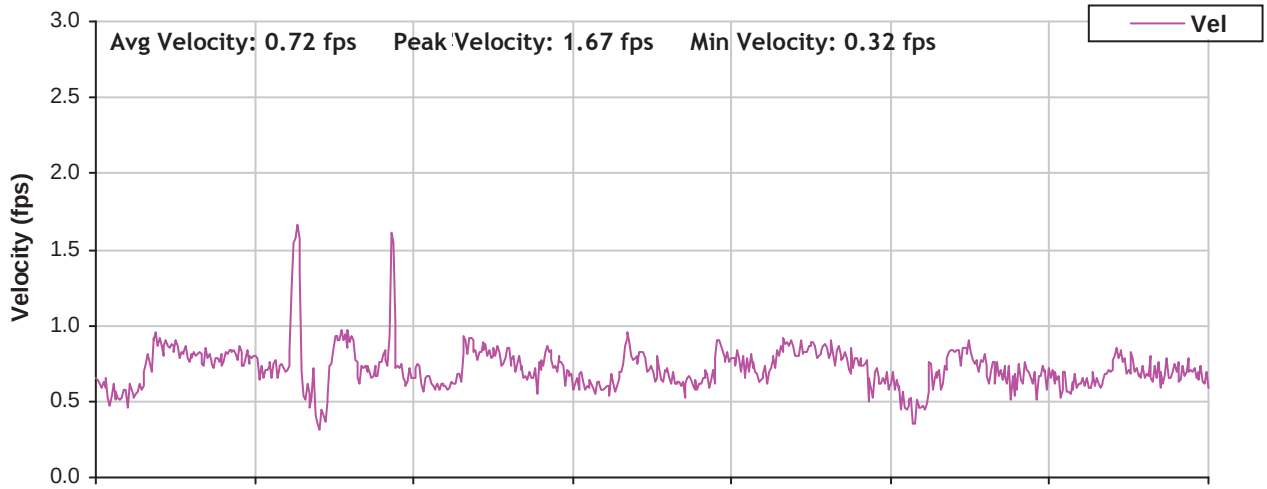


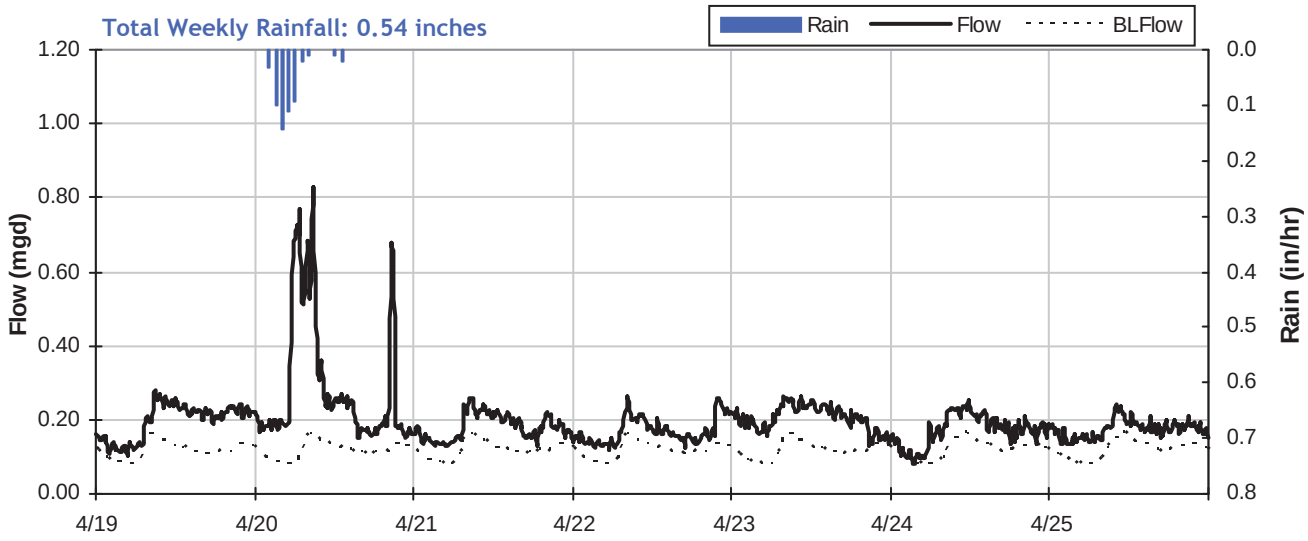
Avg Flow: 0.272 mgd Peak Flow: 0.959 mgd Min Flow: 0.111 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 4



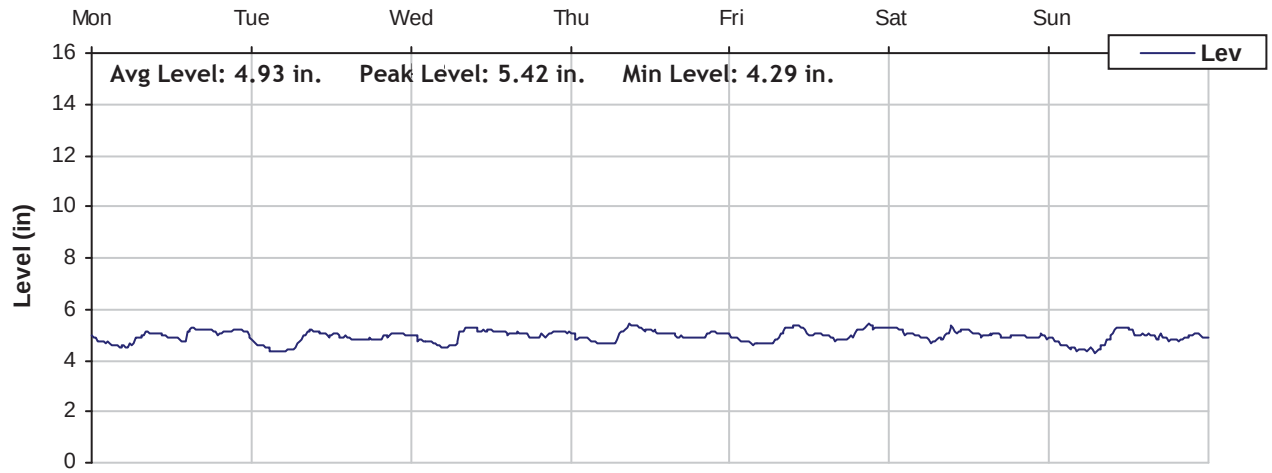


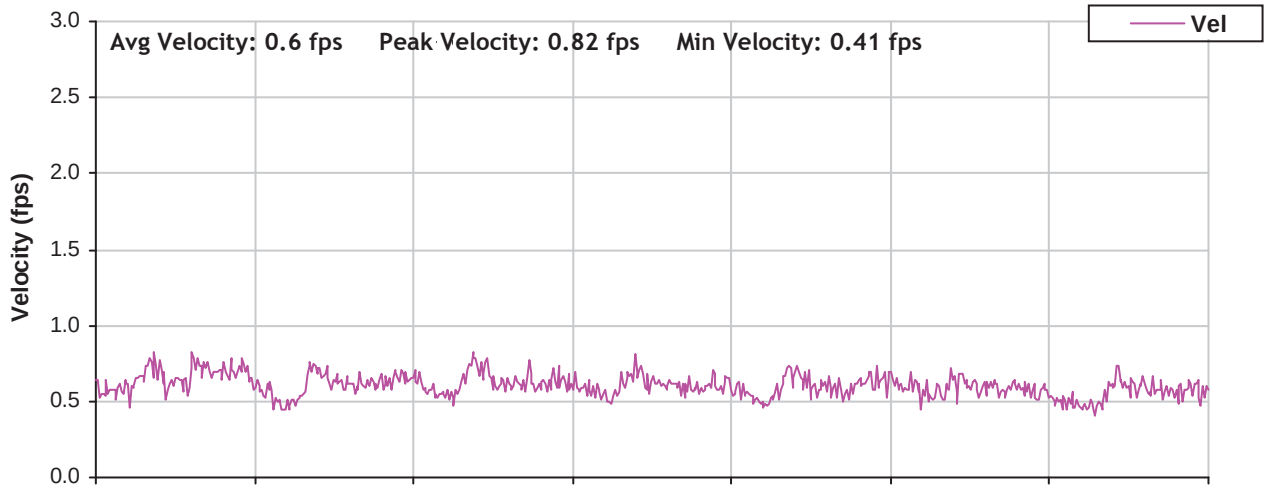


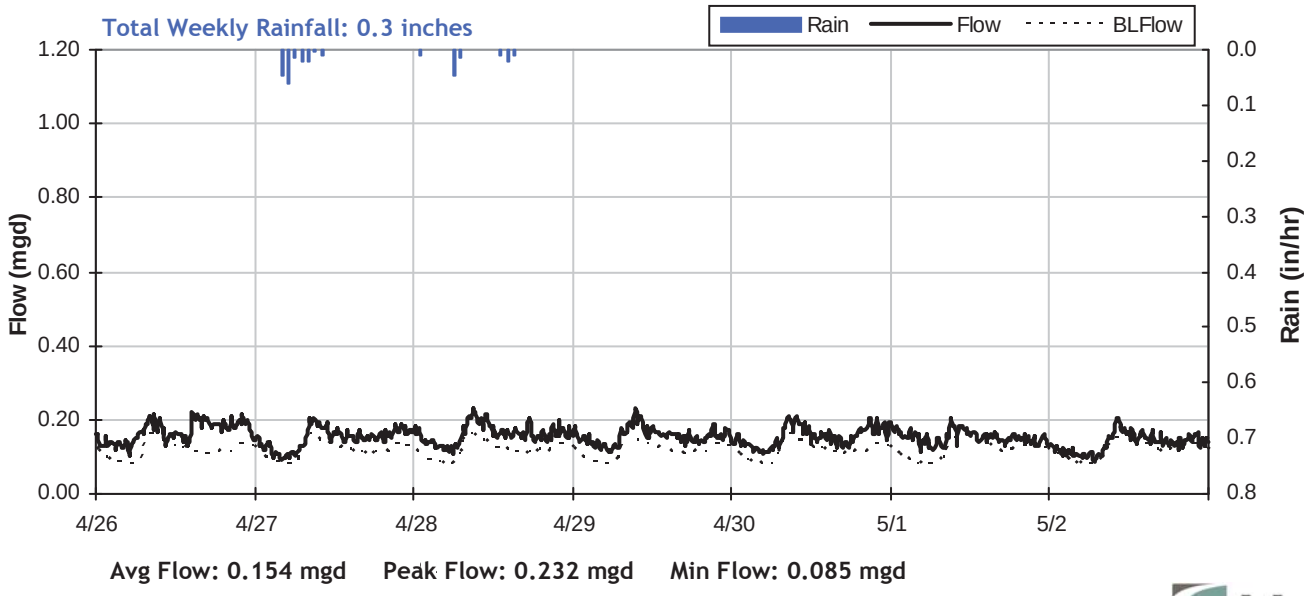
Avg Flow: 0.198 mgd Peak Flow: 0.826 mgd Min Flow: 0.078 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 4



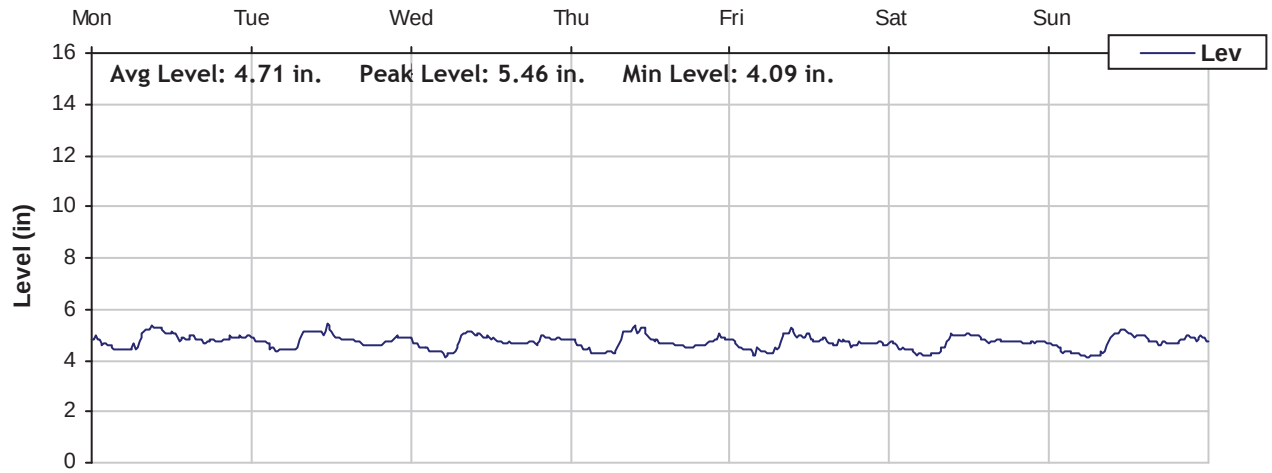


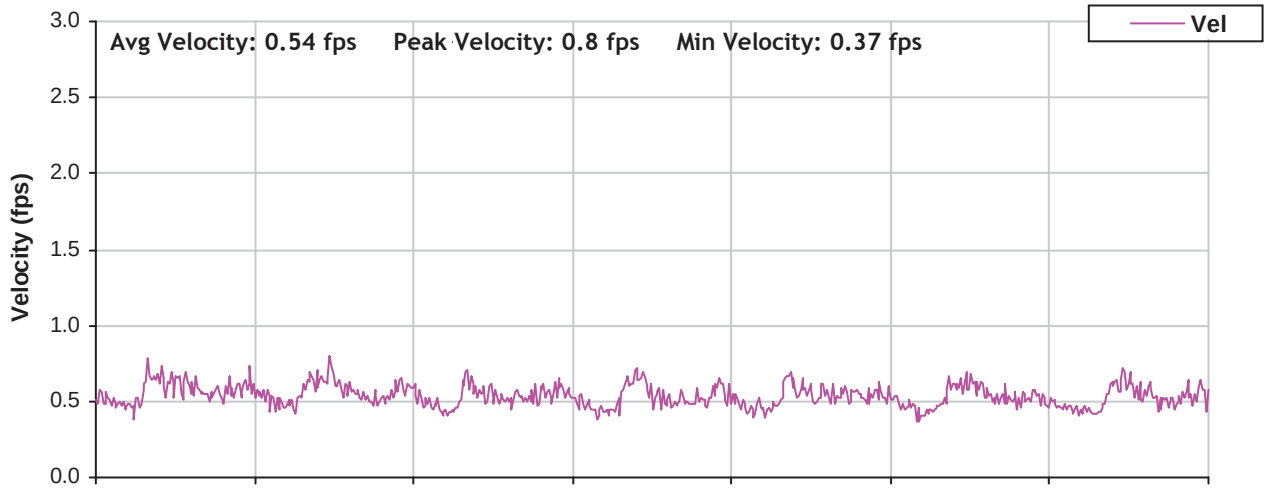


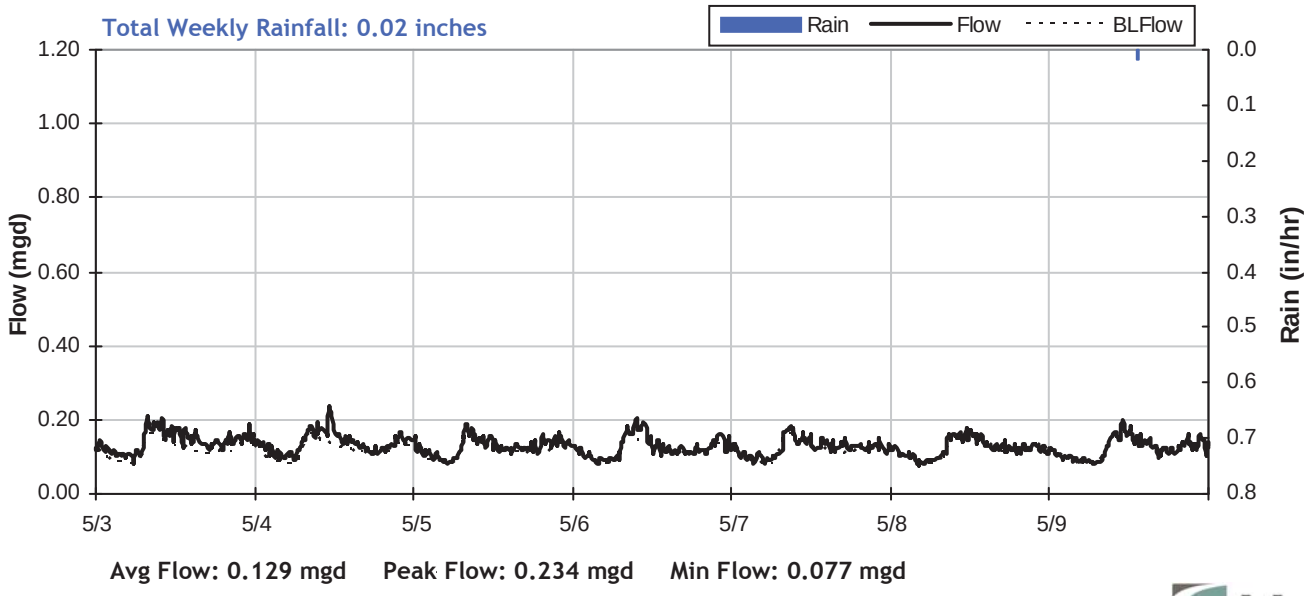
Avg Flow: 0.154 mgd Peak Flow: 0.232 mgd Min Flow: 0.085 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 4



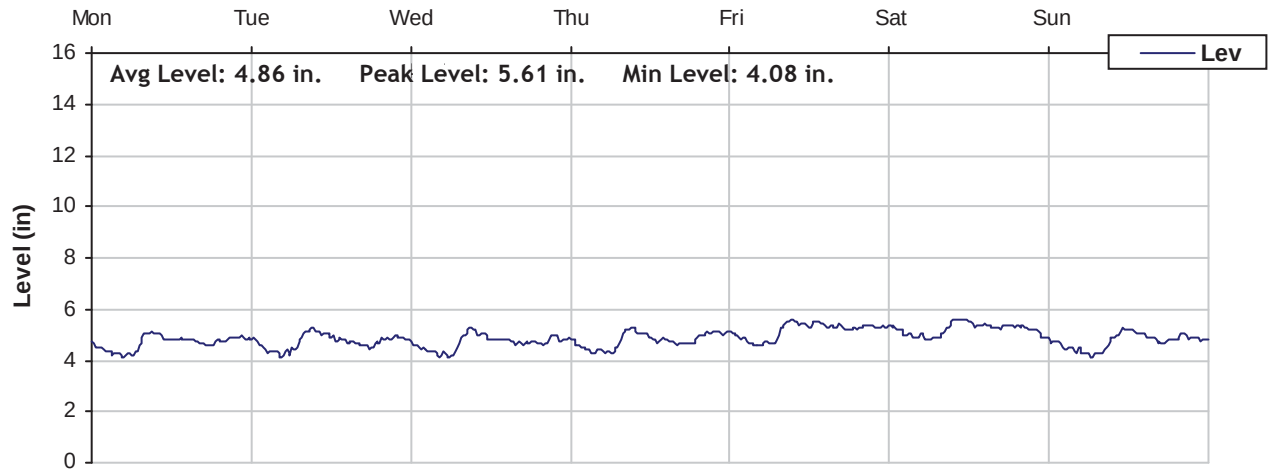


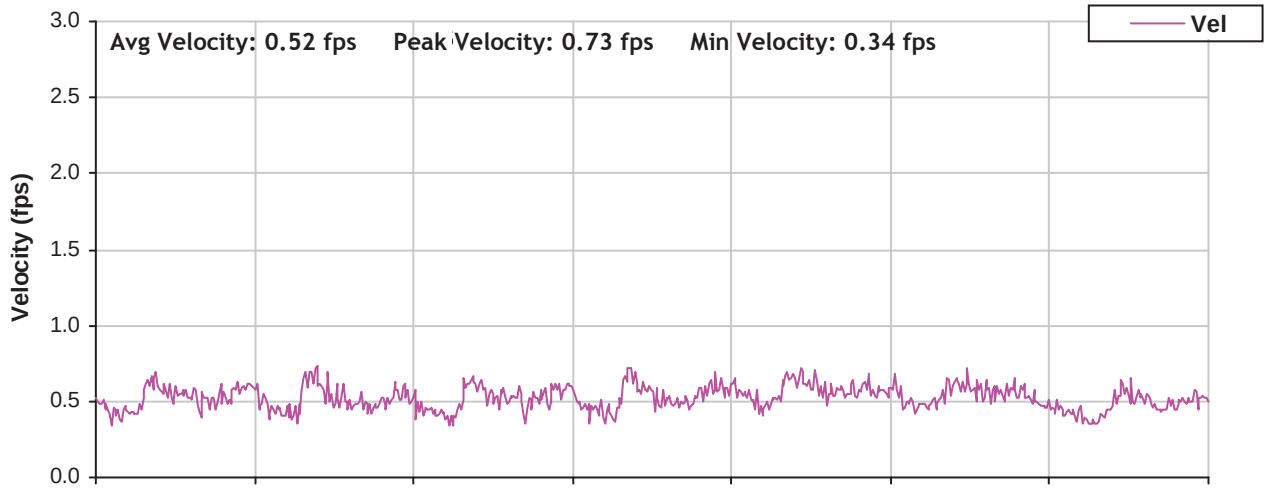


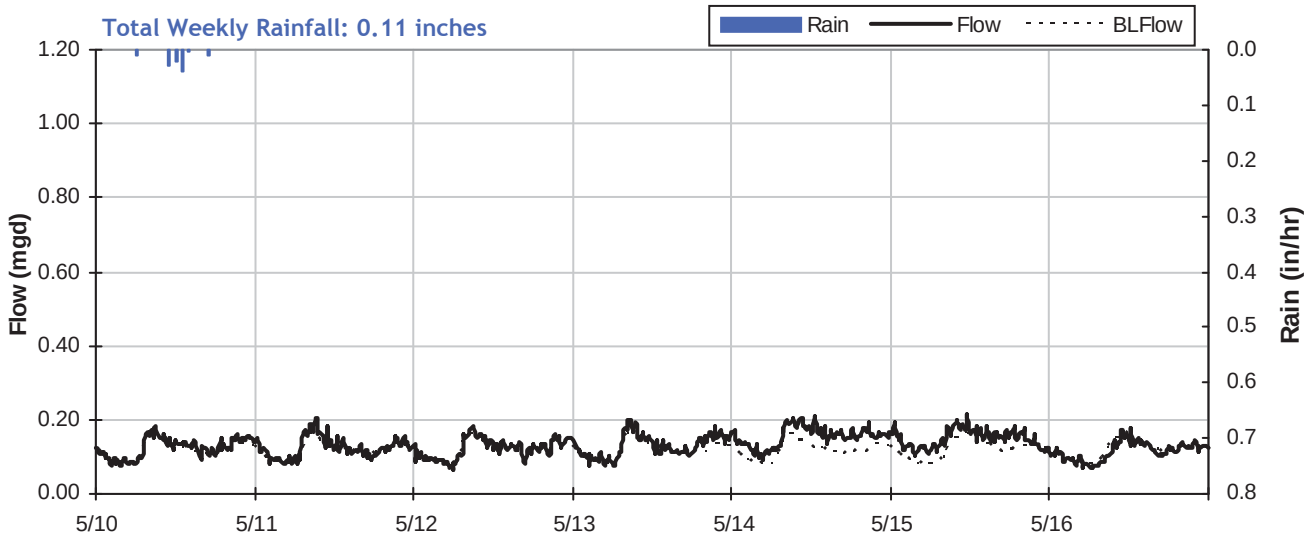
Avg Flow: 0.129 mgd Peak Flow: 0.234 mgd Min Flow: 0.077 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 4



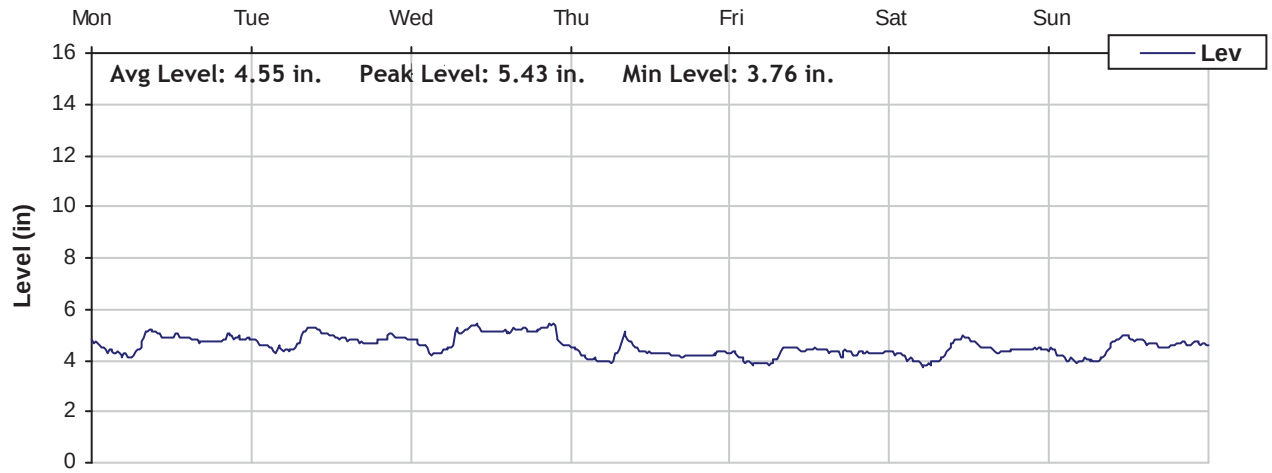


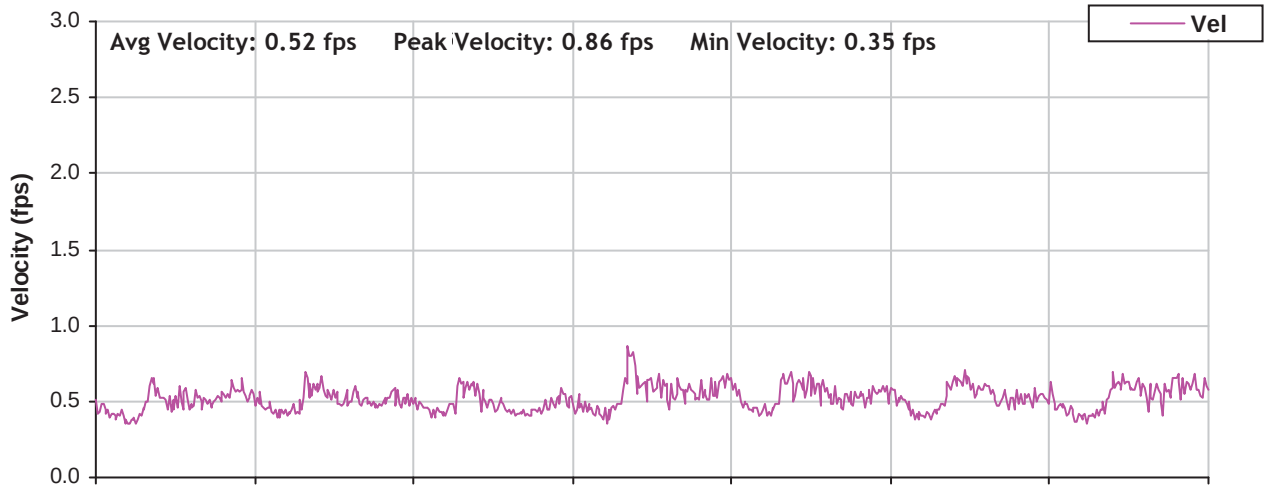


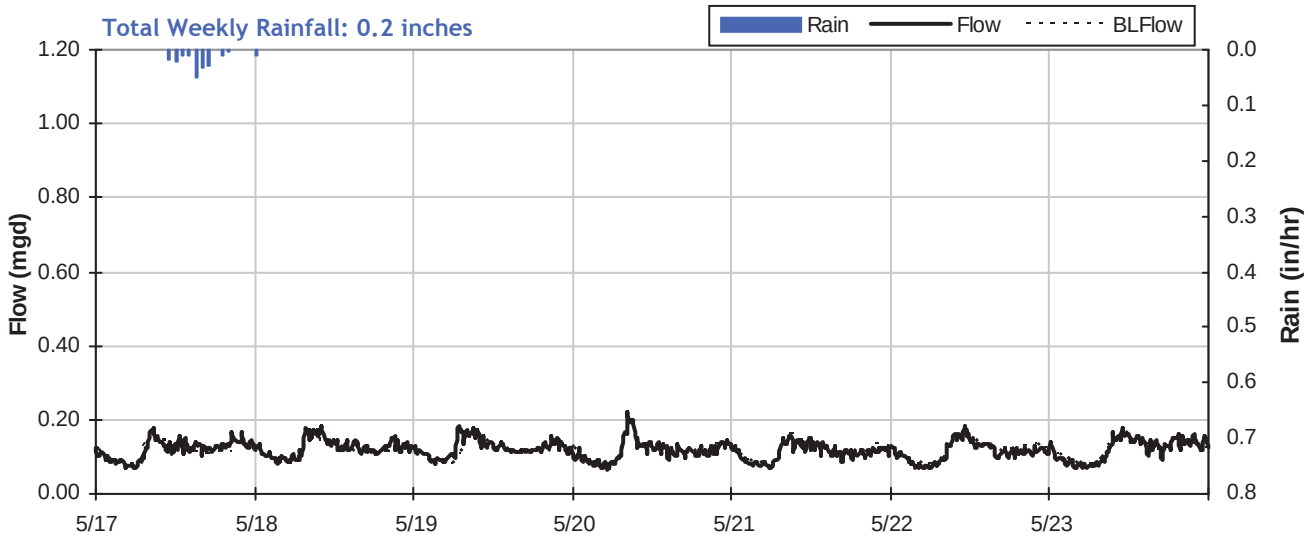
Avg Flow: 0.132 mgd Peak Flow: 0.217 mgd Min Flow: 0.067 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 4



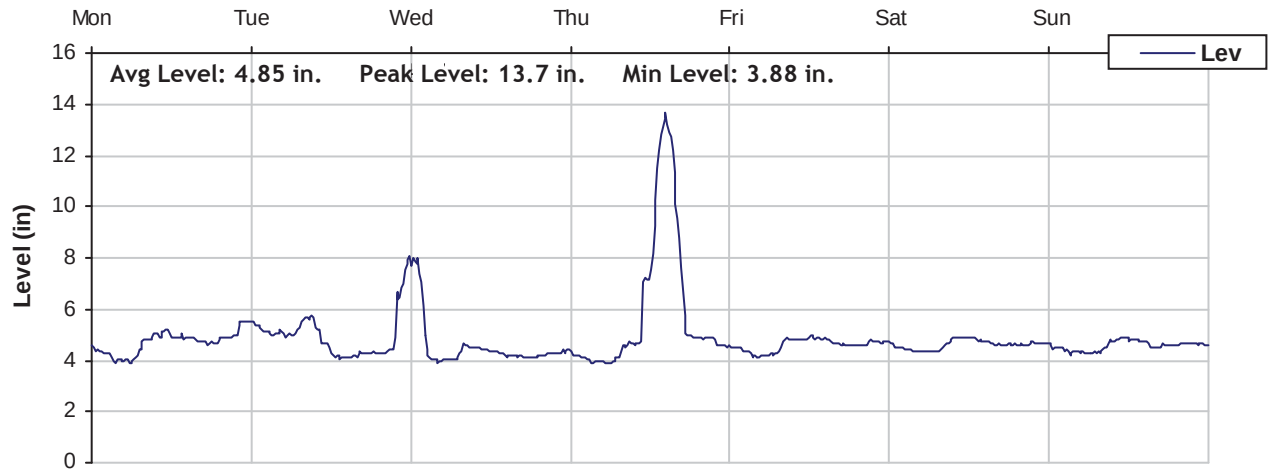


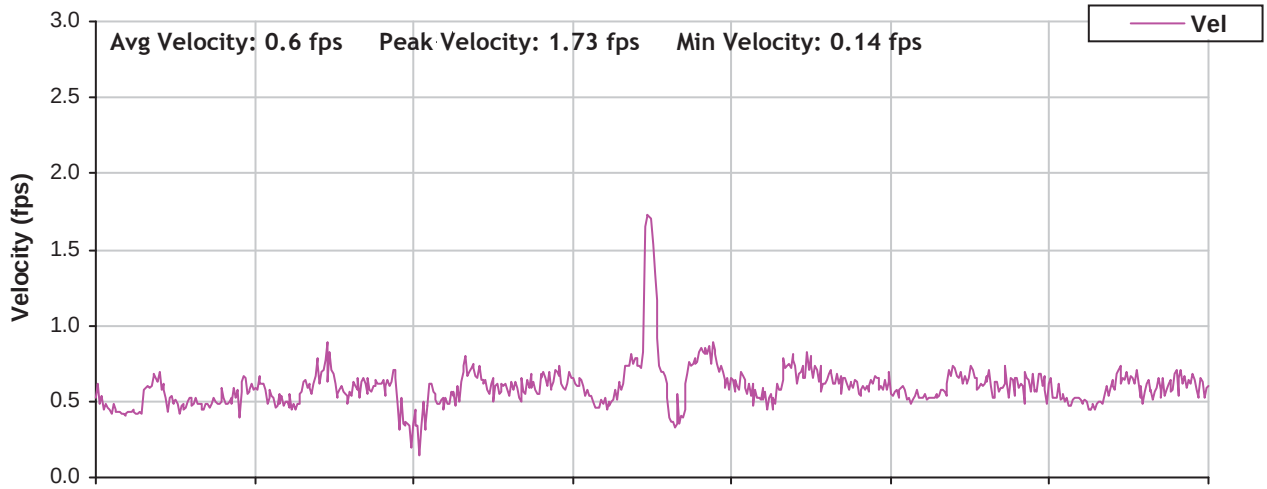


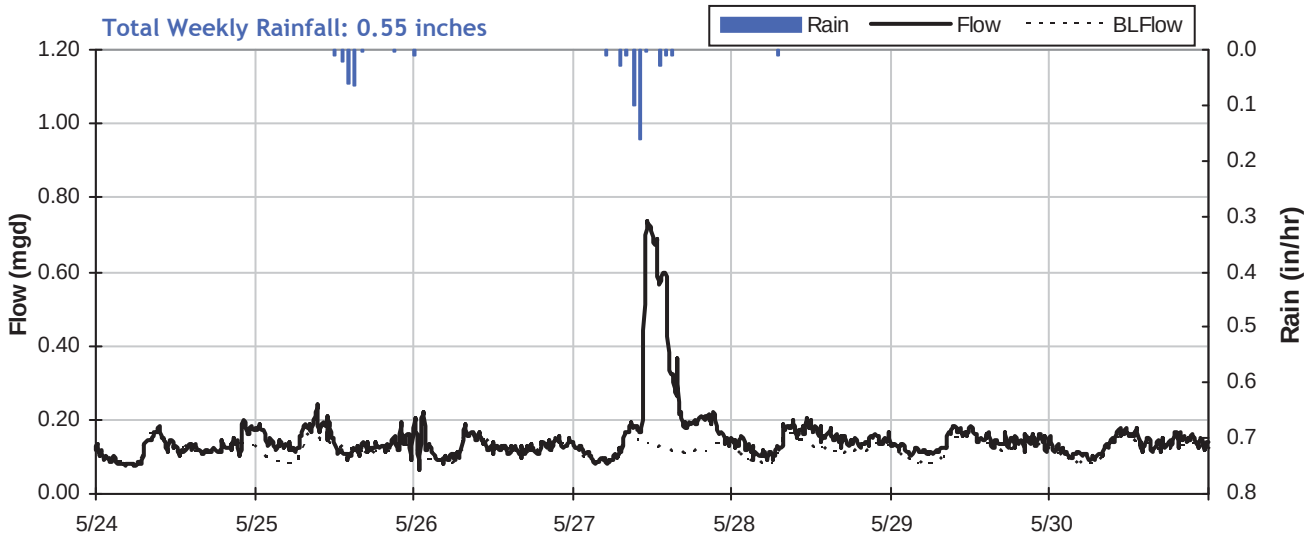
Avg Flow: 0.118 mgd Peak Flow: 0.222 mgd Min Flow: 0.066 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 4



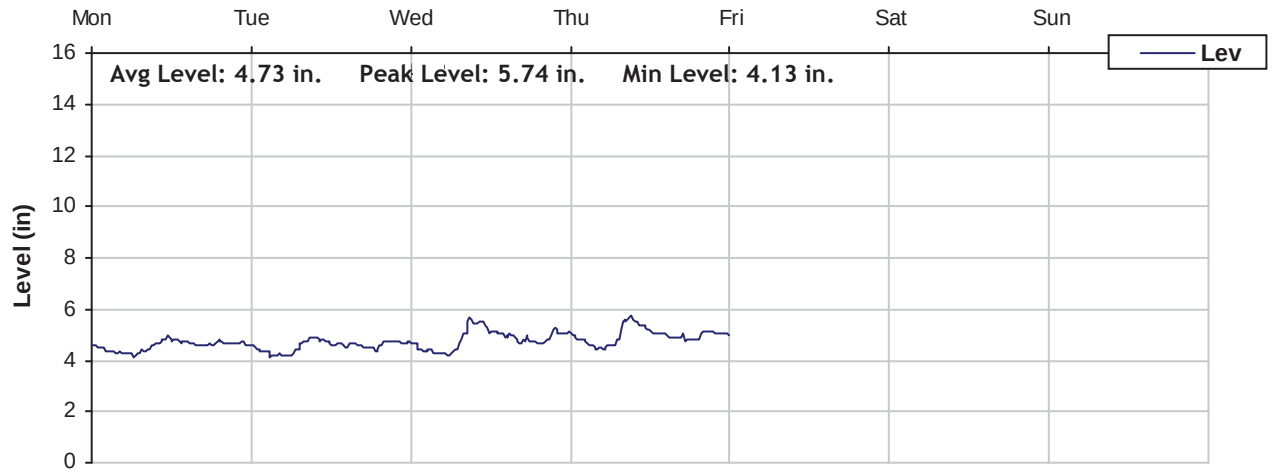


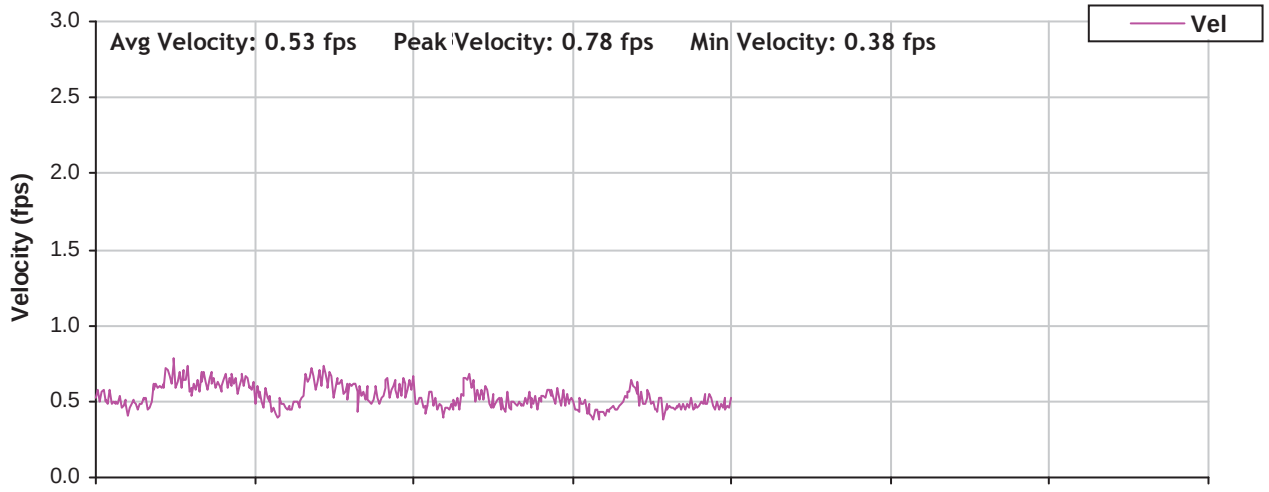


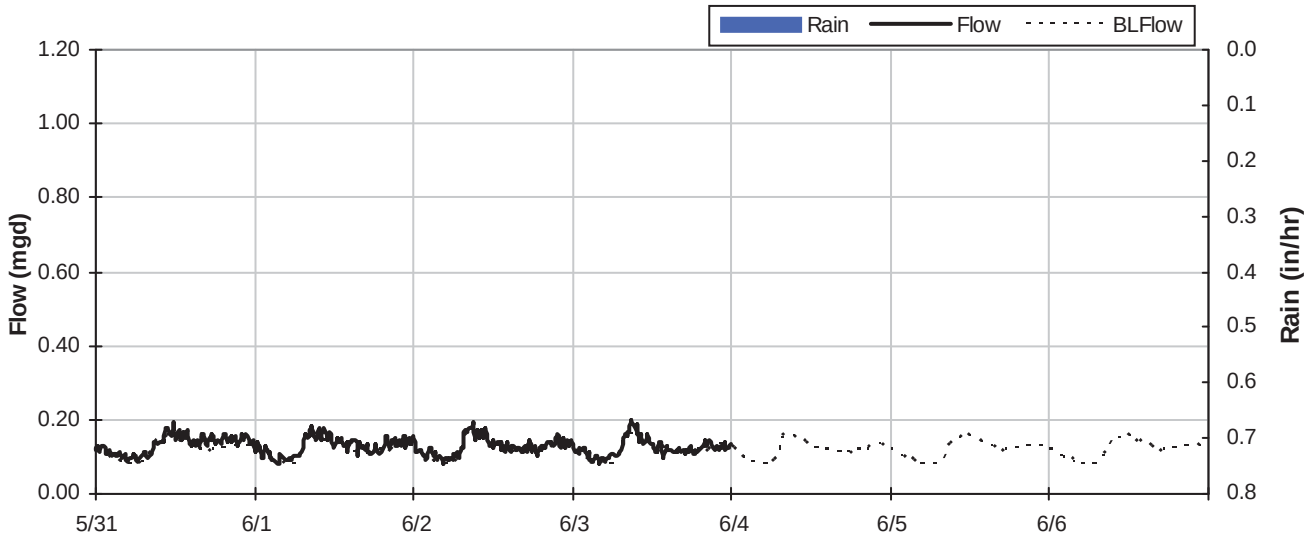
Avg Flow: 0.15 mgd Peak Flow: 0.738 mgd Min Flow: 0.064 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 4







Avg Flow: 0.128 mgd Peak Flow: 0.2 mgd Min Flow: 0.079 mgd

Temporary Flow Monitoring Study

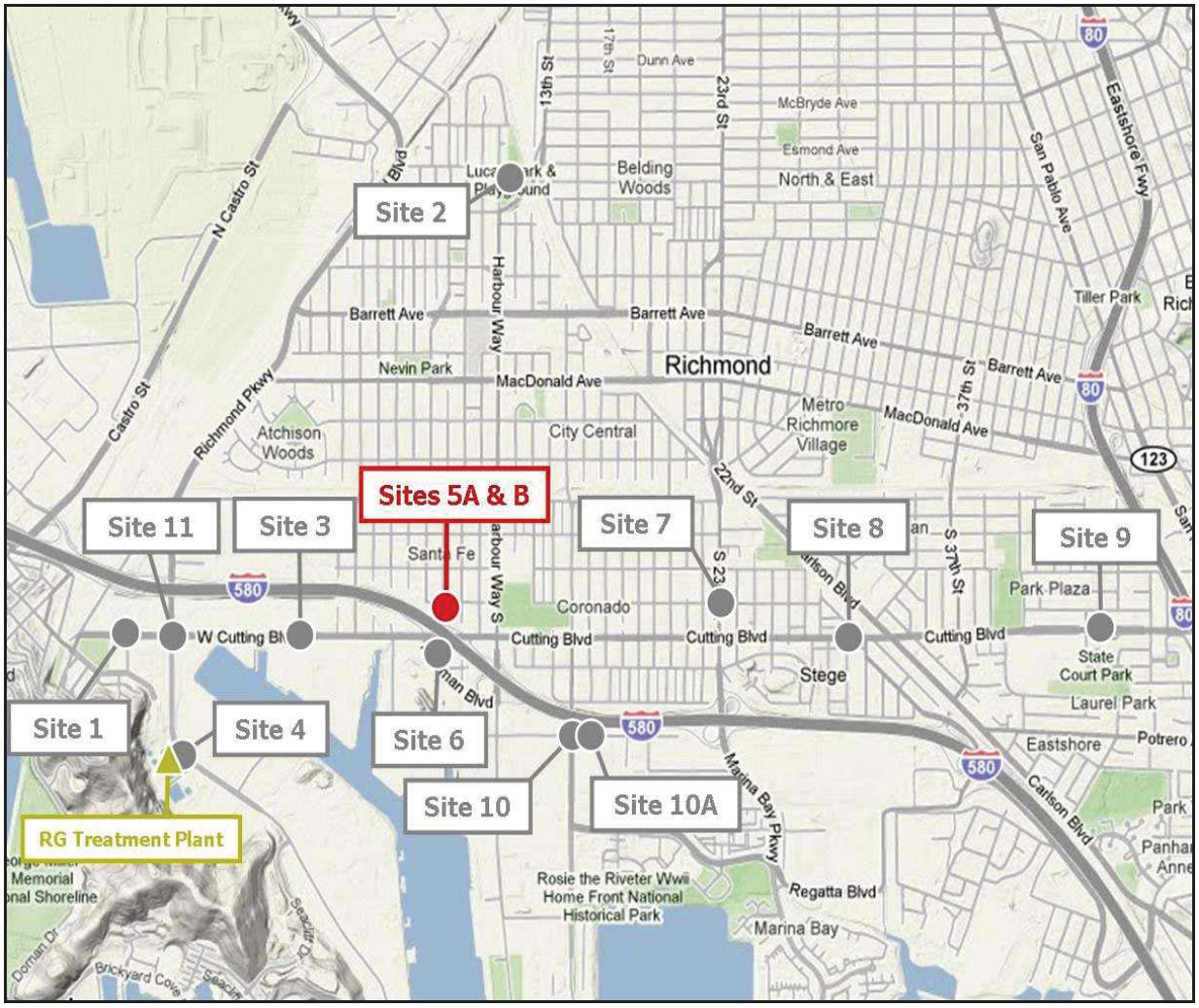
Sanitary Sewer Collection System

Monitoring Site: Site 5A

Location: S 8th Street; south of Virginia Avenue at the dead end

Size/Type Line: 15-inch Sanitary Sewer Pipe

Data Summary Report



V&A

Site Information Report

Monitoring Site: Site 5A

Location: S 8th Street; south of Virginia Avenue at the dead end

Latitude: 37.9257°

Longitude: -122.3622°

Rim Elevation: 11 *feet above sea level*

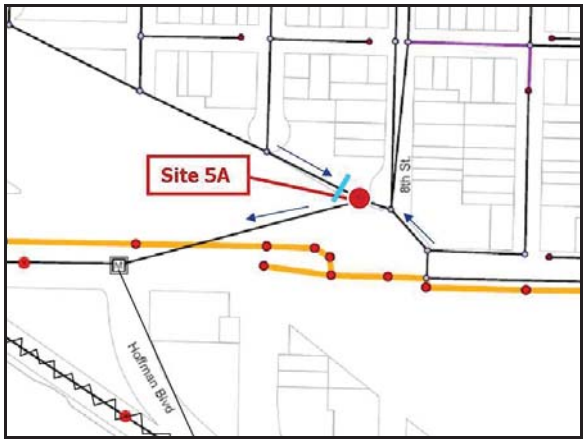
Diameter: 15 *inches*

Average Dry Weather Flow: 0.037 *mgd*

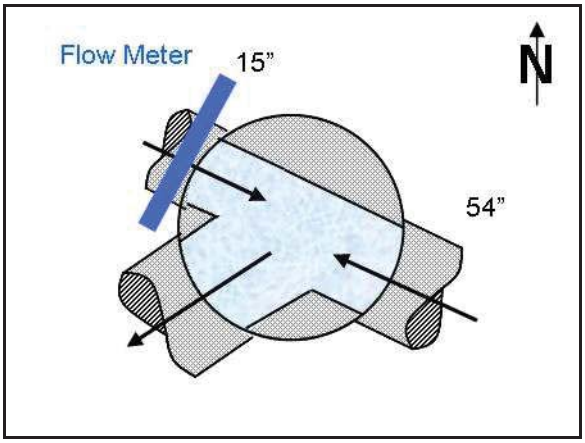
Peak Measured Flow: 1.065 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

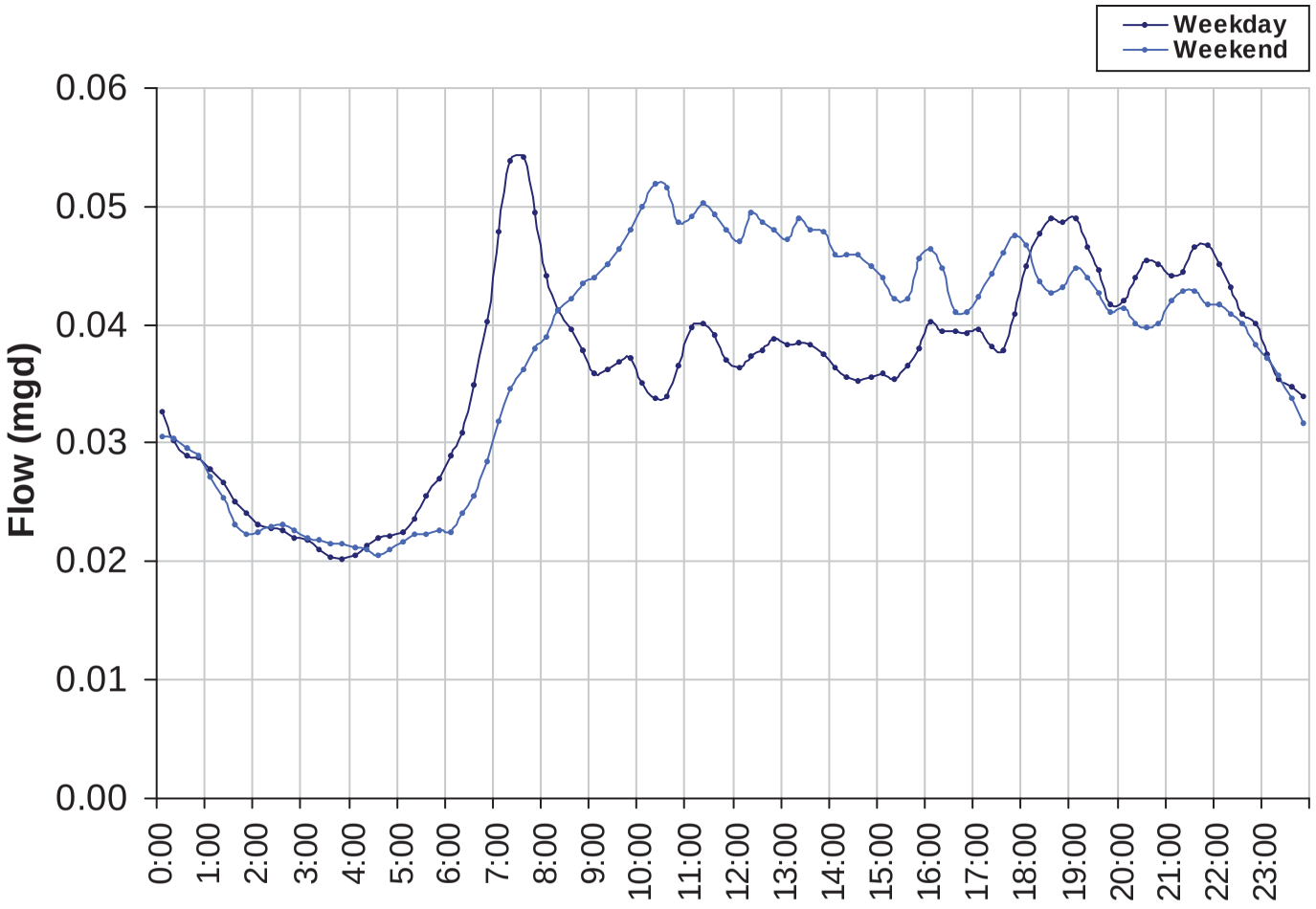


Street View Photo

Plan View Photo

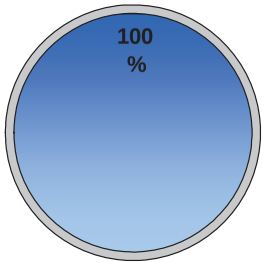
Average Dry Weather Flow

Monitoring Site:
Site 5A



Peak Measured Flow:

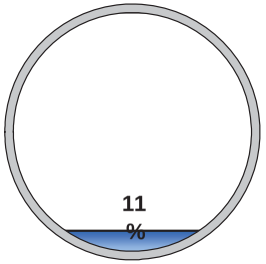
1.06 *mgd*



Peak measured flow shown in weekly graphs on following pages

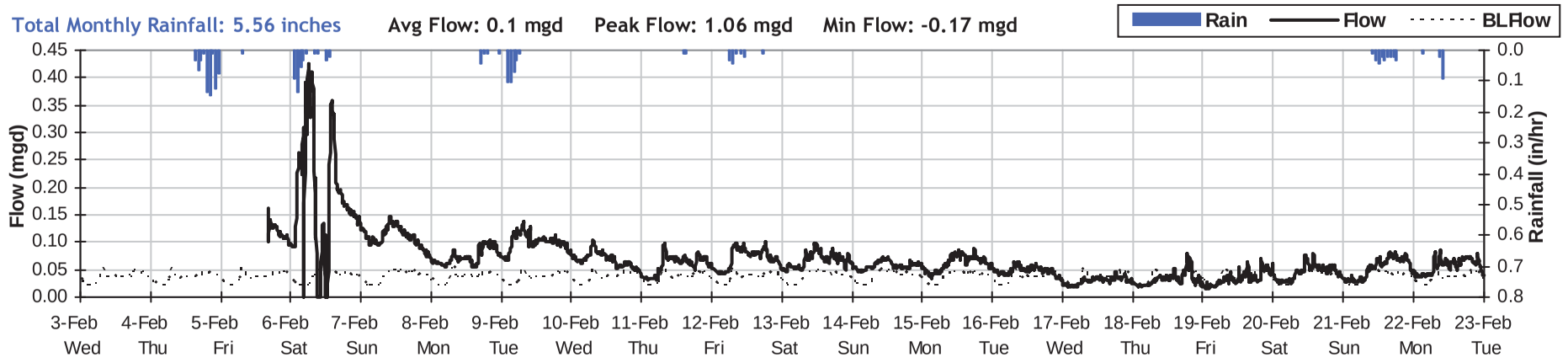
Average Dry Weather Flow:

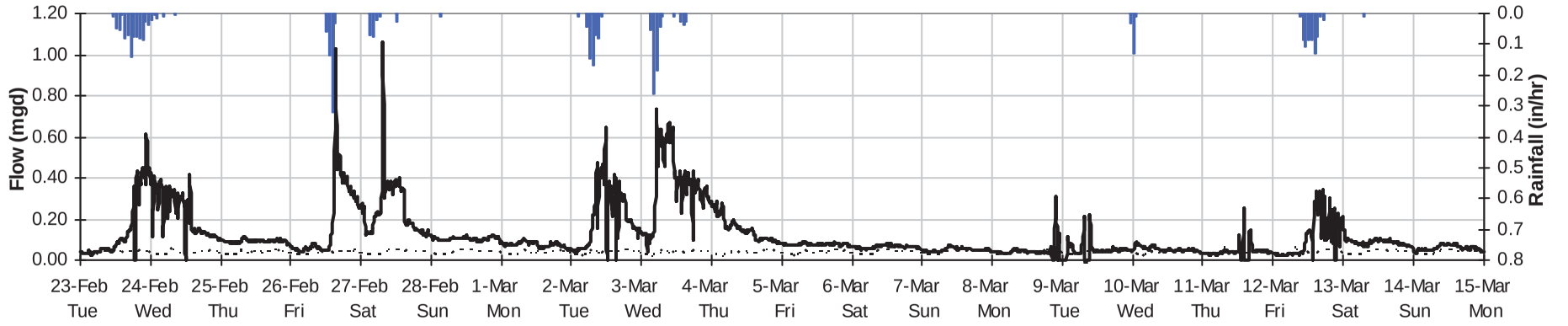
0.04 *mgd*

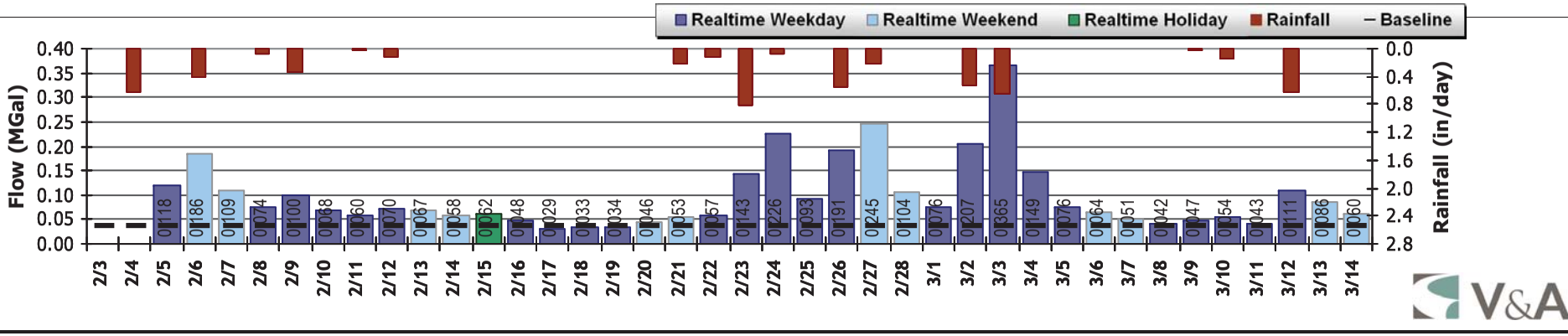


Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 5A





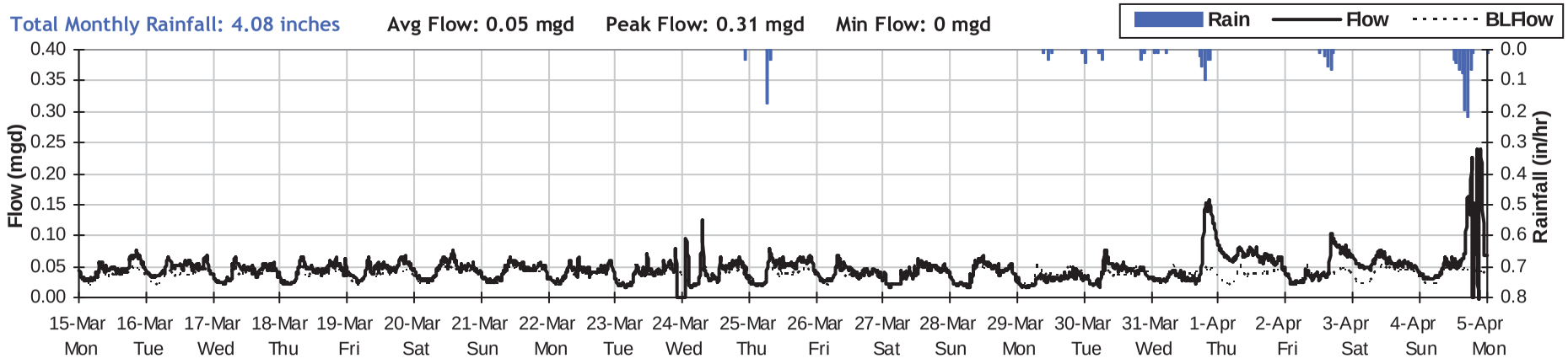


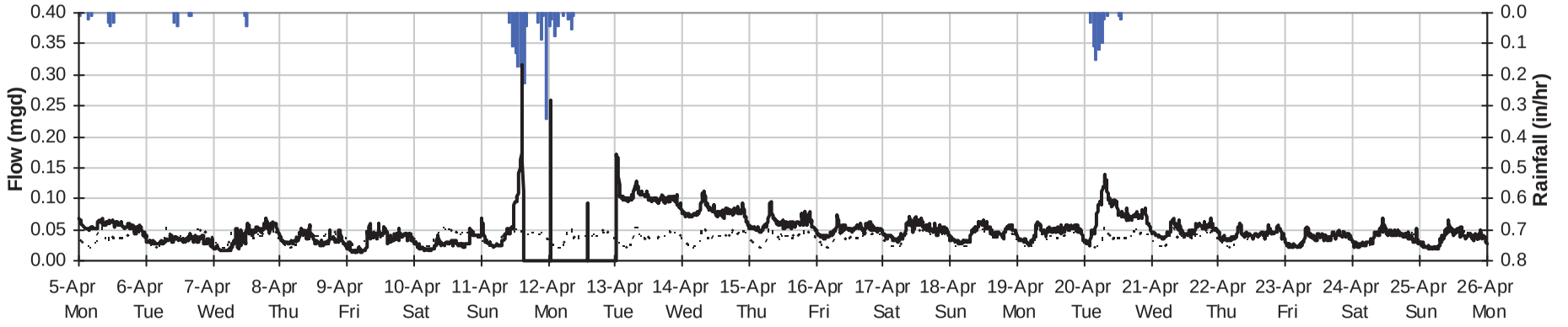
V&A

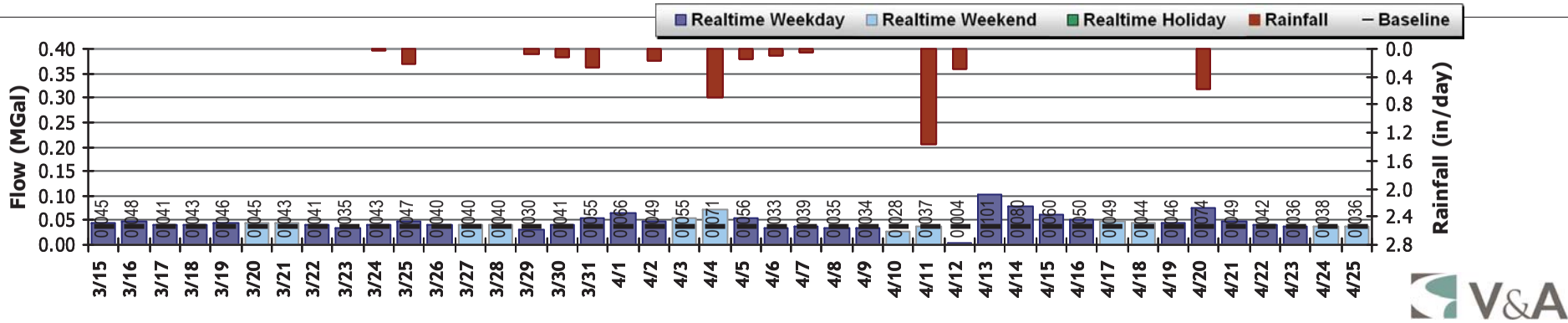
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 5A

Total Monthly Rainfall: 4.08 inches Avg Flow: 0.05 mgd Peak Flow: 0.31 mgd Min Flow: 0 mgd





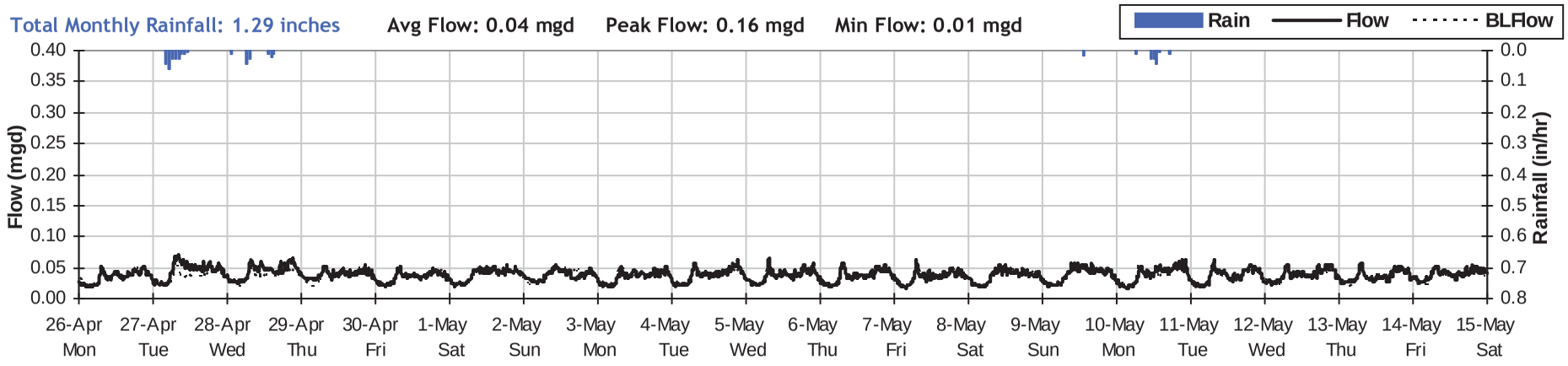


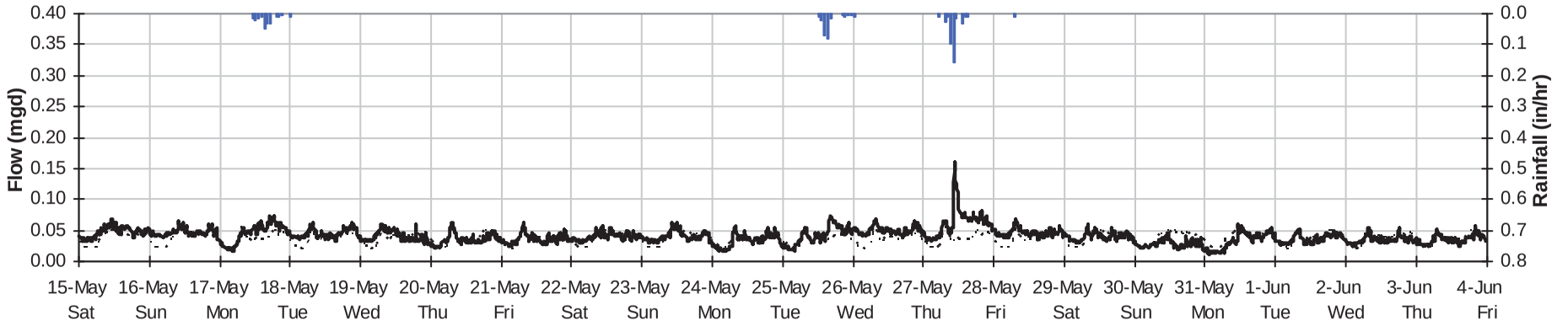
V&A

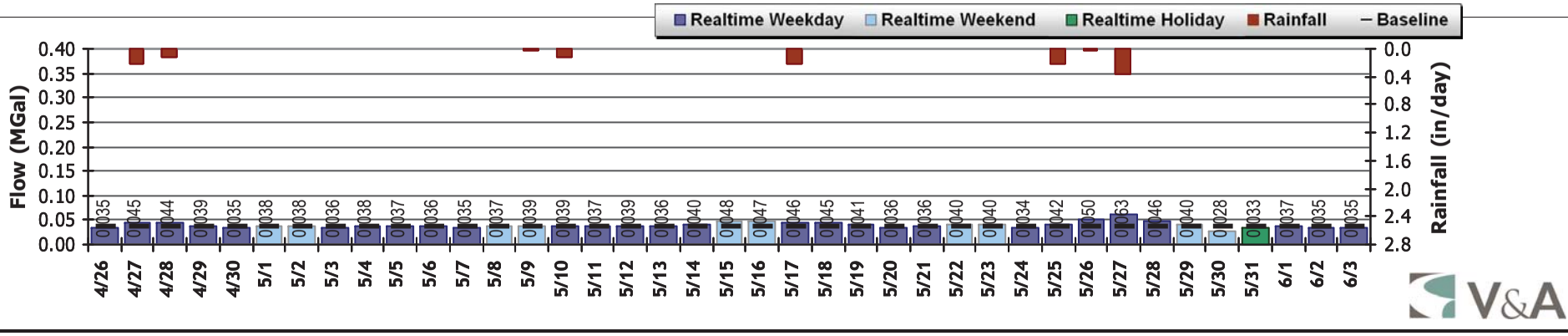
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 5A

Total Monthly Rainfall: 1.29 inches Avg Flow: 0.04 mgd Peak Flow: 0.16 mgd Min Flow: 0.01 mgd





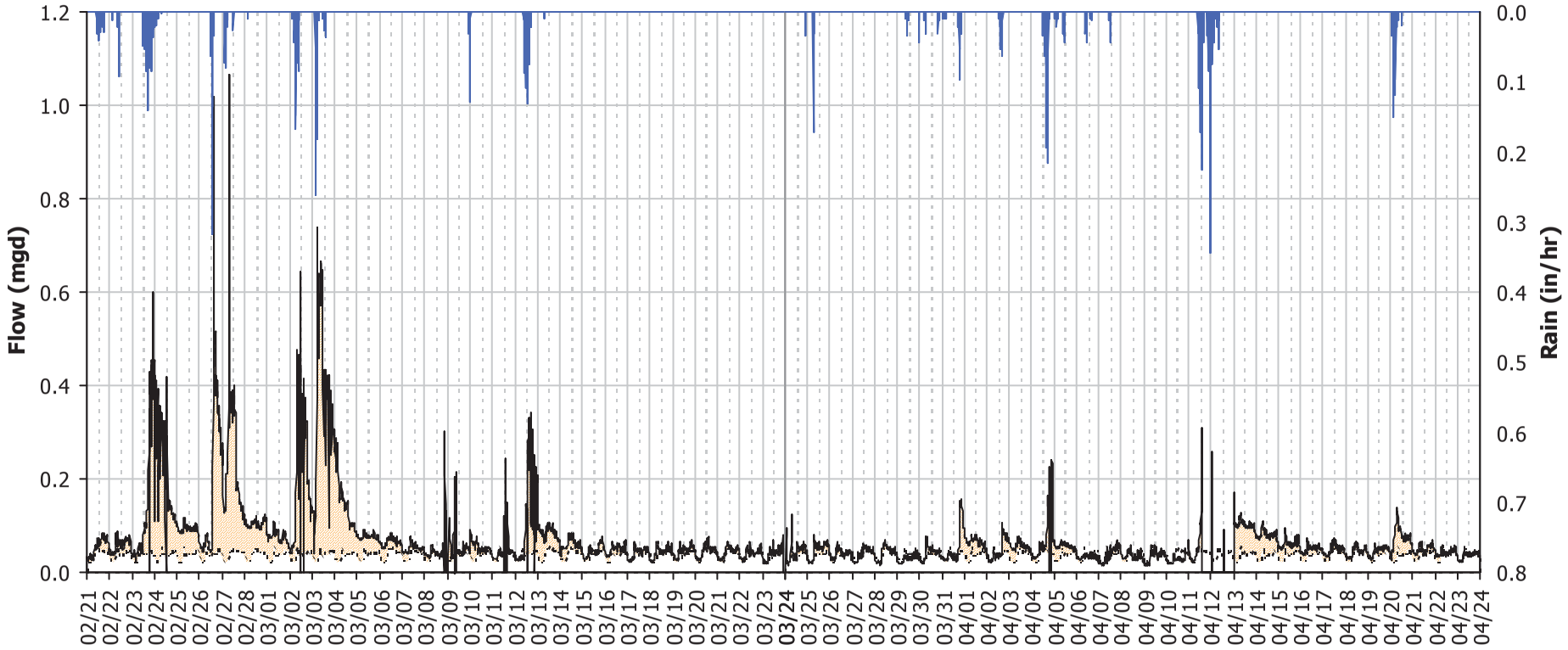


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 5A

Multiple Events Detail I/I Graph

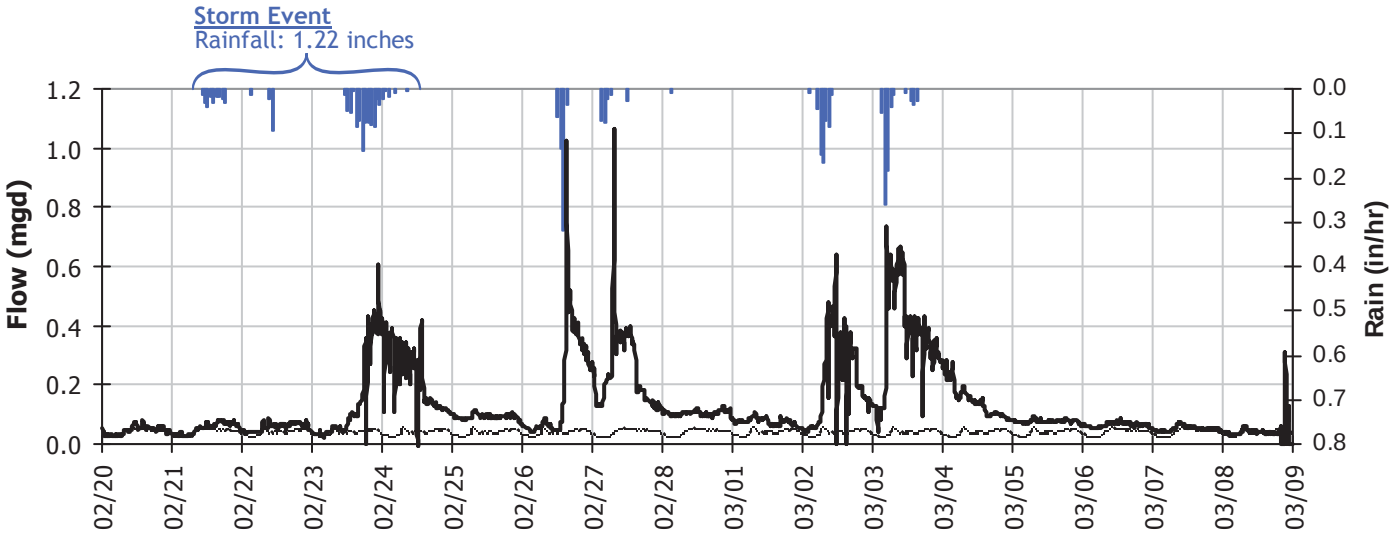


Multiple Events I/I Analysis

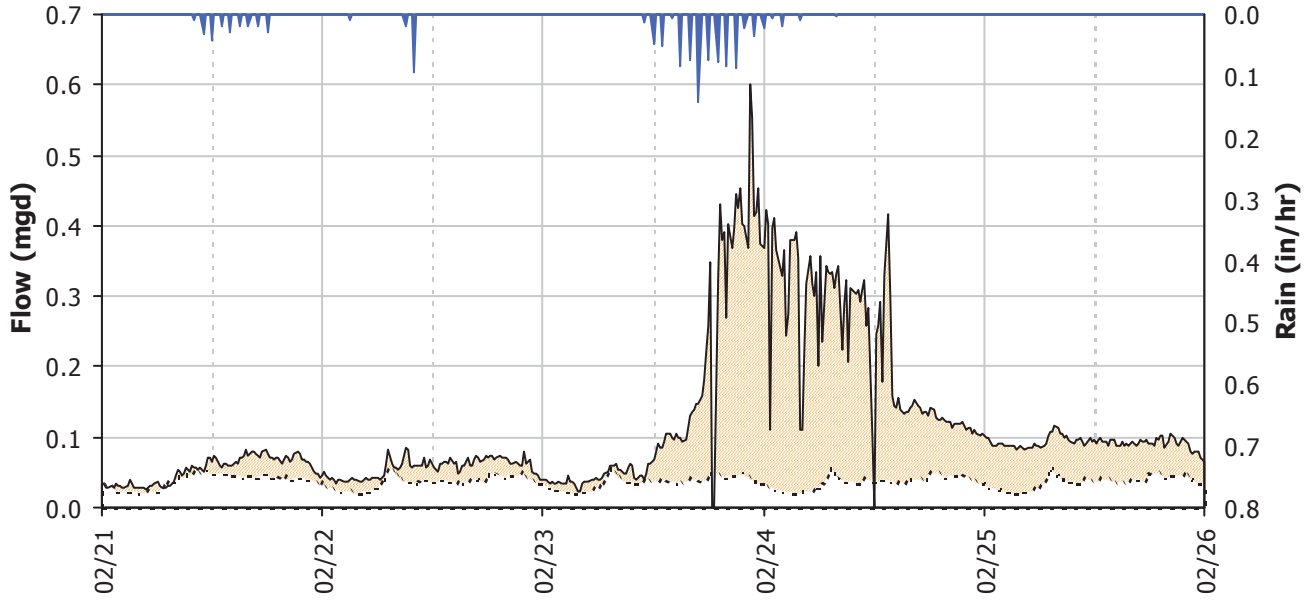
Rainfall:	8.06	*inches*	**Baseline Flow:**	0.04	*mgd*
Peak Flow:	1.06	*mgd*	**PF:**	29.02	
Peak I/I Rate:	1.03	*mgd*	**Pk I/I:ADWF:**	28.03	
Peak Level:	68.79	*inches*	**d/D Ratio:**	4.59	
Total I/I:	2,130,000	*gallons*	**R-Value:**	20.9%	
			I/I per ADWF:	7.2	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 5A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

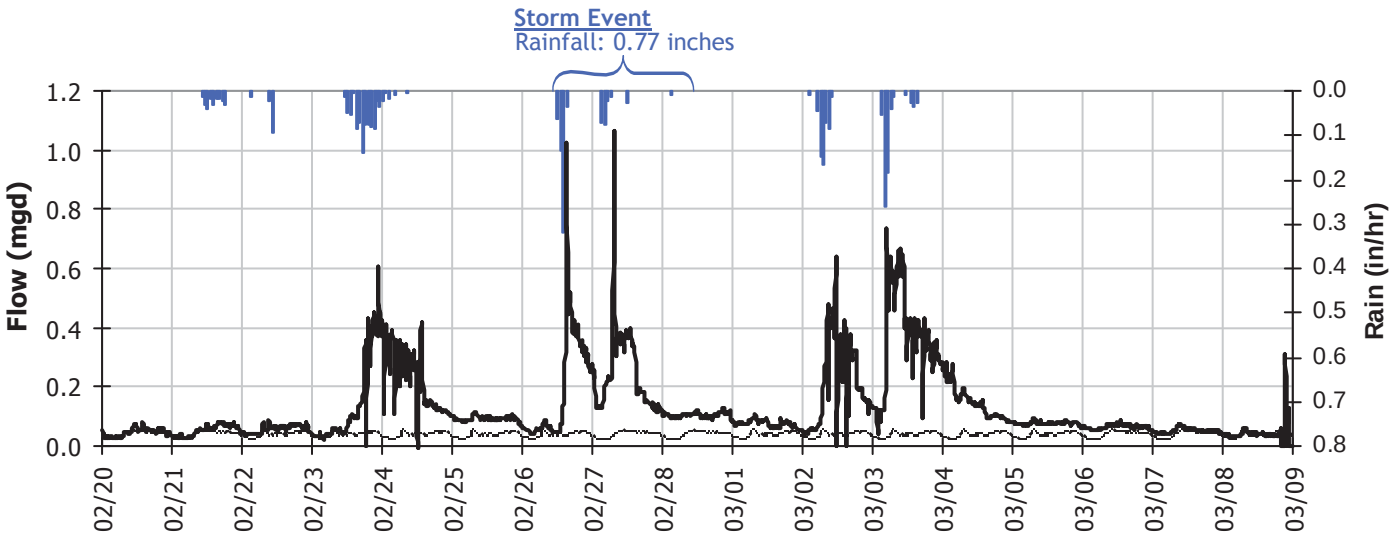
Rainfall:	1.22	*inches*		
Baseline Flow:	0.04	*mgd*		
Peak Flow:	0.60	*mgd*	**PF:**	16.40
Peak I/I Rate:	0.56	*mgd*	**Pk I/I:ADWF:**	15.28
Peak Level:	58.40	*inches*	**d/D Ratio:**	3.89
Total I/I:	390,000	*gallons*	**R-Value:**	25.3%
			I/I per ADWF:	8.72 *per in-rain*

Average Infiltration Rate on 2/25 (% of ADWF): 155.2%

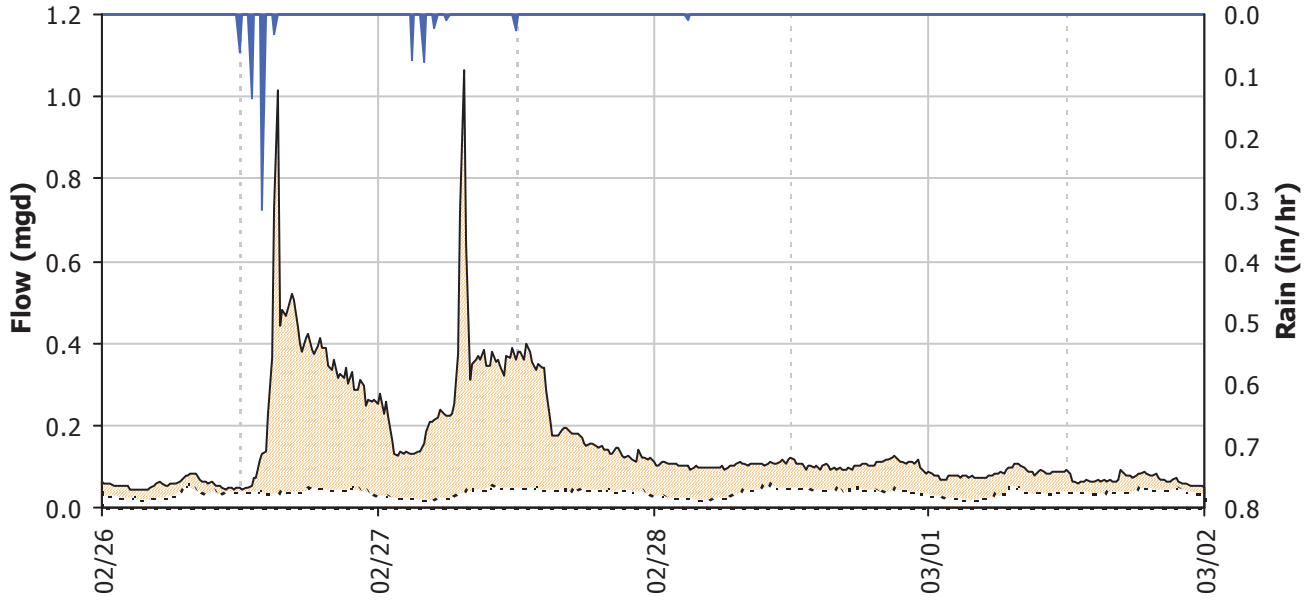
I/I Summary
Event 2

Monitoring Site:
Site 5A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



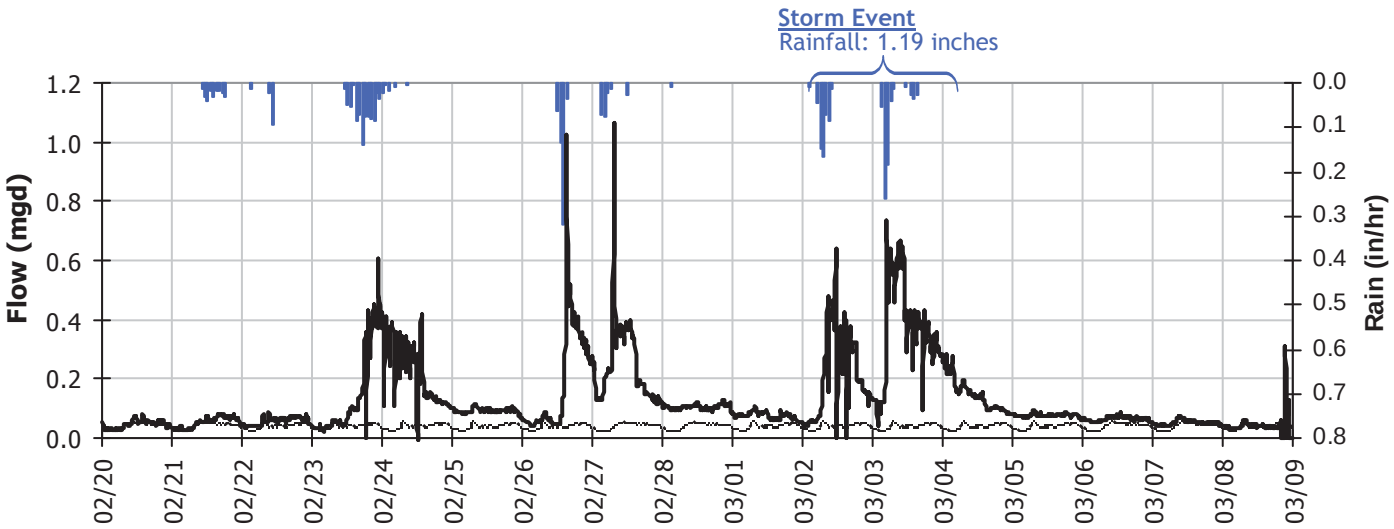
Storm Event #2 I/I Analysis

Rainfall:	0.77	*inches*		
Baseline Flow:	0.04	*mgd*		
Peak Flow:	1.06	*mgd*	**PF:**	29.02
Peak I/I Rate:	1.03	*mgd*	**Pk I/I:ADWF:**	28.03
Peak Level:	42.20	*inches*	**d/D Ratio:**	2.81
Total I/I:	467,000	*gallons*	**R-Value:**	48.0%
			I/I per ADWF:	16.54 *per in-rain*

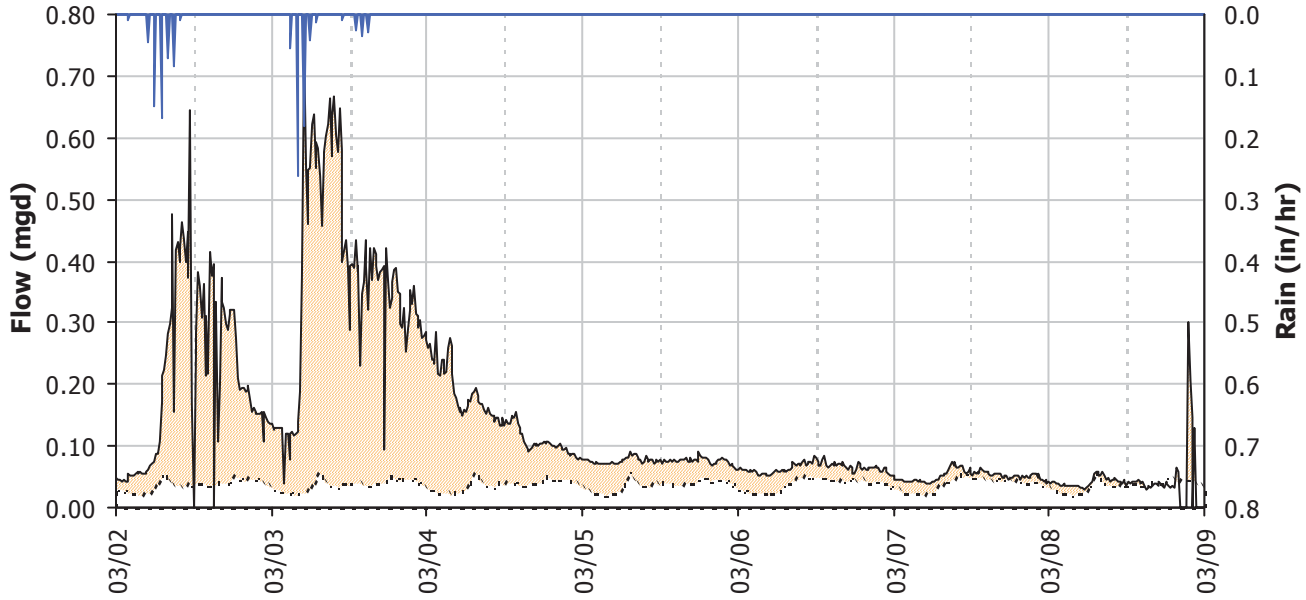
Average Infiltration Rate on 3/1 (% of ADWF): 108.3%

	I/I Summary Event 3	**Monitoring Site:** Site 5A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #3 I/I Analysis

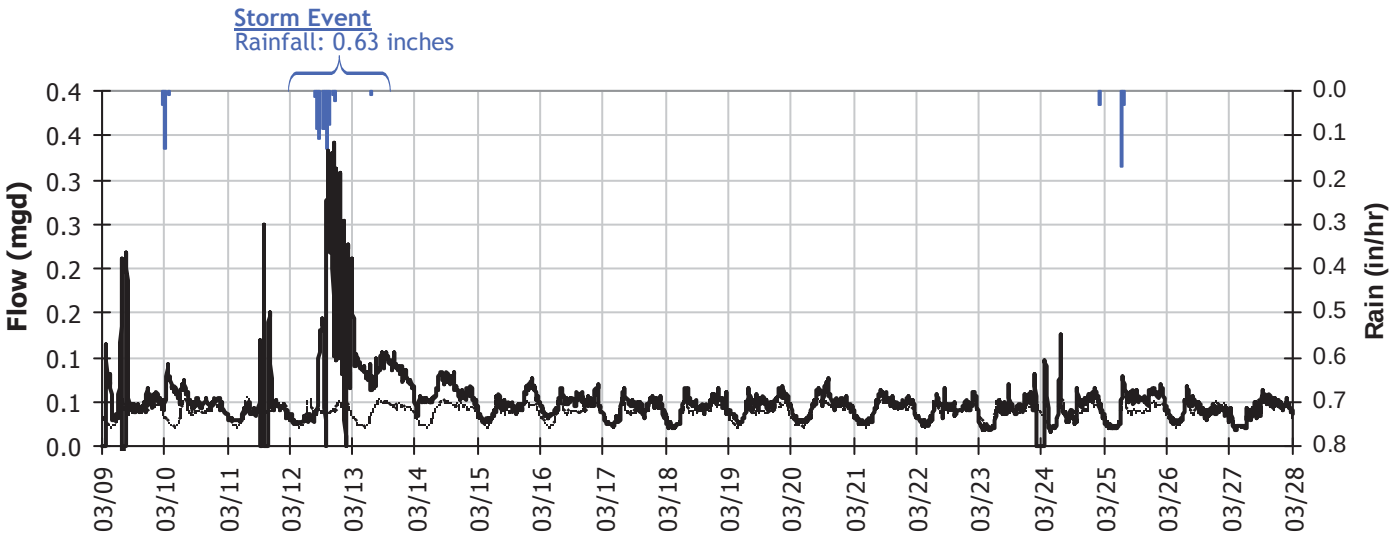
Rainfall:	1.19	*inches*		
Baseline Flow:	0.04	*mgd*		
Peak Flow:	0.74	*mgd*	**PF:**	20.11
Peak I/I Rate:	0.72	*mgd*	**Pk I/I:ADWF:**	19.49
Peak Level:	68.79	*inches*	**d/D Ratio:**	4.59
Total I/I:	697,000	*gallons*	**R-Value:**	46.5%
			I/I per ADWF:	15.99 *per in-rain*

Average Infiltration Rate on 3/5 (% of ADWF): 110.5%

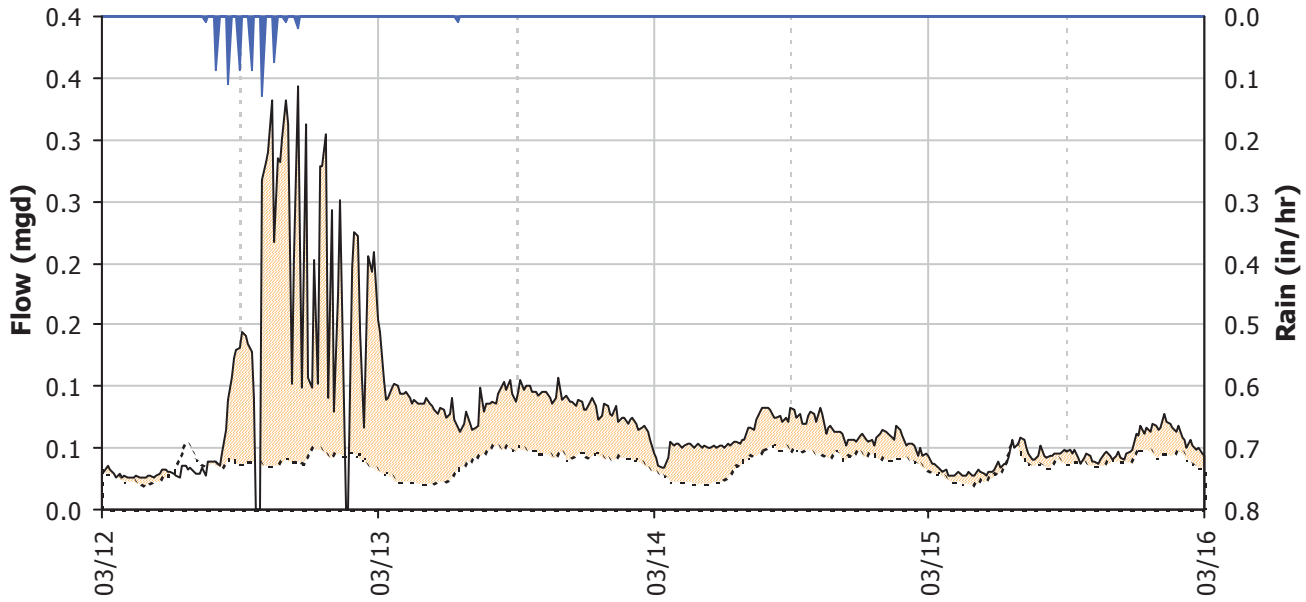
I/I Summary
Event 4

Monitoring Site:
Site 5A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

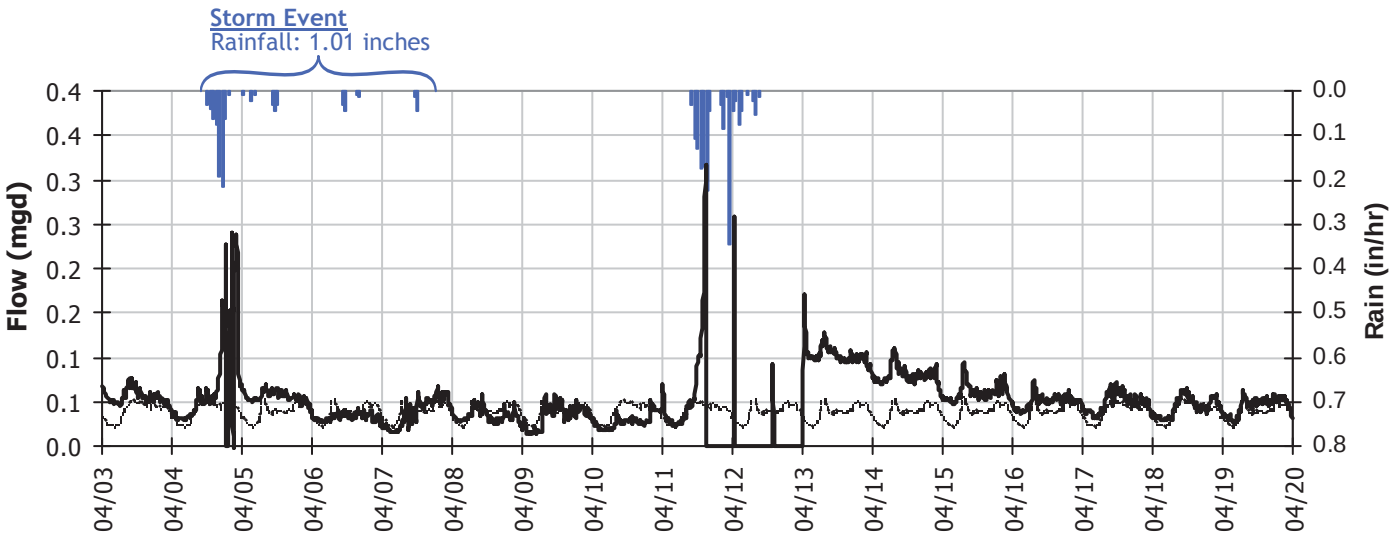
Rainfall:	0.63	*inches*		
Baseline Flow:	0.04	*mgd*		
Peak Flow:	0.34	*mgd*	**PF:**	9.34
Peak I/I Rate:	0.30	*mgd*	**Pk I/I:ADWF:**	8.26
Peak Level:	39.82	*inches*	**d/D Ratio:**	2.65
Total I/I:	155,000	*gallons*	**R-Value:**	19.5%
			I/I per ADWF:	6.71 *per in-rain*

Average Infiltration Rate on 3/14 (% of ADWF): 58.5%

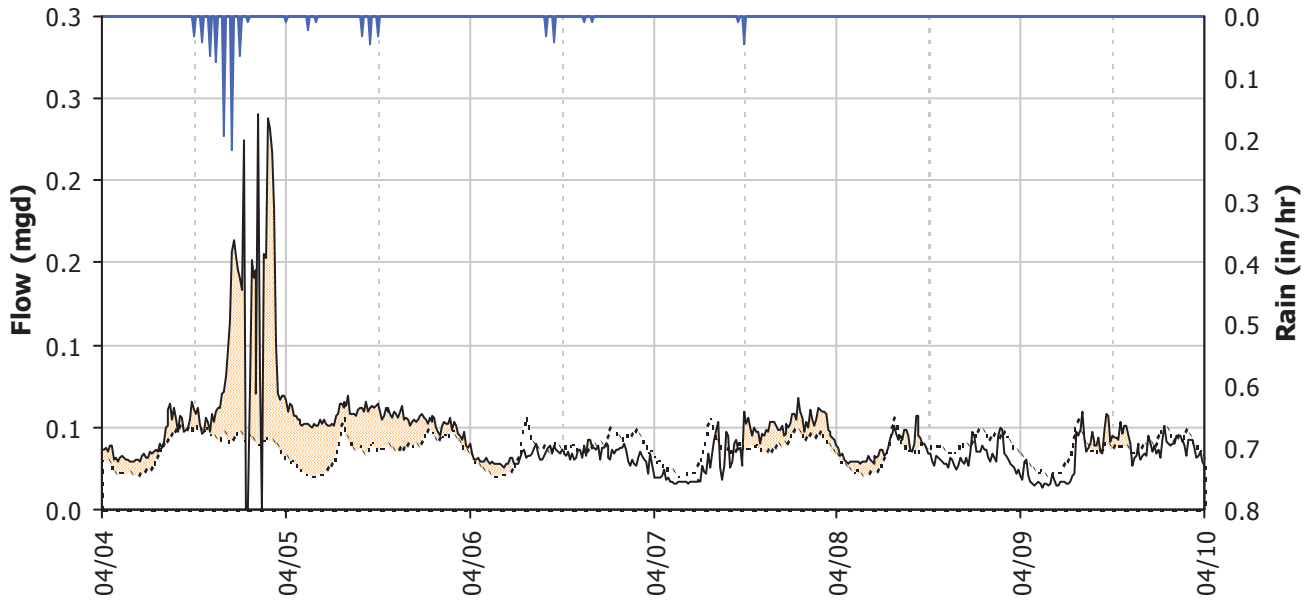
I/I Summary
Event 5

Monitoring Site:
Site 5A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #5 I/I Analysis

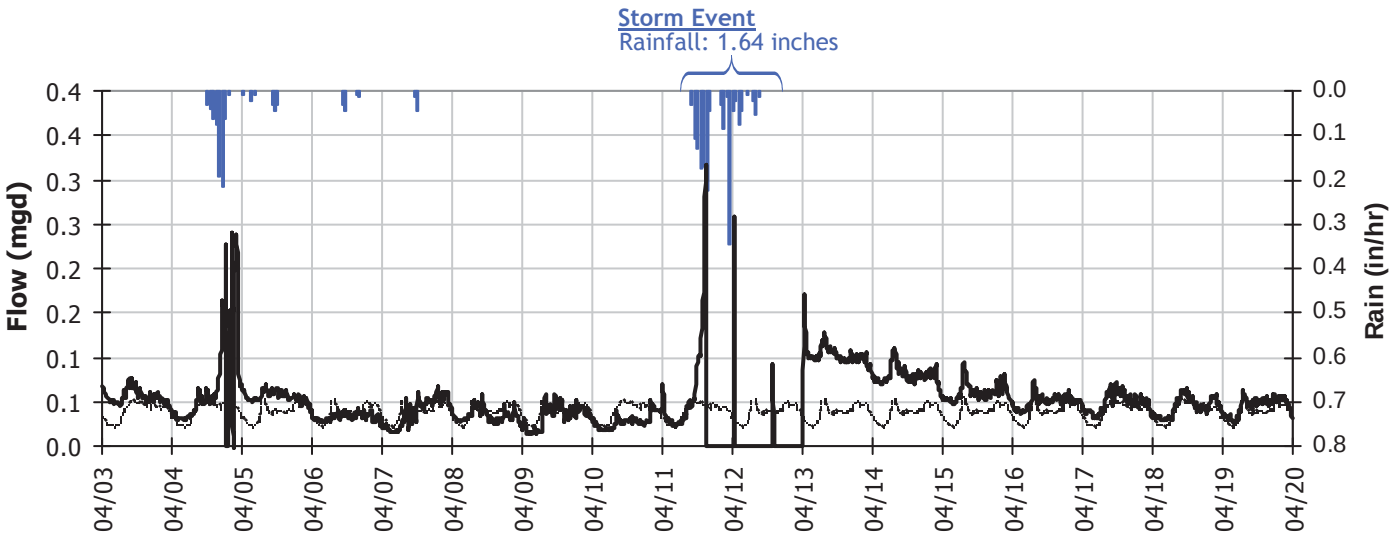
Rainfall:	1.01	*inches*		
Baseline Flow:	0.04	*mgd*		
Peak Flow:	0.24	*mgd*	**PF:**	6.55
Peak I/I Rate:	0.20	*mgd*	**Pk I/I:ADWF:**	5.46
Peak Level:	16.82	*inches*	**d/D Ratio:**	1.12
Total I/I:	48,000	*gallons*	**R-Value:**	3.7%
			I/I per ADWF:	1.29 *per in-rain*

Average Infiltration Rate on 4/8 (% of ADWF): -4.7%

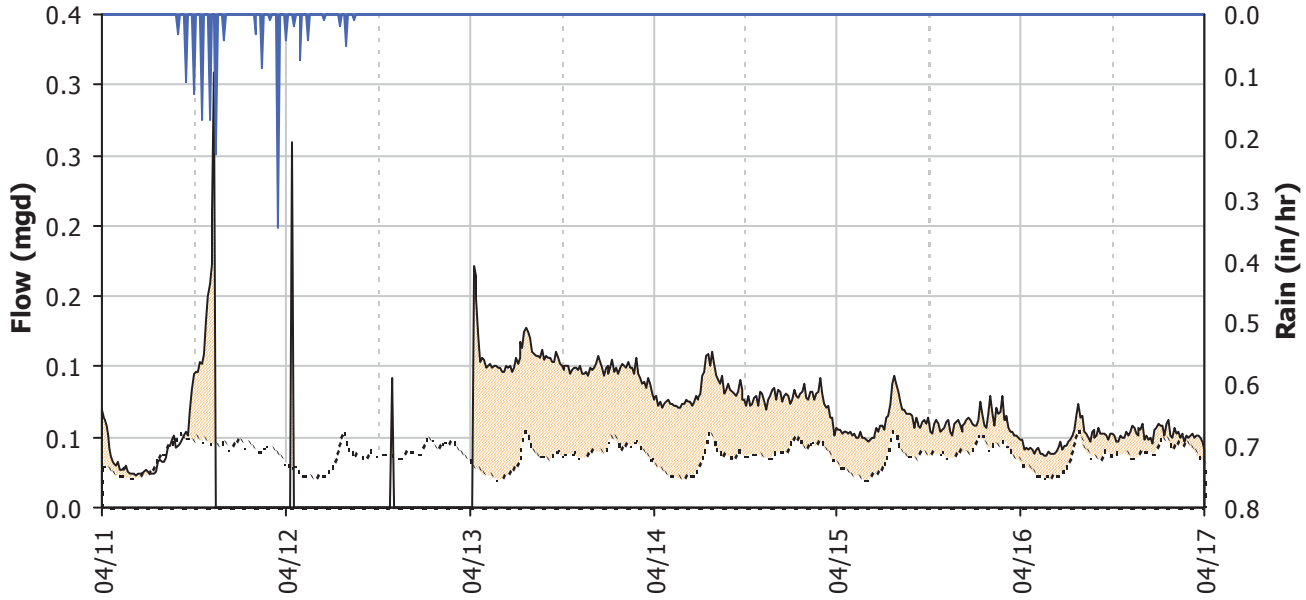
I/I Summary
Event 6

Monitoring Site:
Site 5A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



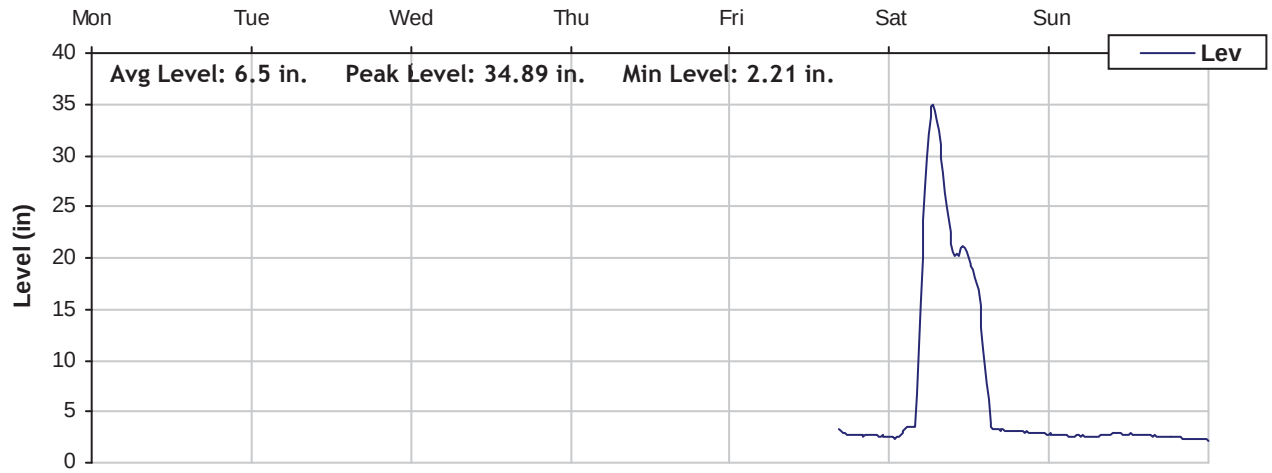
Storm Event #6 I/I Analysis

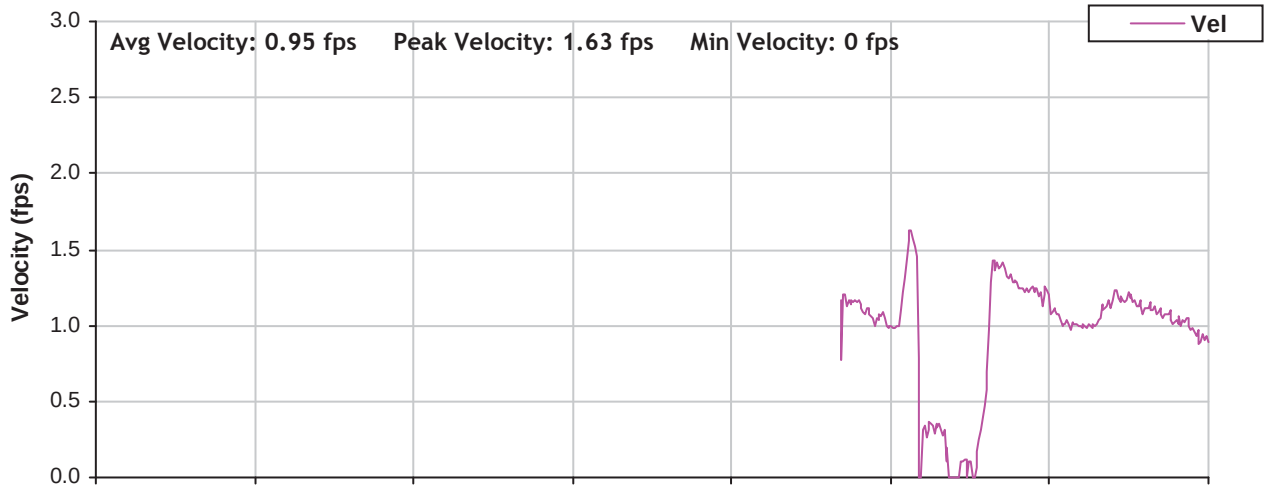
Rainfall:	1.64	*inches*		
Baseline Flow:	0.04	*mgd*		
Peak Flow:	0.31	*mgd*	**PF:**	8.43
Peak I/I Rate:	0.26	*mgd*	**Pk I/I:ADWF:**	7.21
Peak Level:	63.56	*inches*	**d/D Ratio:**	4.24
Total I/I:	113,000	*gallons*	**R-Value:**	5.4%
			I/I per ADWF:	1.87 *per in-rain*

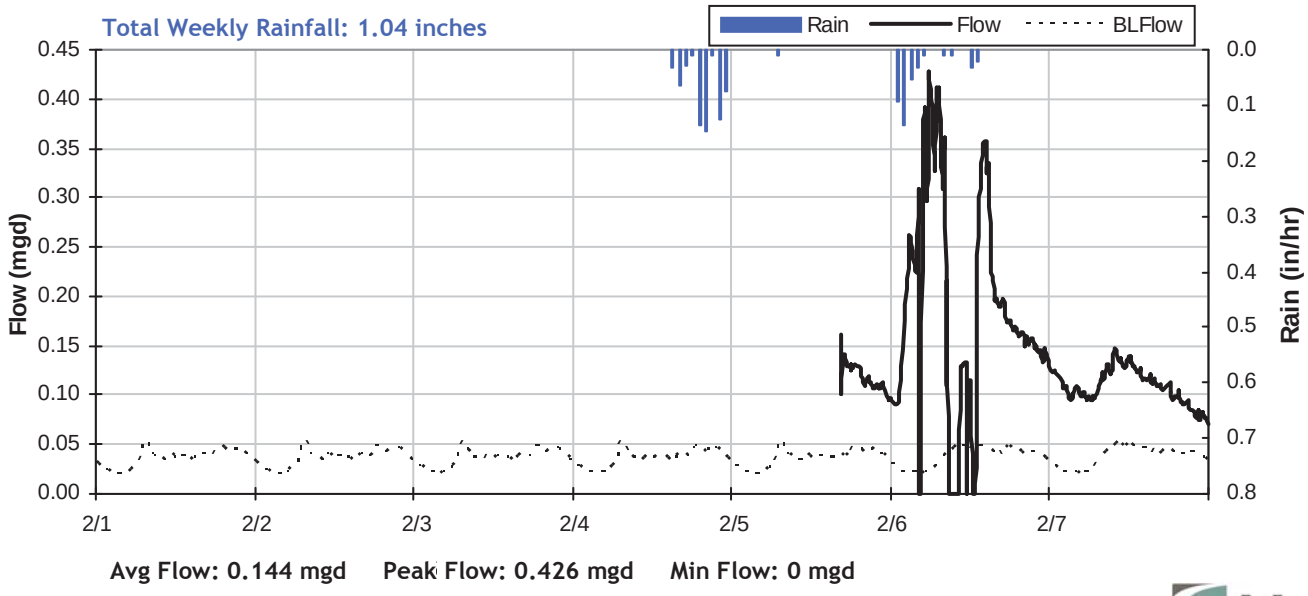
Average Infiltration Rate on 4/14 (% of ADWF): 119.6%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 5A

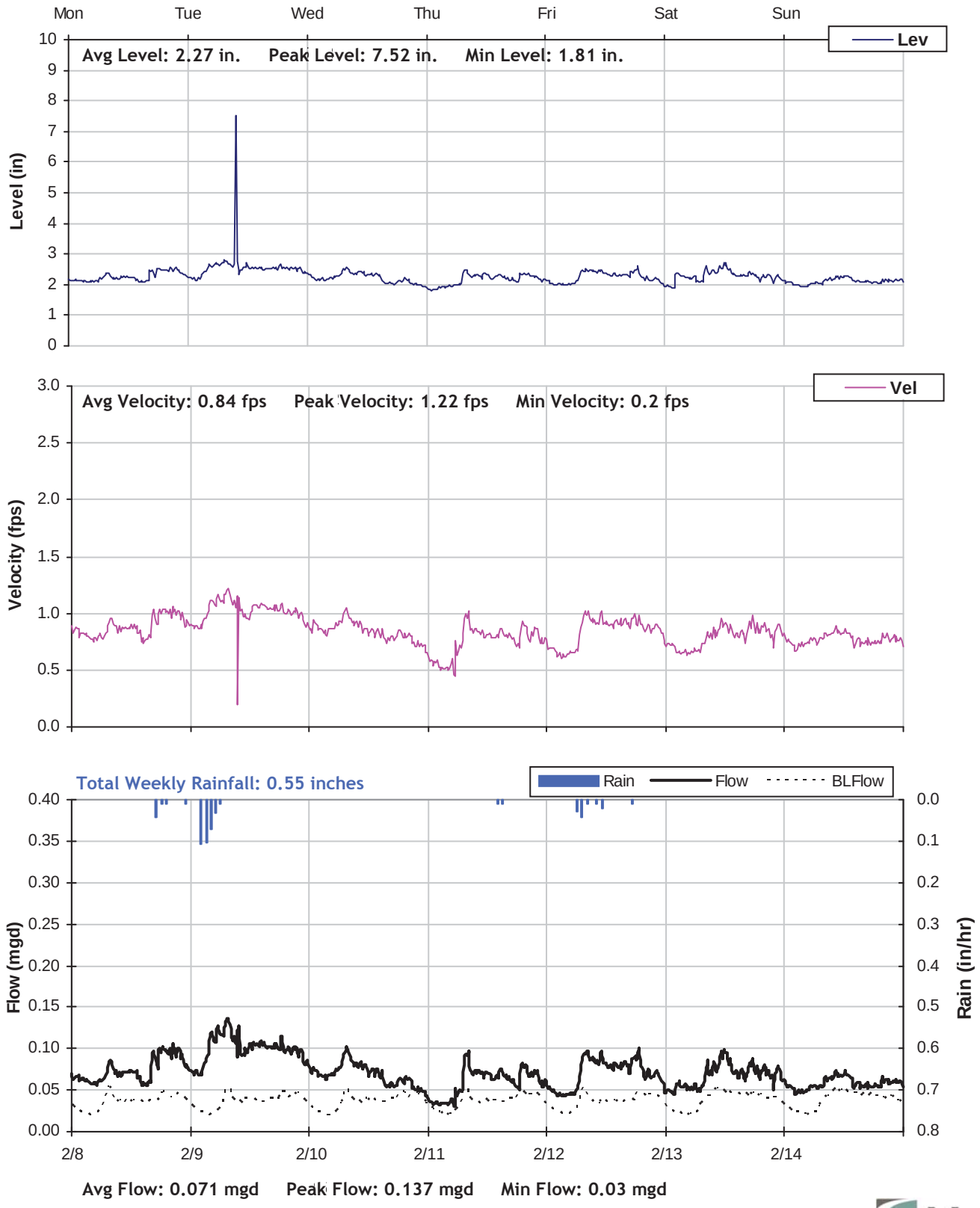






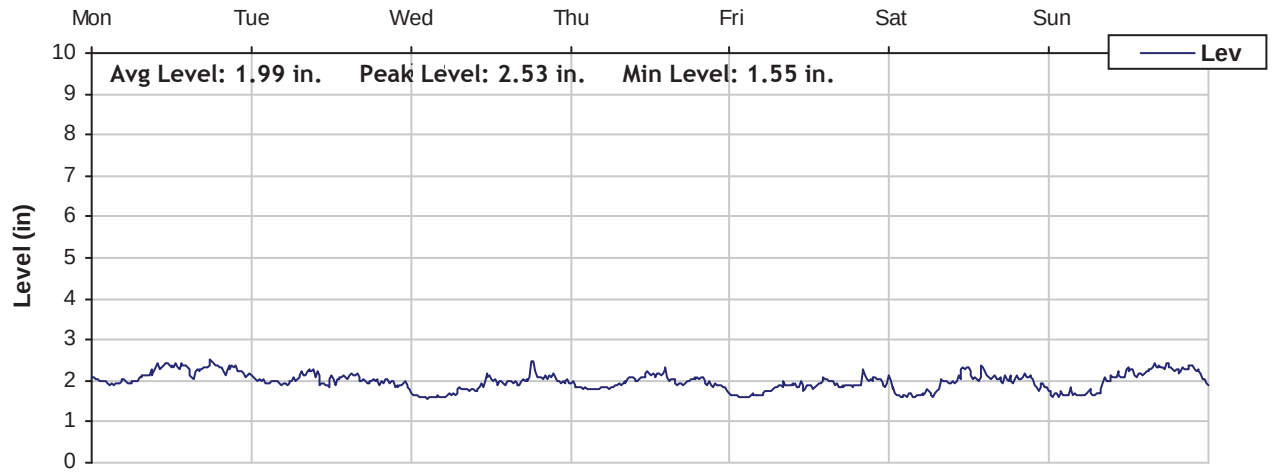
Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

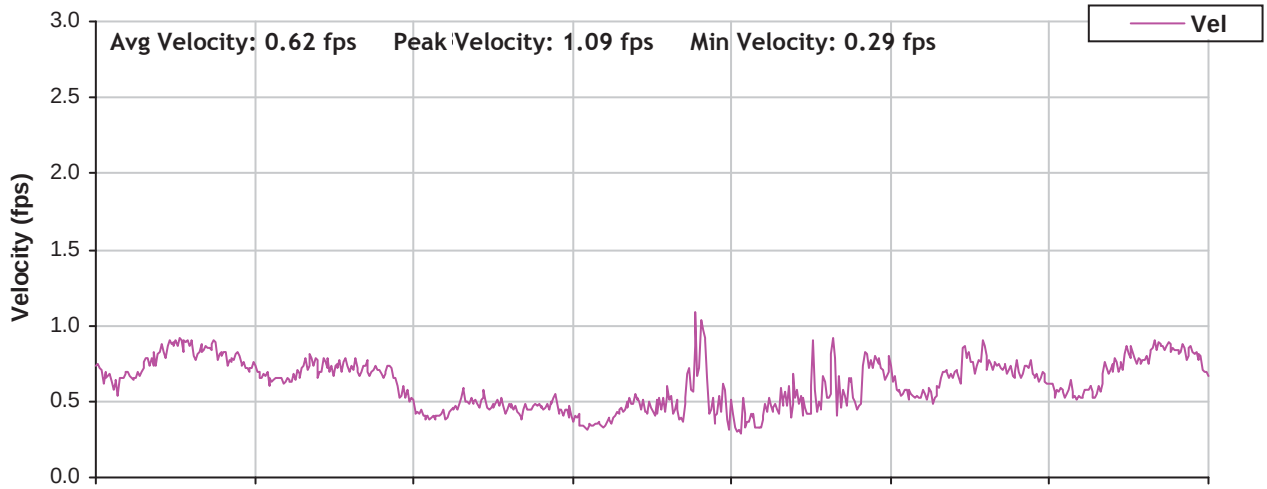
Monitoring Site:
Site 5A

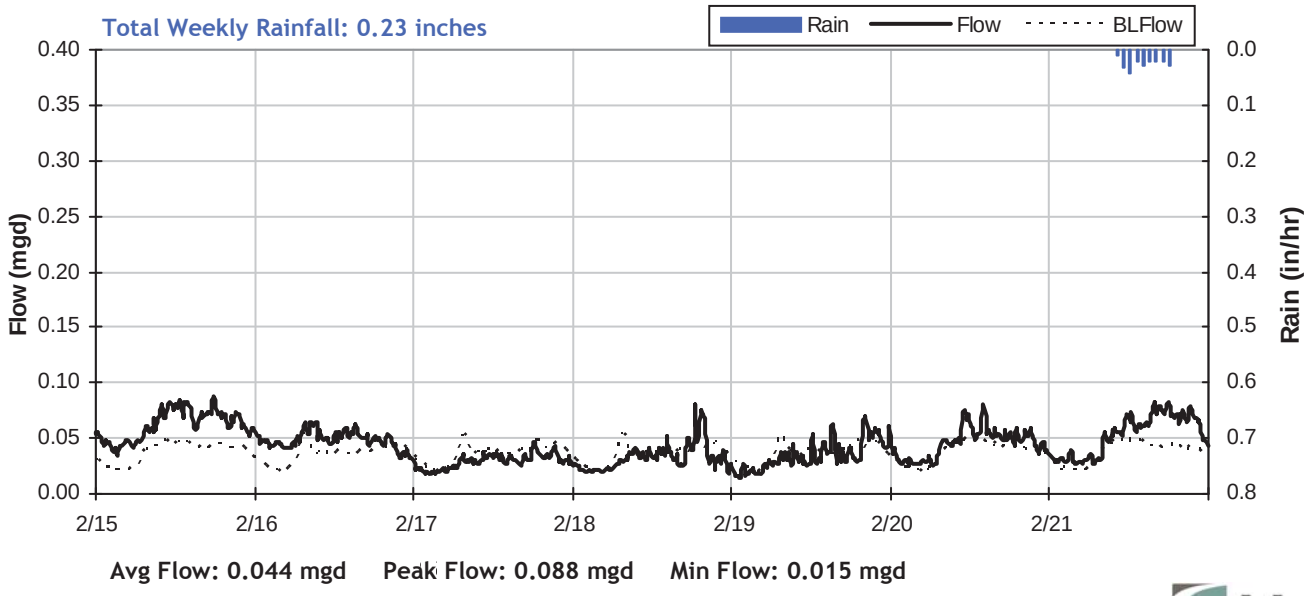


Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 5A



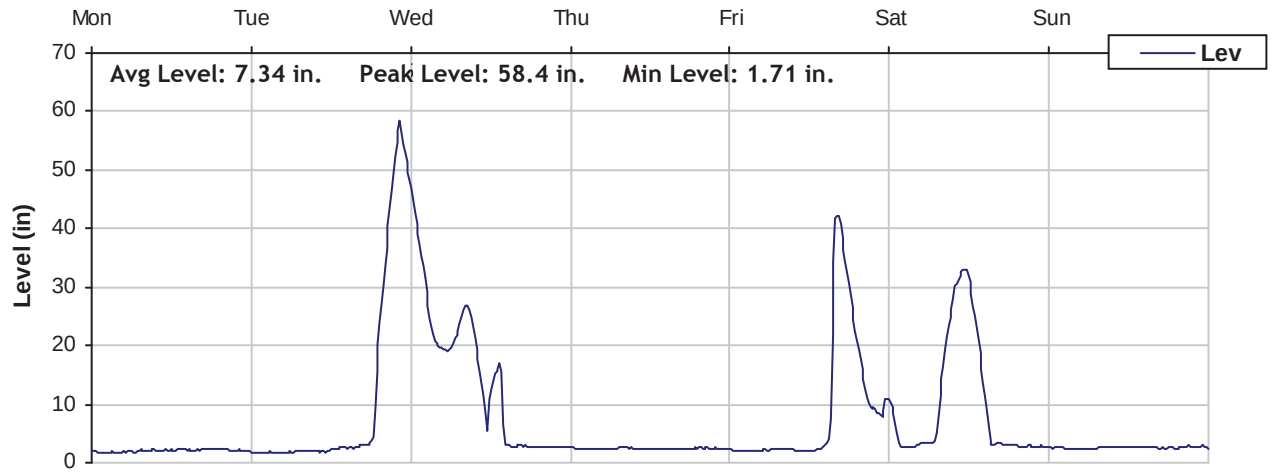


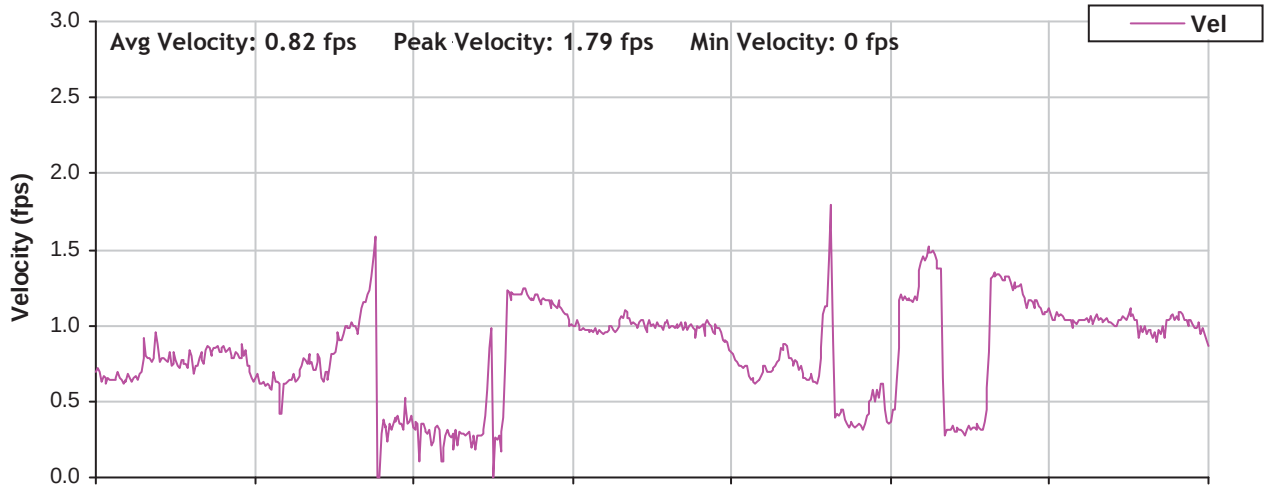


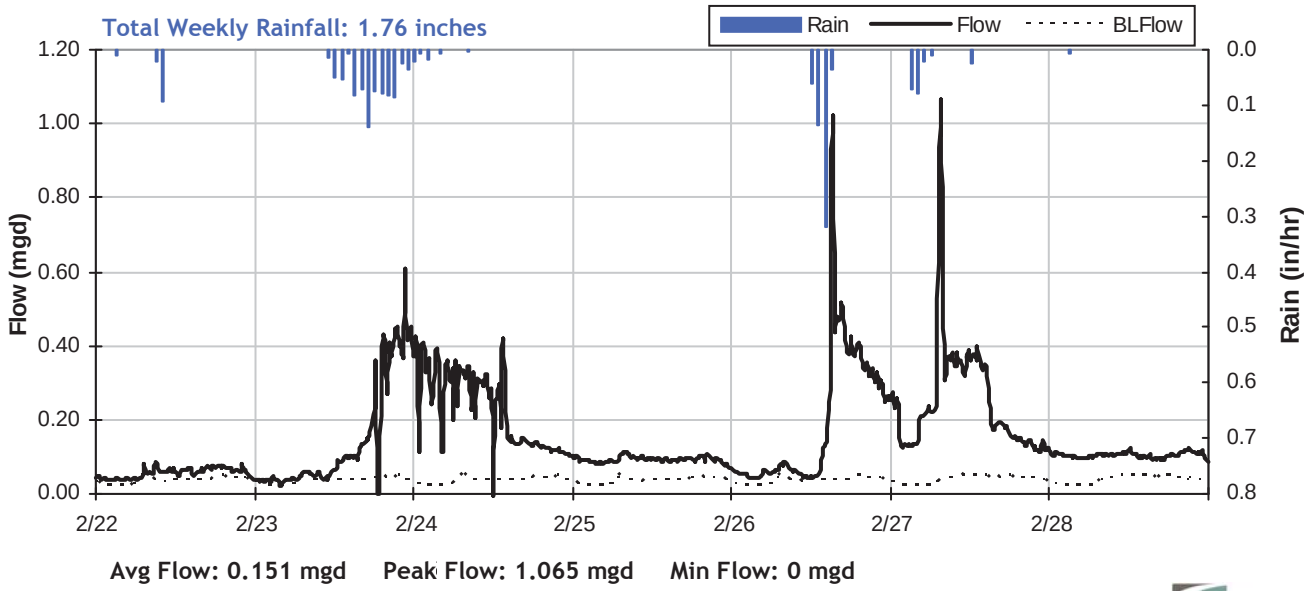
Avg Flow: 0.044 mgd Peak Flow: 0.088 mgd Min Flow: 0.015 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 5A



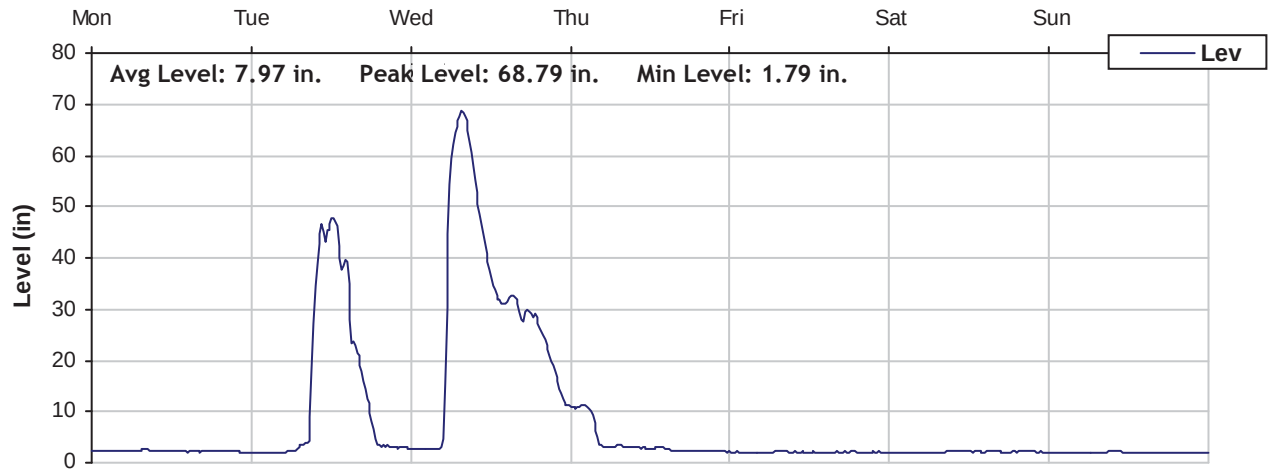


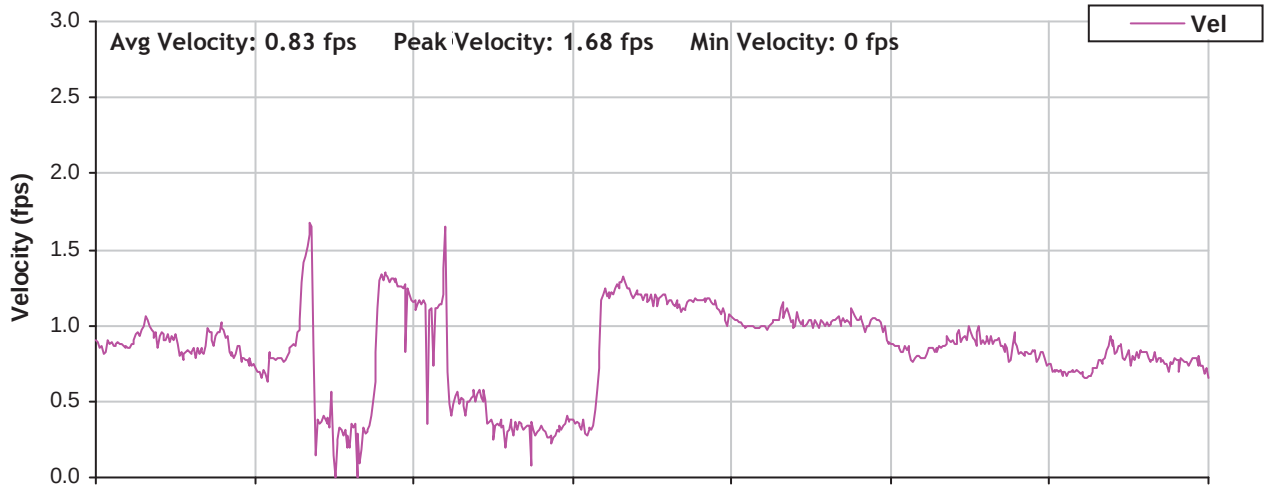


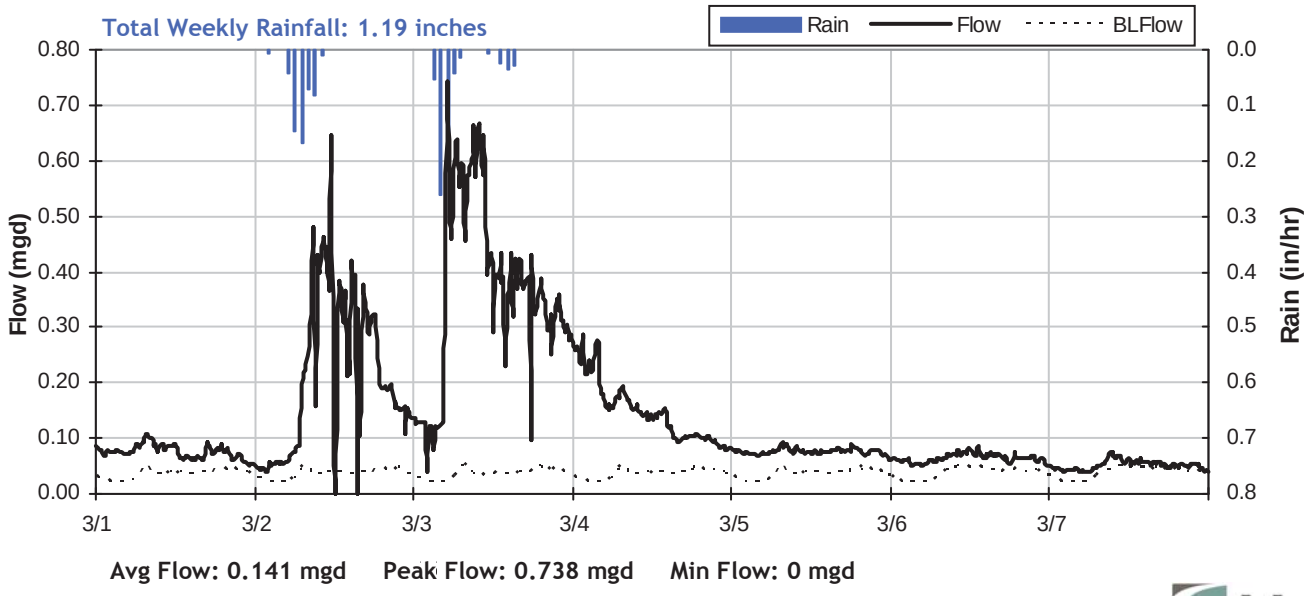
Avg Flow: 0.151 mgd Peak Flow: 1.065 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 5A



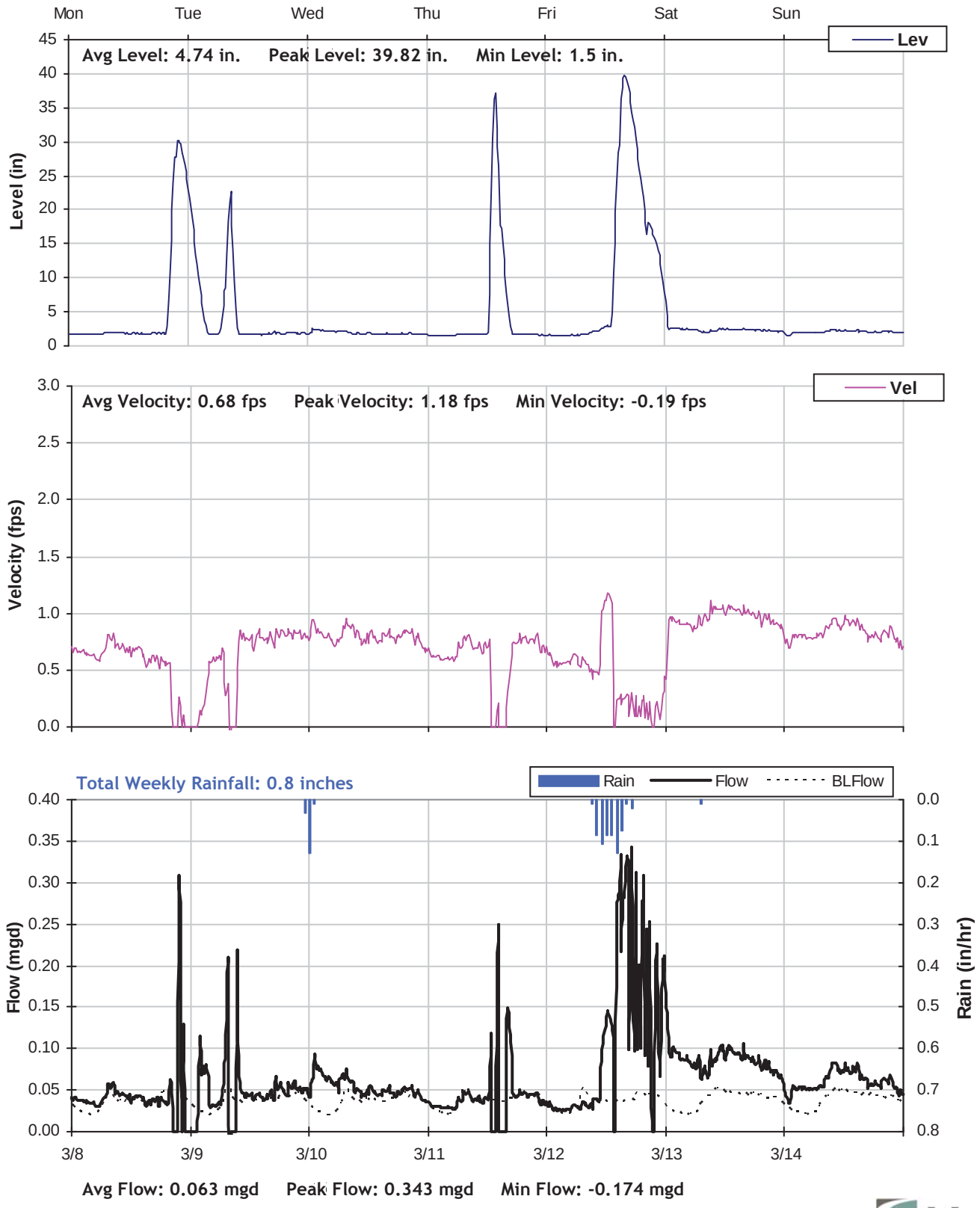




Avg Flow: 0.141 mgd Peak Flow: 0.738 mgd Min Flow: 0 mgd

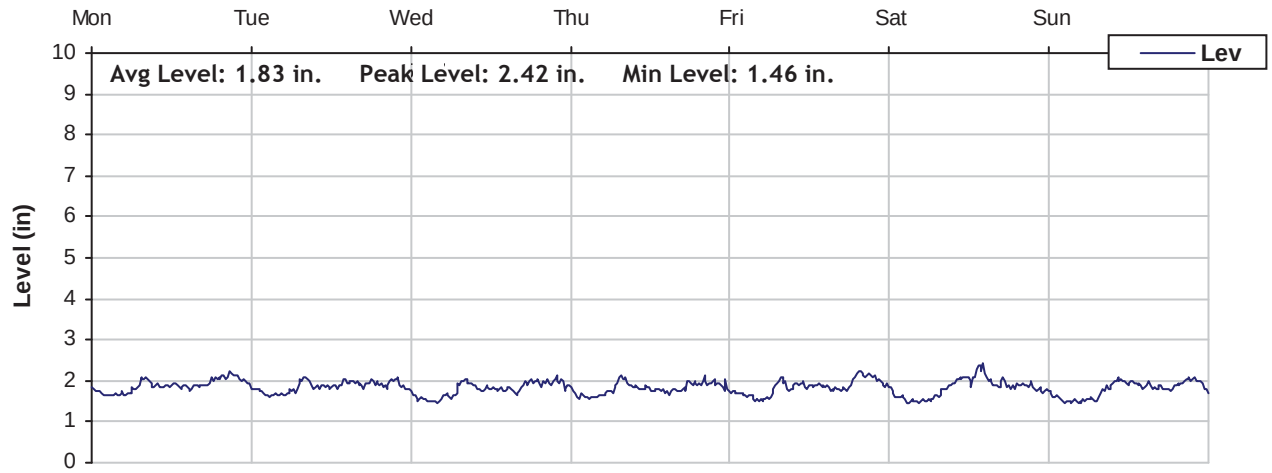
Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

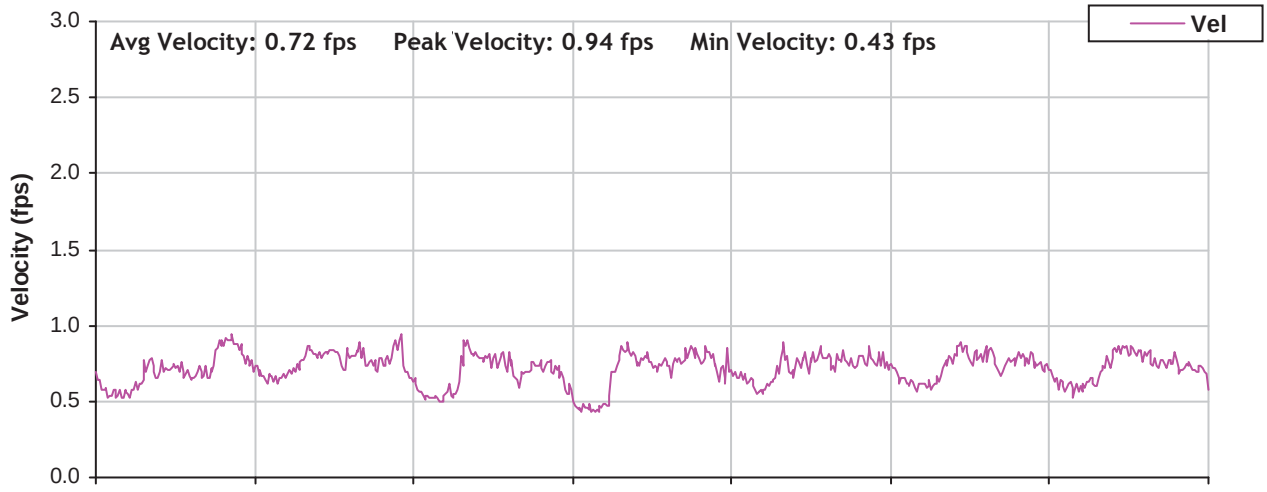
Monitoring Site:
Site 5A

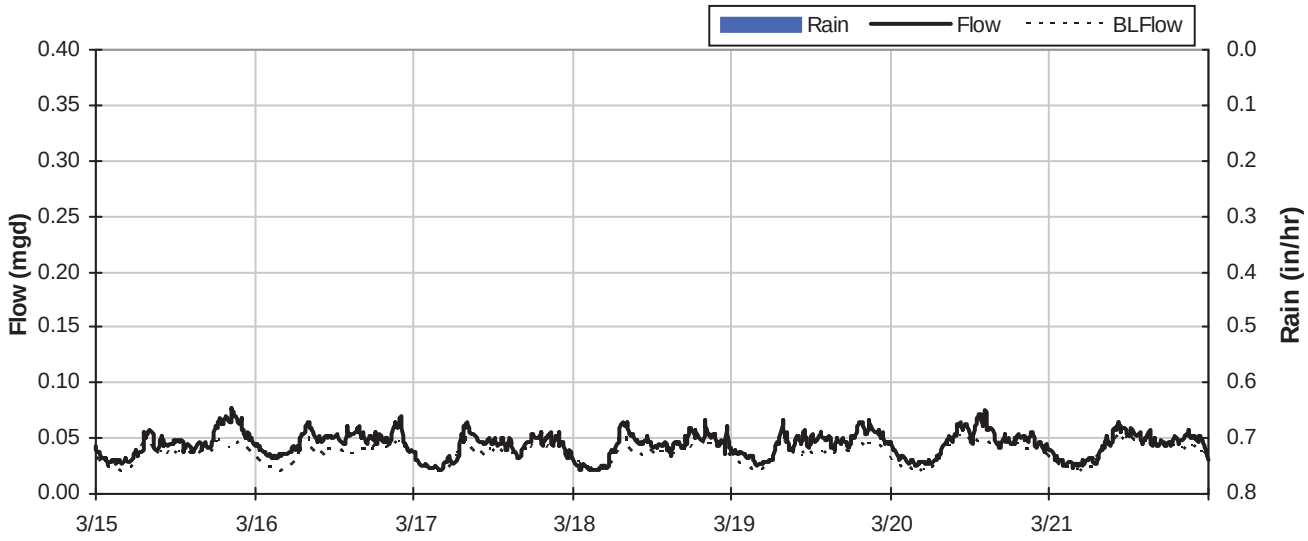


Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

Monitoring Site:
Site 5A



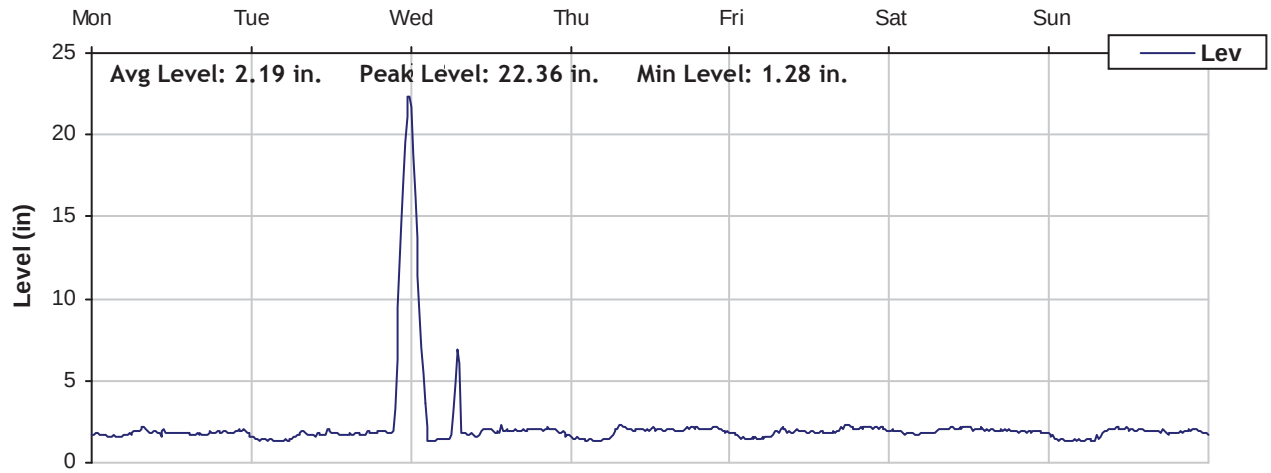


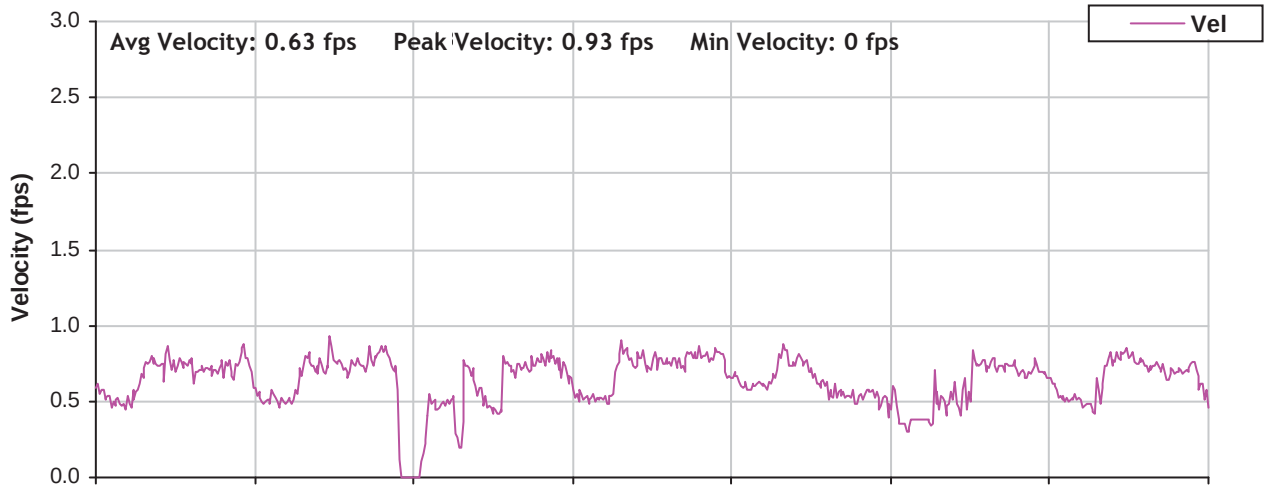


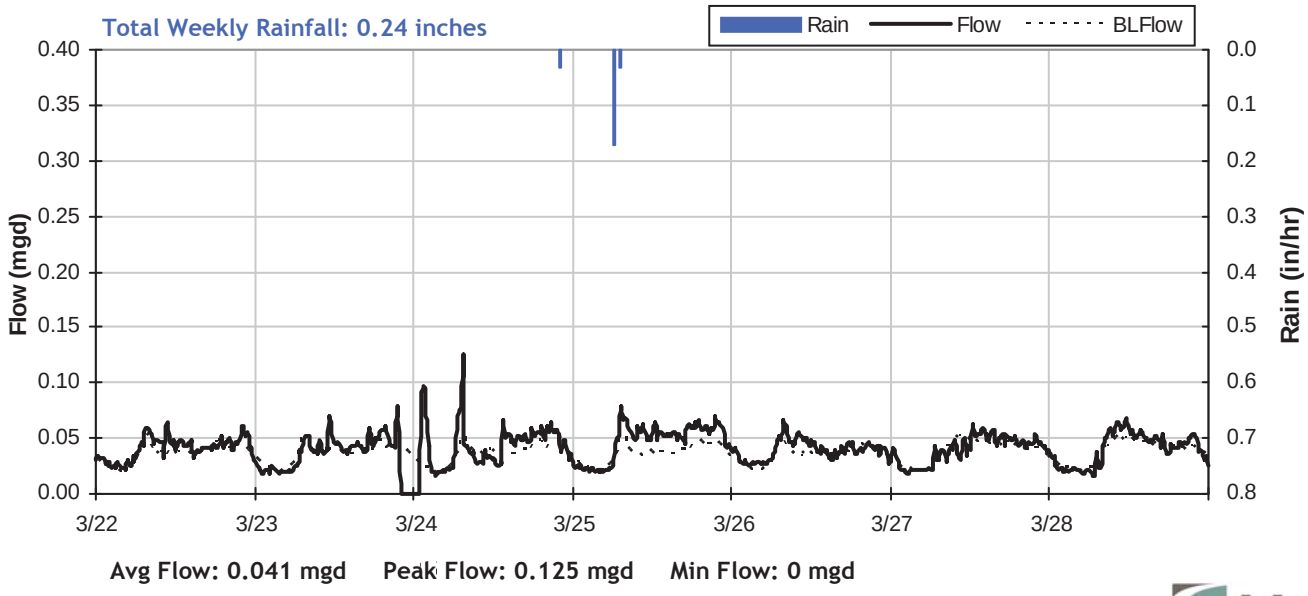
Avg Flow: 0.045 mgd Peak Flow: 0.077 mgd Min Flow: 0.021 mgd

Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 5A



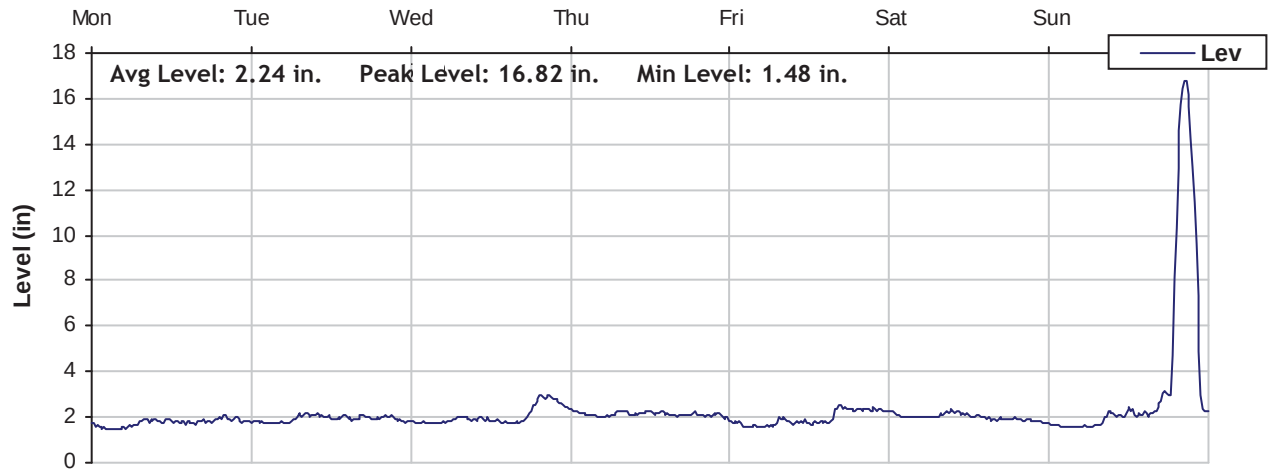


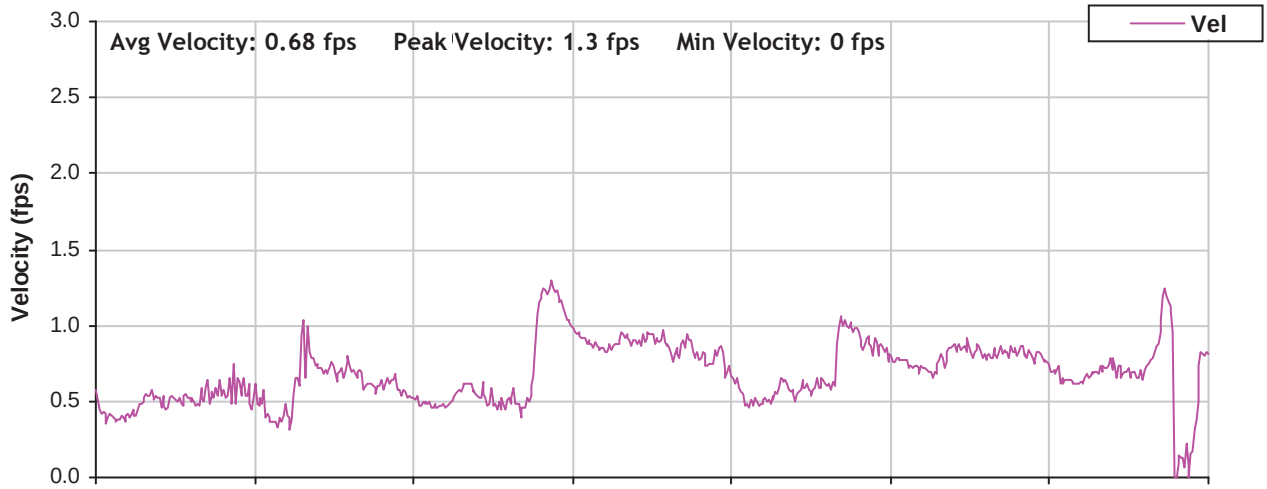


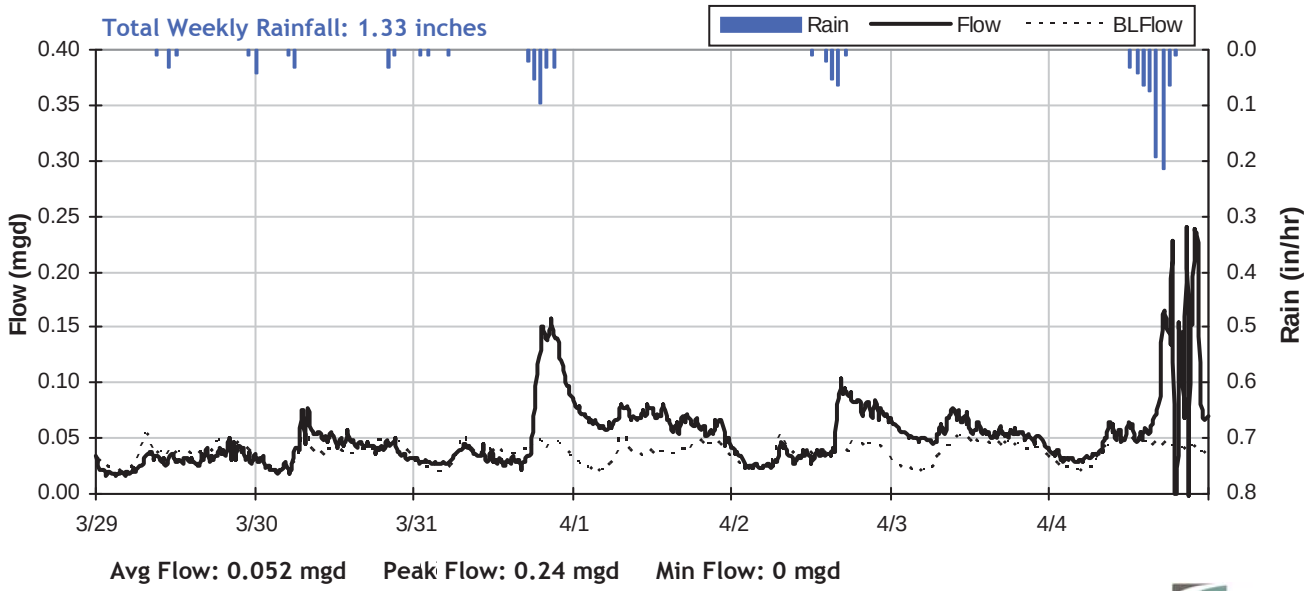
Avg Flow: 0.041 mgd Peak Flow: 0.125 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 5A



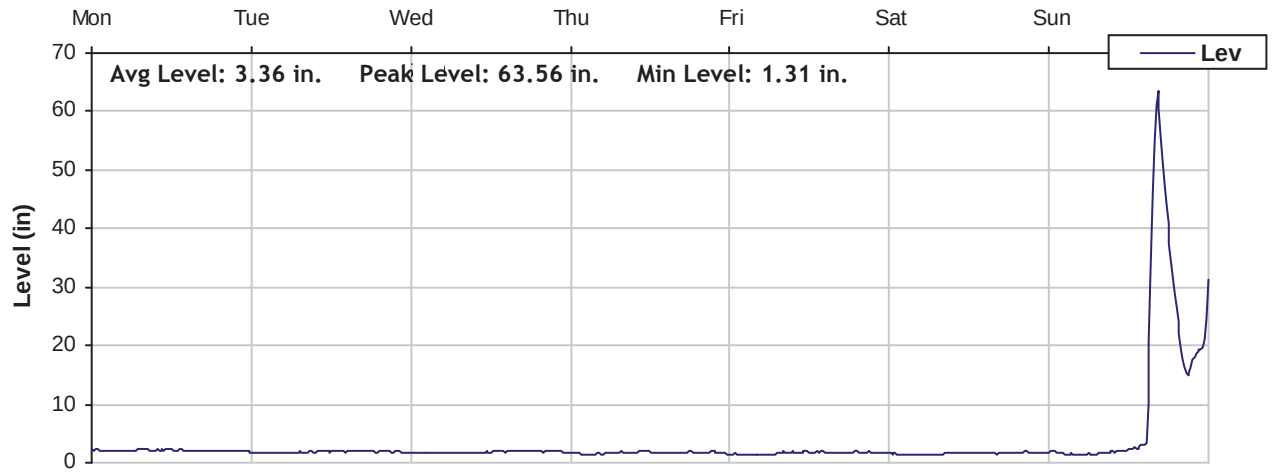


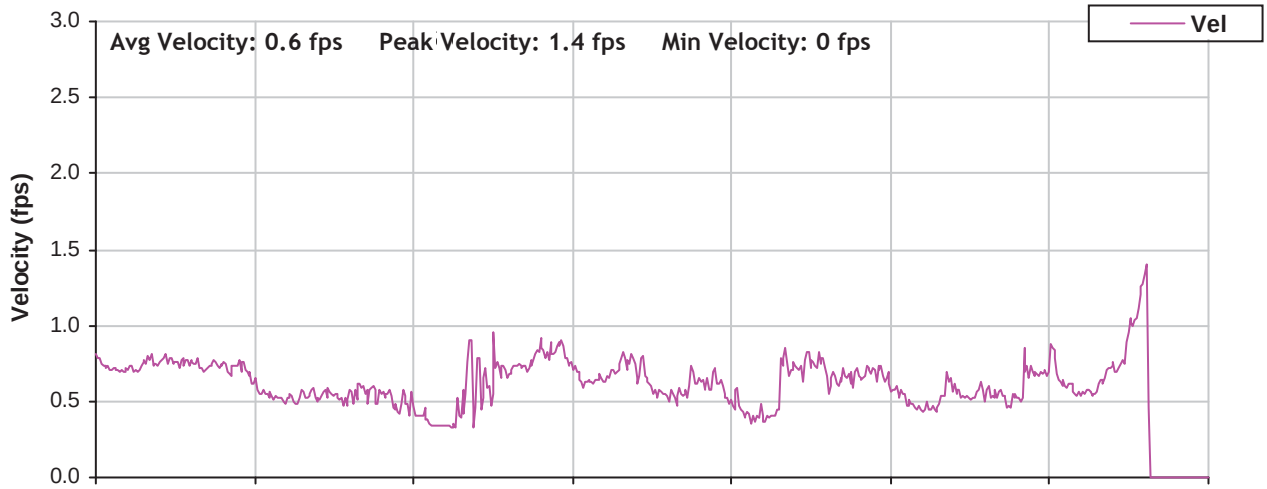


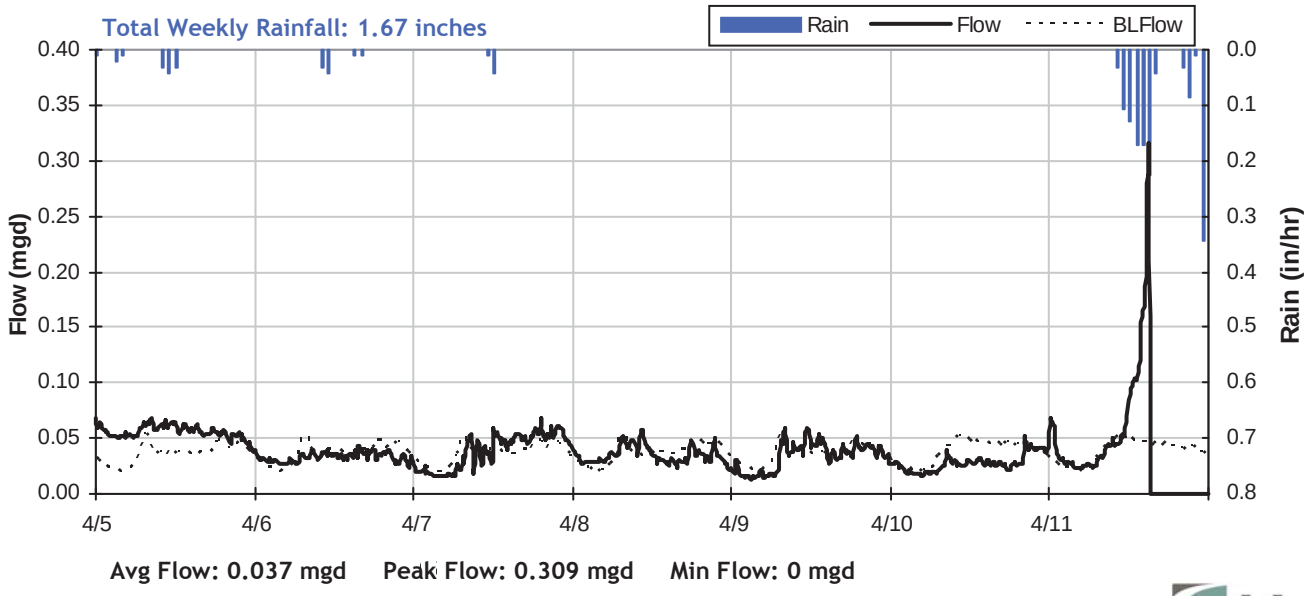
Avg Flow: 0.052 mgd Peak Flow: 0.24 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 5A



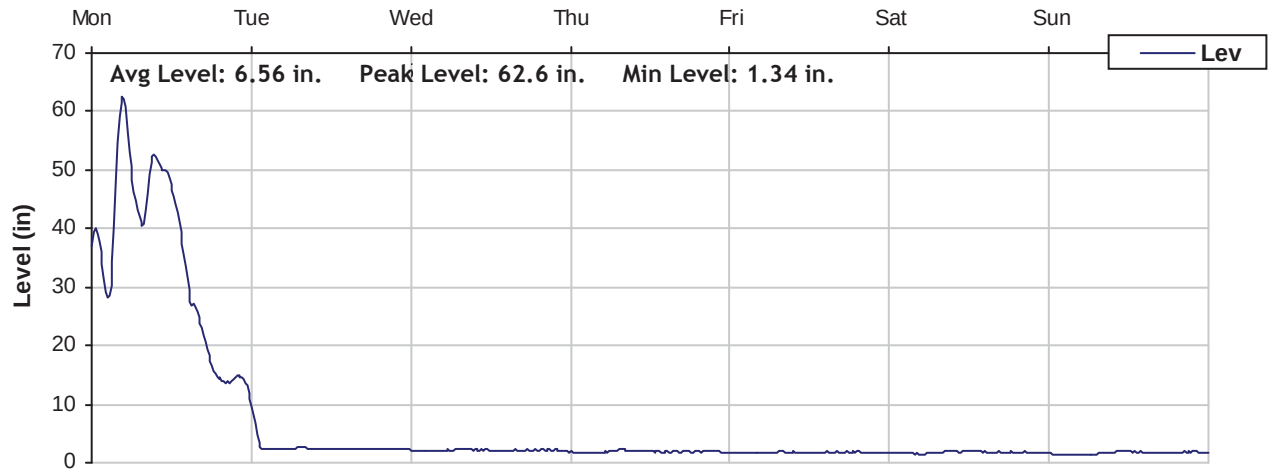


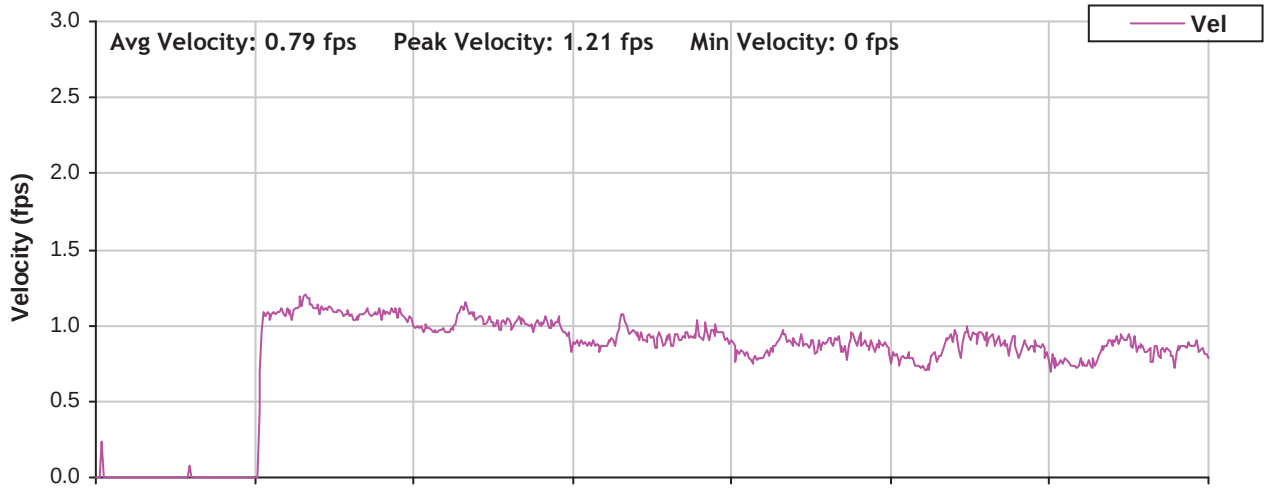


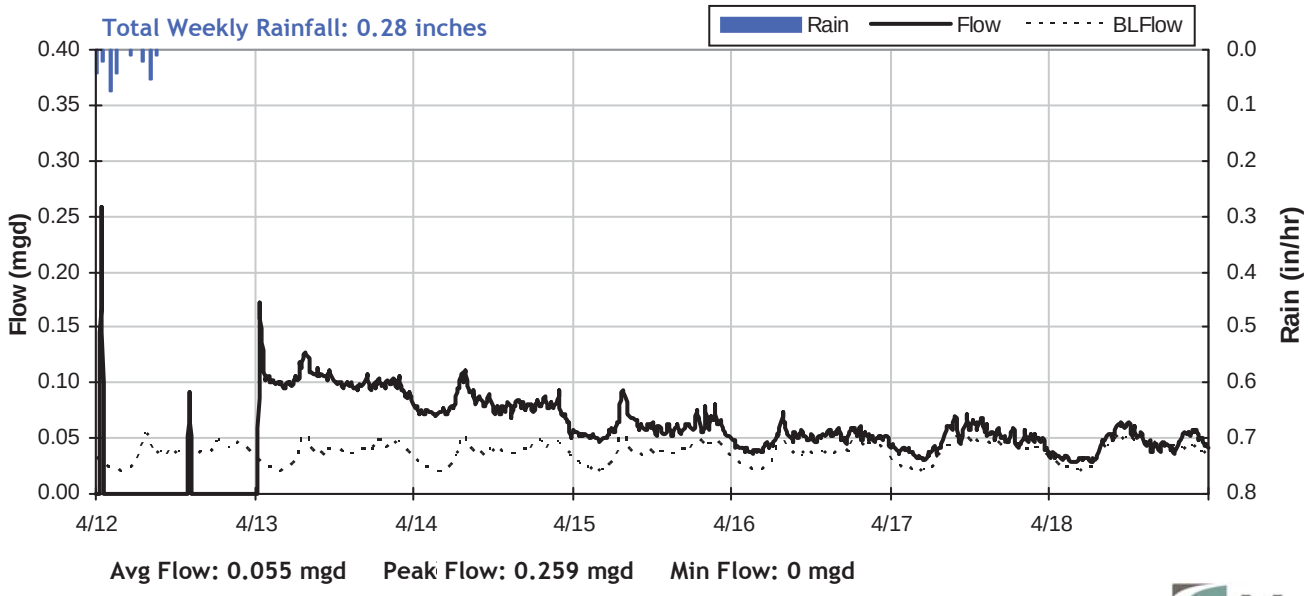
Avg Flow: 0.037 mgd Peak Flow: 0.309 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 5A



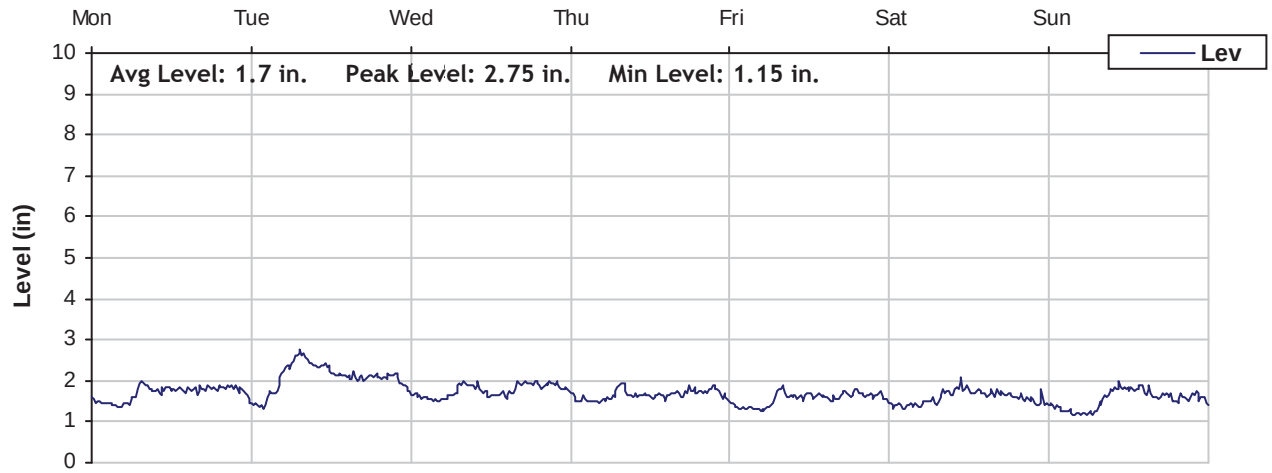


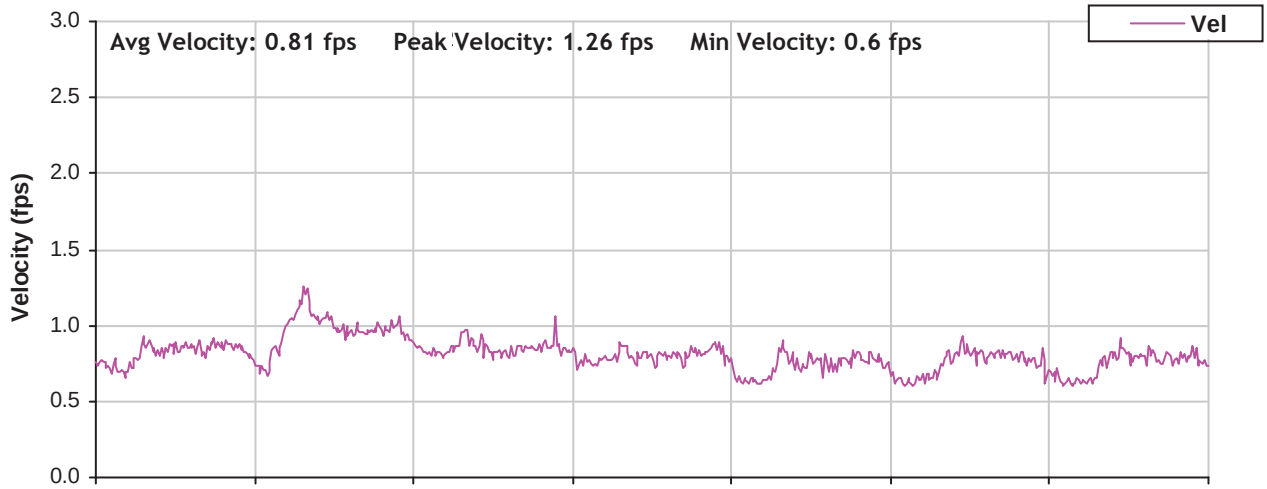


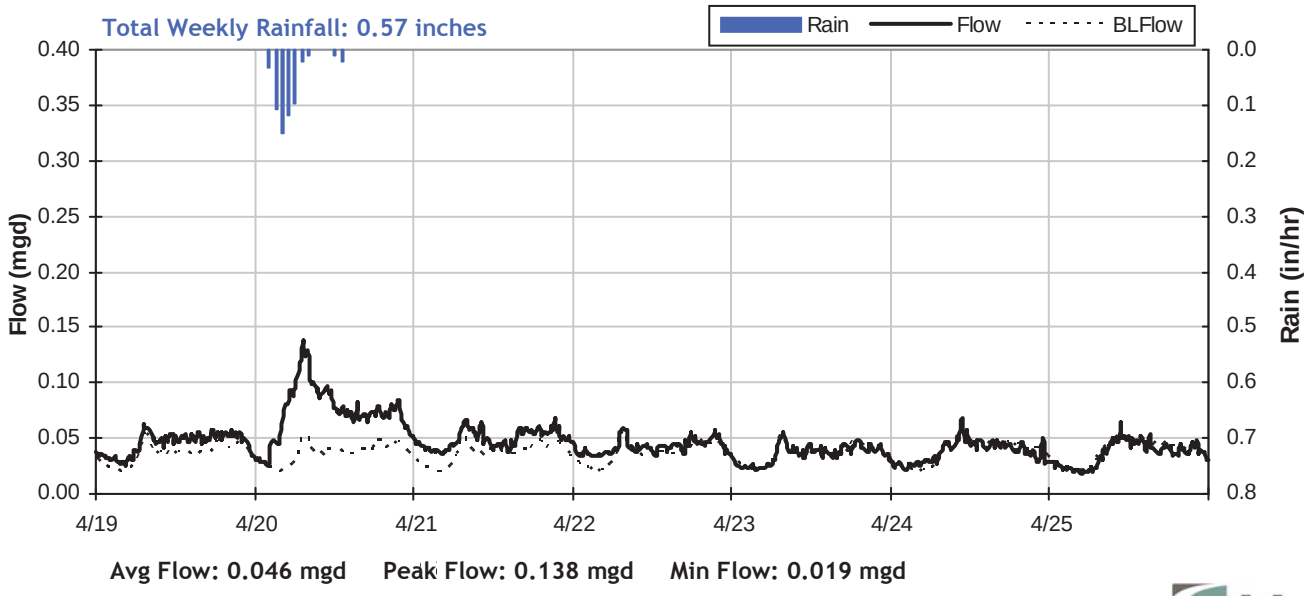
Avg Flow: 0.055 mgd Peak Flow: 0.259 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 5A



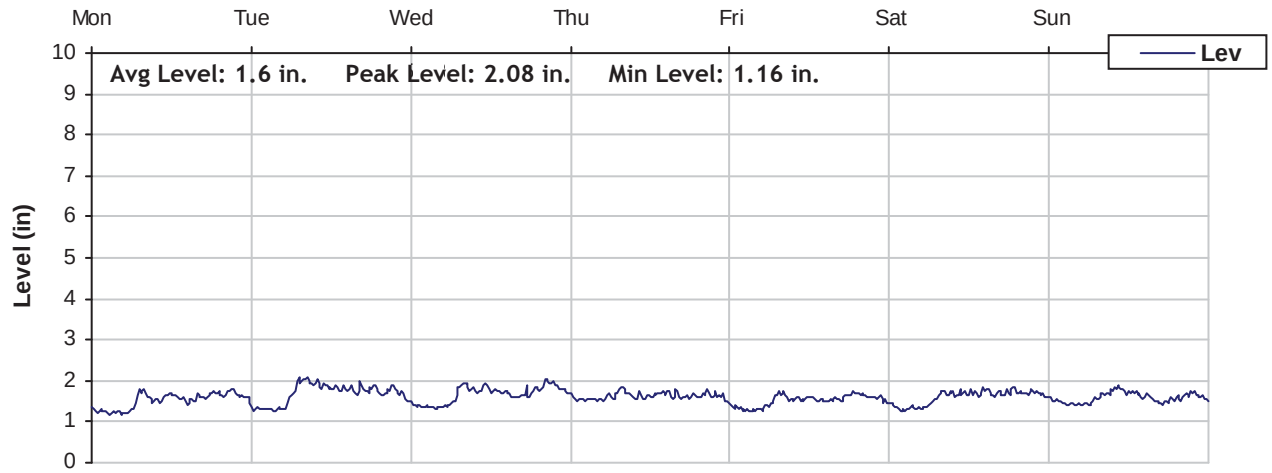


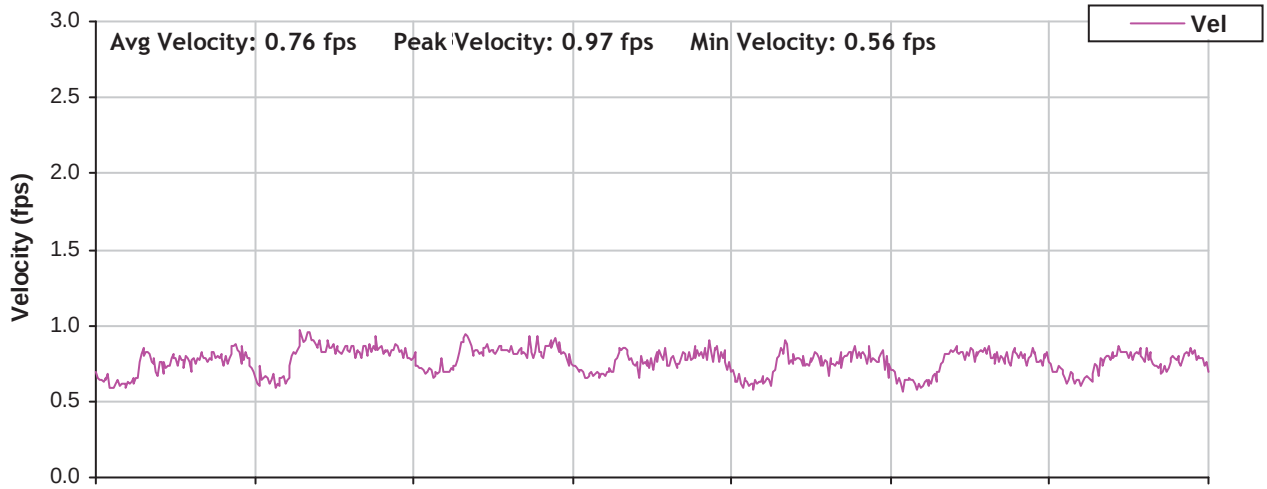


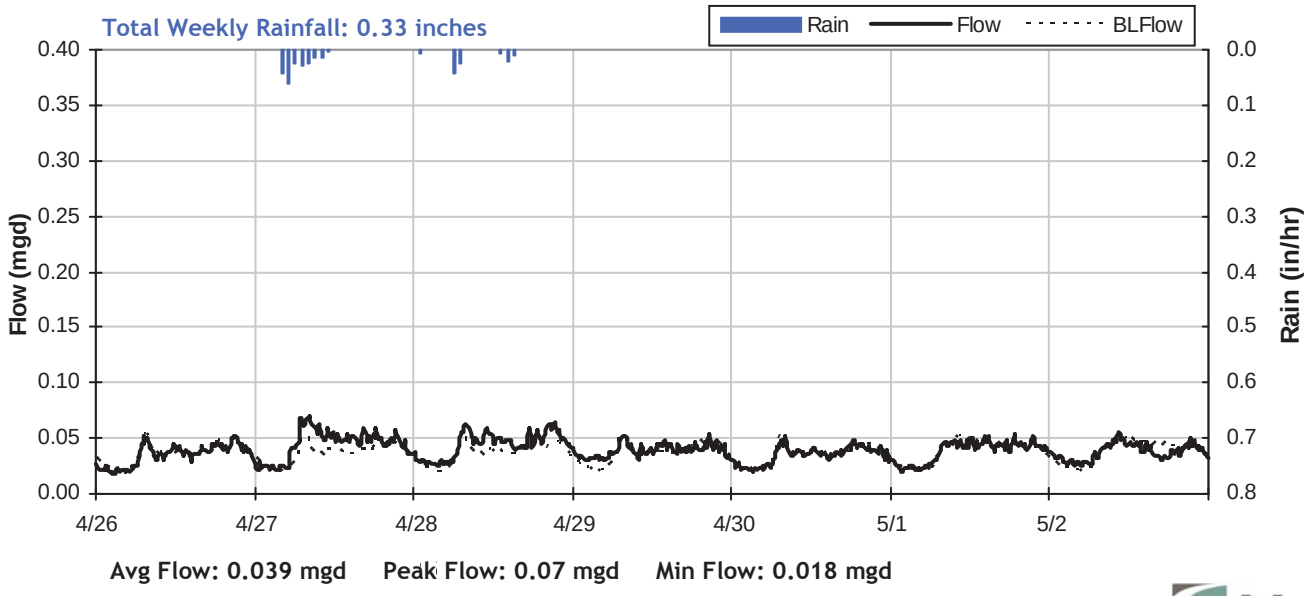
Avg Flow: 0.046 mgd Peak Flow: 0.138 mgd Min Flow: 0.019 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 5A



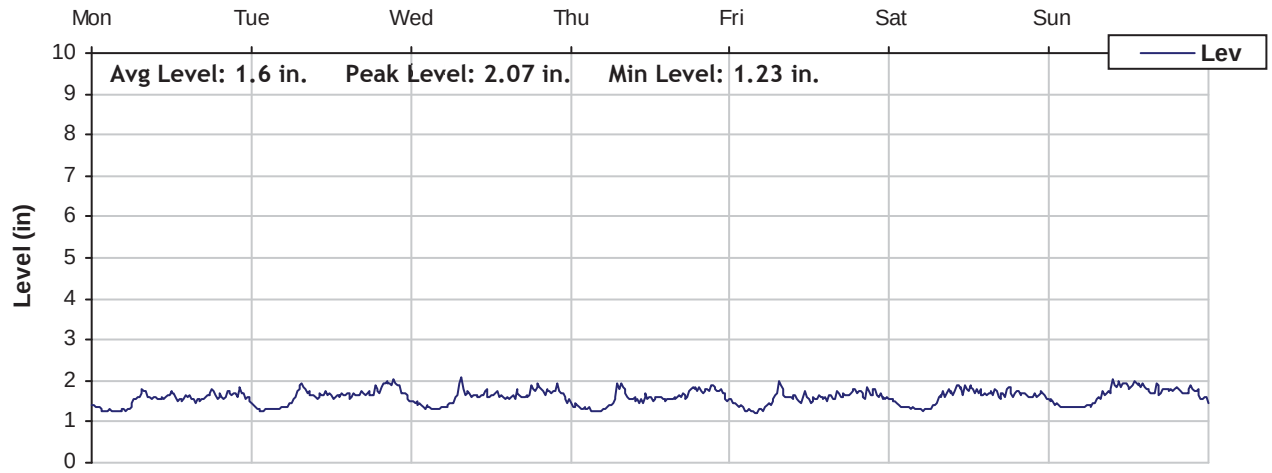


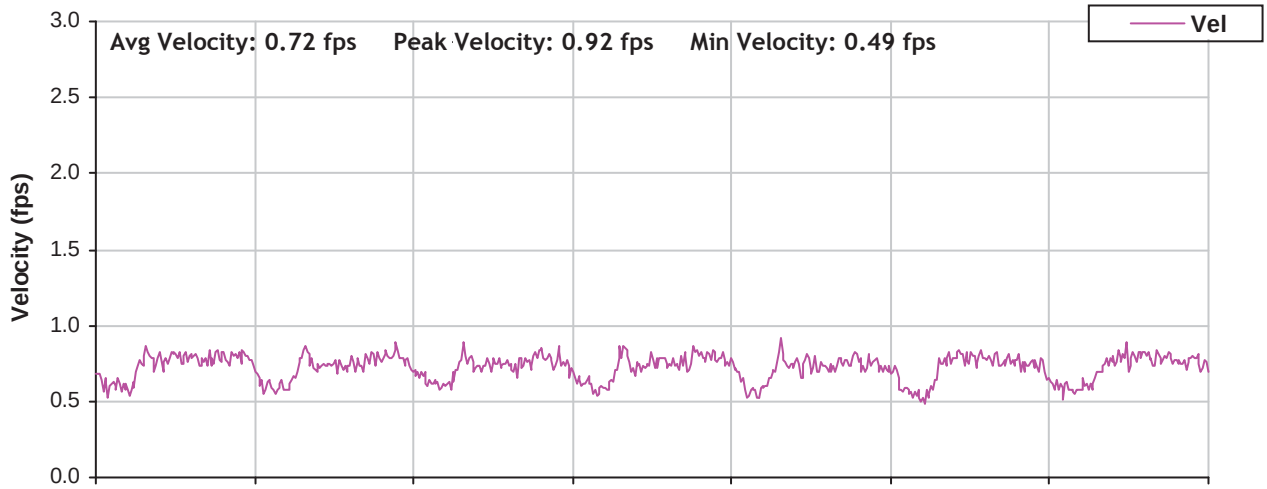


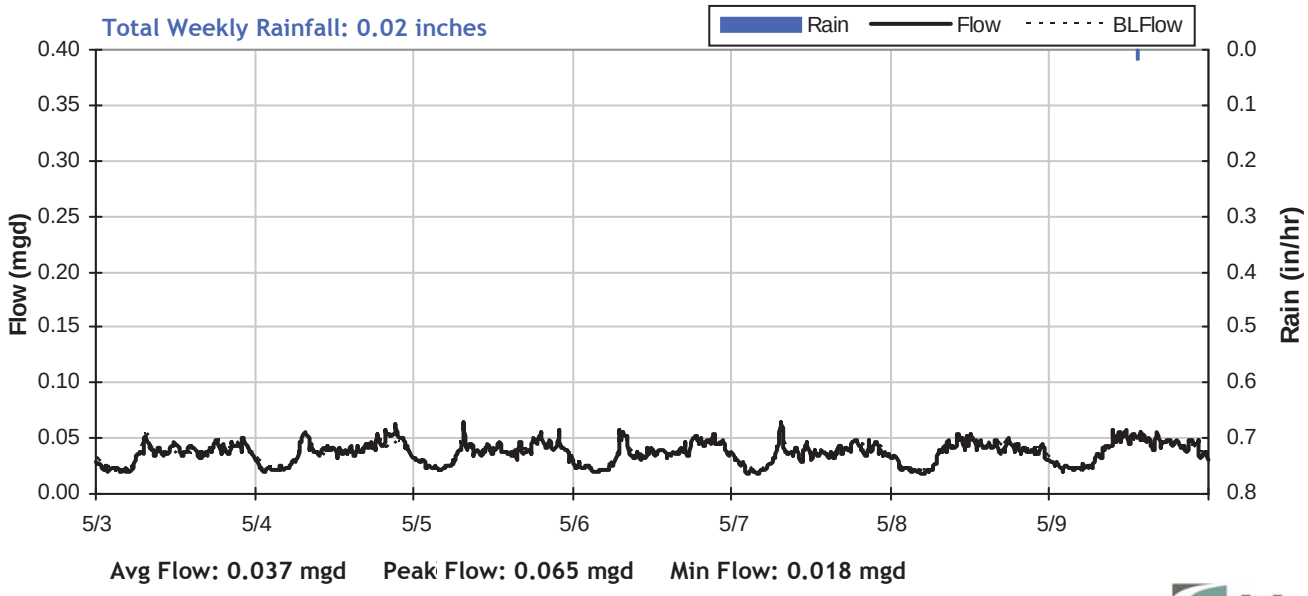
Avg Flow: 0.039 mgd Peak Flow: 0.07 mgd Min Flow: 0.018 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 5A



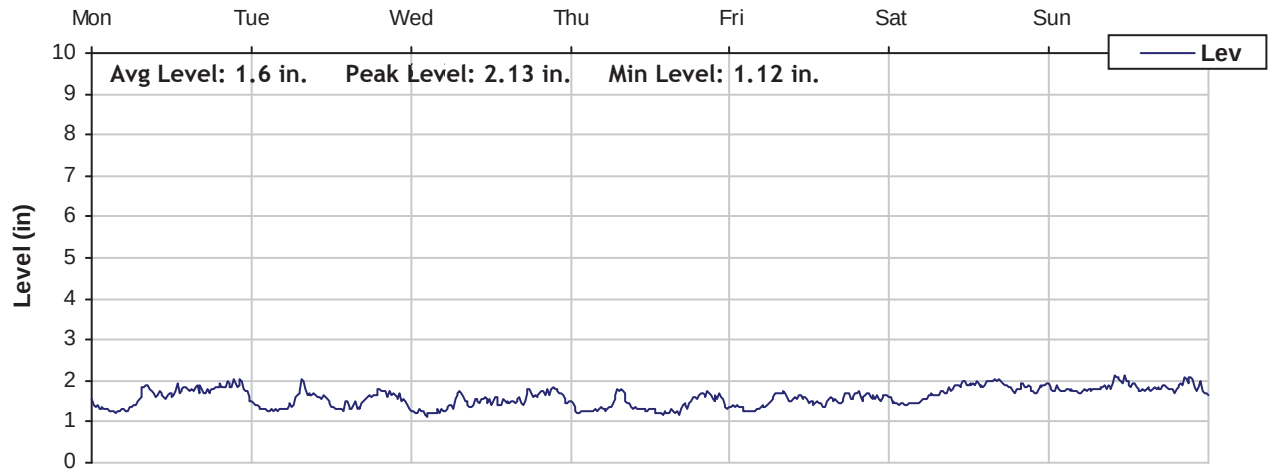


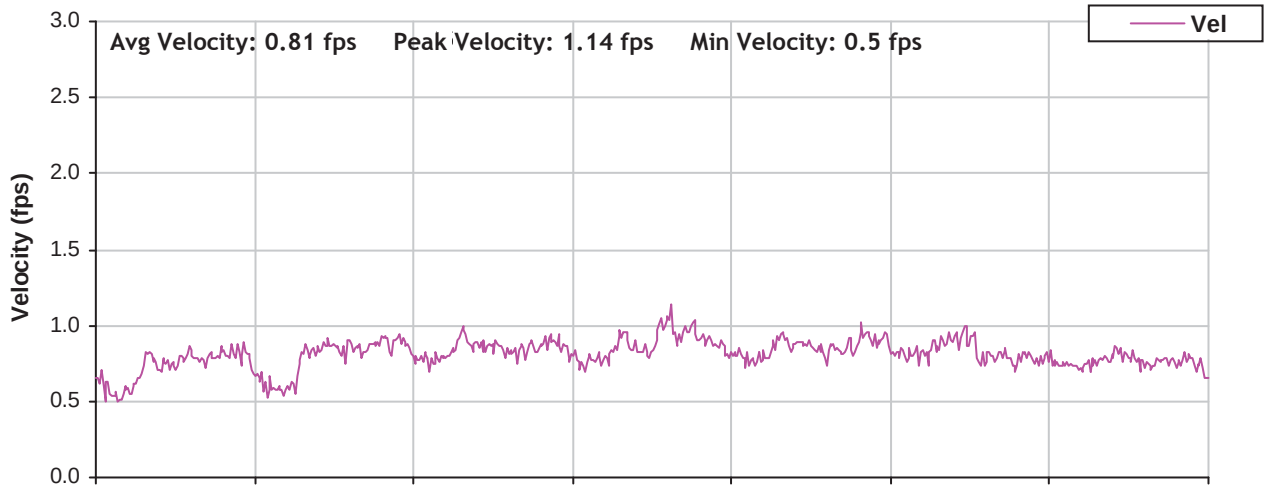


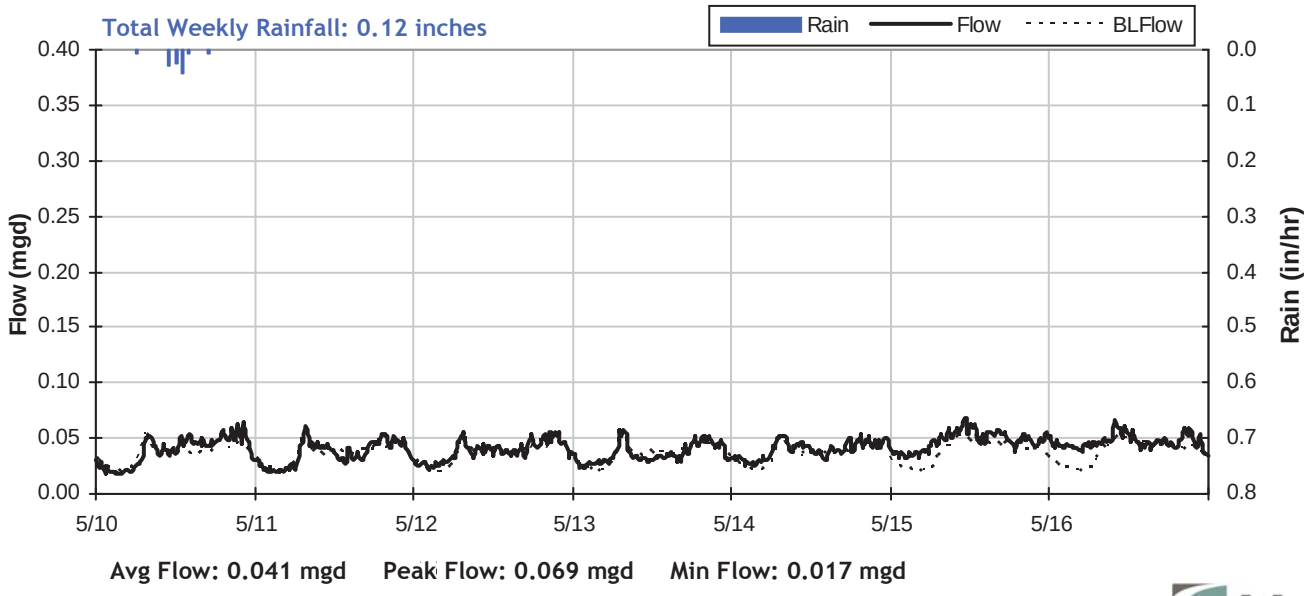
Avg Flow: 0.037 mgd Peak Flow: 0.065 mgd Min Flow: 0.018 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 5A



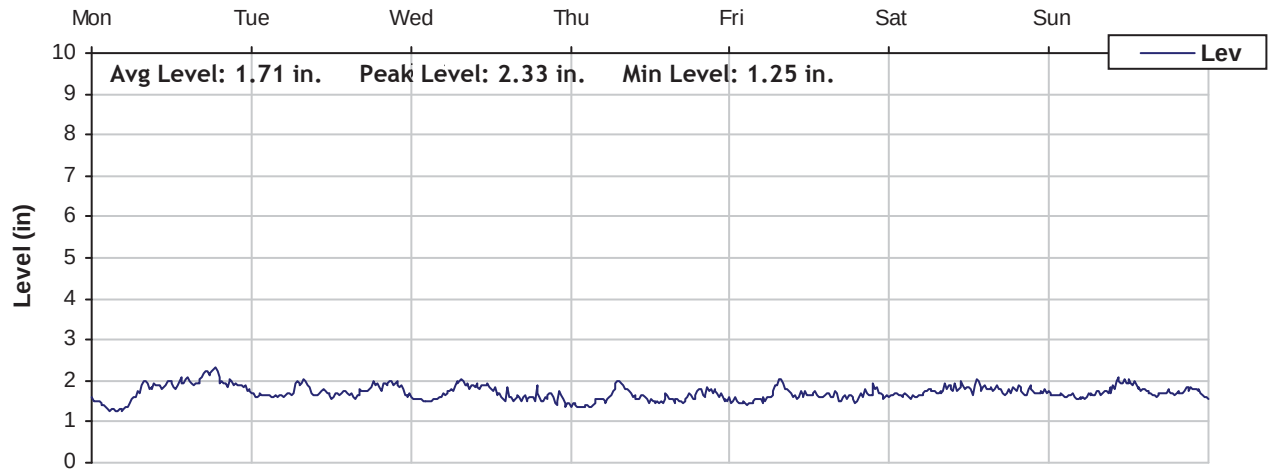


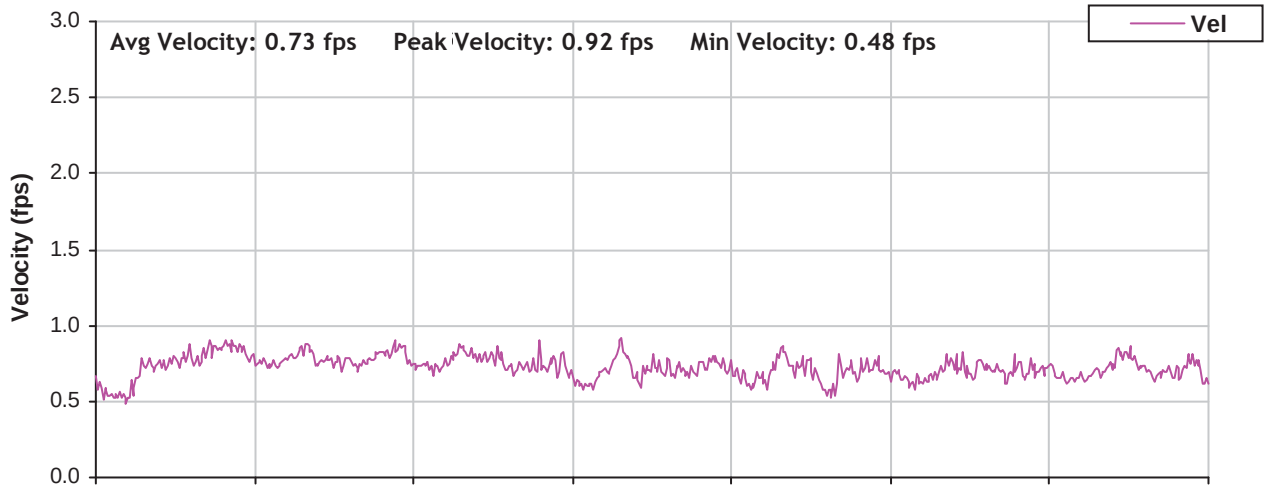


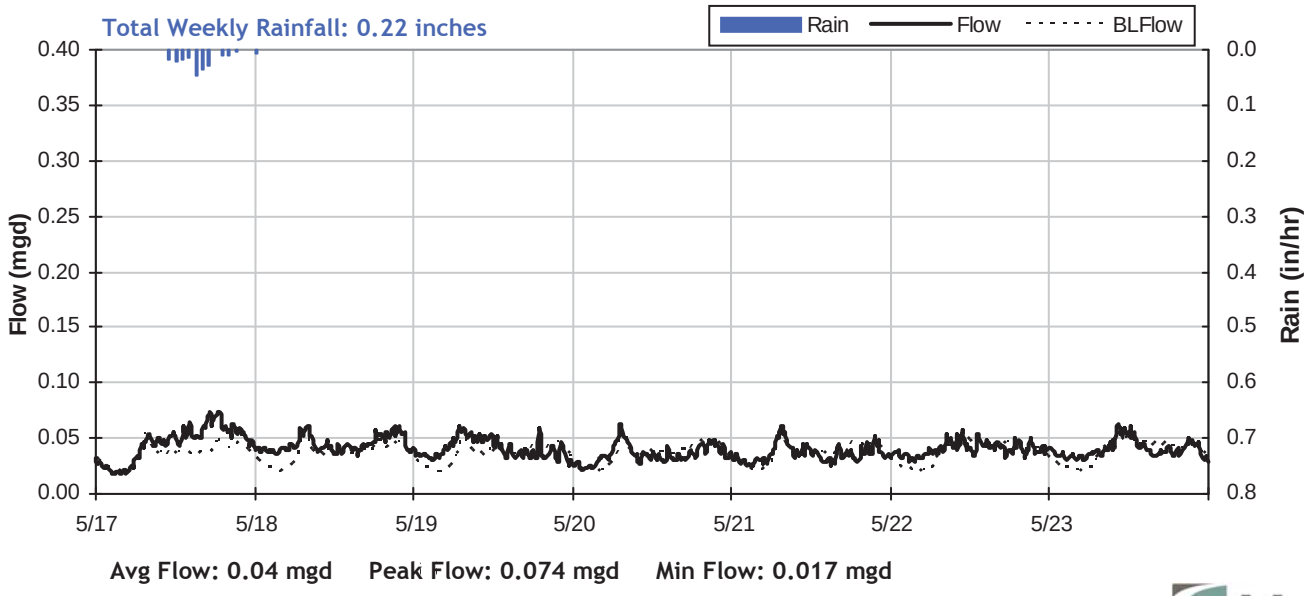
Avg Flow: 0.041 mgd Peak Flow: 0.069 mgd Min Flow: 0.017 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 5A



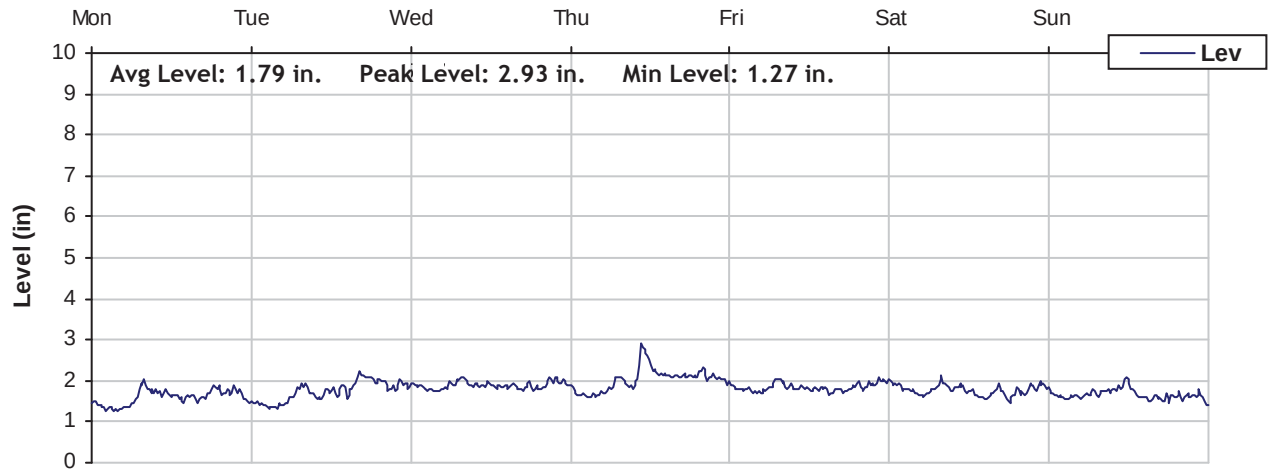


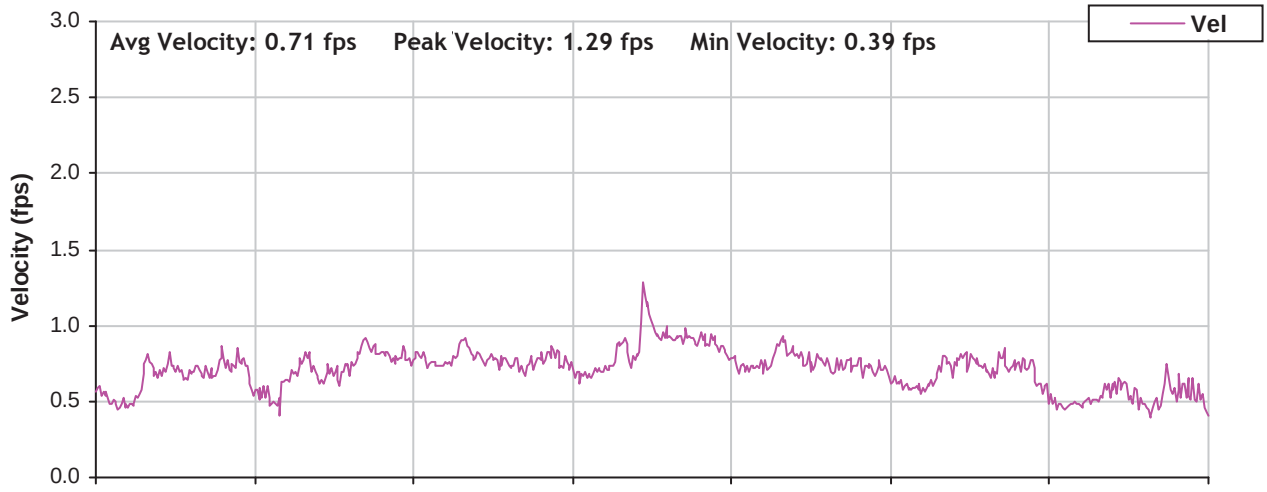


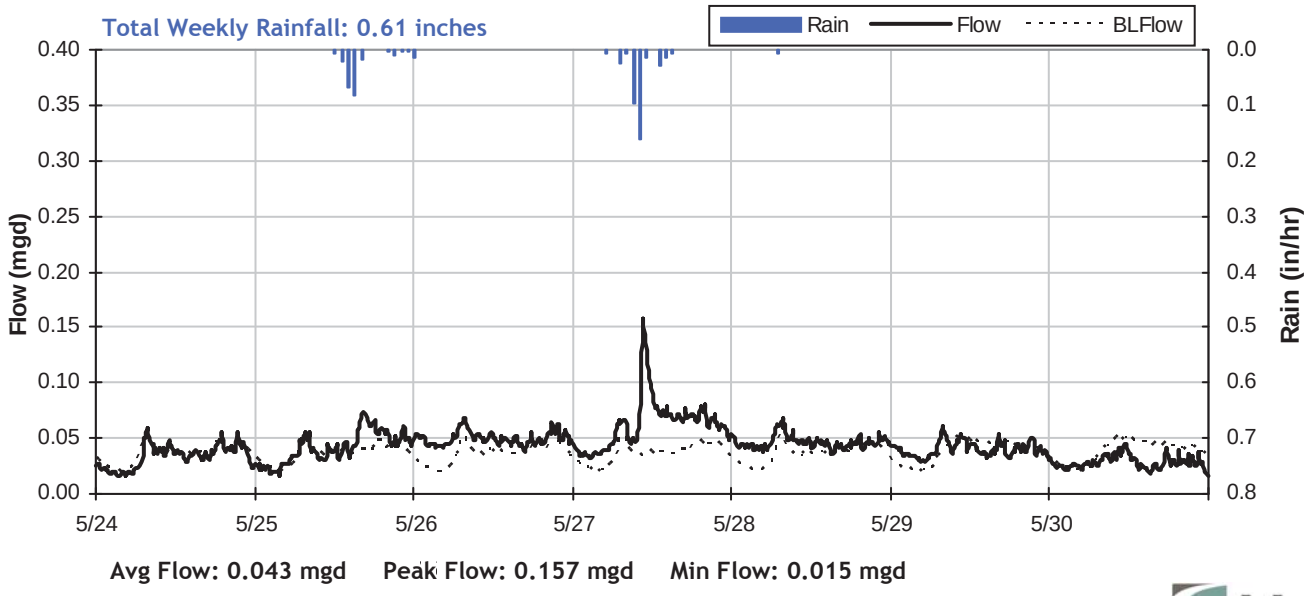
Avg Flow: 0.04 mgd Peak Flow: 0.074 mgd Min Flow: 0.017 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 5A





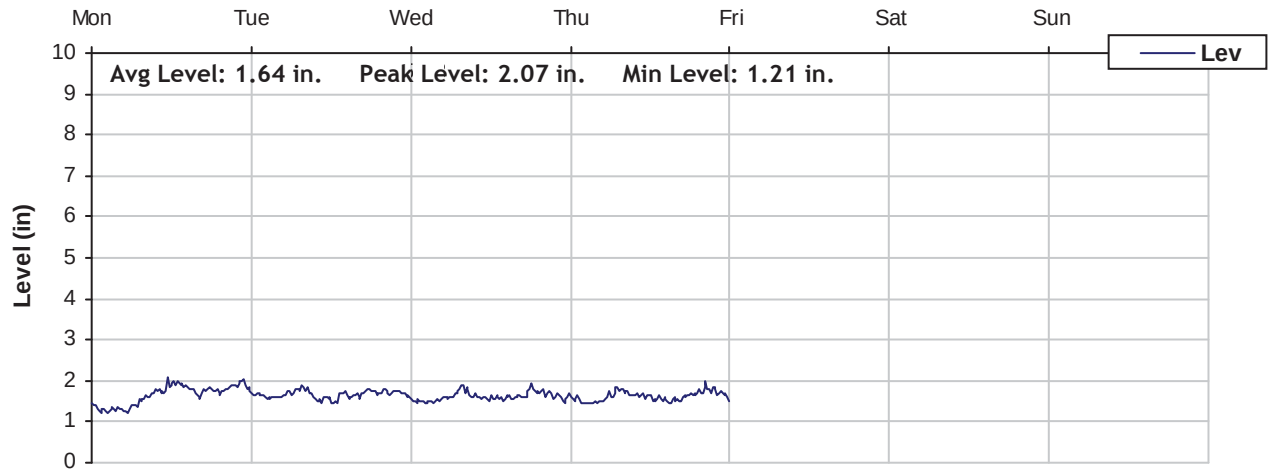


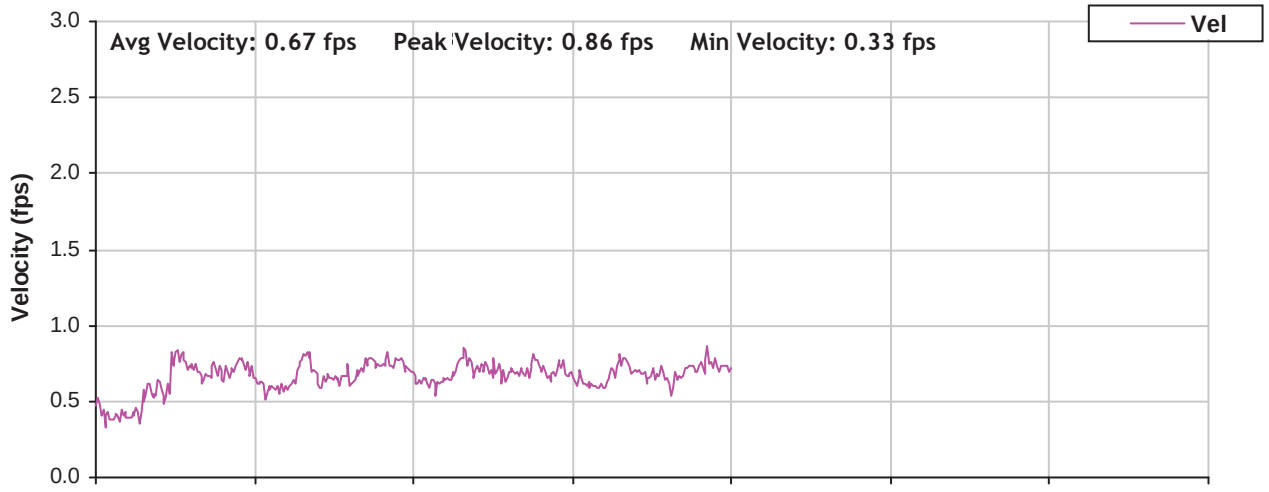
Avg Flow: 0.043 mgd Peak Flow: 0.157 mgd Min Flow: 0.015 mgd

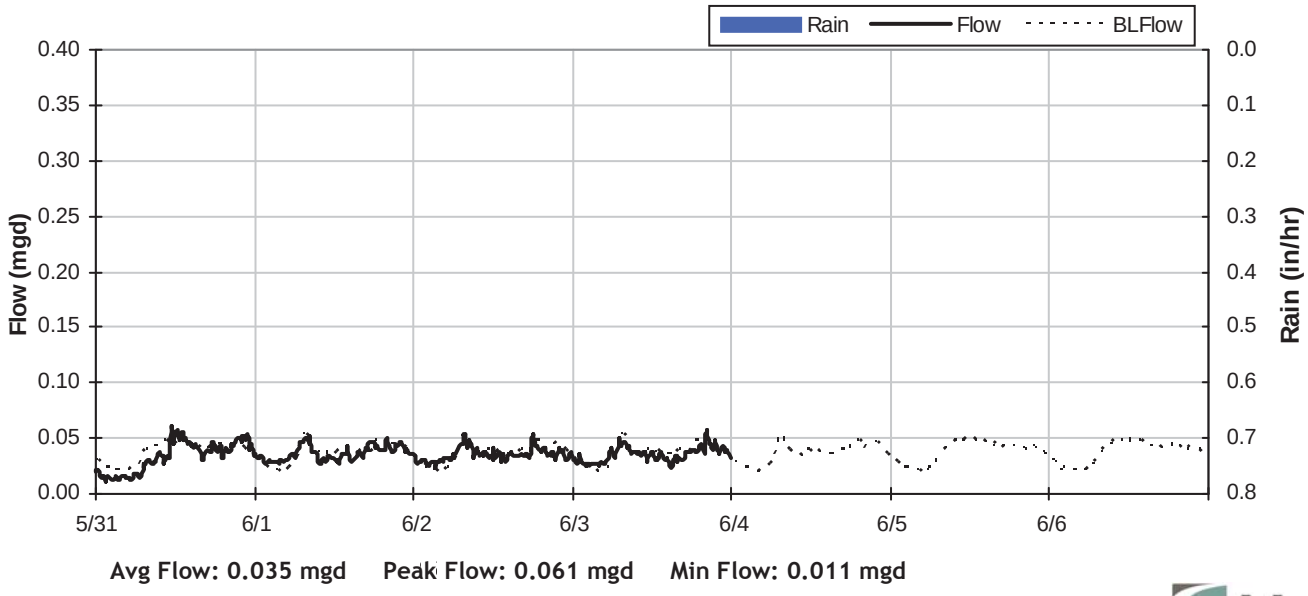
V&A

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 5A







Avg Flow: 0.035 mgd Peak Flow: 0.061 mgd Min Flow: 0.011 mgd

Temporary Flow Monitoring Study

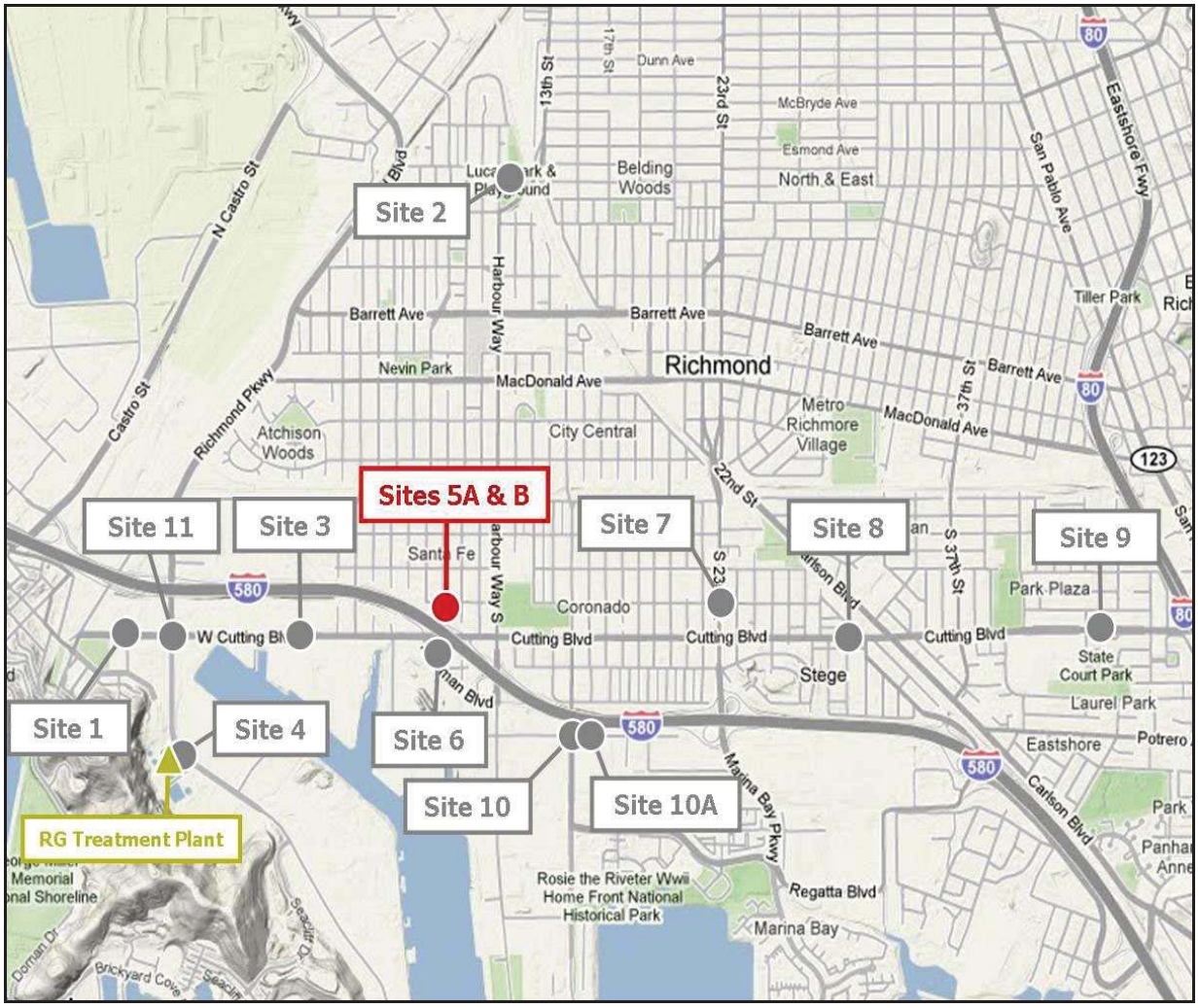
Sanitary Sewer Collection System

Monitoring Site: Site 5B

Location: S 8th Street; south of Virginia Avenue at the dead end

Size/Type Line: 54-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 5B

Location: S 8th Street; south of Virginia Avenue at the dead end

Latitude: 37.9257°

Longitude: -122.3622°

Rim Elevation: 11 *feet above sea level*

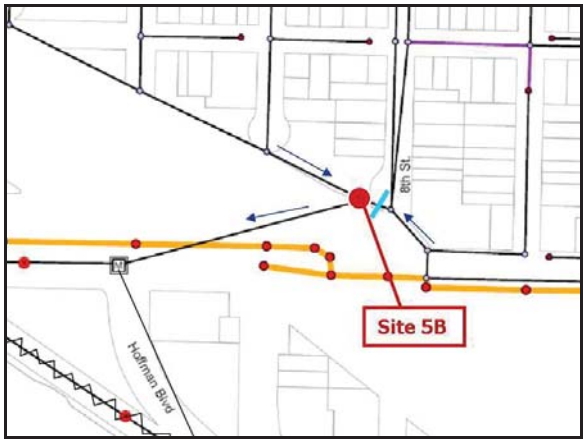
Diameter: 54 *inches*

Average Dry Weather Flow: 1.968 *mgd*

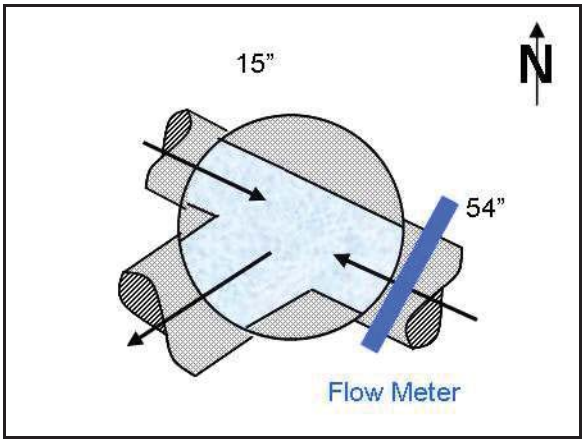
Peak Measured Flow: 17.699 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

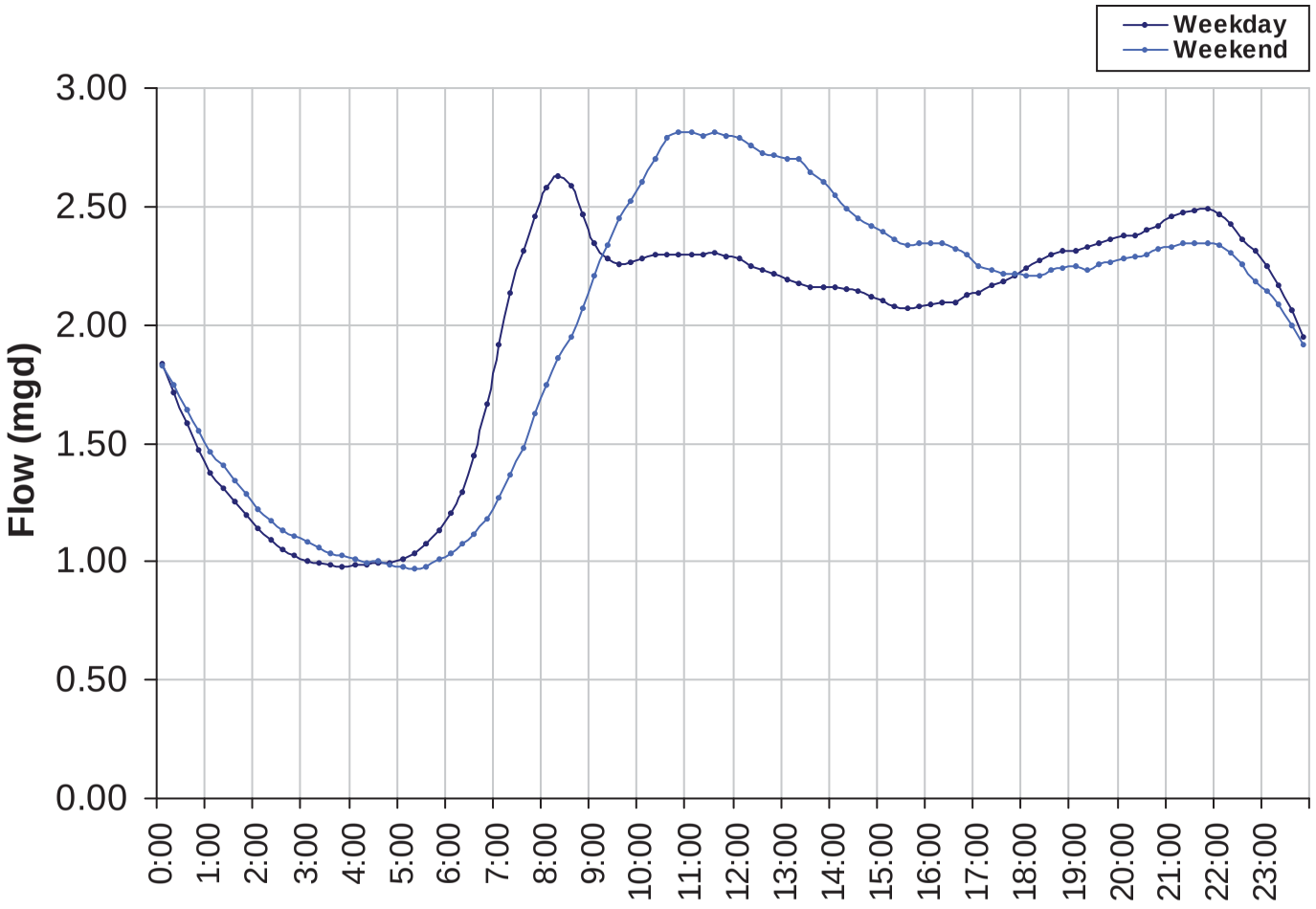


Street View Photo

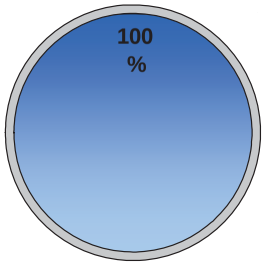
Plan View Photo

Average Dry Weather Flow

Monitoring Site:
Site 5B

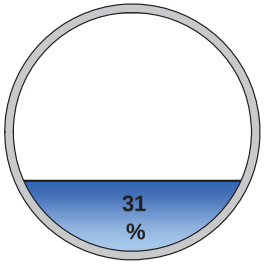


Peak Measured Flow:
17.70 *mgd*



Peak measured flow shown in weekly graphs on following pages

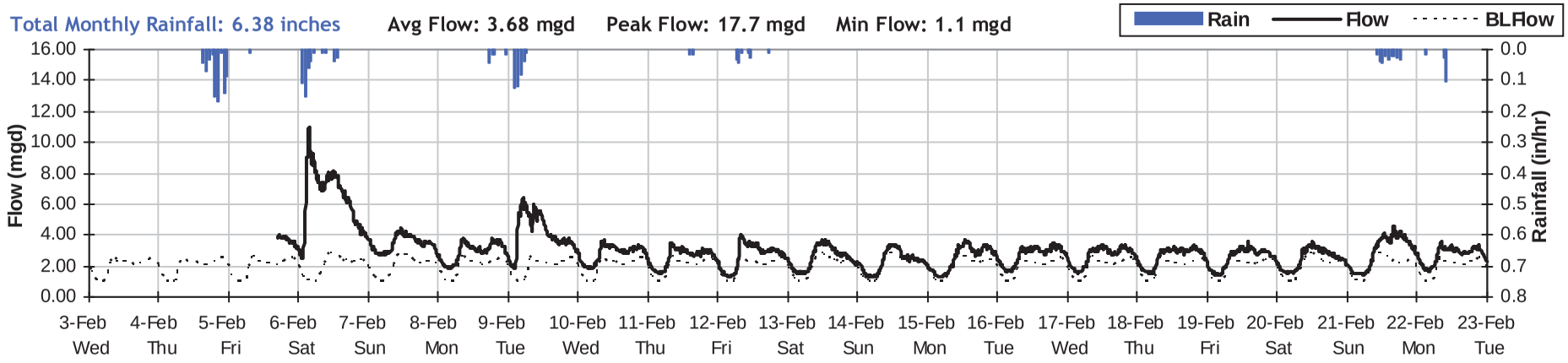
Average Dry Weather Flow:
1.97 *mgd*

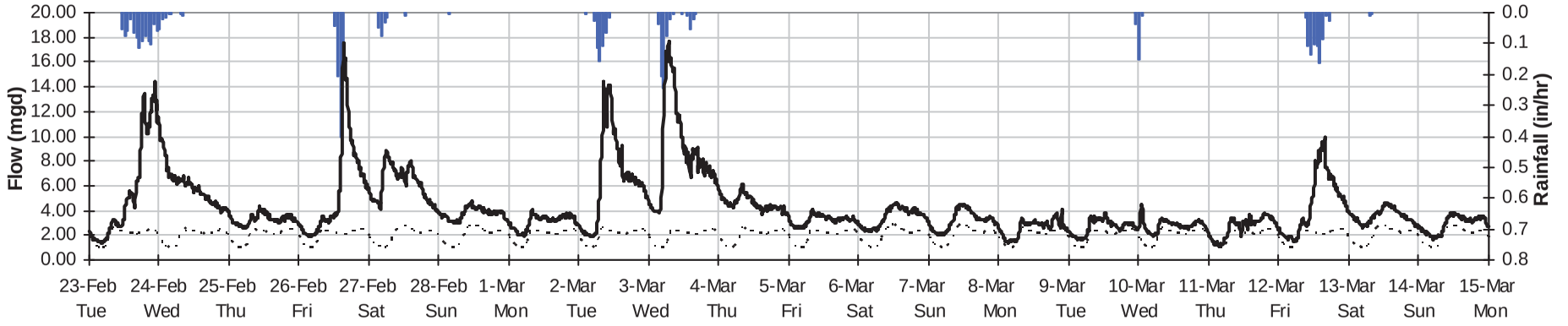


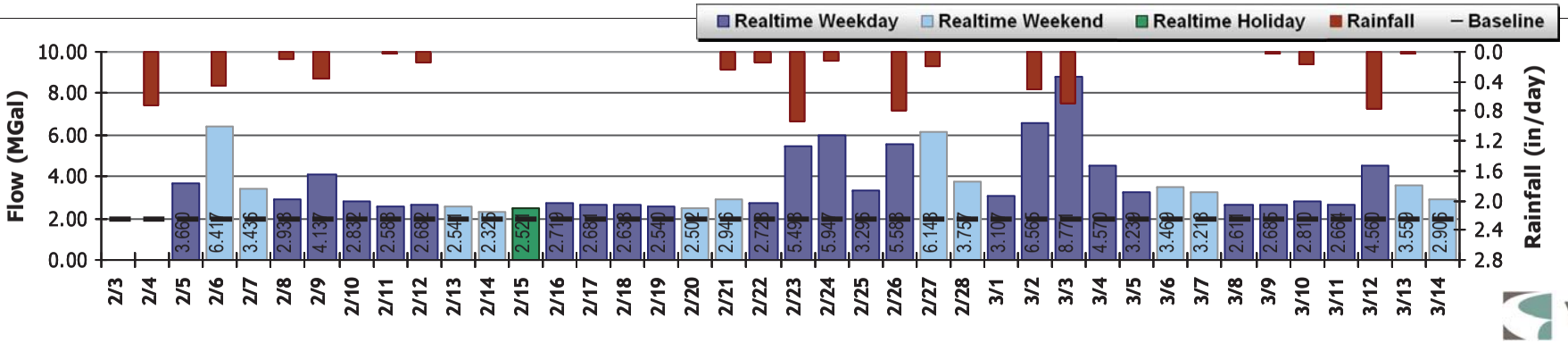
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 5B

Total Monthly Rainfall: 6.38 inches Avg Flow: 3.68 mgd Peak Flow: 17.7 mgd Min Flow: 1.1 mgd





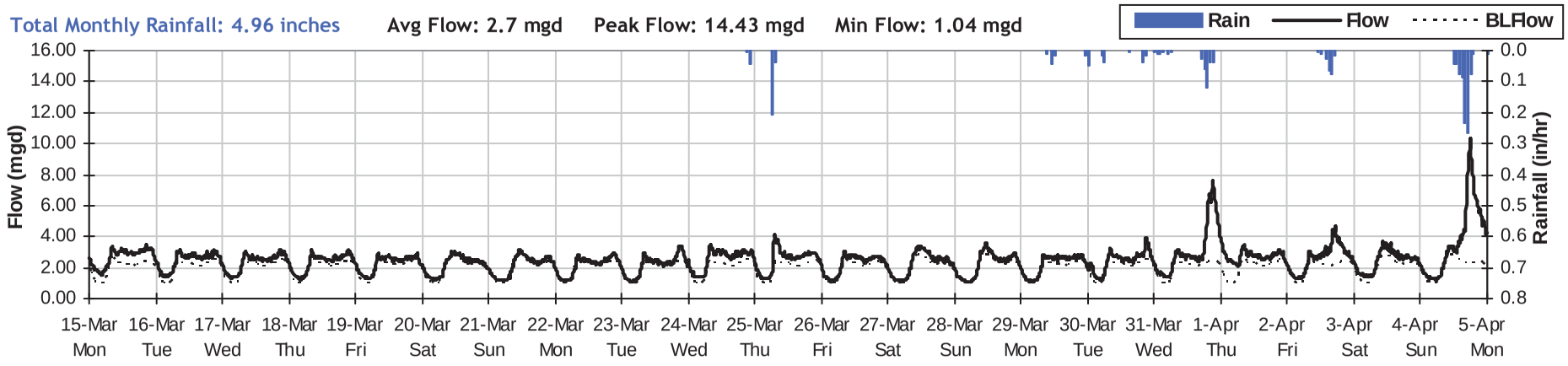


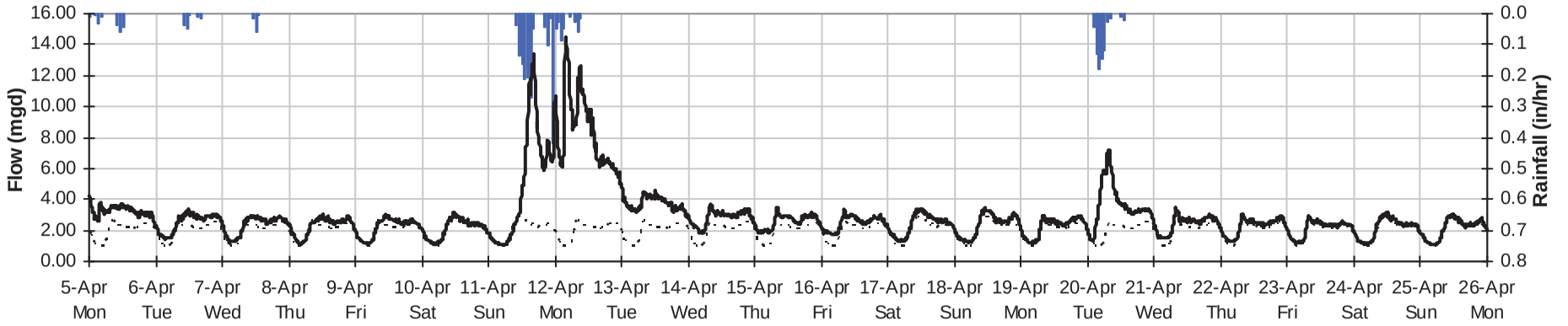
V&A

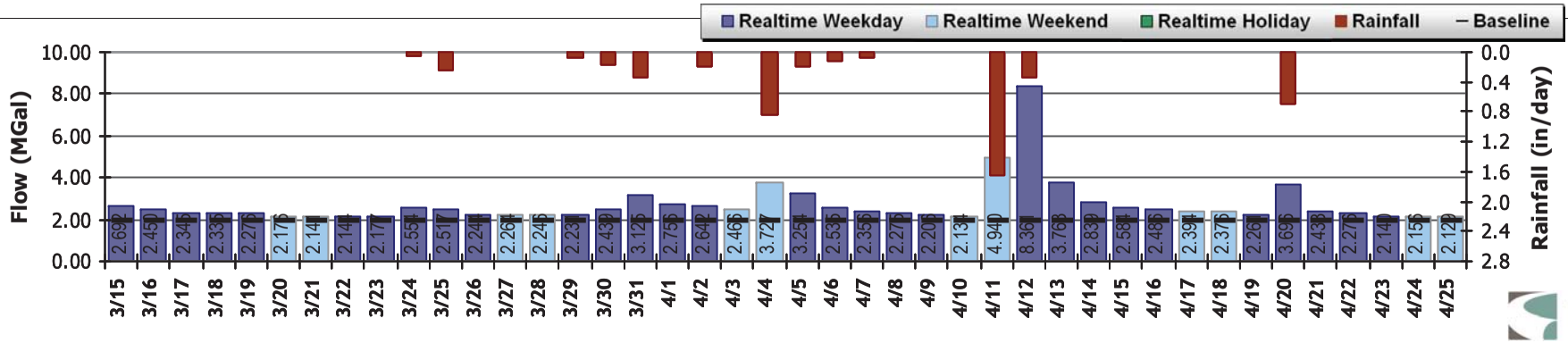
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 5B

Total Monthly Rainfall: 4.96 inches Avg Flow: 2.7 mgd Peak Flow: 14.43 mgd Min Flow: 1.04 mgd





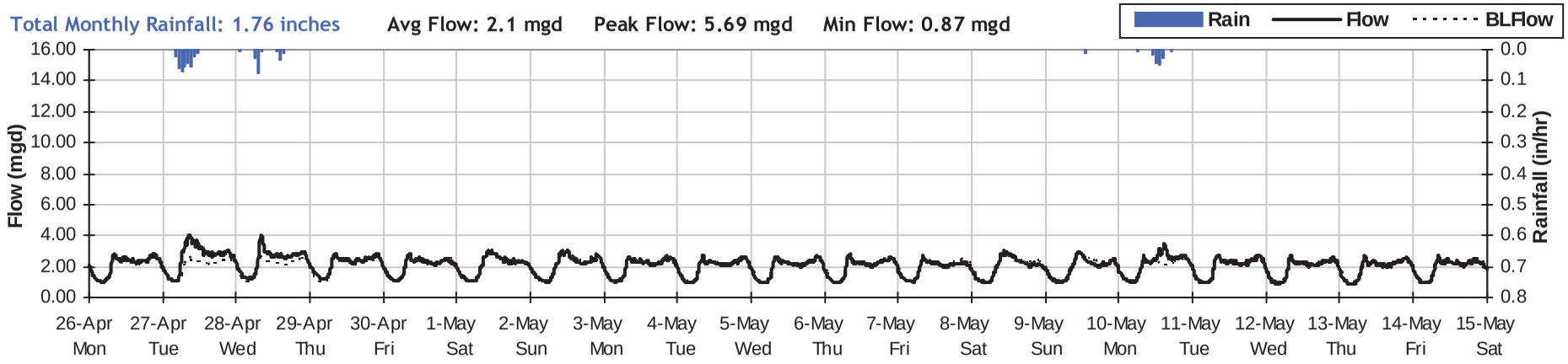


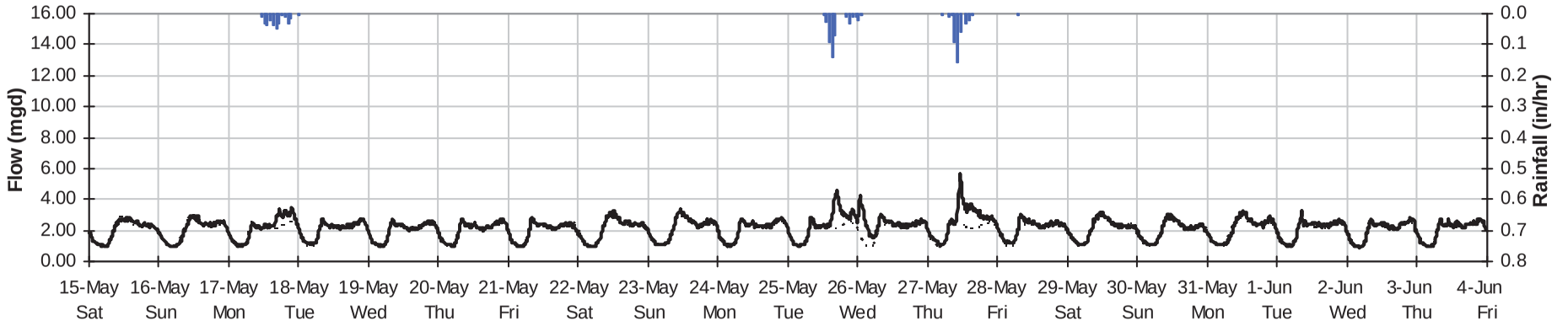
V&A

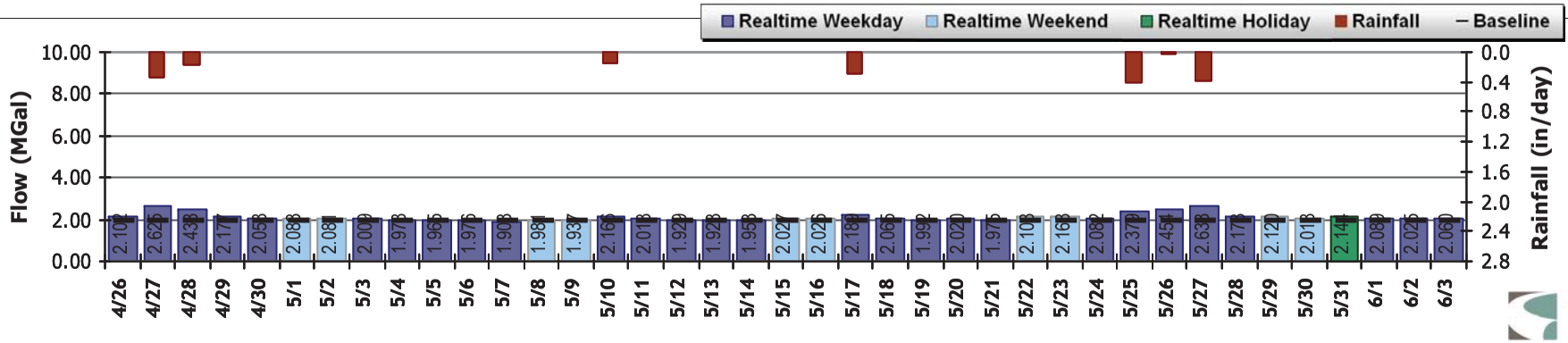
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 5B

Total Monthly Rainfall: 1.76 inches Avg Flow: 2.1 mgd Peak Flow: 5.69 mgd Min Flow: 0.87 mgd





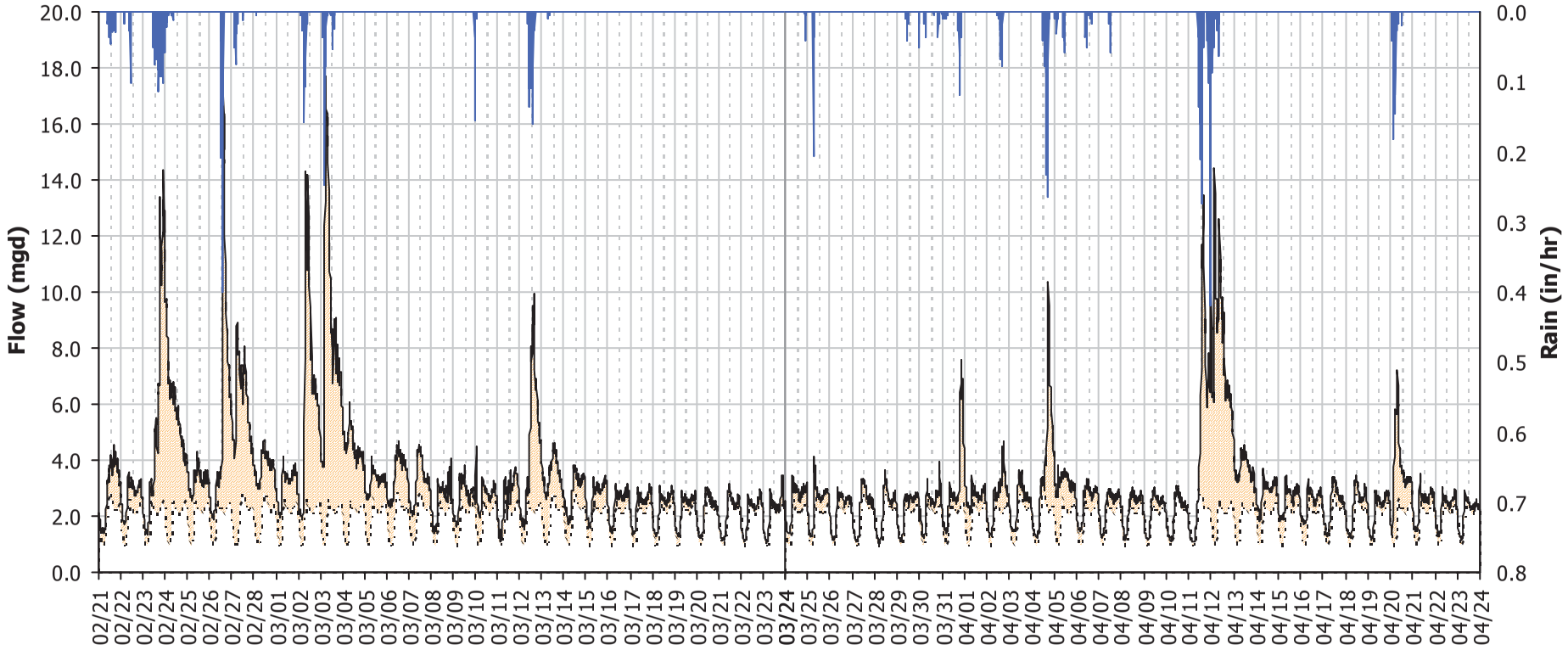


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 5B

Multiple Events Detail I/I Graph



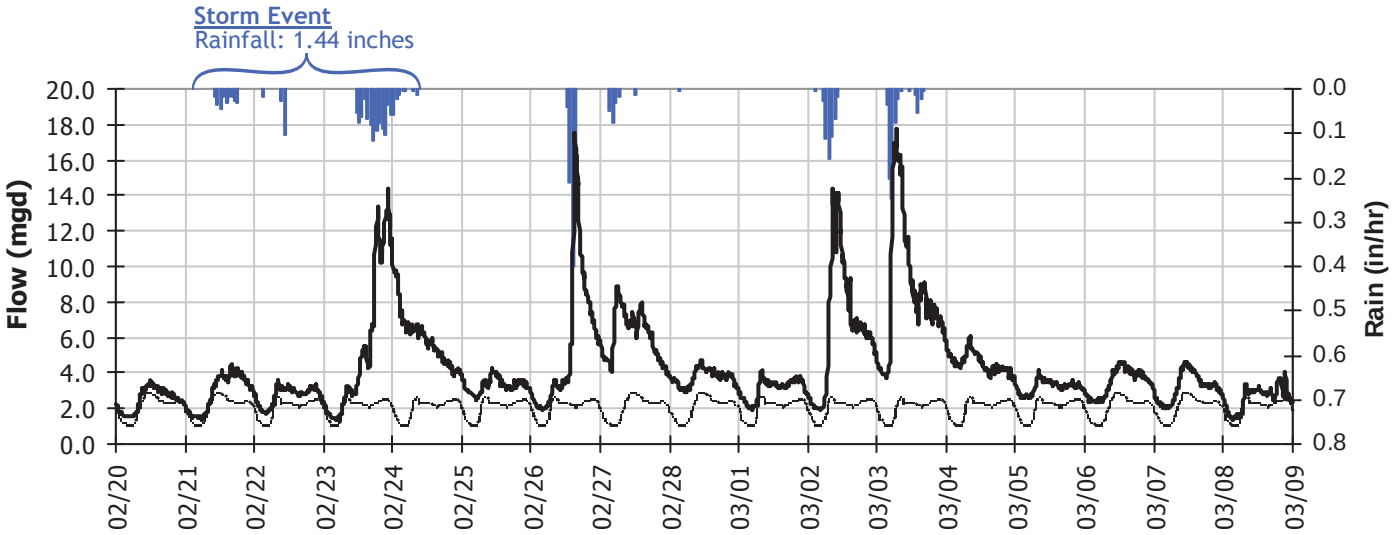
Multiple Events I/I Analysis

Rainfall:	9.54	*inches*	**Baseline Flow:**	1.97	*mgd*
Peak Flow:	17.70	*mgd*	**PF:**	8.99	
Peak I/I Rate:	16.04	*mgd*	**Pk I/I:ADWF:**	8.15	
Peak Level:	137.77	*inches*	**d/D Ratio:**	2.55	
Total I/I:	77,884,000	*gallons*	**R-Value:**	16.8%	
			I/I per ADWF:	4.1	*per in-rain*

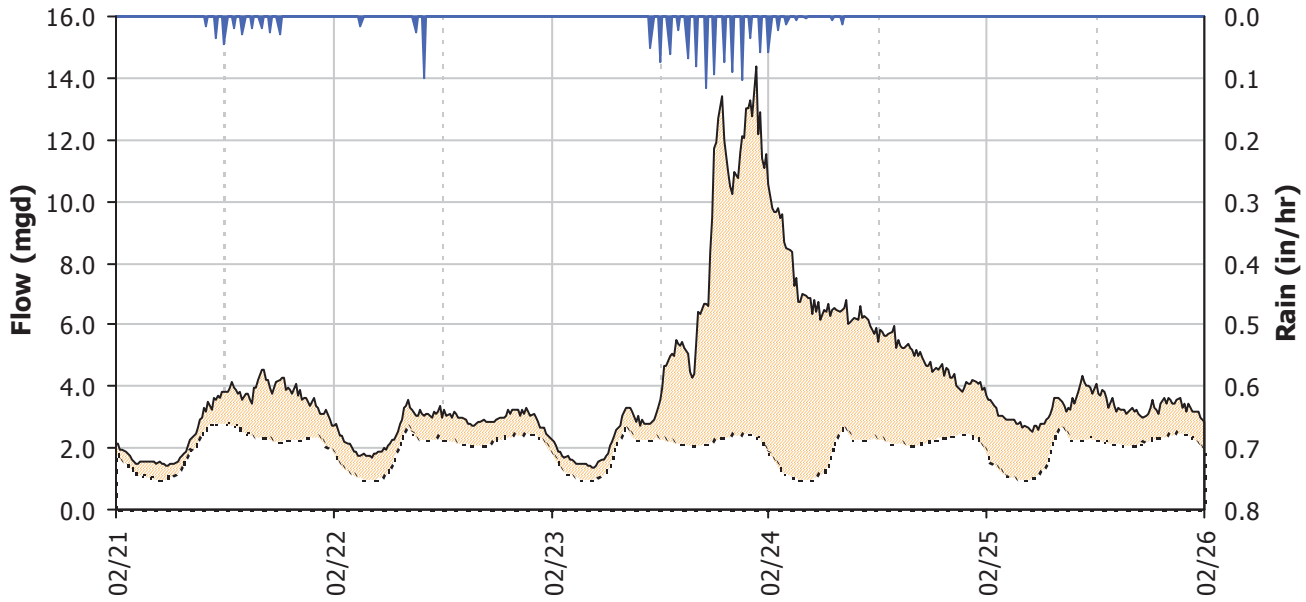
V&A

	I/I Summary Event 1	**Monitoring Site:** Site 5B

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



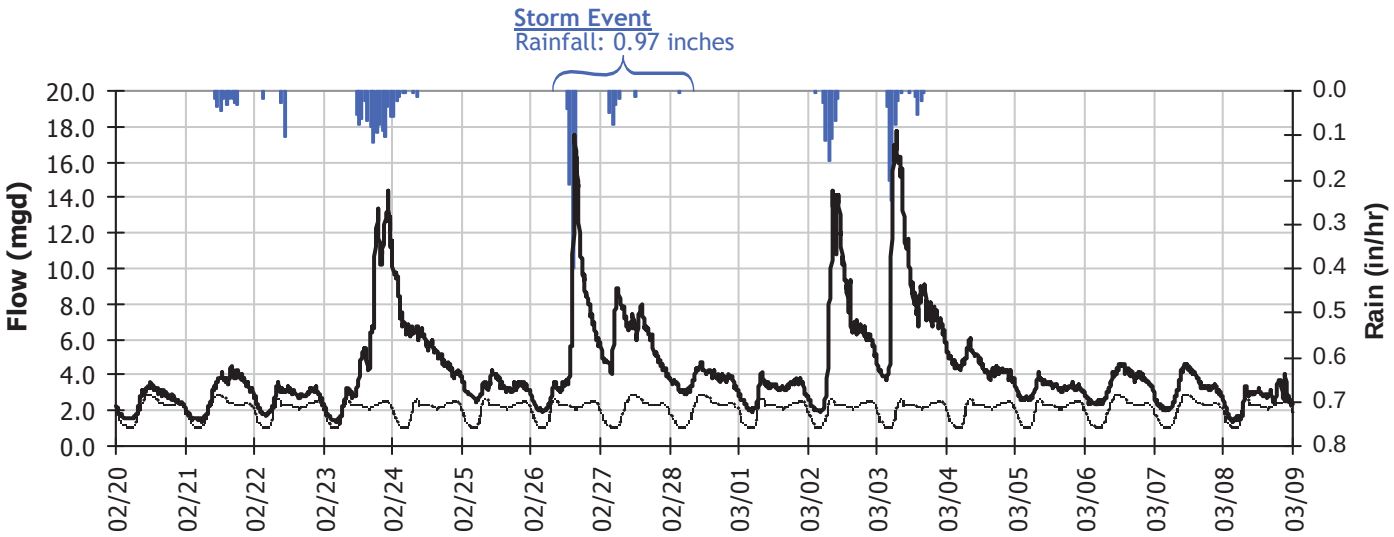
Storm Event #1 I/I Analysis

Rainfall:	1.44	*inches*		
Baseline Flow:	1.97	*mgd*		
Peak Flow:	14.37	*mgd*	**PF:**	7.30
Peak I/I Rate:	12.01	*mgd*	**Pk I/I:ADWF:**	6.10
Peak Level:	127.35	*inches*	**d/D Ratio:**	2.36
Total I/I:	10,595,000	*gallons*	**R-Value:**	15.1%
			I/I per ADWF:	3.73 *per in-rain*

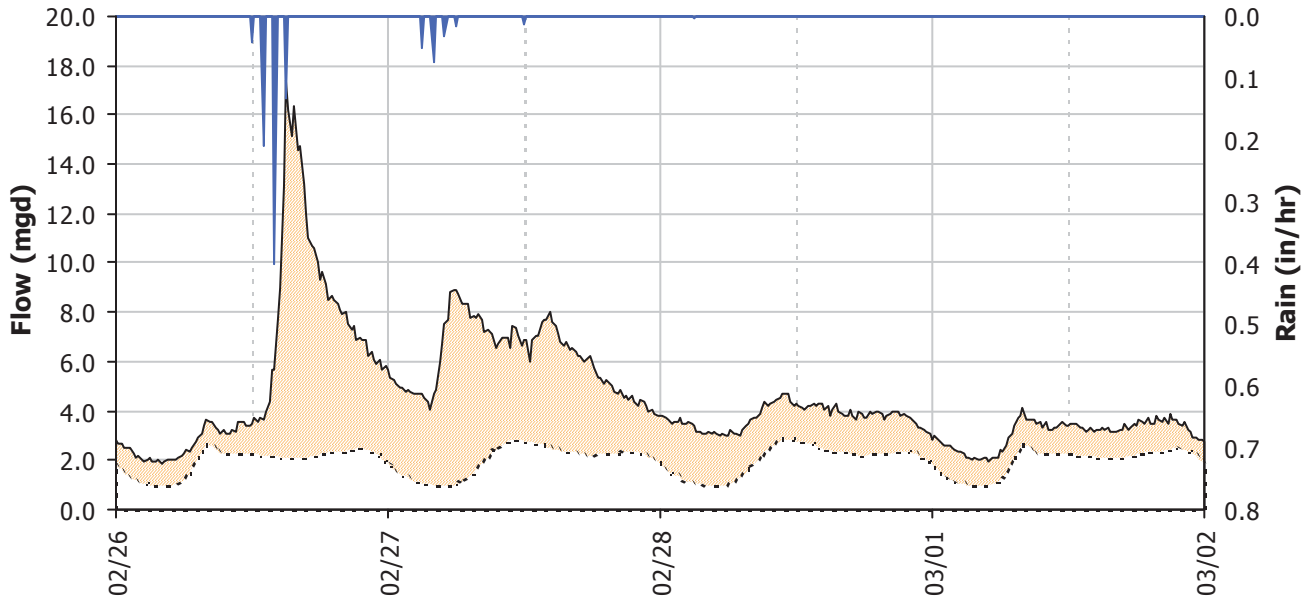
Average Infiltration Rate on 2/25 (% of ADWF): 68.2%

	I/I Summary Event 2	**Monitoring Site:** Site 5B

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #2 I/I Analysis

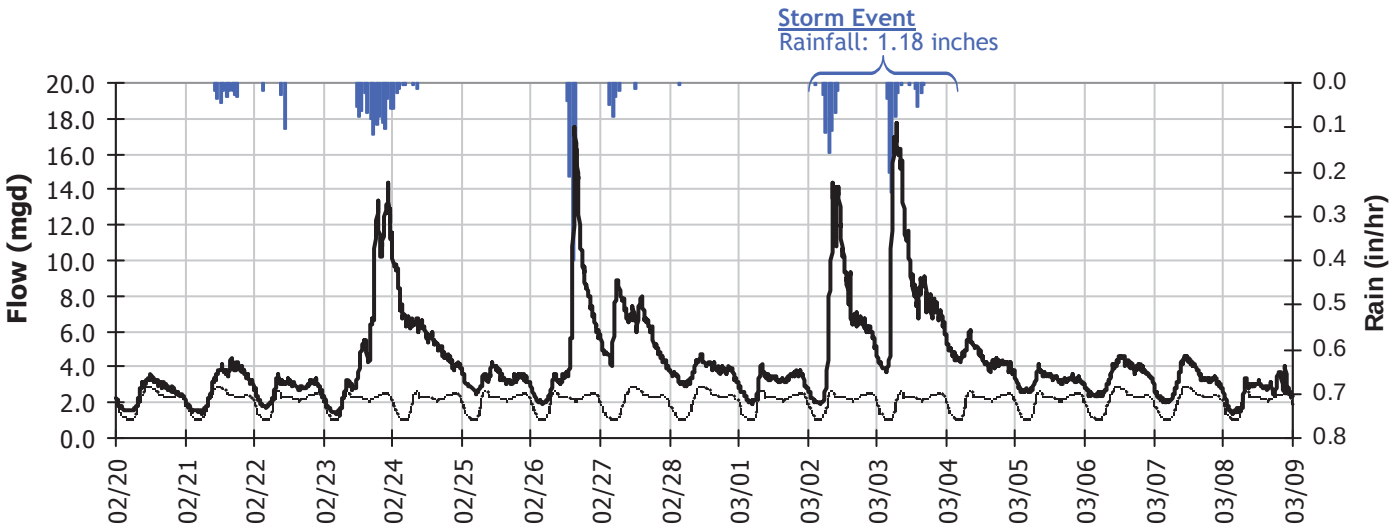
Rainfall:	0.97	*inches*		
Baseline Flow:	1.97	*mgd*		
Peak Flow:	17.39	*mgd*	**PF:**	8.84
Peak I/I Rate:	15.29	*mgd*	**Pk I/I:ADWF:**	7.77
Peak Level:	111.12	*inches*	**d/D Ratio:**	2.06
Total I/I:	10,697,000	*gallons*	**R-Value:**	22.6%
			I/I per ADWF:	5.58 *per in-rain*

Average Infiltration Rate on 3/1 (% of ADWF): 58.6%

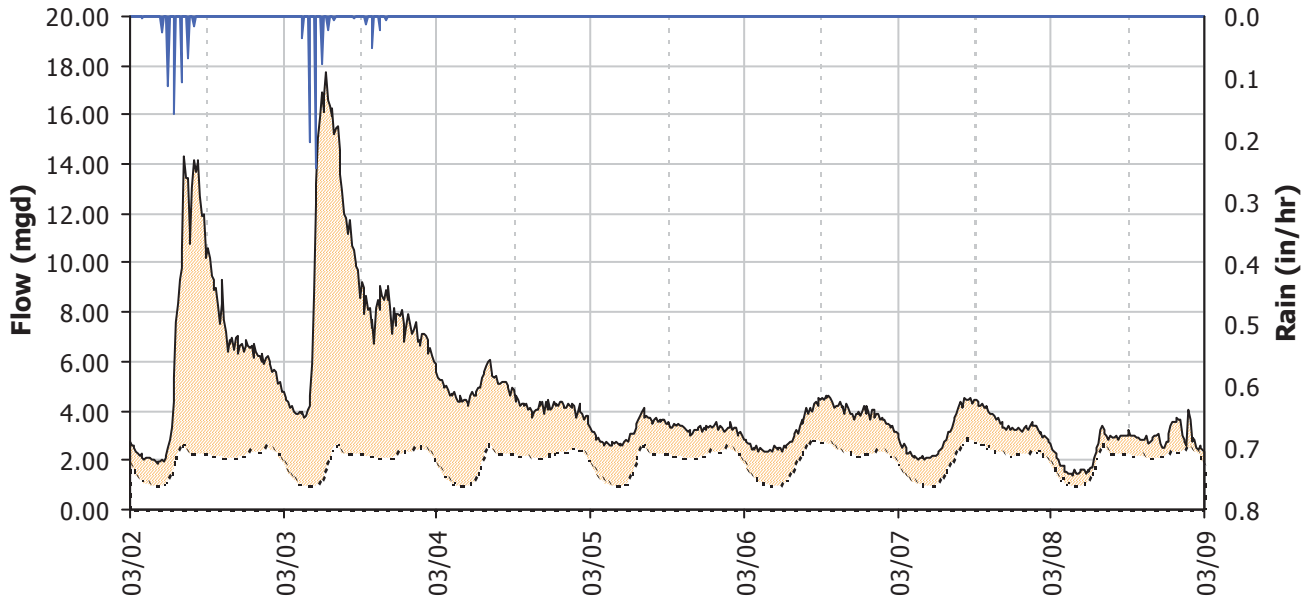
I/I Summary
Event 3

Monitoring Site:
Site 5B

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



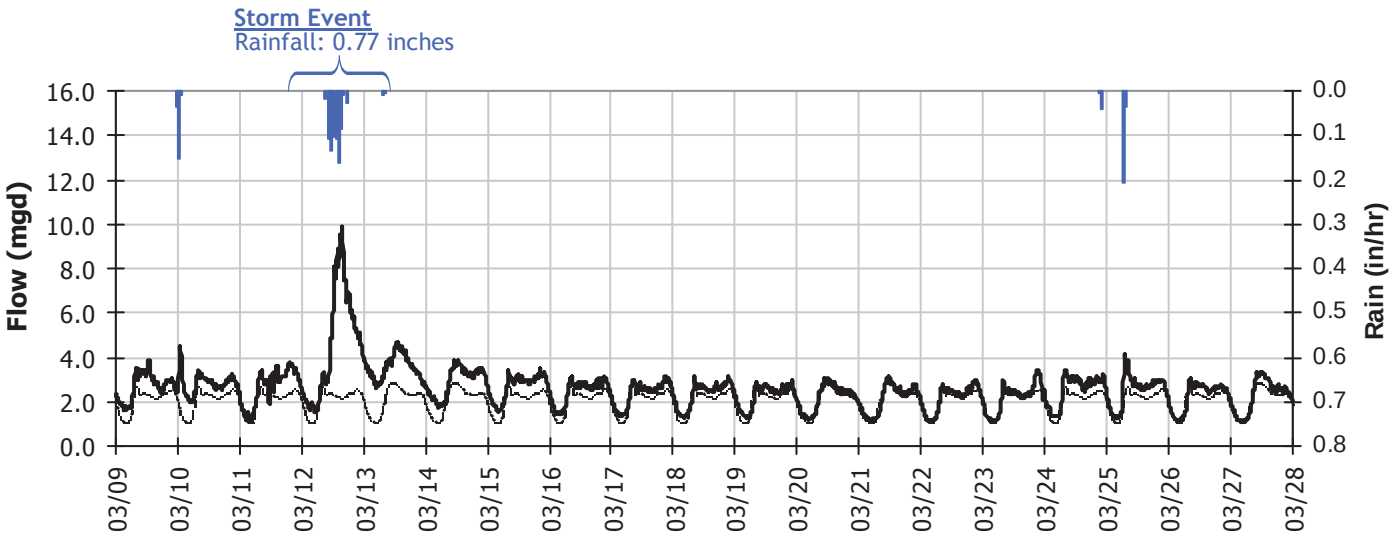
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	1.97	*mgd*		
Peak Flow:	17.70	*mgd*	**PF:**	8.99
Peak I/I Rate:	16.04	*mgd*	**Pk I/I:ADWF:**	8.15
Peak Level:	137.77	*inches*	**d/D Ratio:**	2.55
Total I/I:	18,671,000	*gallons*	**R-Value:**	32.4%
			I/I per ADWF:	8.01 *per in-rain*

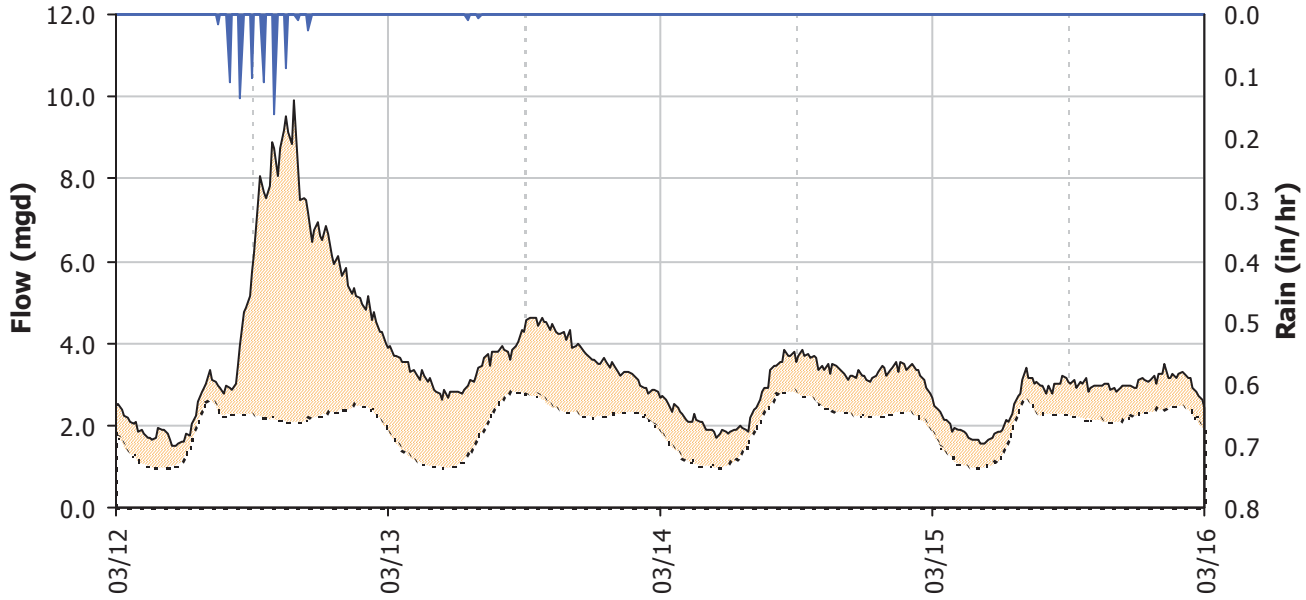
Average Infiltration Rate on 3/5 (% of ADWF): 65.3%

	I/I Summary Event 4	**Monitoring Site:** Site 5B

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

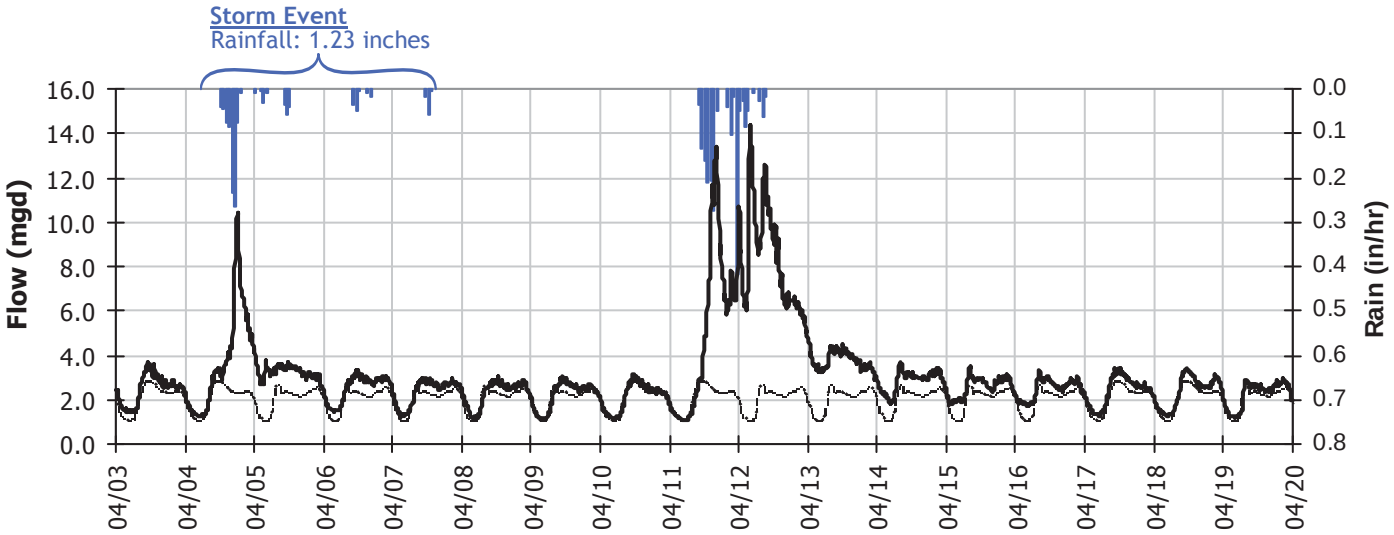
Rainfall:	0.77	*inches*		
Baseline Flow:	1.97	*mgd*		
Peak Flow:	9.92	*mgd*	**PF:**	5.04
Peak I/I Rate:	7.85	*mgd*	**Pk I/I:ADWF:**	3.99
Peak Level:	108.79	*inches*	**d/D Ratio:**	2.01
Total I/I:	5,821,000	*gallons*	**R-Value:**	15.5%
			I/I per ADWF:	3.83 *per in-rain*

Average Infiltration Rate on 3/14 (% of ADWF): 45.8%

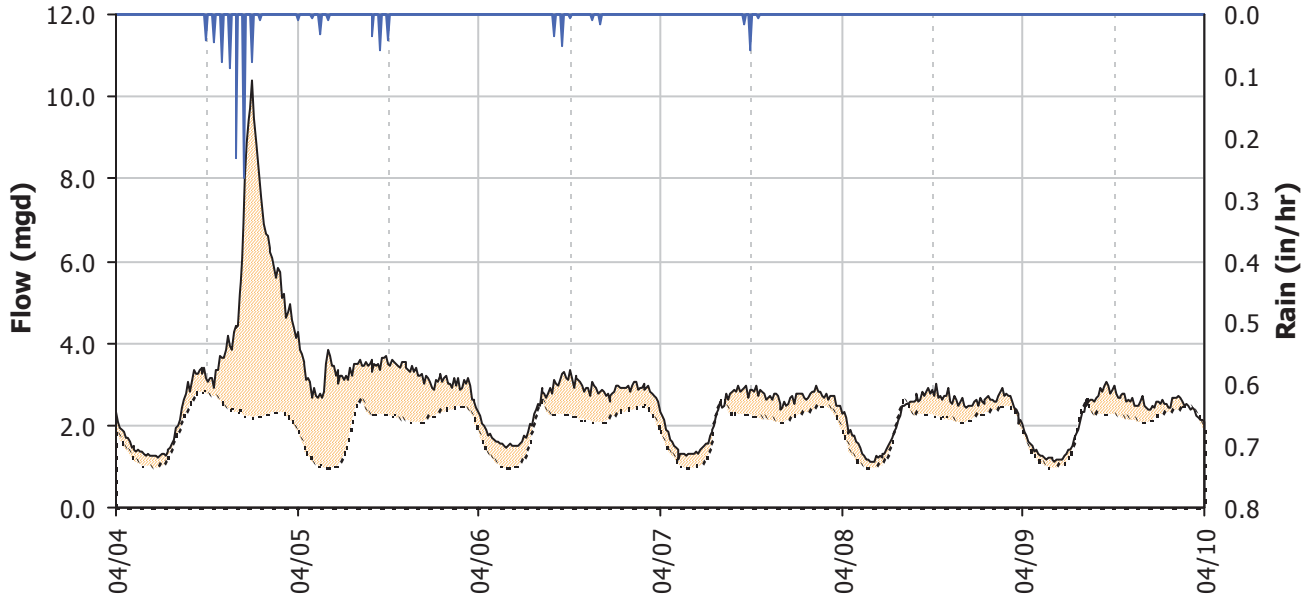
I/I Summary
Event 5

Monitoring Site:
Site 5B

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #5 I/I Analysis

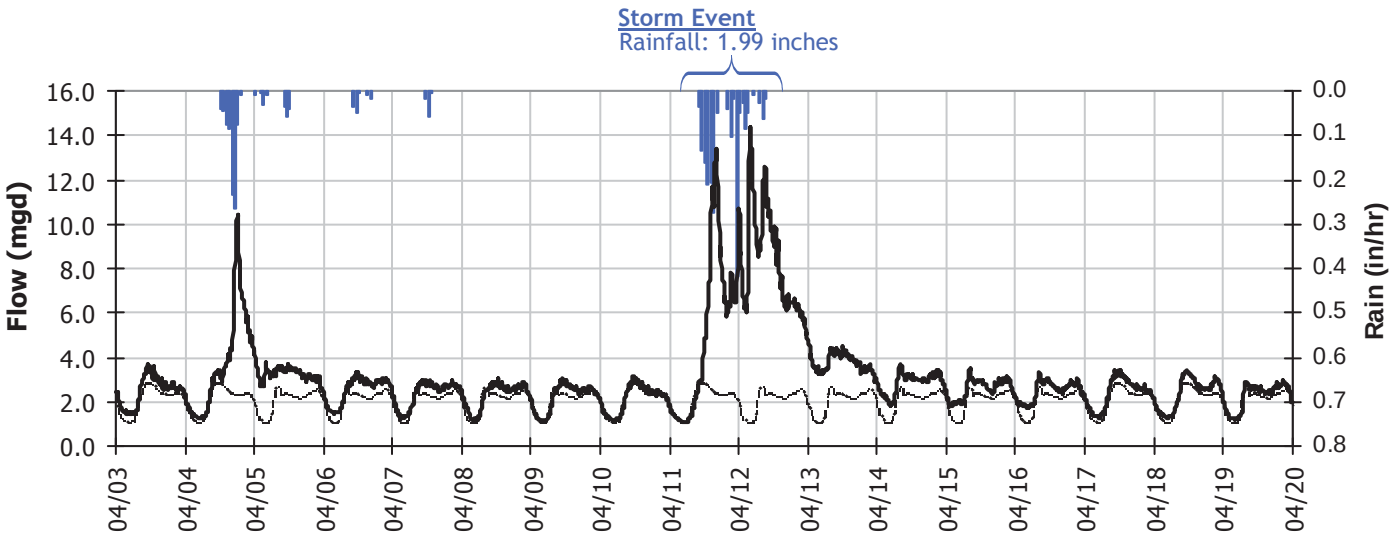
Rainfall:	1.23	*inches*		
Baseline Flow:	1.97	*mgd*		
Peak Flow:	10.38	*mgd*	**PF:**	5.28
Peak I/I Rate:	8.18	*mgd*	**Pk I/I:ADWF:**	4.16
Peak Level:	85.90	*inches*	**d/D Ratio:**	1.59
Total I/I:	4,572,000	*gallons*	**R-Value:**	7.7%
			I/I per ADWF:	1.89 *per in-rain*

Average Infiltration Rate on 4/8 (% of ADWF): 16.1%

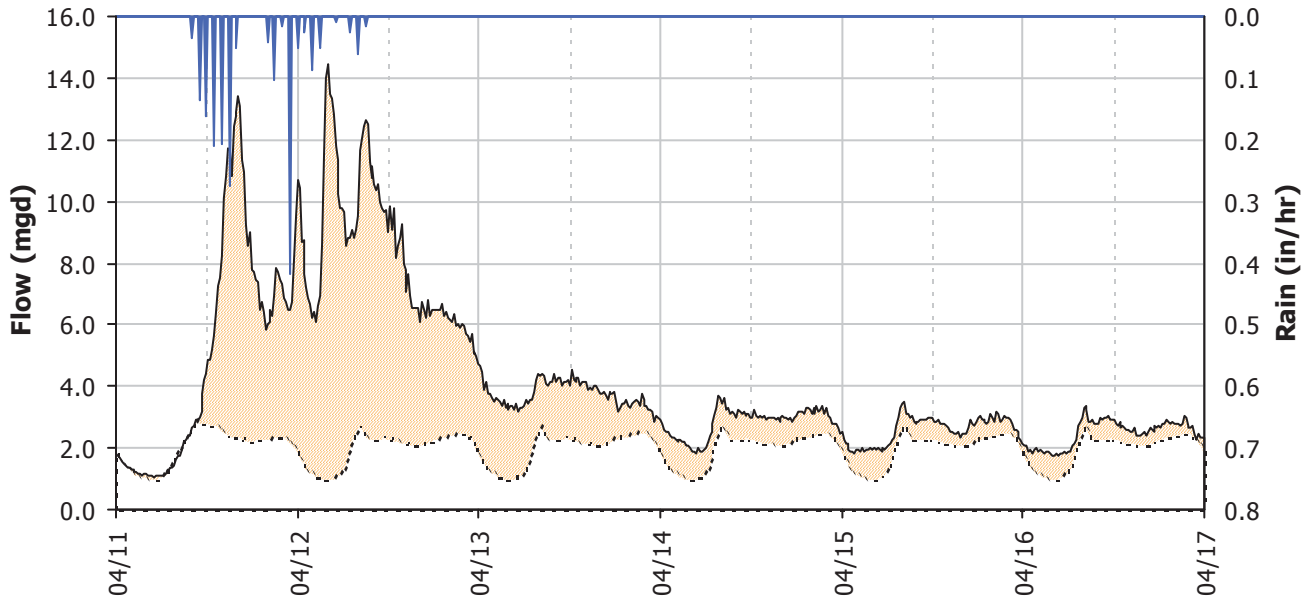
V&A

	I/I Summary Event 6	**Monitoring Site:** Site 5B

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



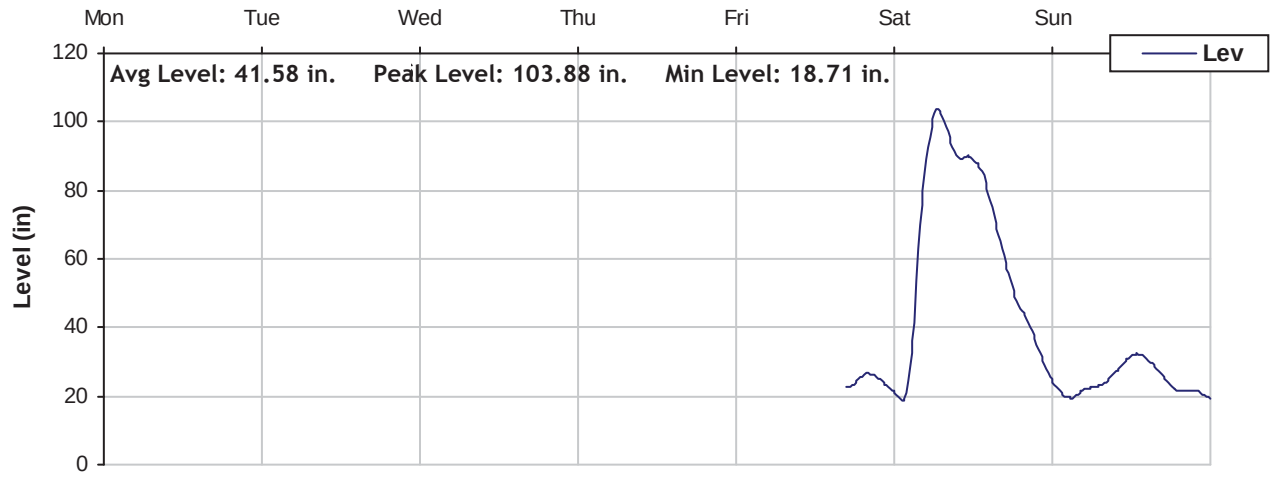
Storm Event #6 I/I Analysis

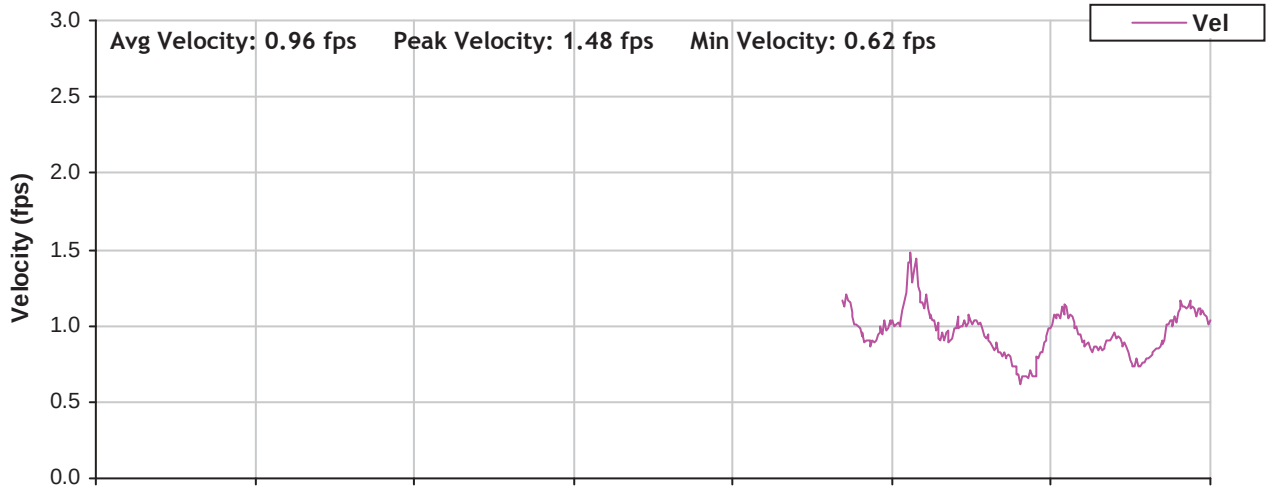
Rainfall:	1.99	*inches*		
Baseline Flow:	1.97	*mgd*		
Peak Flow:	14.43	*mgd*	**PF:**	7.33
Peak I/I Rate:	13.44	*mgd*	**Pk I/I:ADWF:**	6.83
Peak Level:	132.61	*inches*	**d/D Ratio:**	2.46
Total I/I:	13,195,000	*gallons*	**R-Value:**	13.7%
			I/I per ADWF:	3.38 *per in-rain*

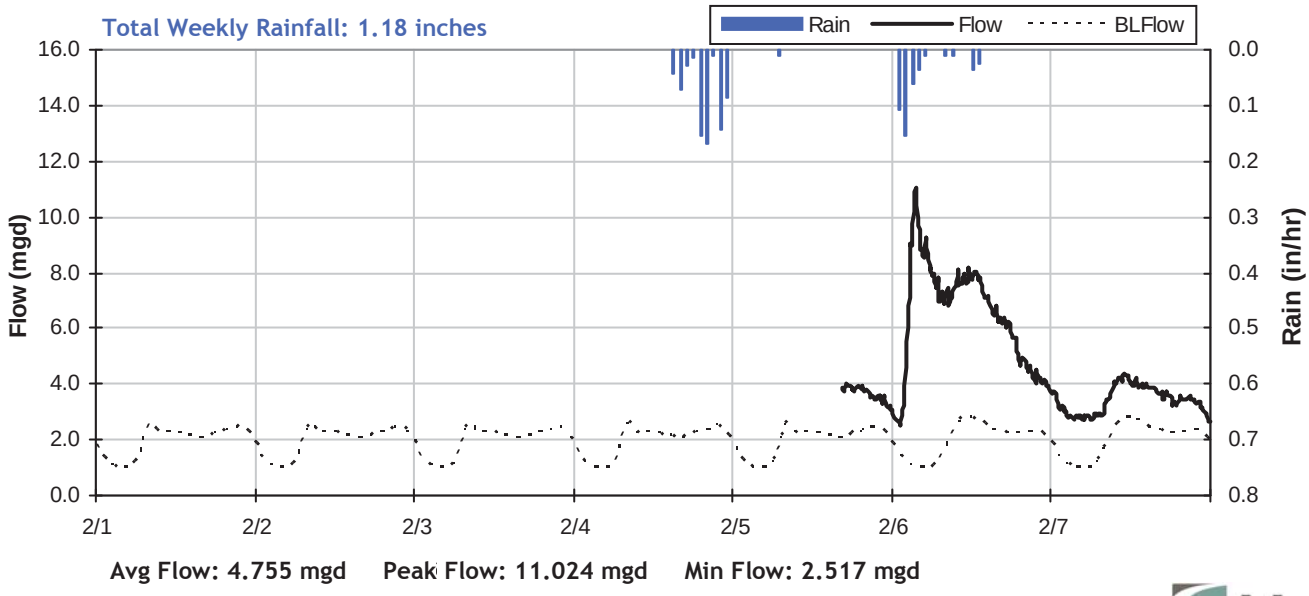
Average Infiltration Rate on 4/14 (% of ADWF): 44.9%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 5B



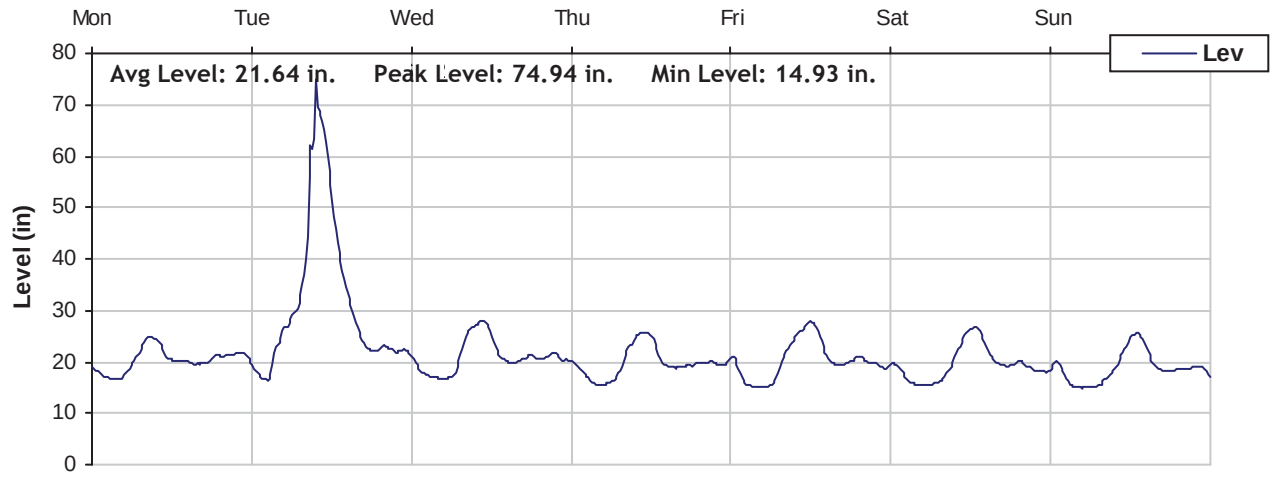


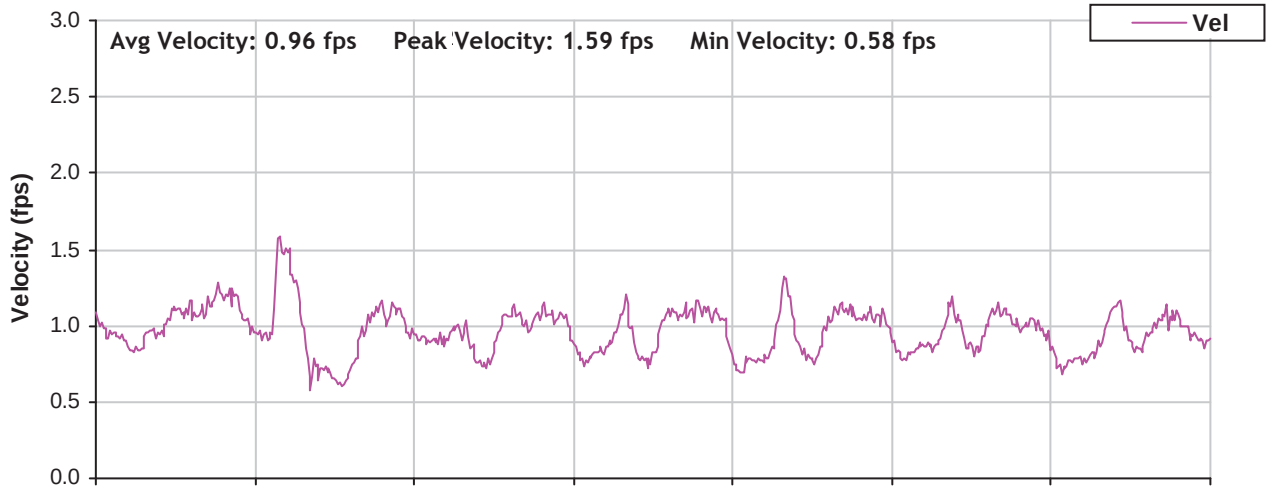


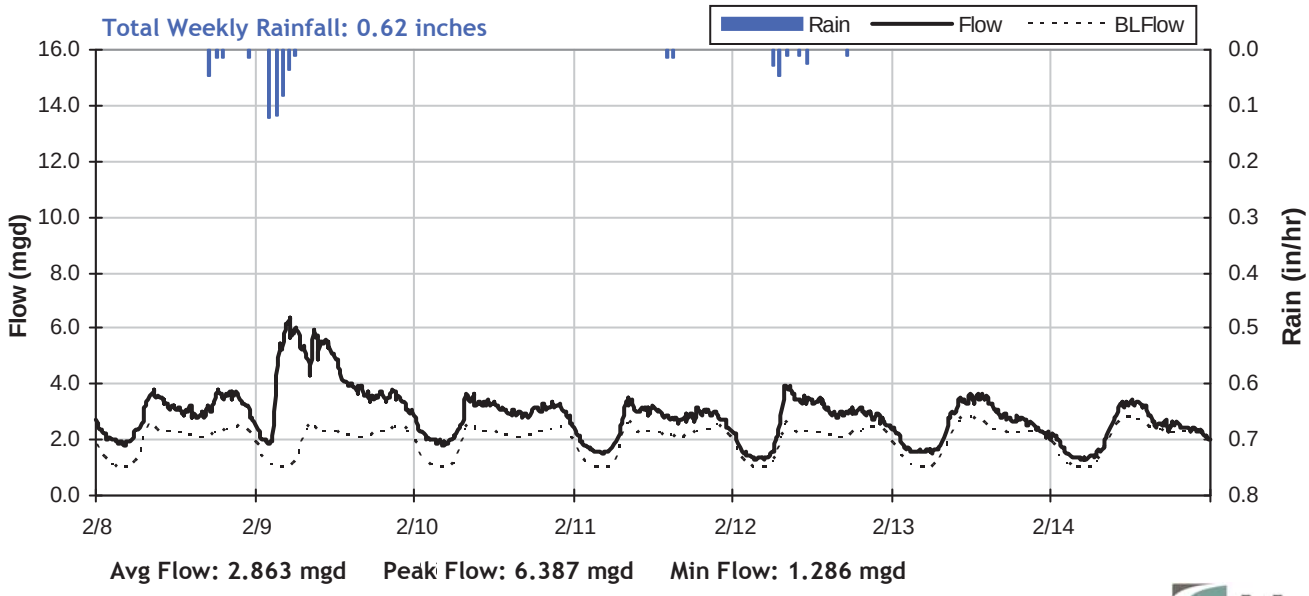
Avg Flow: 4.755 mgd Peak Flow: 11.024 mgd Min Flow: 2.517 mgd

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 5B

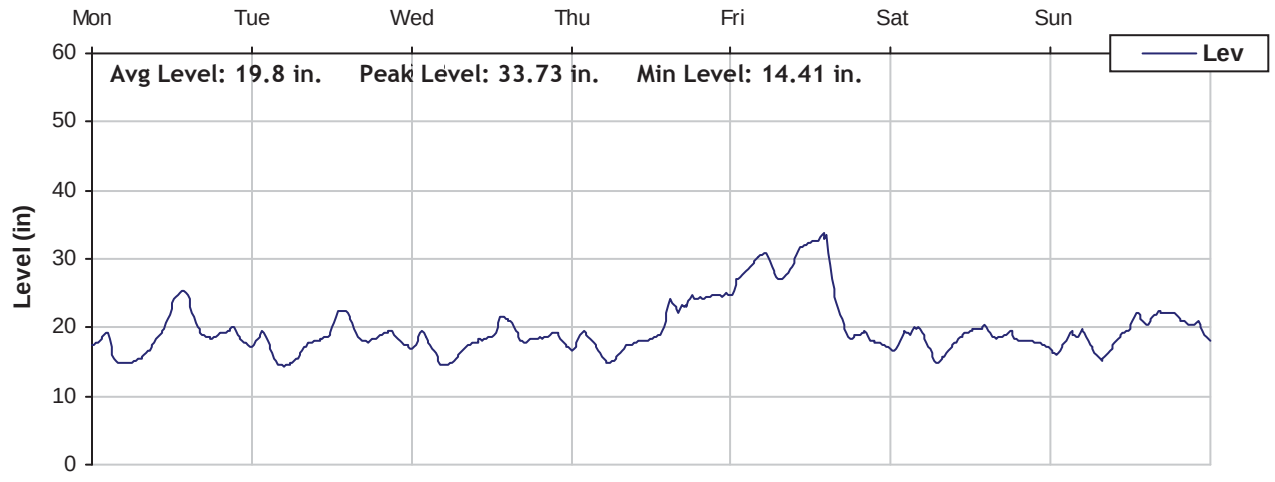


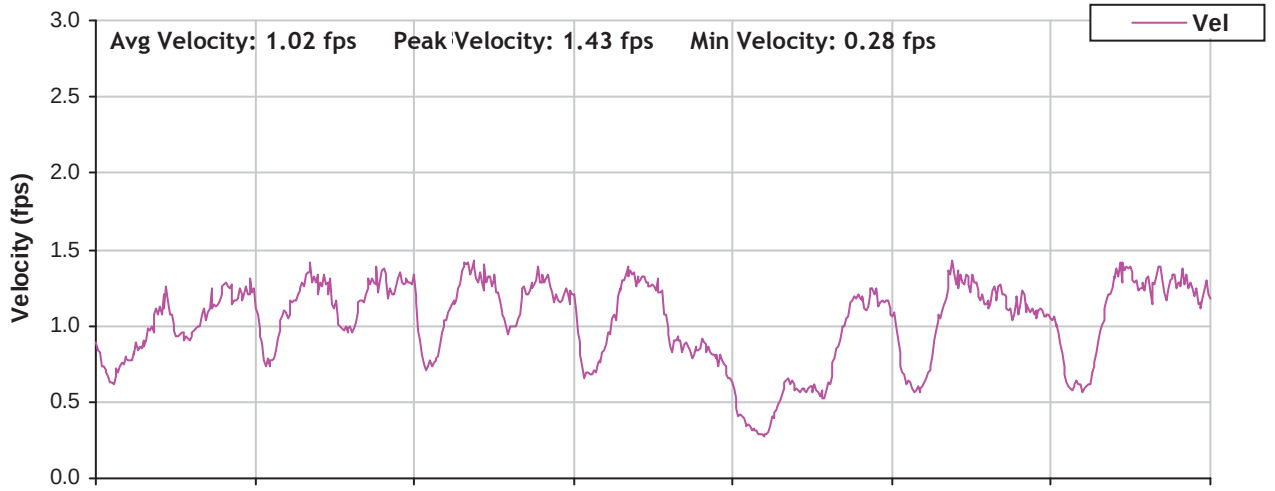


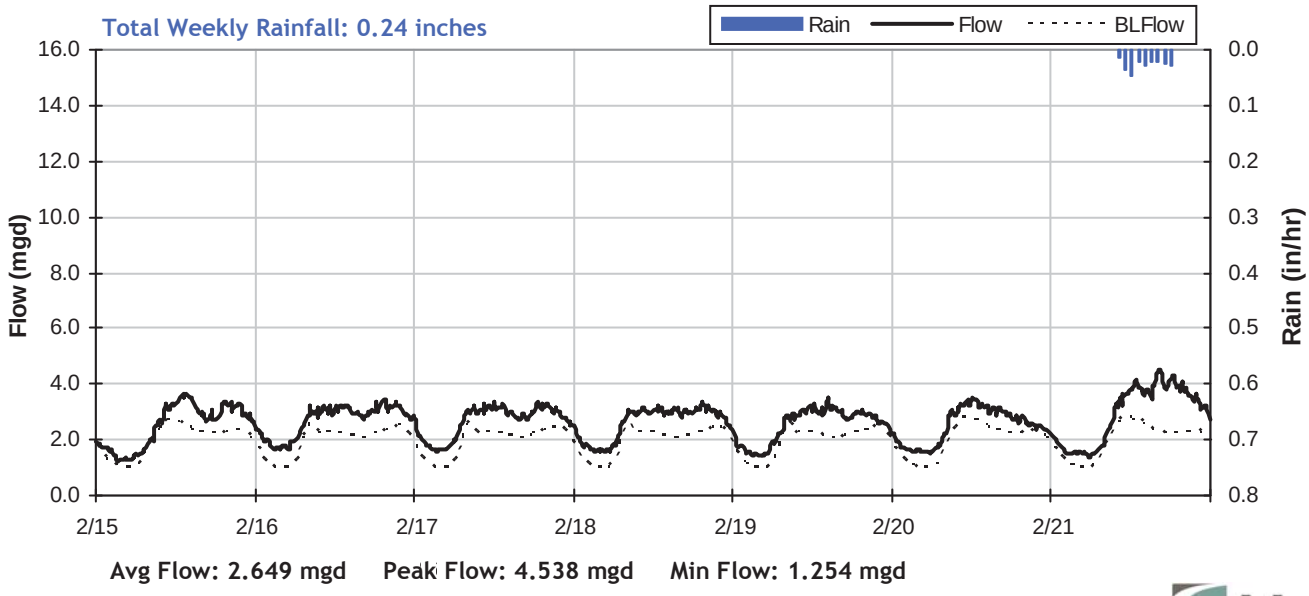


Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 5B

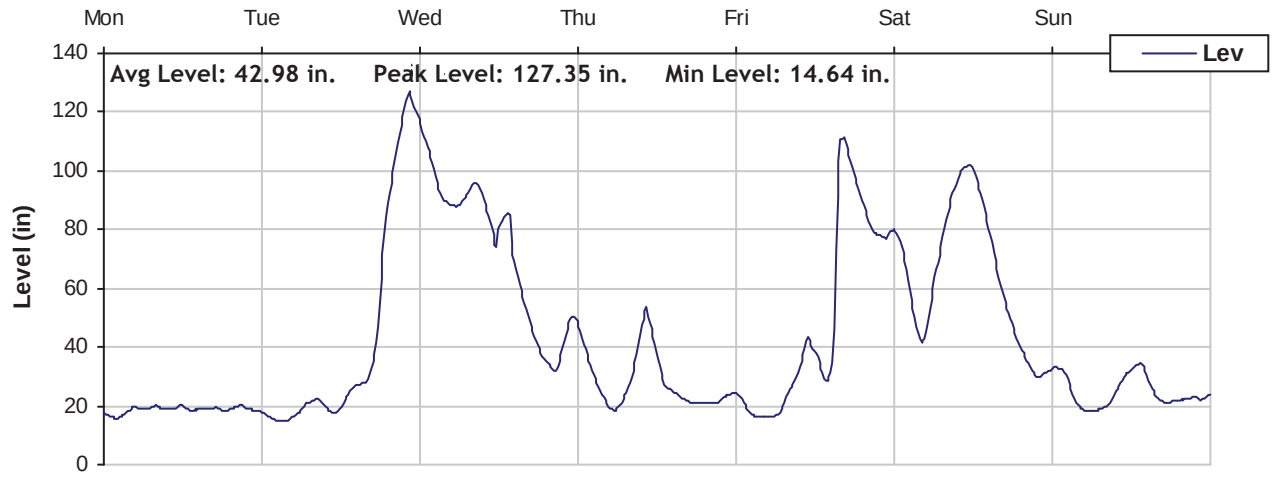


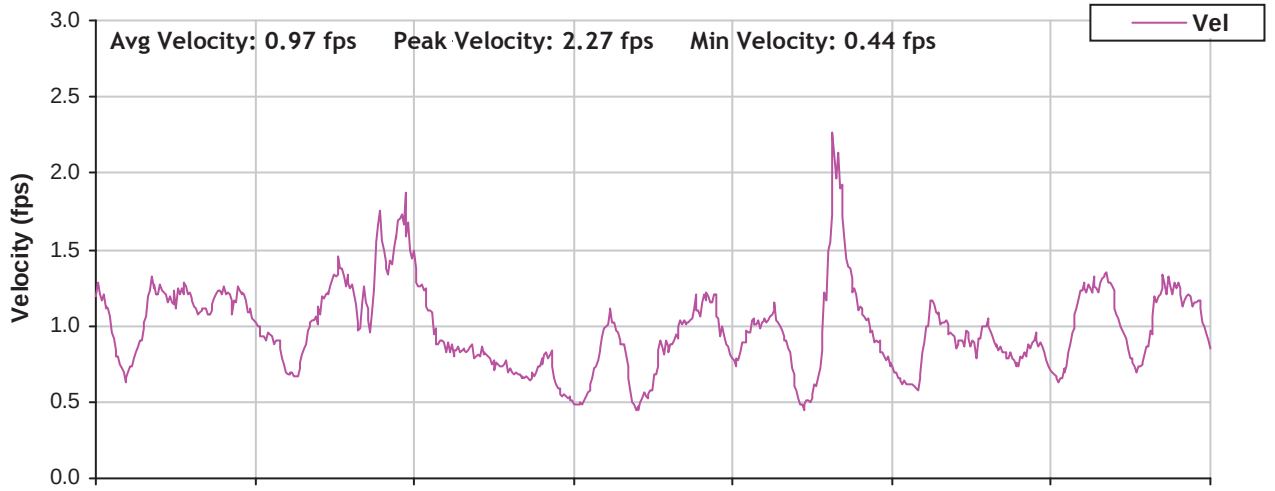


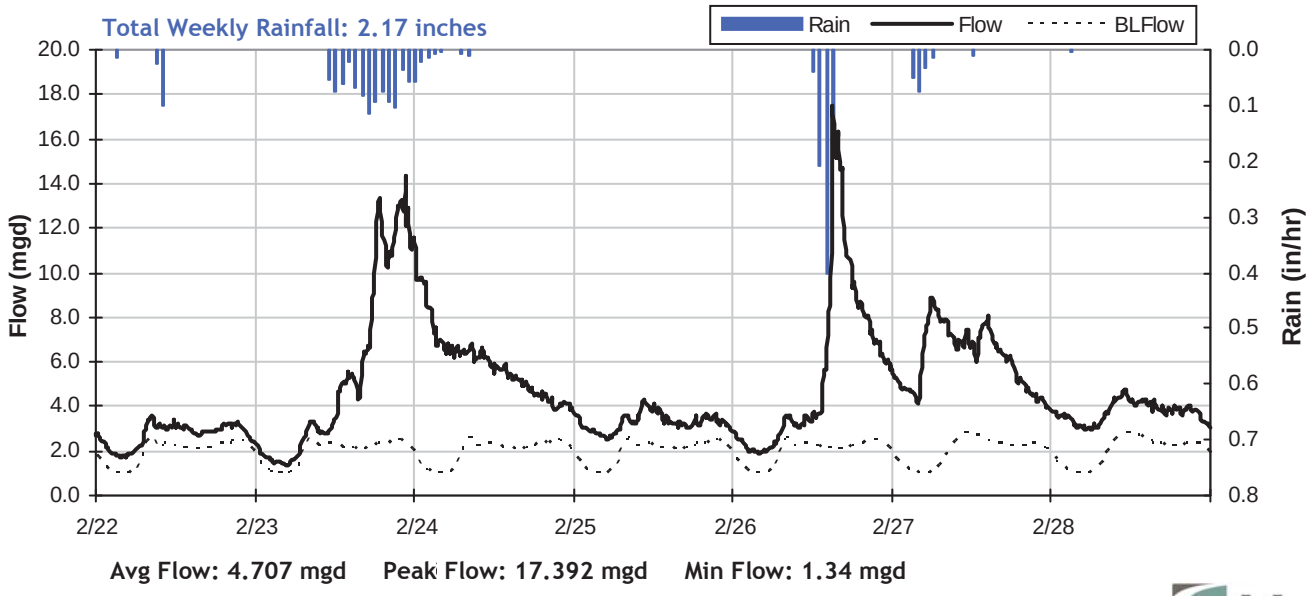


Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 5B



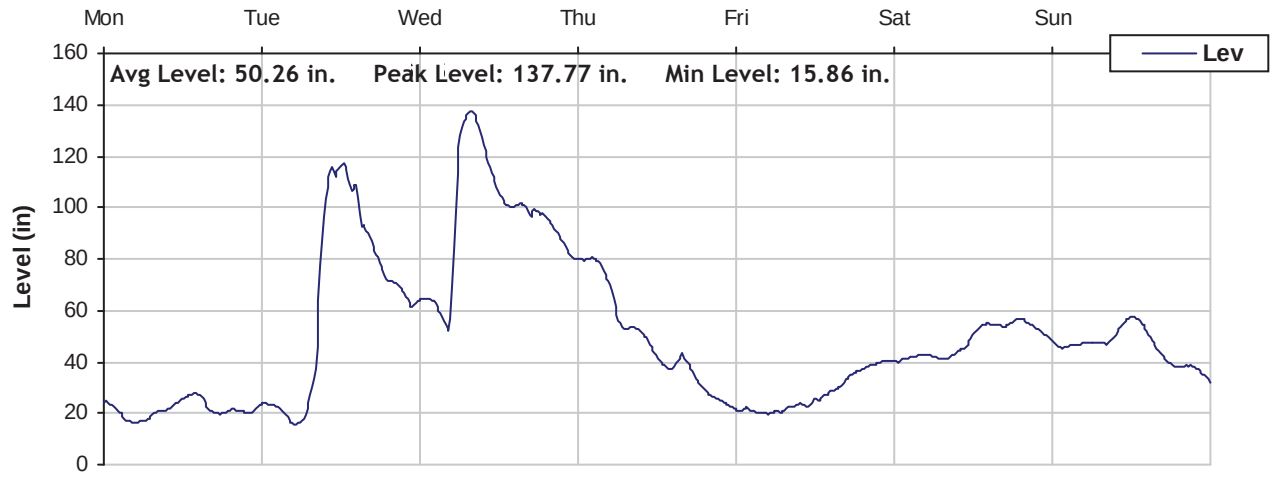


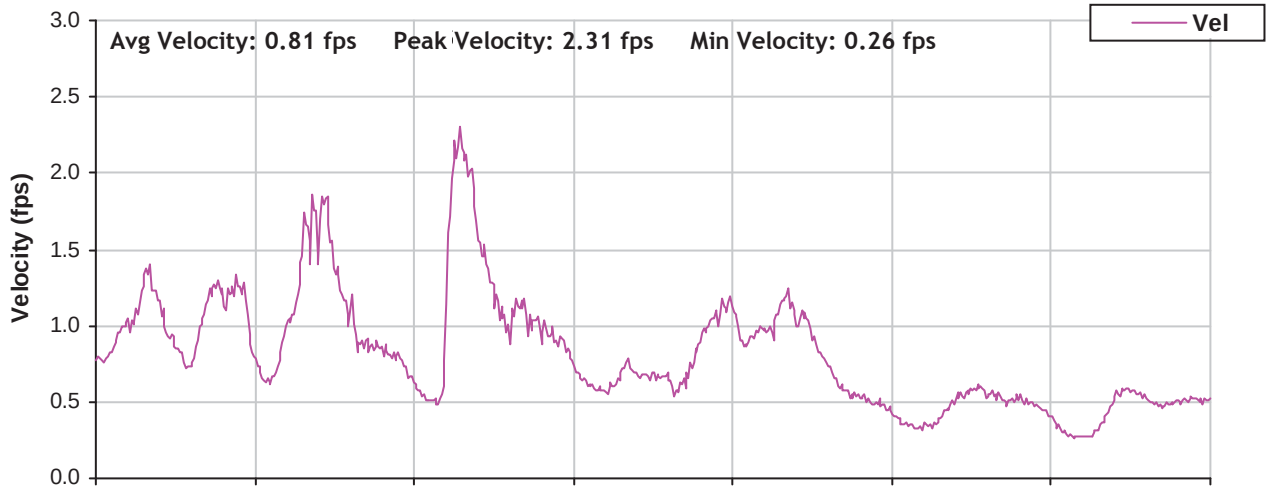


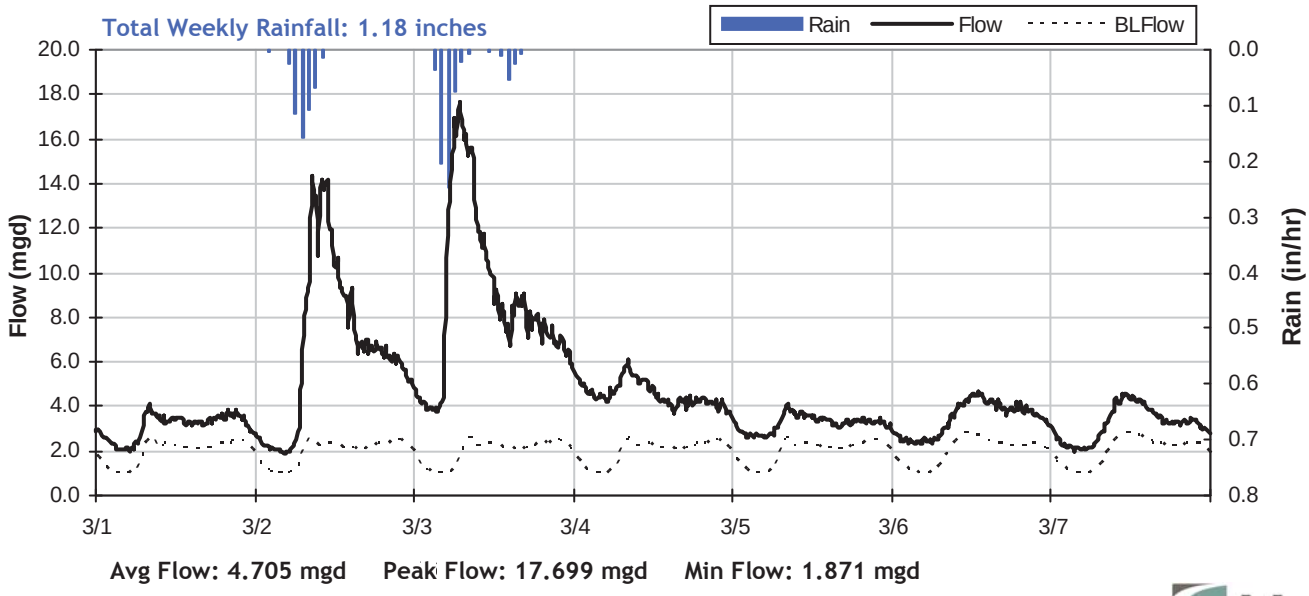
Avg Flow: 4.707 mgd Peak Flow: 17.392 mgd Min Flow: 1.34 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 5B



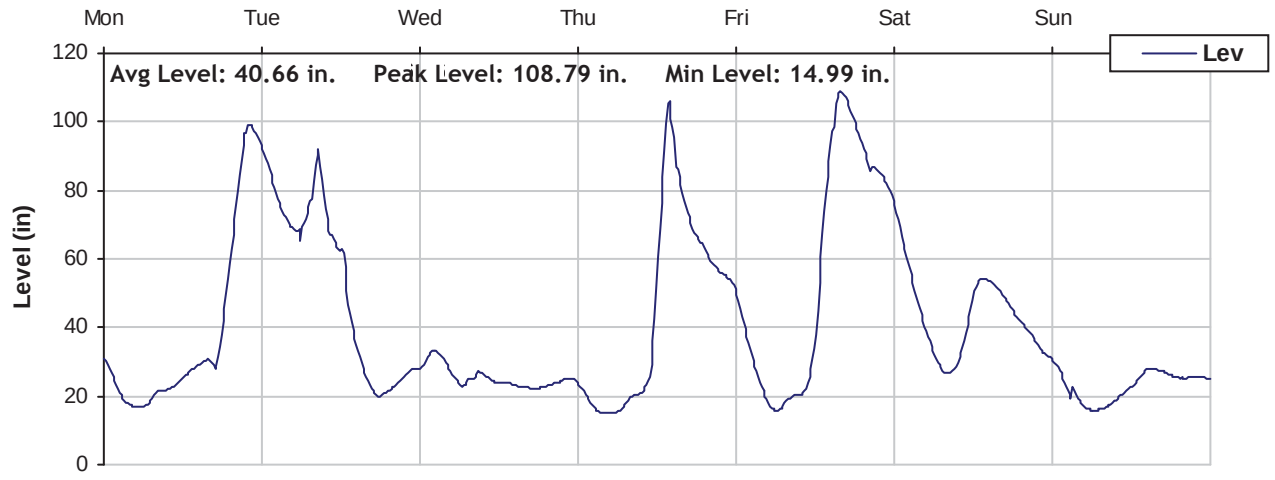


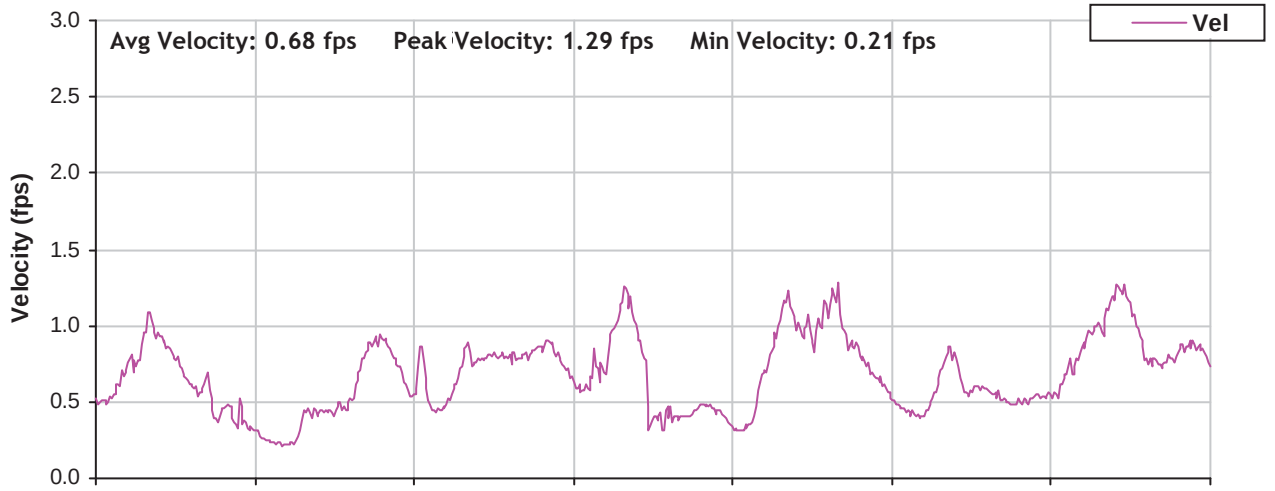


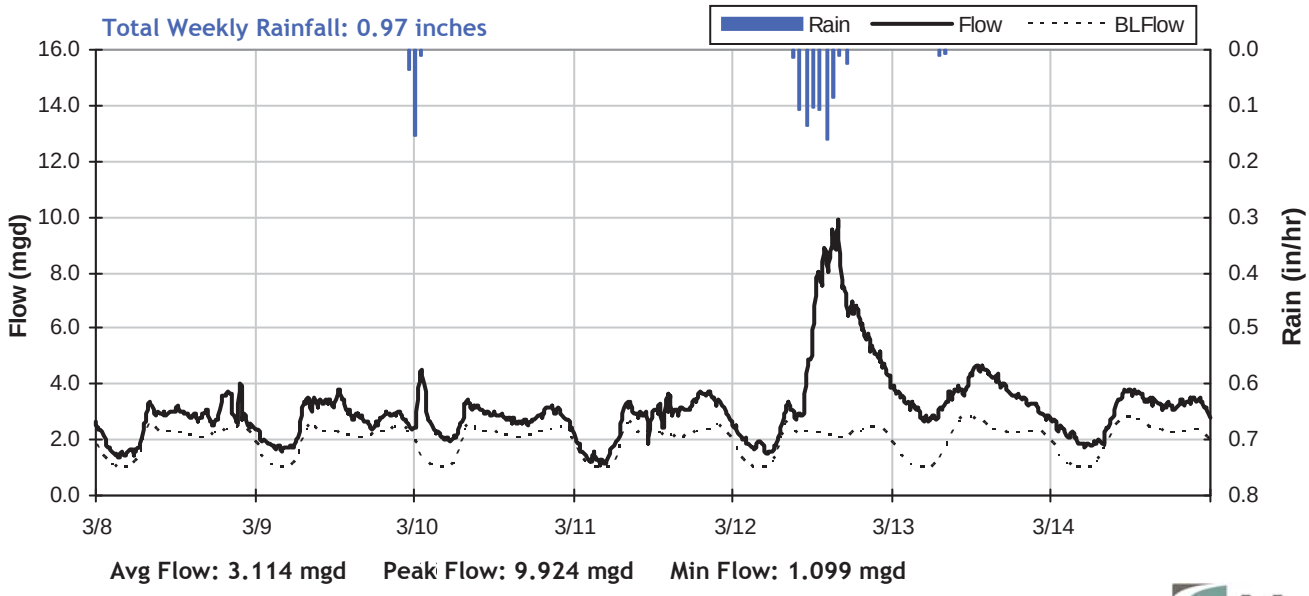
Avg Flow: 4.705 mgd Peak Flow: 17.699 mgd Min Flow: 1.871 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 5B

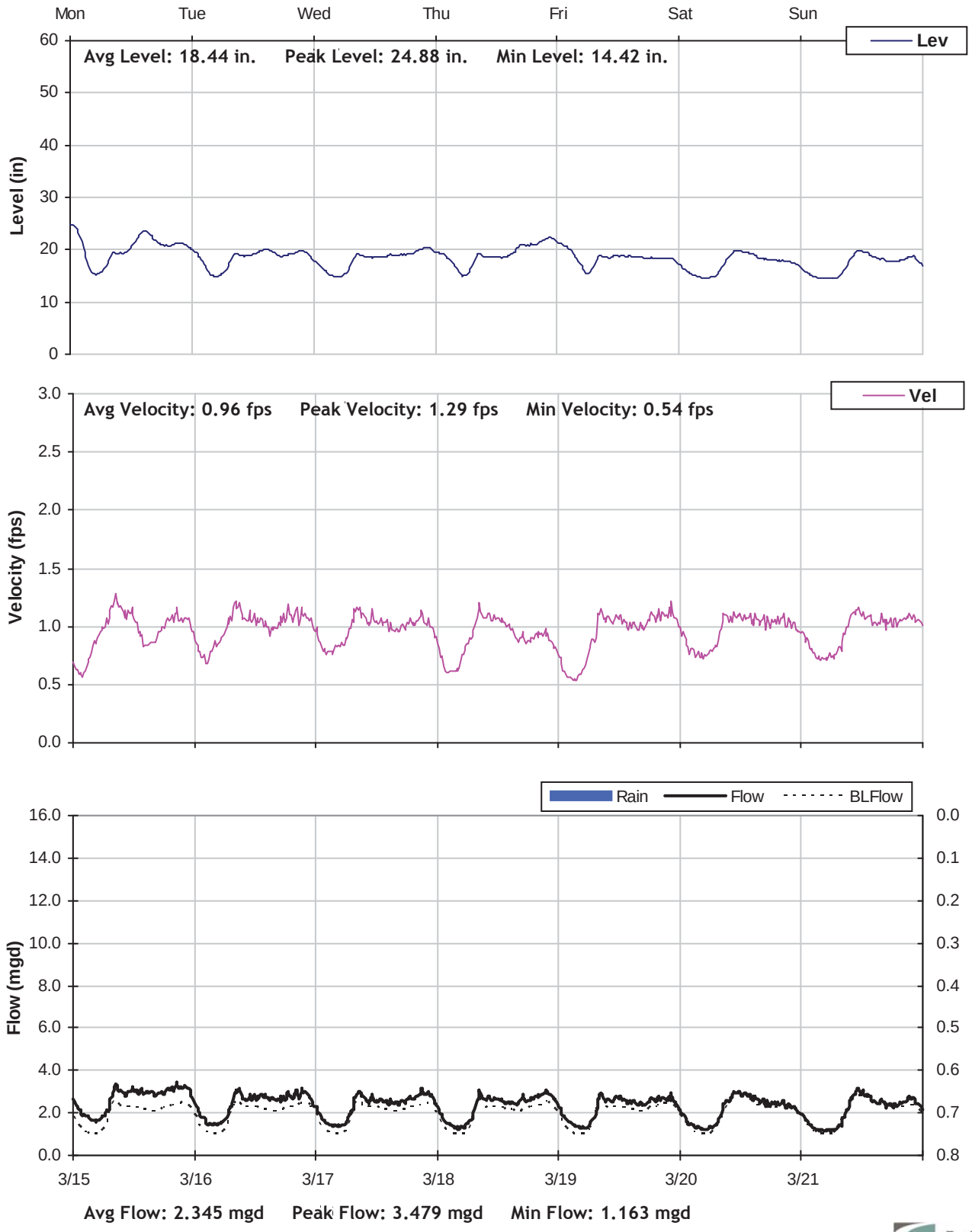






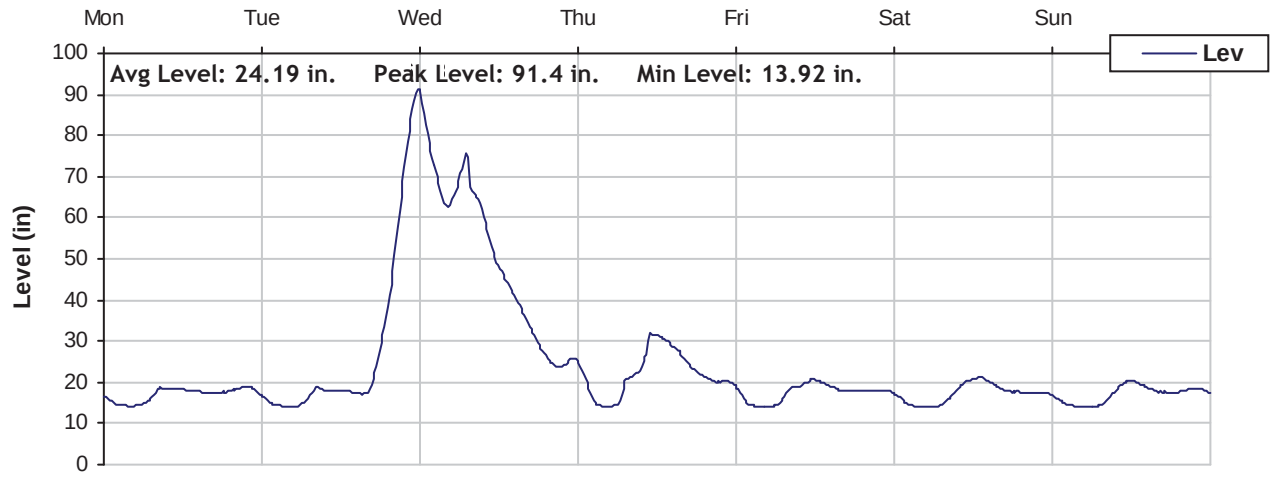
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

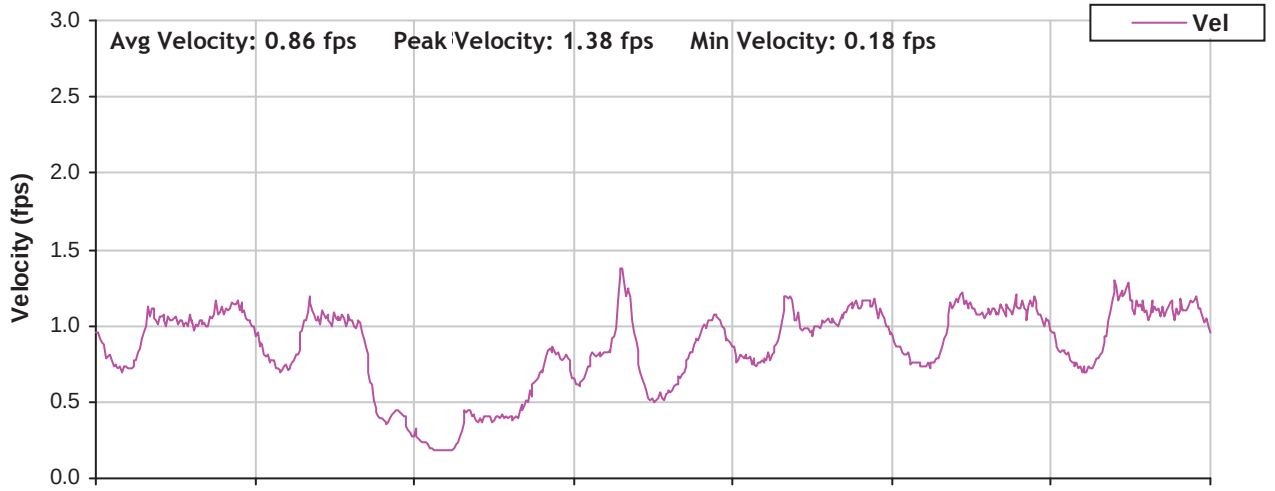
Monitoring Site:
Site 5B

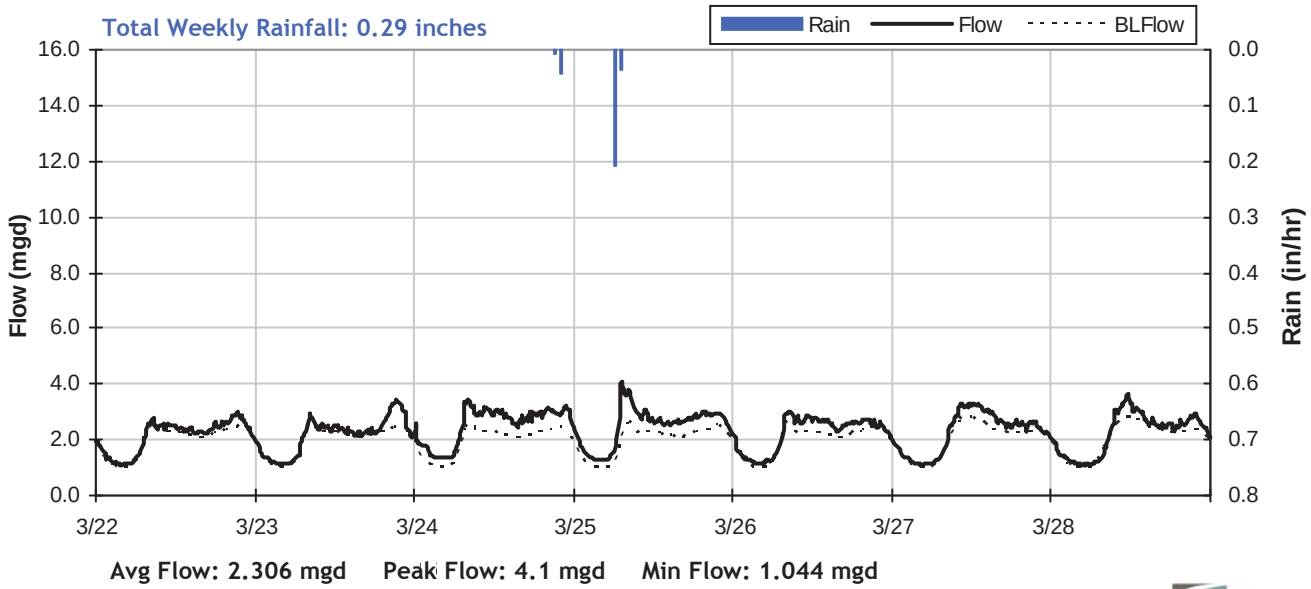


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 5B



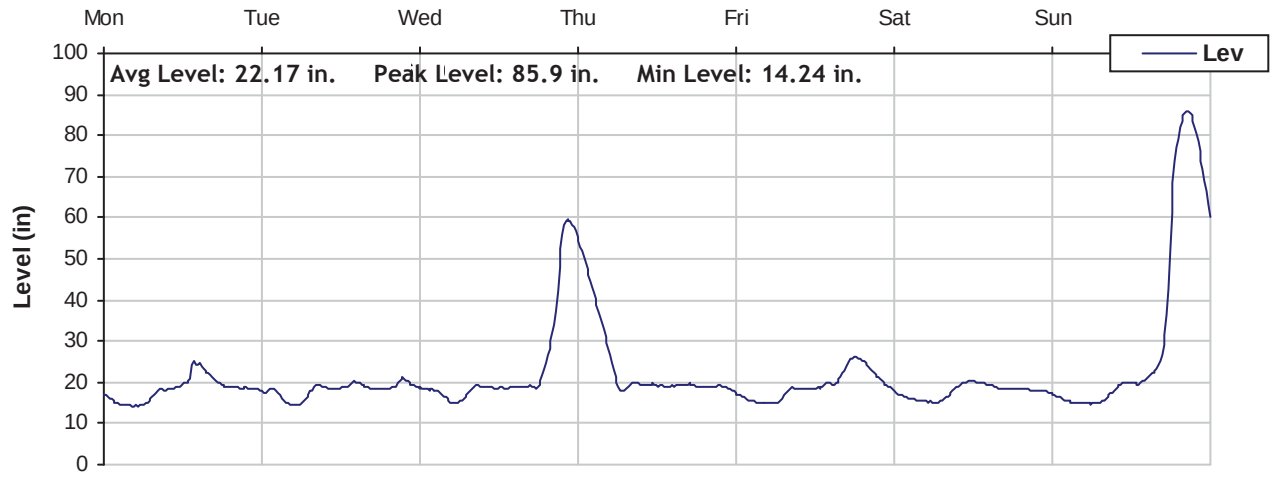


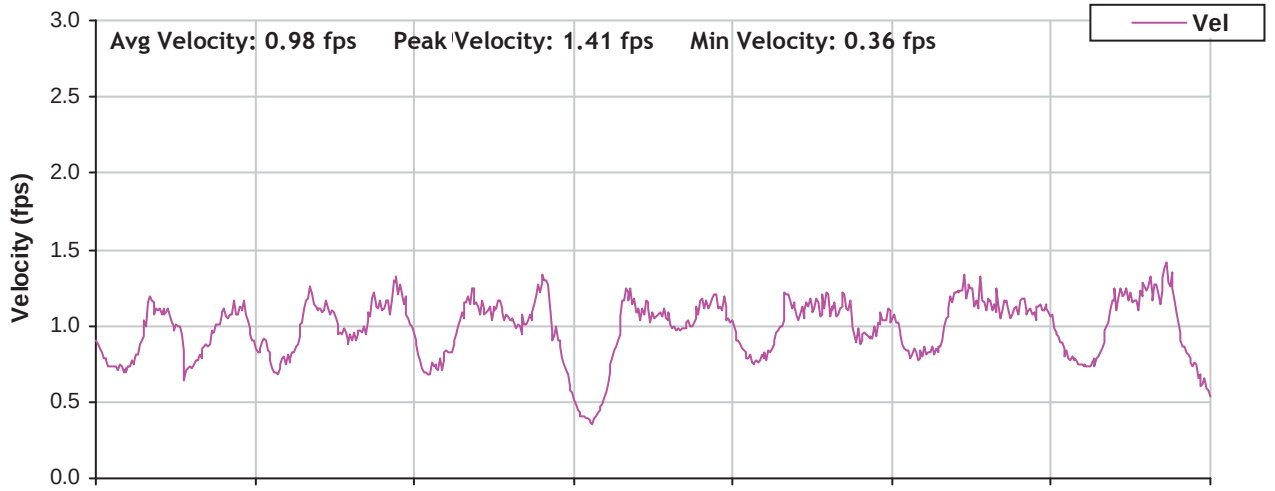


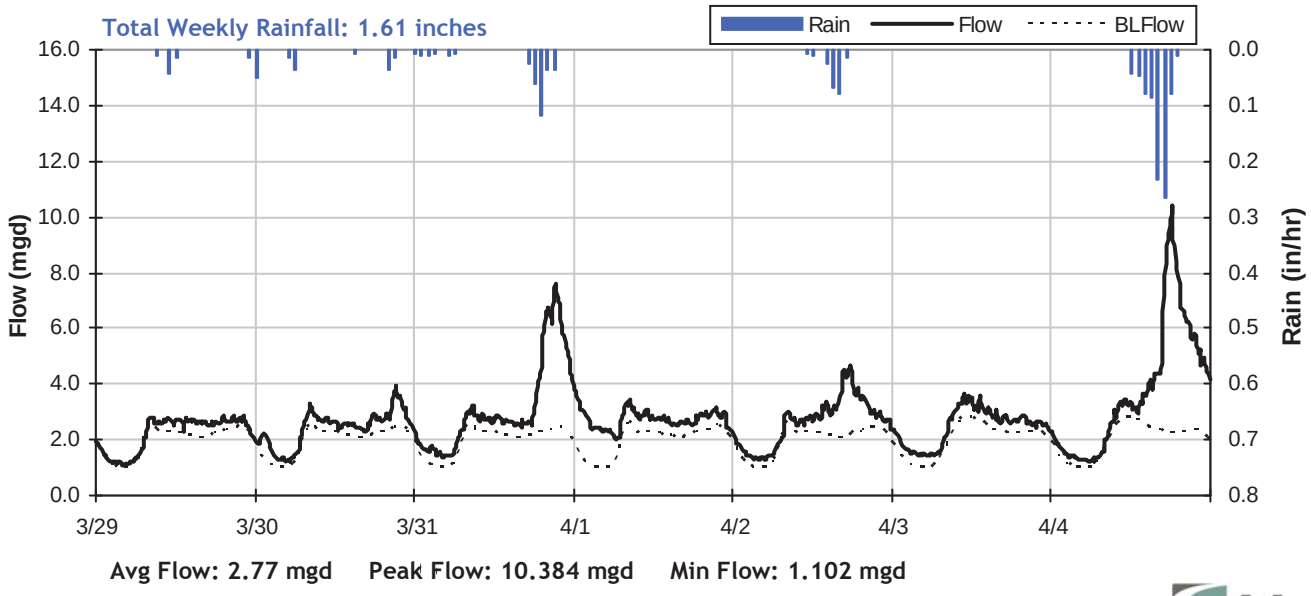
Avg Flow: 2.306 mgd Peak Flow: 4.1 mgd Min Flow: 1.044 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 5B



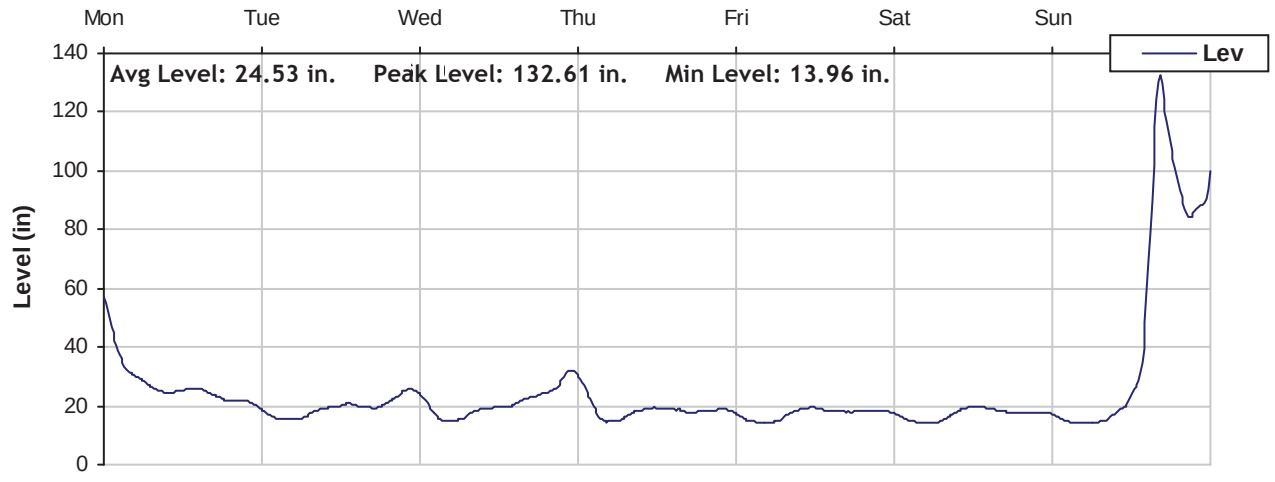


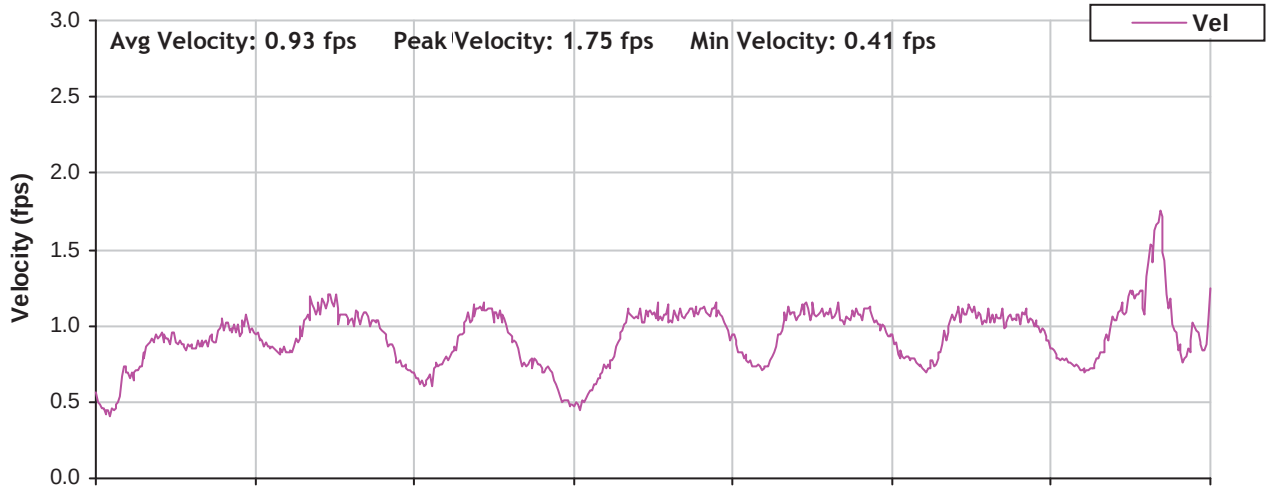


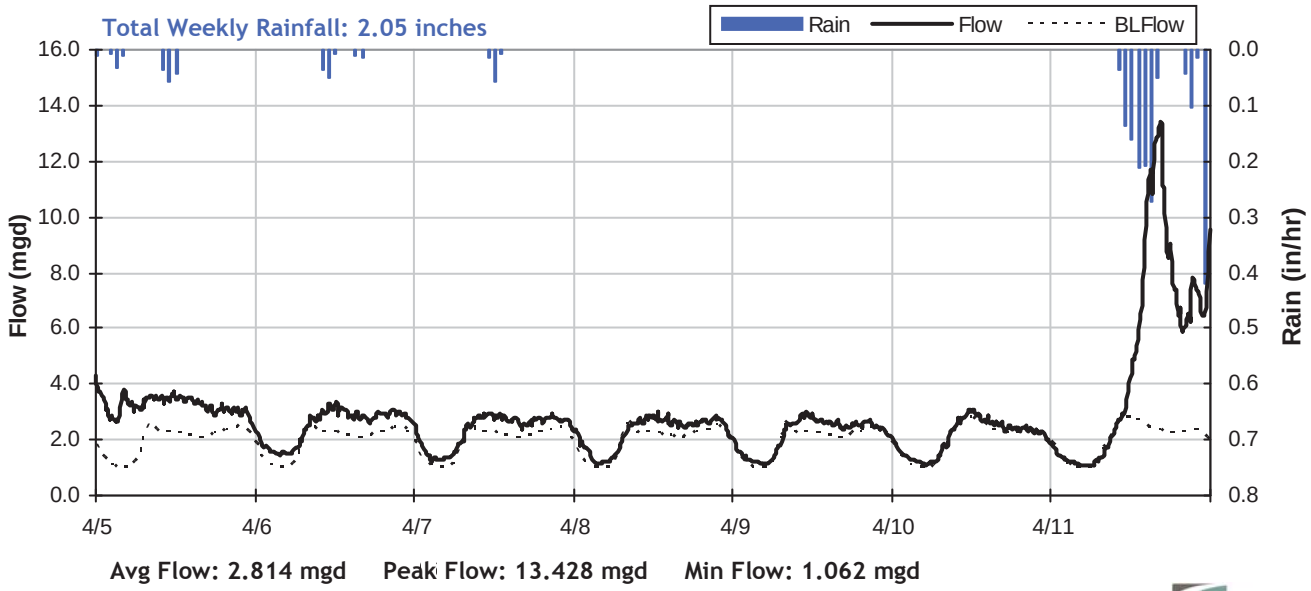
Avg Flow: 2.77 mgd Peak Flow: 10.384 mgd Min Flow: 1.102 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 5B

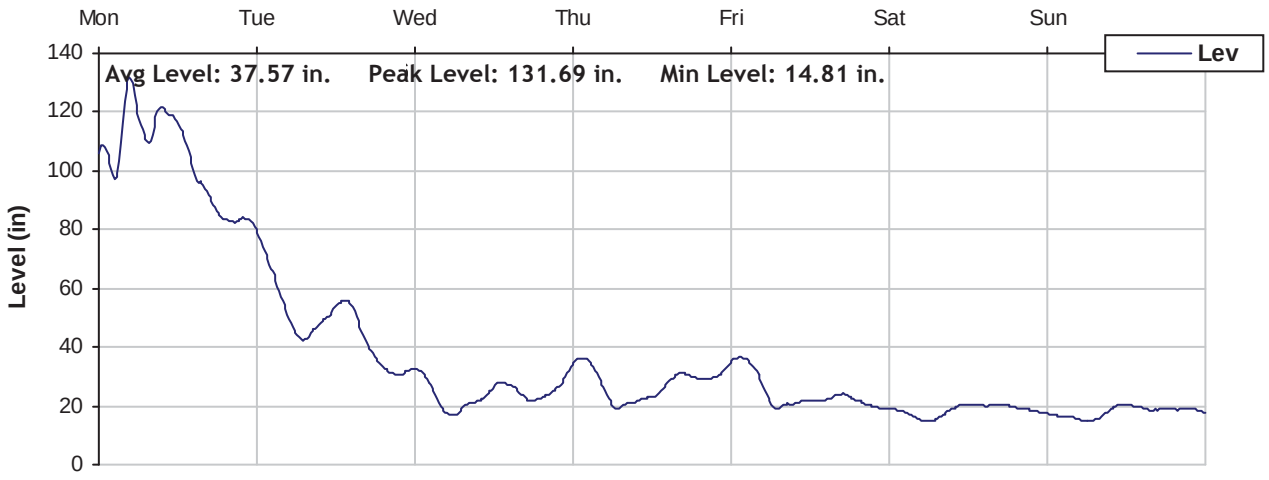


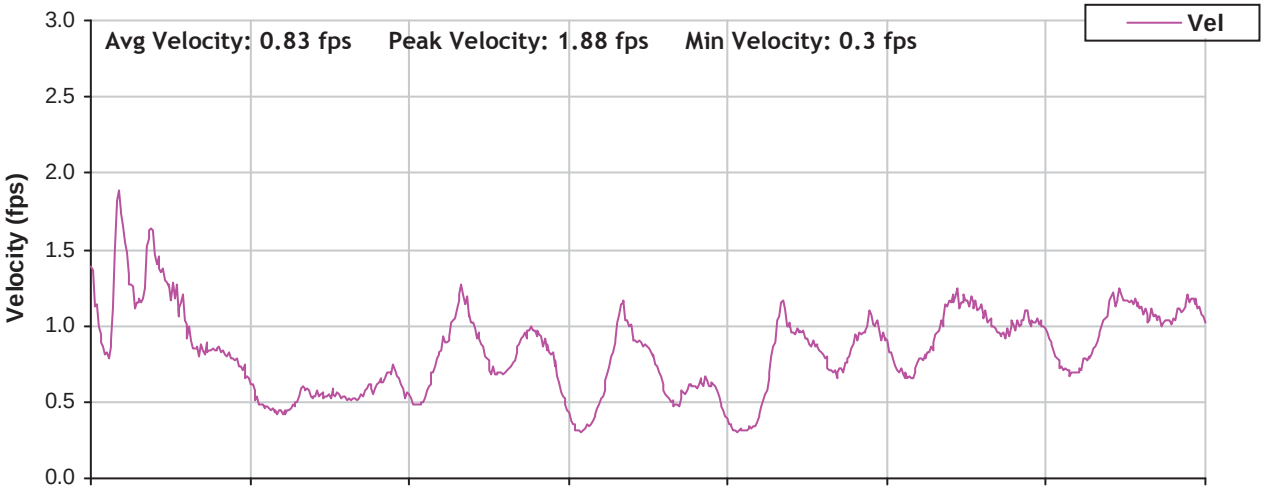


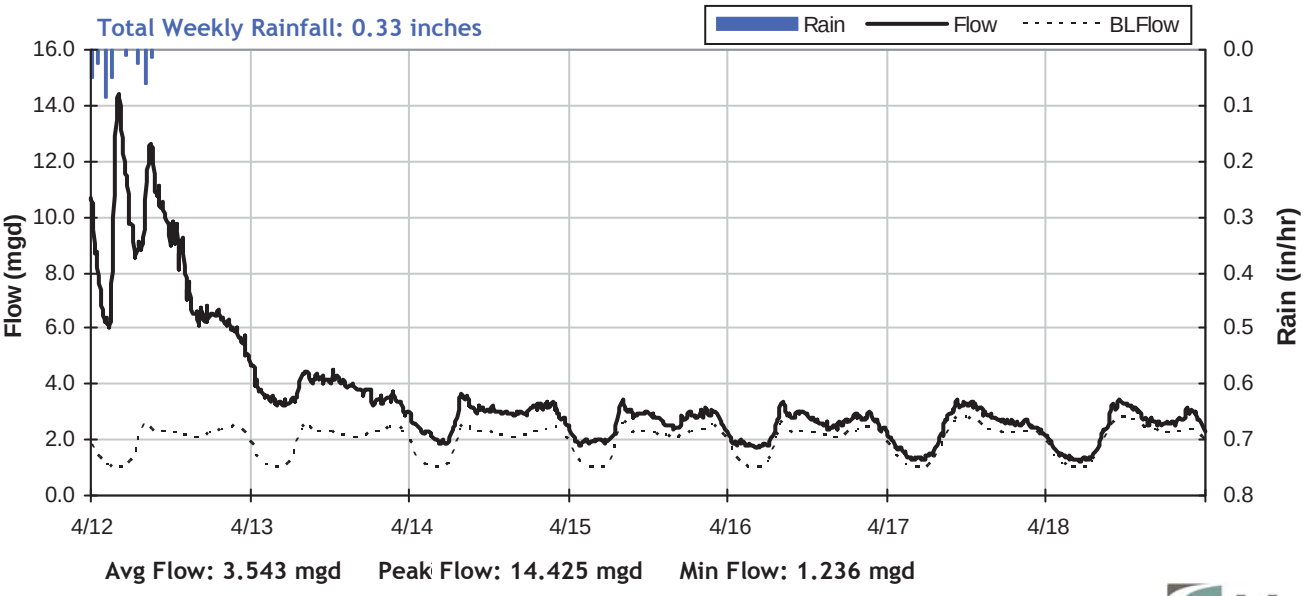


Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 5B



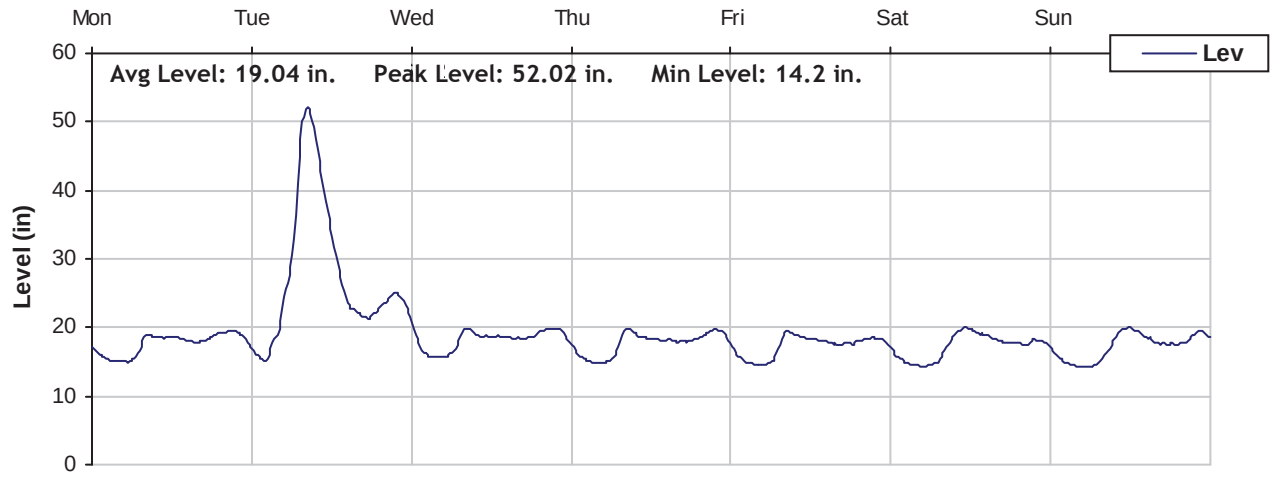


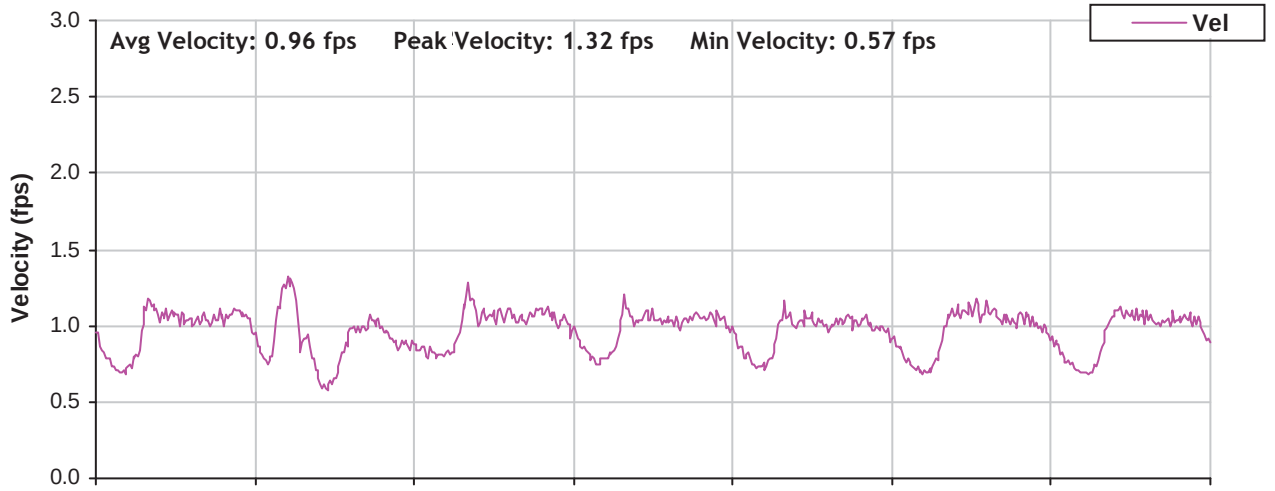


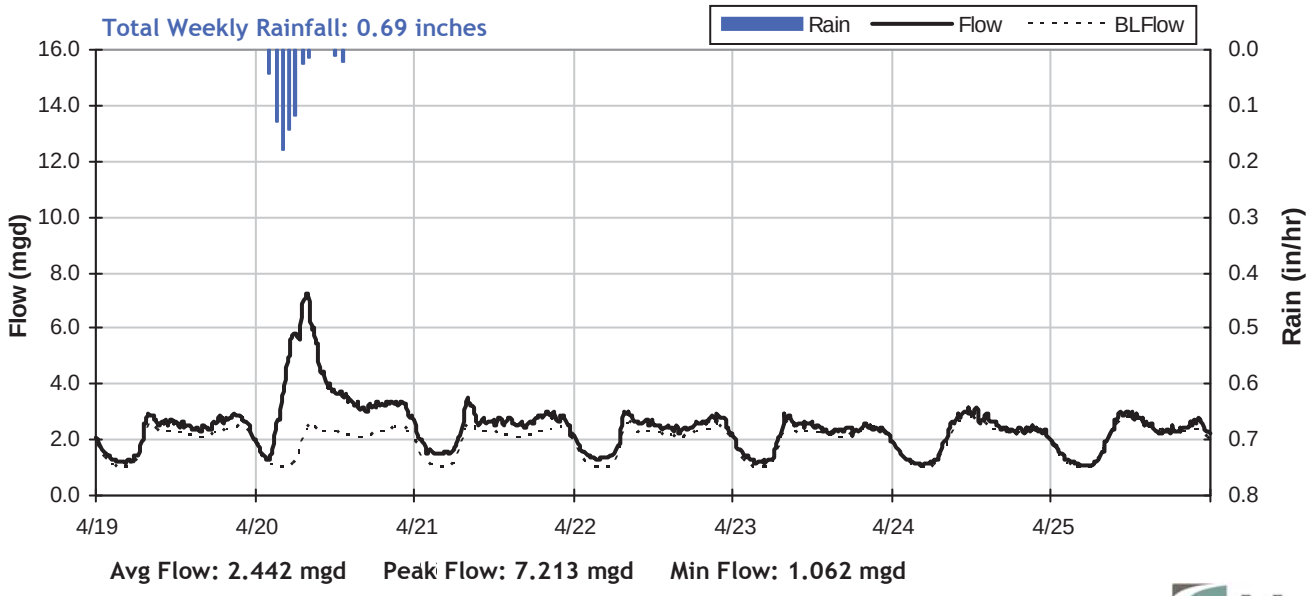
Avg Flow: 3.543 mgd Peak Flow: 14.425 mgd Min Flow: 1.236 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 5B



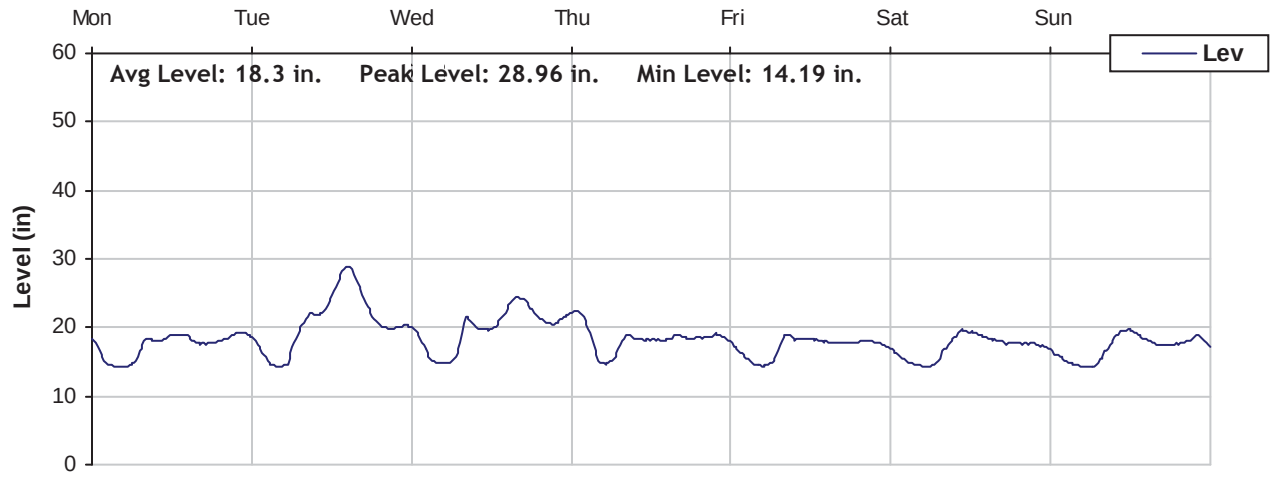


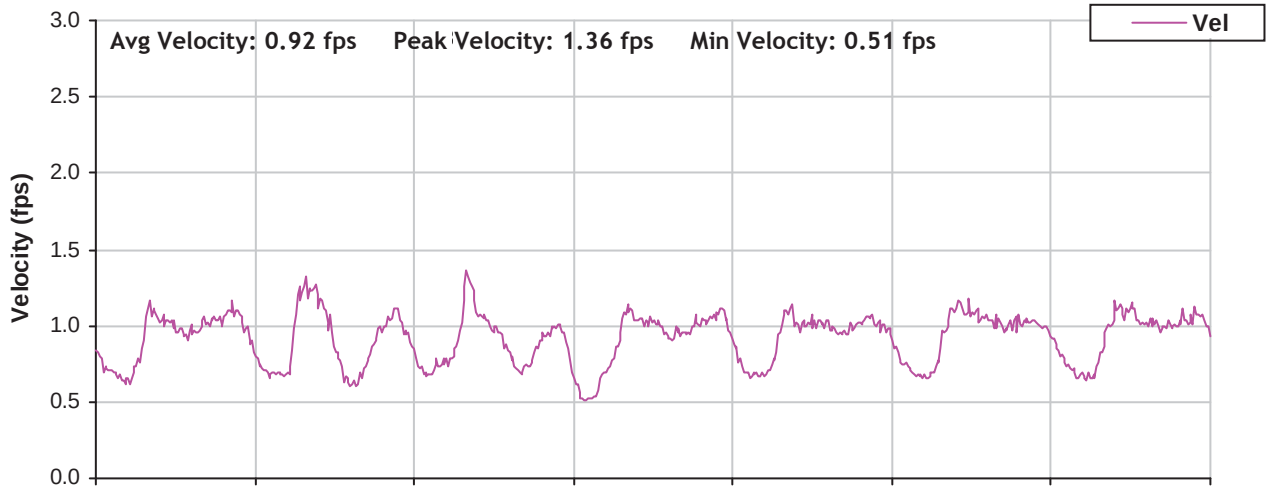


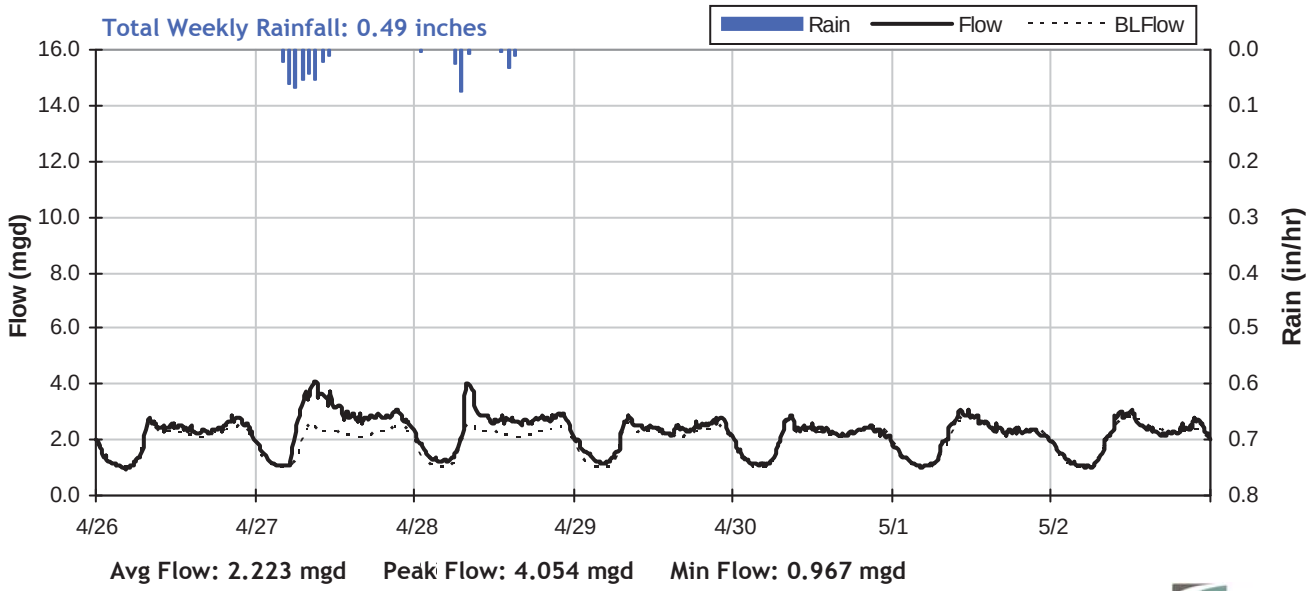
Avg Flow: 2.442 mgd Peak Flow: 7.213 mgd Min Flow: 1.062 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 5B



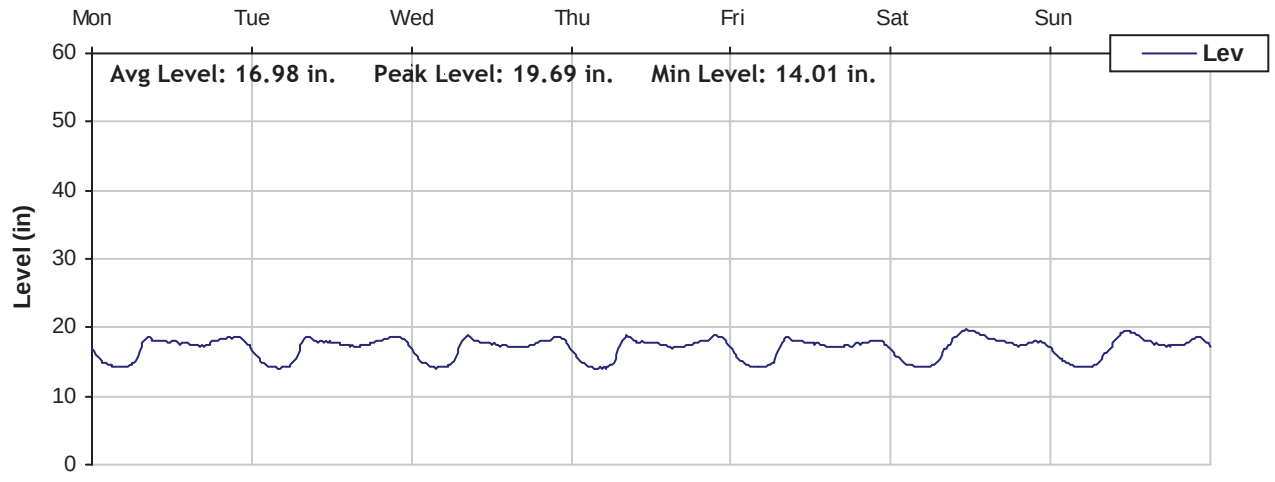


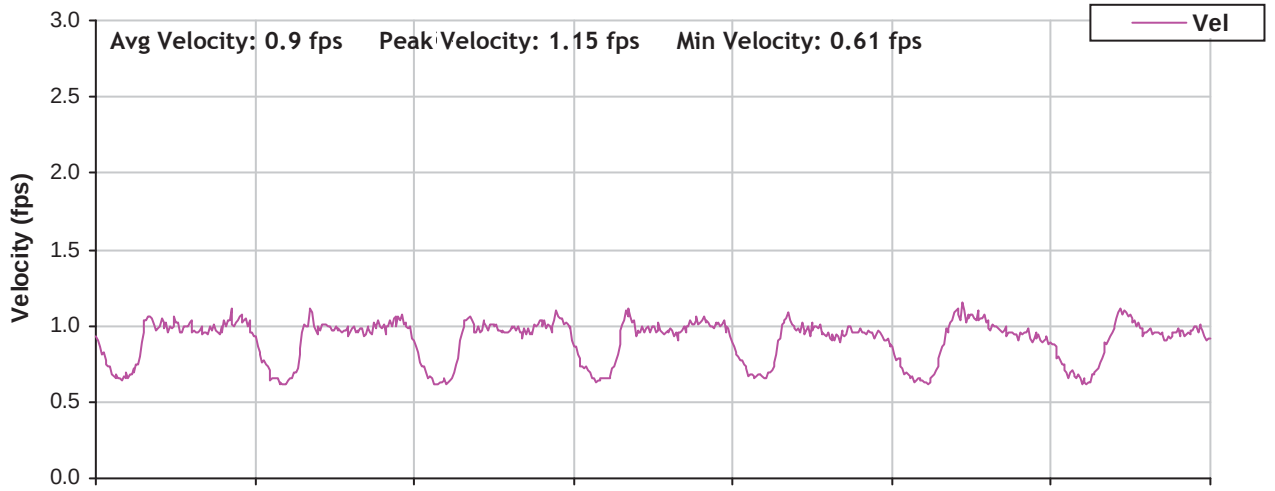


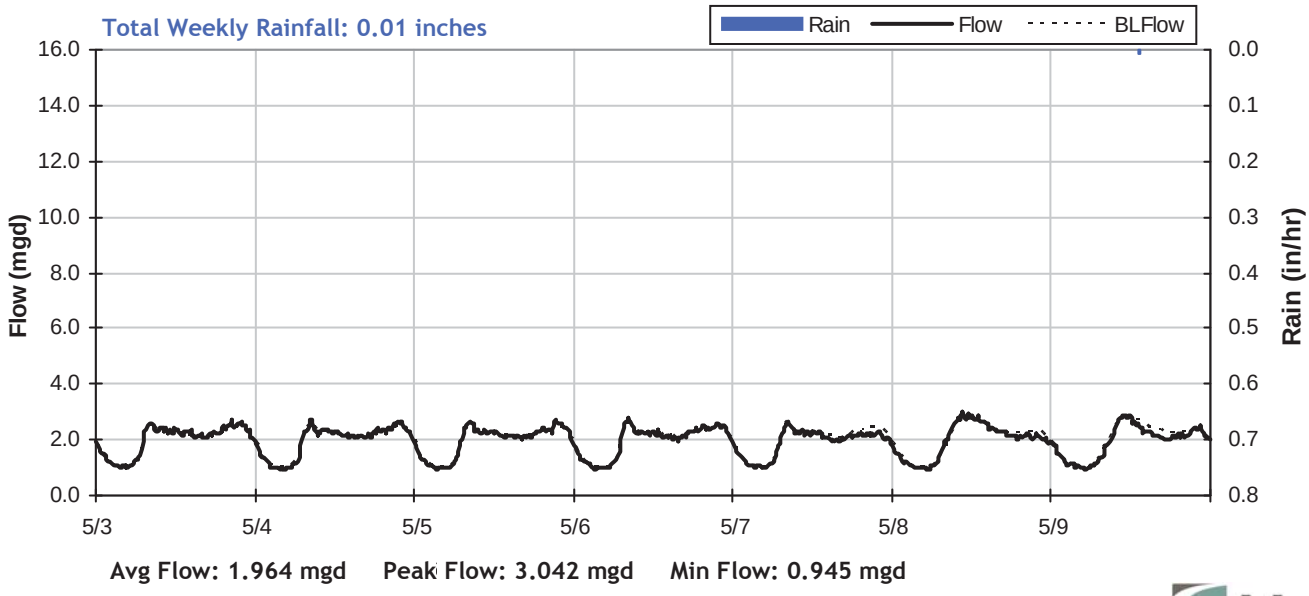
Avg Flow: 2.223 mgd Peak Flow: 4.054 mgd Min Flow: 0.967 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 5B



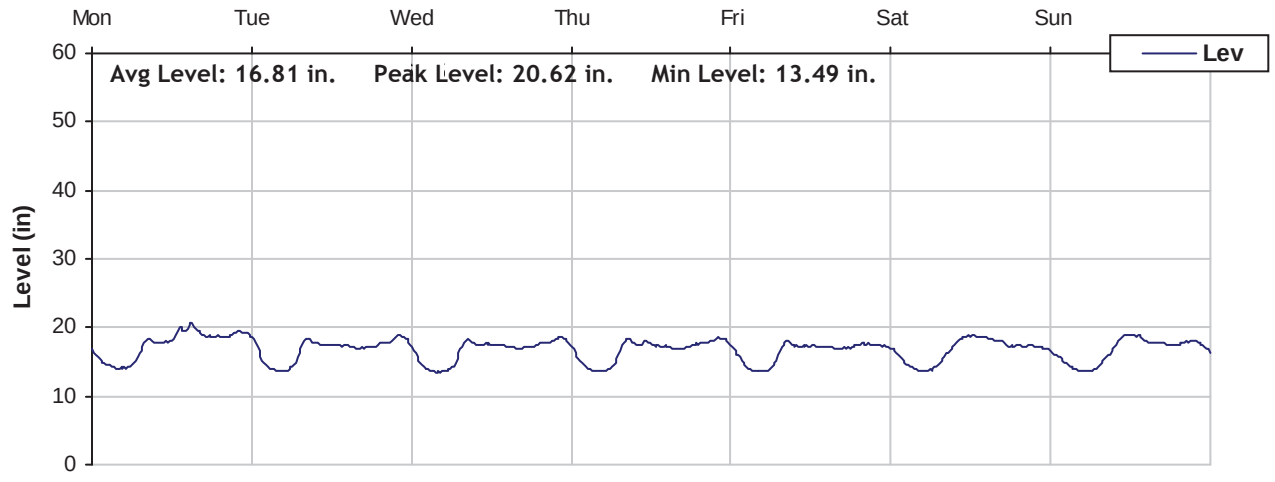


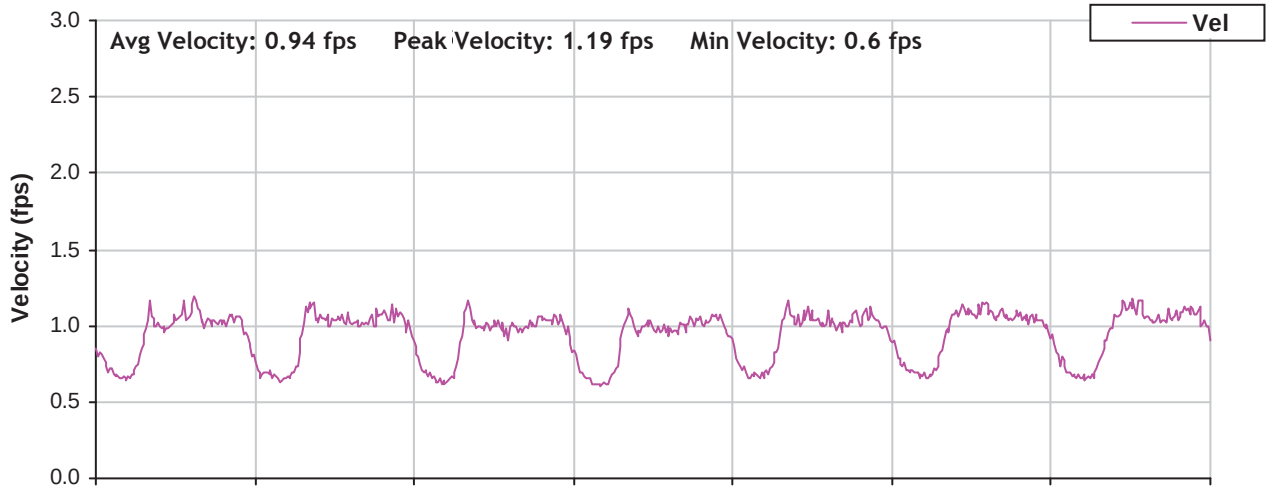


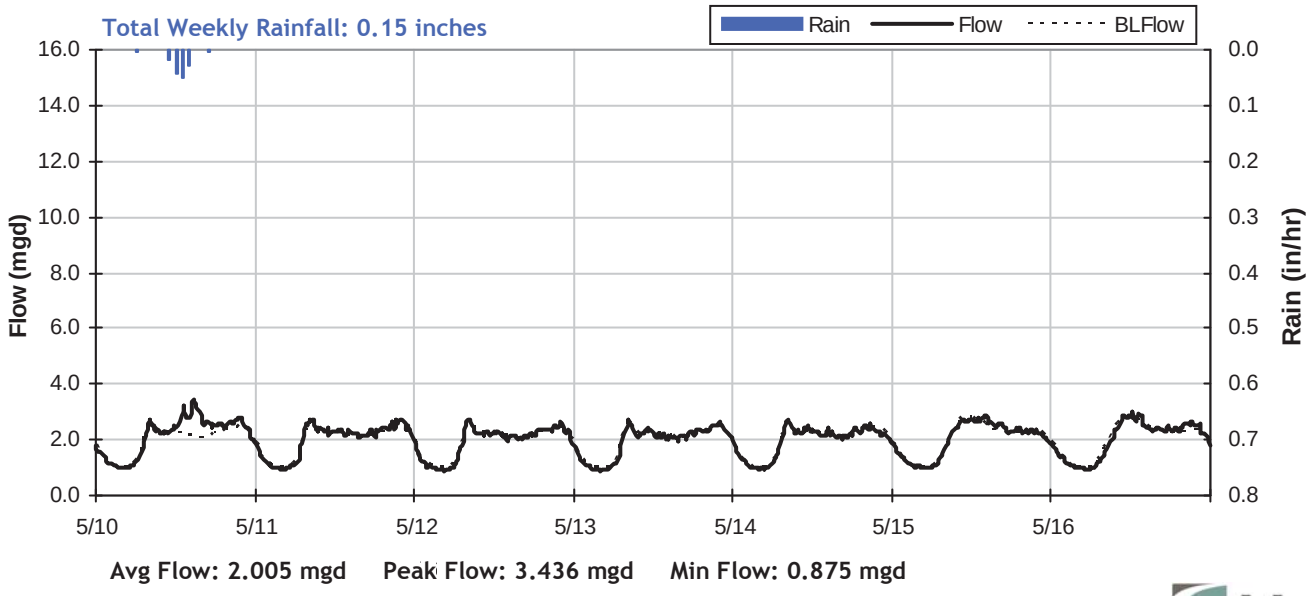
Avg Flow: 1.964 mgd Peak Flow: 3.042 mgd Min Flow: 0.945 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 5B



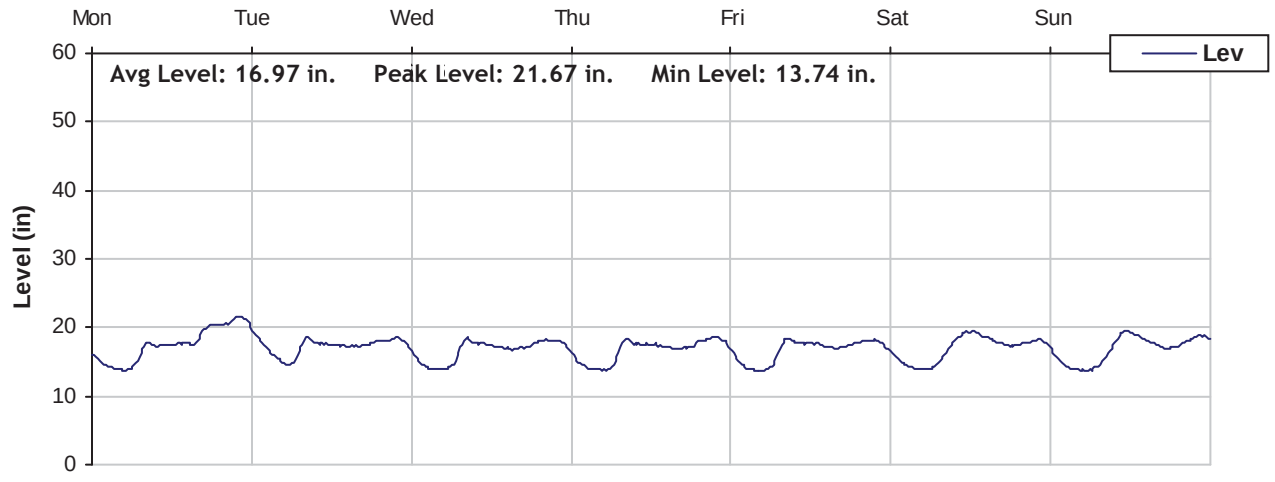


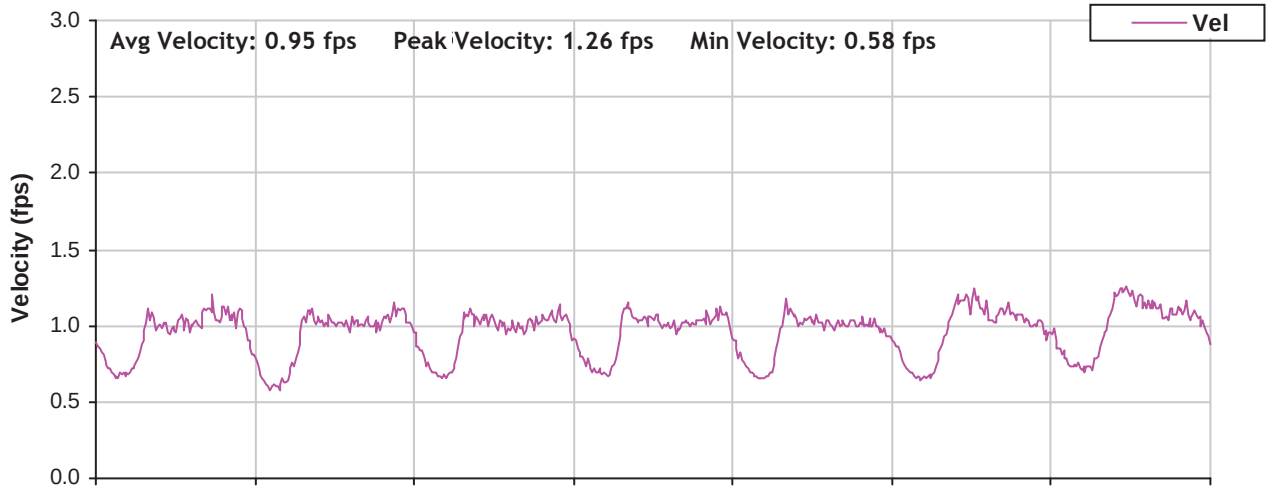


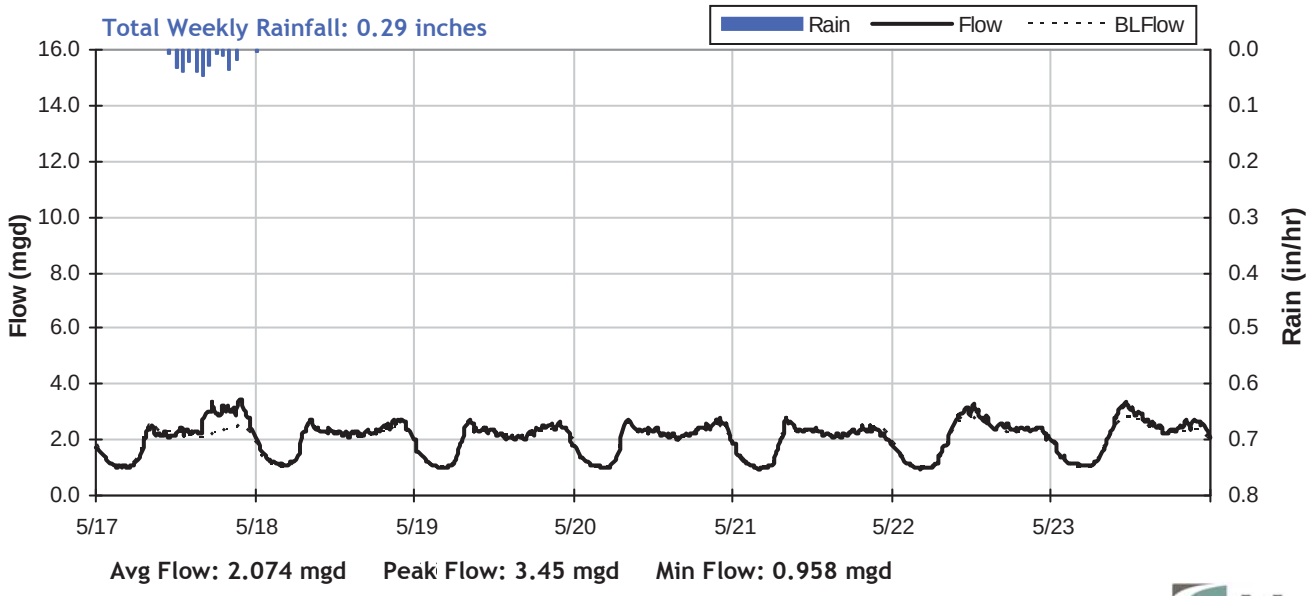
Avg Flow: 2.005 mgd Peak Flow: 3.436 mgd Min Flow: 0.875 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 5B

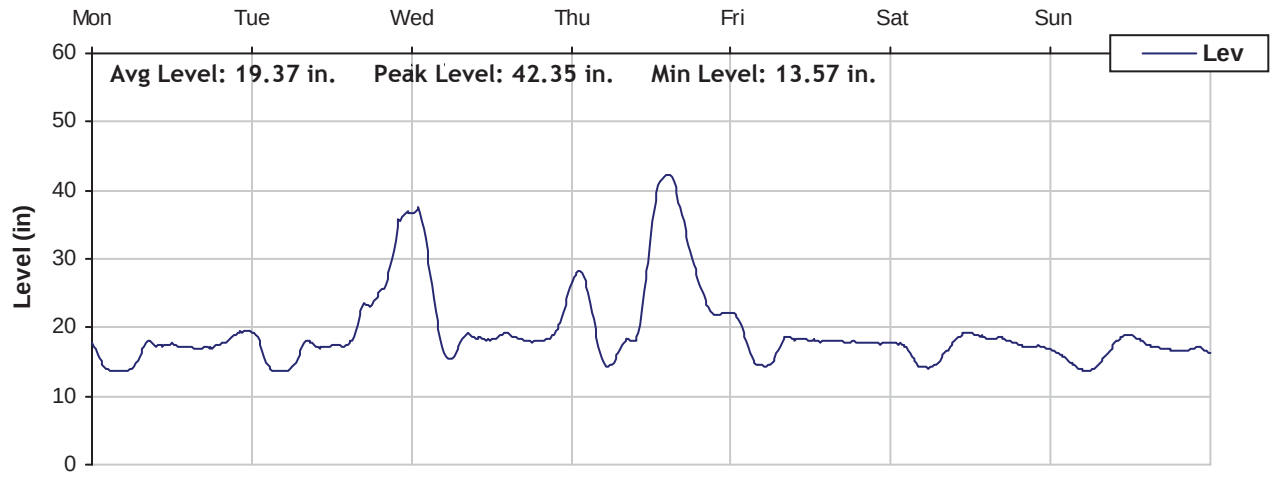


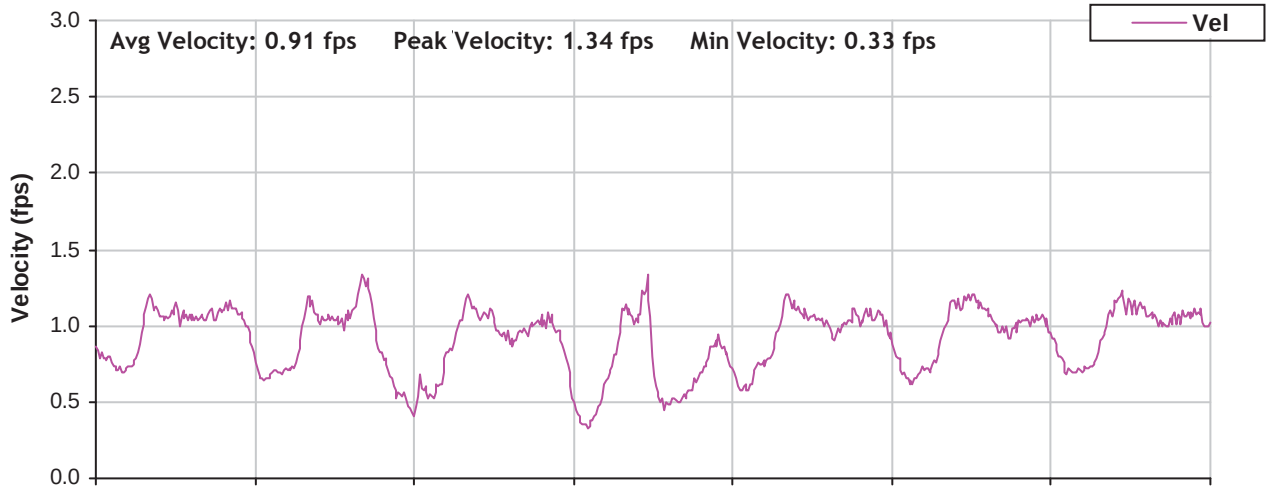


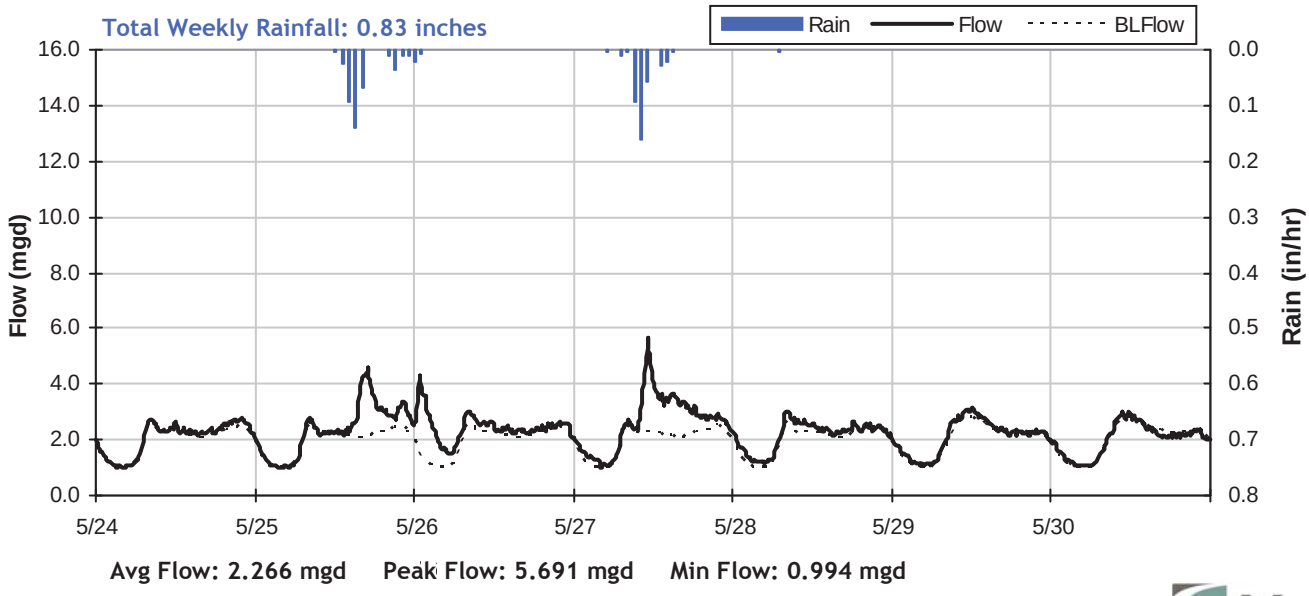


Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 5B



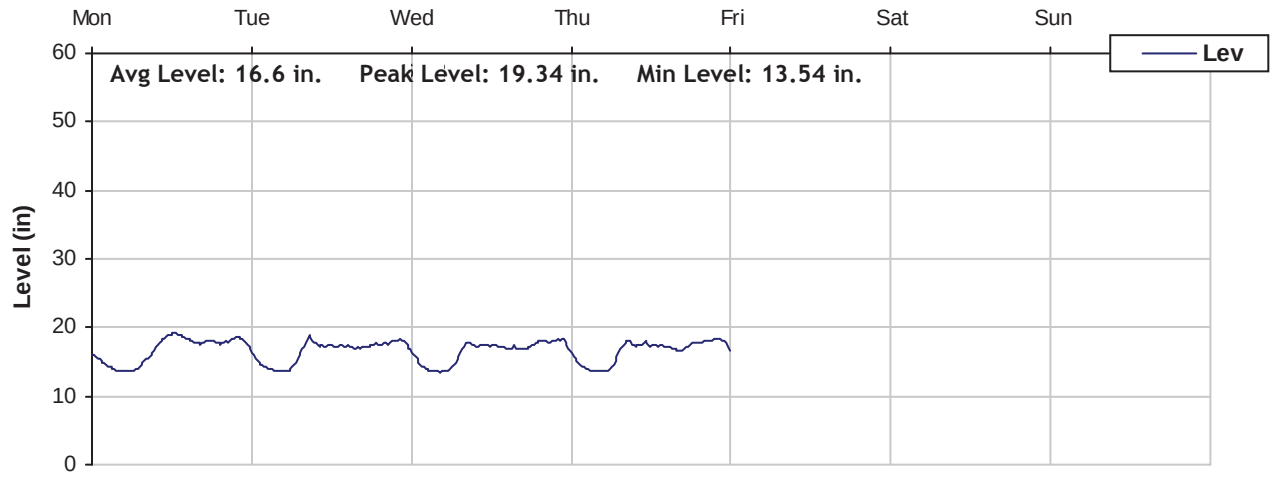


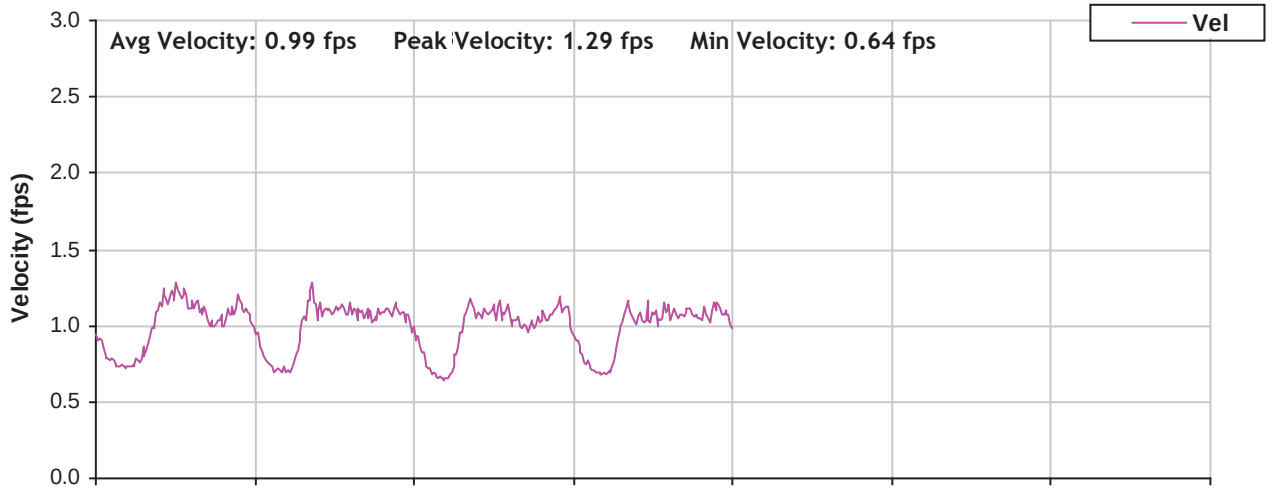


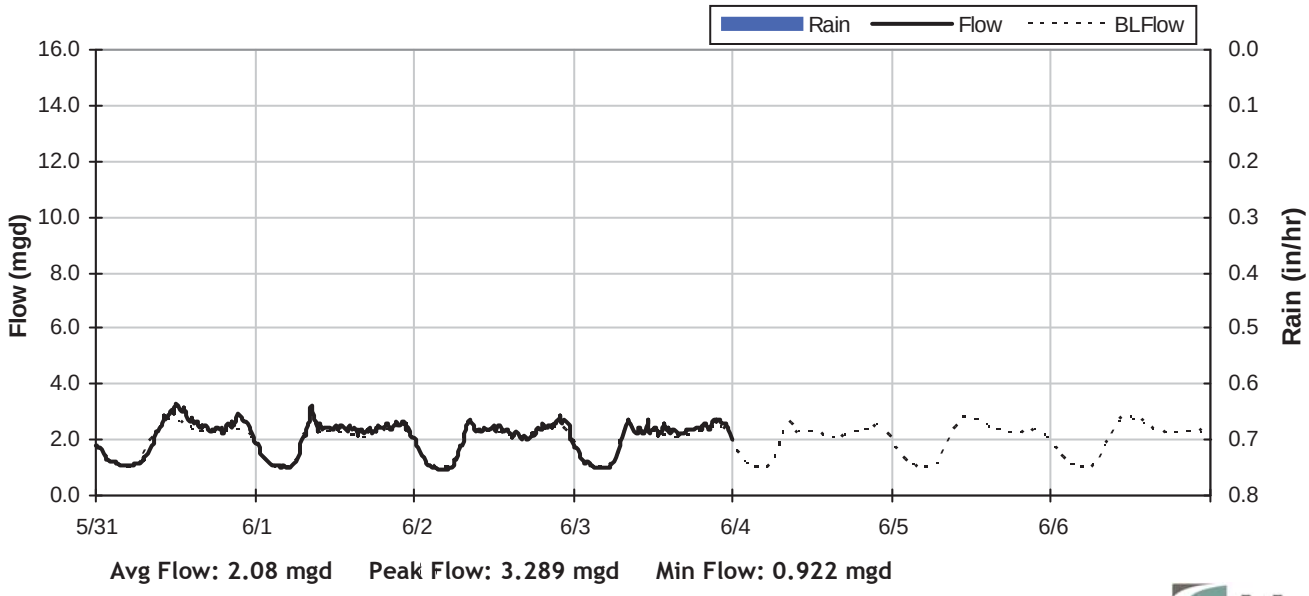
Avg Flow: 2.266 mgd Peak Flow: 5.691 mgd Min Flow: 0.994 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 5B







Avg Flow: 2.08 mgd Peak Flow: 3.289 mgd Min Flow: 0.922 mgd

Temporary Flow Monitoring Study

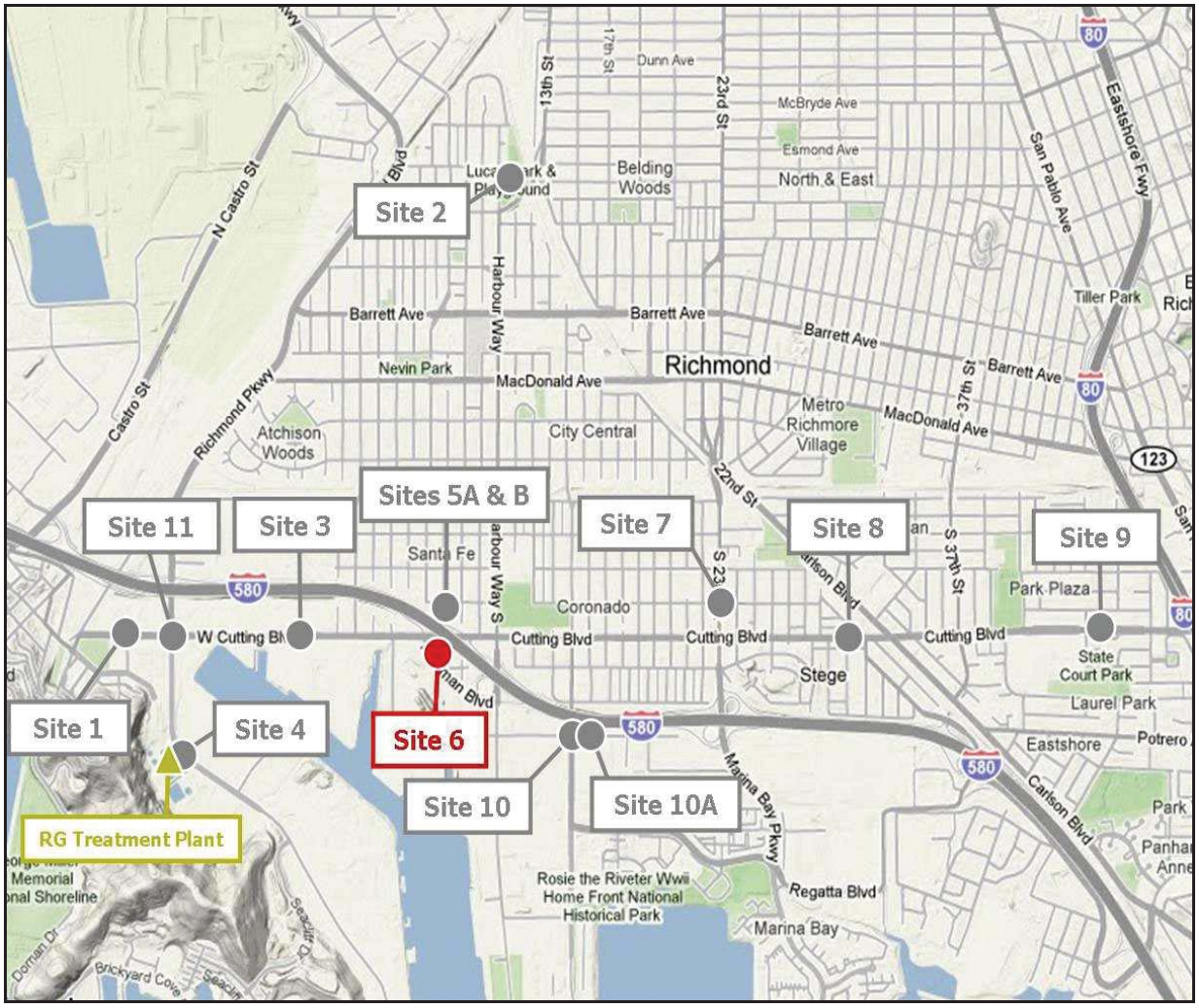
Sanitary Sewer Collection System

Monitoring Site: Site 6

Location: Hoffman Boulevard; south of Cutting Boulevard

Size/Type Line: 36-inch Sanitary Sewer Pipe

Data Summary Report



V&A

Site Information Report

Monitoring Site: Site 6

Location: Hoffman Boulevard; south of Cutting Boulevard

Latitude: 37.9240°

Longitude: -122.3632°

Rim Elevation: 9 *feet above sea level*

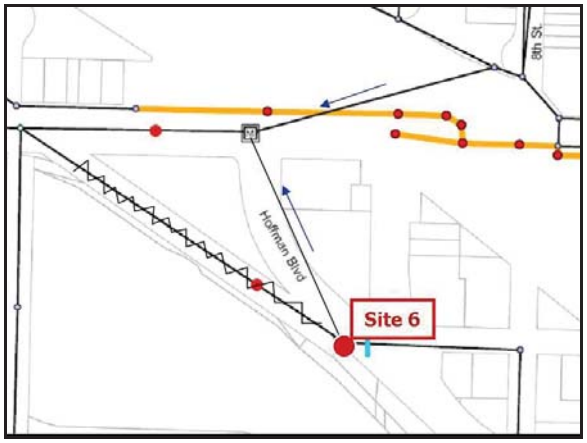
Diameter: 36 *inches*

Average Dry Weather Flow: 1.845 *mgd*

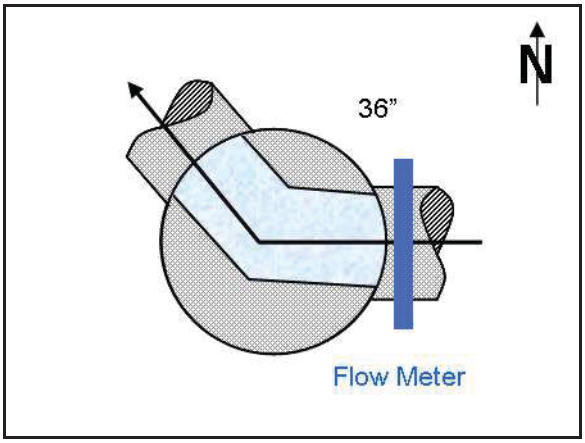
Peak Measured Flow: 7.701 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

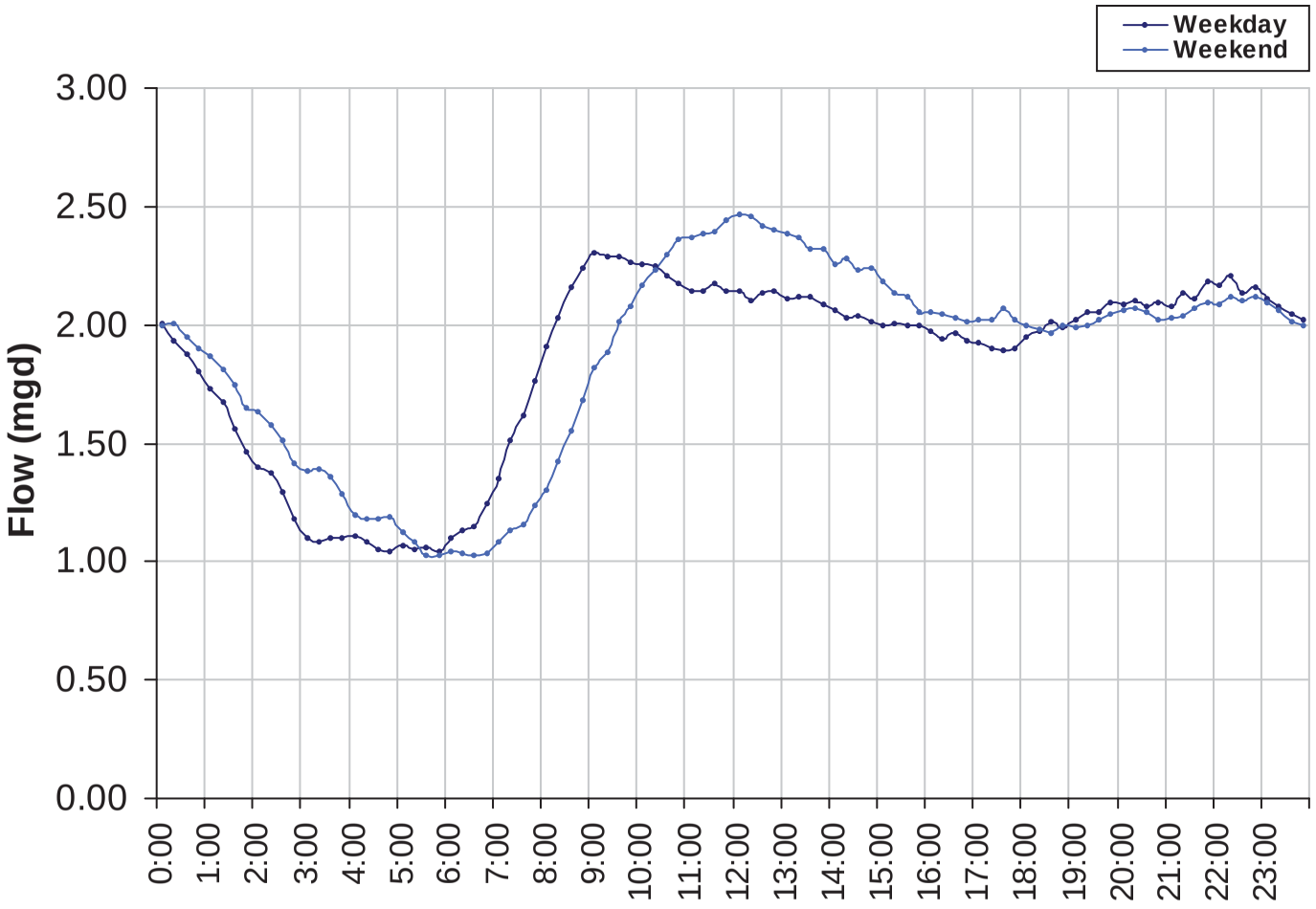


Street View Photo

Plan View Photo

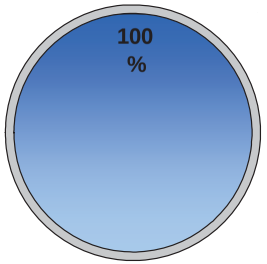
Average Dry Weather Flow

Monitoring Site:
Site 6



Peak Measured Flow:

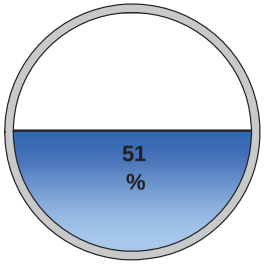
7.70 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

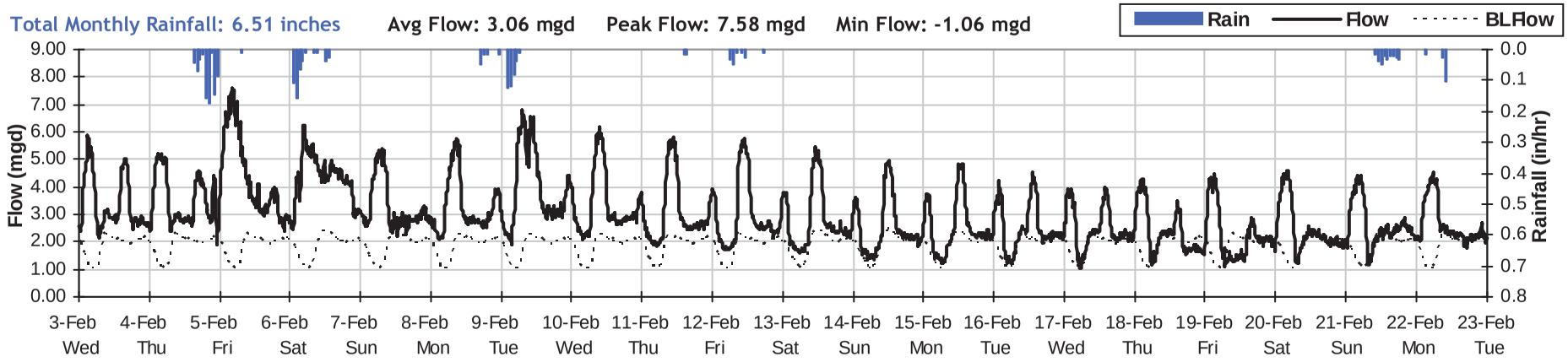
1.85 *mgd*

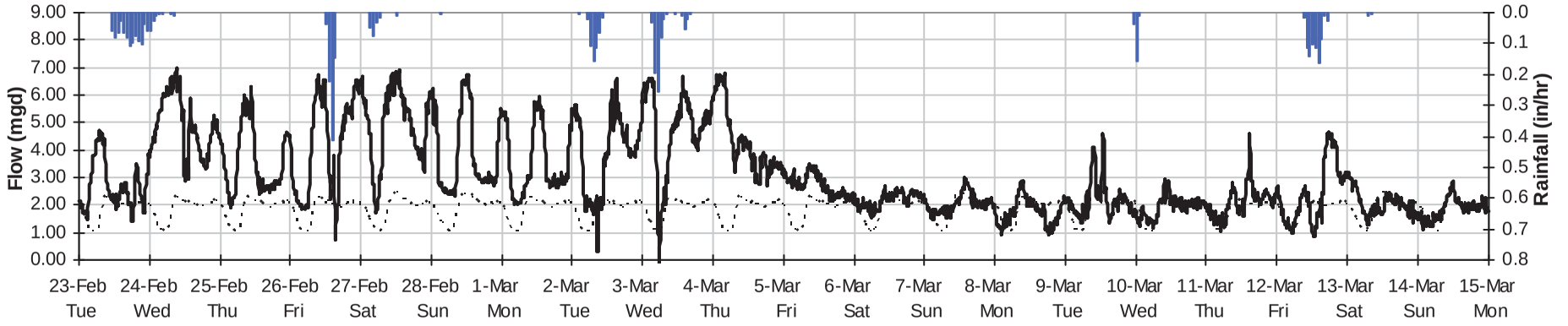


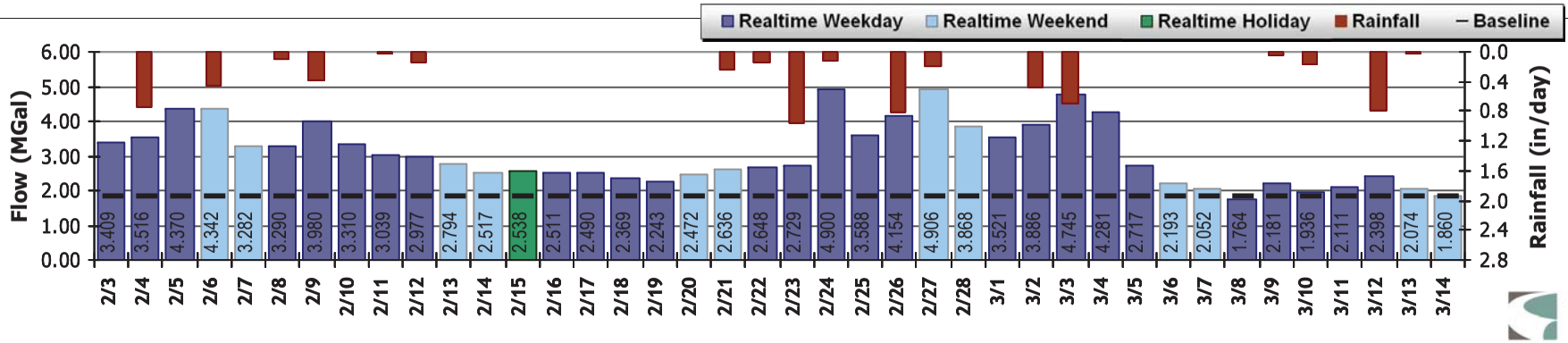
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 6

Total Monthly Rainfall: 6.51 inches Avg Flow: 3.06 mgd Peak Flow: 7.58 mgd Min Flow: -1.06 mgd





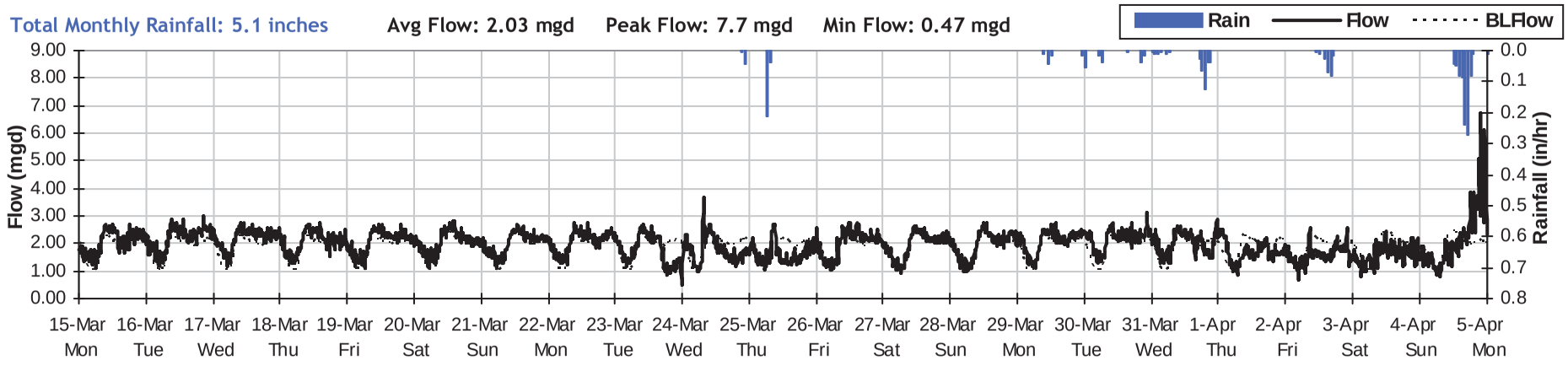


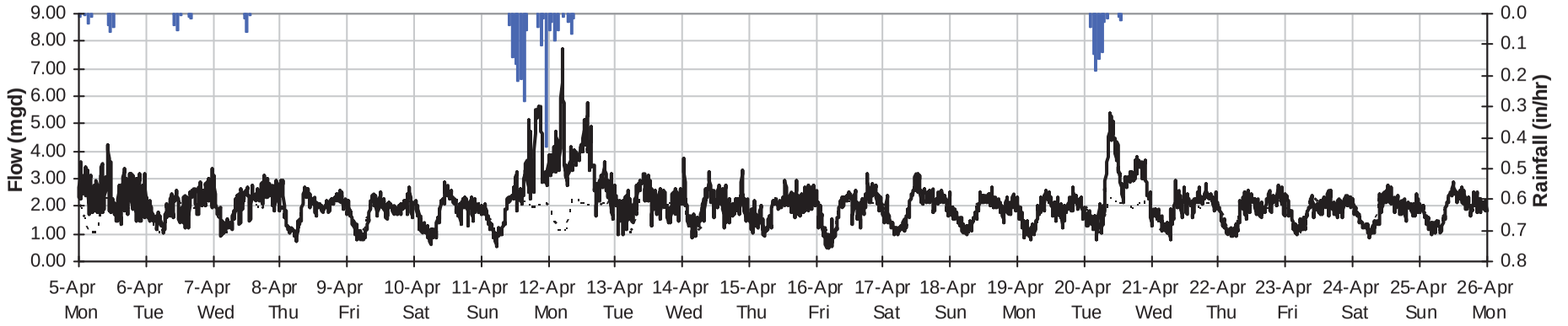
V&A

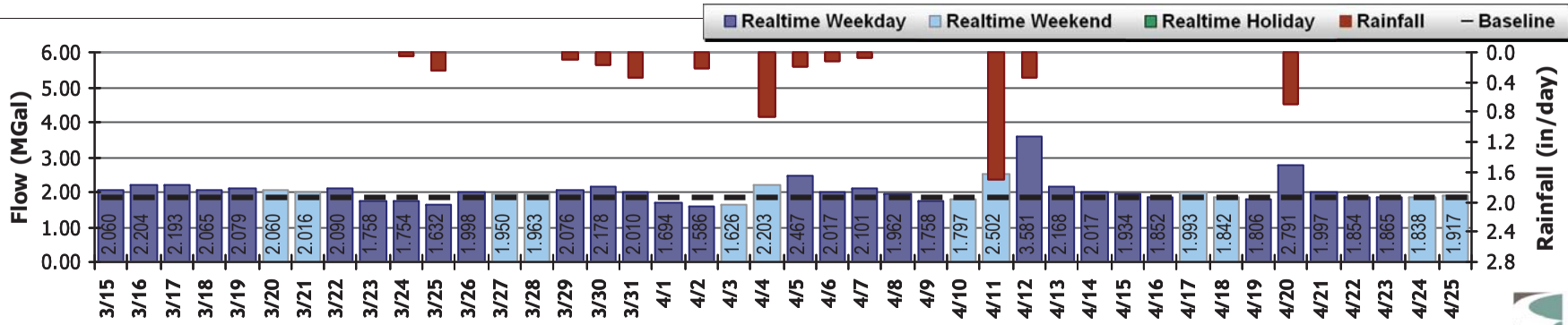
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 6

Total Monthly Rainfall: 5.1 inches Avg Flow: 2.03 mgd Peak Flow: 7.7 mgd Min Flow: 0.47 mgd





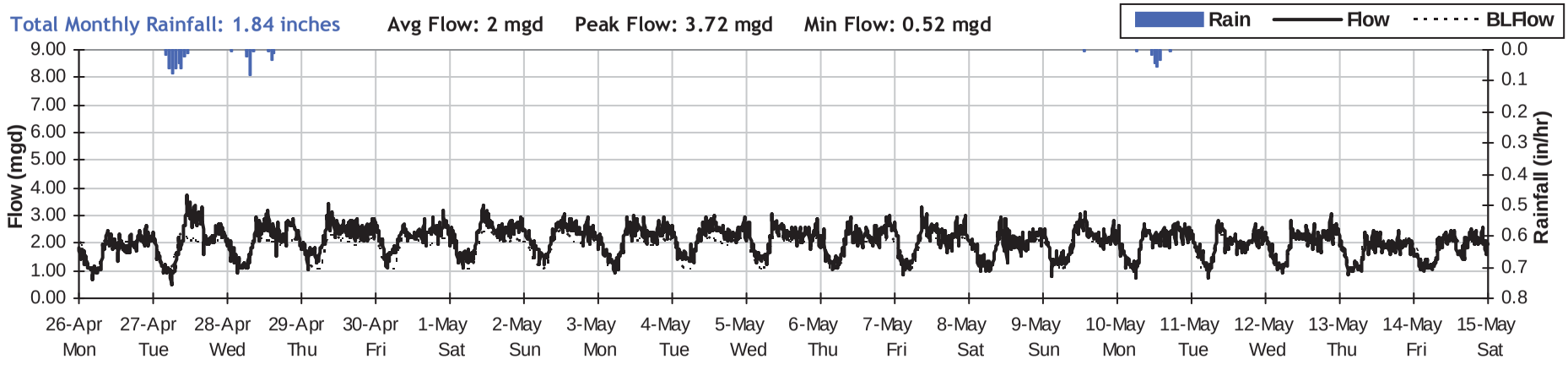


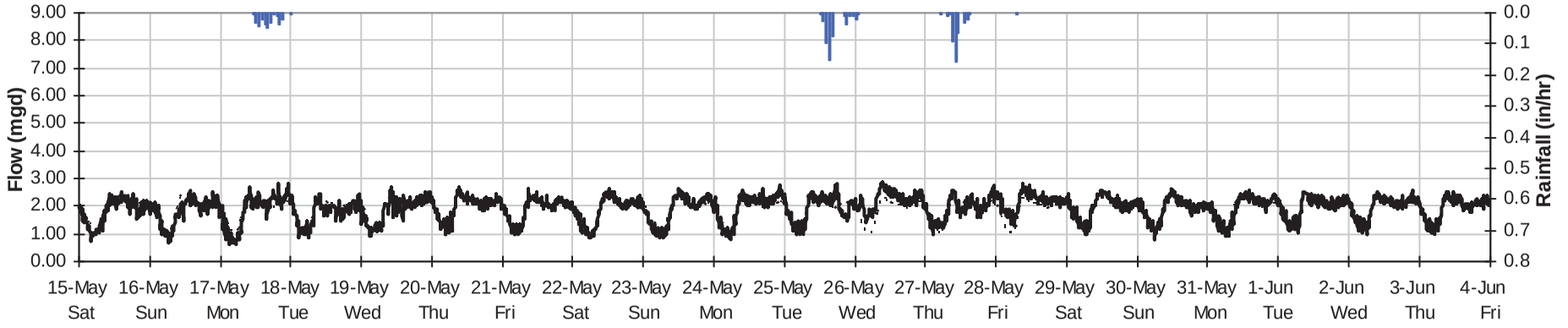
V&A

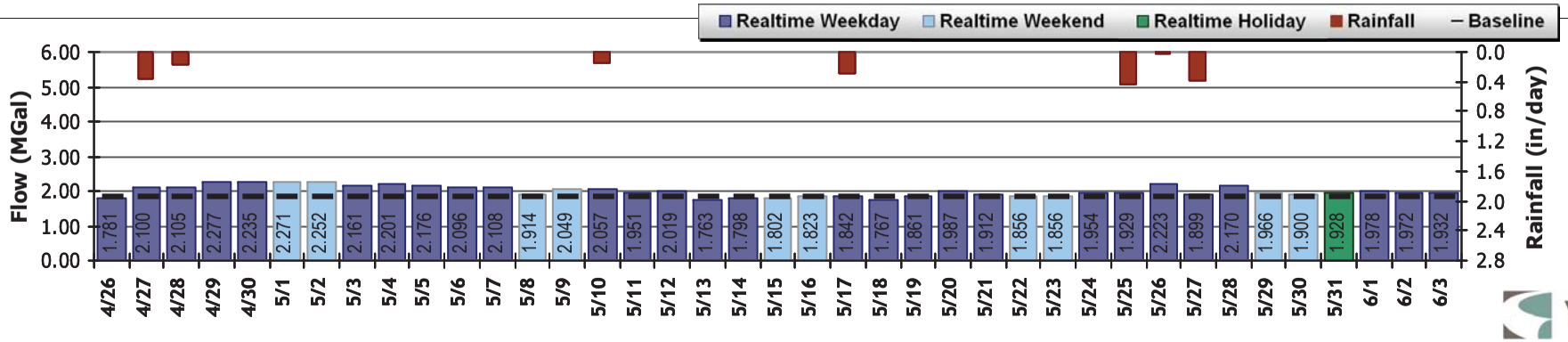
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 6

Total Monthly Rainfall: 1.84 inches Avg Flow: 2 mgd Peak Flow: 3.72 mgd Min Flow: 0.52 mgd





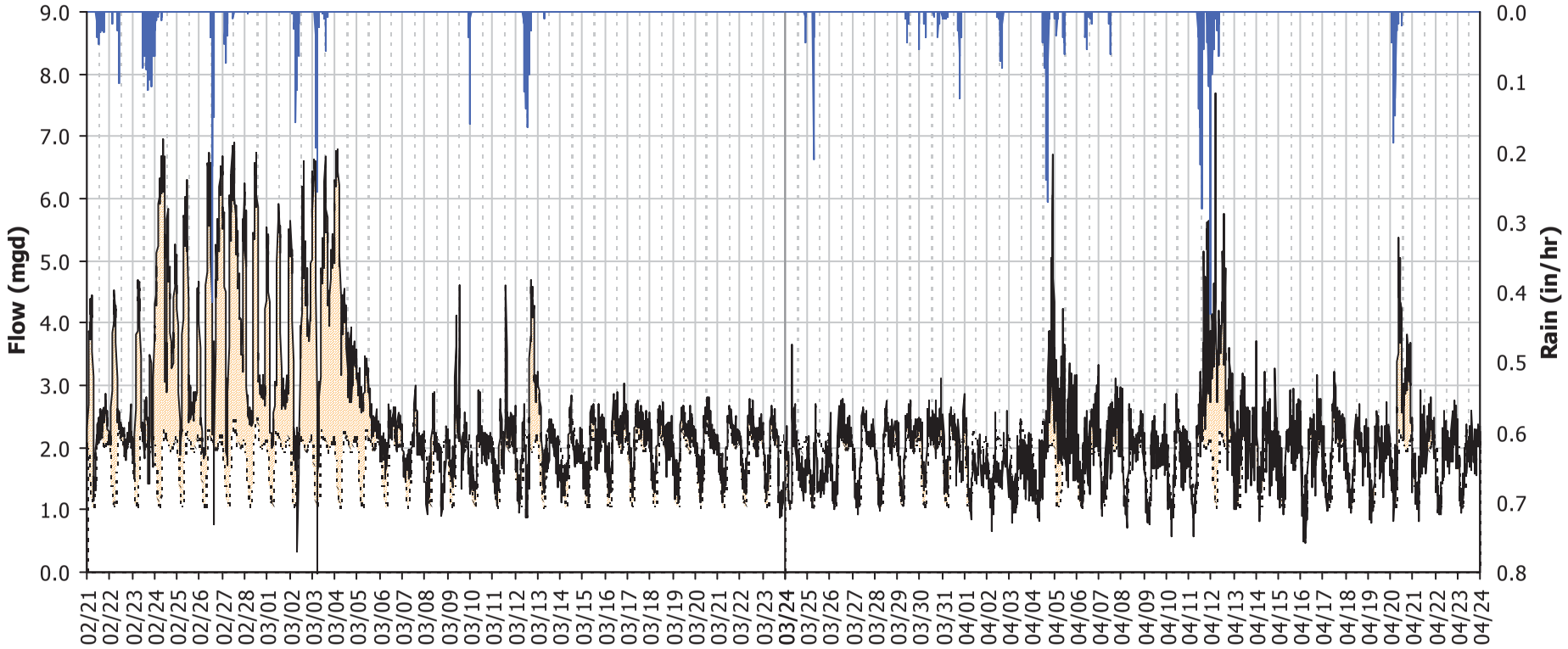


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 6

Multiple Events Detail I/I Graph

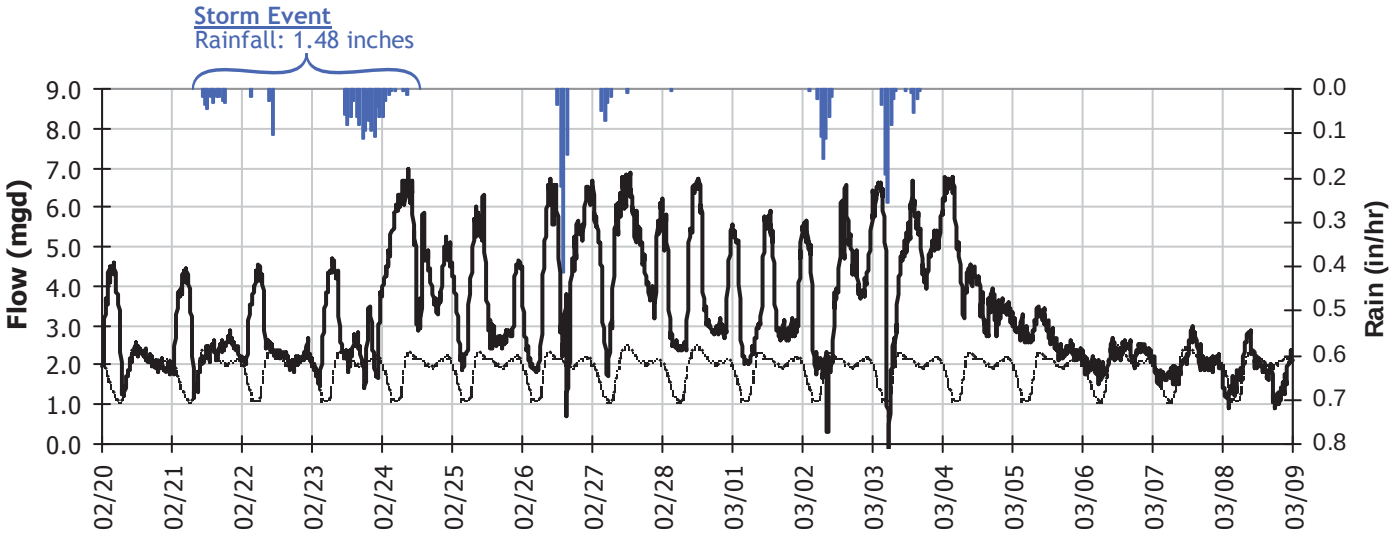


Multiple Events I/I Analysis

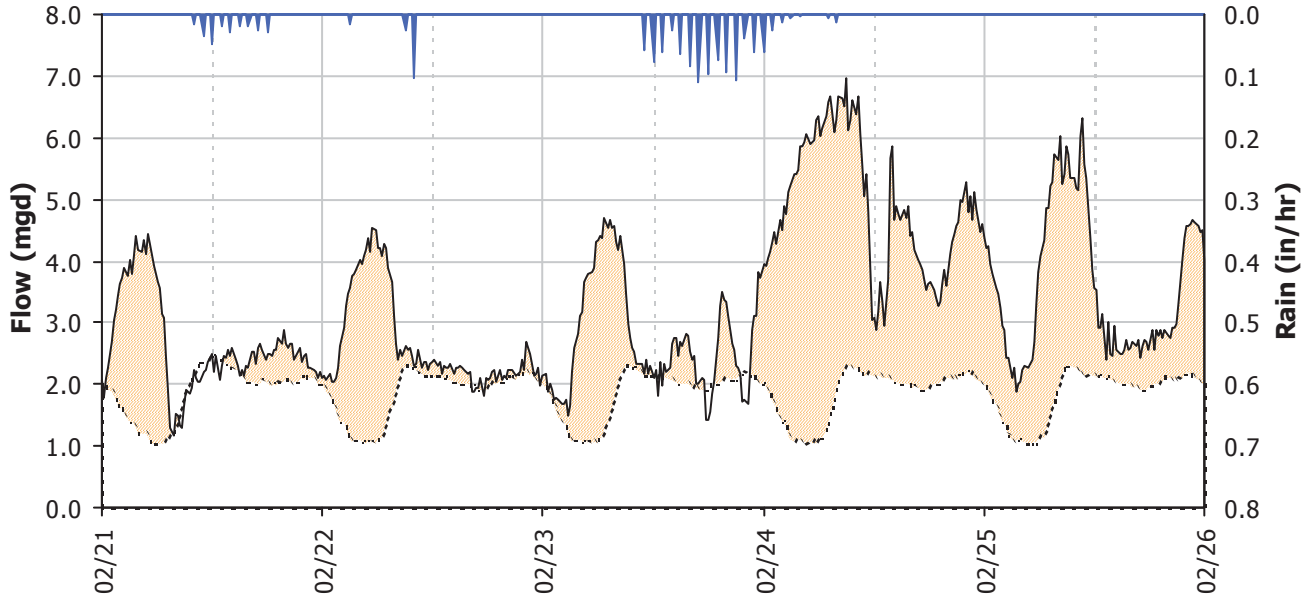
Rainfall:	9.77	*inches*	**Baseline Flow:**	1.85	*mgd*
Peak Flow:	7.70	*mgd*	**PF:**	4.17	
Peak I/I Rate:	6.63	*mgd*	**Pk I/I:ADWF:**	3.60	
Peak Level:	134.68	*inches*	**d/D Ratio:**	3.74	
Total I/I:	34,273,000	*gallons*	**R-Value:**	6.7%	
			I/I per ADWF:	1.9	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 6

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

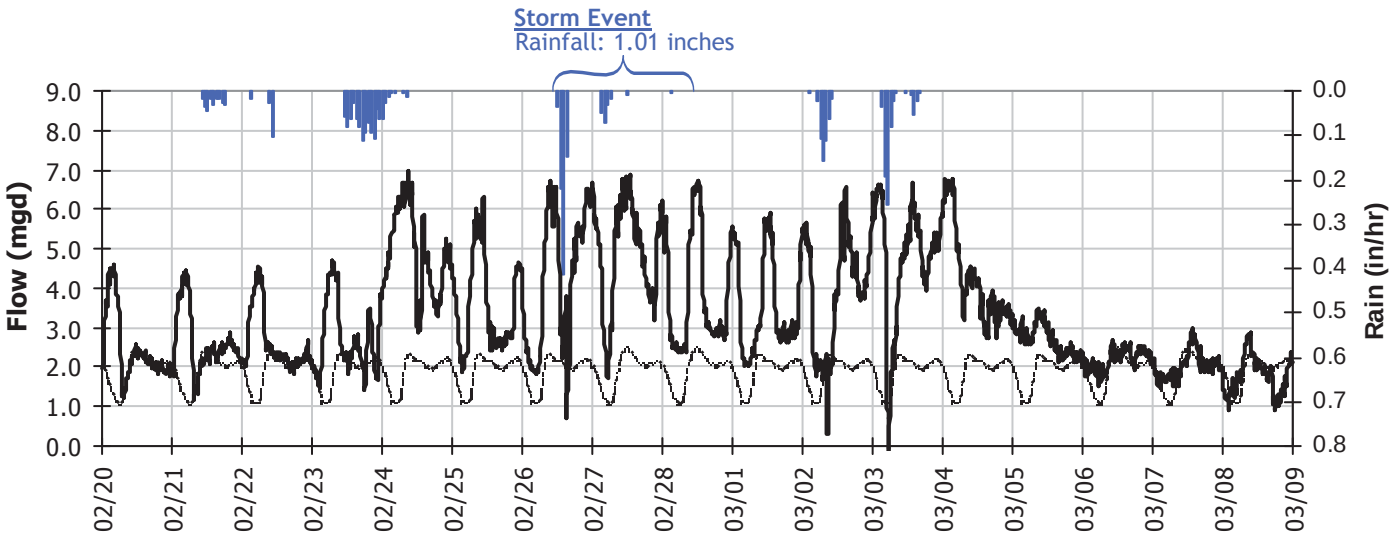
Rainfall:	1.48	*inches*		
Baseline Flow:	1.85	*mgd*		
Peak Flow:	6.96	*mgd*	**PF:**	3.77
Peak I/I Rate:	5.23	*mgd*	**Pk I/I:ADWF:**	2.84
Peak Level:	126.48	*inches*	**d/D Ratio:**	3.51
Total I/I:	7,306,000	*gallons*	**R-Value:**	9.4%
			I/I per ADWF:	2.68 *per in-rain*

Average Infiltration Rate on 2/25 (% of ADWF): 95.2%

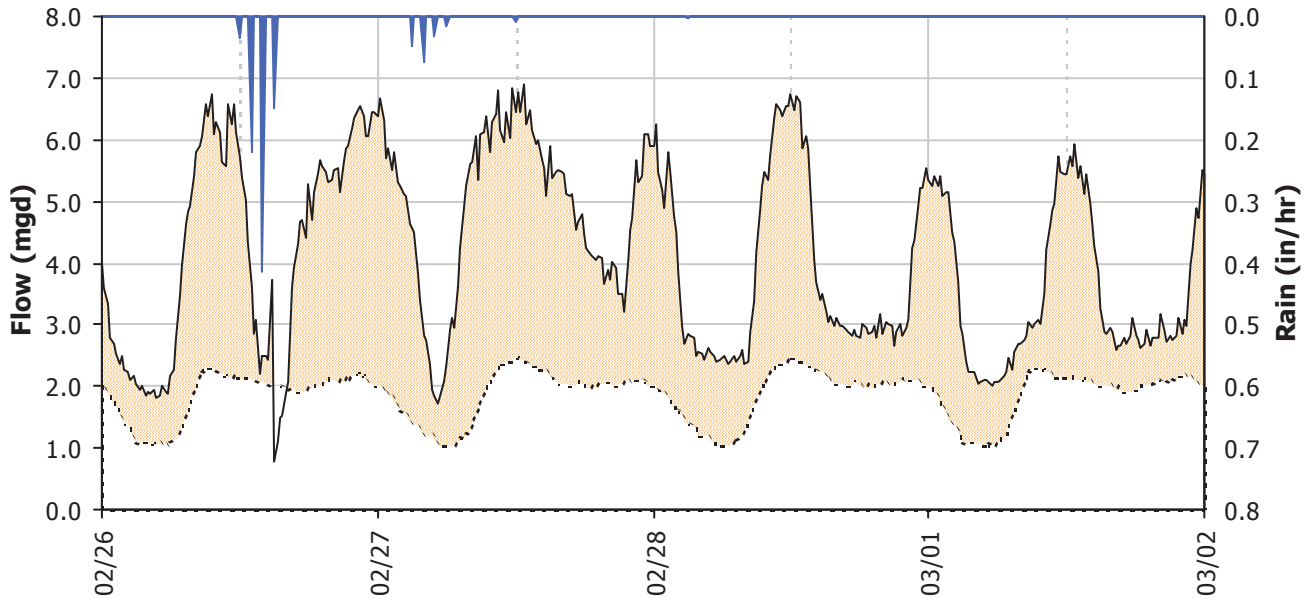
V&A

	I/I Summary Event 2	**Monitoring Site:** Site 6

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



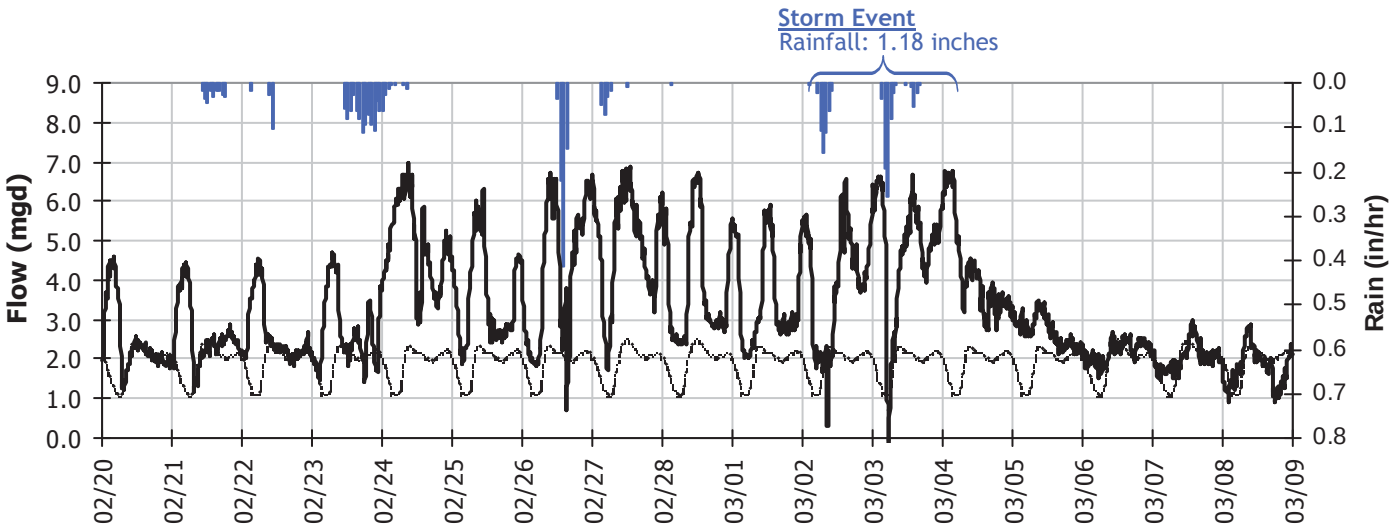
Storm Event #2 I/I Analysis

Rainfall:	1.01	*inches*		
Baseline Flow:	1.85	*mgd*		
Peak Flow:	6.90	*mgd*	**PF:**	3.74
Peak I/I Rate:	4.68	*mgd*	**Pk I/I:ADWF:**	2.54
Peak Level:	109.94	*inches*	**d/D Ratio:**	3.05
Total I/I:	9,086,000	*gallons*	**R-Value:**	17.1%
			I/I per ADWF:	4.90 *per in-rain*

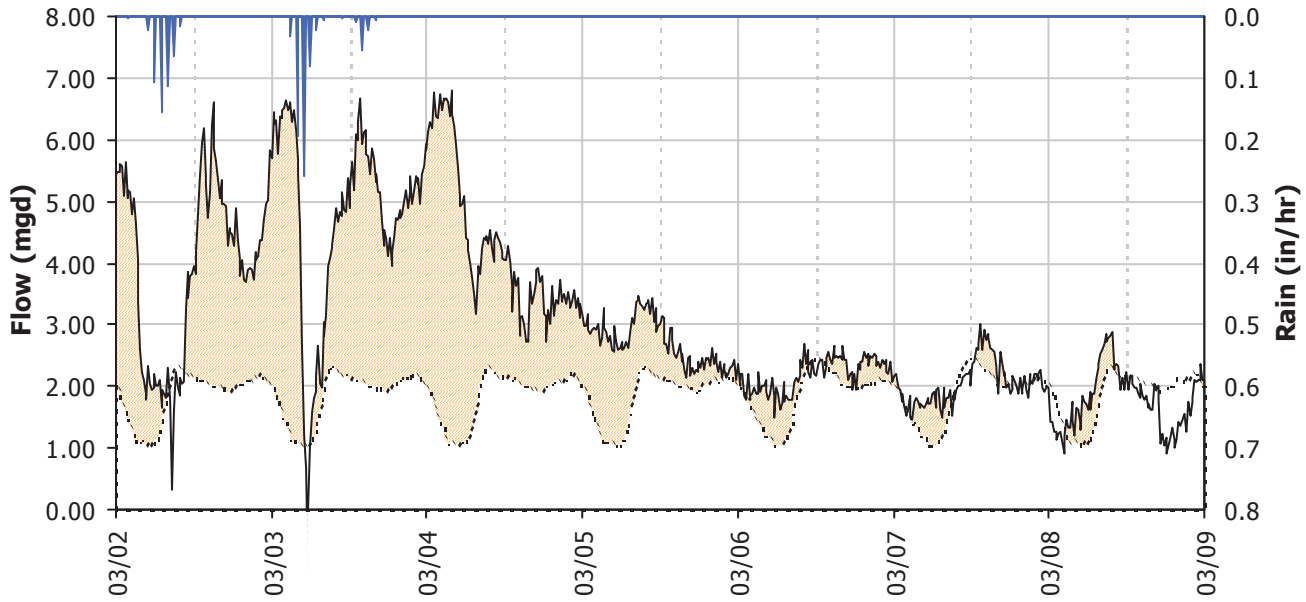
Average Infiltration Rate on 3/1 (% of ADWF): 92.4%

	I/I Summary Event 3	**Monitoring Site:** Site 6

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



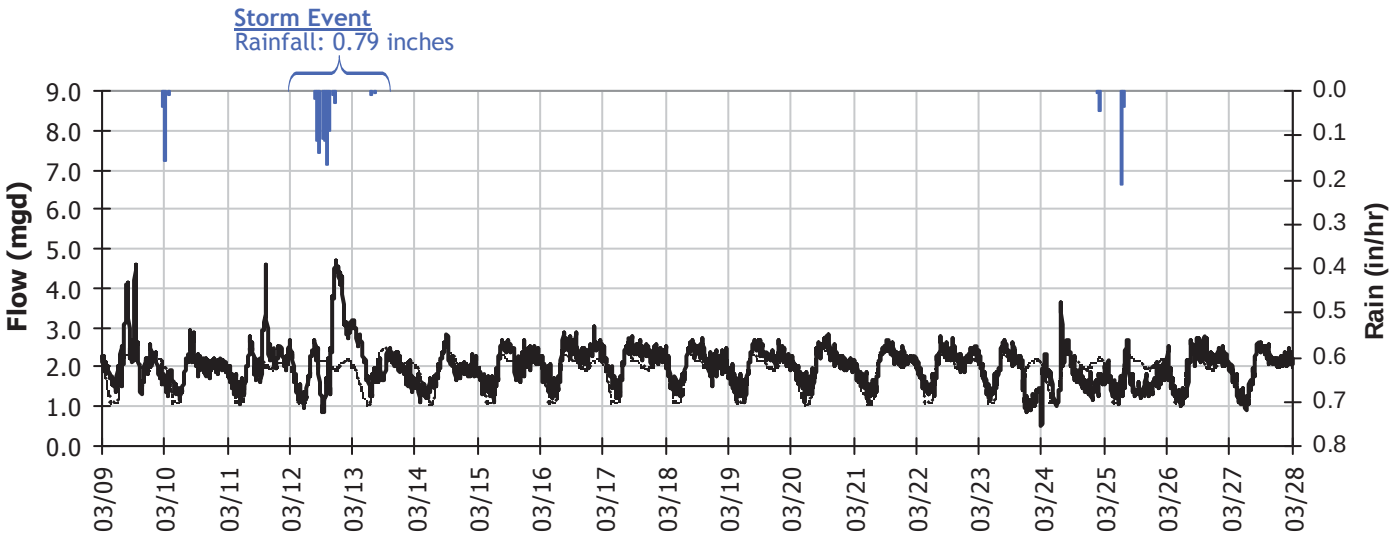
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	1.85	*mgd*		
Peak Flow:	6.79	*mgd*	**PF:**	3.68
Peak I/I Rate:	5.69	*mgd*	**Pk I/I:ADWF:**	3.08
Peak Level:	134.68	*inches*	**d/D Ratio:**	3.74
Total I/I:	8,724,000	*gallons*	**R-Value:**	14.0%
			I/I per ADWF:	3.99 *per in-rain*

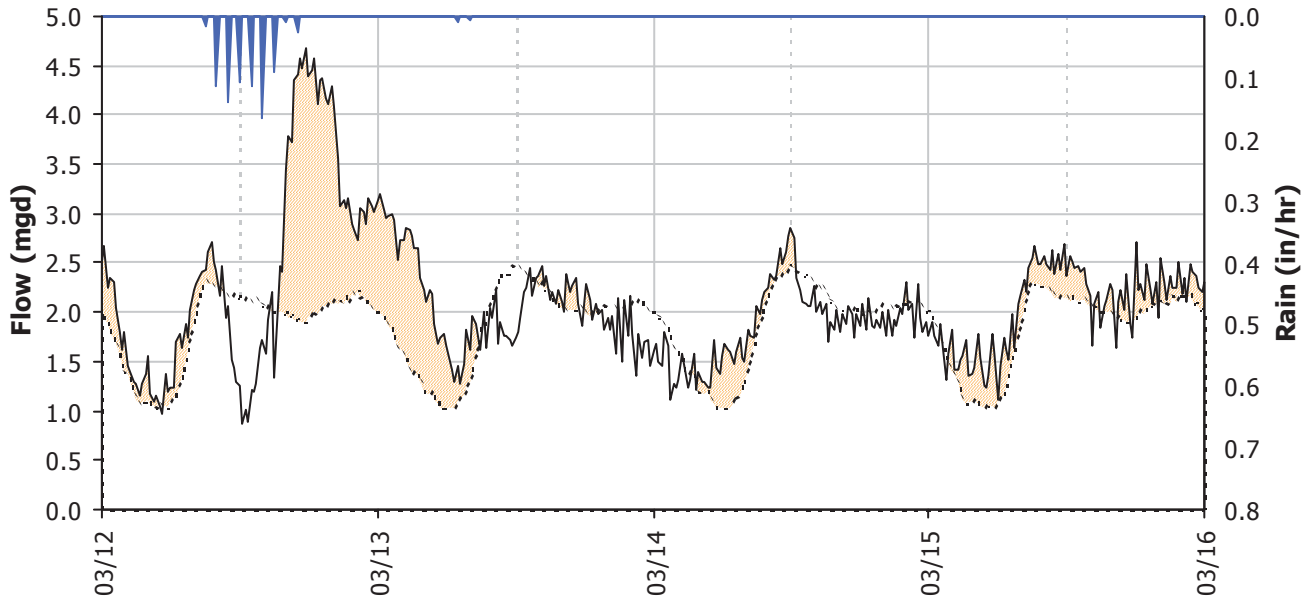
Average Infiltration Rate on 3/5 (% of ADWF): 47.5%

	I/I Summary Event 4	**Monitoring Site:** Site 6

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



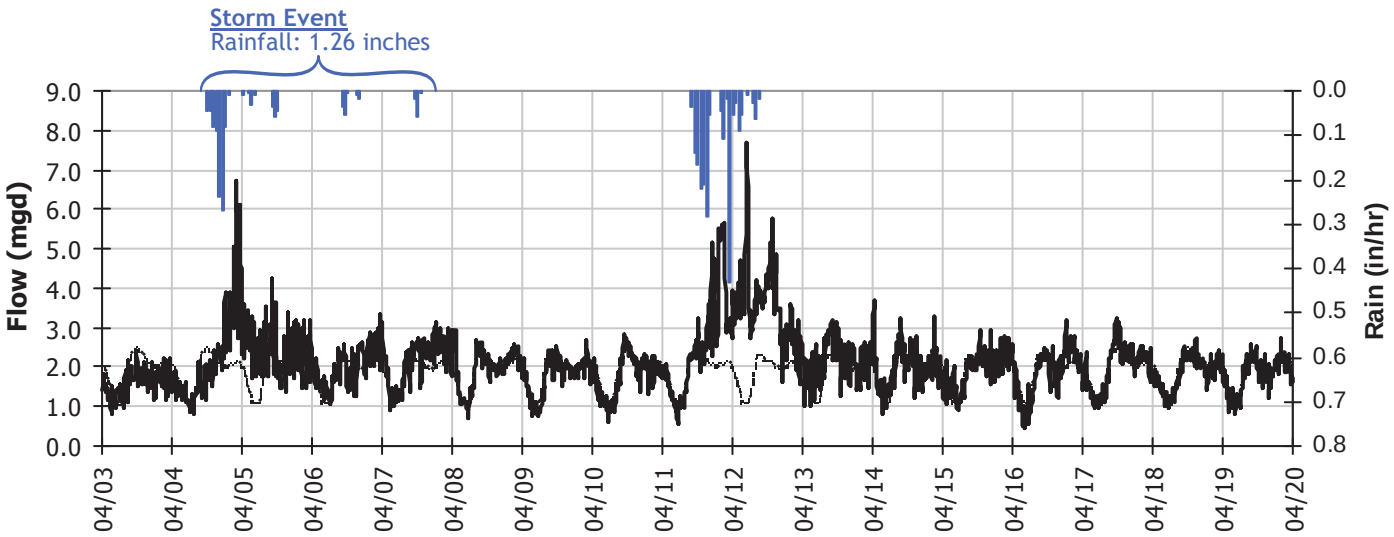
Storm Event #1 I/I Analysis

Rainfall:	0.79	*inches*		
Baseline Flow:	1.85	*mgd*		
Peak Flow:	4.68	*mgd*	**PF:**	2.54
Peak I/I Rate:	2.78	*mgd*	**Pk I/I:ADWF:**	1.50
Peak Level:	110.25	*inches*	**d/D Ratio:**	3.06
Total I/I:	997,000	*gallons*	**R-Value:**	2.4%
			I/I per ADWF:	0.68 *per in-rain*

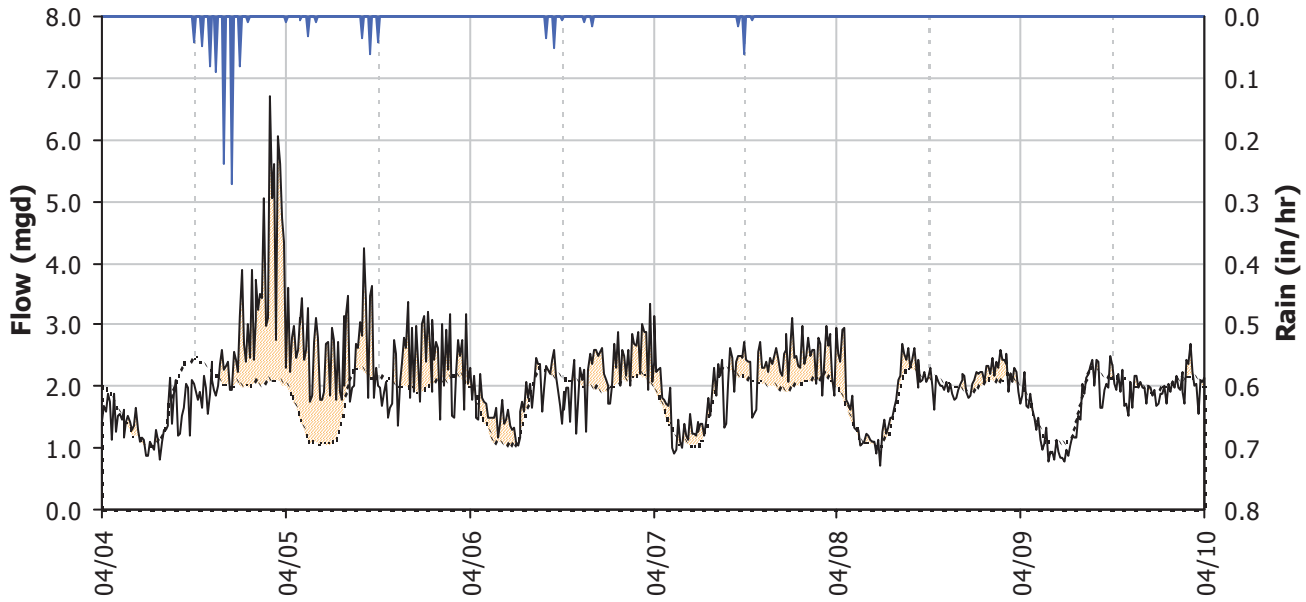
Average Infiltration Rate on 3/14 (% of ADWF): -0.1%

	I/I Summary Event 5	**Monitoring Site:** Site 6

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



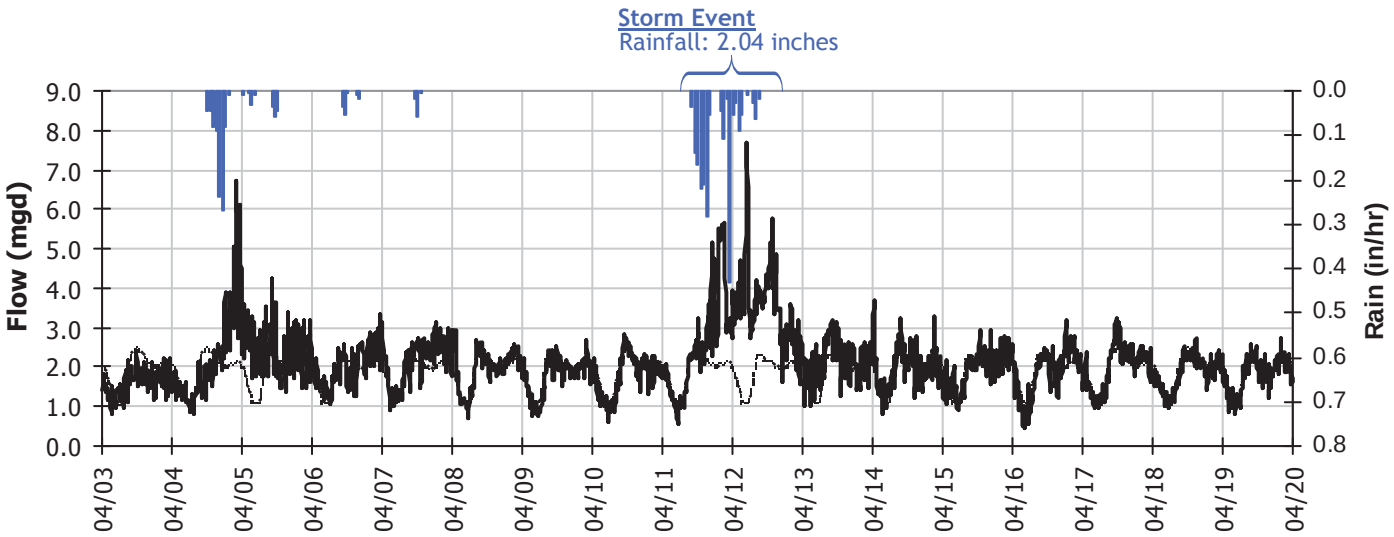
Storm Event #5 I/I Analysis

Rainfall:	1.26	*inches*		
Baseline Flow:	1.85	*mgd*		
Peak Flow:	6.70	*mgd*	**PF:**	3.63
Peak I/I Rate:	4.61	*mgd*	**Pk I/I:ADWF:**	2.50
Peak Level:	88.84	*inches*	**d/D Ratio:**	2.47
Total I/I:	1,456,000	*gallons*	**R-Value:**	2.2%
			I/I per ADWF:	0.63 *per in-rain*

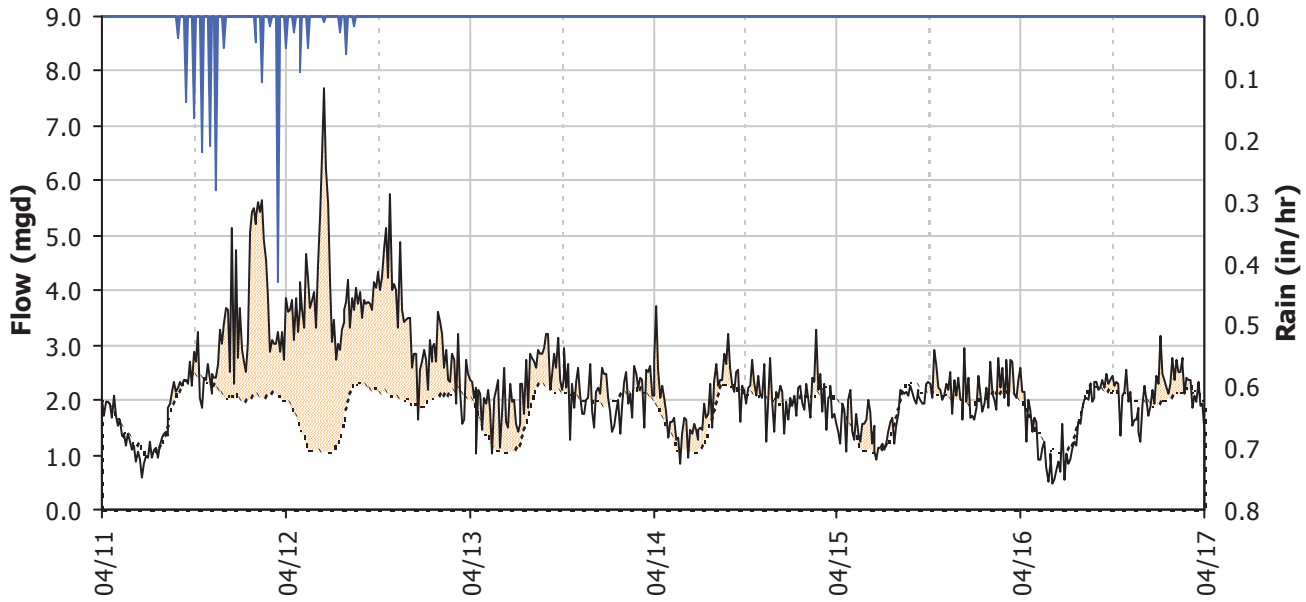
Average Infiltration Rate on 4/8 (% of ADWF): 6.5%

	I/I Summary Event 6	**Monitoring Site:** Site 6

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



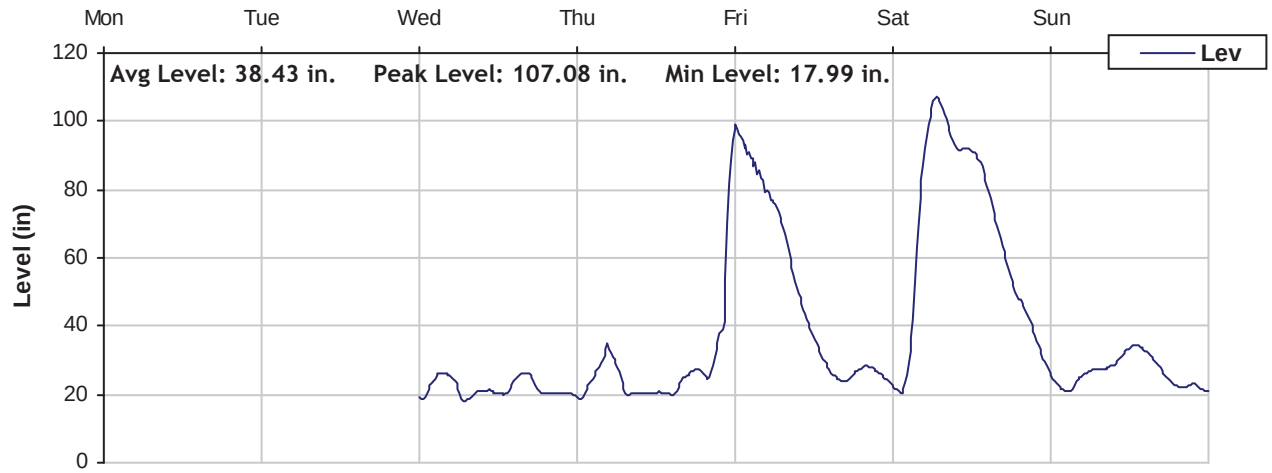
Storm Event #6 I/I Analysis

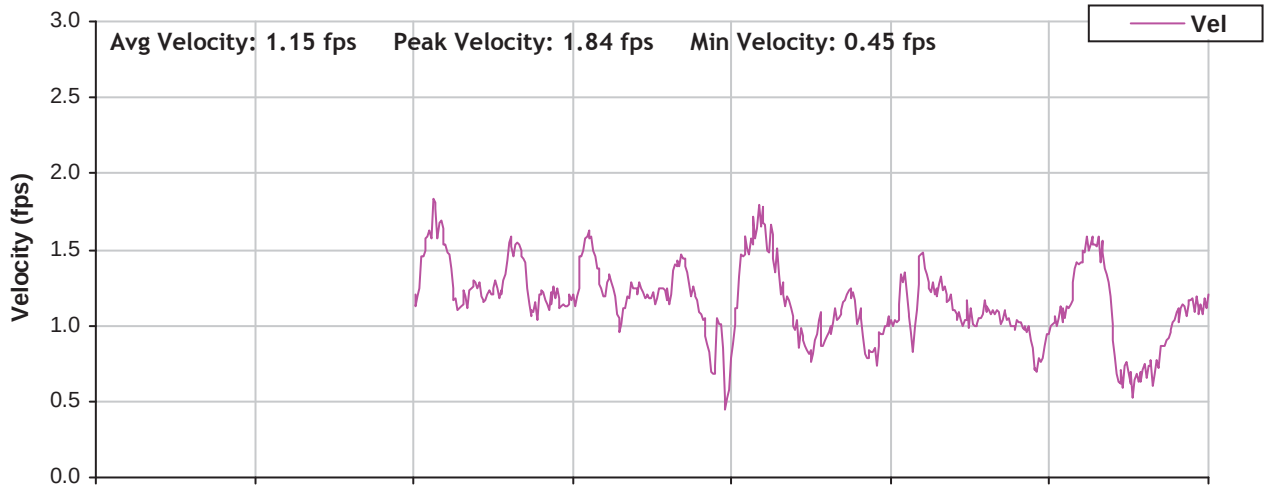
Rainfall:	2.04	*inches*		
Baseline Flow:	1.85	*mgd*		
Peak Flow:	7.70	*mgd*	**PF:**	4.17
Peak I/I Rate:	6.63	*mgd*	**Pk I/I:ADWF:**	3.60
Peak Level:	131.87	*inches*	**d/D Ratio:**	3.66
Total I/I:	2,994,000	*gallons*	**R-Value:**	2.8%
			I/I per ADWF:	0.80 *per in-rain*

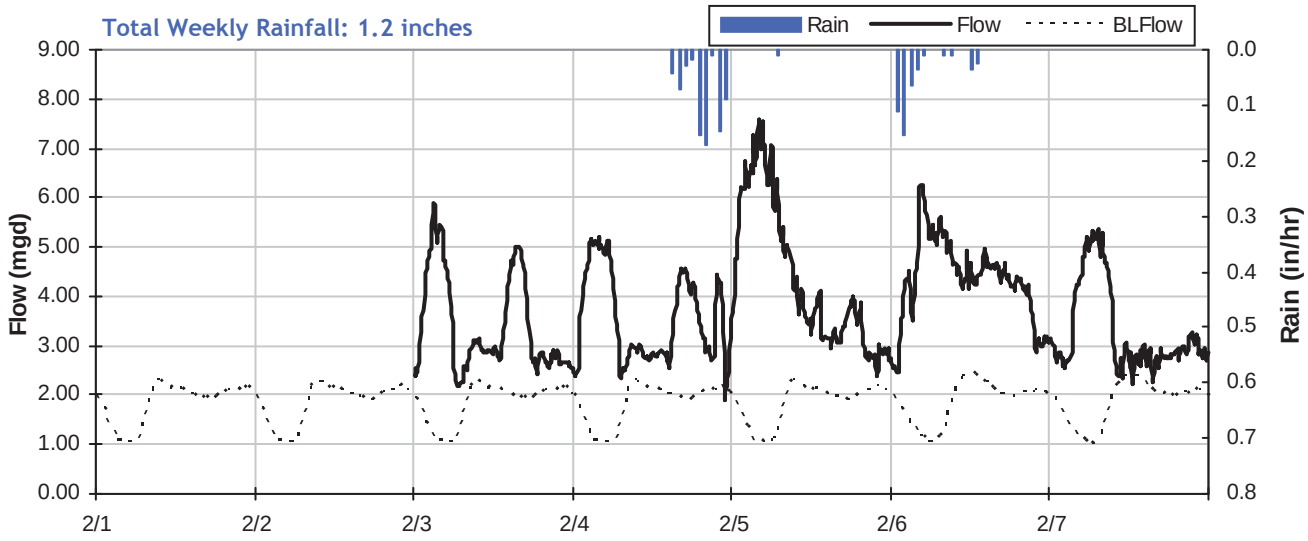
Average Infiltration Rate on 4/14 (% of ADWF): 9.3%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 6





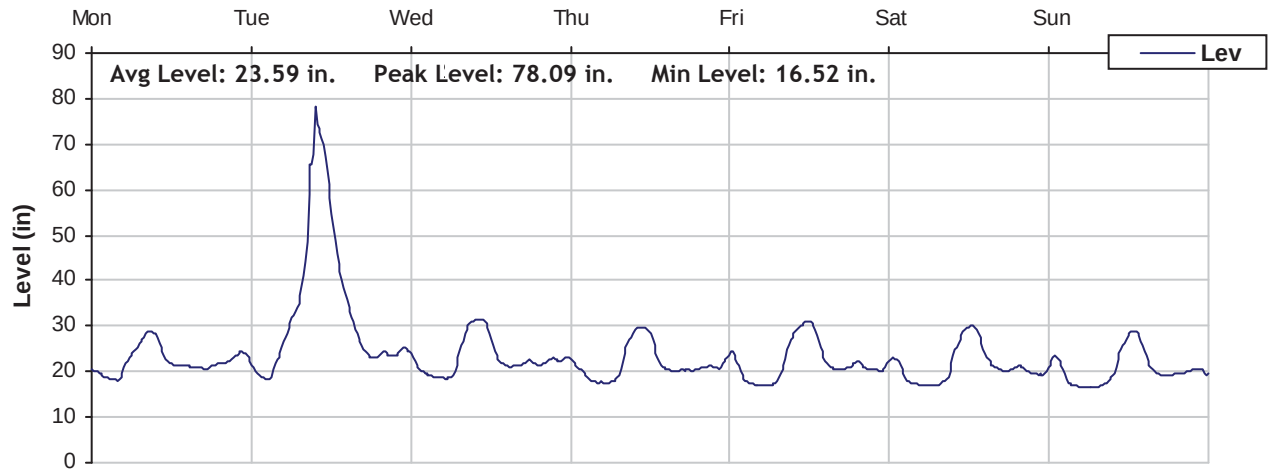


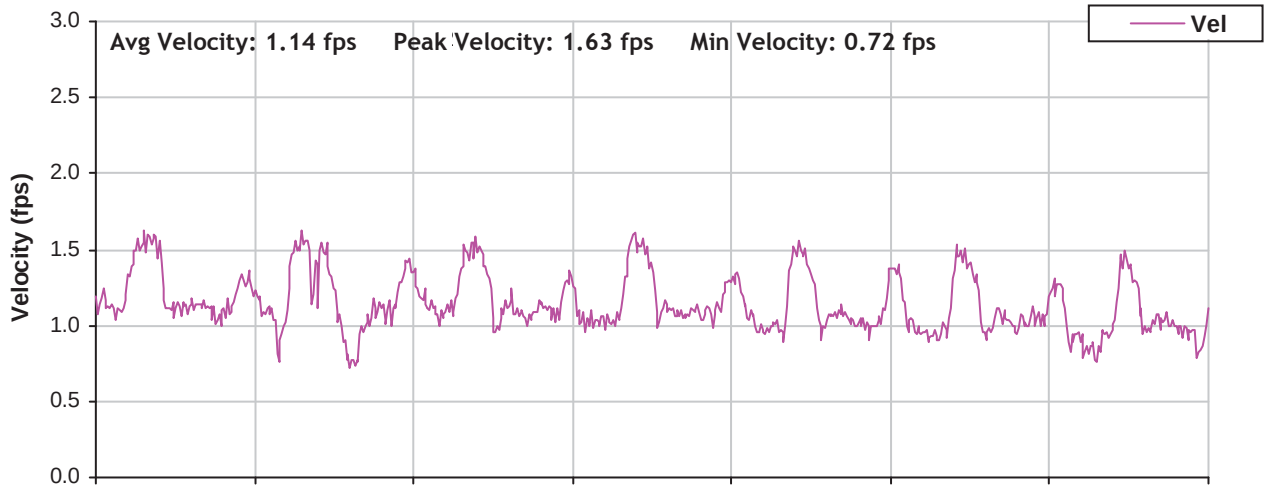
Avg Flow: 3.784 mgd Peak Flow: 7.58 mgd Min Flow: 1.899 mgd

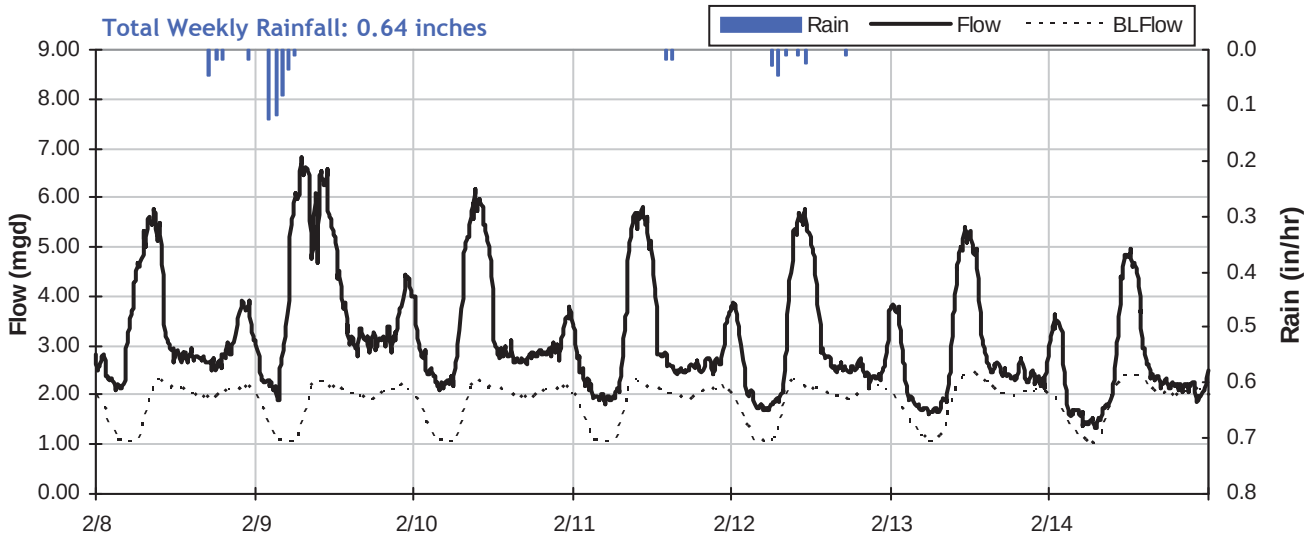
V&A

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 6



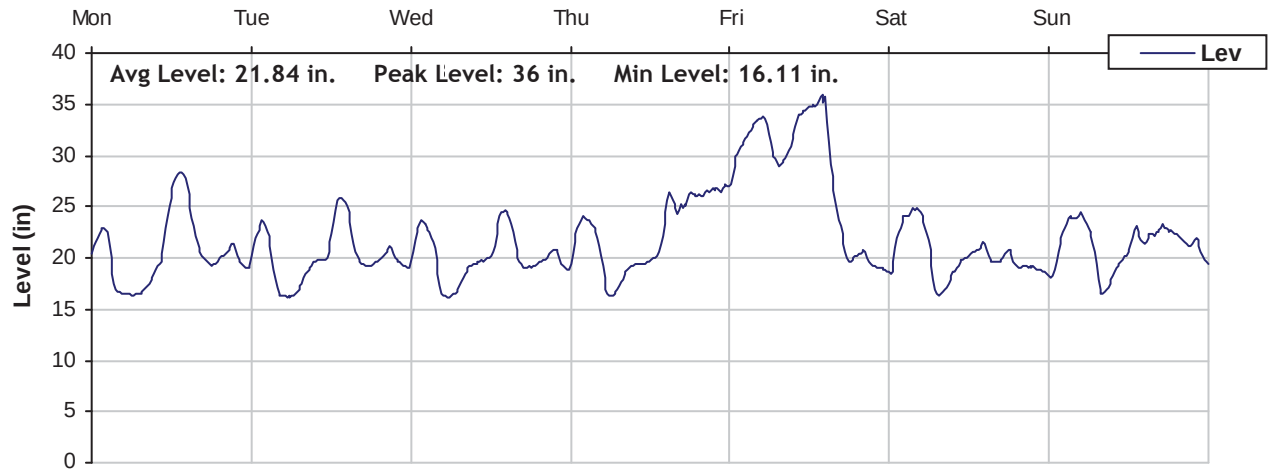


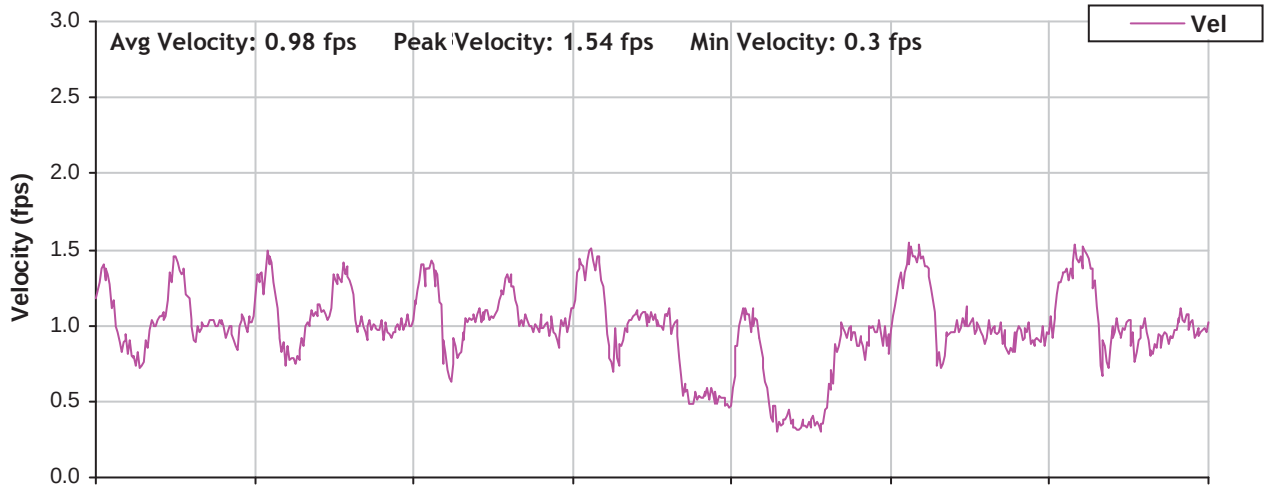


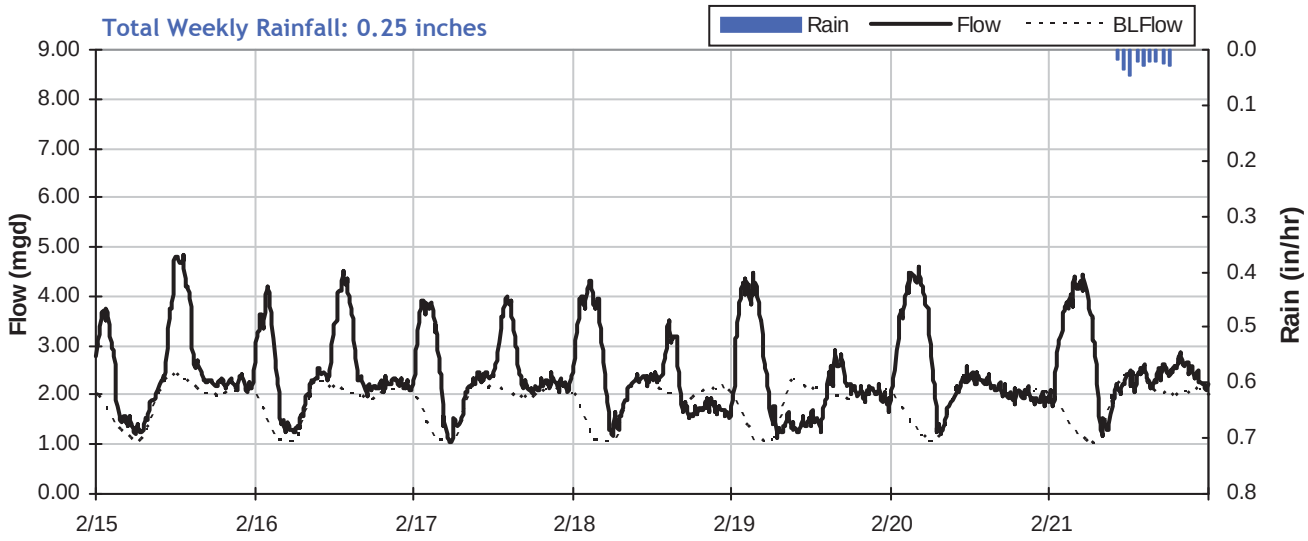
Avg Flow: 3.13 mgd Peak Flow: 6.821 mgd Min Flow: 1.337 mgd

Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 6



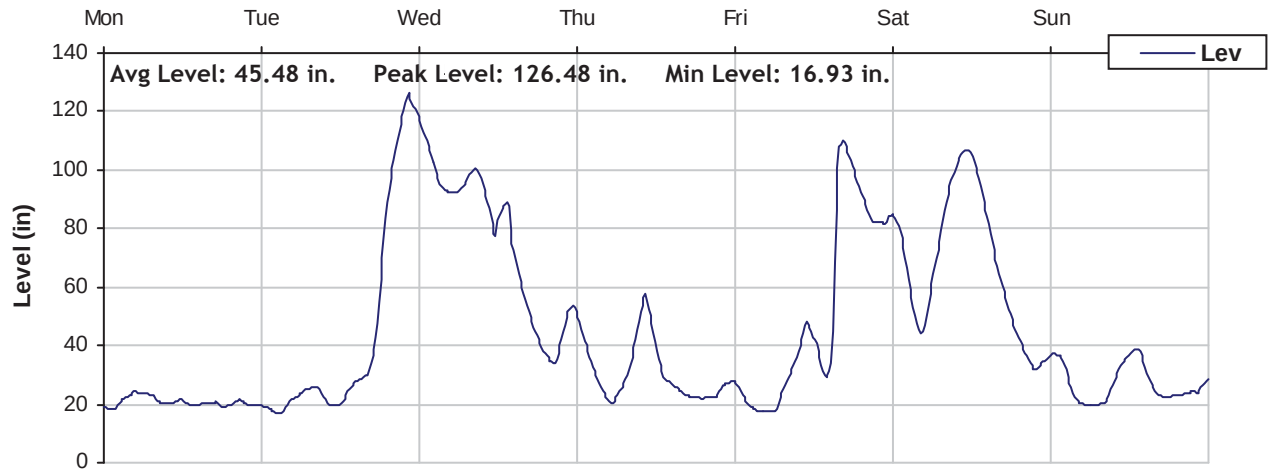


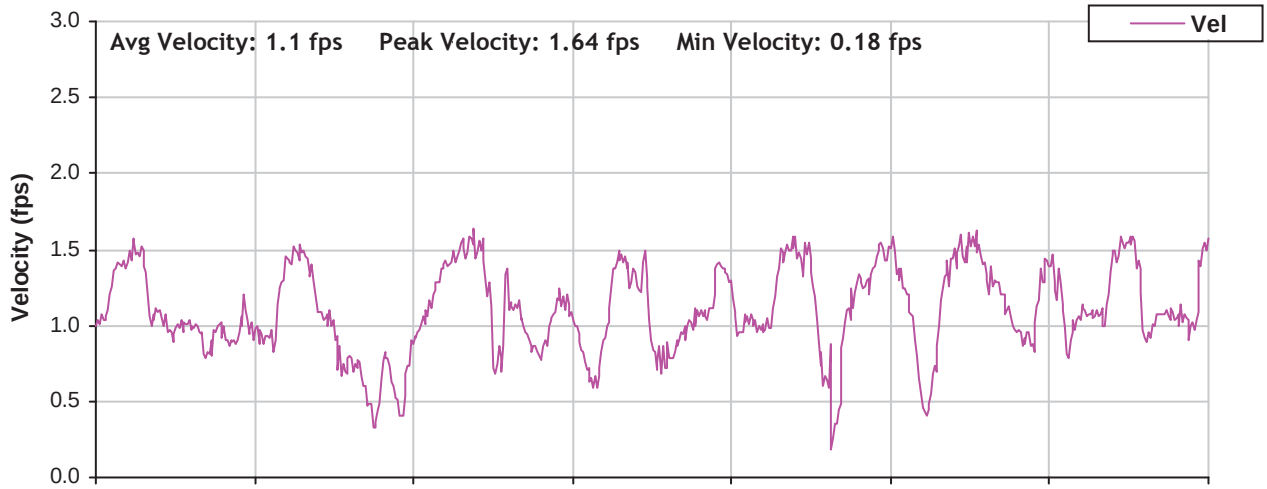


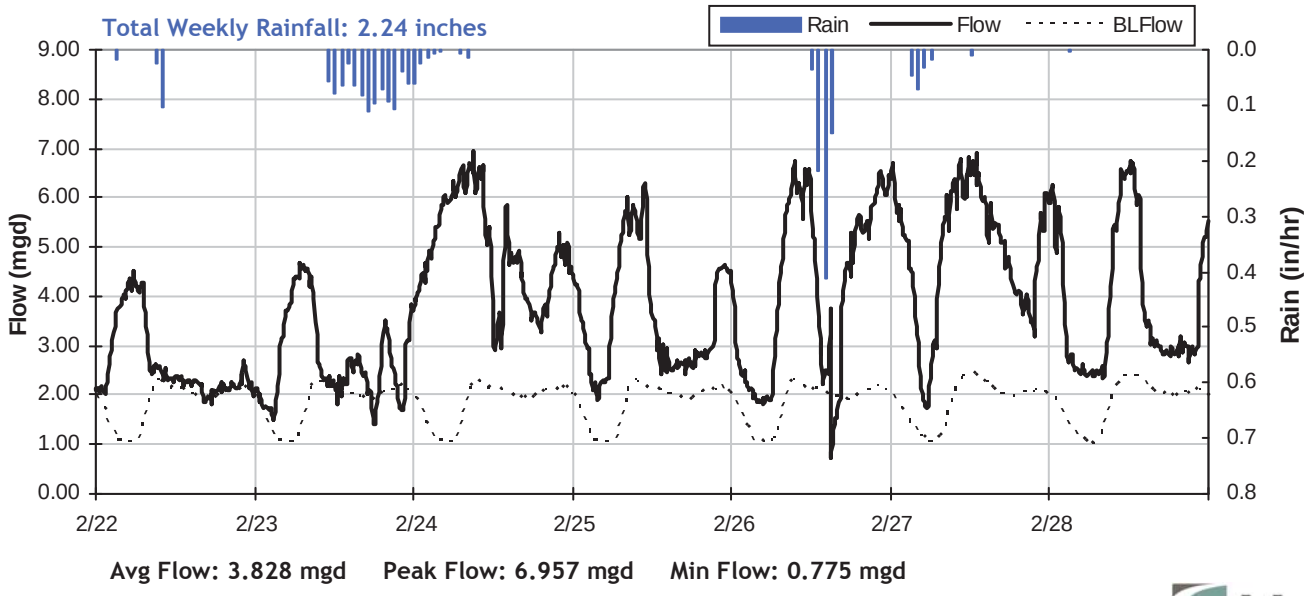
Avg Flow: 2.466 mgd Peak Flow: 4.833 mgd Min Flow: 1.051 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 6



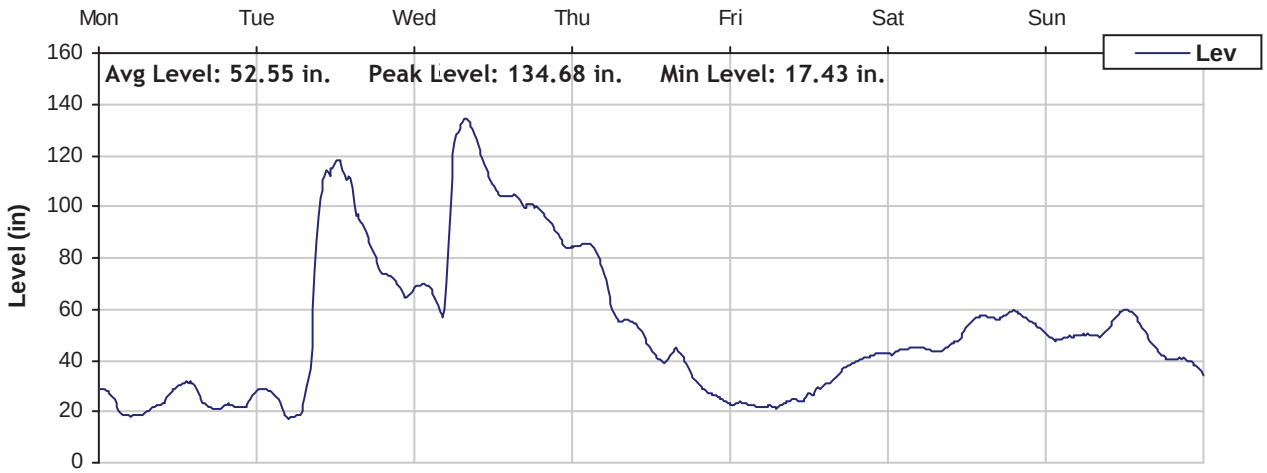


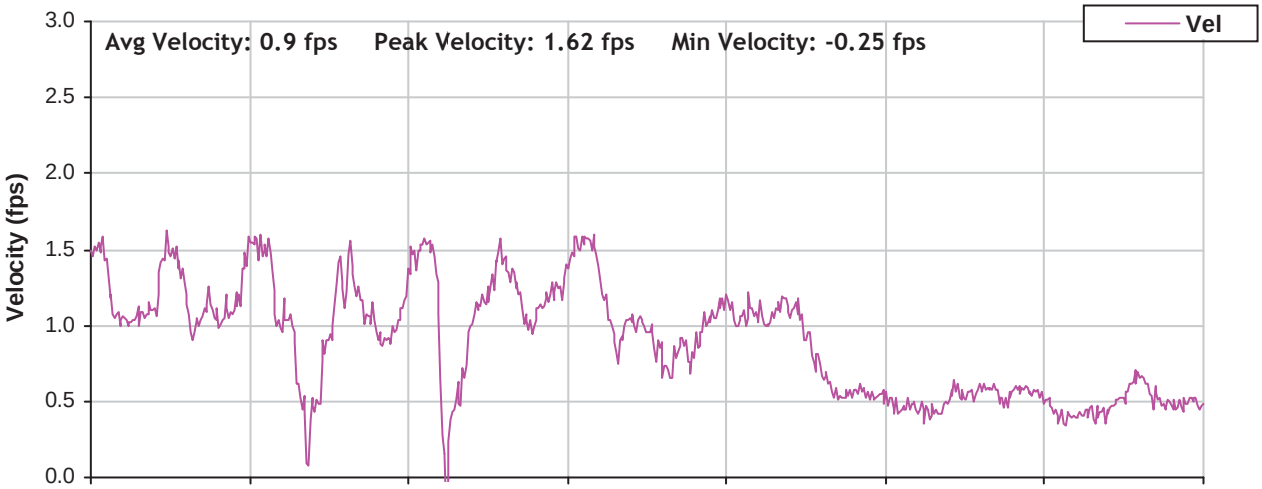


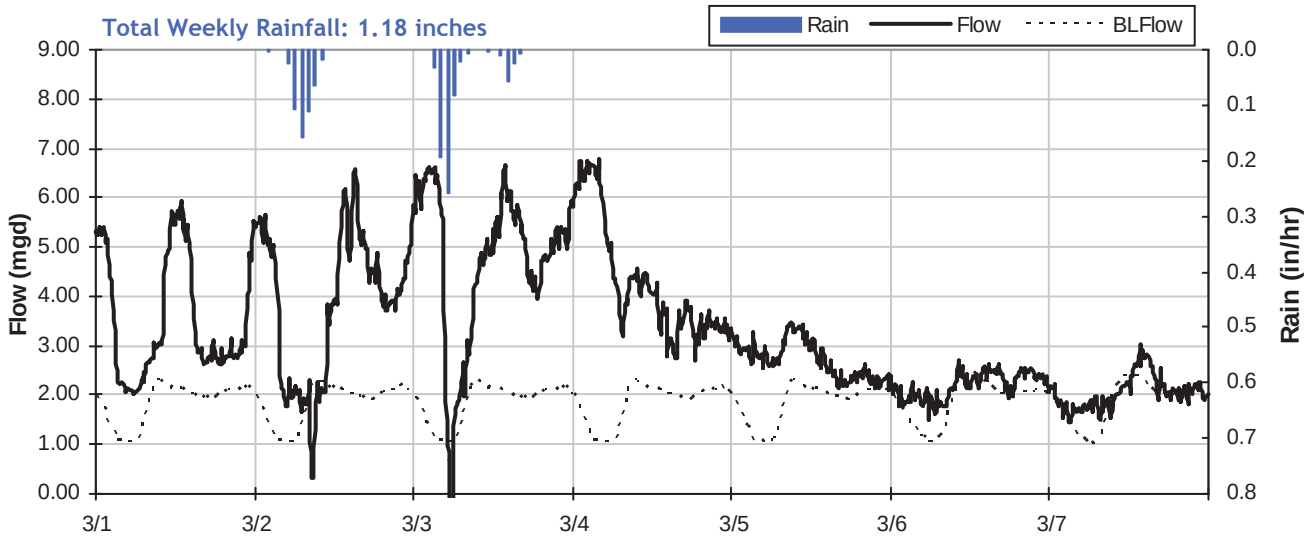
Avg Flow: 3.828 mgd Peak Flow: 6.957 mgd Min Flow: 0.775 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 6



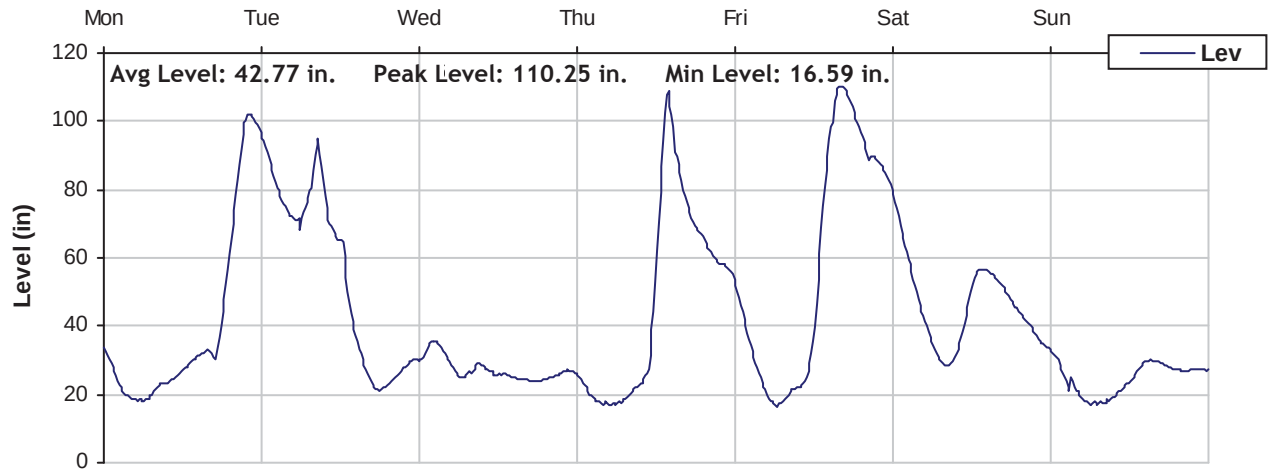


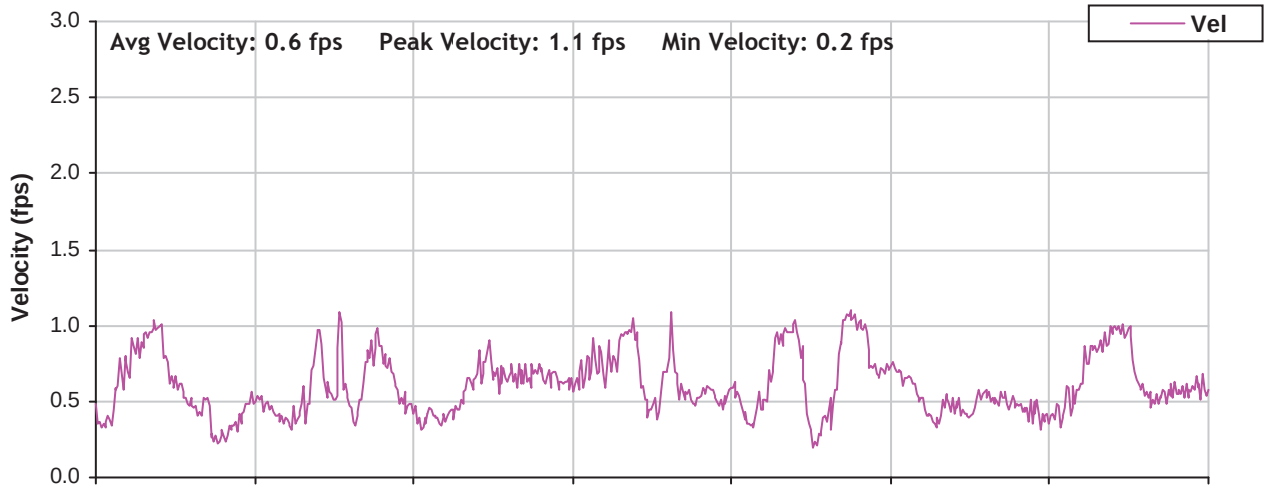


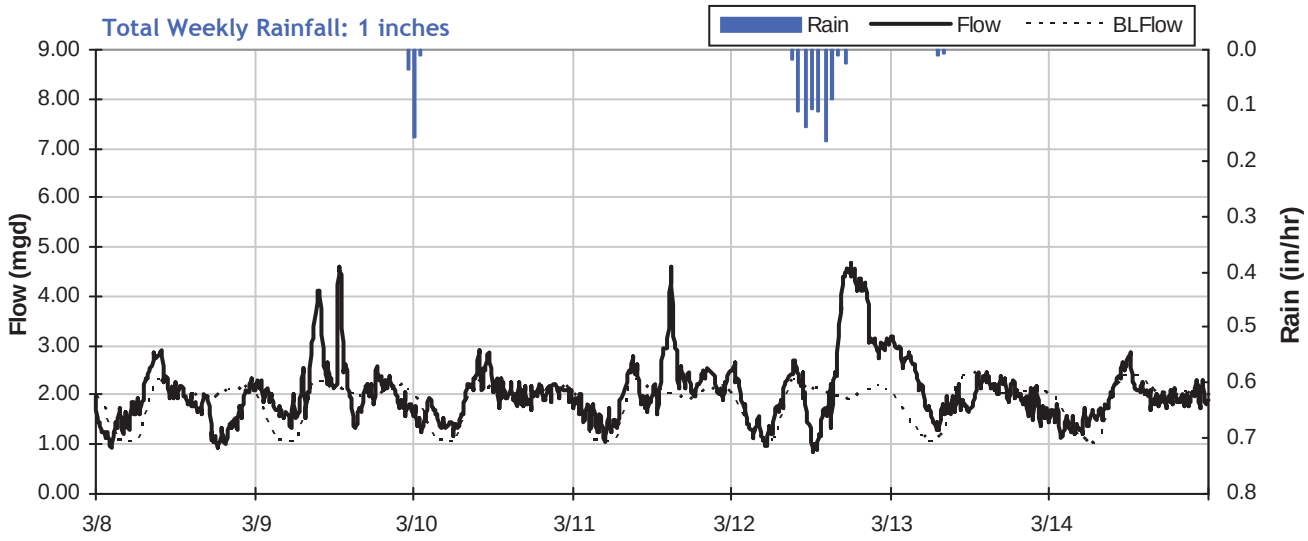
Avg Flow: 3.342 mgd Peak Flow: 6.79 mgd Min Flow: -1.063 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 6



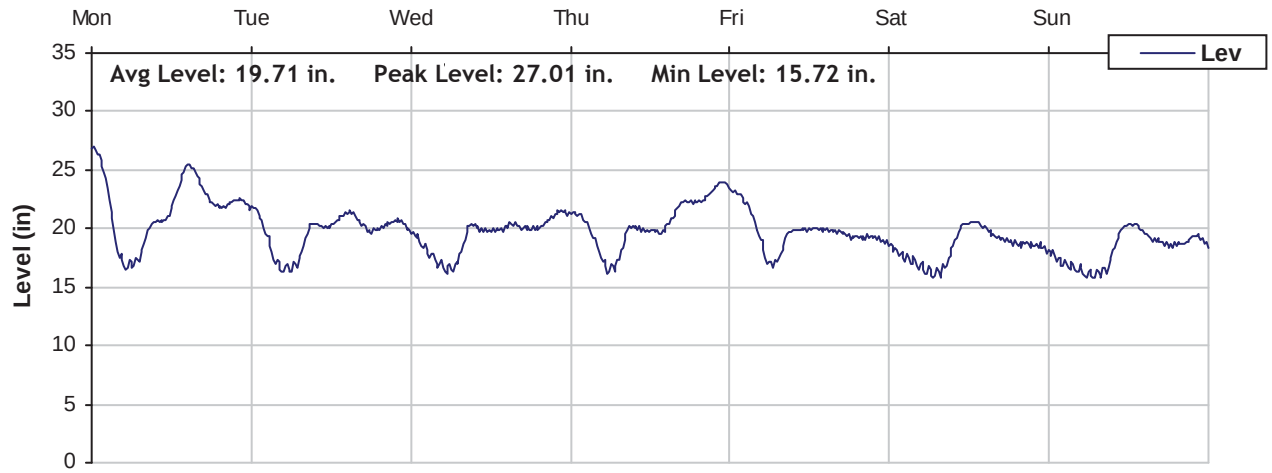


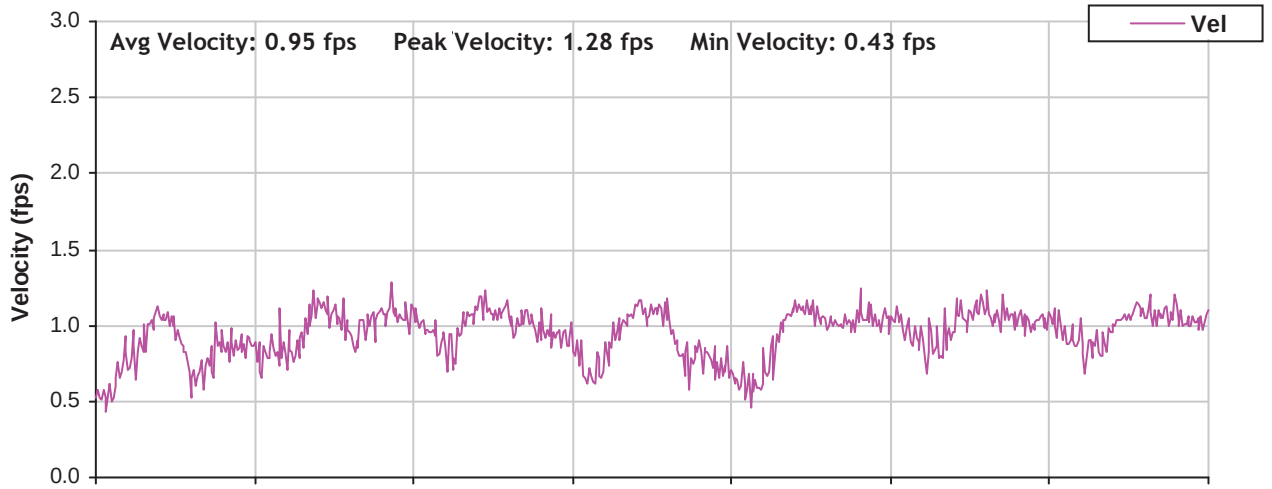


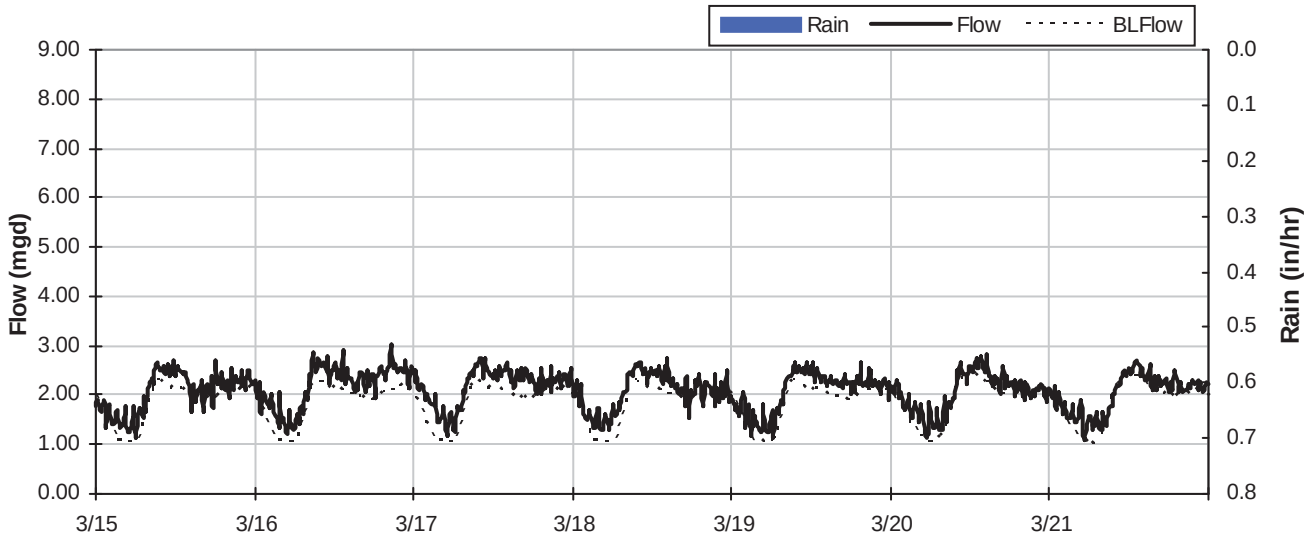
Avg Flow: 2.046 mgd Peak Flow: 4.678 mgd Min Flow: 0.866 mgd

Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

Monitoring Site:
Site 6



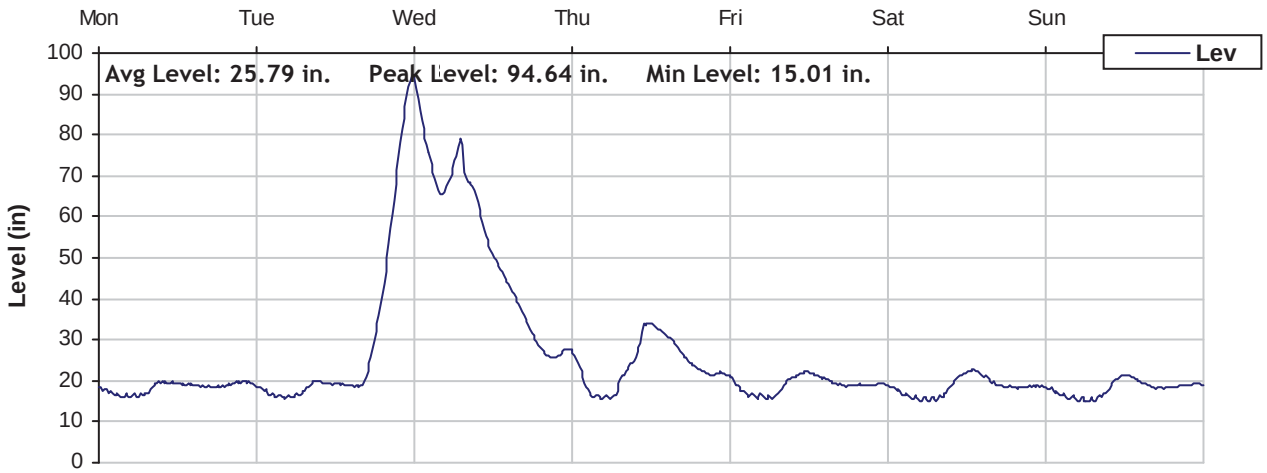


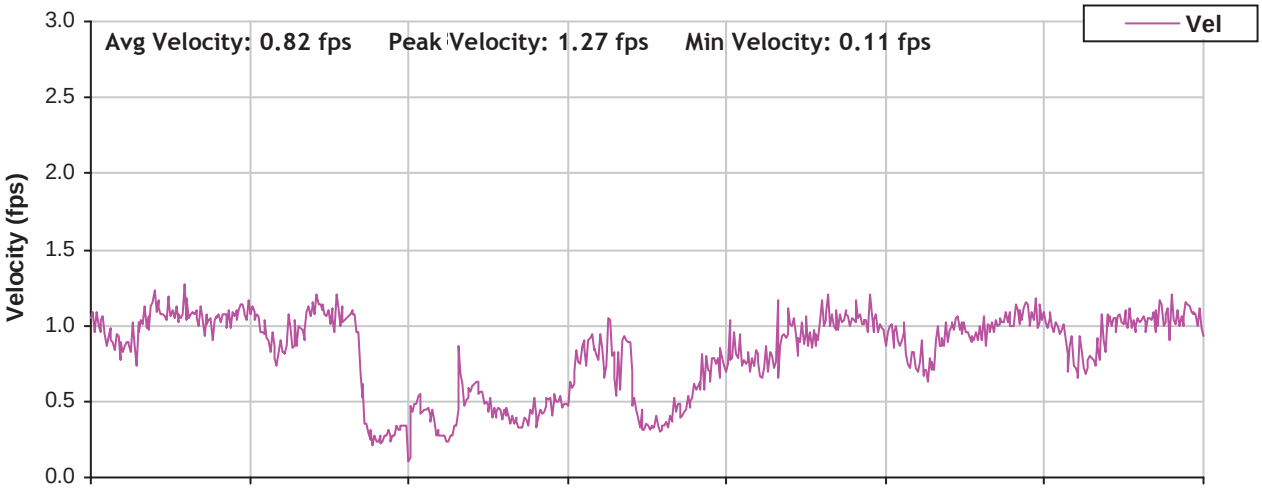


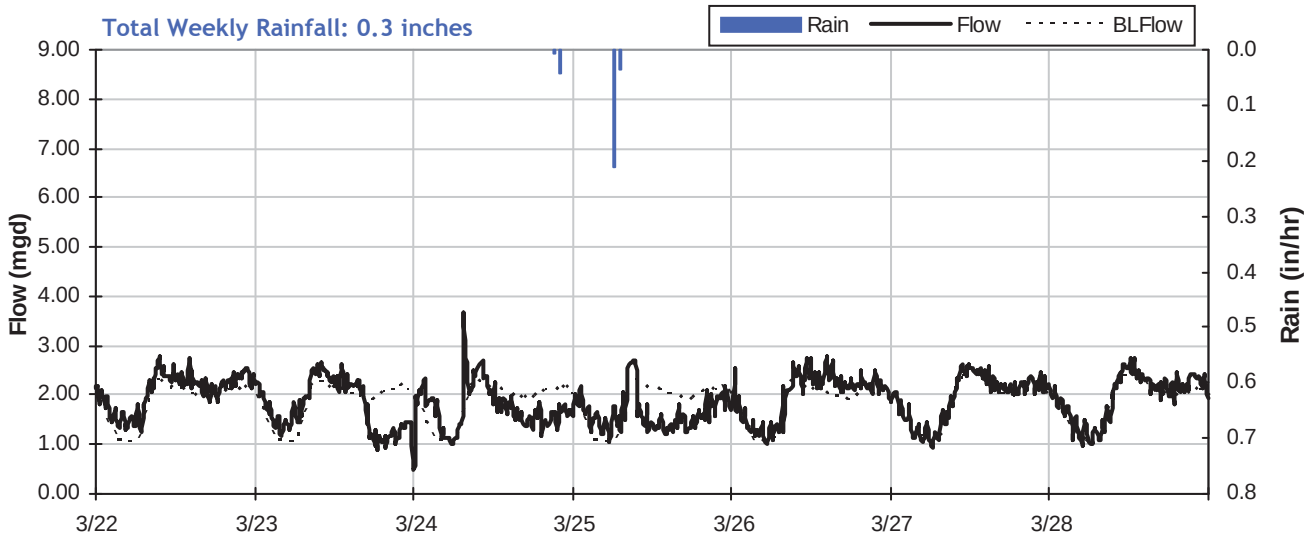
Avg Flow: 2.097 mgd Peak Flow: 3.029 mgd Min Flow: 1.108 mgd

Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 6



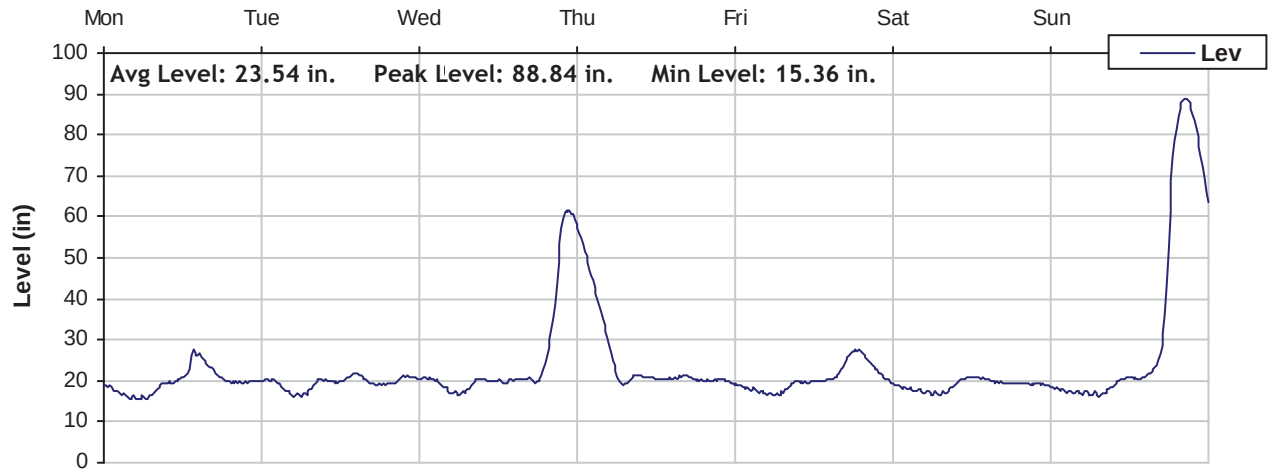


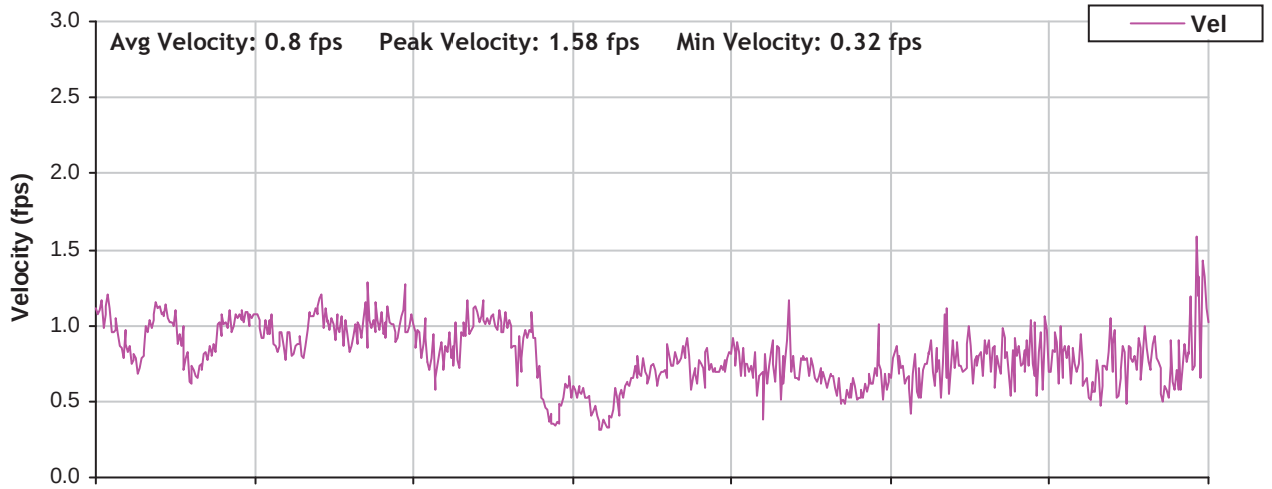


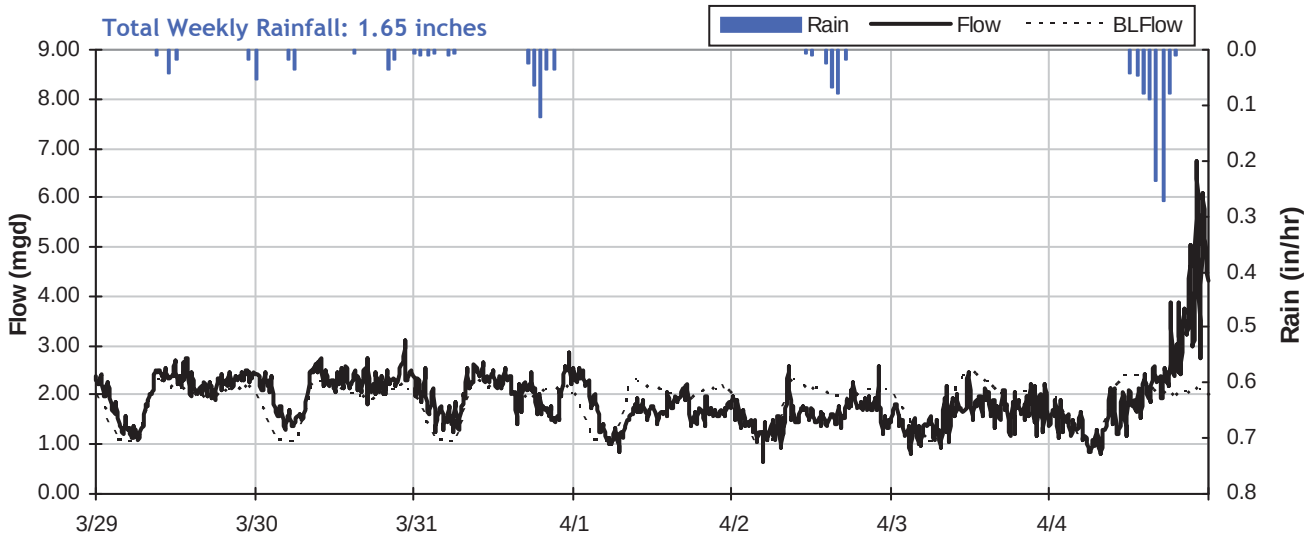
Avg Flow: 1.878 mgd Peak Flow: 3.645 mgd Min Flow: 0.486 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 6



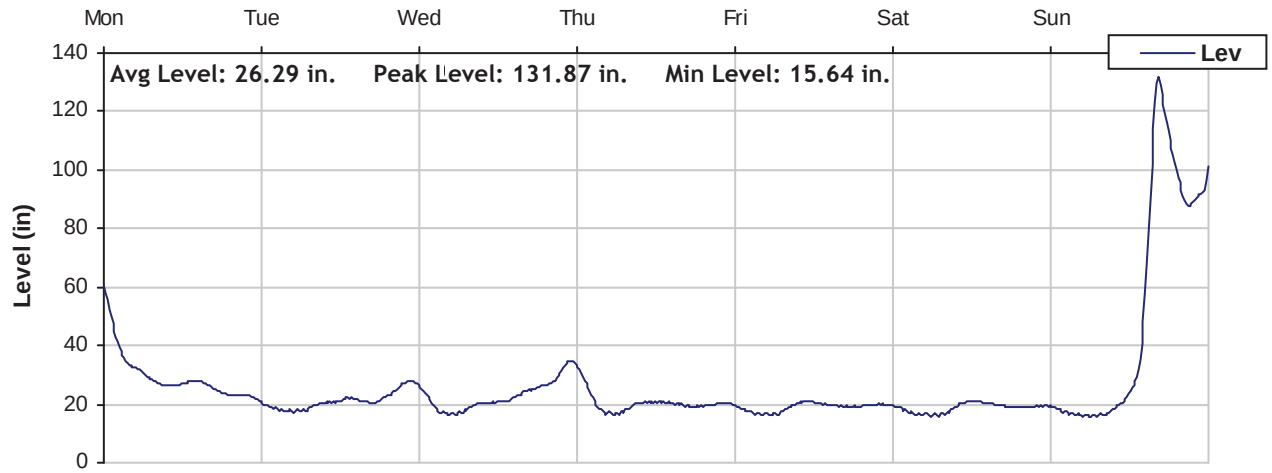


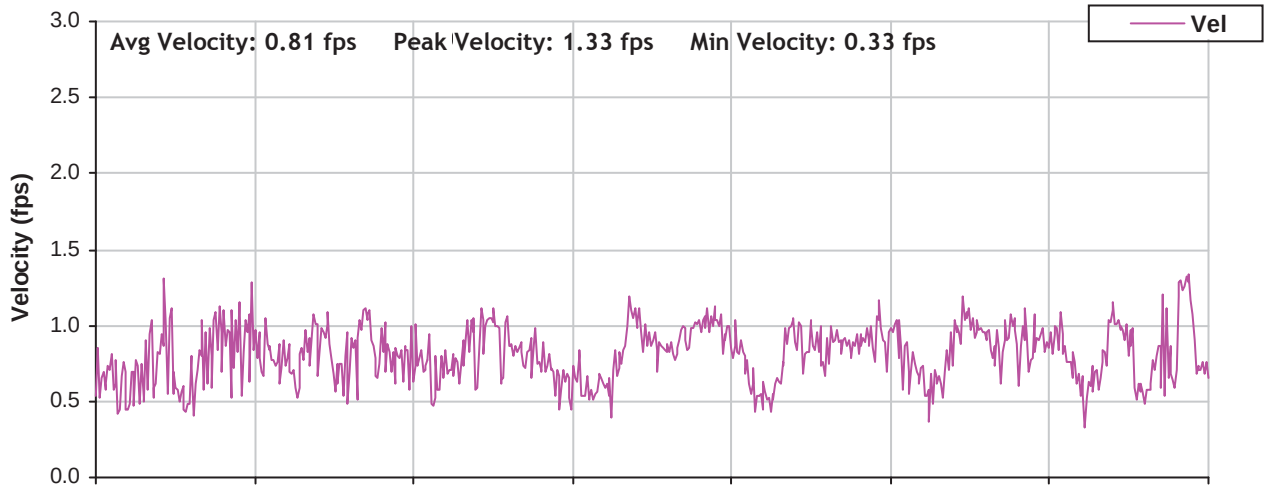


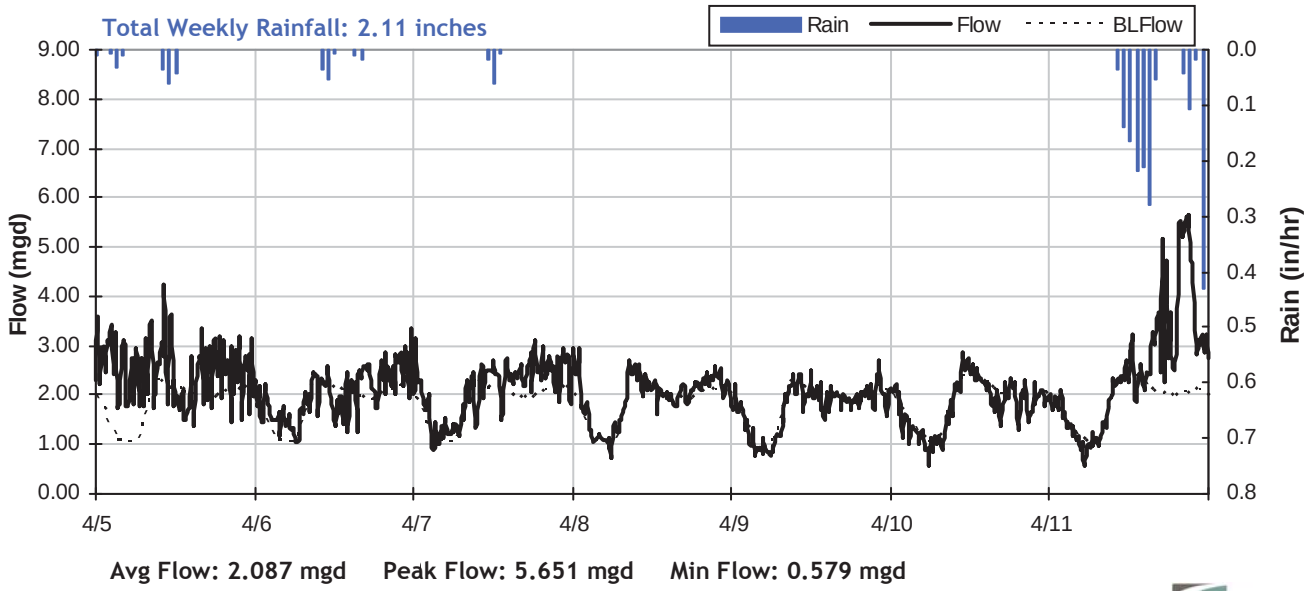
Avg Flow: 1.91 mgd Peak Flow: 6.699 mgd Min Flow: 0.658 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 6



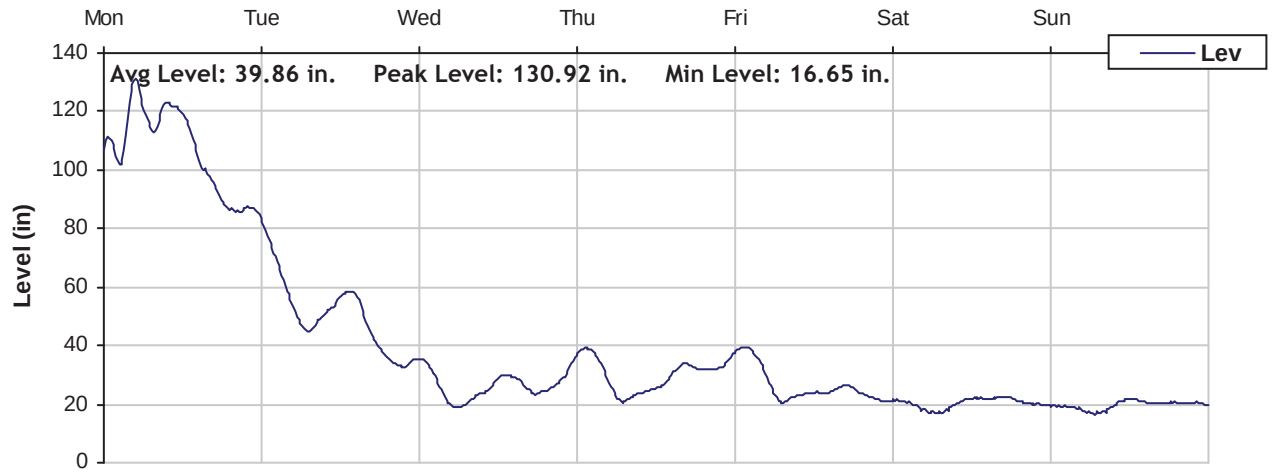


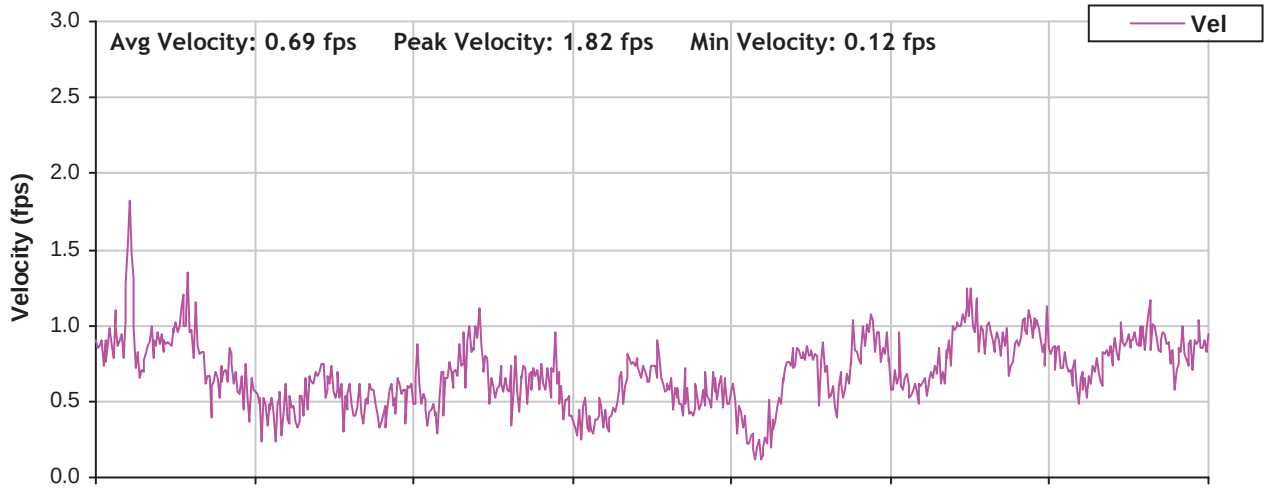


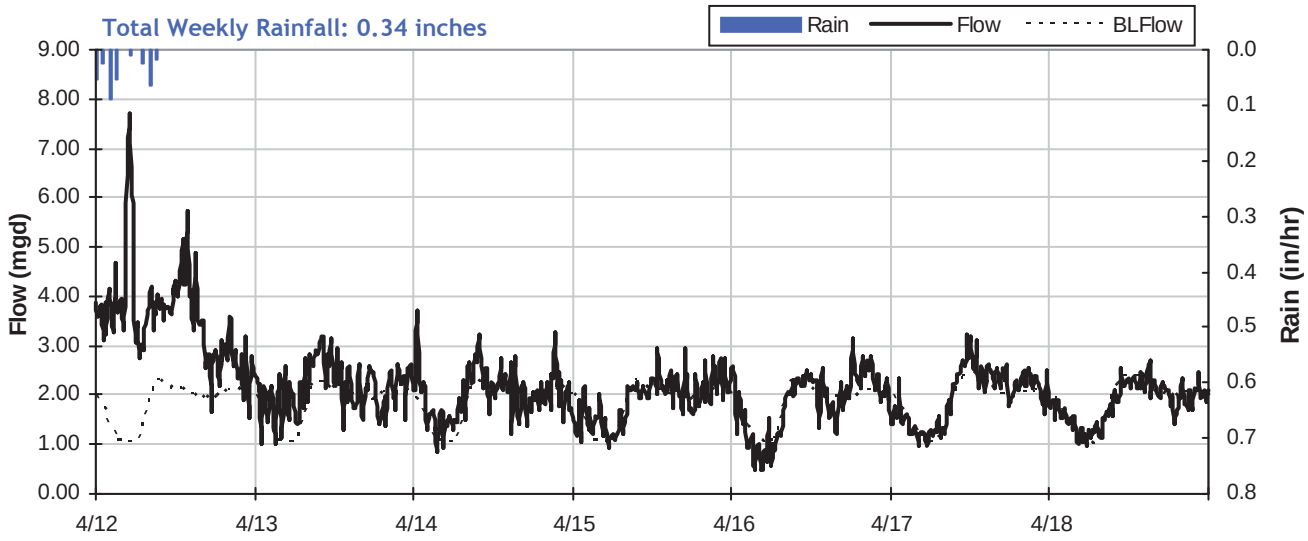
Avg Flow: 2.087 mgd Peak Flow: 5.651 mgd Min Flow: 0.579 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 6



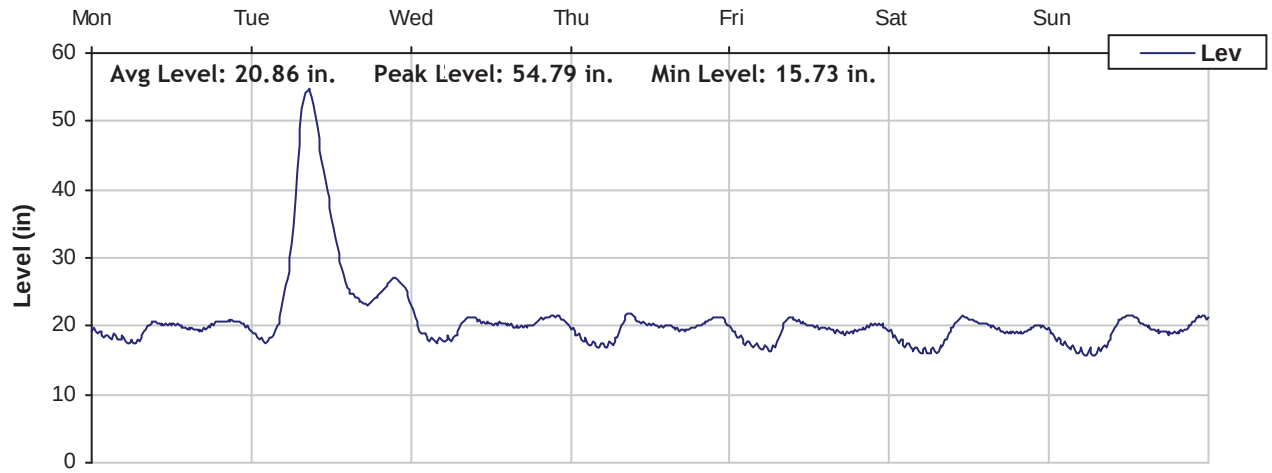


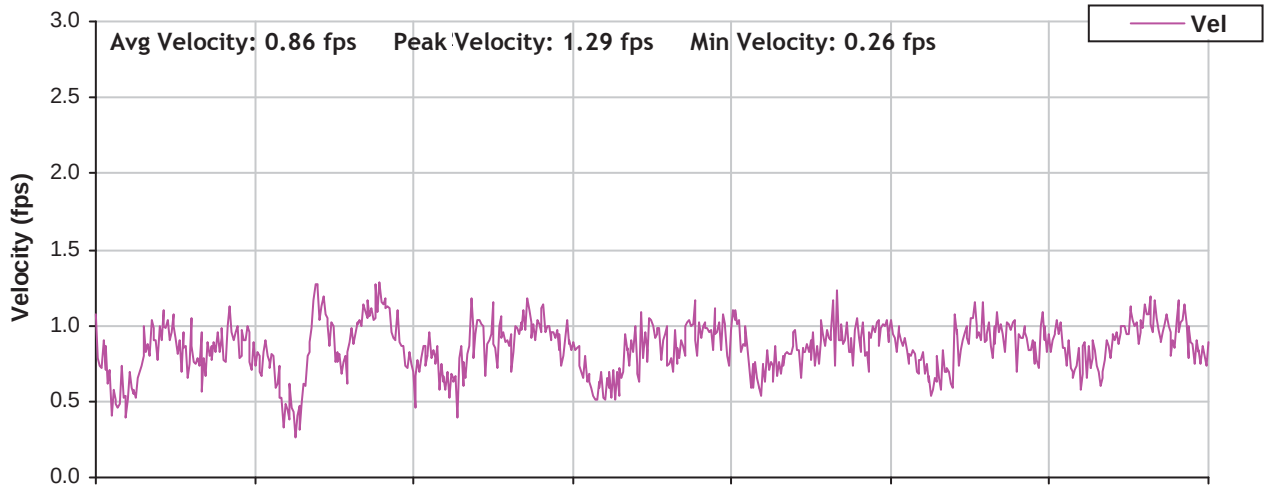


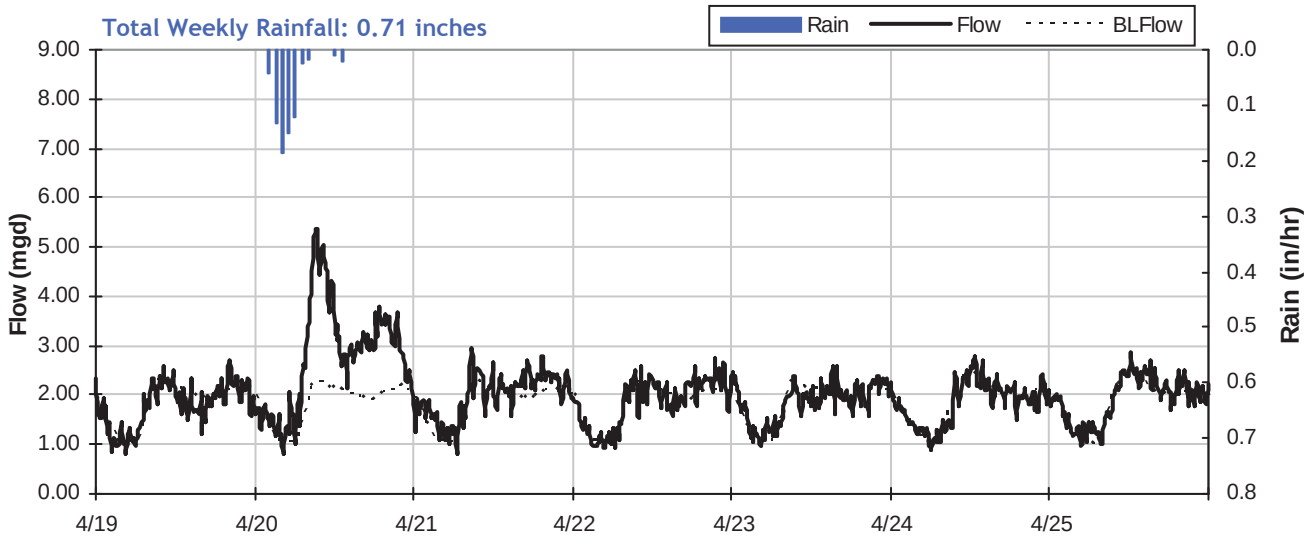
Avg Flow: 2.198 mgd Peak Flow: 7.701 mgd Min Flow: 0.466 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 6



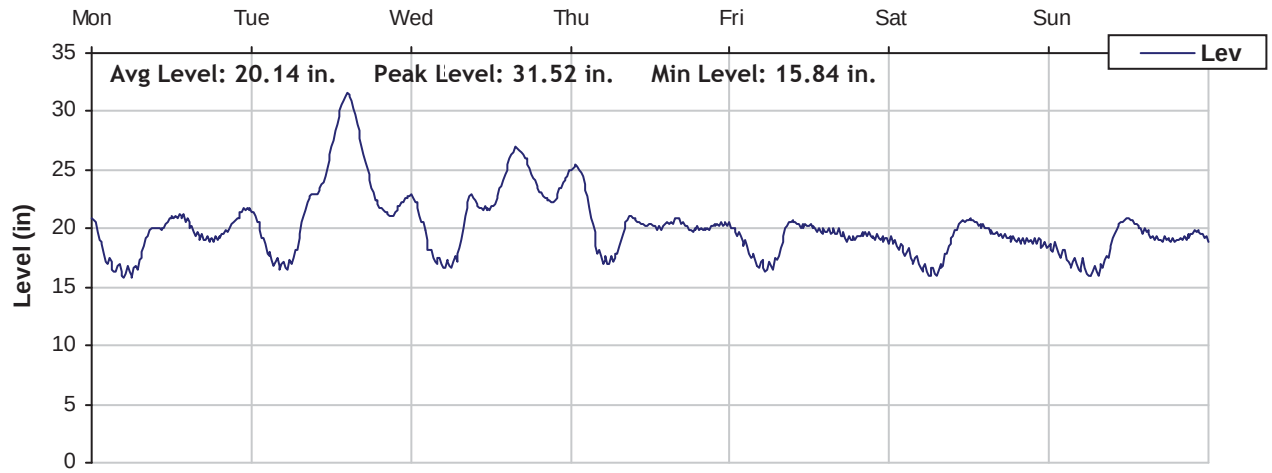


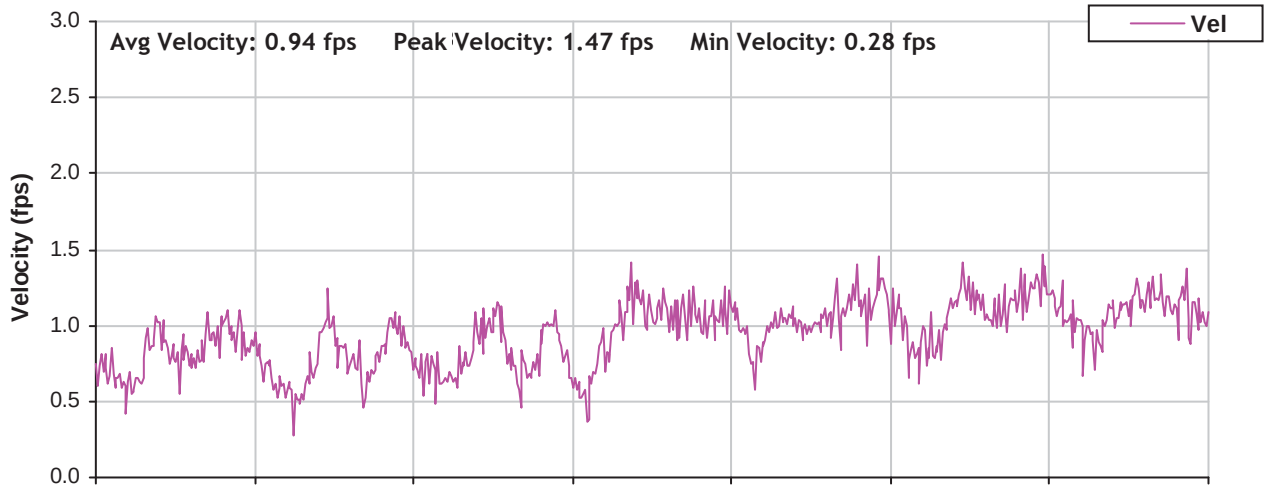


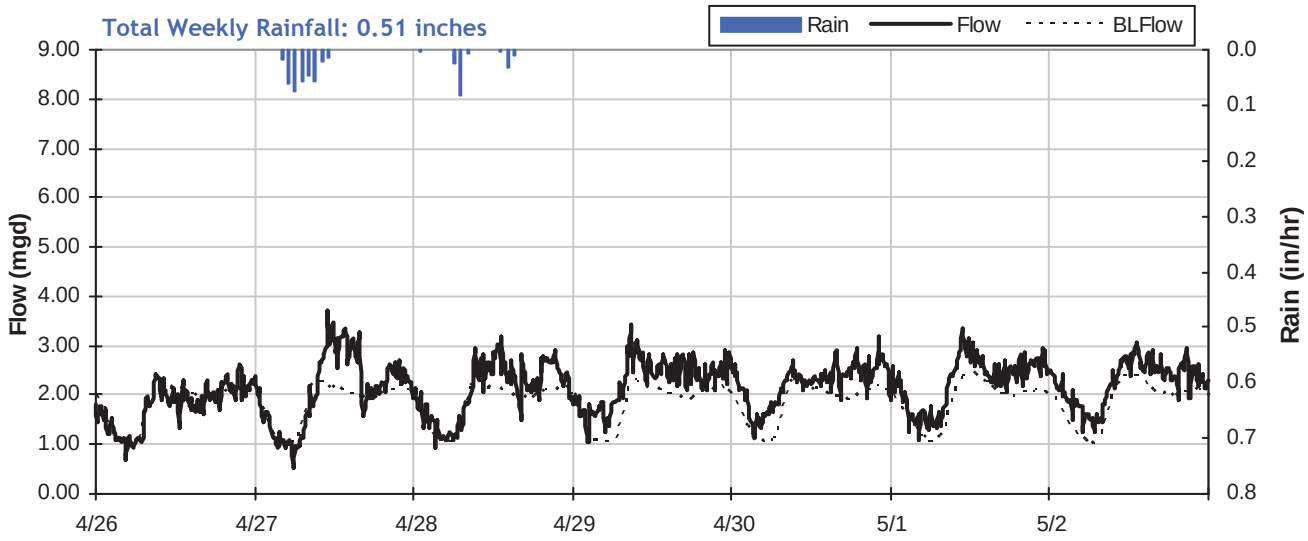
Avg Flow: 2.01 mgd Peak Flow: 5.377 mgd Min Flow: 0.79 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 6





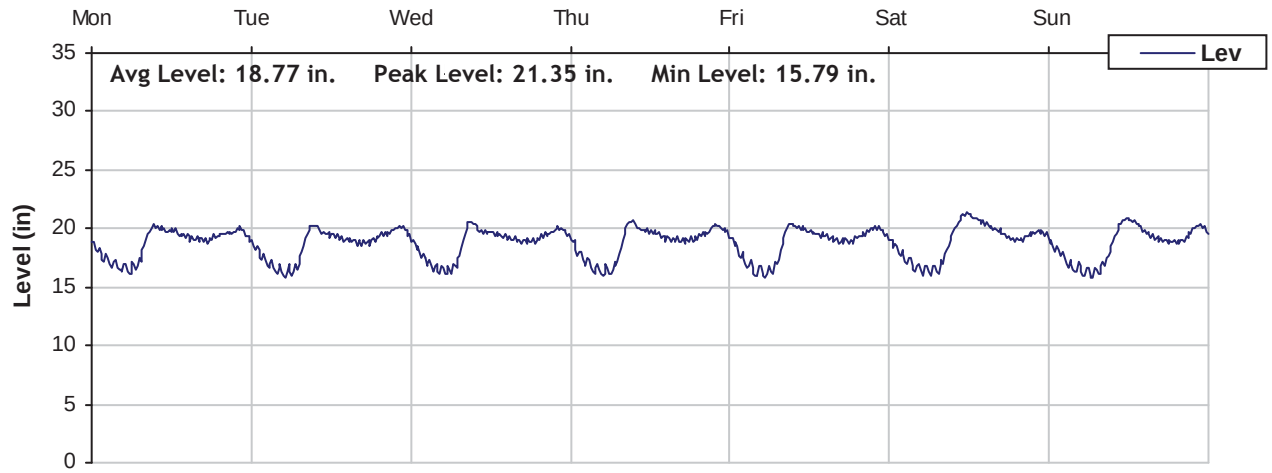


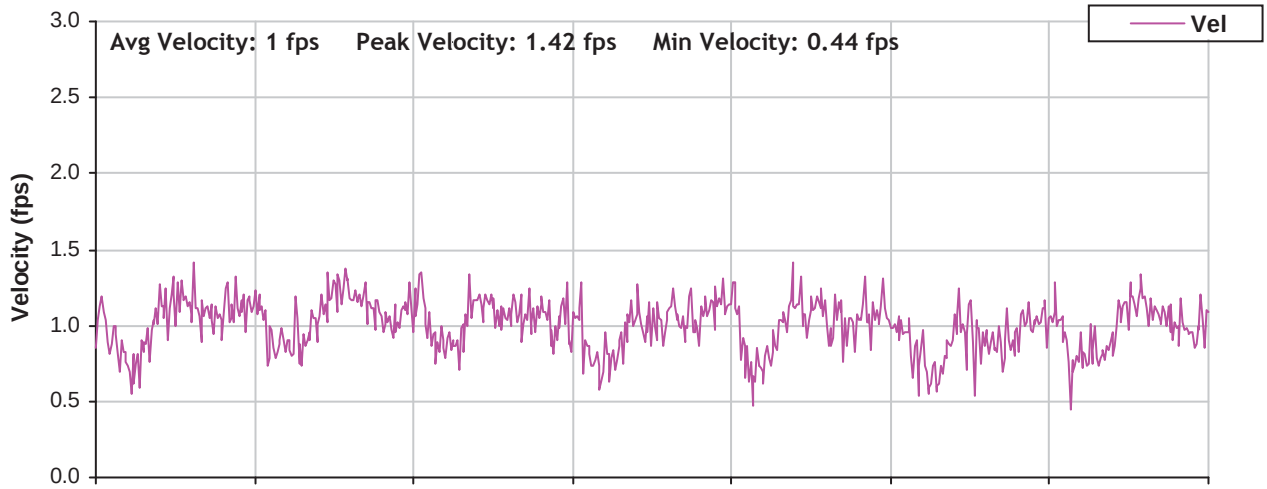
Avg Flow: 2.146 mgd Peak Flow: 3.717 mgd Min Flow: 0.518 mgd

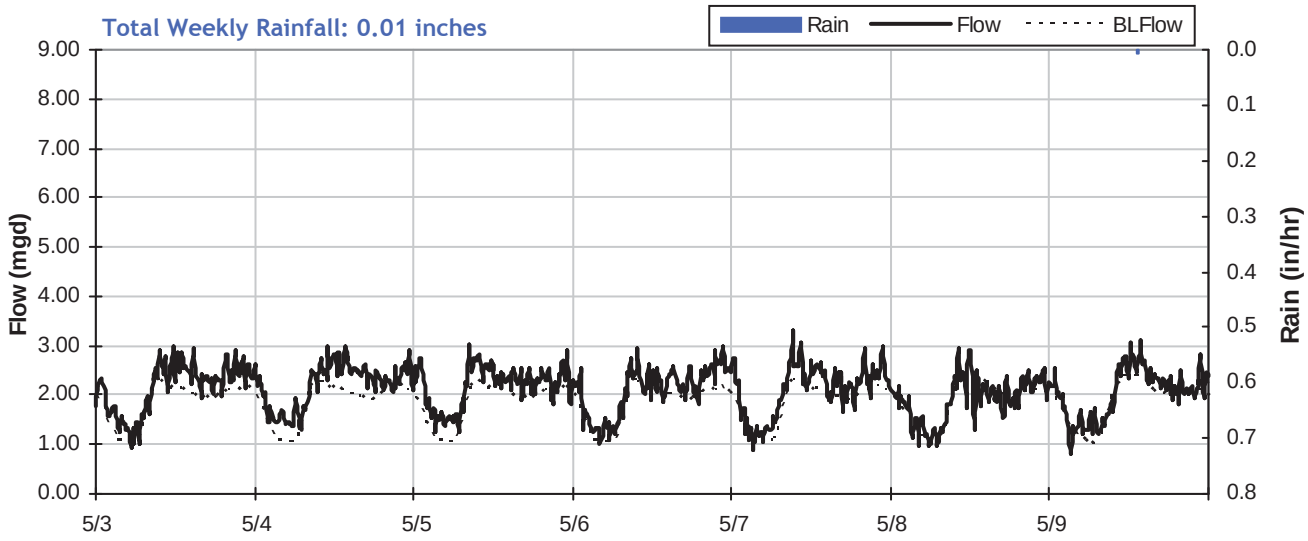
V&A

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 6



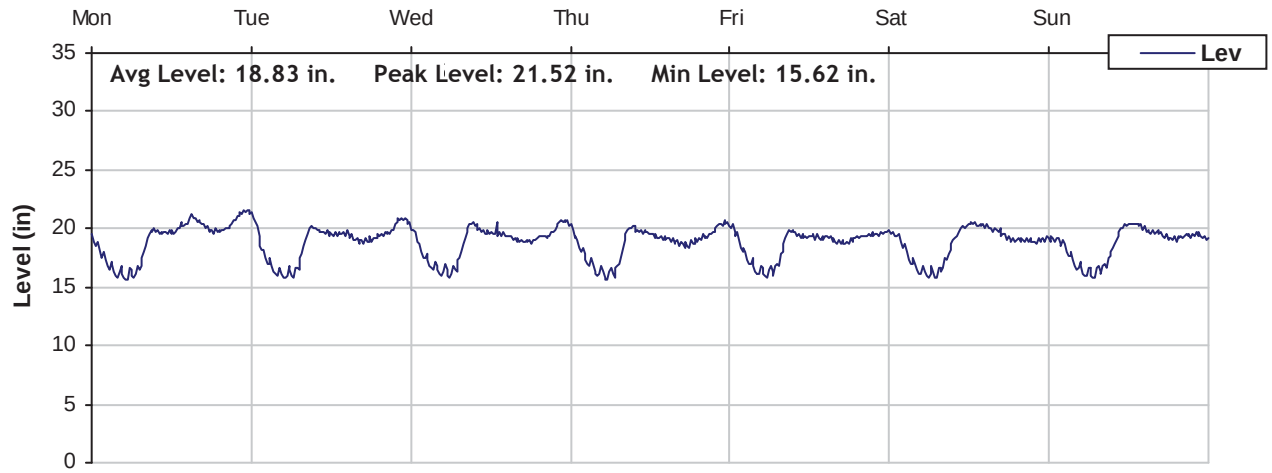


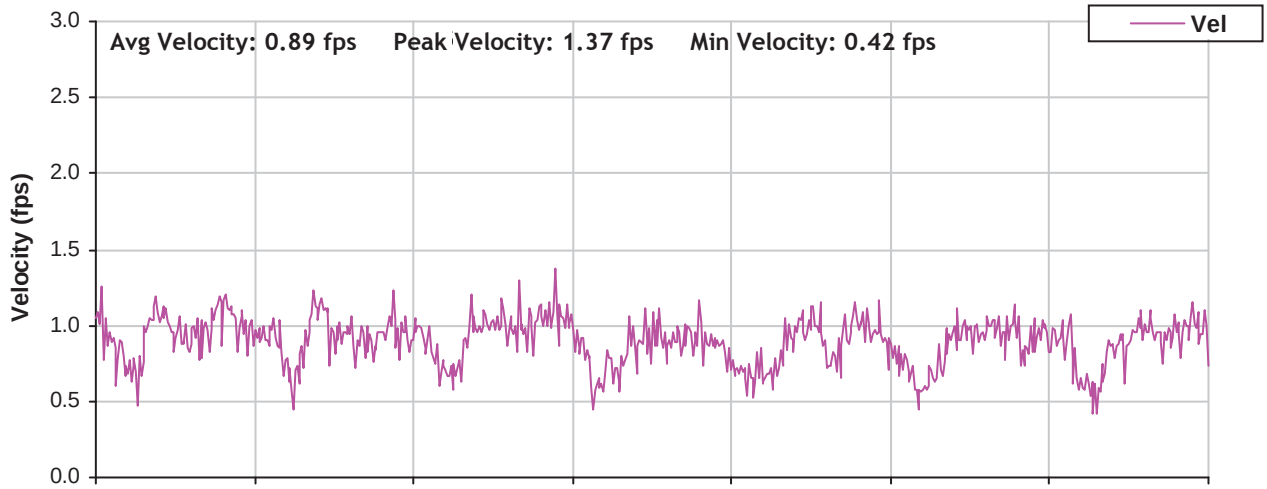


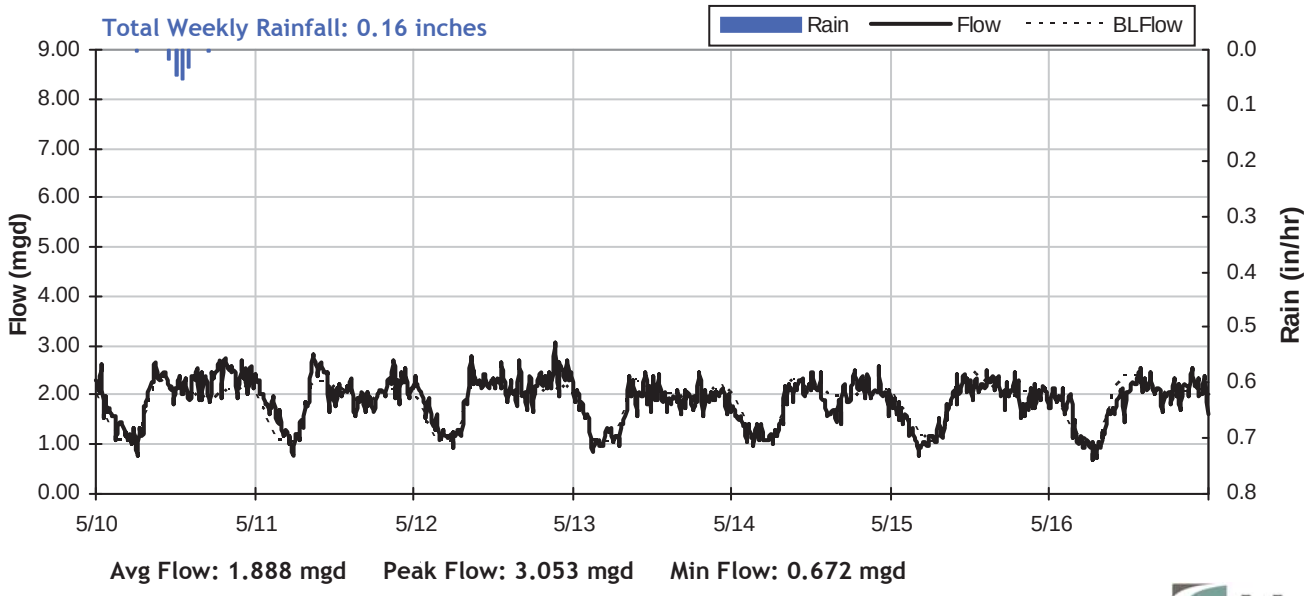
Avg Flow: 2.101 mgd Peak Flow: 3.306 mgd Min Flow: 0.811 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 6



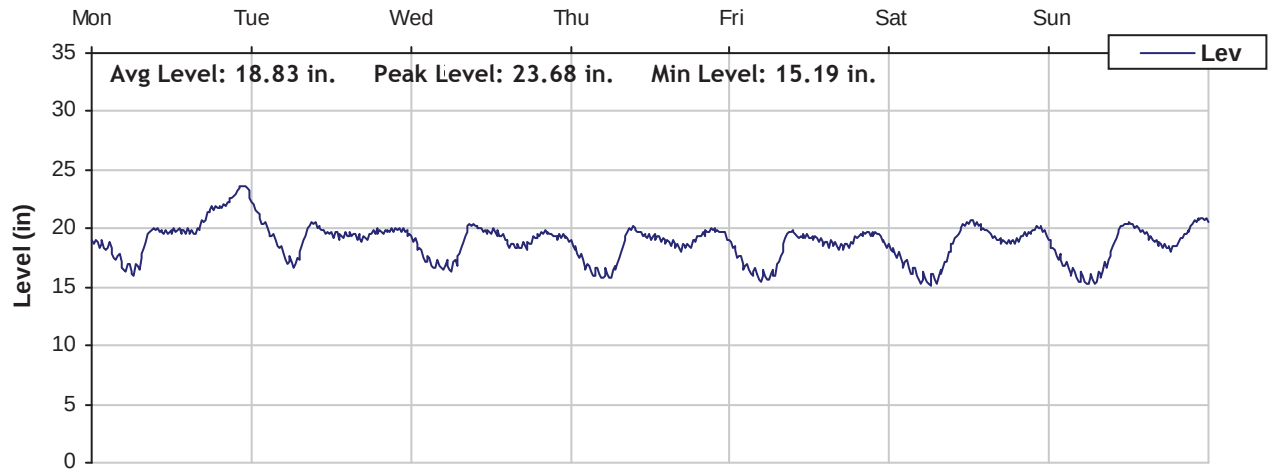


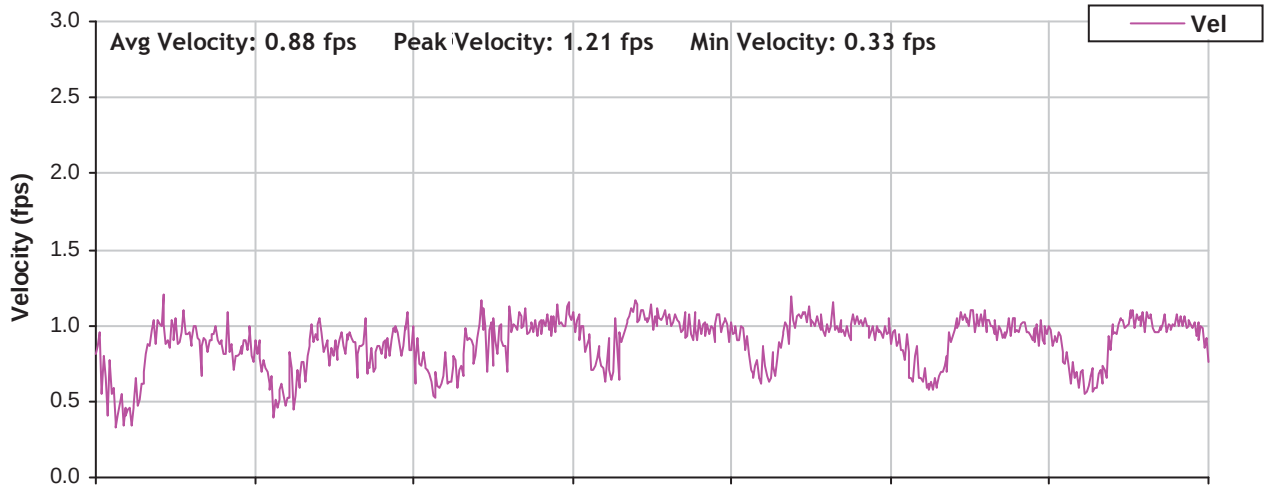


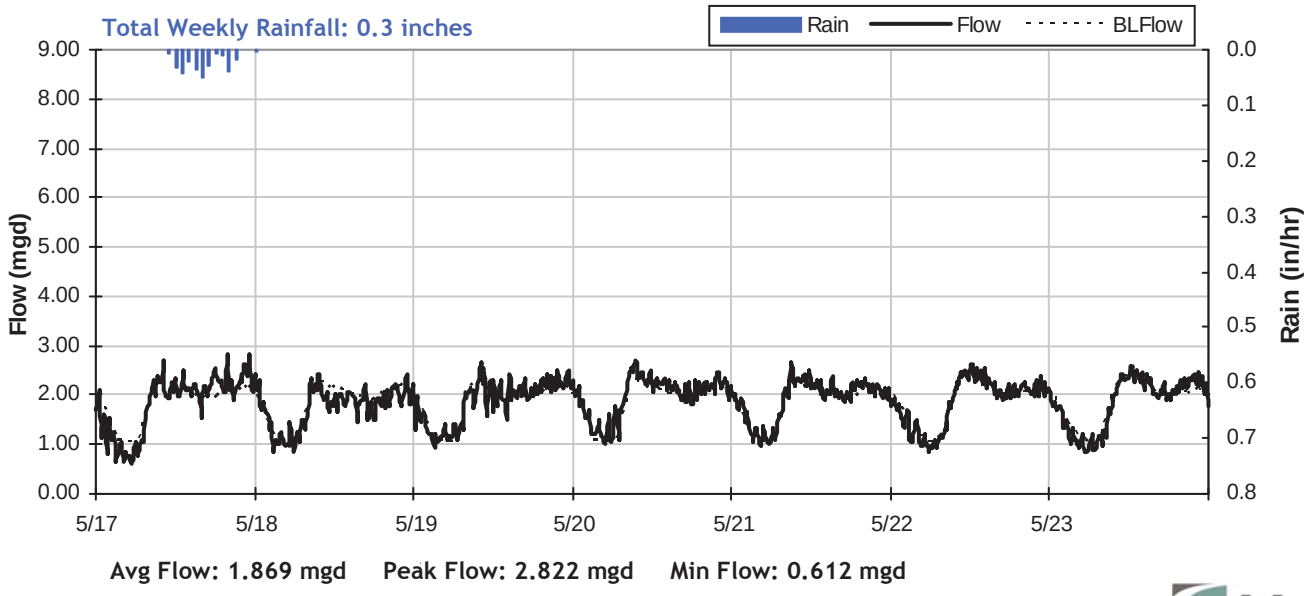
Avg Flow: 1.888 mgd Peak Flow: 3.053 mgd Min Flow: 0.672 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 6



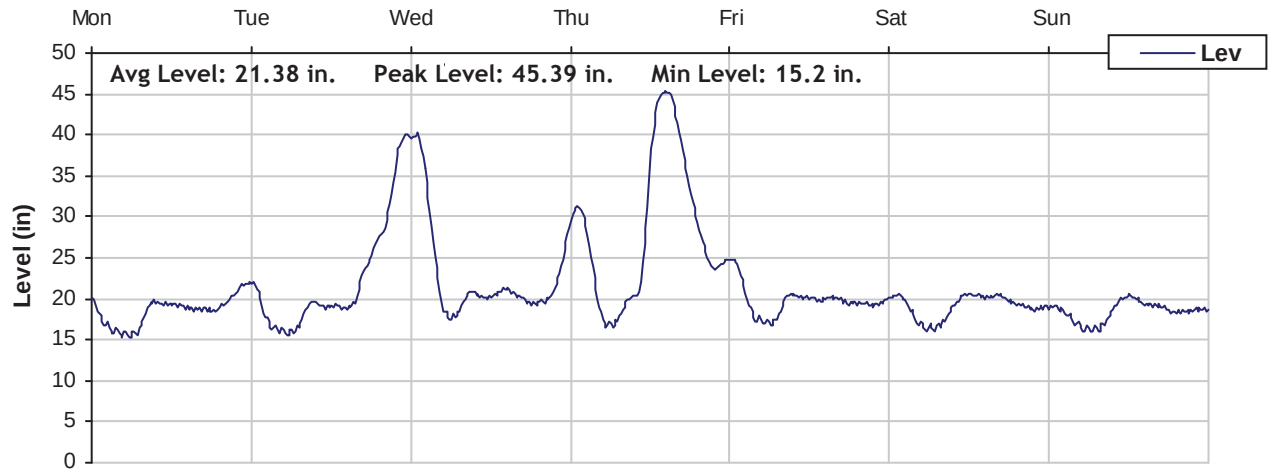


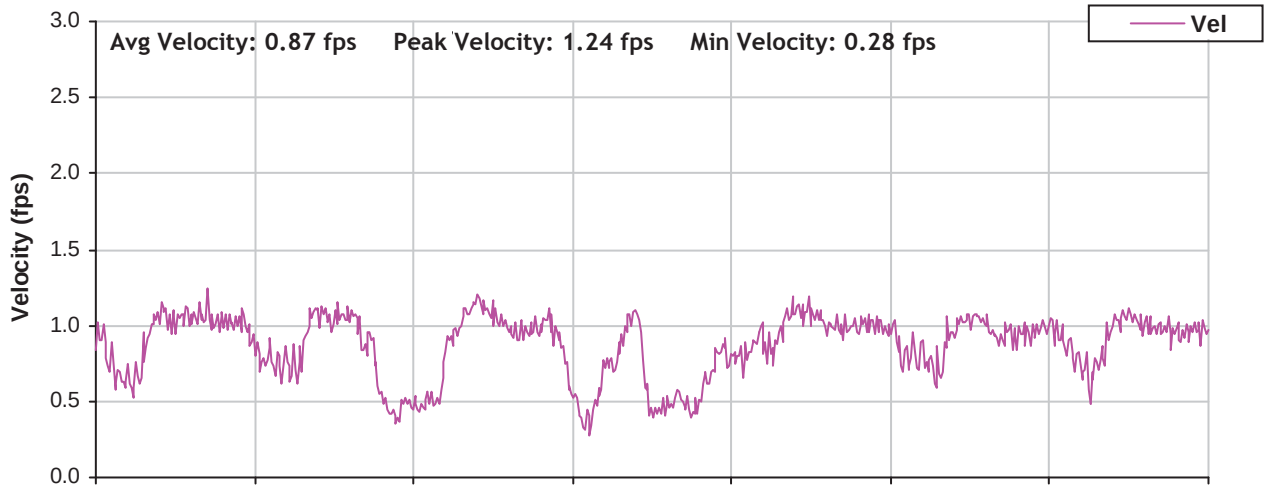


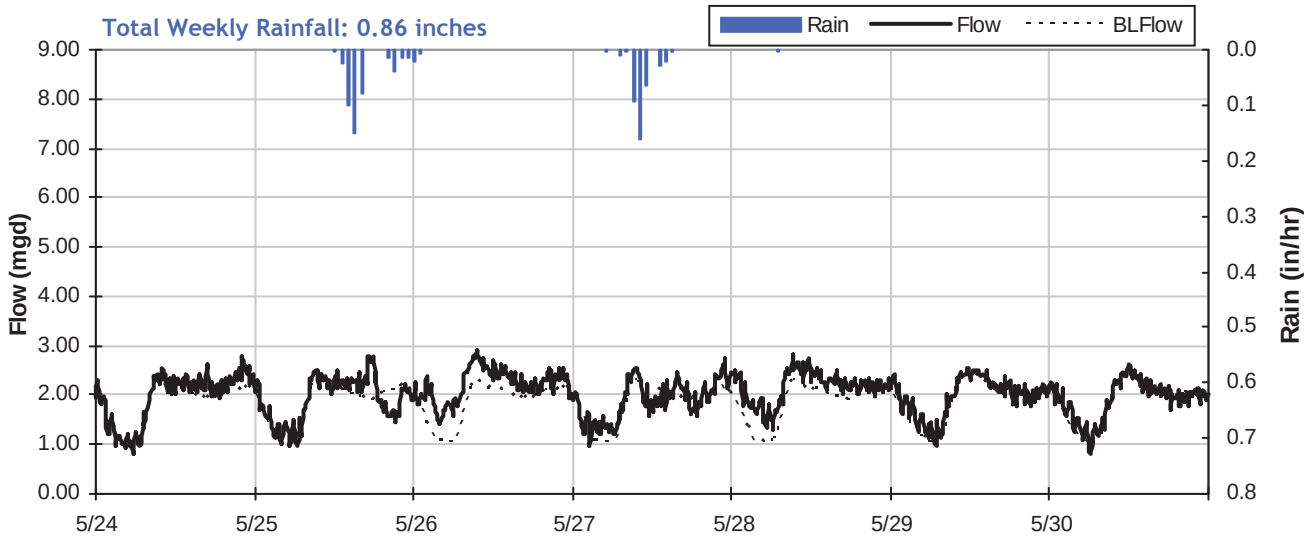
Avg Flow: 1.869 mgd Peak Flow: 2.822 mgd Min Flow: 0.612 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 6



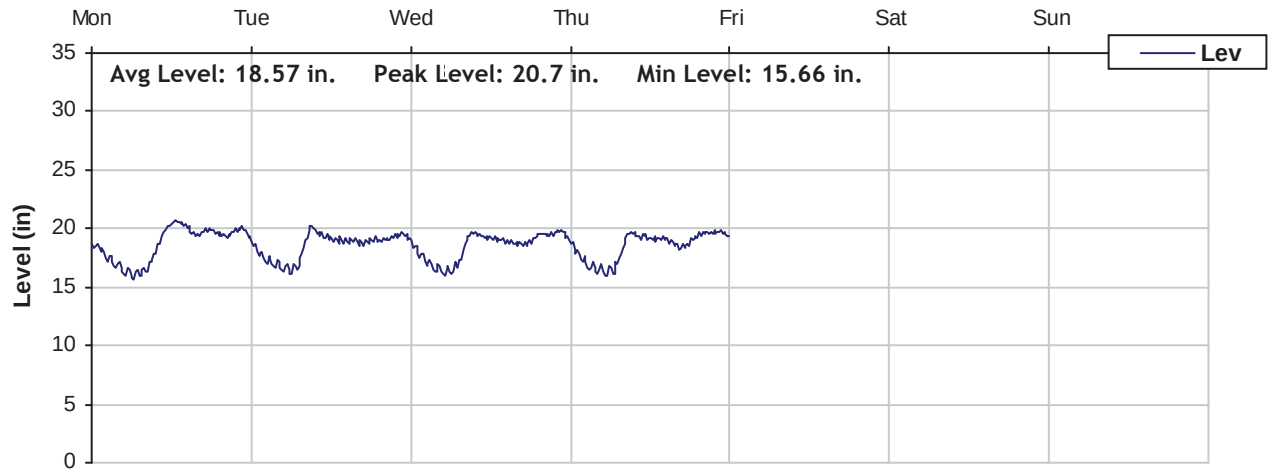


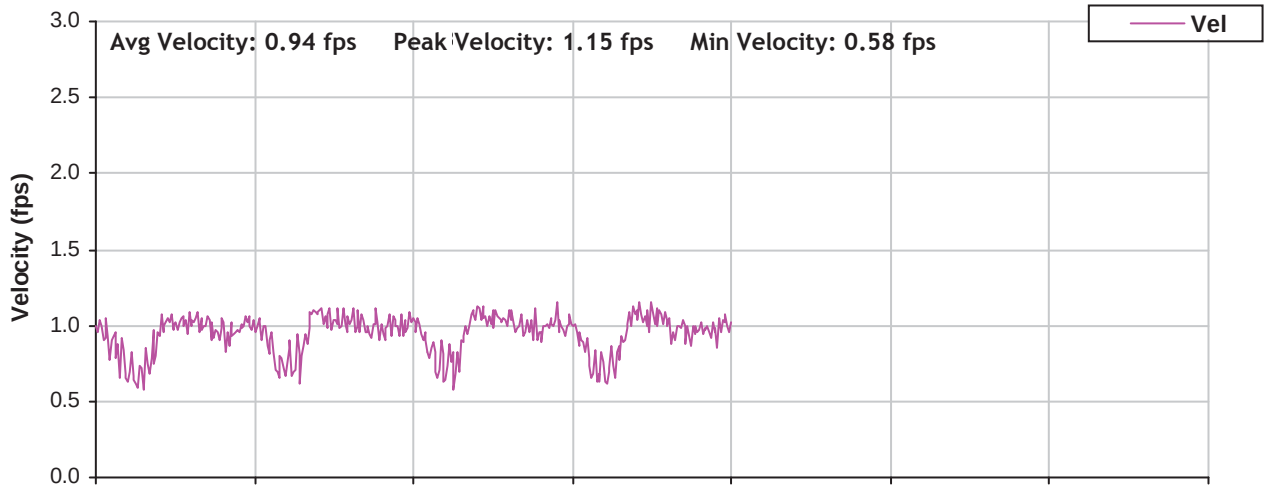


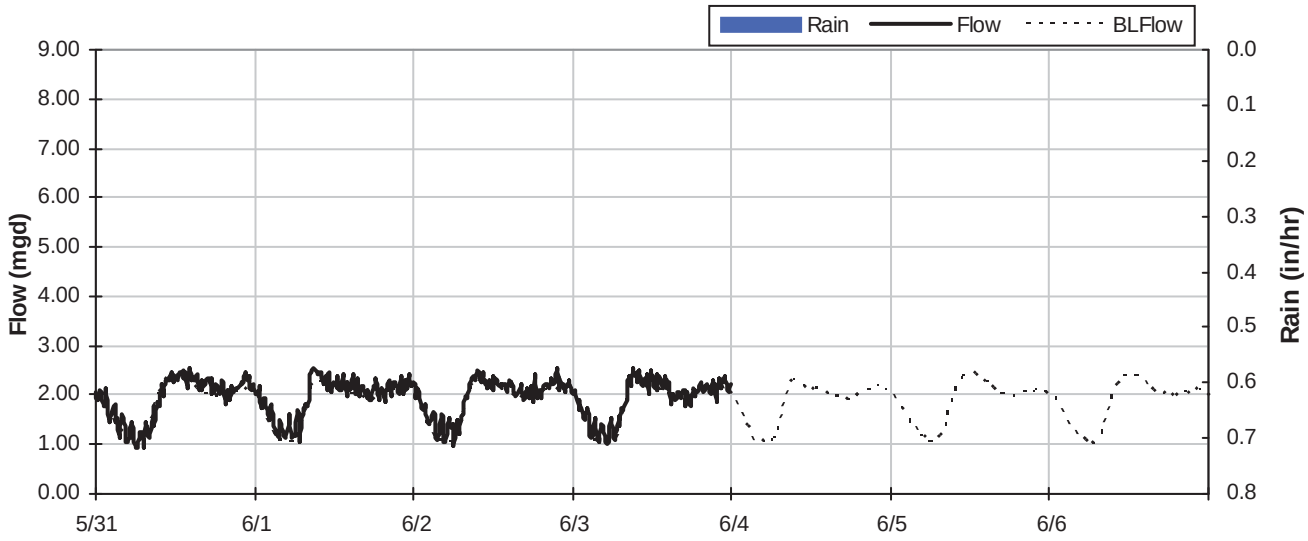
Avg Flow: 2.006 mgd Peak Flow: 2.906 mgd Min Flow: 0.8 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 6







Avg Flow: 1.952 mgd Peak Flow: 2.552 mgd Min Flow: 0.933 mgd

Temporary Flow Monitoring Study

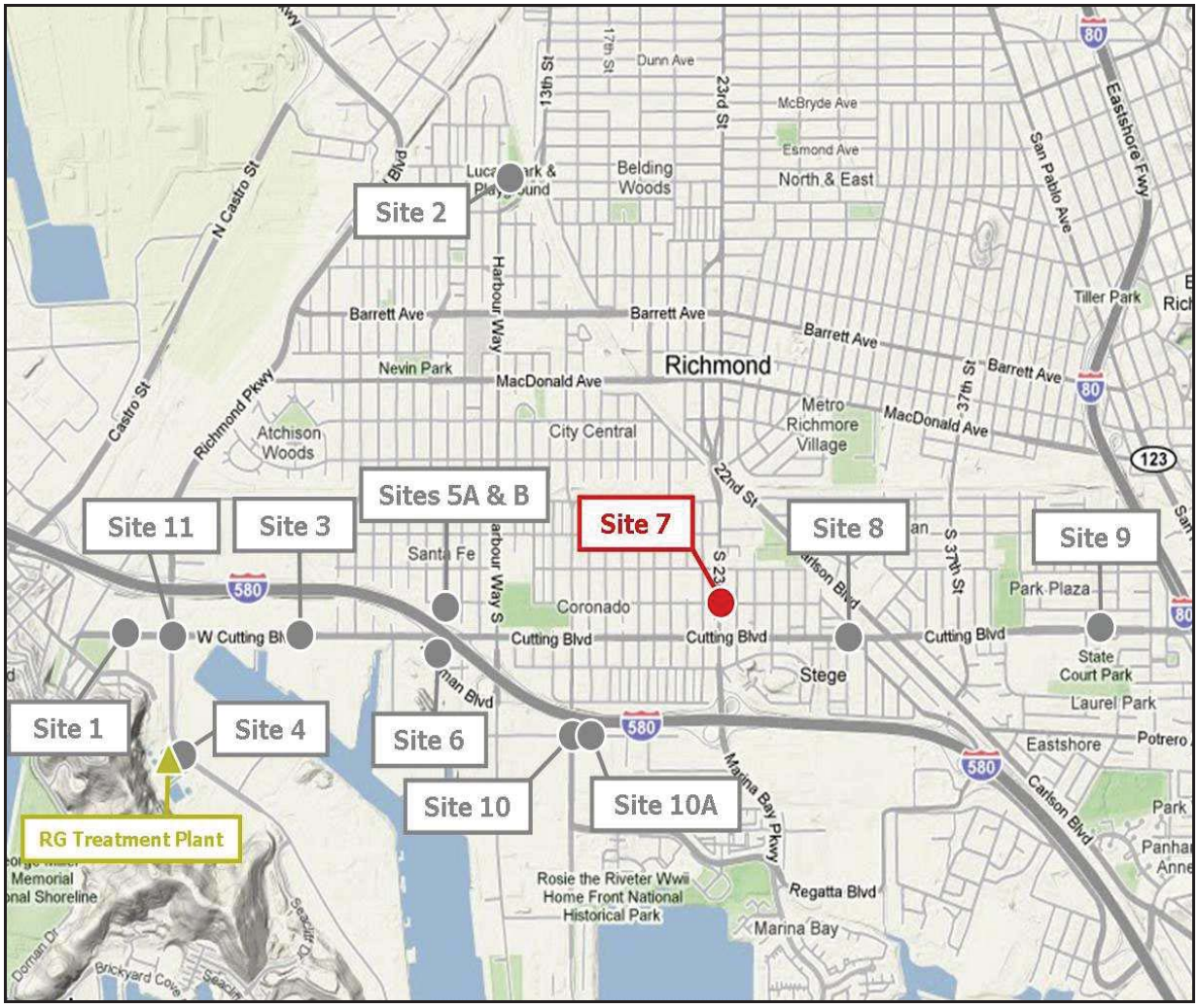
Sanitary Sewer Collection System

Monitoring Site: Site 7

Location: Intersection of Virginia Avenue and S 23rd Street

Size/Type Line: 21-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 7

Location: Intersection of Virginia Avenue and S 23rd Street

Latitude: 37.9266°

Longitude: -122.3477°

Rim Elevation: 30 *feet above sea level*

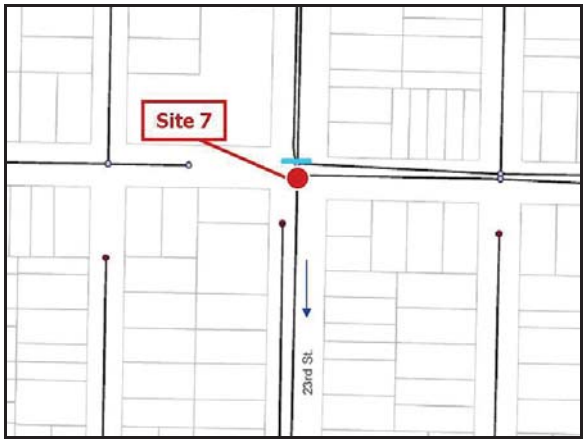
Diameter: 21 *inches*

Average Dry Weather Flow: 0.680 *mgd*

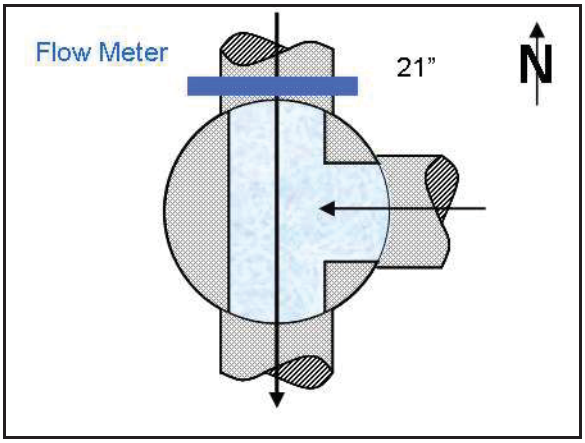
Peak Measured Flow: 5.190 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

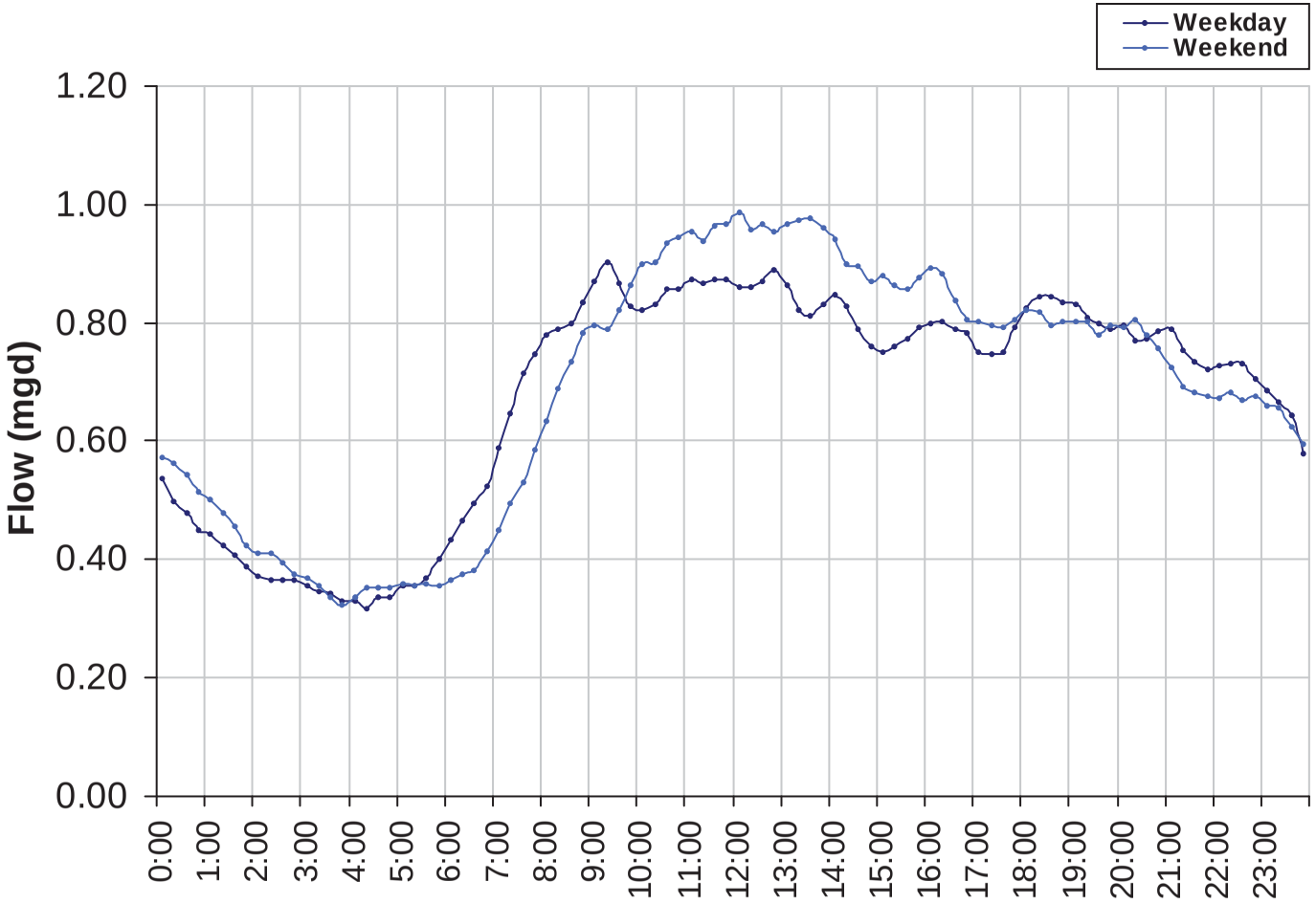


Street View Photo

Plan View Photo

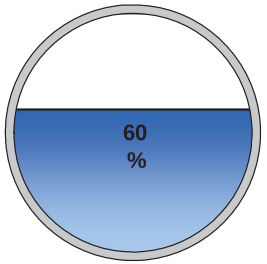
Average Dry Weather Flow

Monitoring Site:
Site 7



Peak Measured Flow:

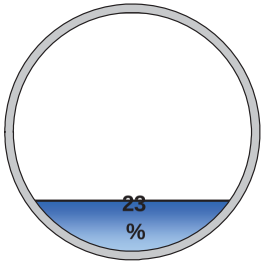
5.19 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

0.68 *mgd*

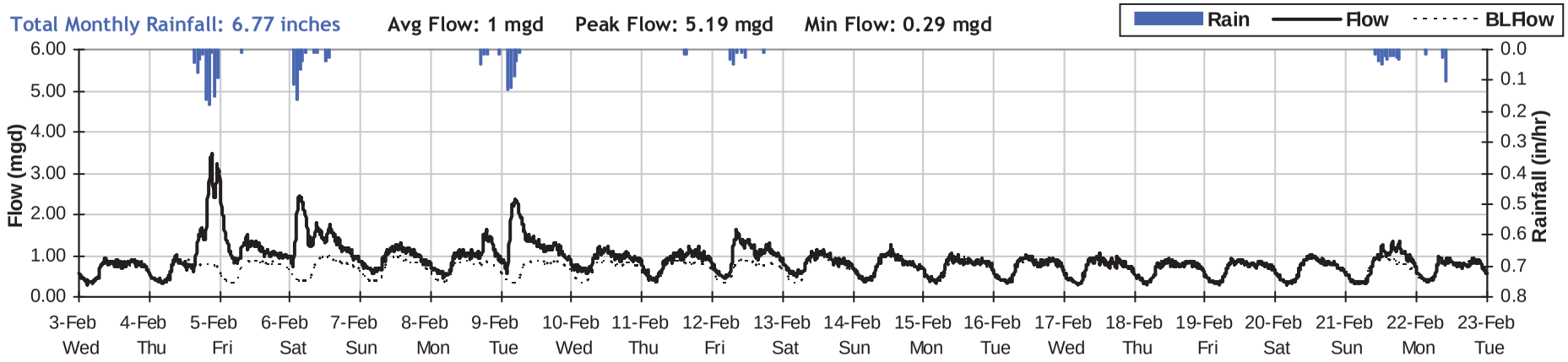


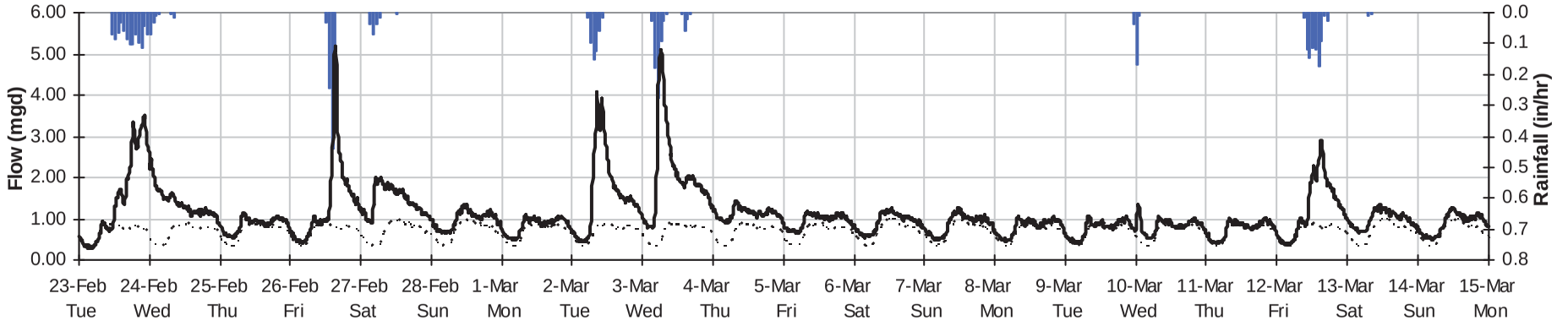
V&A

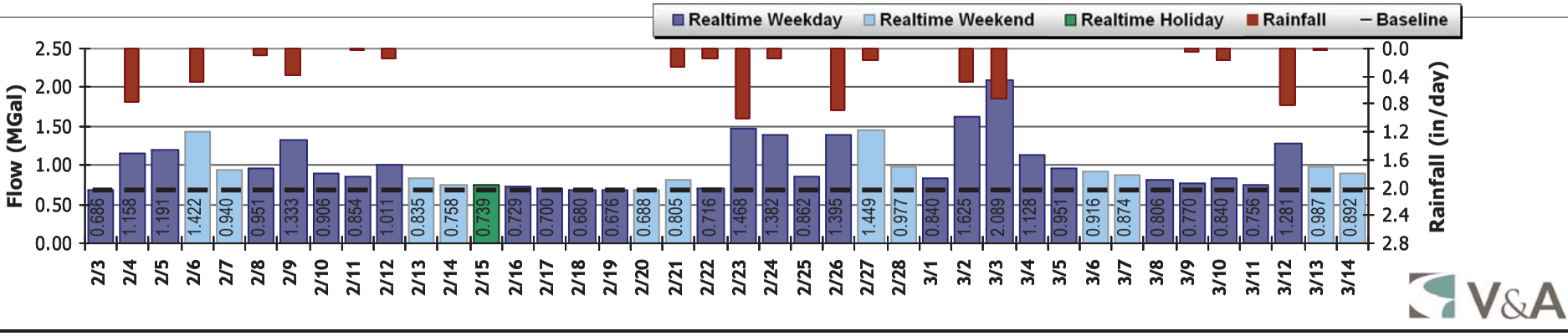
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 7

Total Monthly Rainfall: 6.77 inches Avg Flow: 1 mgd Peak Flow: 5.19 mgd Min Flow: 0.29 mgd





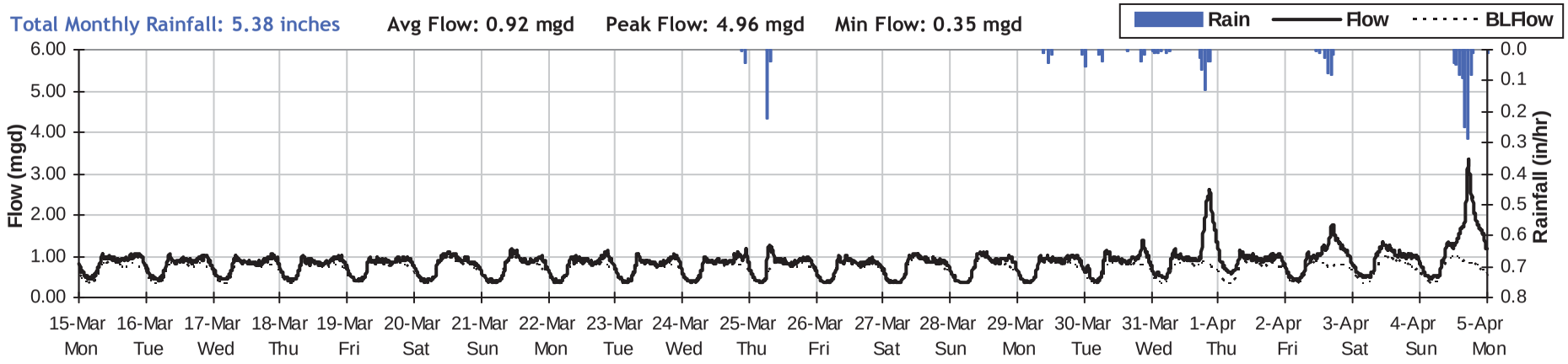


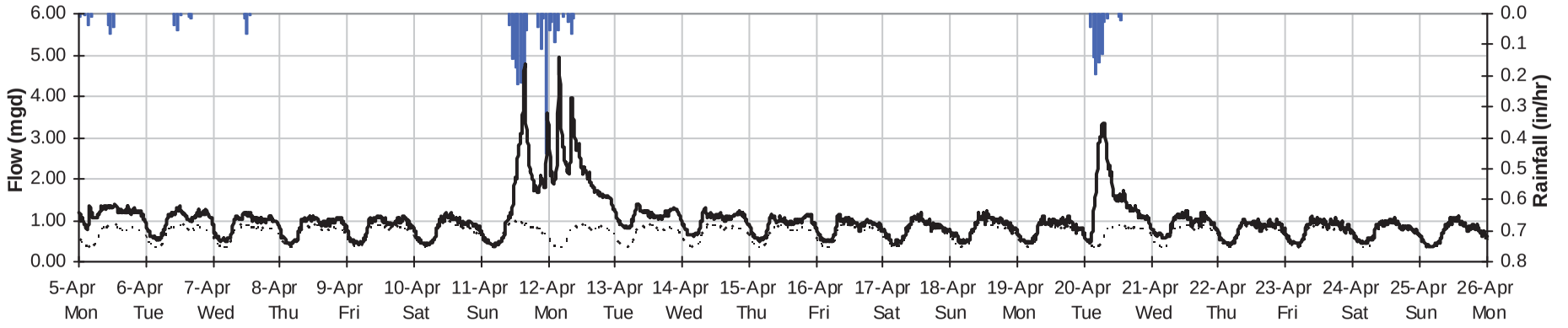
V&A

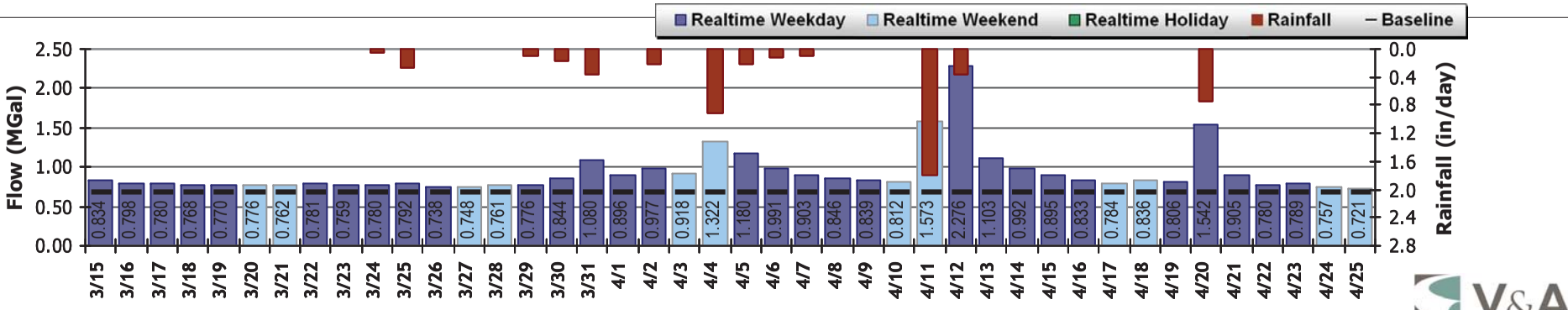
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 7

Total Monthly Rainfall: 5.38 inches Avg Flow: 0.92 mgd Peak Flow: 4.96 mgd Min Flow: 0.35 mgd





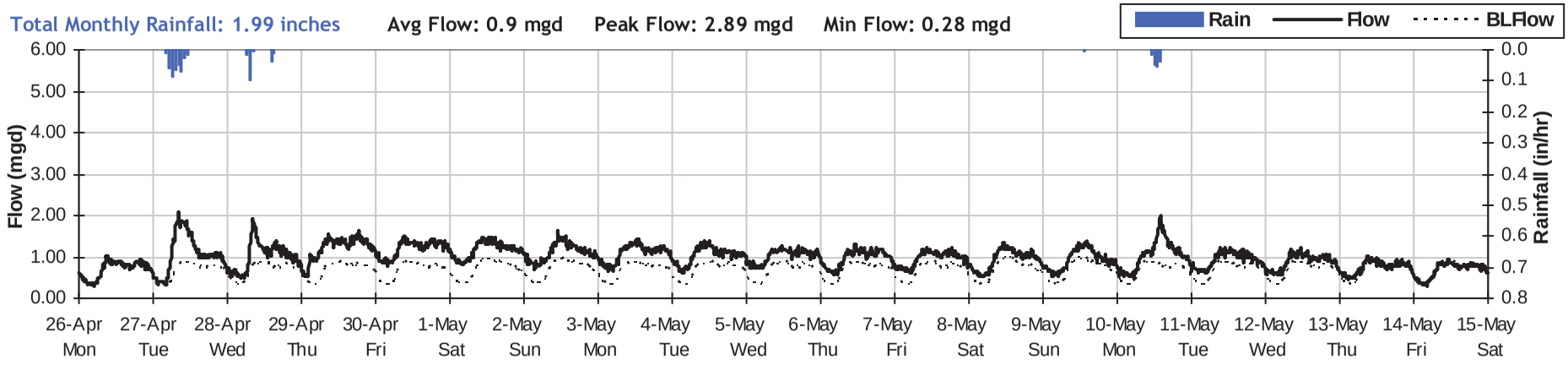


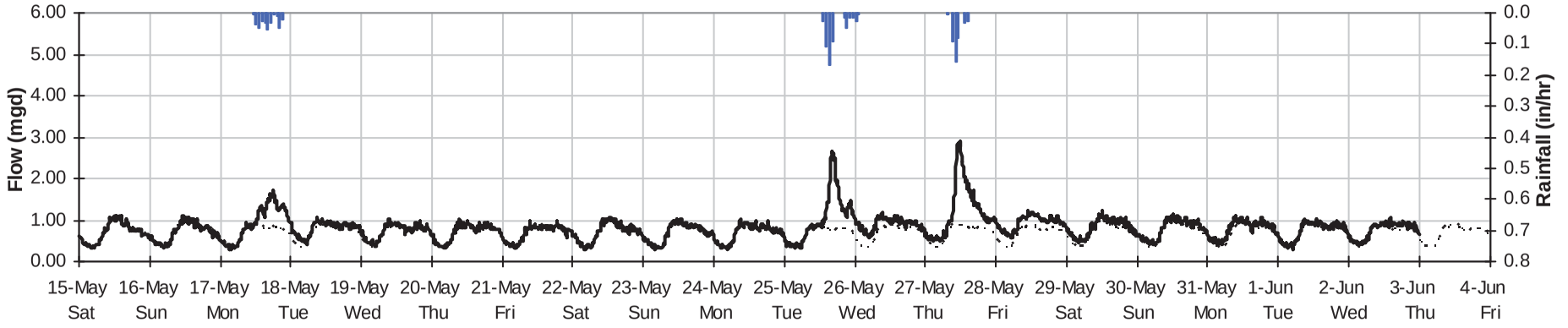
V&A

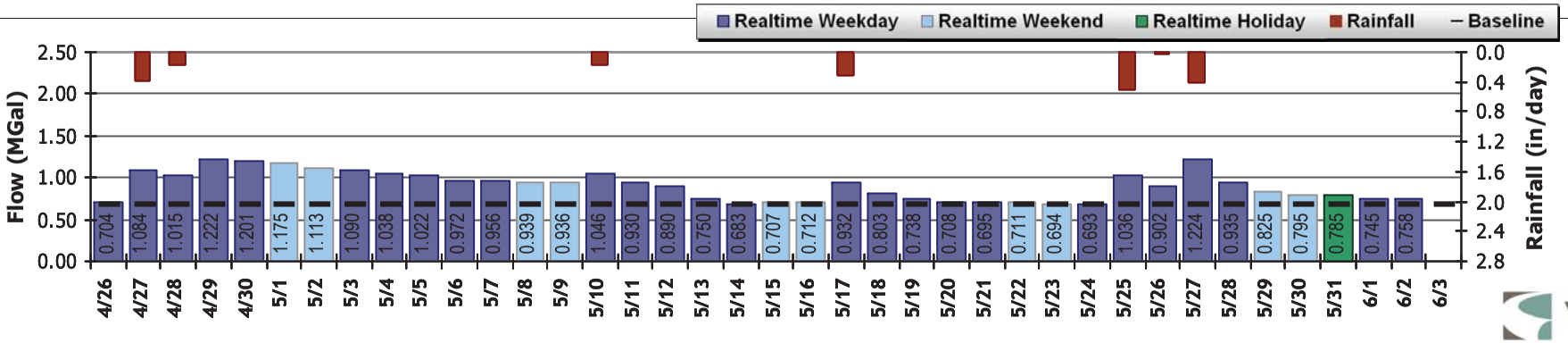
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 7

Total Monthly Rainfall: 1.99 inches Avg Flow: 0.9 mgd Peak Flow: 2.89 mgd Min Flow: 0.28 mgd





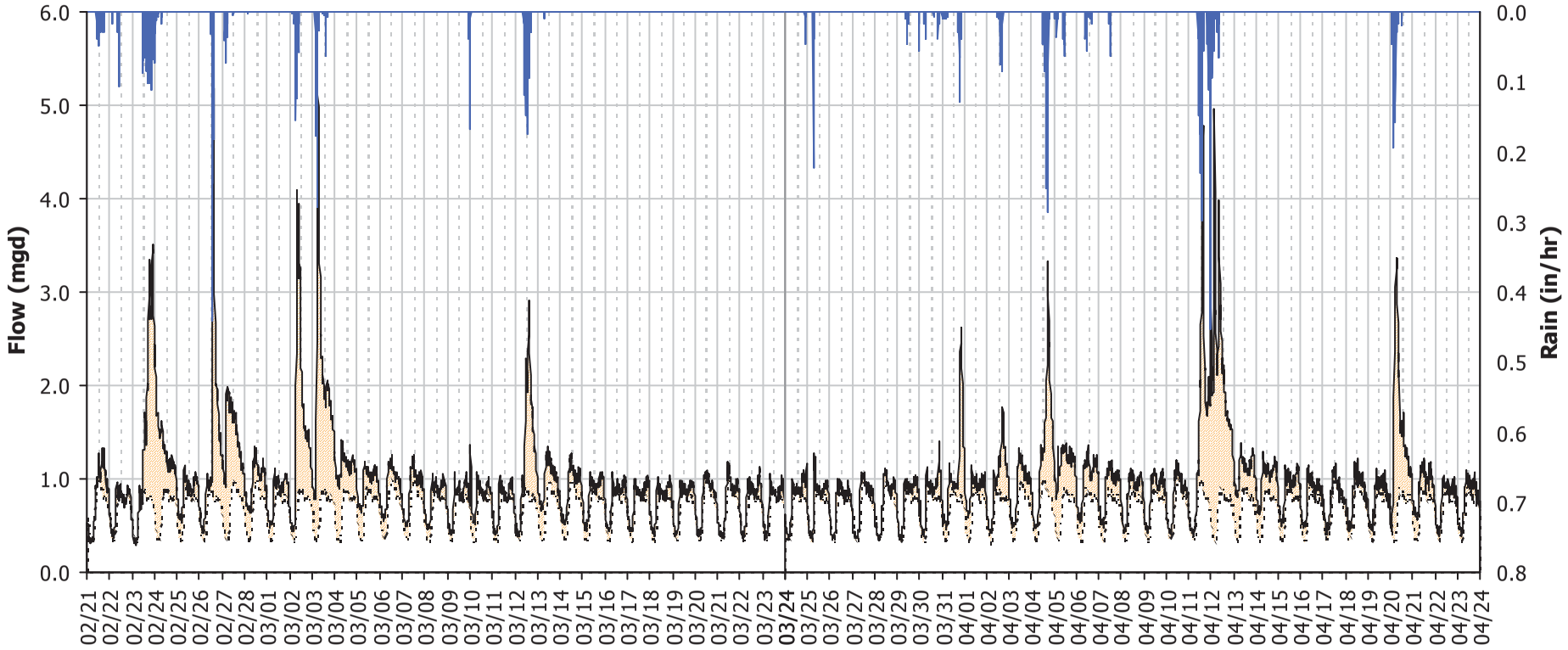


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 7

Multiple Events Detail I/I Graph

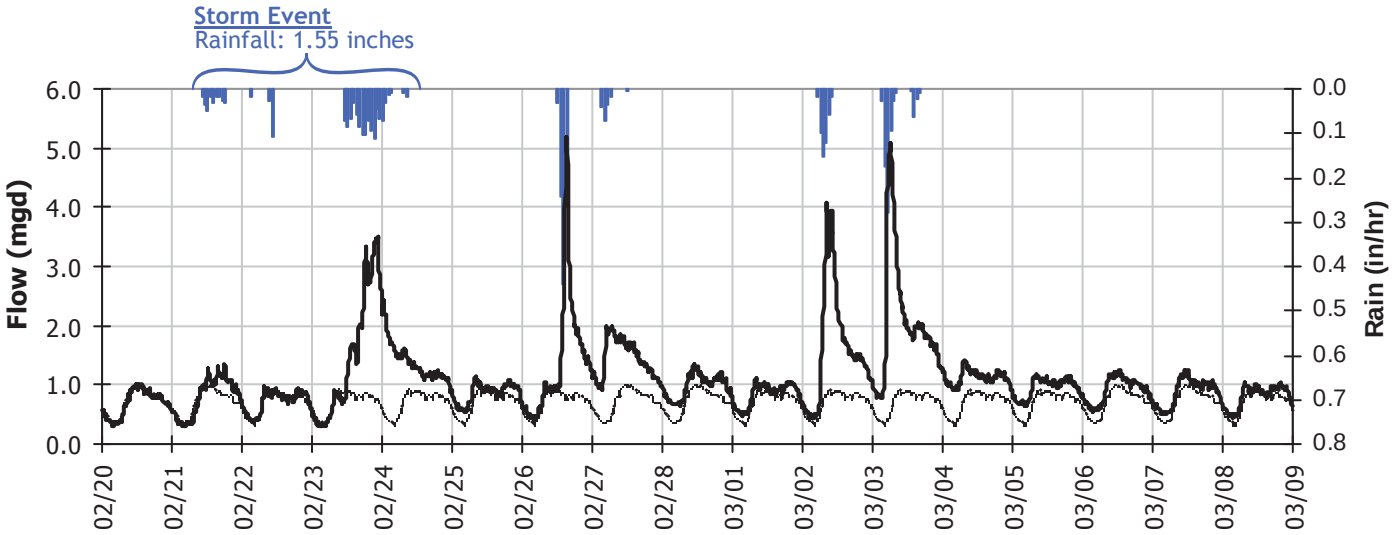


Multiple Events I/I Analysis

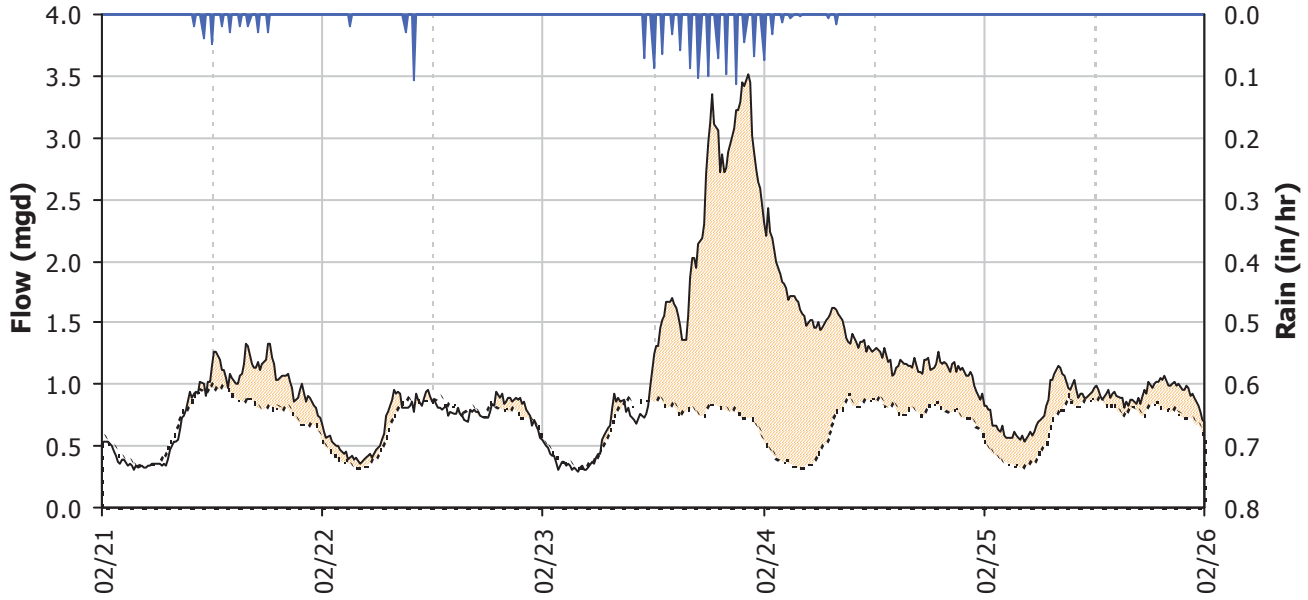
Rainfall:	10.24	*inches*	**Baseline Flow:**	0.68	*mgd*
Peak Flow:	5.19	*mgd*	**PF:**	7.64	
Peak I/I Rate:	4.64	*mgd*	**Pk I/I:ADWF:**	6.82	
Peak Level:	12.66	*inches*	**d/D Ratio:**	0.60	
Total I/I:	19,031,000	*gallons*	**R-Value:**	14.9%	
			I/I per ADWF:	2.7	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 7

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



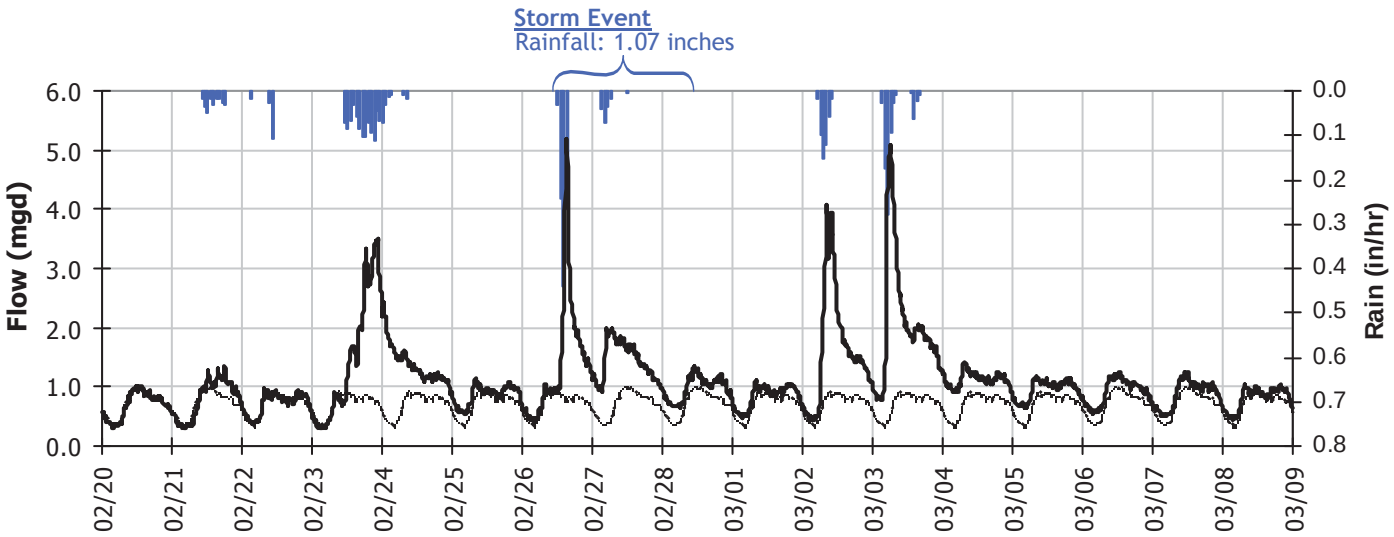
Storm Event #1 I/I Analysis

Rainfall:	1.55	*inches*		
Baseline Flow:	0.68	*mgd*		
Peak Flow:	3.51	*mgd*	**PF:**	5.17
Peak I/I Rate:	2.78	*mgd*	**Pk I/I:ADWF:**	4.09
Peak Level:	10.62	*inches*	**d/D Ratio:**	0.51
Total I/I:	1,842,000	*gallons*	**R-Value:**	9.5%
			I/I per ADWF:	1.75 *per in-rain*

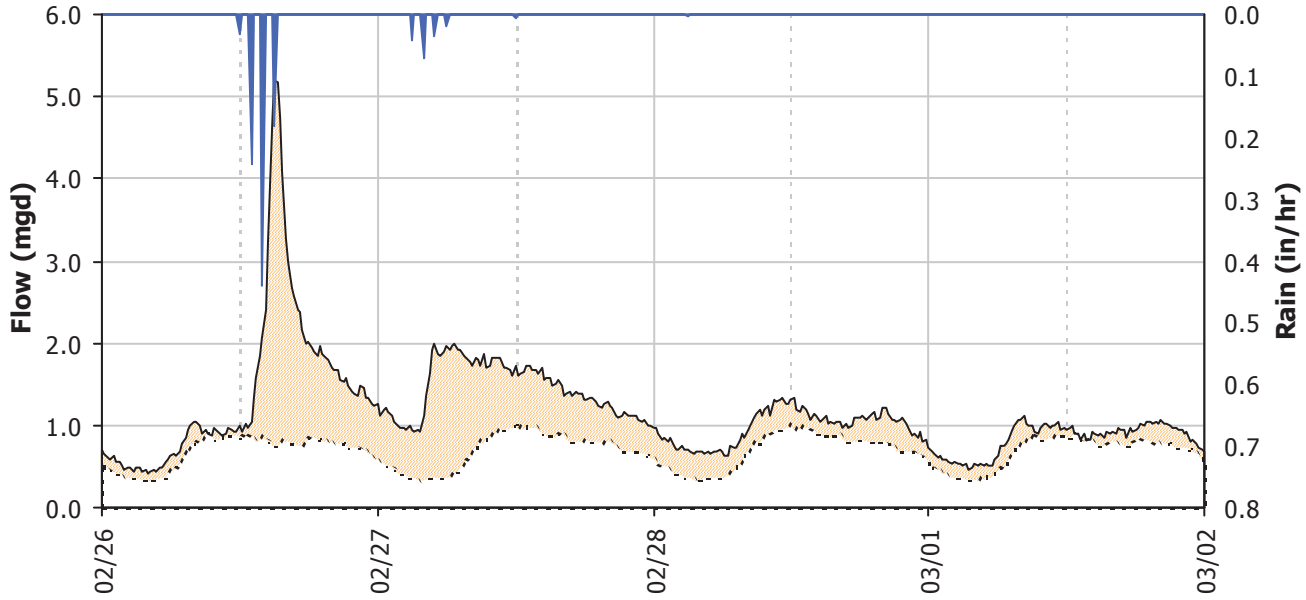
Average Infiltration Rate on 2/25 (% of ADWF): 27.5%

	I/I Summary Event 2	**Monitoring Site:** Site 7

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #2 I/I Analysis

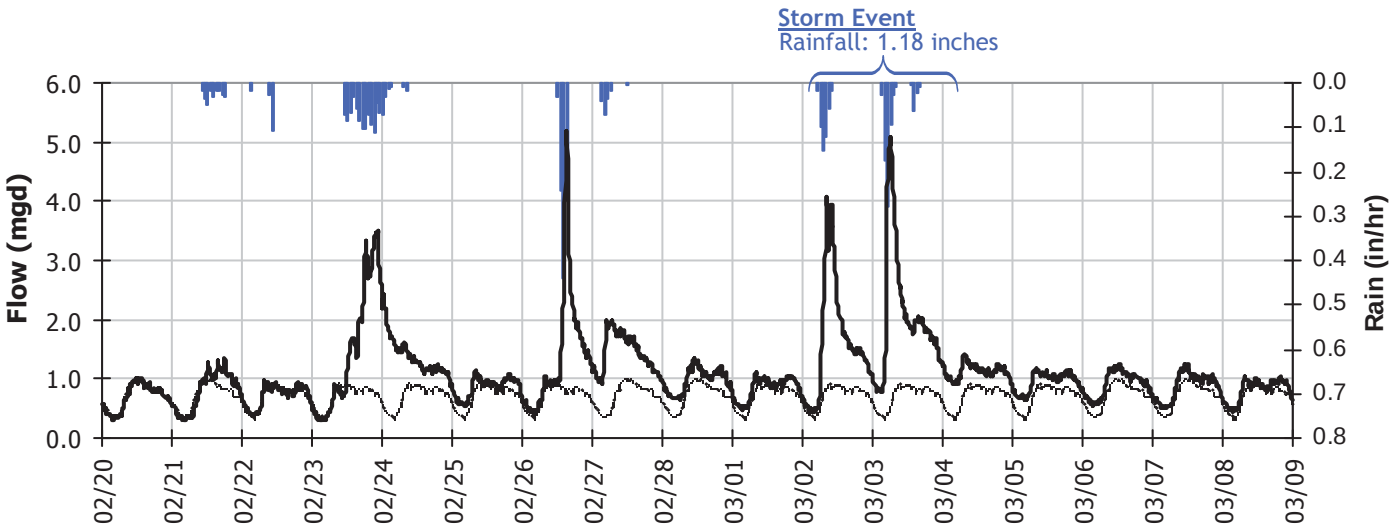
Rainfall:	1.07 *inches*			
Baseline Flow:	0.68 *mgd*			
Peak Flow:	5.19 *mgd*	**PF:**	7.64	
Peak I/I Rate:	4.44 *mgd*	**Pk I/I:ADWF:**	6.53	
Peak Level:	12.37 *inches*	**d/D Ratio:**	0.59	
Total I/I:	1,934,000 *gallons*	**R-Value:**	14.4%	
		I/I per ADWF:	2.66 *per in-rain*	

Average Infiltration Rate on 3/1 (% of ADWF): 24.3%

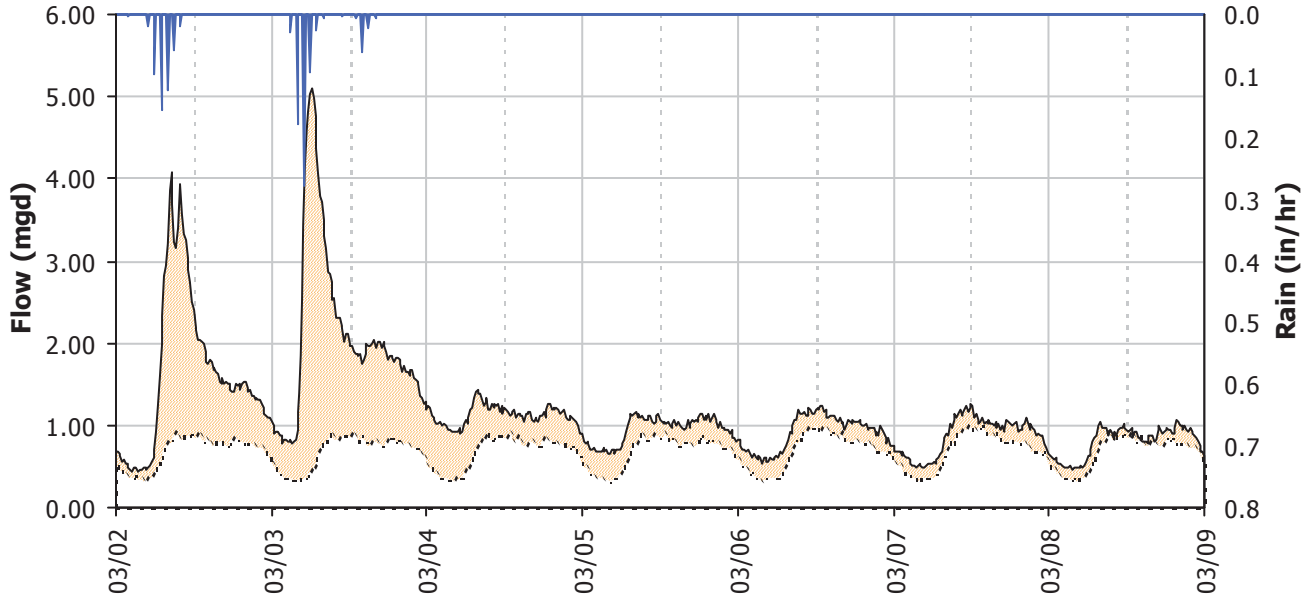
V&A

	I/I Summary Event 3	**Monitoring Site:** Site 7

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #3 I/I Analysis

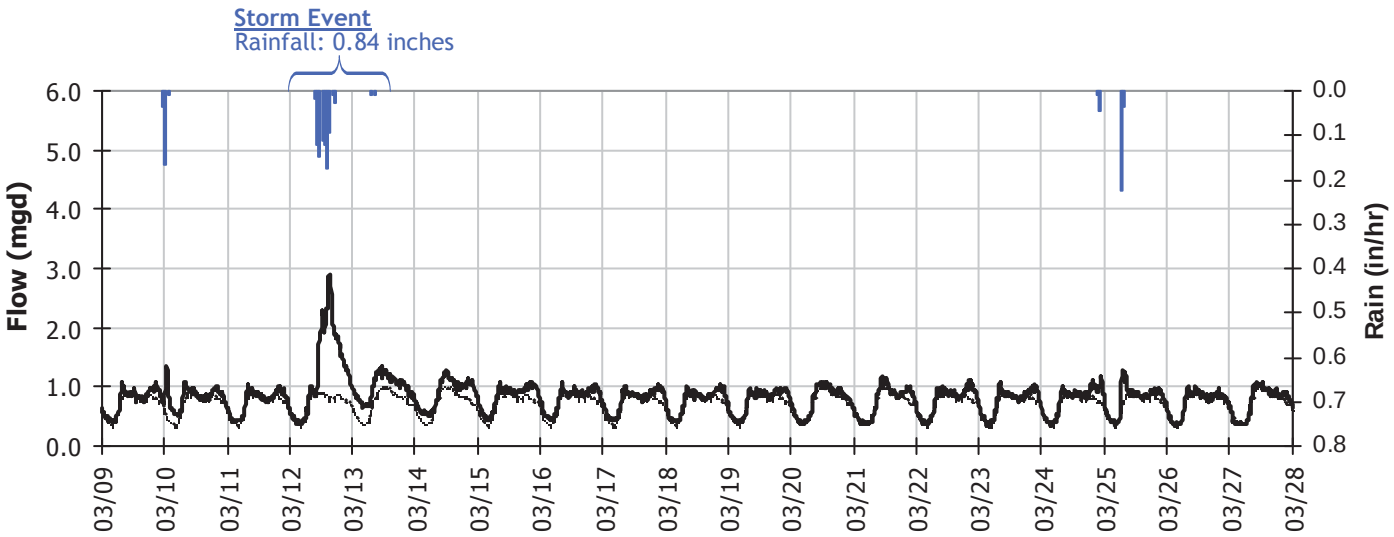
Rainfall:	1.18	*inches*		
Baseline Flow:	0.68	*mgd*		
Peak Flow:	5.10	*mgd*	**PF:**	7.51
Peak I/I Rate:	4.64	*mgd*	**Pk I/I:ADWF:**	6.82
Peak Level:	12.66	*inches*	**d/D Ratio:**	0.60
Total I/I:	3,633,000	*gallons*	**R-Value:**	24.6%
			I/I per ADWF:	4.52 *per in-rain*

Average Infiltration Rate on 3/5 (% of ADWF): 40.7%

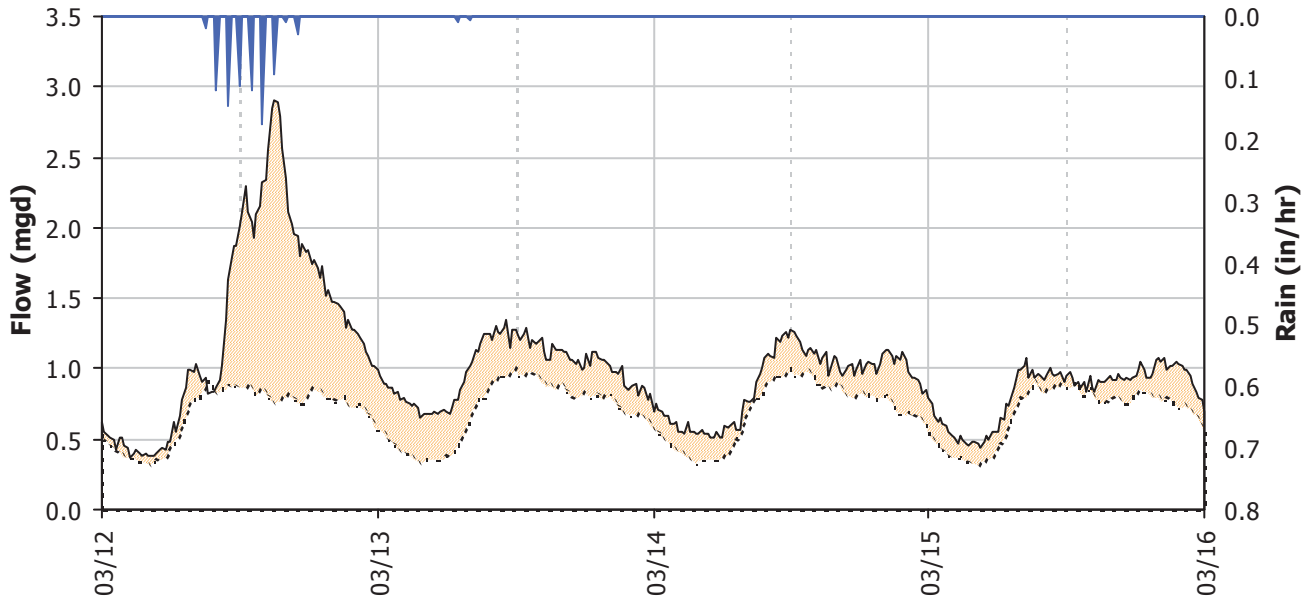
I/I Summary
Event 4

Monitoring Site:
Site 7

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

Rainfall:	0.84 *inches*			
Baseline Flow:	0.68 *mgd*			
Peak Flow:	2.90 *mgd*	**PF:**	4.27	
Peak I/I Rate:	2.15 *mgd*	**Pk I/I:ADWF:**	3.17	
Peak Level:	9.80 *inches*	**d/D Ratio:**	0.47	
Total I/I:	1,267,000 *gallons*	**R-Value:**	12.1%	
		I/I per ADWF:	2.22 *per in-rain*	

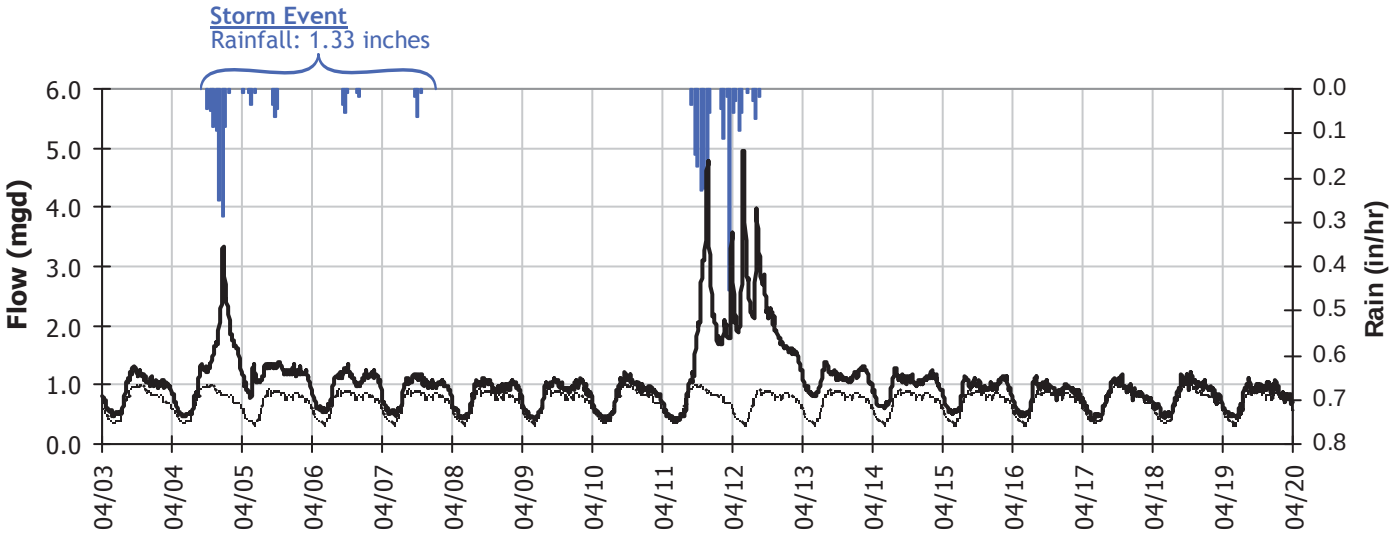
Average Infiltration Rate on 3/14 (% of ADWF): 29.8%

V&A

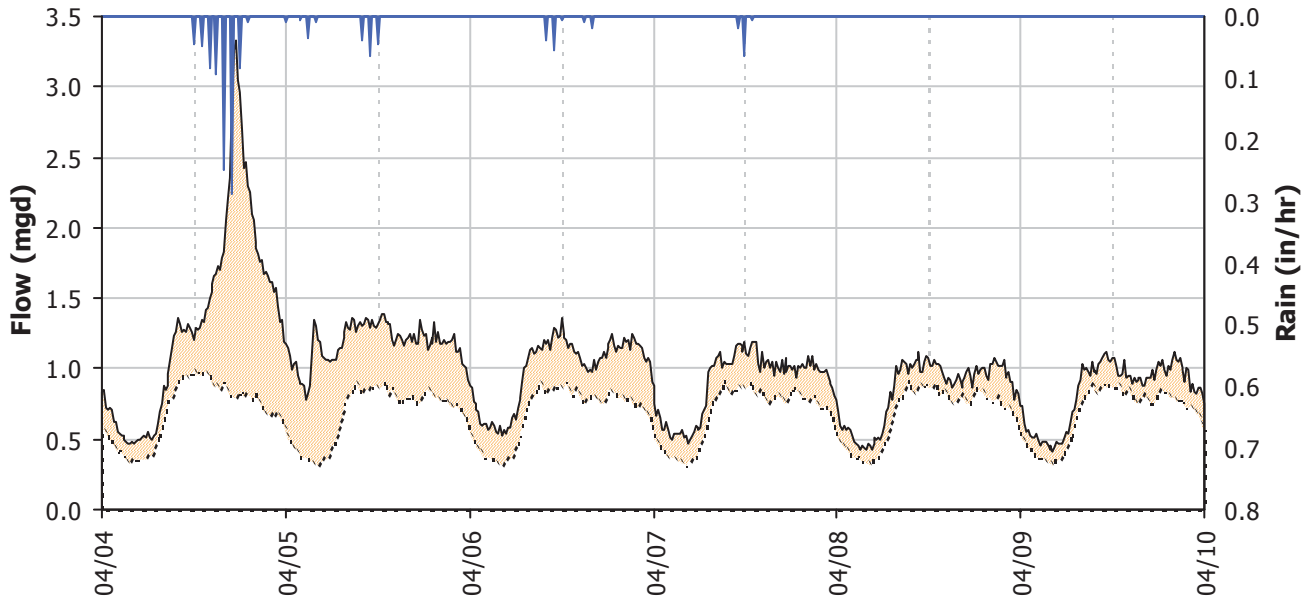
I/I Summary
Event 5

Monitoring Site:
Site 7

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #5 I/I Analysis

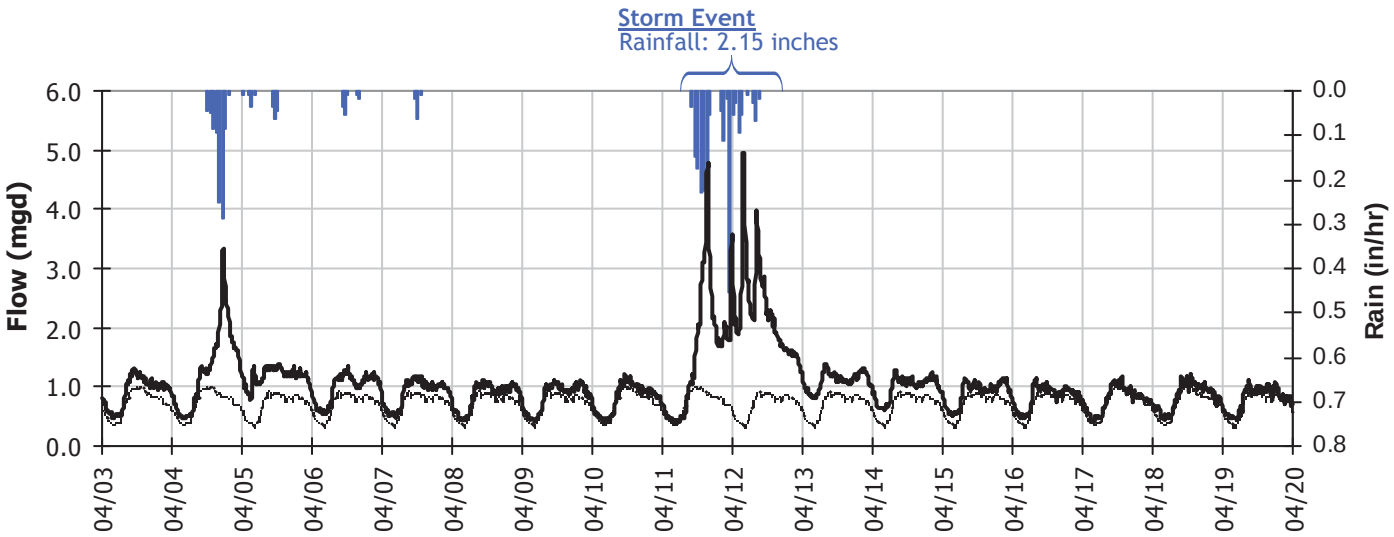
Rainfall:	1.33	*inches*		
Baseline Flow:	0.68	*mgd*		
Peak Flow:	3.33	*mgd*	**PF:**	4.90
Peak I/I Rate:	2.53	*mgd*	**Pk I/I:ADWF:**	3.73
Peak Level:	10.61	*inches*	**d/D Ratio:**	0.51
Total I/I:	2,014,000	*gallons*	**R-Value:**	12.1%
			I/I per ADWF:	2.22 *per in-rain*

Average Infiltration Rate on 4/8 (% of ADWF): 25.3%

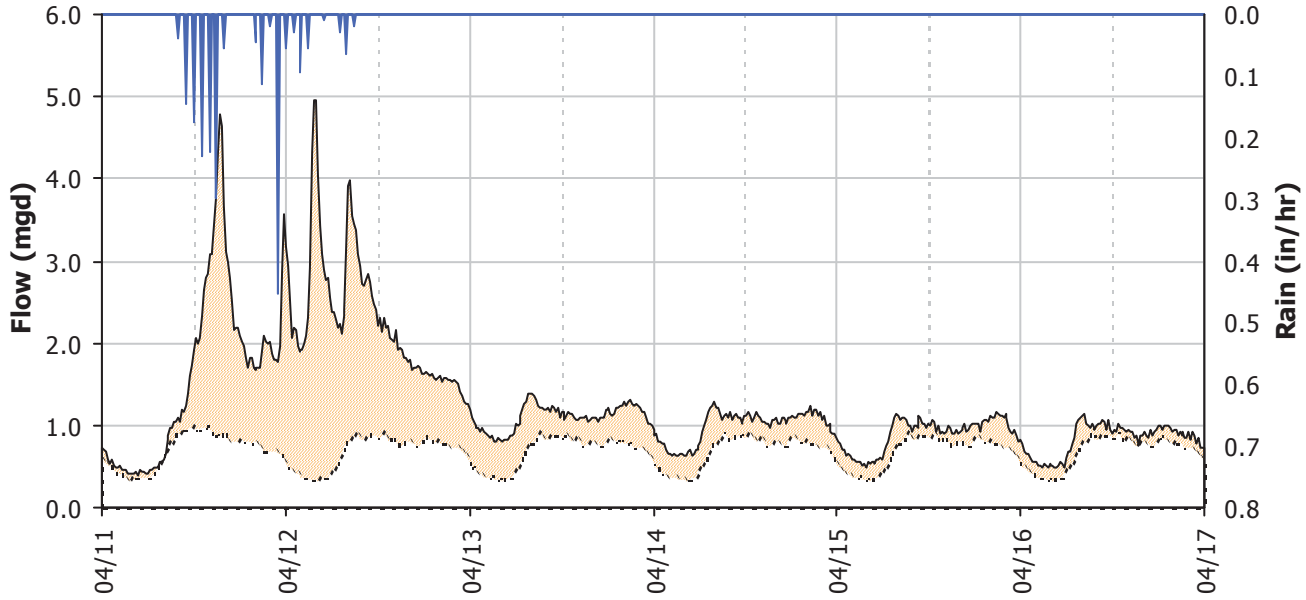
I/I Summary
Event 6

Monitoring Site:
Site 7

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



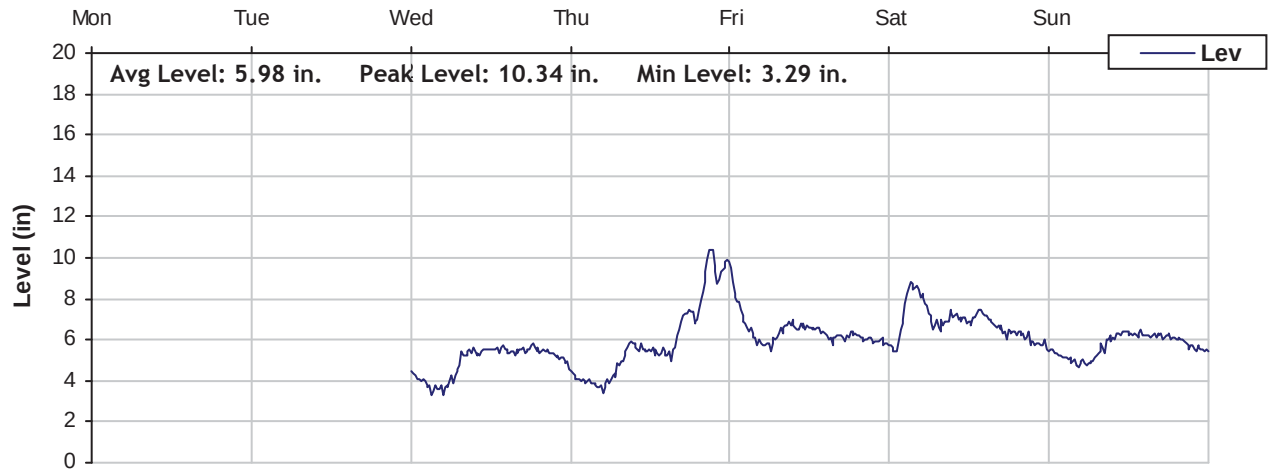
Storm Event #6 I/I Analysis

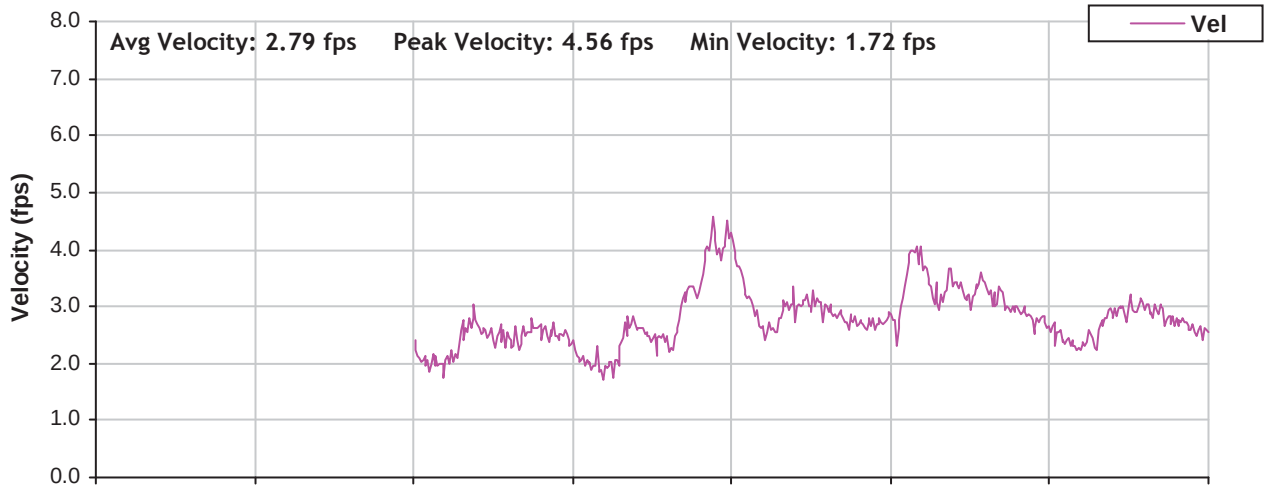
Rainfall:	2.15 *inches*			
Baseline Flow:	0.68 *mgd*			
Peak Flow:	4.96 *mgd*	**PF:**	7.30	
Peak I/I Rate:	4.63 *mgd*	**Pk I/I:ADWF:**	6.81	
Peak Level:	12.64 *inches*	**d/D Ratio:**	0.60	
Total I/I:	3,605,000 *gallons*	**R-Value:**	13.4%	
		I/I per ADWF:	2.47 *per in-rain*	

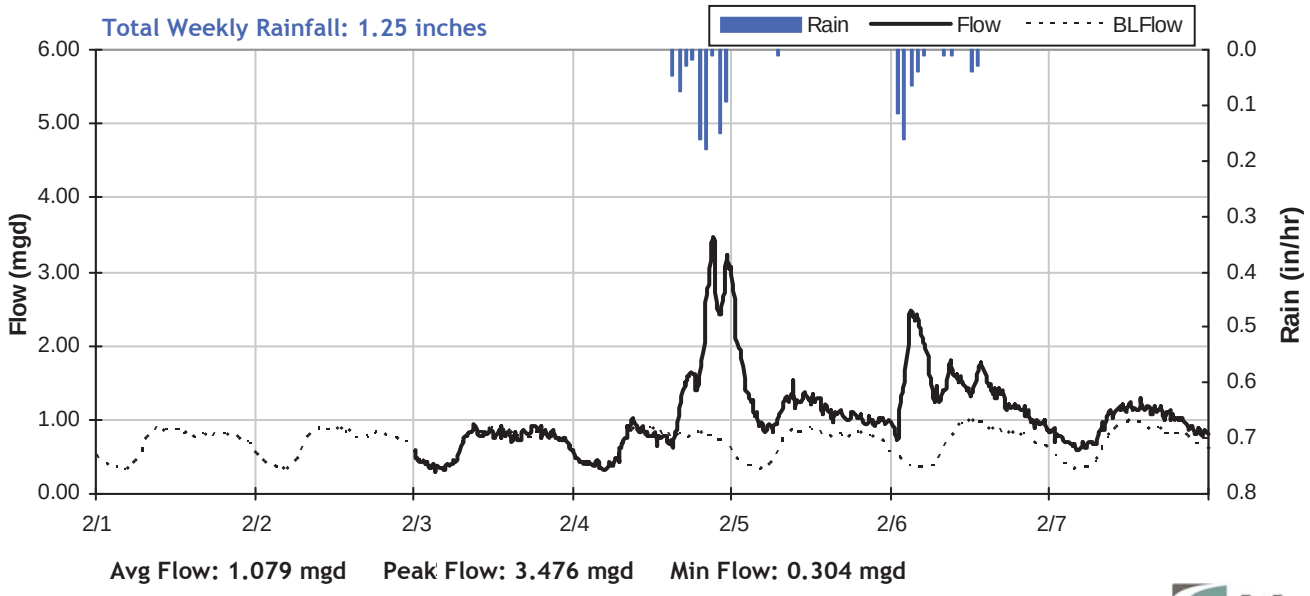
Average Infiltration Rate on 4/14 (% of ADWF): 46.9%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 7



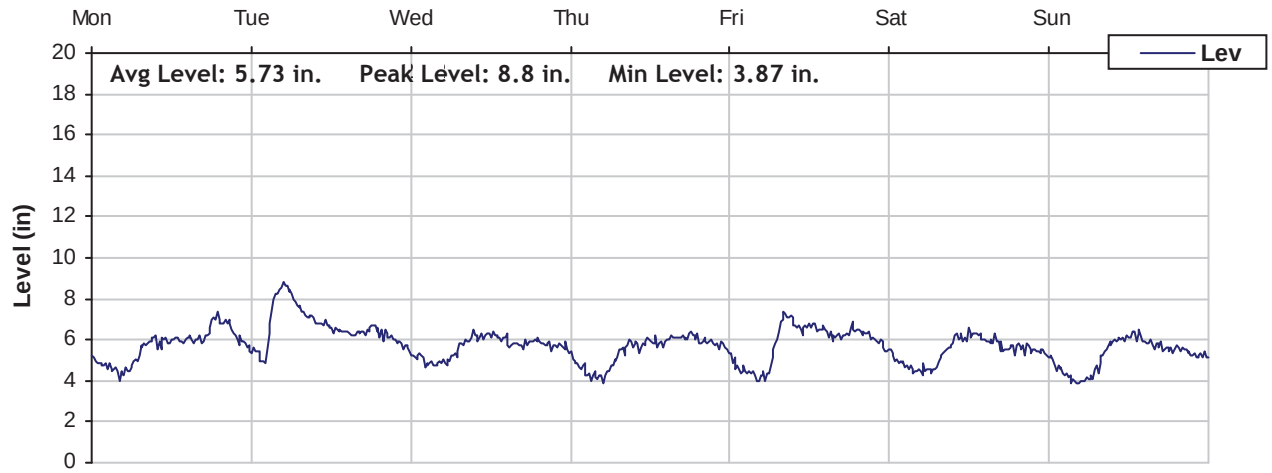


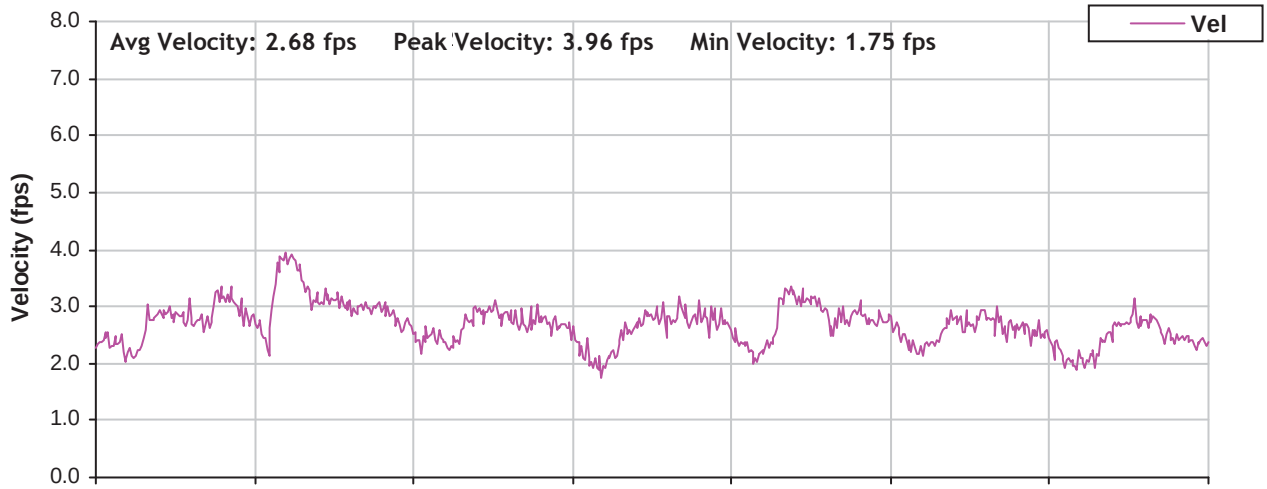


Avg Flow: 1.079 mgd Peak Flow: 3.476 mgd Min Flow: 0.304 mgd

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 7

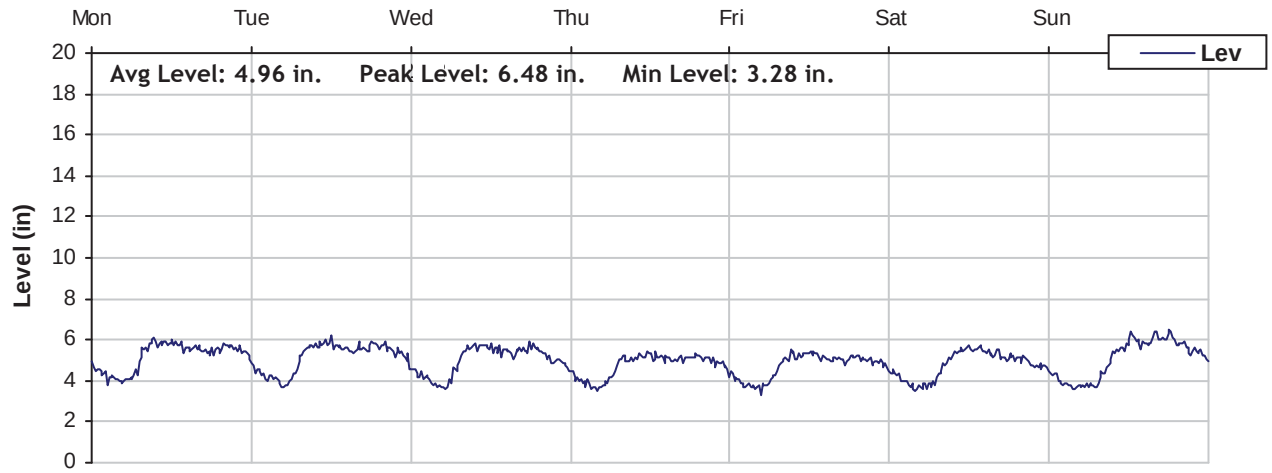


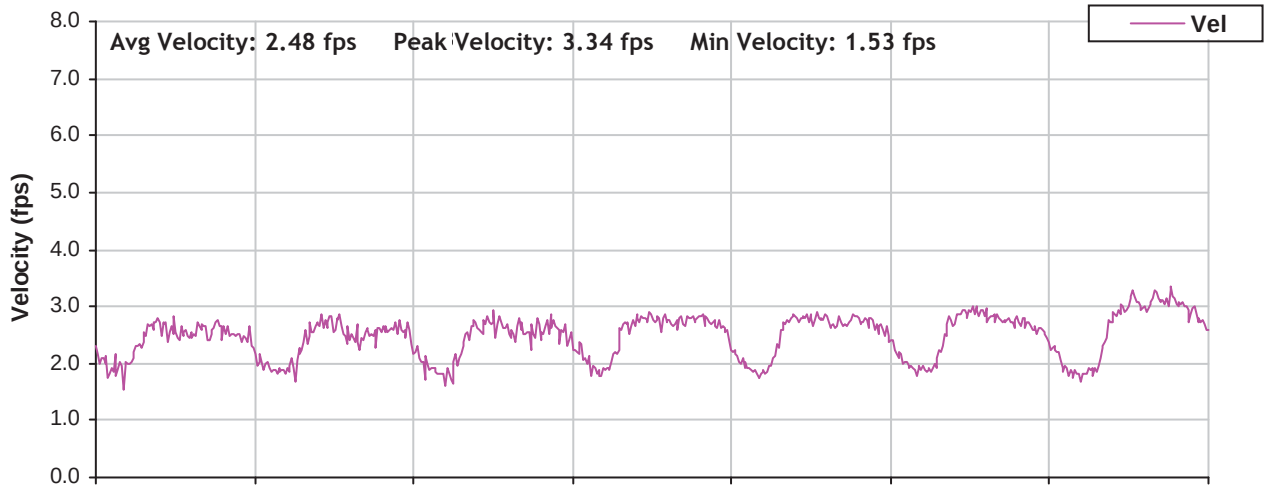


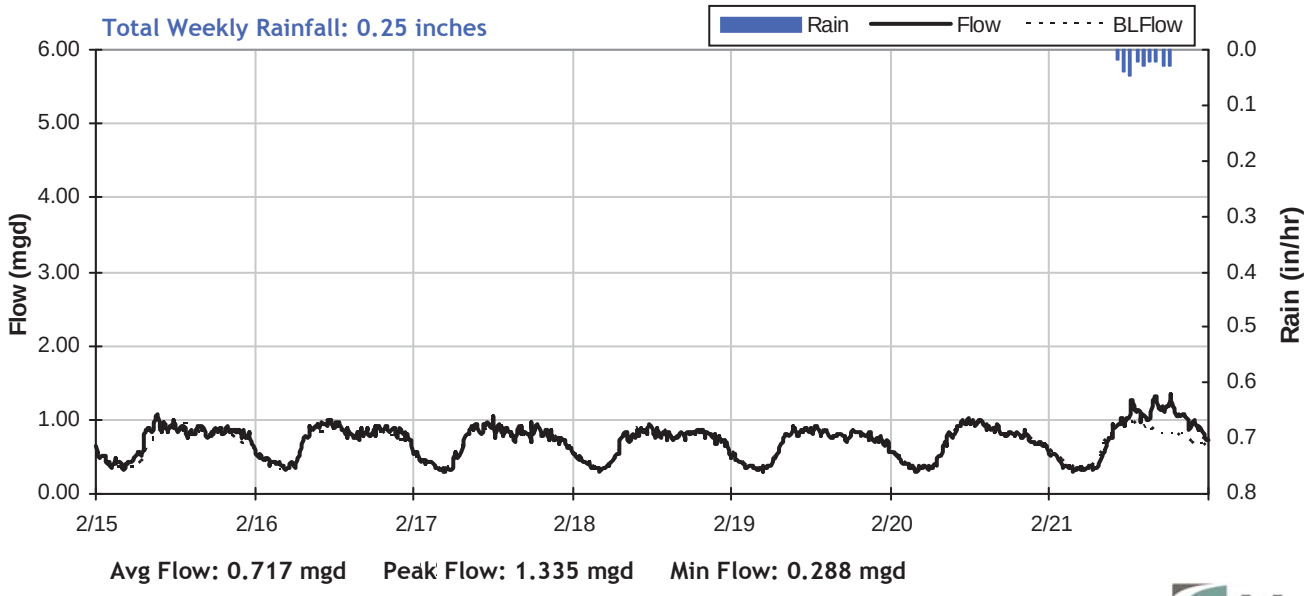
Avg Flow: 0.95 mgd Peak Flow: 2.351 mgd Min Flow: 0.37 mgd

Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 7



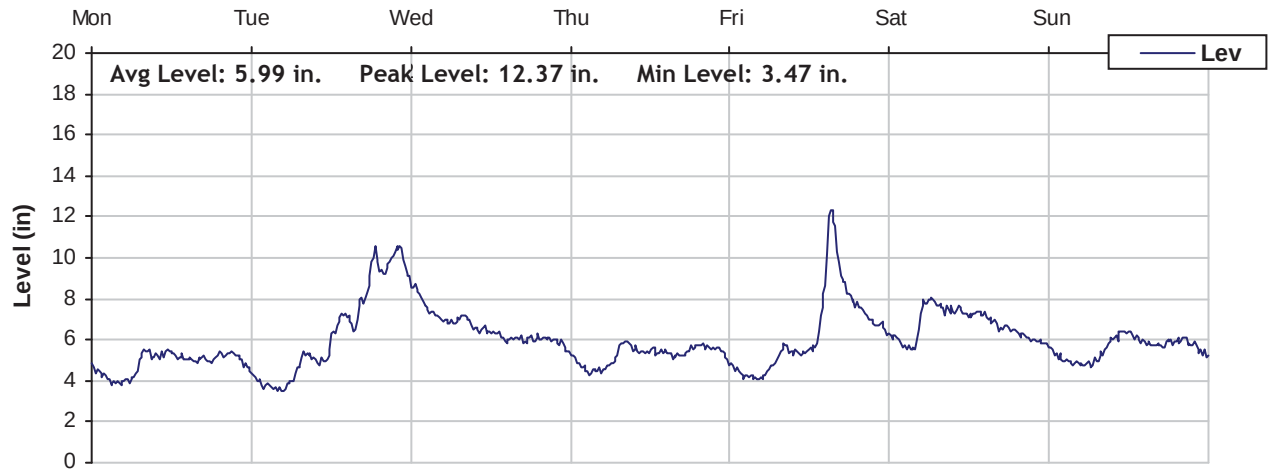


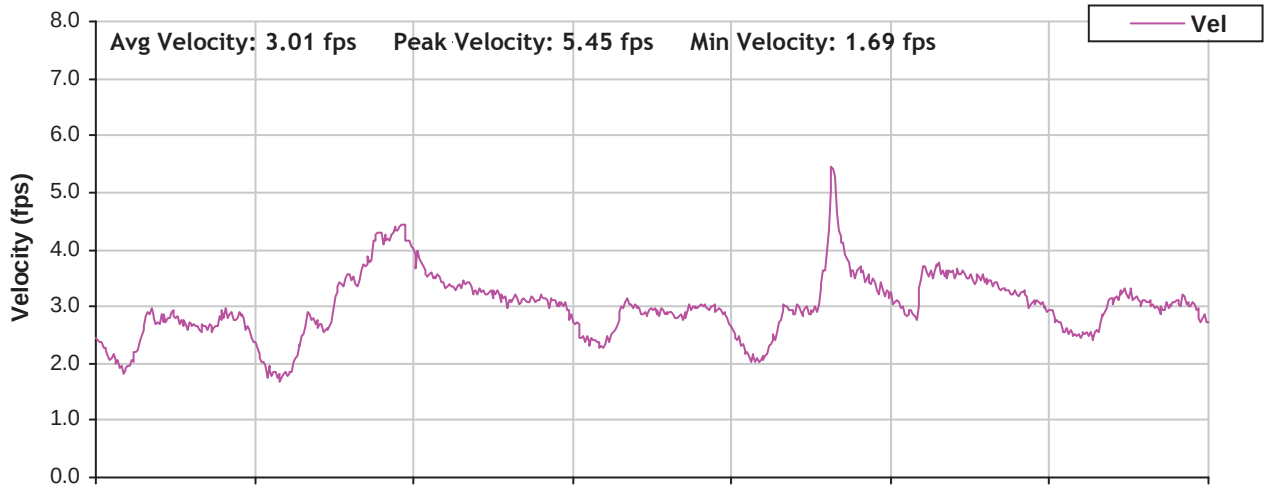


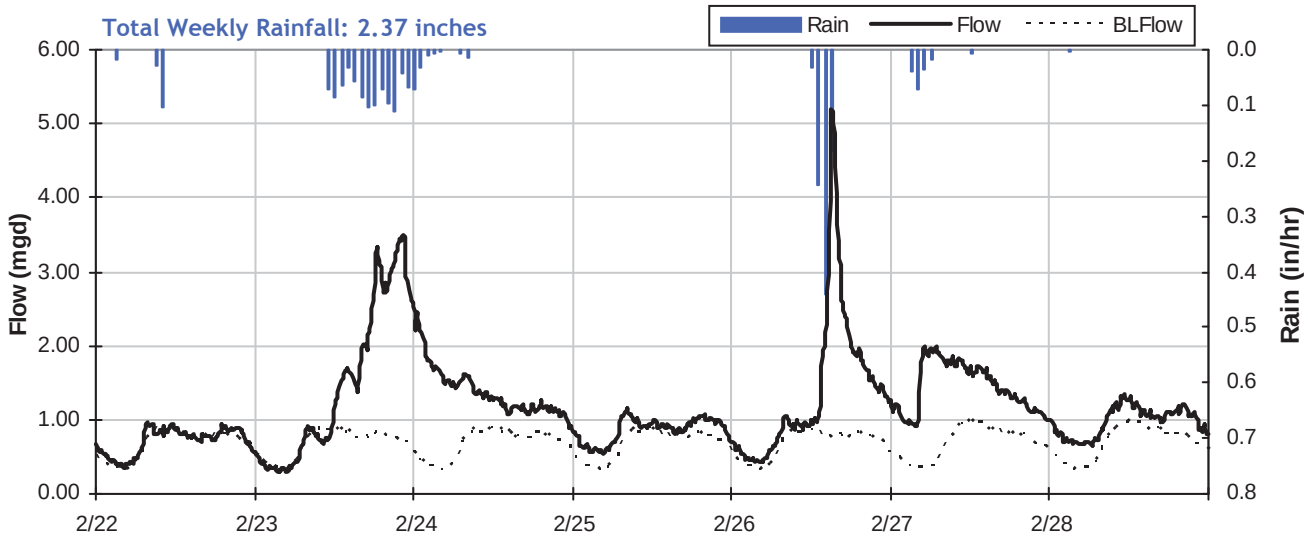
Avg Flow: 0.717 mgd Peak Flow: 1.335 mgd Min Flow: 0.288 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 7



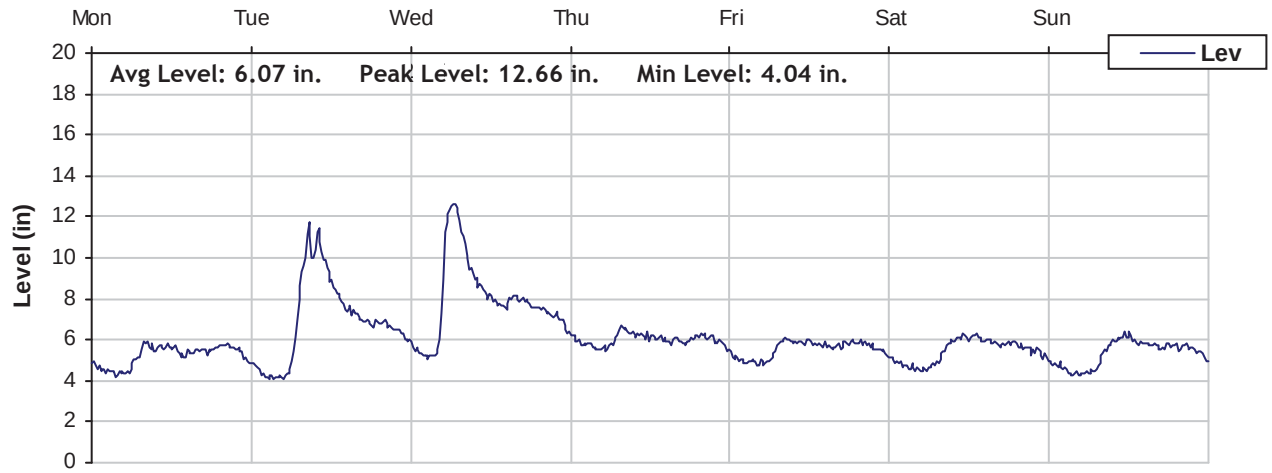


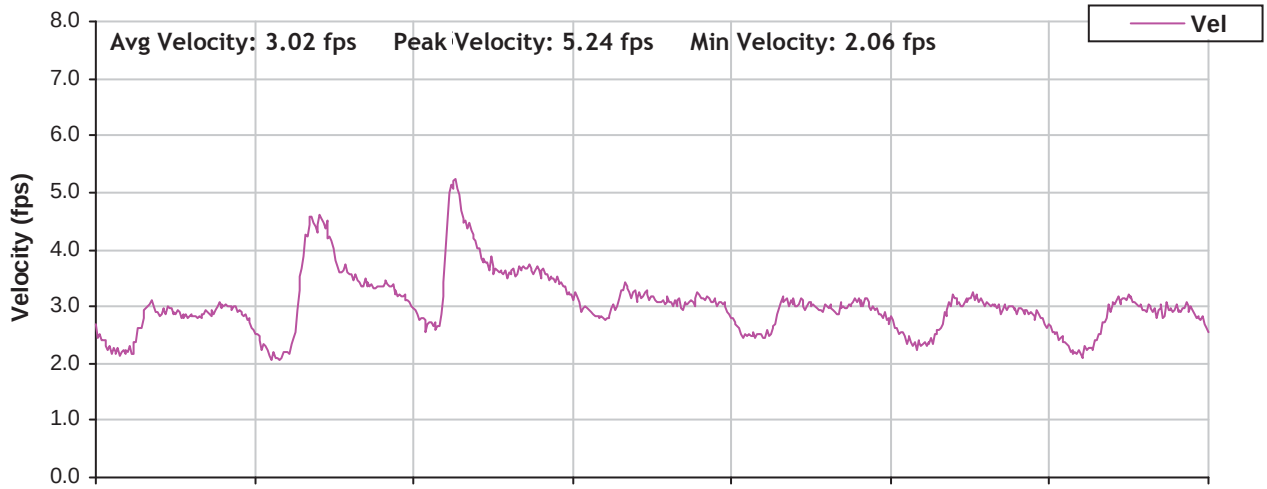


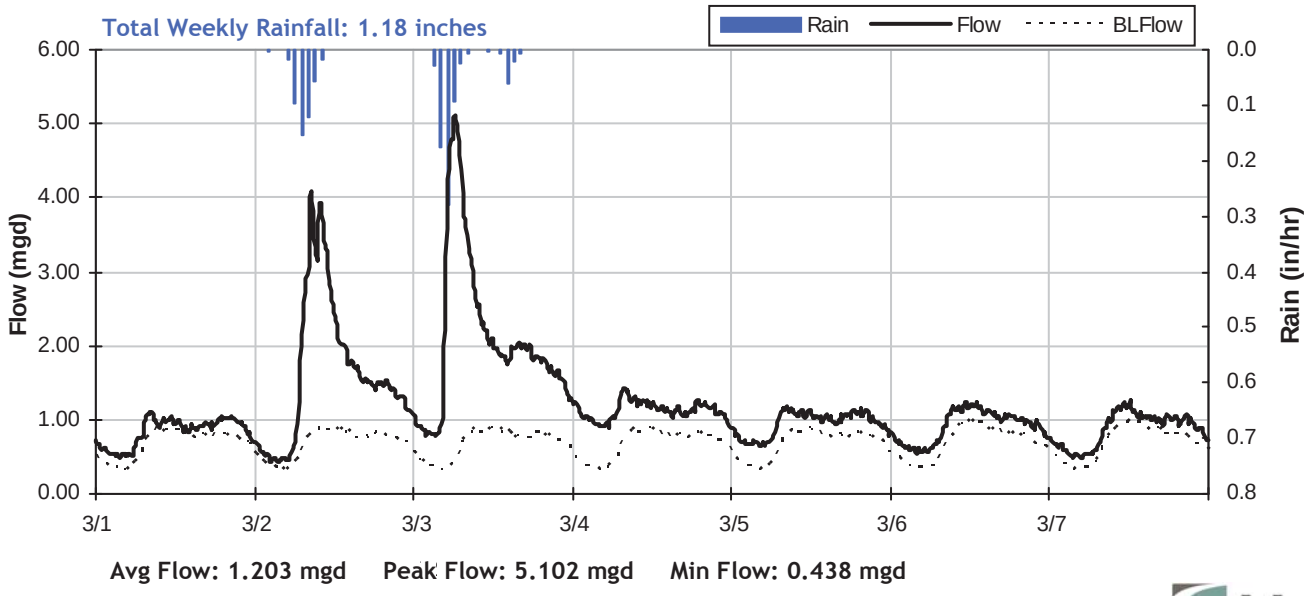
Avg Flow: 1.178 mgd Peak Flow: 5.19 mgd Min Flow: 0.288 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 7



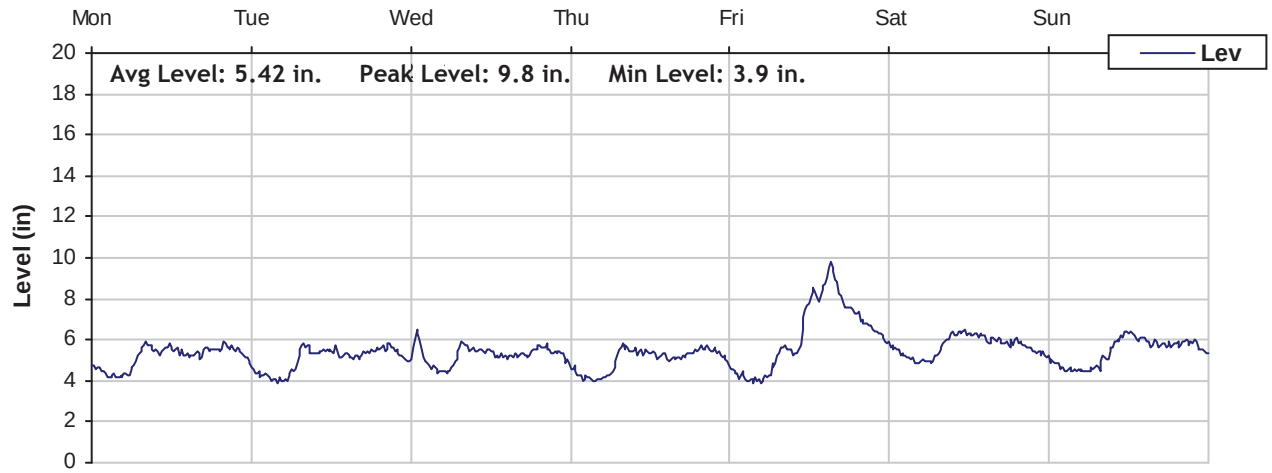


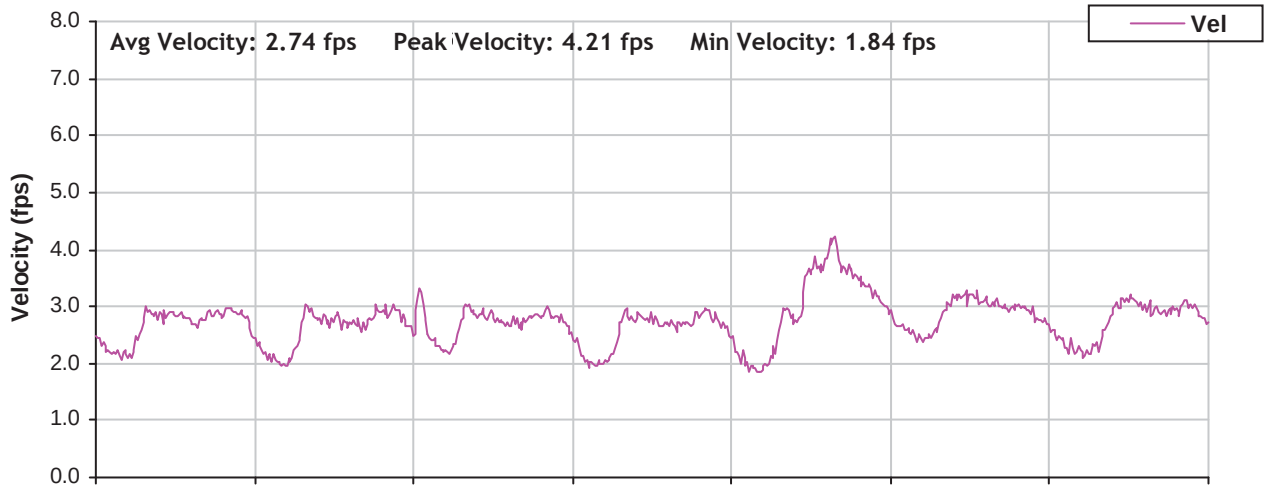


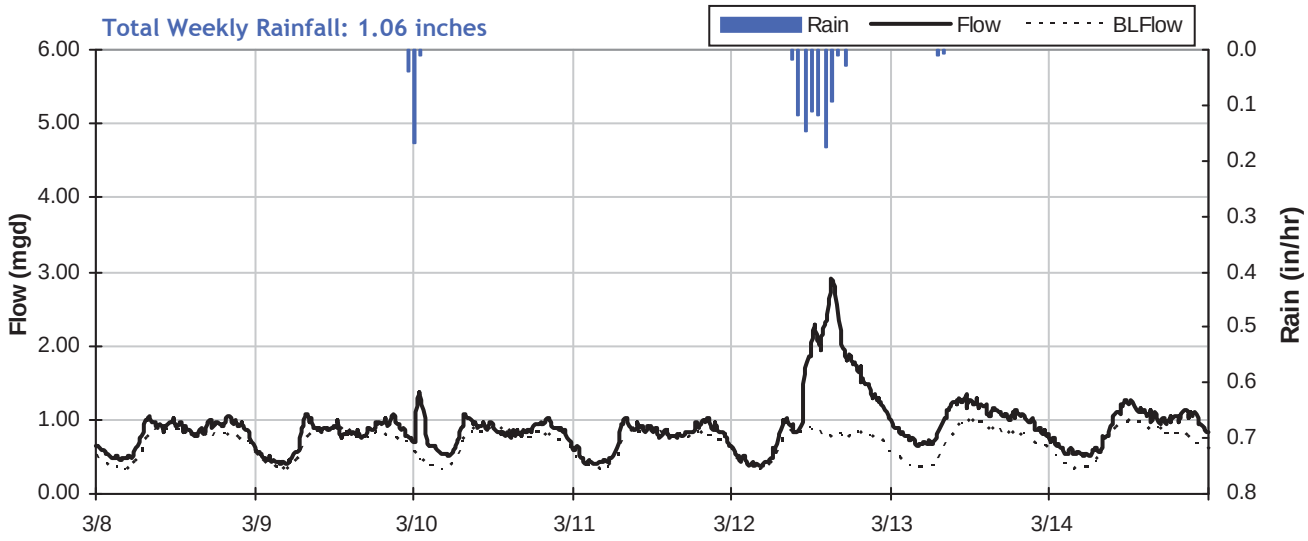
Avg Flow: 1.203 mgd Peak Flow: 5.102 mgd Min Flow: 0.438 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 7



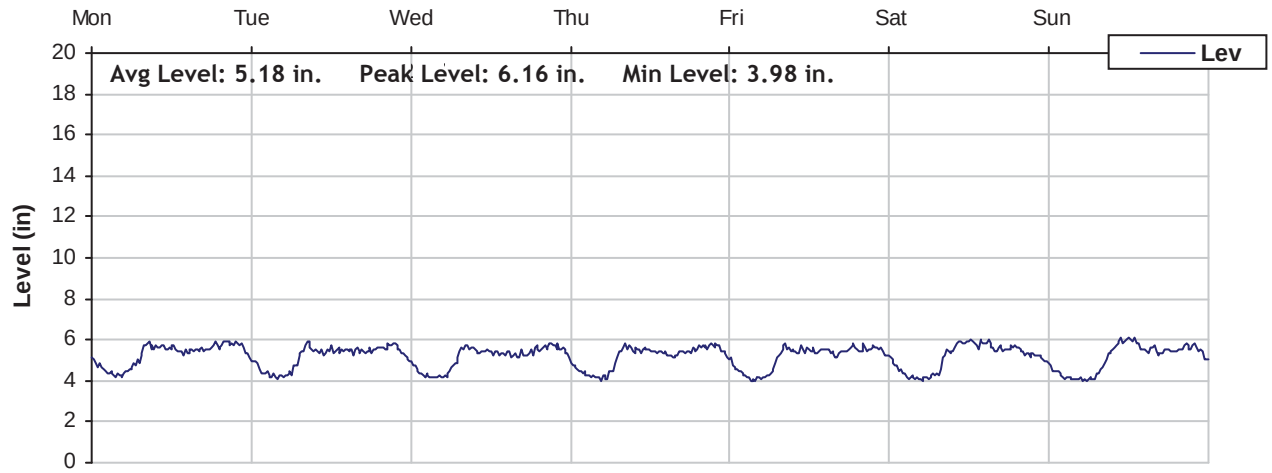


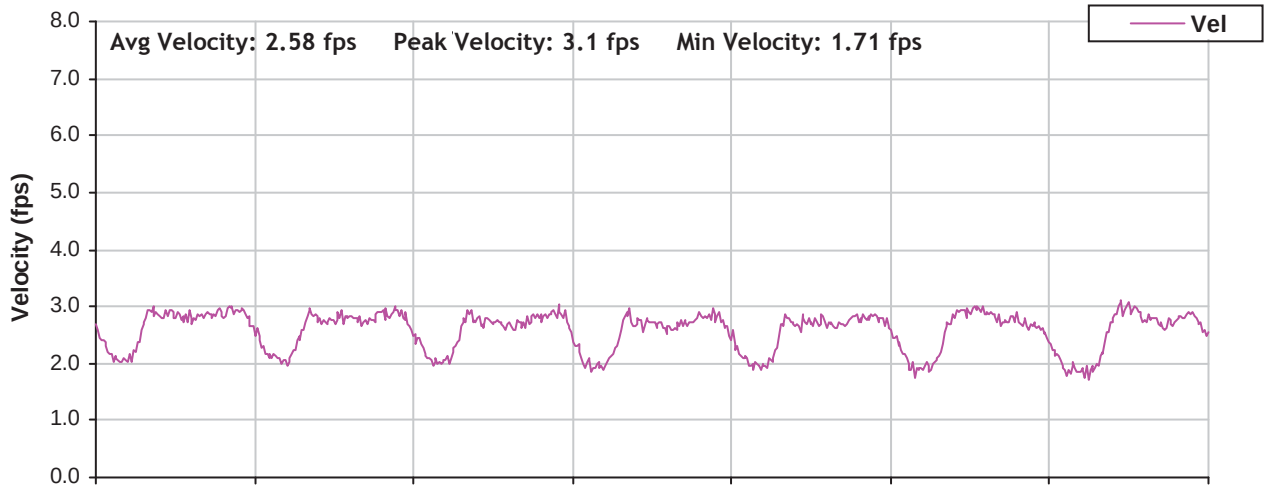


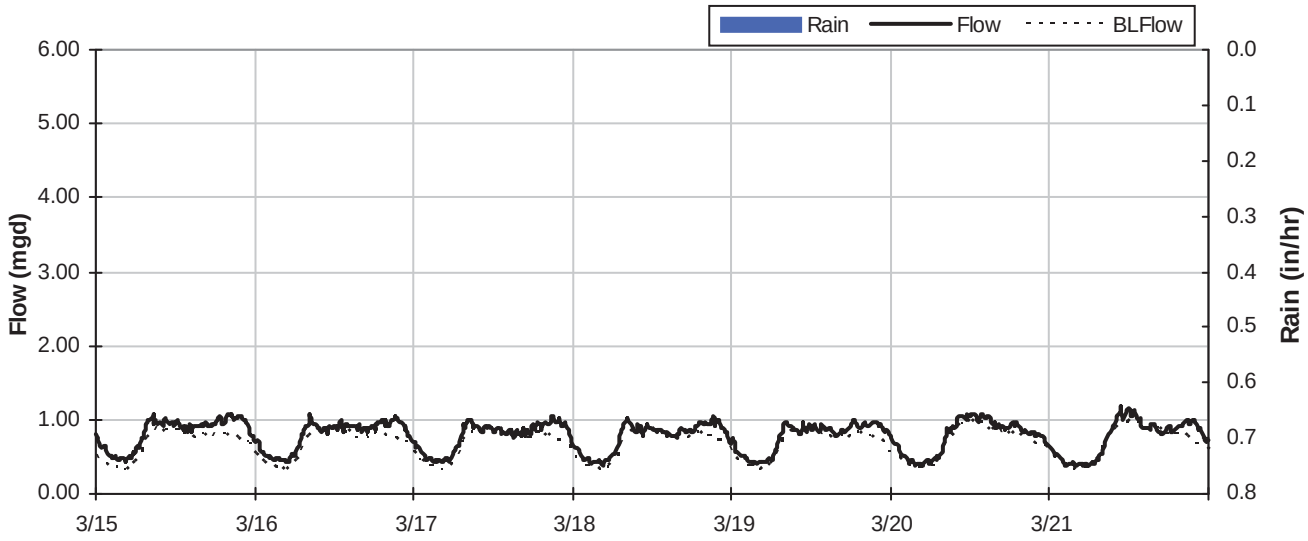
Avg Flow: 0.905 mgd Peak Flow: 2.904 mgd Min Flow: 0.375 mgd

Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

Monitoring Site:
Site 7



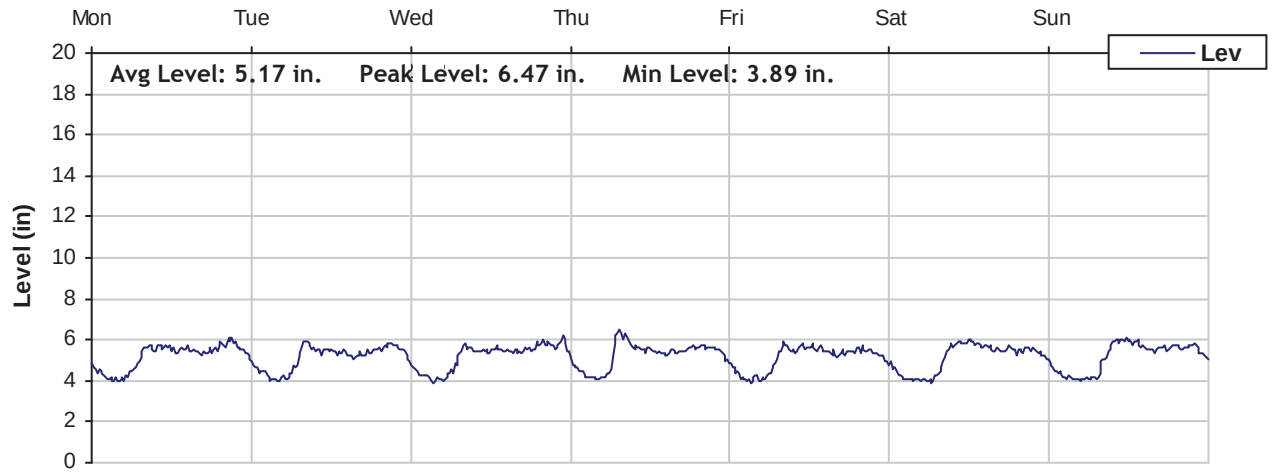


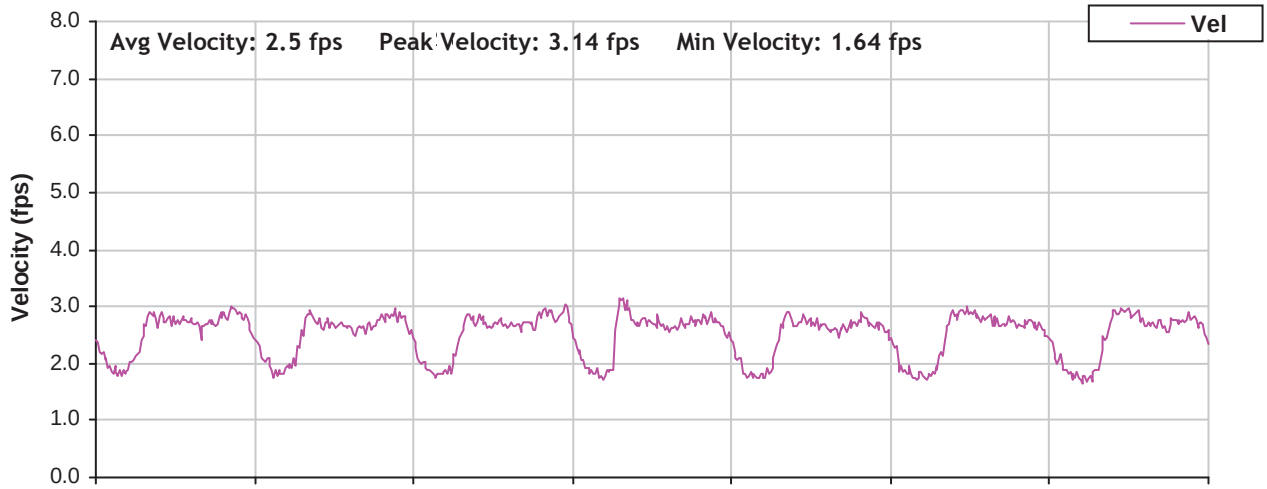


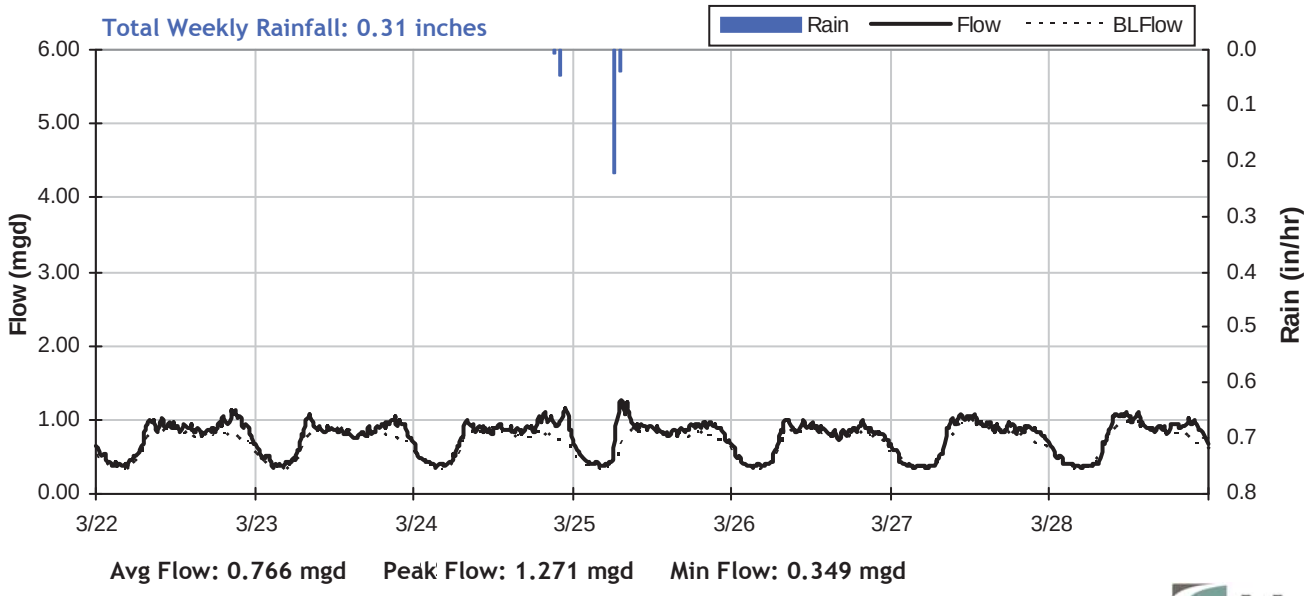
Avg Flow: 0.784 mgd Peak Flow: 1.177 mgd Min Flow: 0.367 mgd

Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 7



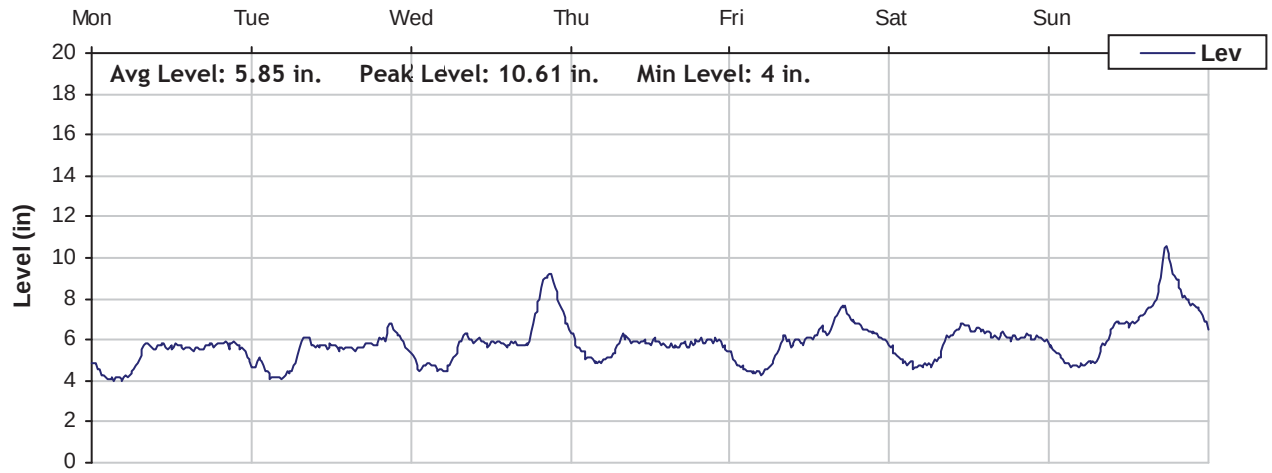


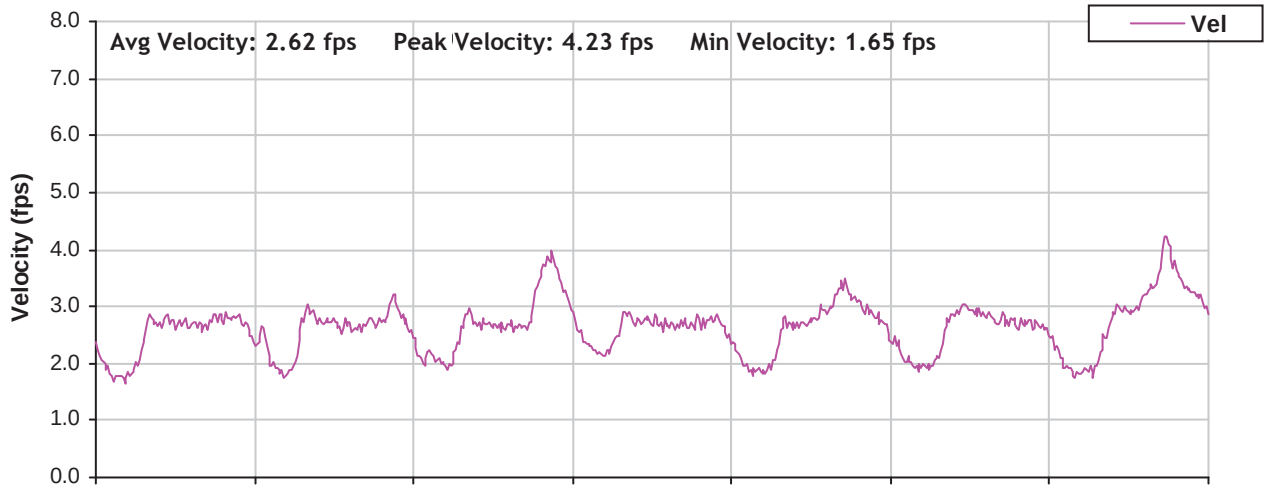


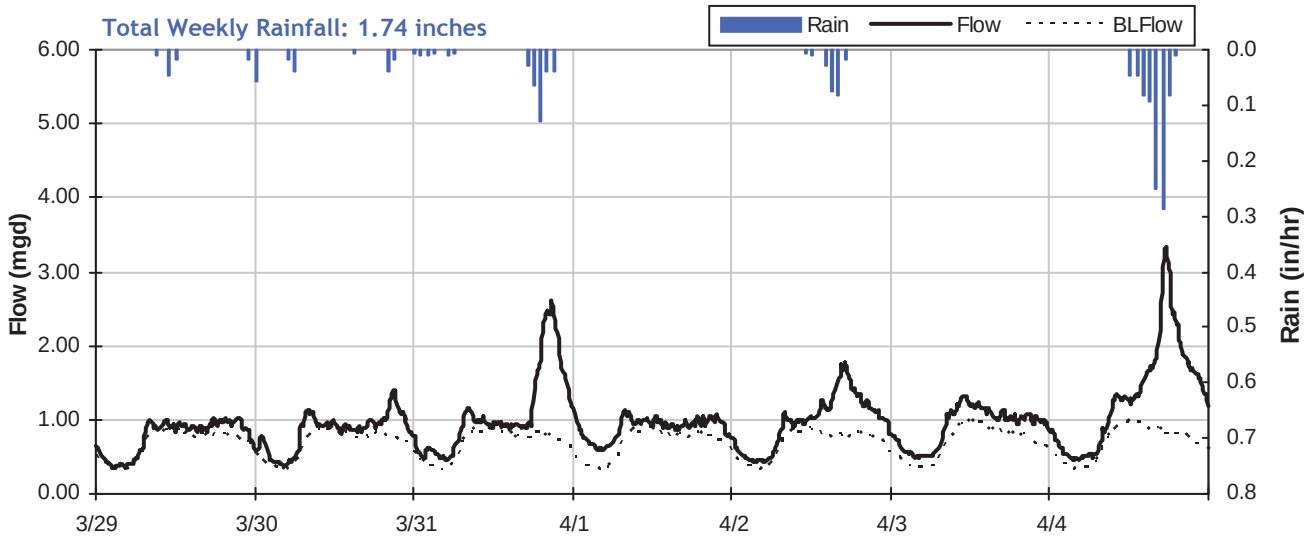
Avg Flow: 0.766 mgd Peak Flow: 1.271 mgd Min Flow: 0.349 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 7



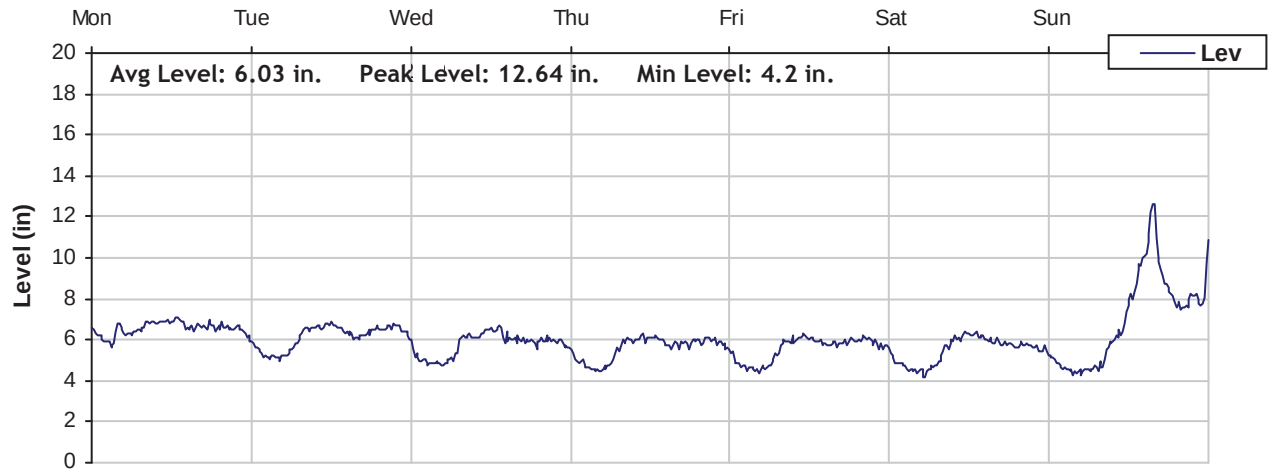


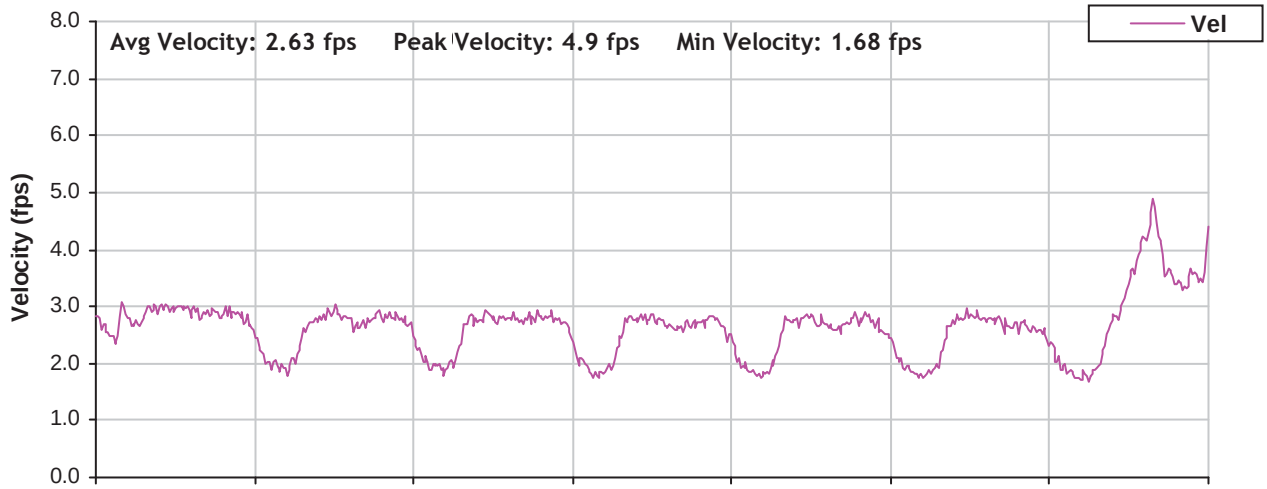


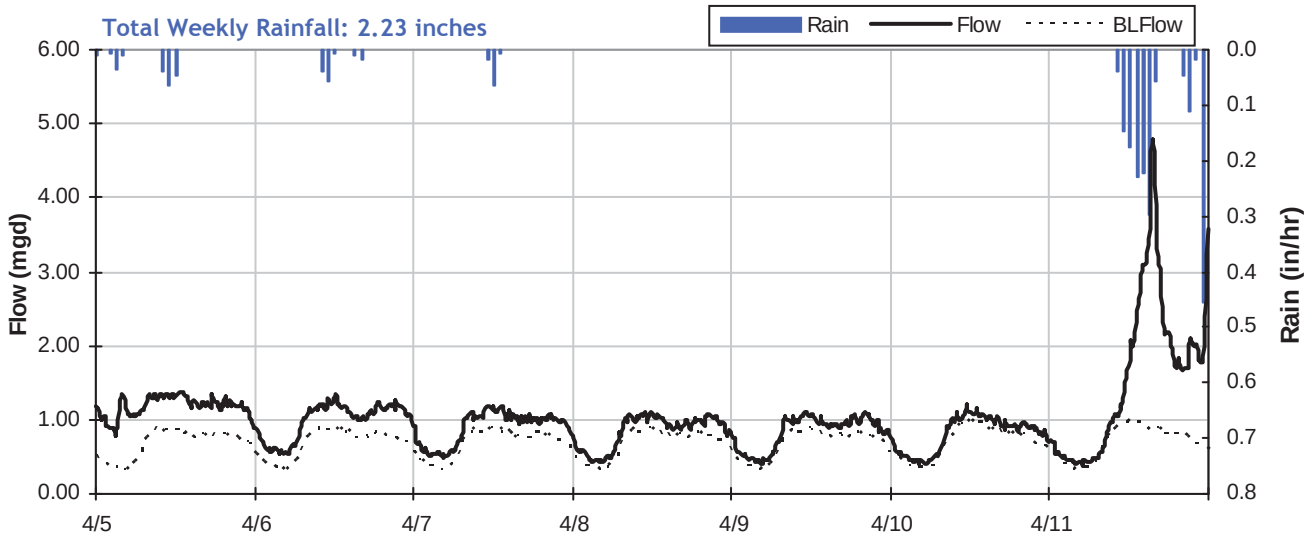
Avg Flow: 0.973 mgd Peak Flow: 3.328 mgd Min Flow: 0.348 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 7



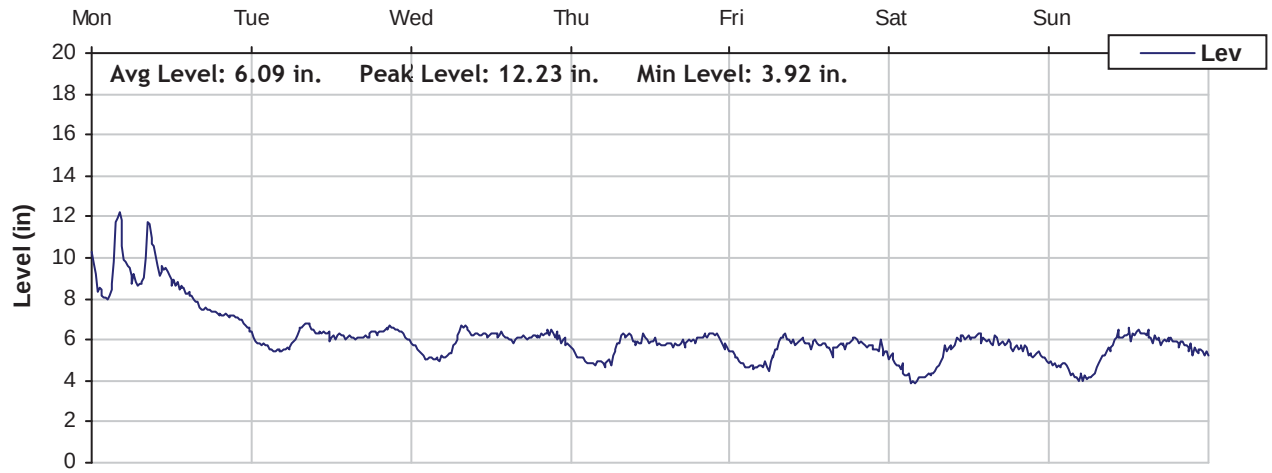


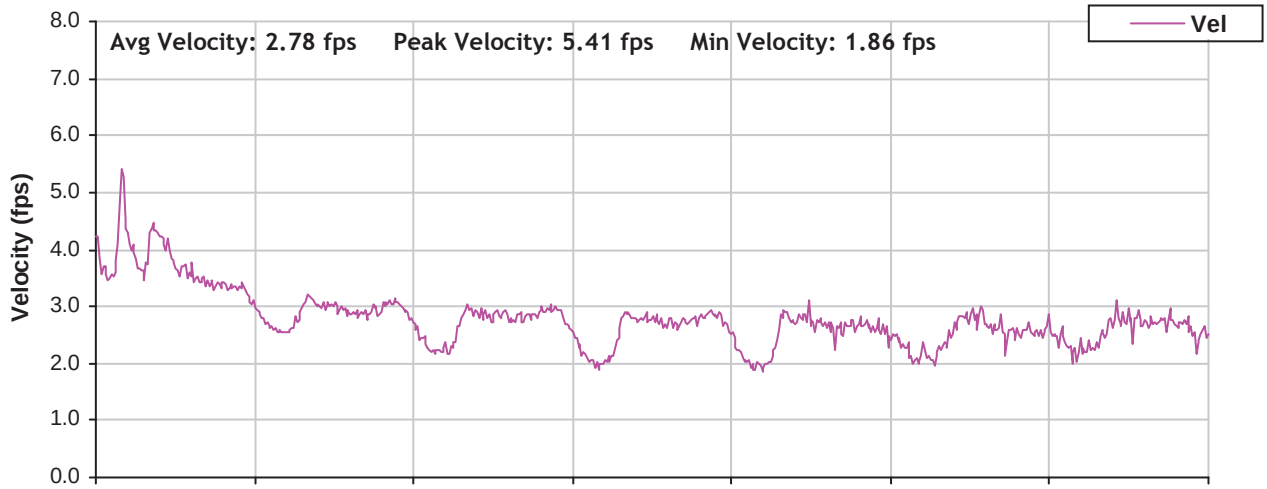


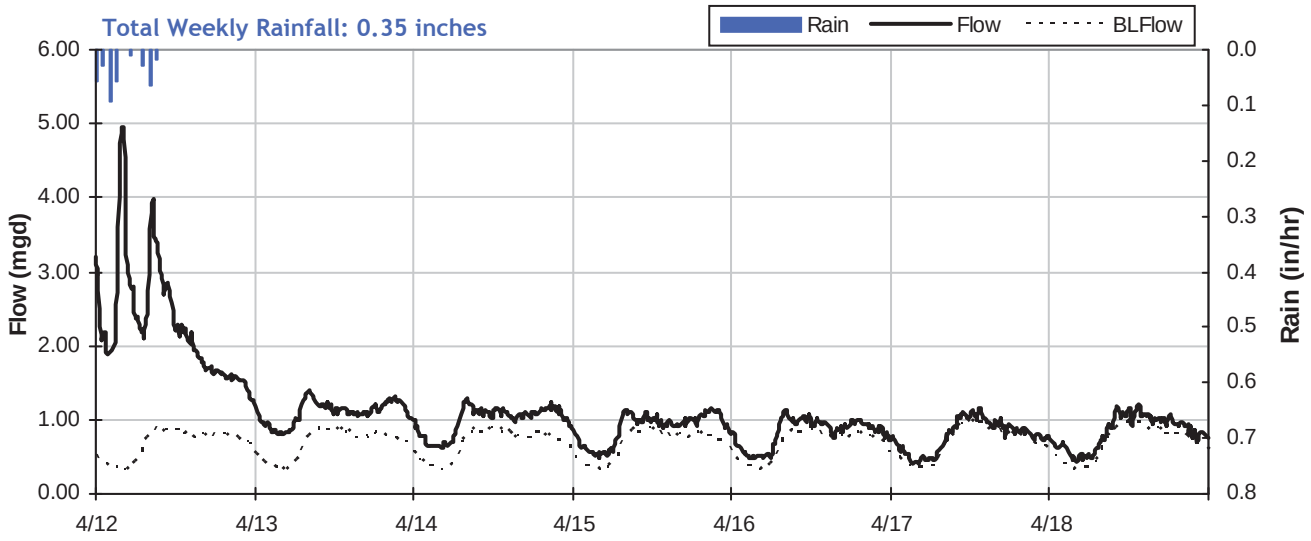
Avg Flow: 1.021 mgd Peak Flow: 4.787 mgd Min Flow: 0.383 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 7



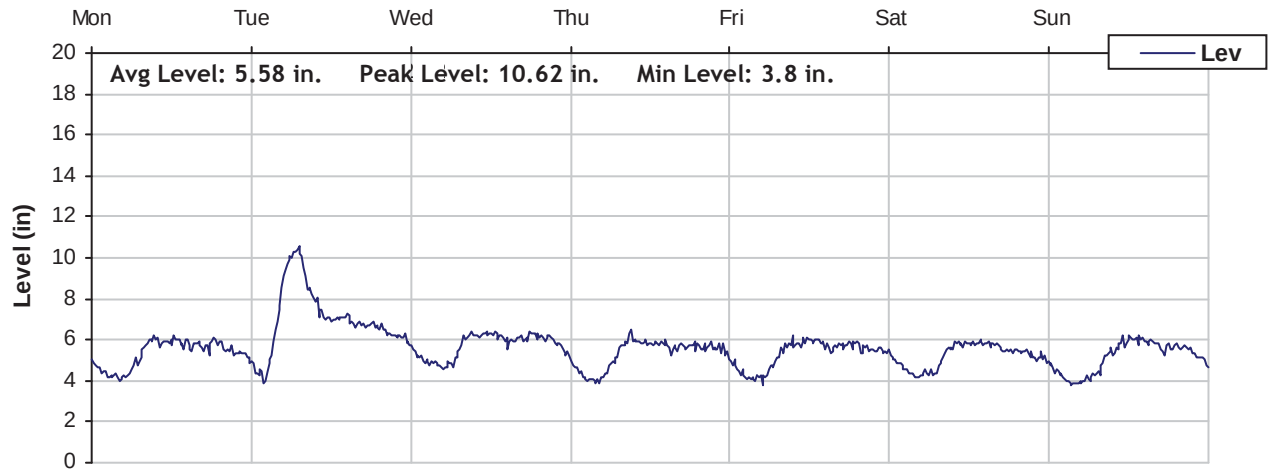


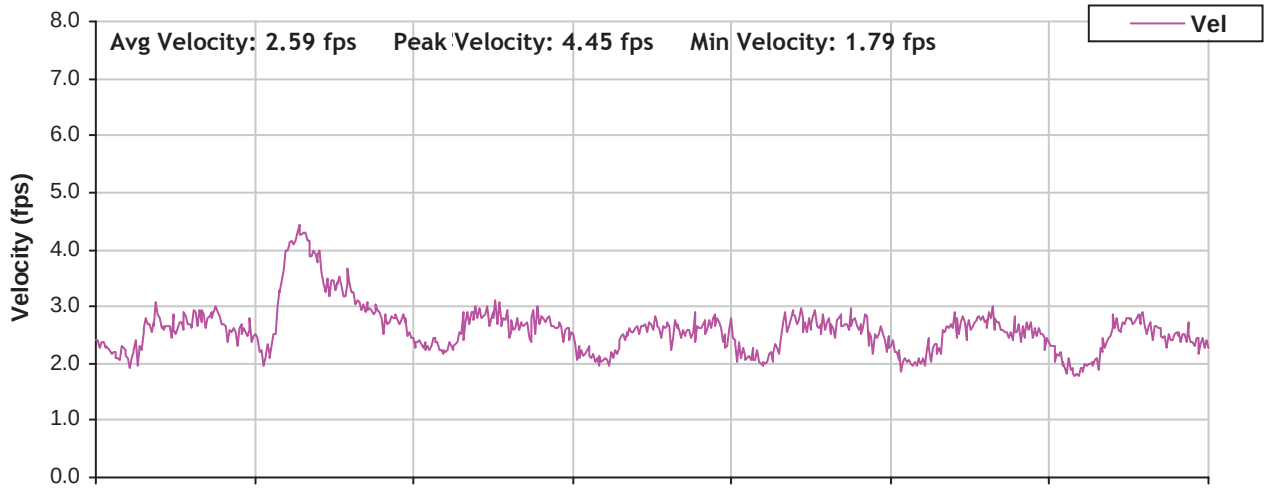


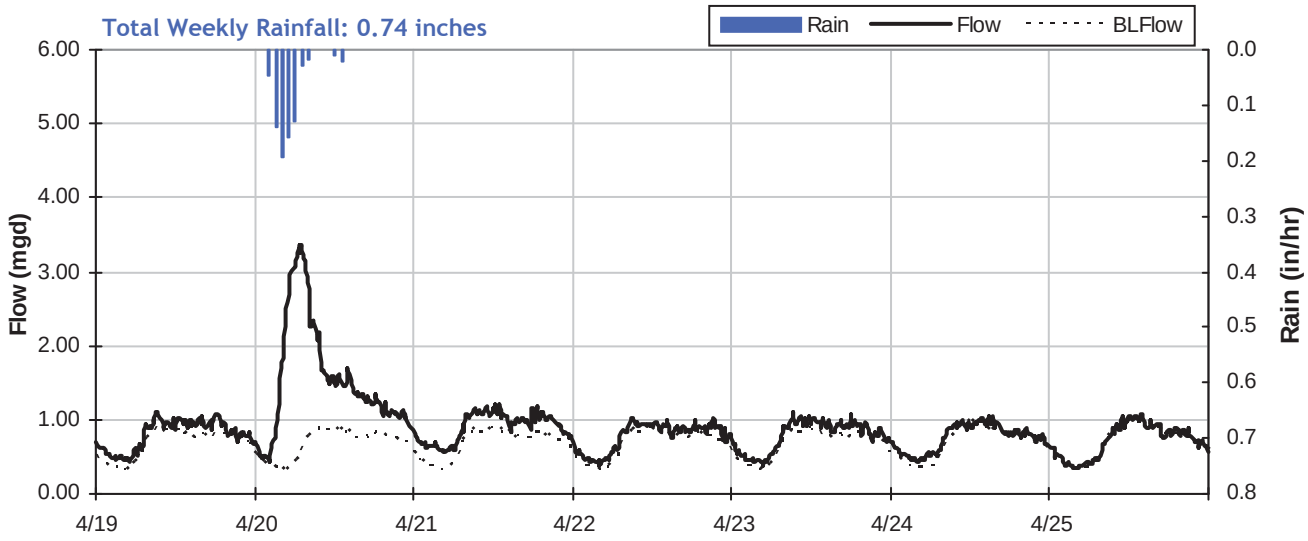
Avg Flow: 1.103 mgd Peak Flow: 4.959 mgd Min Flow: 0.401 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 7



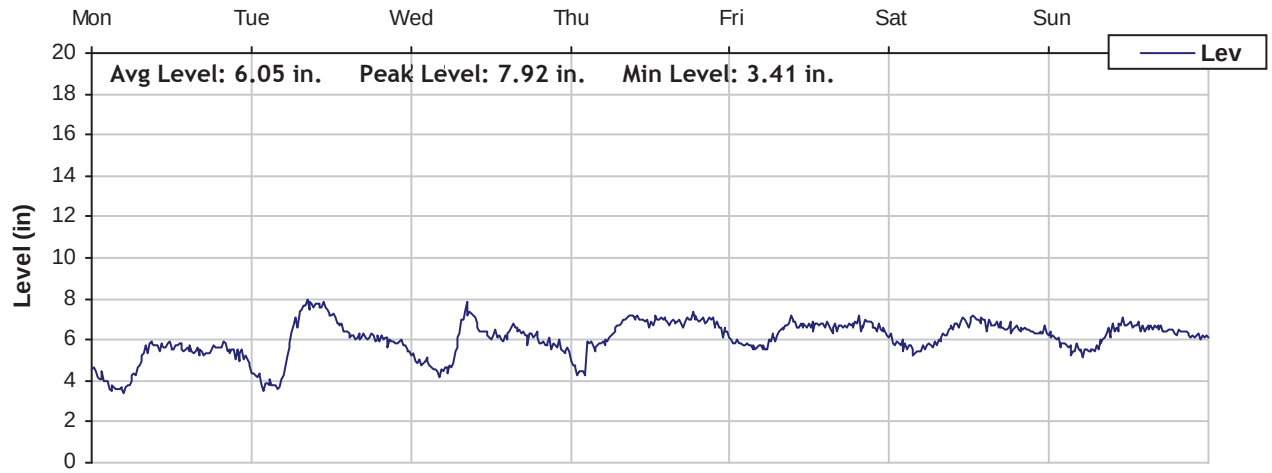


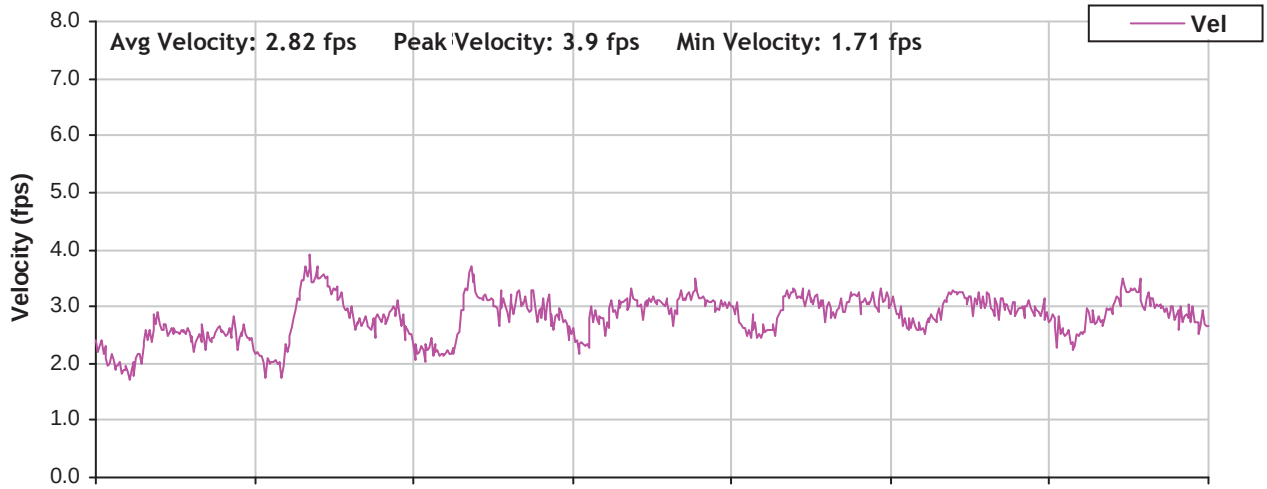


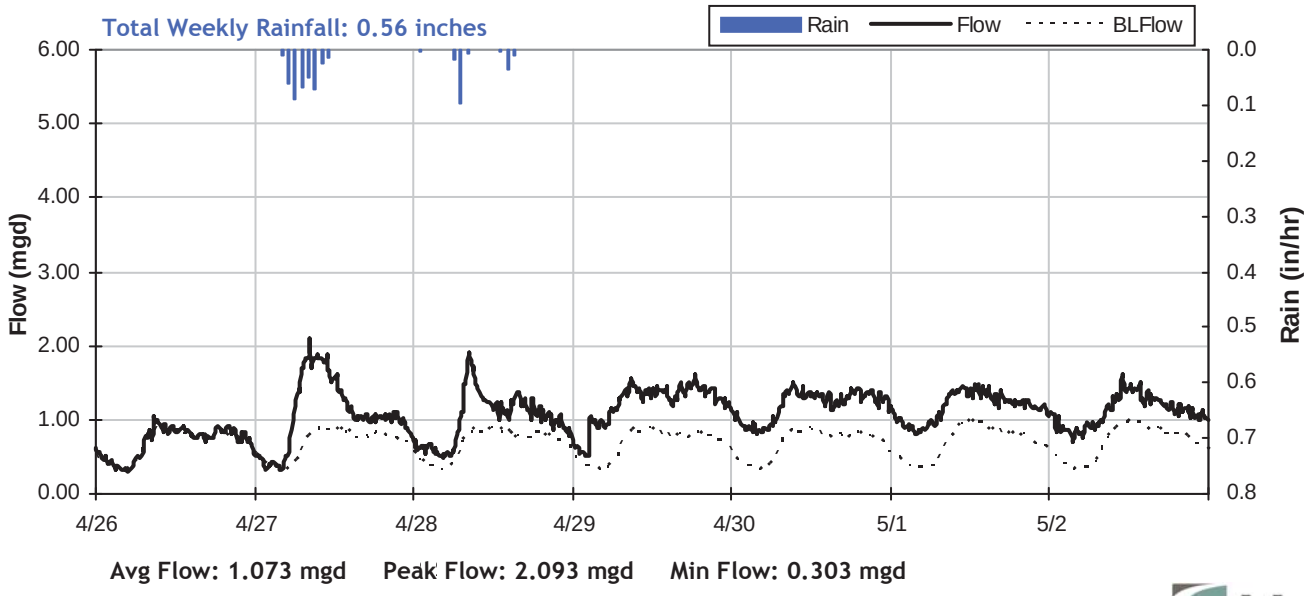
Avg Flow: 0.9 mgd Peak Flow: 3.367 mgd Min Flow: 0.354 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 7



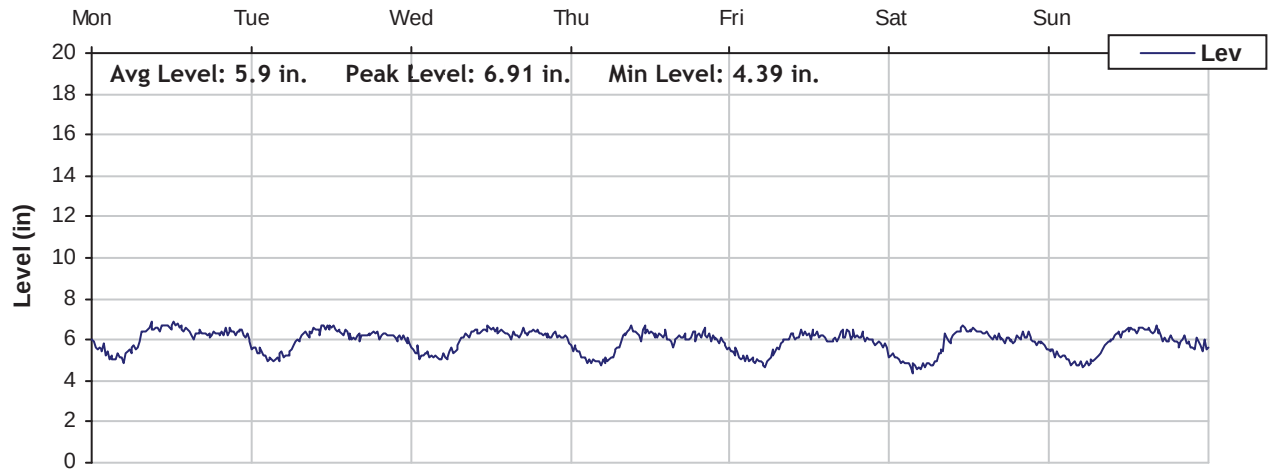


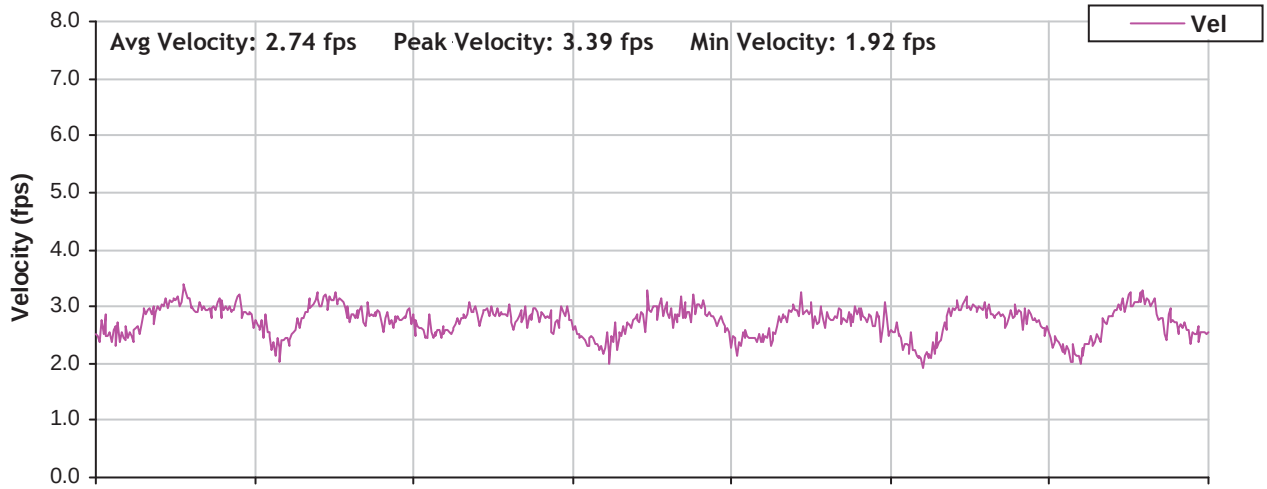


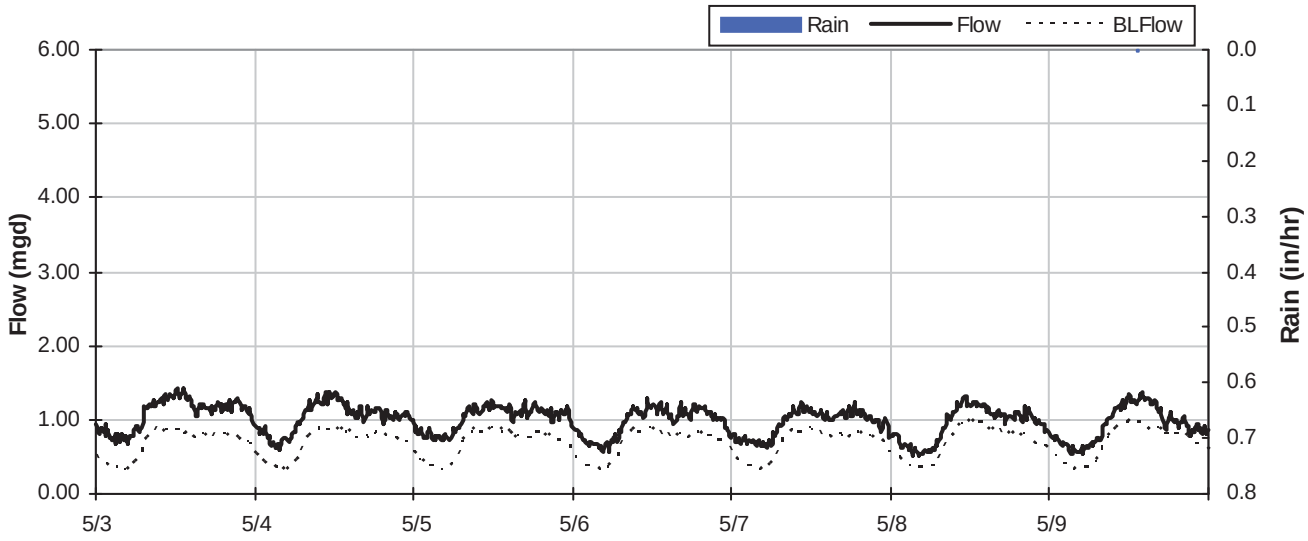
Avg Flow: 1.073 mgd Peak Flow: 2.093 mgd Min Flow: 0.303 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 7



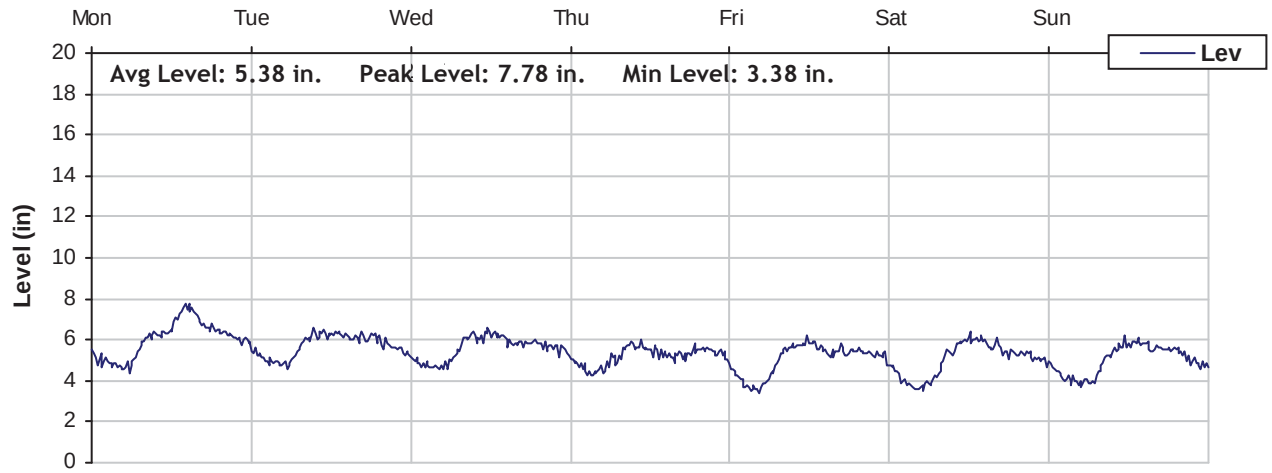


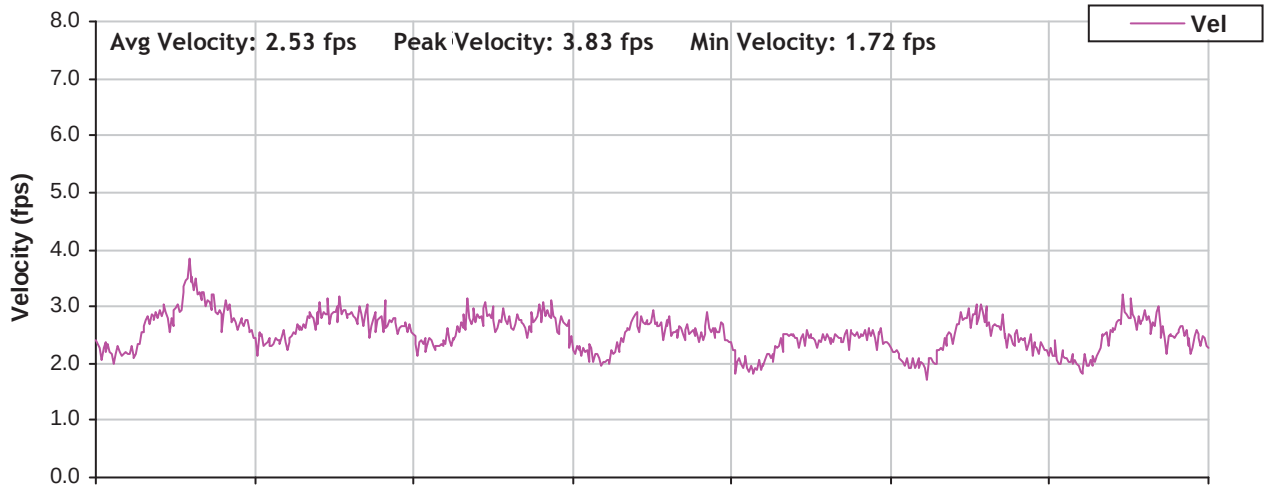


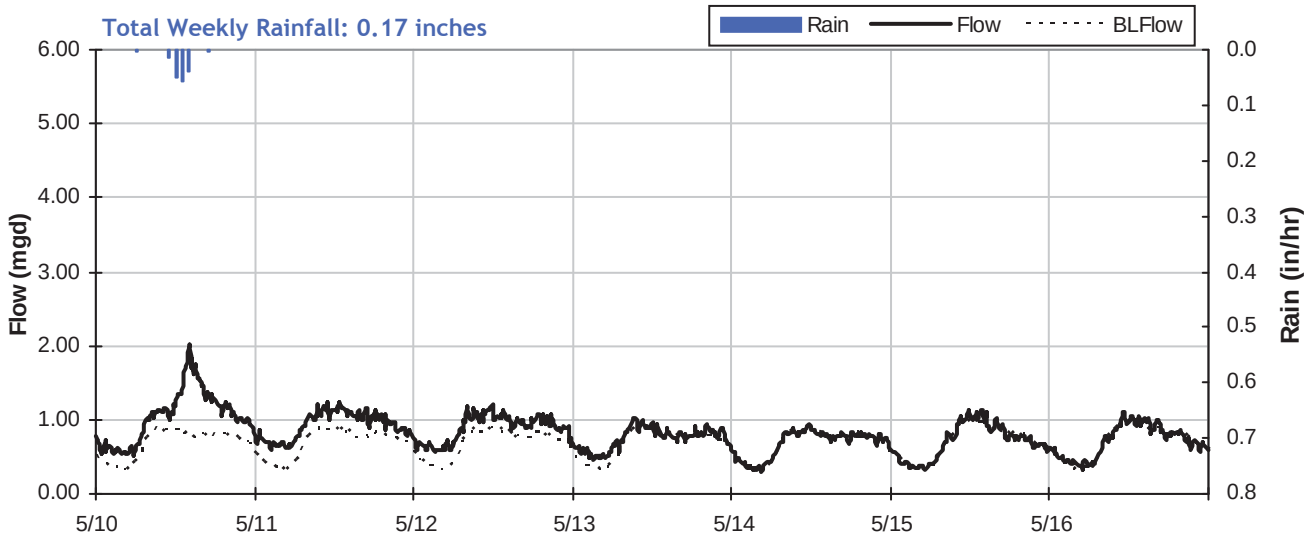
Avg Flow: 0.993 mgd Peak Flow: 1.436 mgd Min Flow: 0.523 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 7



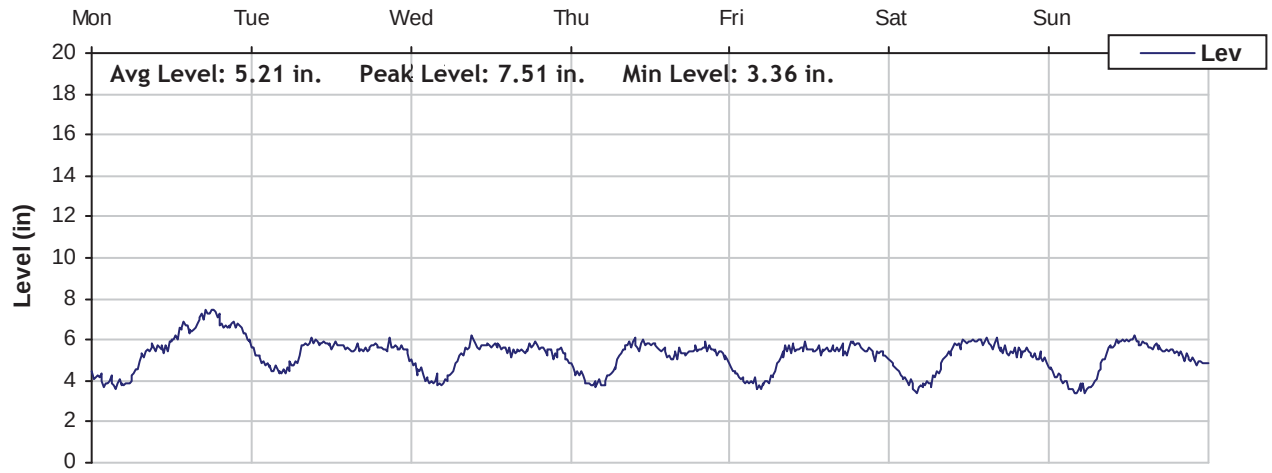


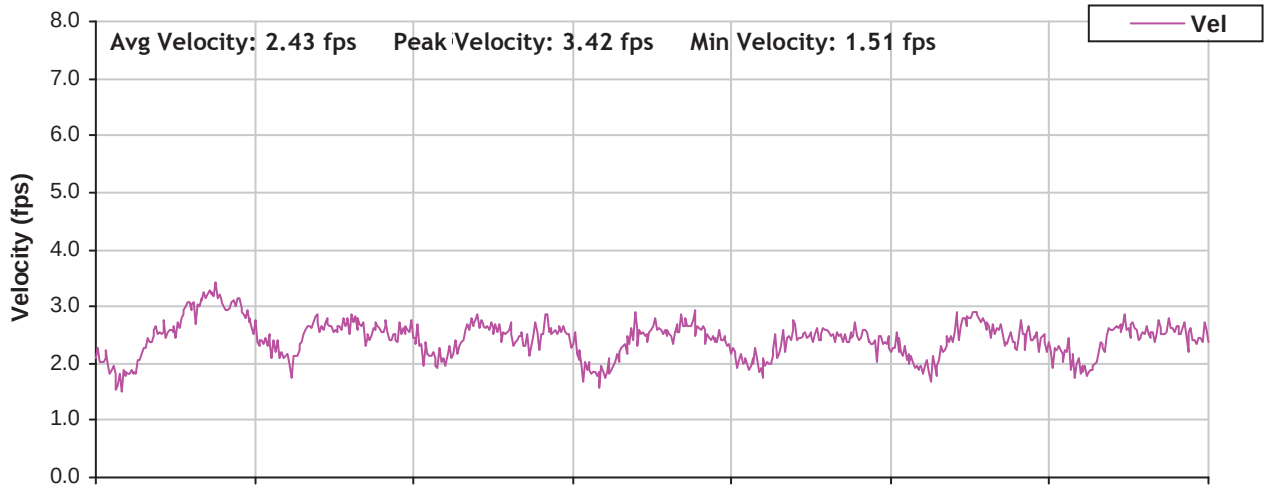


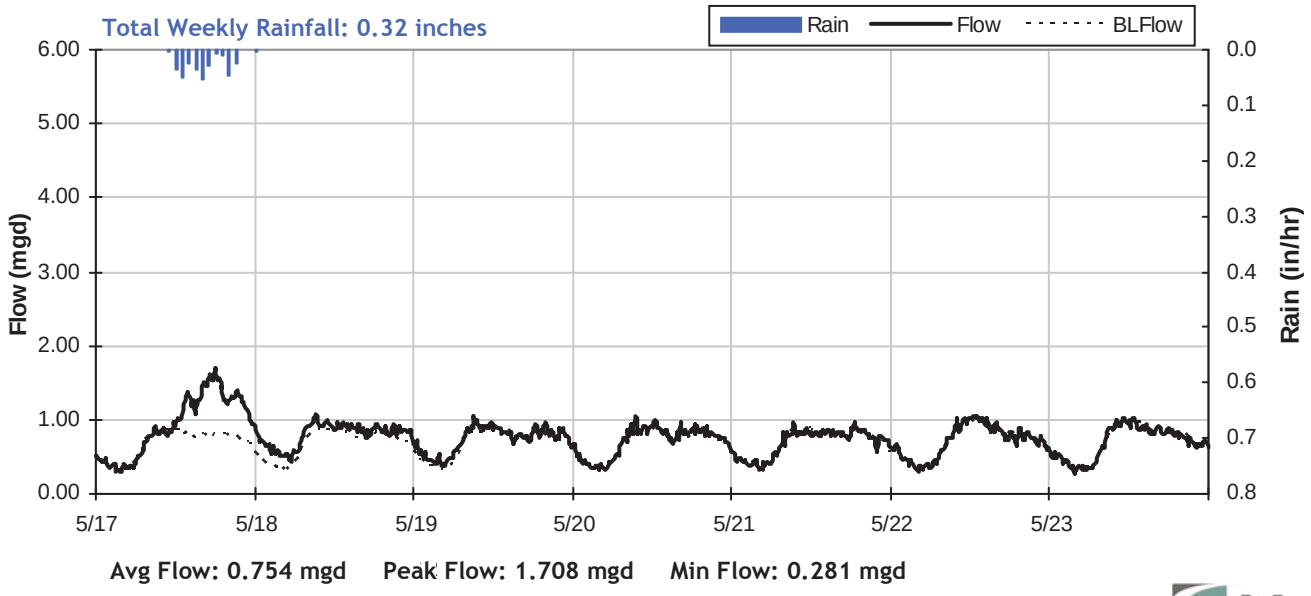
Avg Flow: 0.817 mgd Peak Flow: 2.006 mgd Min Flow: 0.304 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 7



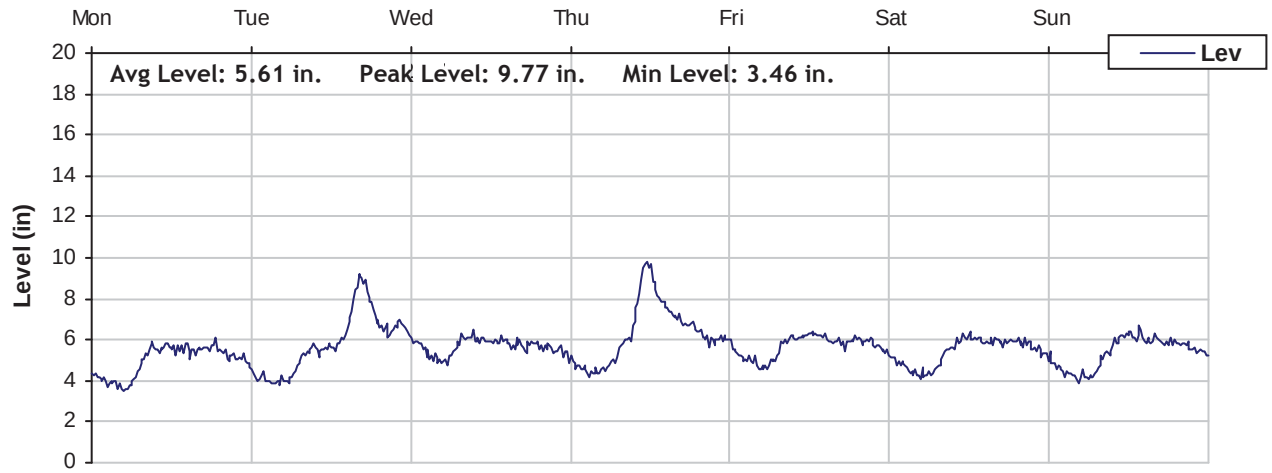


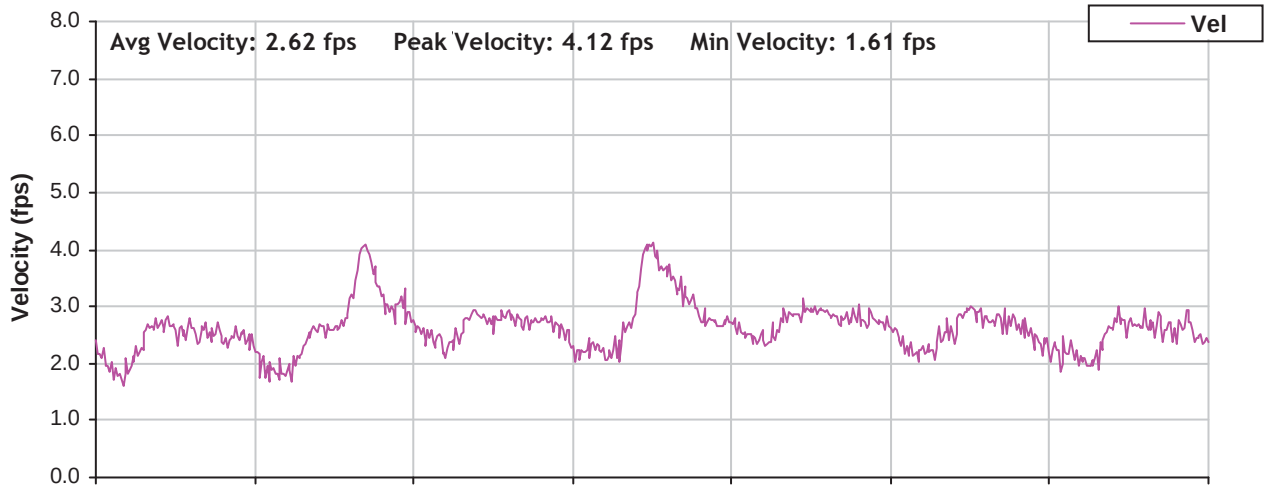


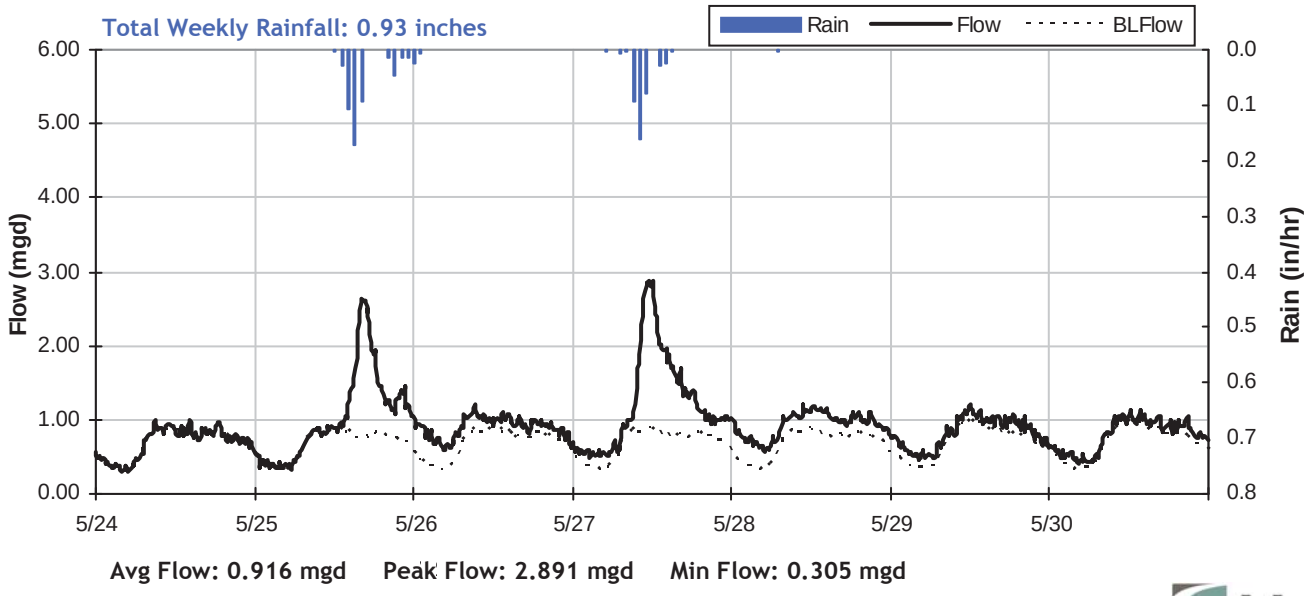
Avg Flow: 0.754 mgd Peak Flow: 1.708 mgd Min Flow: 0.281 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 7



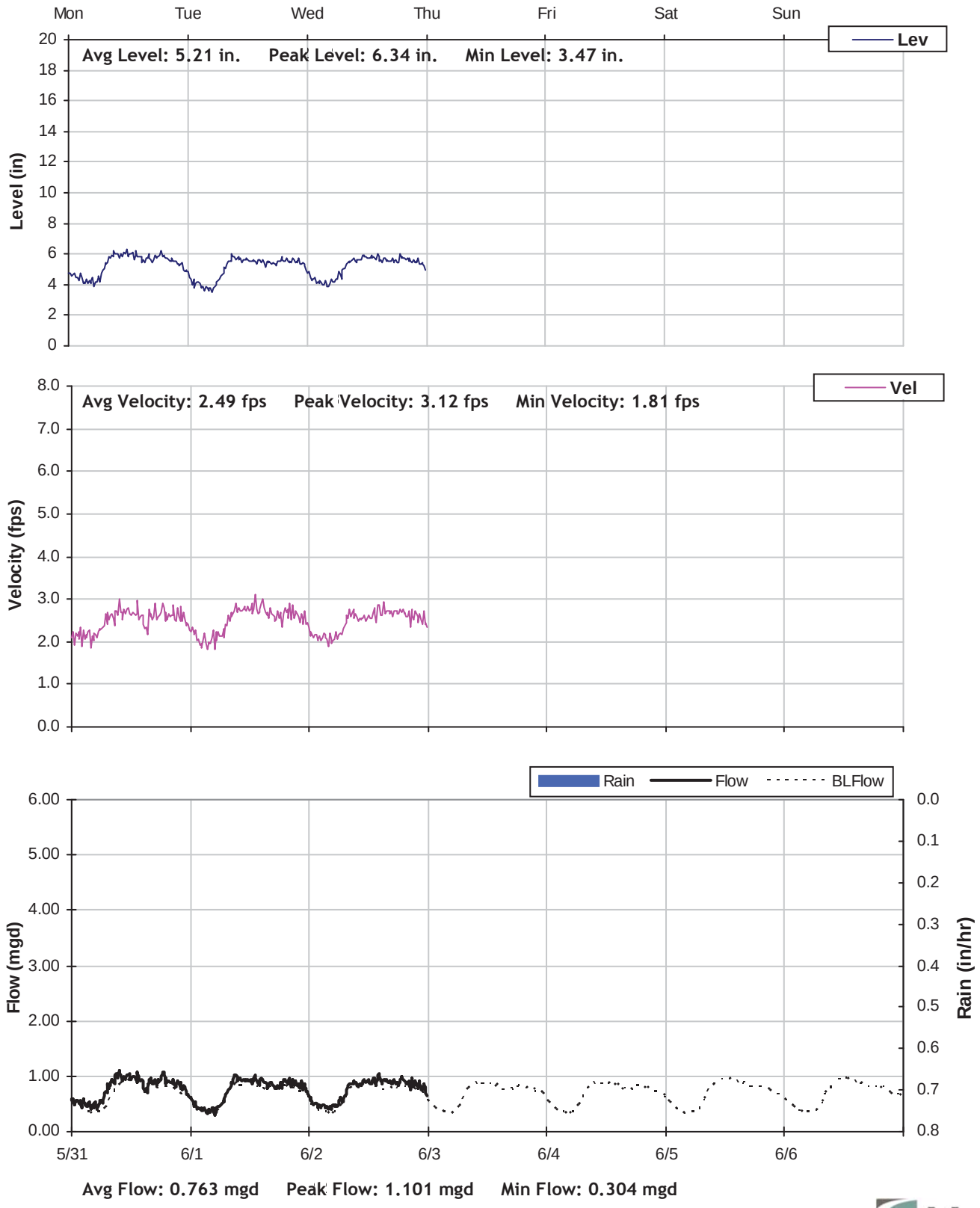




Avg Flow: 0.916 mgd Peak Flow: 2.891 mgd Min Flow: 0.305 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 7



Temporary Flow Monitoring Study

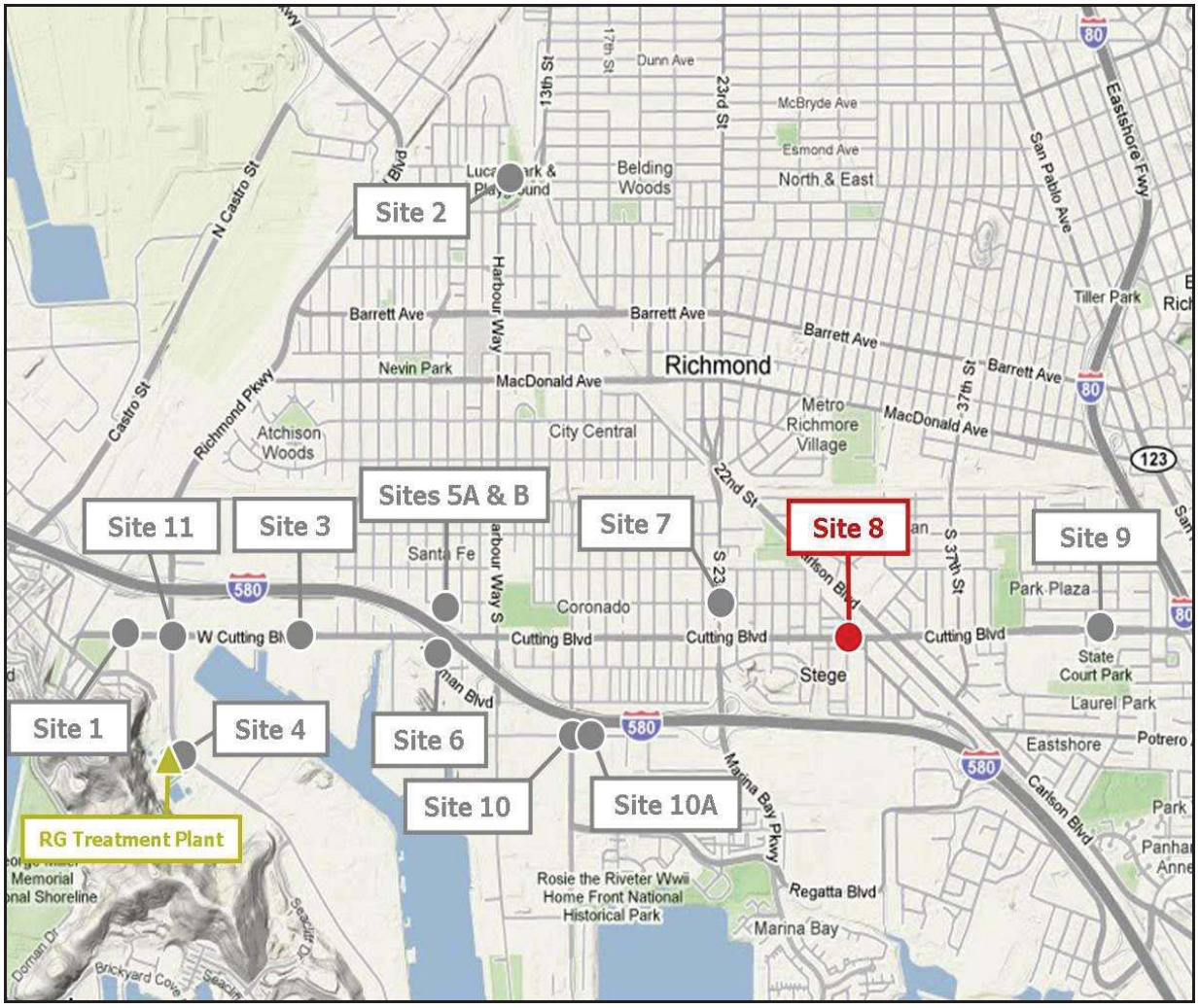
Sanitary Sewer Collection System

Monitoring Site: Site 8

Location: Cutting Boulevard at S 30th Street

Size/Type Line: 24-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 8

Location: Cutting Boulevard at S 30th Street

Latitude: 37.9252°

Longitude: -122.3405°

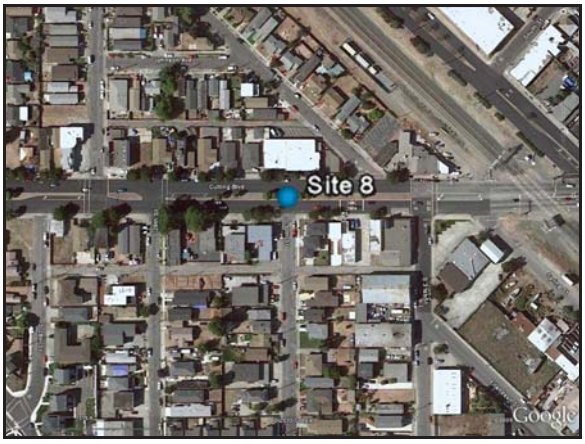
Rim Elevation: 37 *feet above sea level*

Diameter: 24 *inches*

Average Dry Weather Flow: 0.465 *mgd*

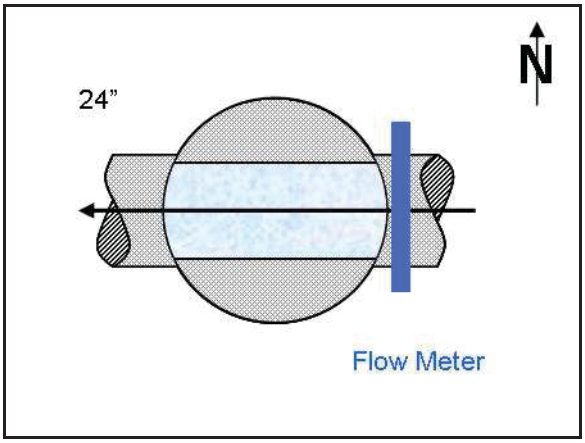
Peak Measured Flow: 5.659 *mgd*

Satellite Photo



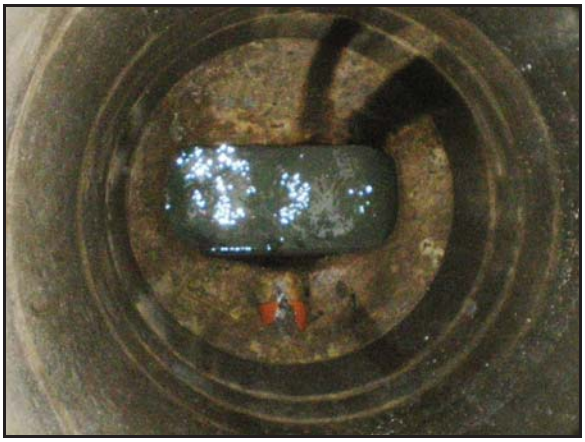
Sanitary Map

Flow Sketch



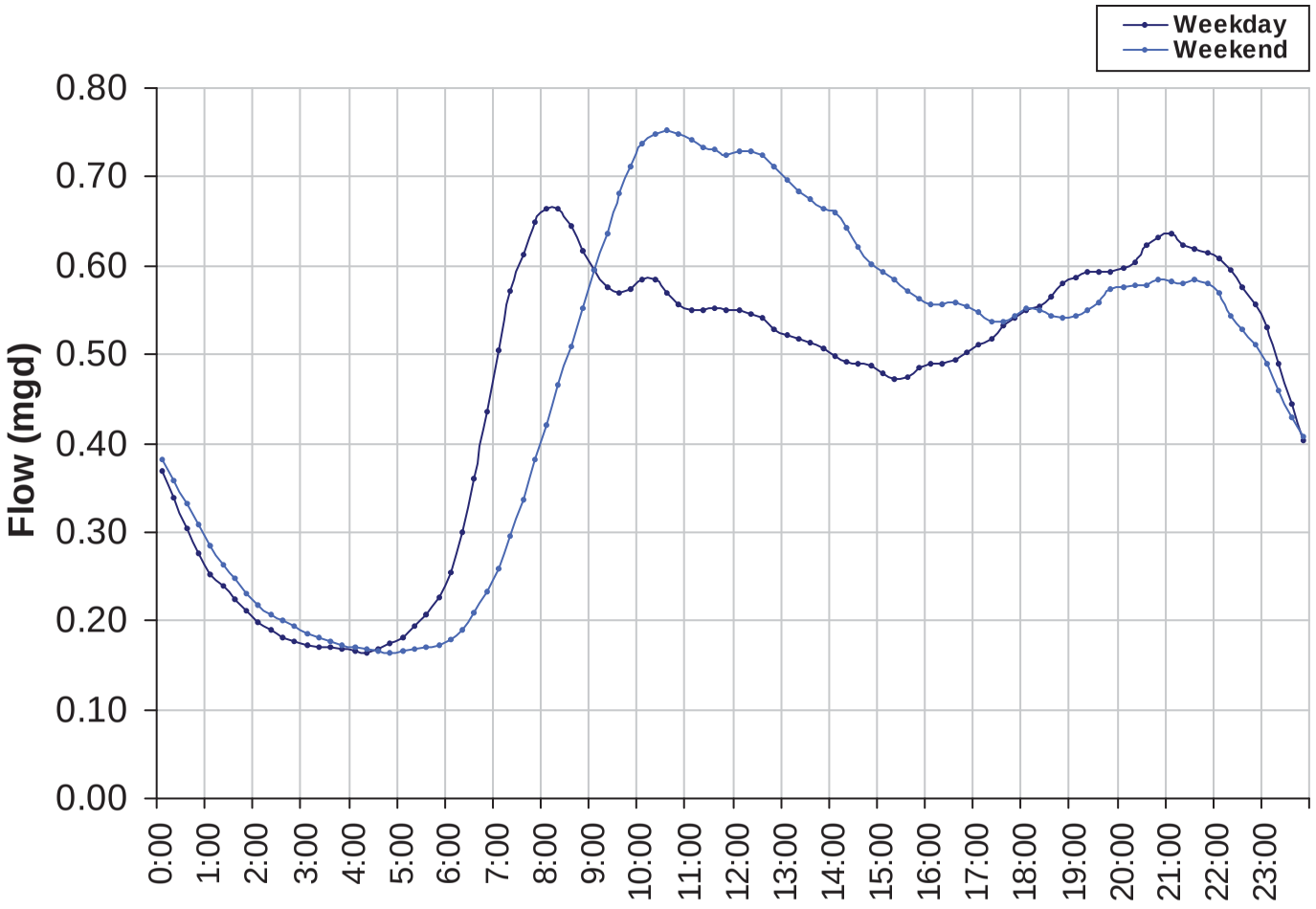
Street View Photo

Plan View Photo



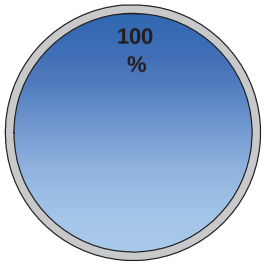
Average Dry Weather Flow

Monitoring Site:
Site 8



Peak Measured Flow:

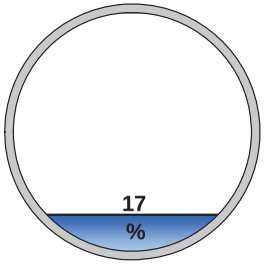
5.66 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

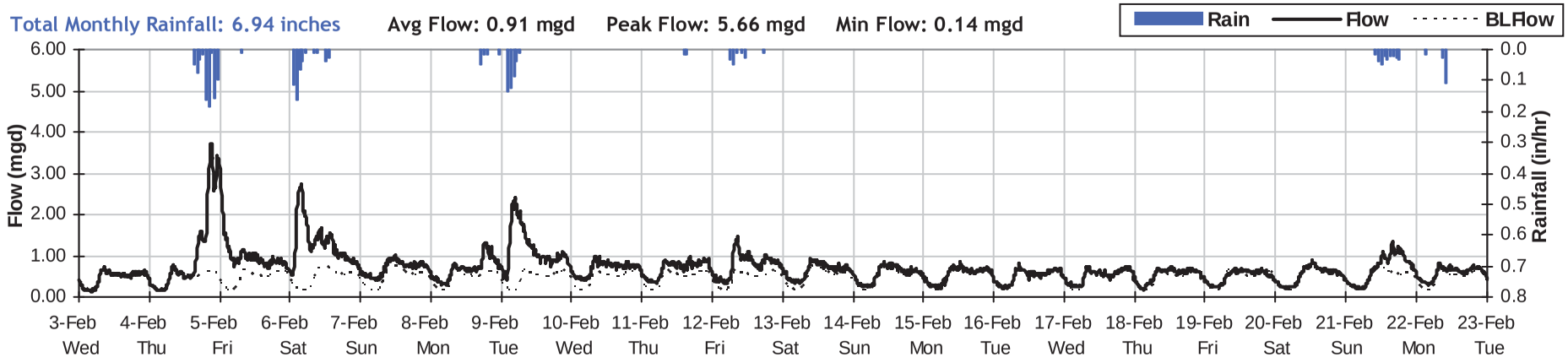
0.46 *mgd*

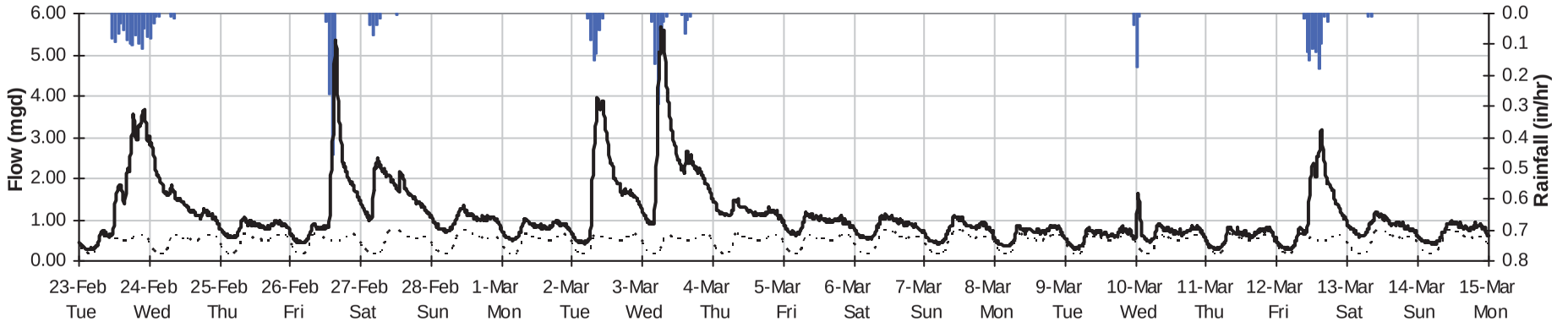


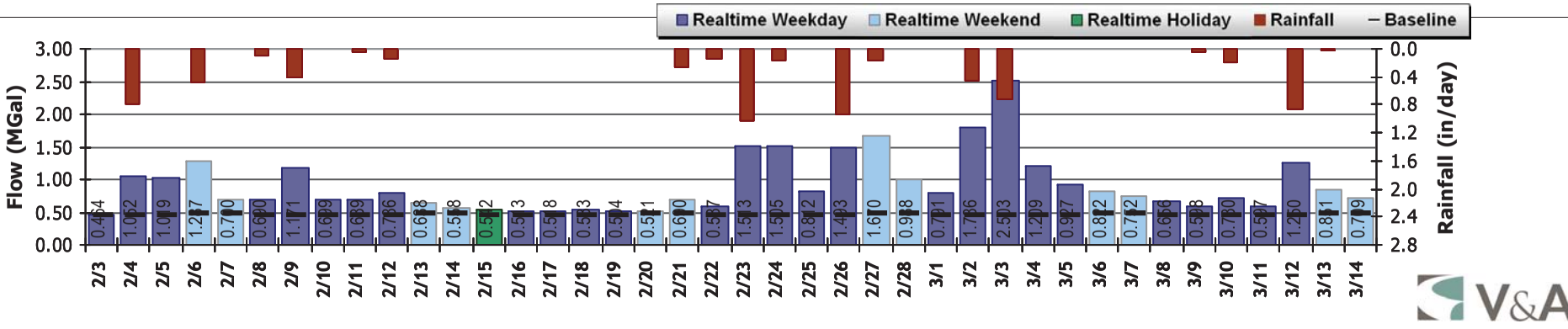
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 8

Total Monthly Rainfall: 6.94 inches Avg Flow: 0.91 mgd Peak Flow: 5.66 mgd Min Flow: 0.14 mgd





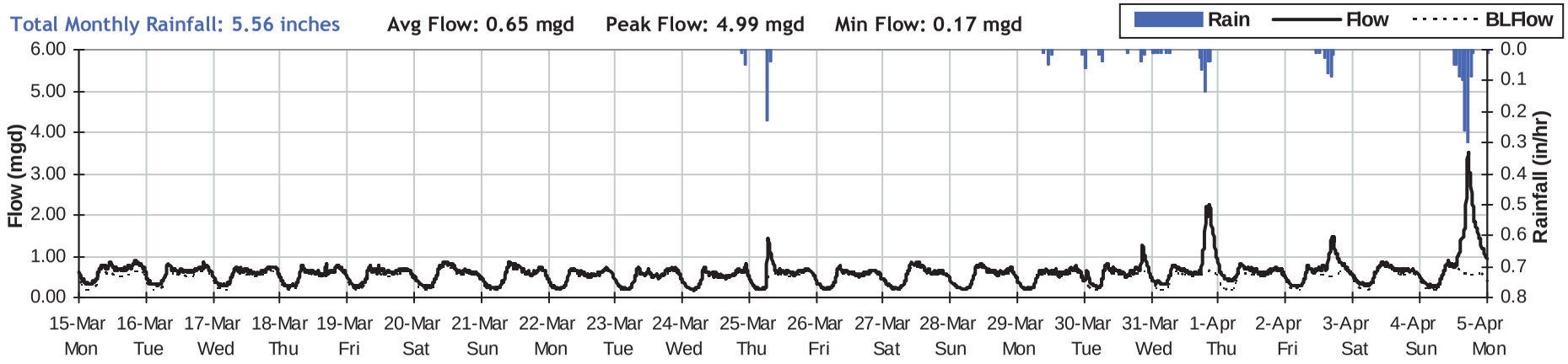


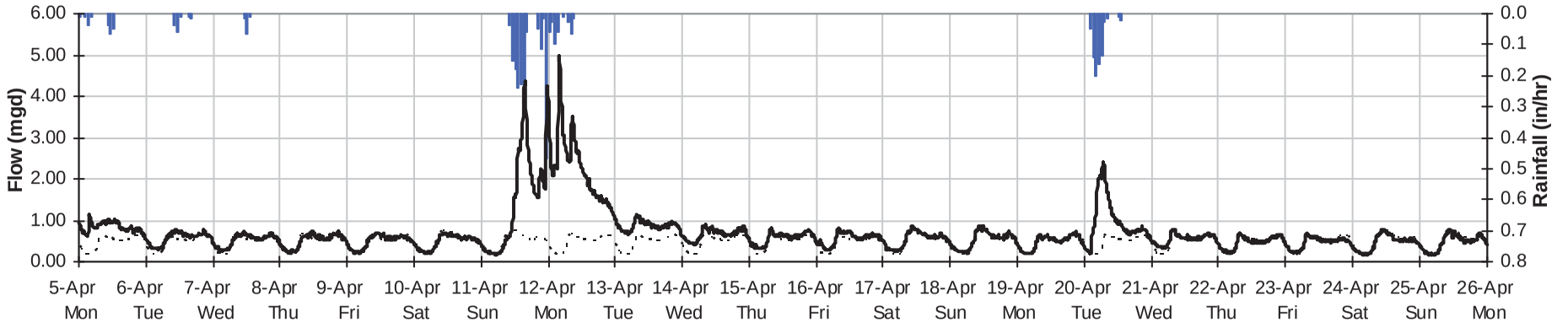
V&A

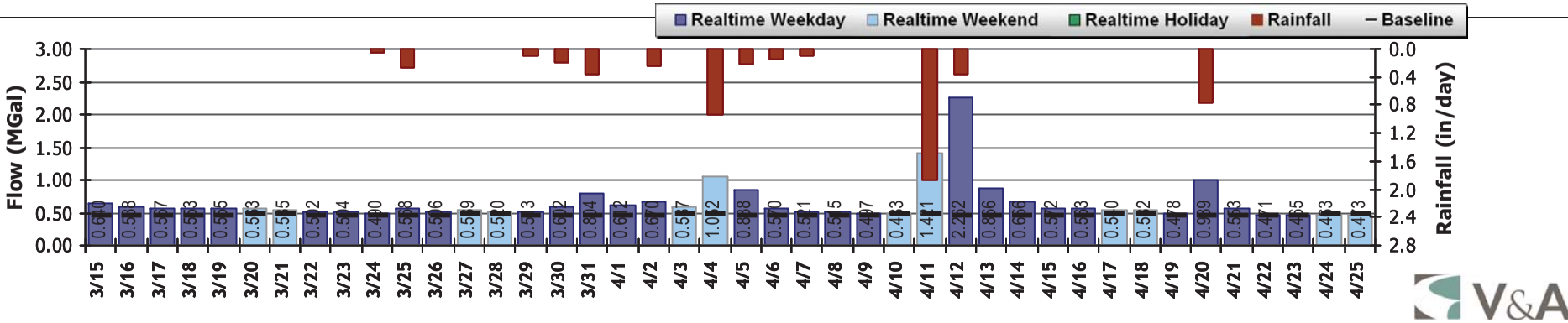
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 8

Total Monthly Rainfall: 5.56 inches Avg Flow: 0.65 mgd Peak Flow: 4.99 mgd Min Flow: 0.17 mgd





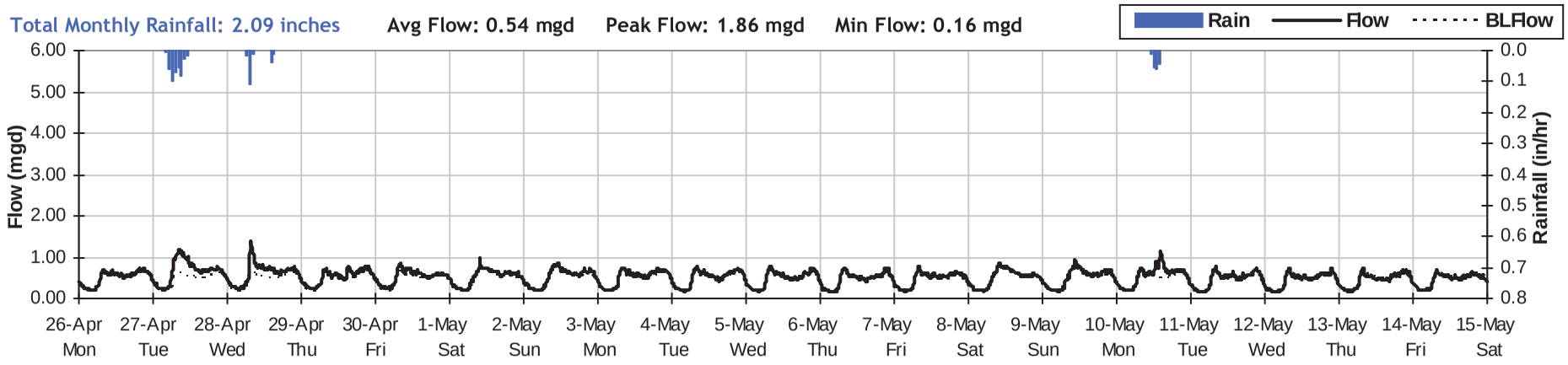


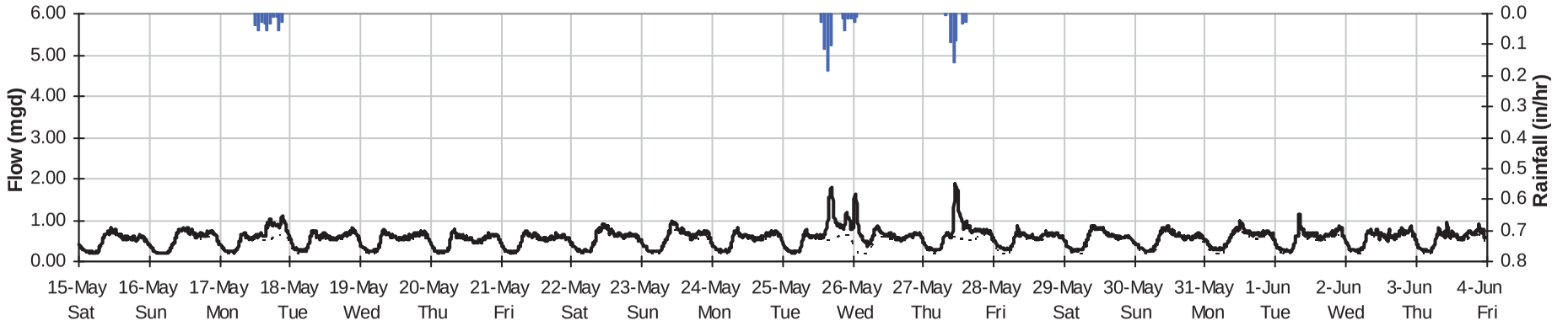
V&A

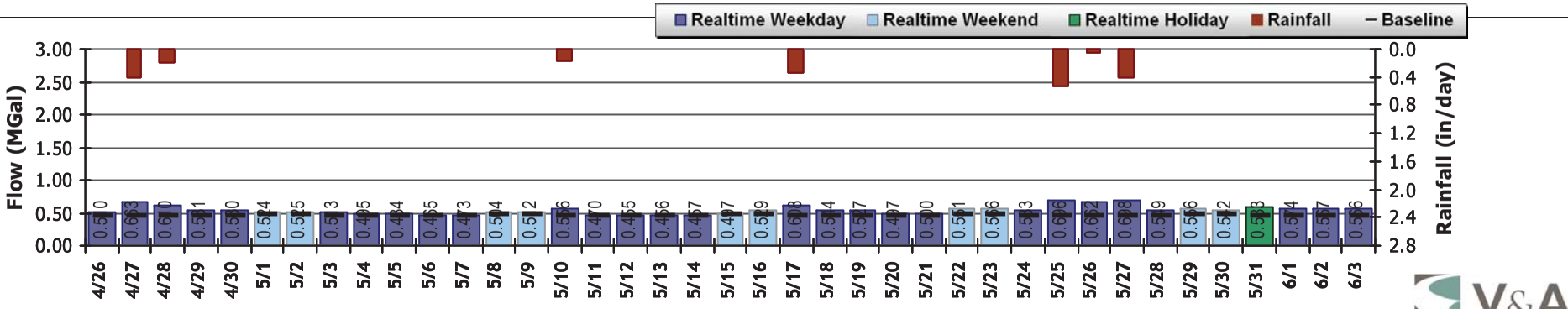
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 8

Total Monthly Rainfall: 2.09 inches Avg Flow: 0.54 mgd Peak Flow: 1.86 mgd Min Flow: 0.16 mgd





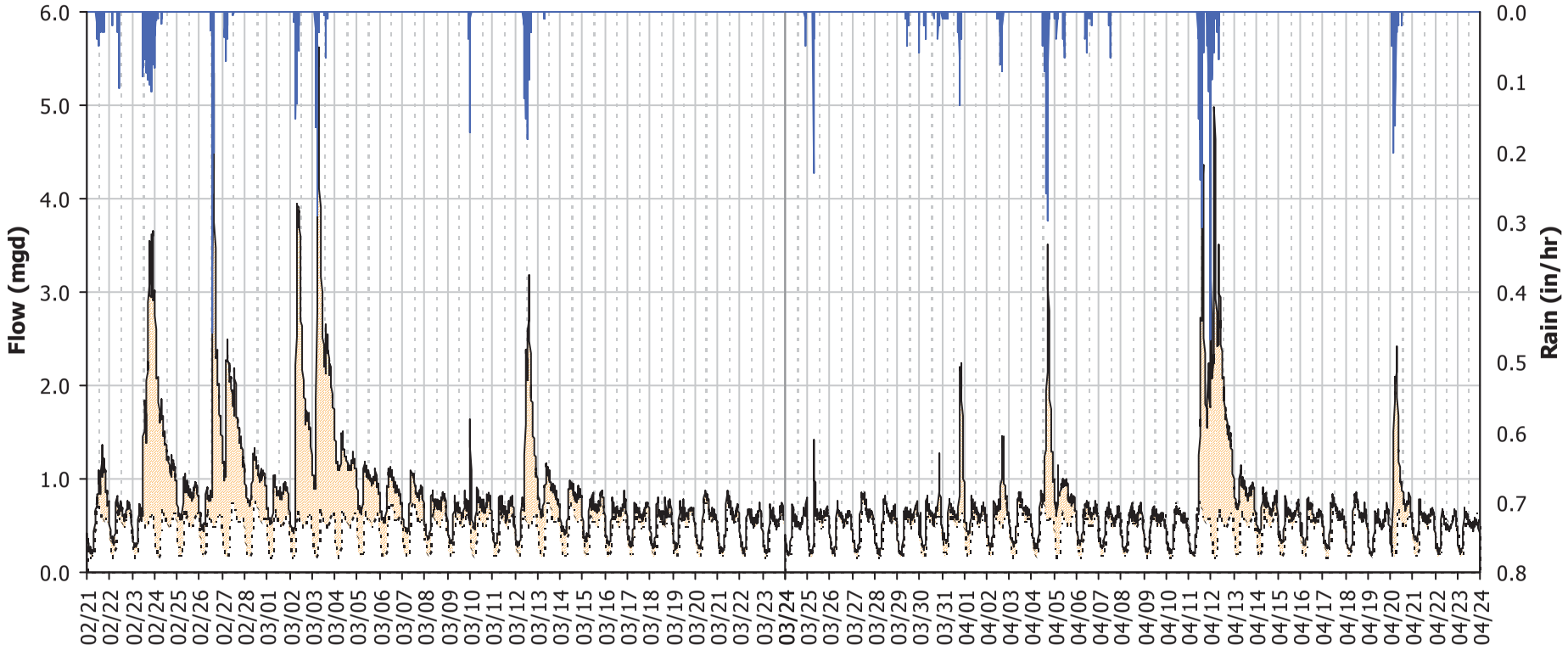


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 8

Multiple Events Detail I/I Graph



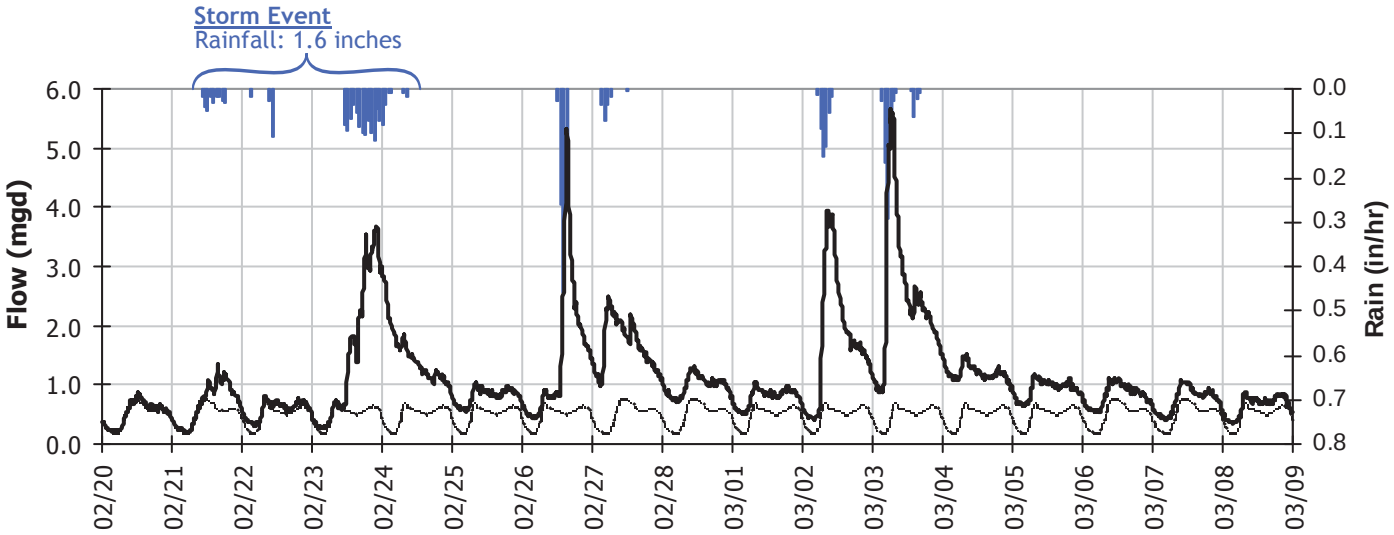
Multiple Events I/I Analysis

Rainfall:	10.55	*inches*	**Baseline Flow:**	0.46	*mgd*
Peak Flow:	5.66	*mgd*	**PF:**	12.18	
Peak I/I Rate:	5.36	*mgd*	**Pk I/I:ADWF:**	11.54	
Peak Level:	31.53	*inches*	**d/D Ratio:**	1.31	
Total I/I:	20,923,000	*gallons*	**R-Value:**	14.9%	
			I/I per ADWF:	4.3	*per in-rain*

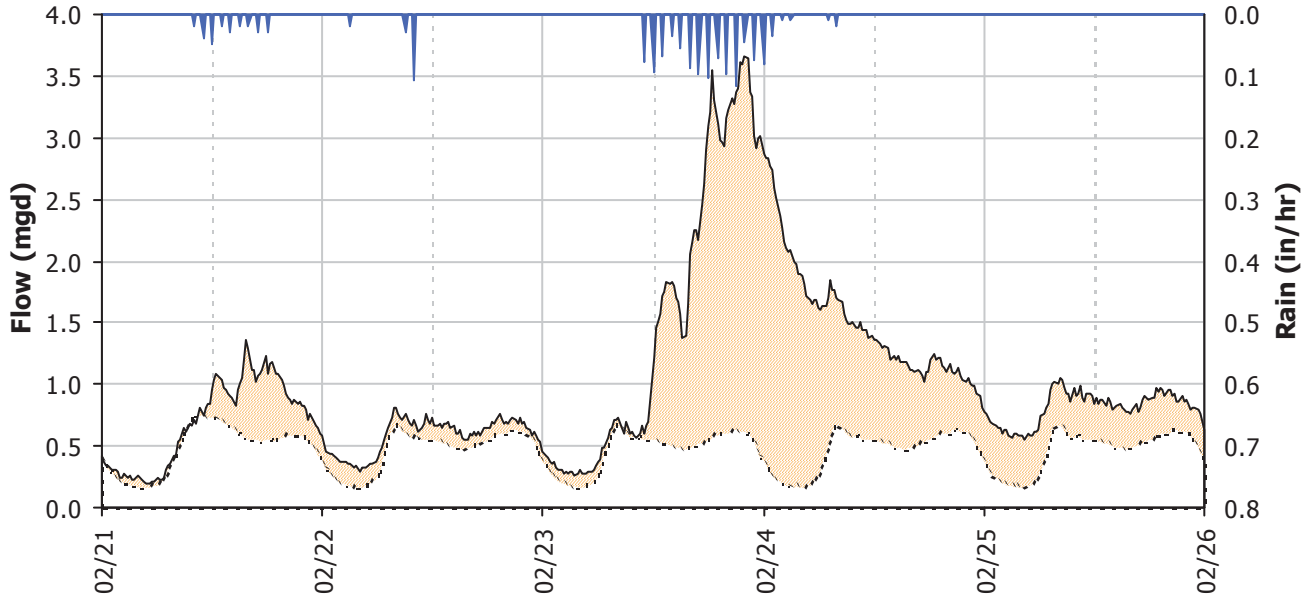
V&A

	I/I Summary Event 1	**Monitoring Site:** Site 8

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



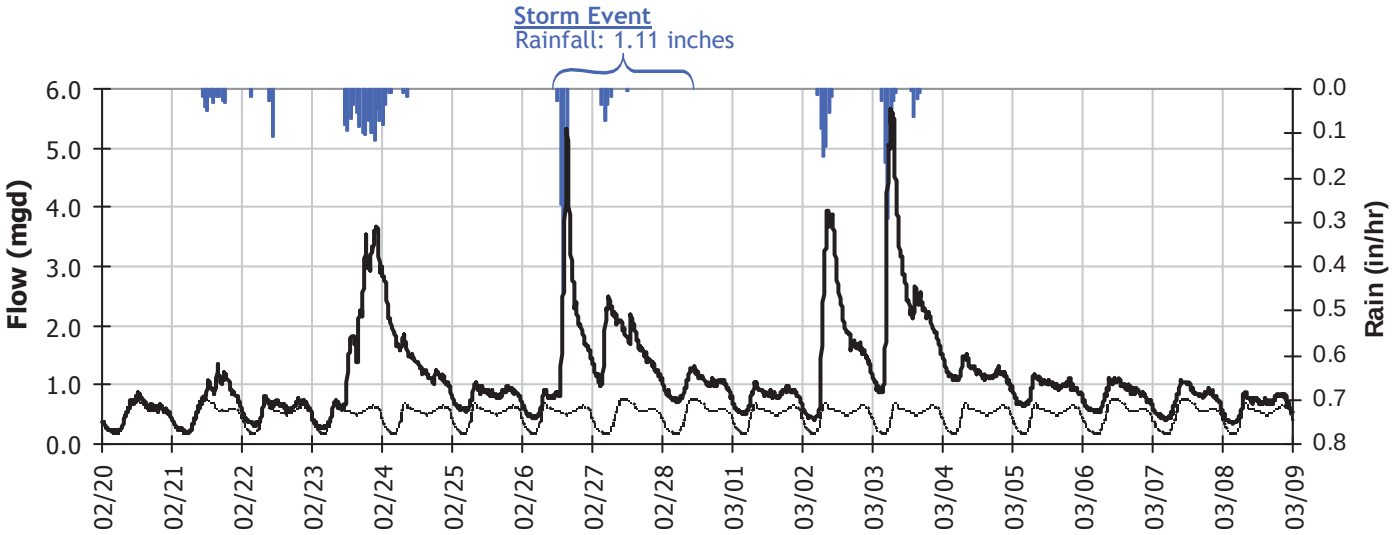
Storm Event #1 I/I Analysis

Rainfall:	1.60	*inches*		
Baseline Flow:	0.46	*mgd*		
Peak Flow:	3.66	*mgd*	**PF:**	7.87
Peak I/I Rate:	3.05	*mgd*	**Pk I/I:ADWF:**	6.57
Peak Level:	13.39	*inches*	**d/D Ratio:**	0.56
Total I/I:	2,793,000	*gallons*	**R-Value:**	13.2%
			I/I per ADWF:	3.77 *per in-rain*

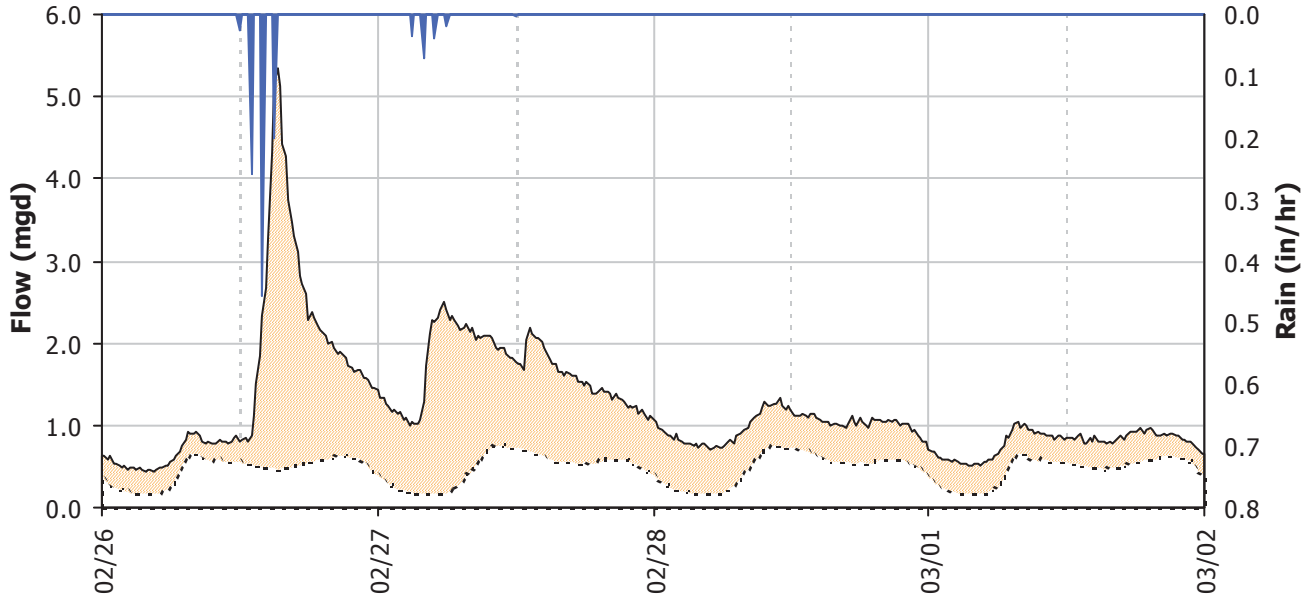
Average Infiltration Rate on 2/25 (% of ADWF): 76.5%

	I/I Summary Event 2	**Monitoring Site:** Site 8

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #2 I/I Analysis

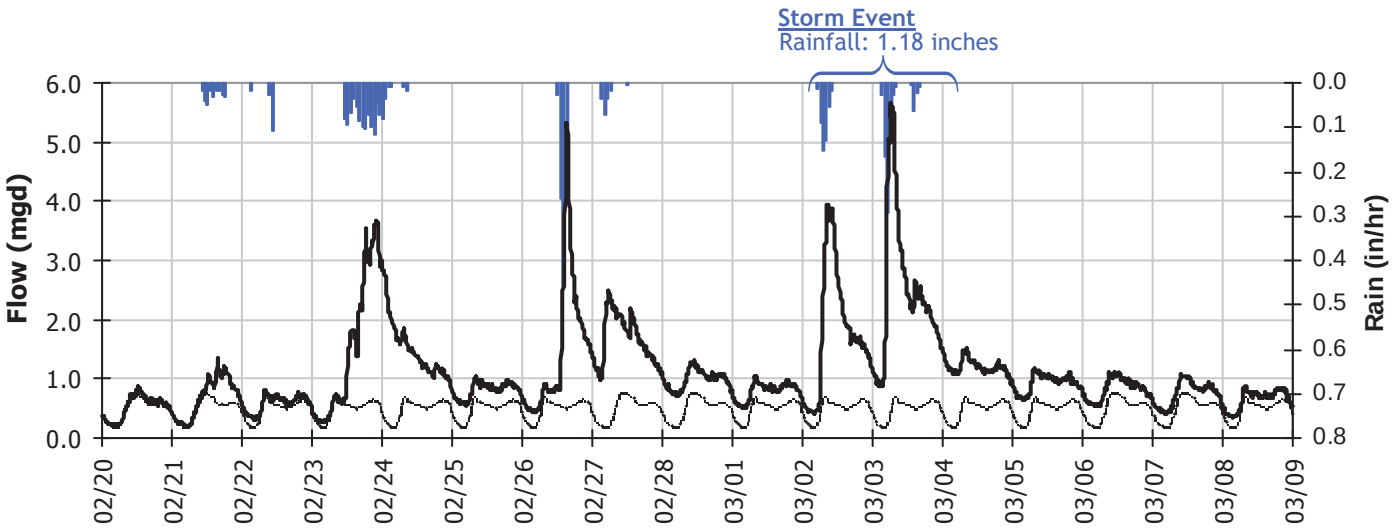
Rainfall:	1.11	*inches*		
Baseline Flow:	0.46	*mgd*		
Peak Flow:	5.34	*mgd*	**PF:**	11.50
Peak I/I Rate:	4.87	*mgd*	**Pk I/I:ADWF:**	10.48
Peak Level:	18.11	*inches*	**d/D Ratio:**	0.75
Total I/I:	3,073,000	*gallons*	**R-Value:**	20.8%
			I/I per ADWF:	5.94 *per in-rain*

Average Infiltration Rate on 3/1 (% of ADWF): 71.9%

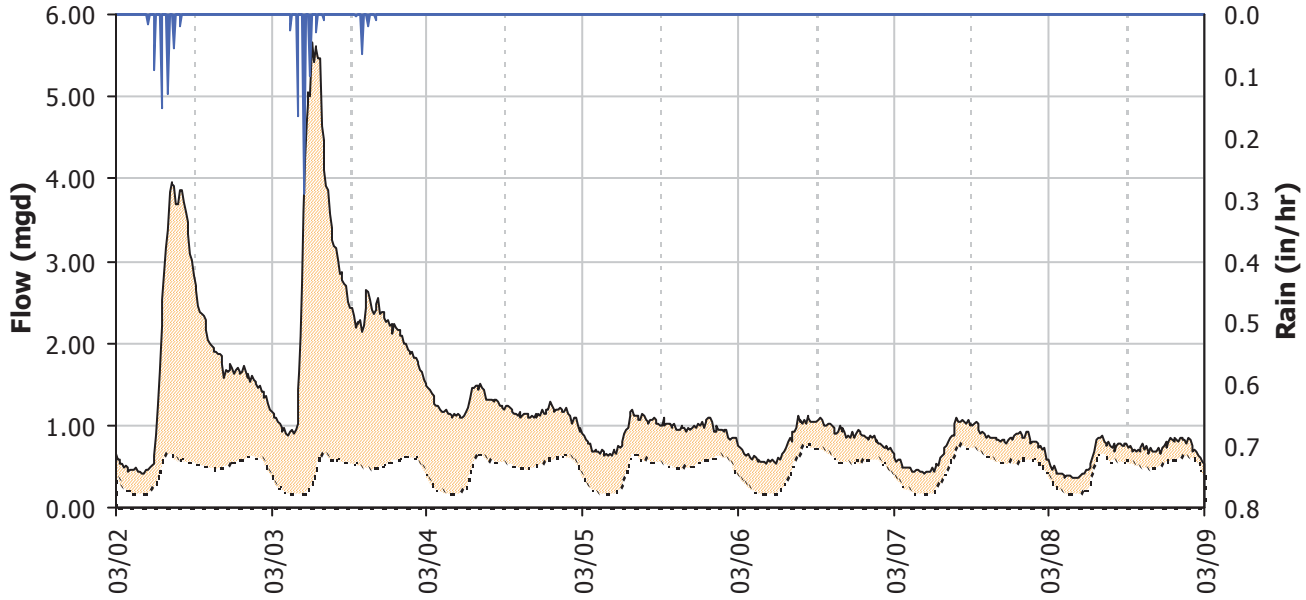
I/I Summary
Event 3

Monitoring Site:
Site 8

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



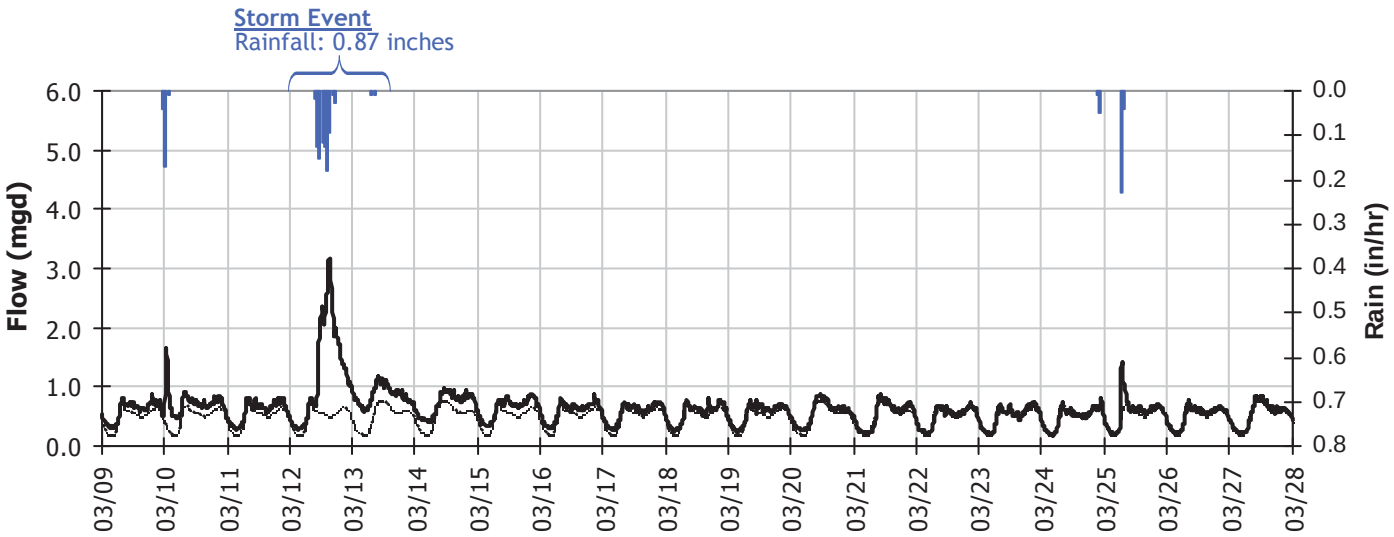
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	0.46	*mgd*		
Peak Flow:	5.66	*mgd*	**PF:**	12.18
Peak I/I Rate:	5.36	*mgd*	**Pk I/I:ADWF:**	11.54
Peak Level:	31.53	*inches*	**d/D Ratio:**	1.31
Total I/I:	5,405,000	*gallons*	**R-Value:**	34.5%
			I/I per ADWF:	9.85 *per in-rain*

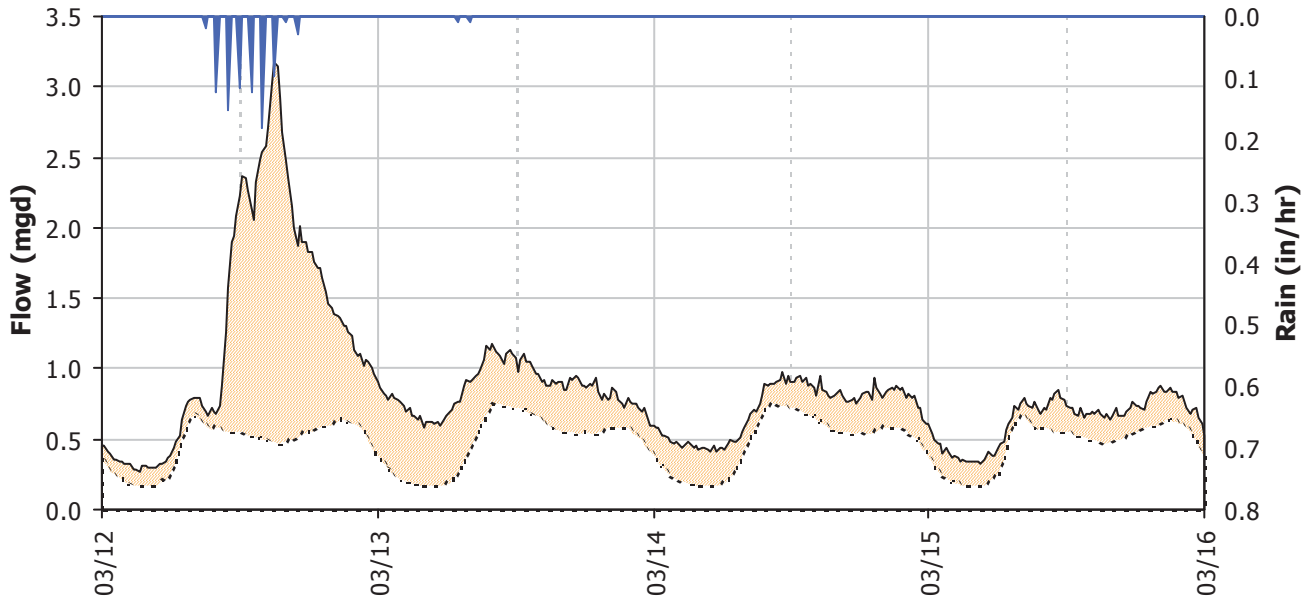
Average Infiltration Rate on 3/5 (% of ADWF): 101.5%

	I/I Summary Event 4	**Monitoring Site:** Site 8

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

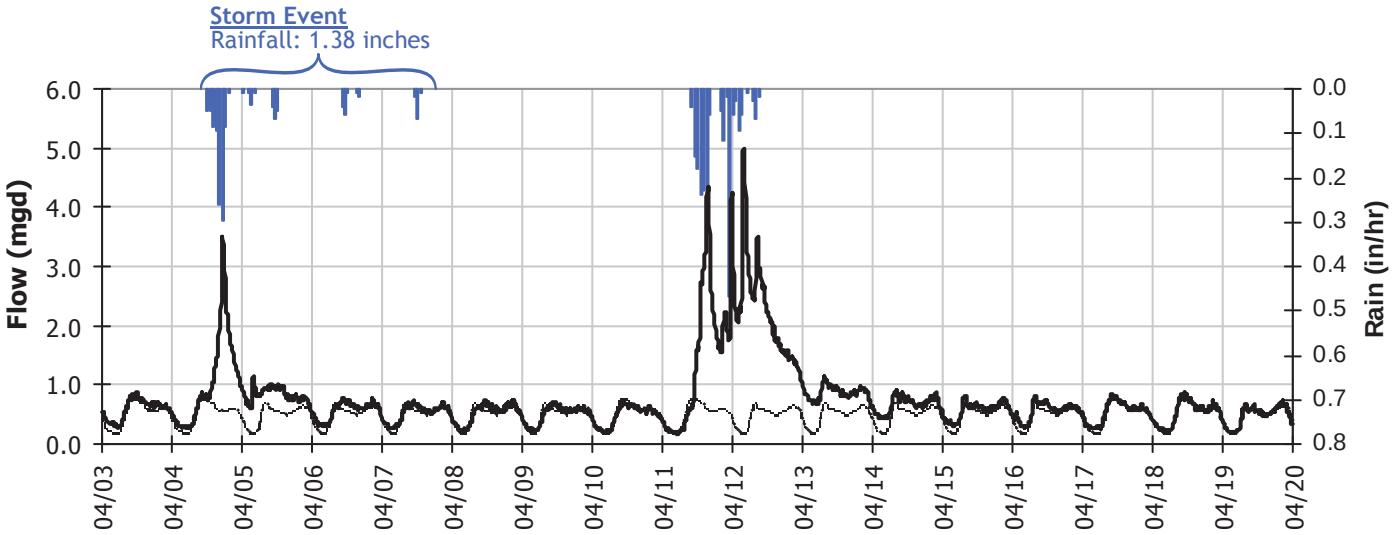
Rainfall:	0.87	*inches*		
Baseline Flow:	0.46	*mgd*		
Peak Flow:	3.18	*mgd*	**PF:**	6.84
Peak I/I Rate:	2.70	*mgd*	**Pk I/I:ADWF:**	5.81
Peak Level:	12.38	*inches*	**d/D Ratio:**	0.52
Total I/I:	1,581,000	*gallons*	**R-Value:**	13.7%
			I/I per ADWF:	3.91 *per in-rain*

Average Infiltration Rate on 3/14 (% of ADWF): 49.2%

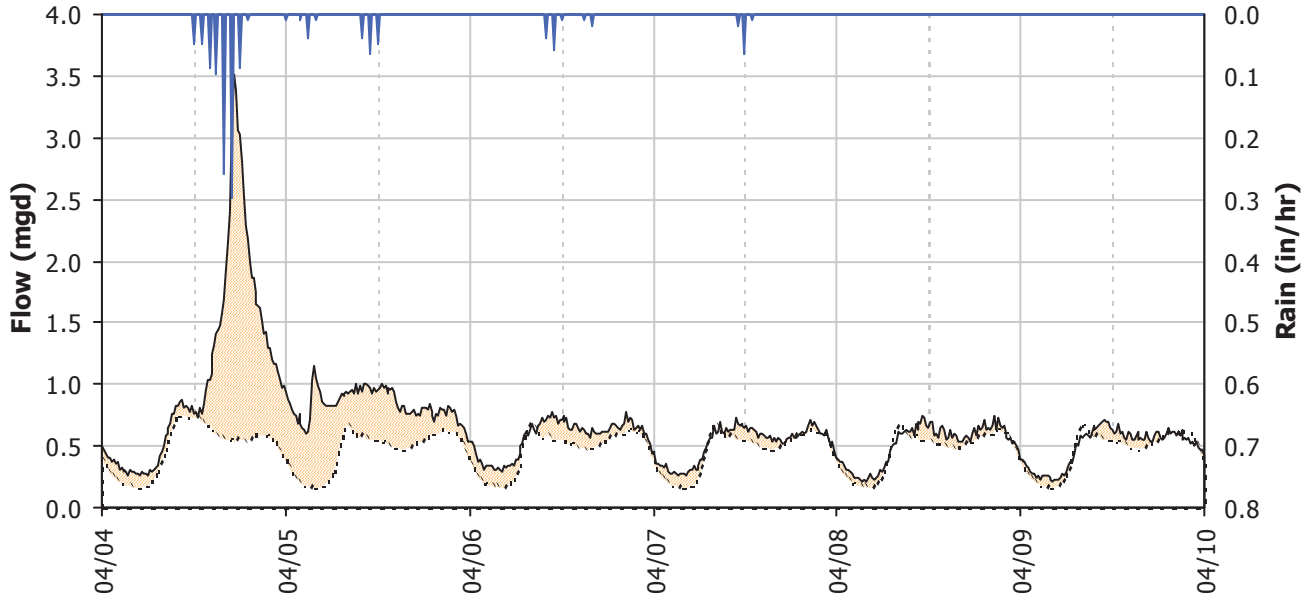
I/I Summary
Event 5

Monitoring Site:
Site 8

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #5 I/I Analysis

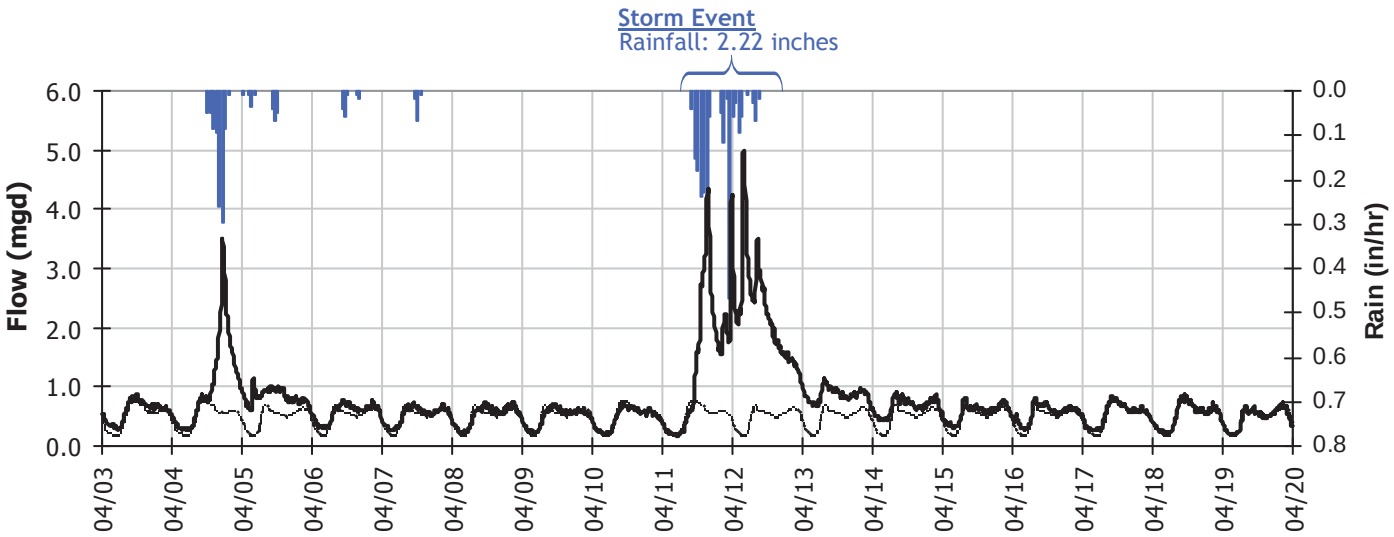
Rainfall:	1.38	*inches*		
Baseline Flow:	0.46	*mgd*		
Peak Flow:	3.51	*mgd*	**PF:**	7.56
Peak I/I Rate:	2.97	*mgd*	**Pk I/I:ADWF:**	6.40
Peak Level:	13.30	*inches*	**d/D Ratio:**	0.55
Total I/I:	1,218,000	*gallons*	**R-Value:**	6.7%
			I/I per ADWF:	1.90 *per in-rain*

Average Infiltration Rate on 4/8 (% of ADWF): 12.0%

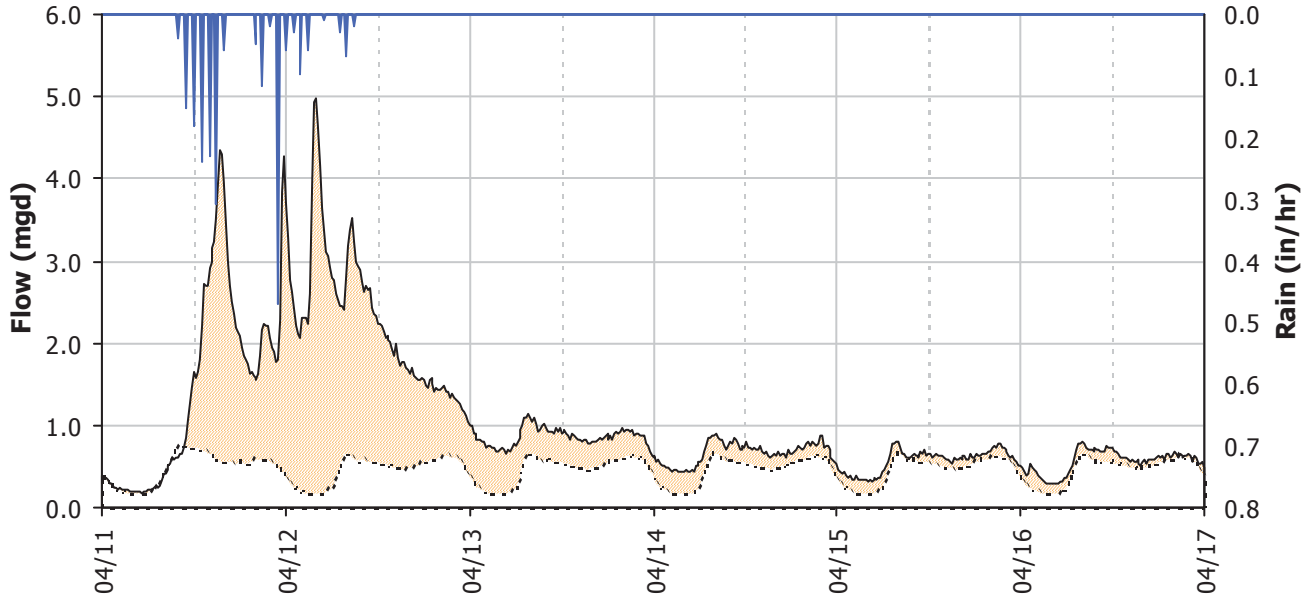
I/I Summary
Event 6

Monitoring Site:
Site 8

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



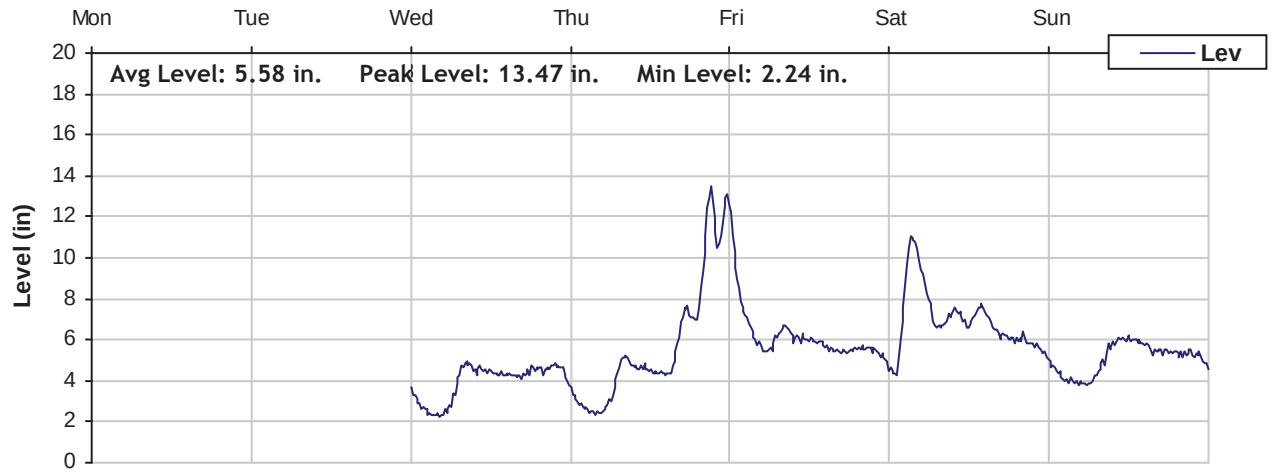
Storm Event #6 I/I Analysis

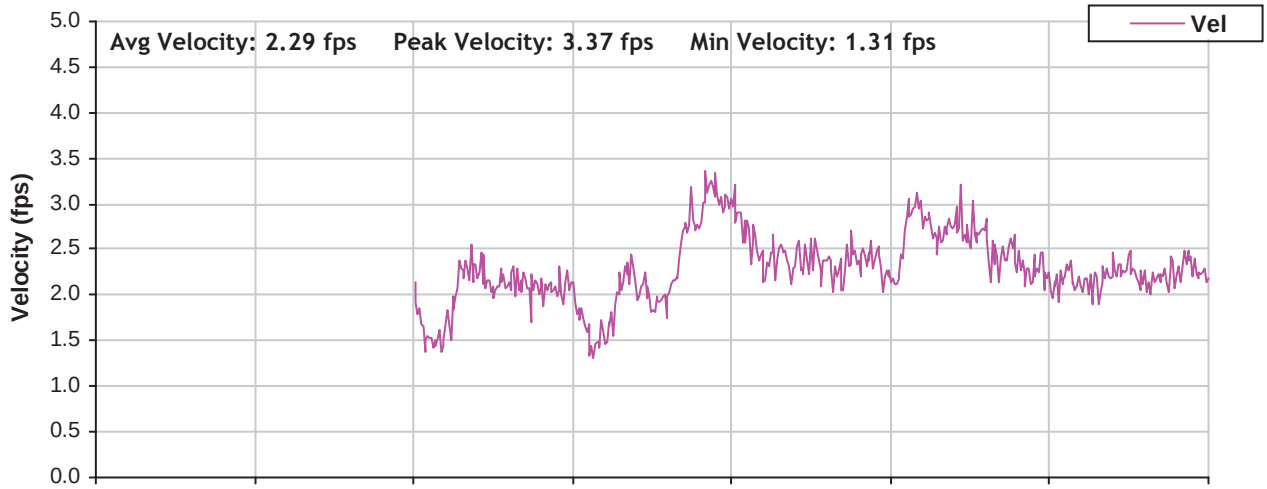
Rainfall:	2.22	*inches*		
Baseline Flow:	0.46	*mgd*		
Peak Flow:	4.99	*mgd*	**PF:**	10.74
Peak I/I Rate:	4.82	*mgd*	**Pk I/I:ADWF:**	10.38
Peak Level:	16.63	*inches*	**d/D Ratio:**	0.69
Total I/I:	3,576,000	*gallons*	**R-Value:**	12.1%
			I/I per ADWF:	3.46 *per in-rain*

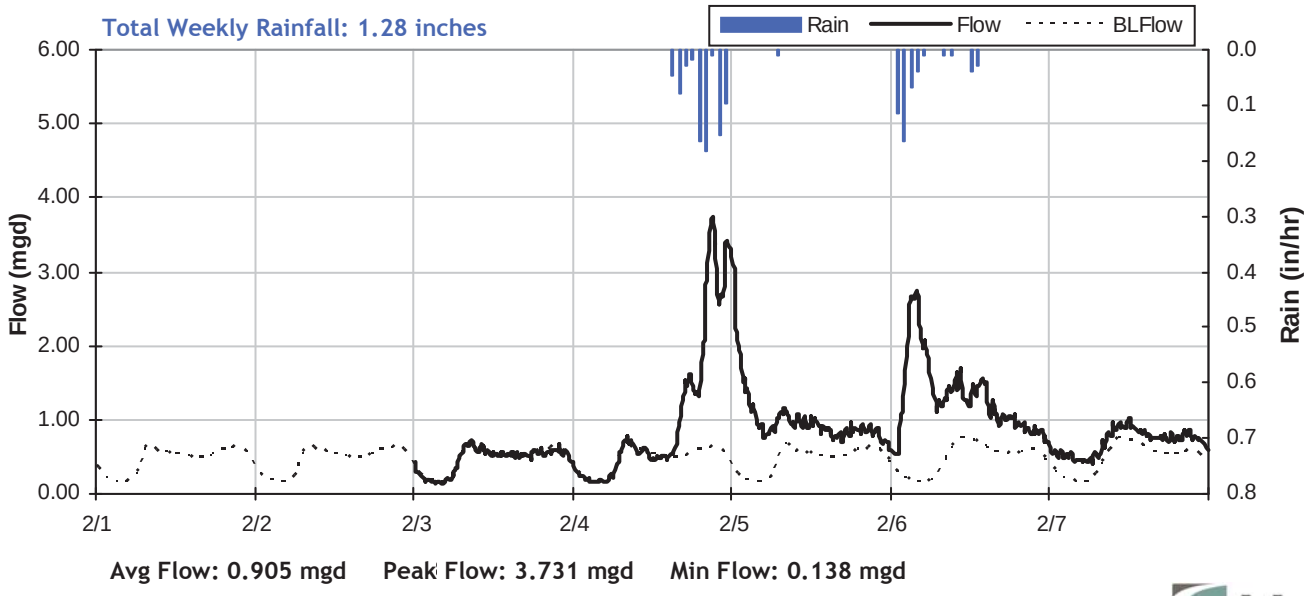
Average Infiltration Rate on 4/14 (% of ADWF): 44.9%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 8

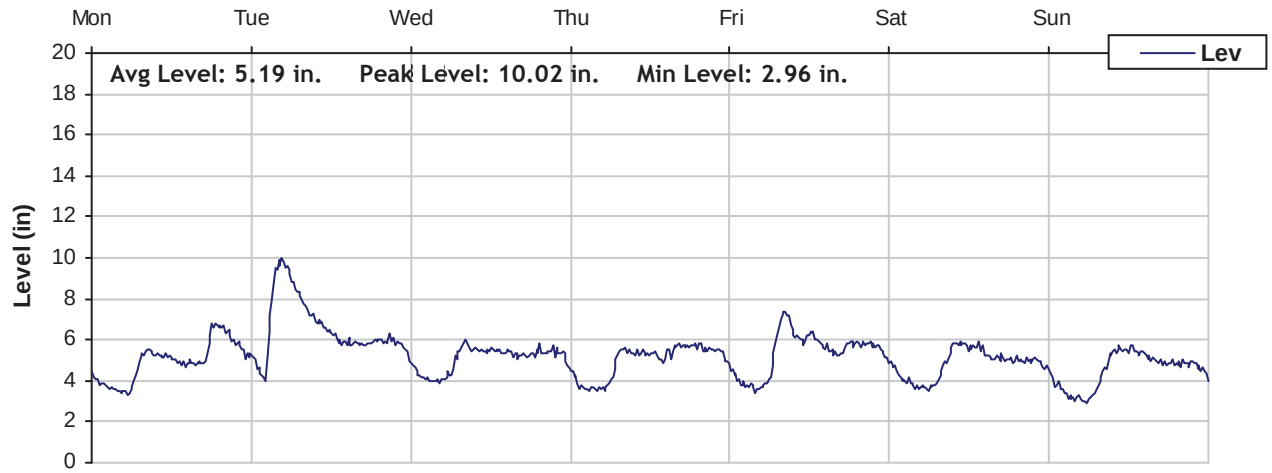


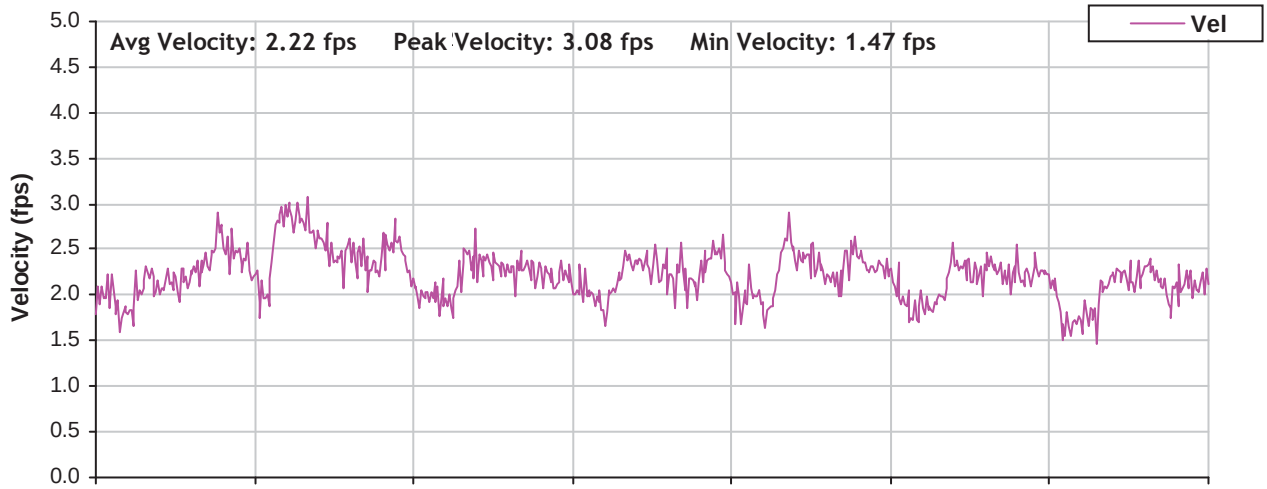


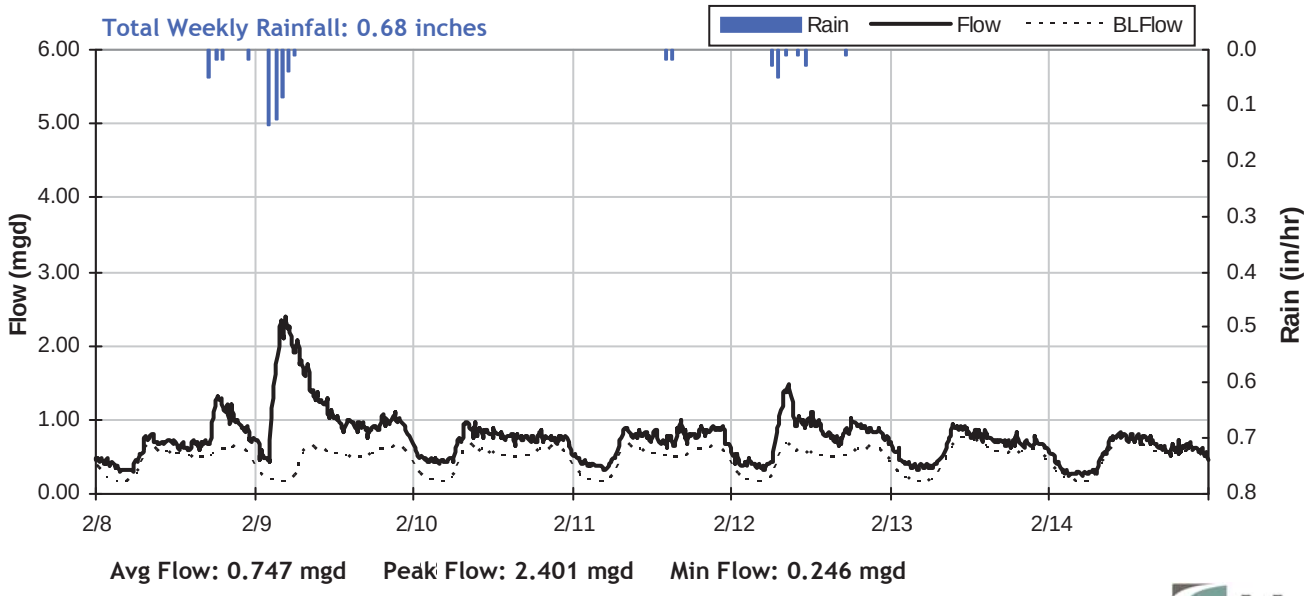


Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 8

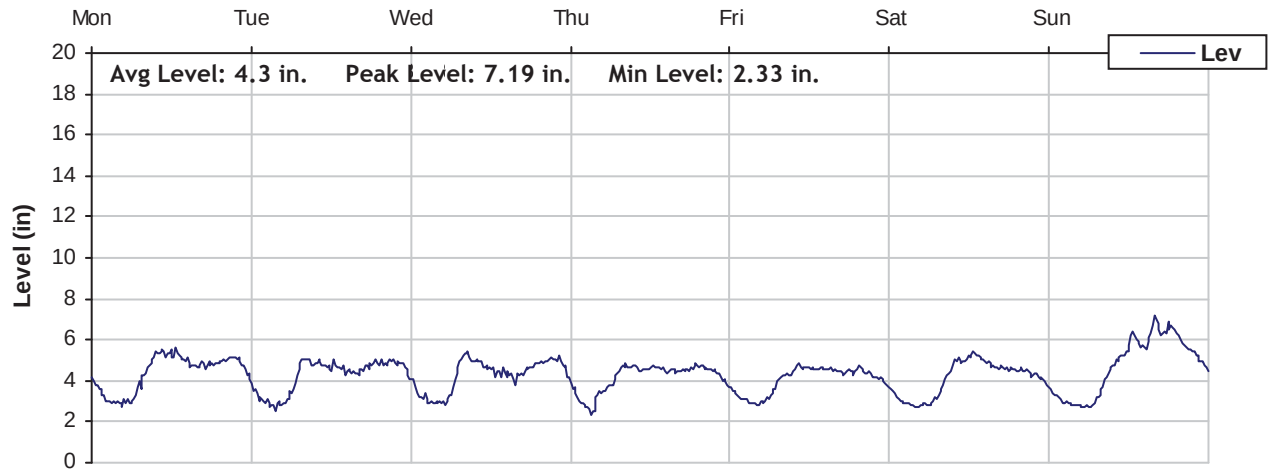


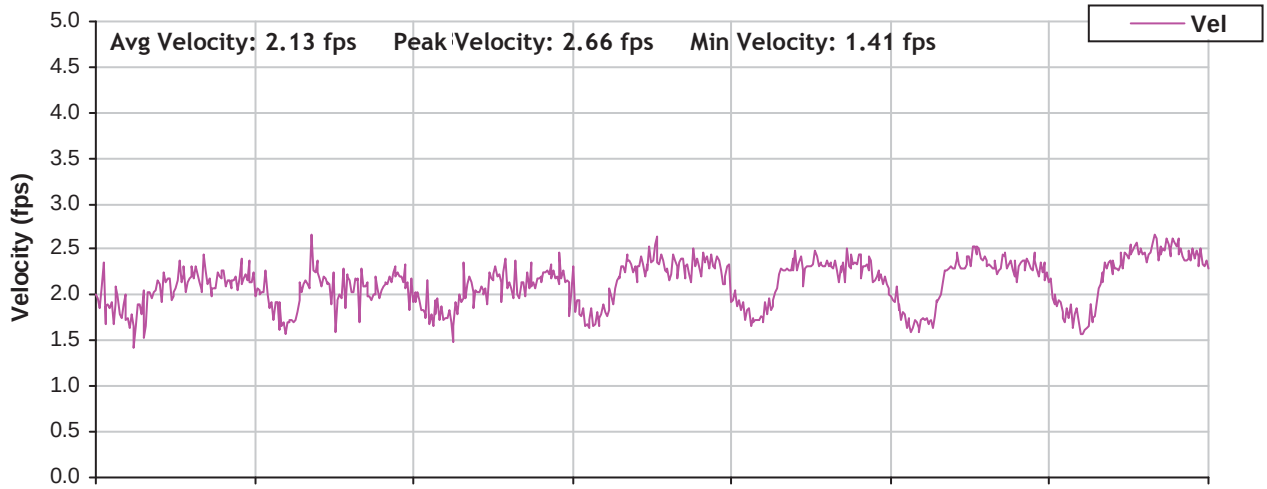


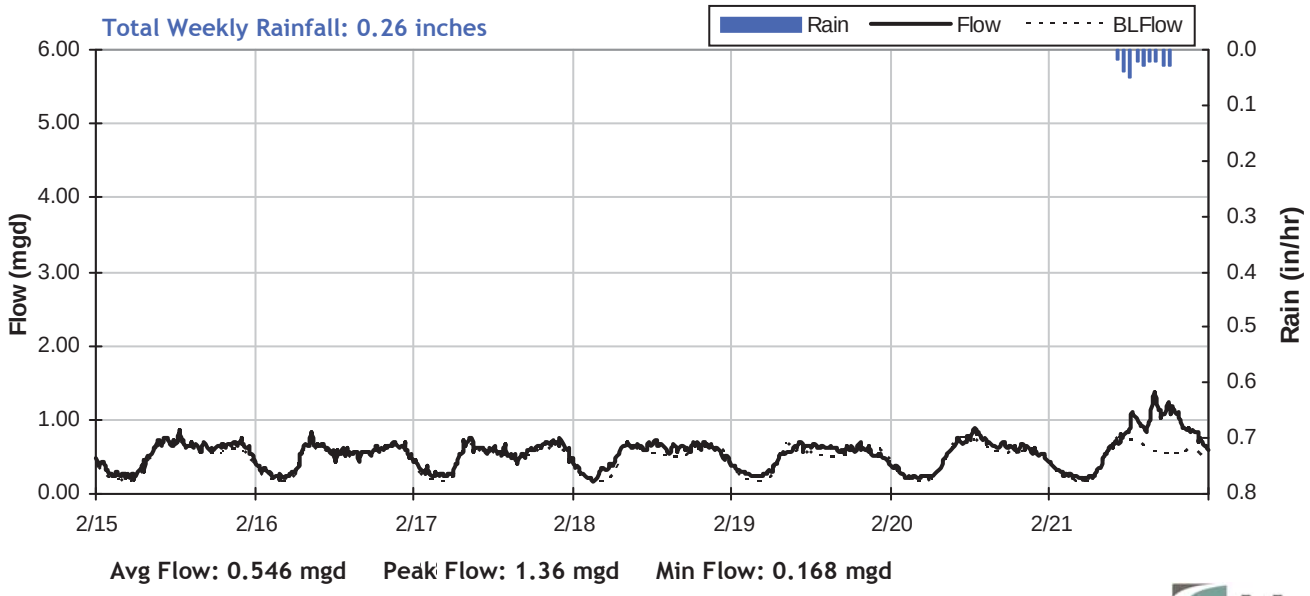


Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 8

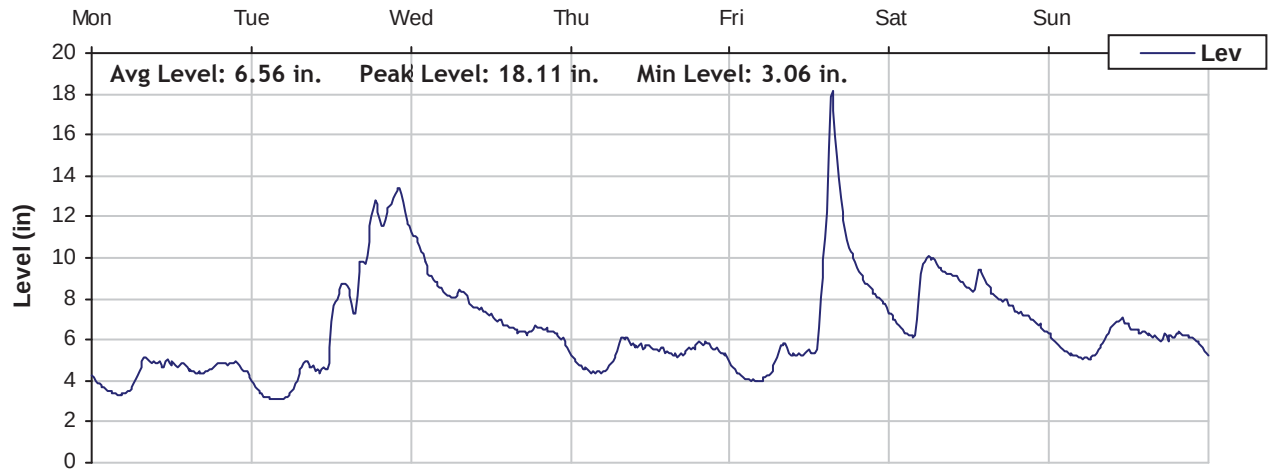


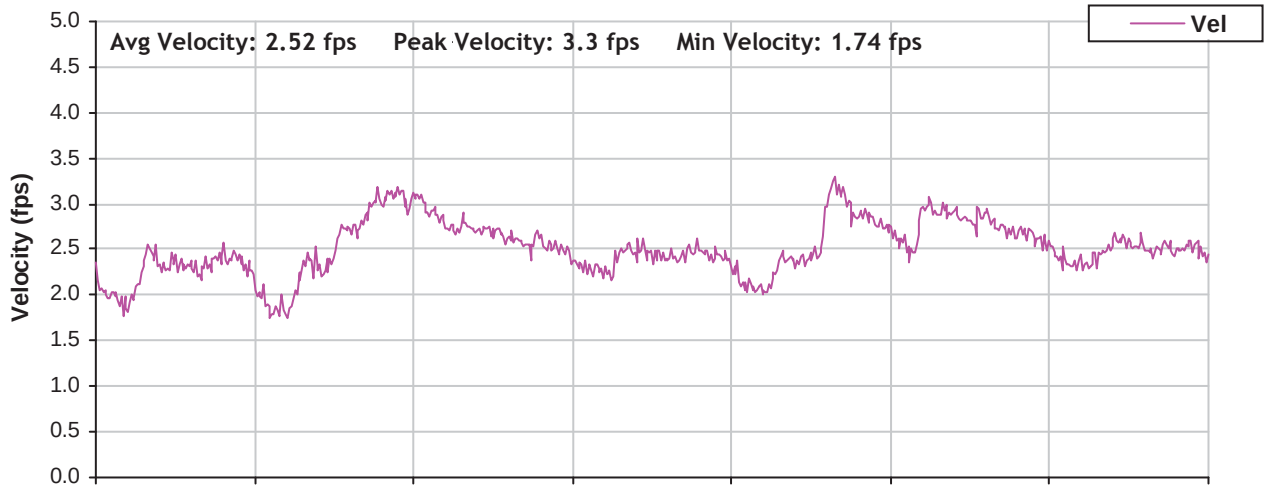


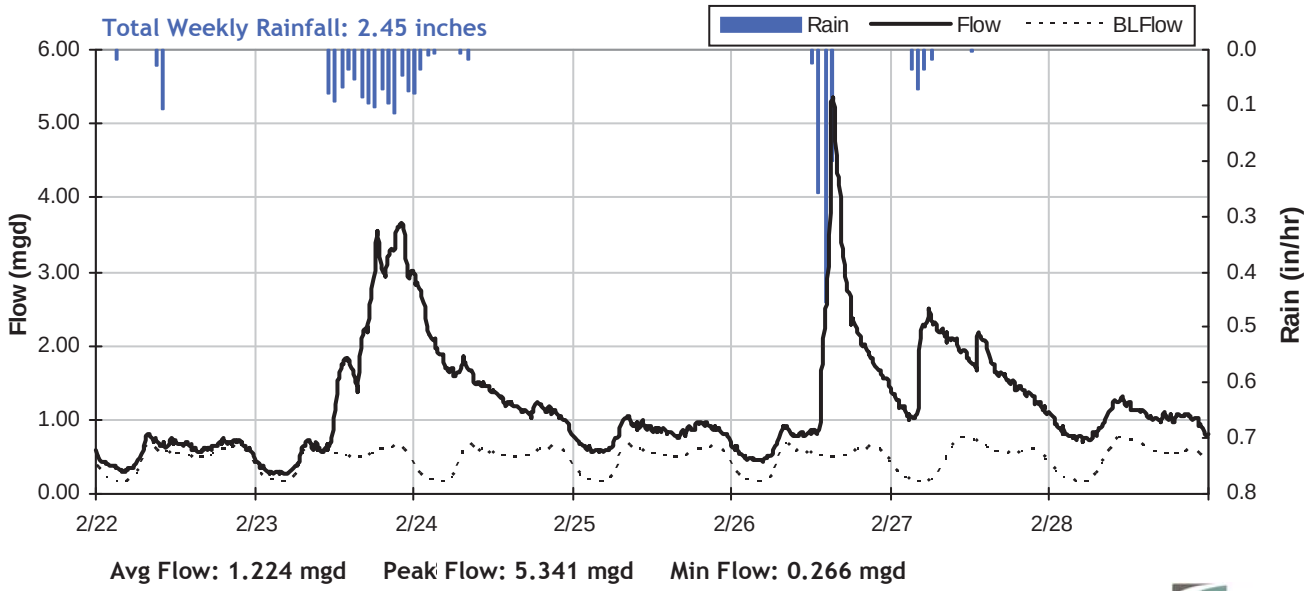


Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 8



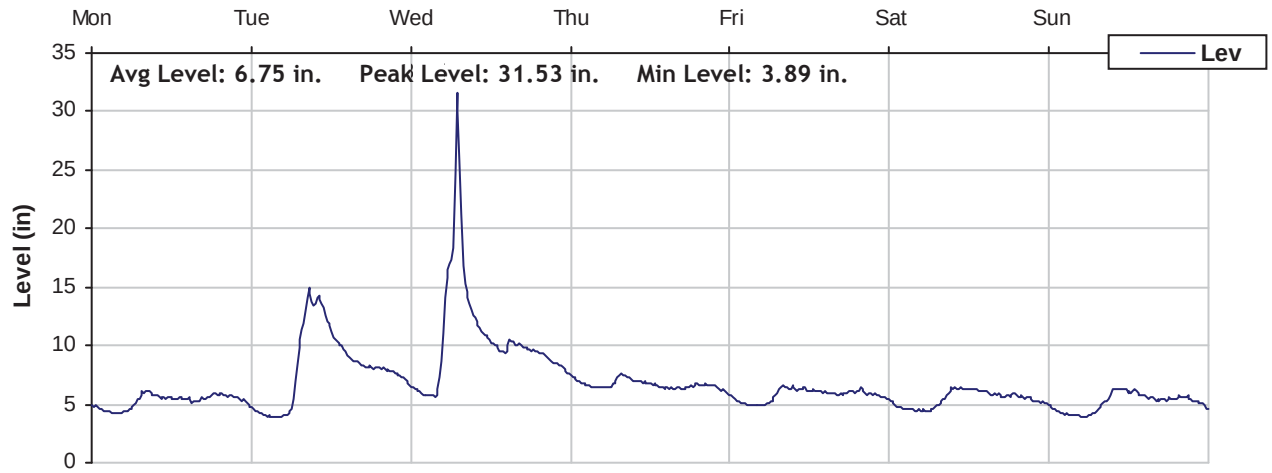


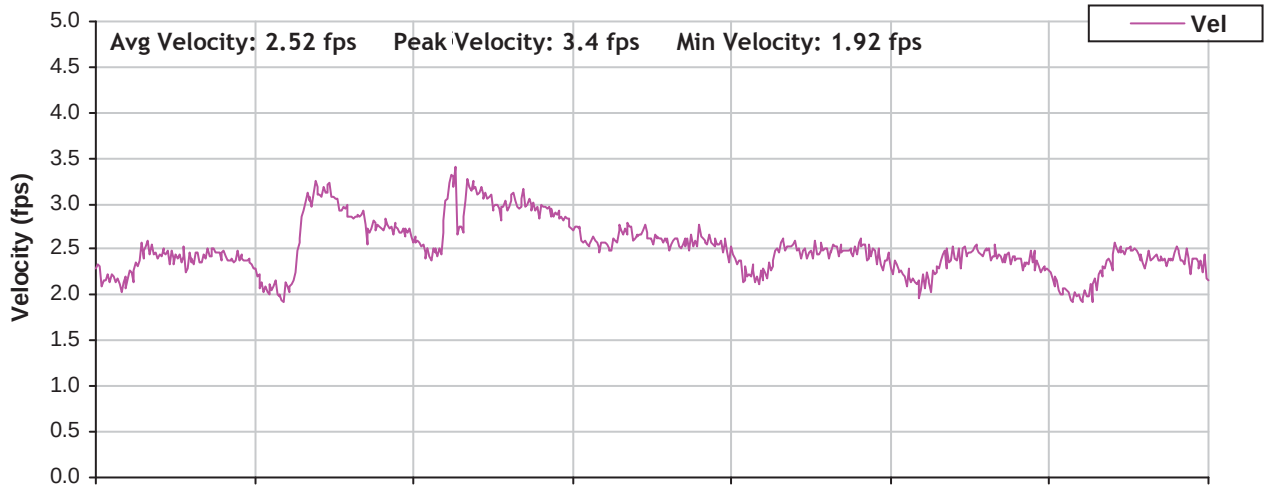


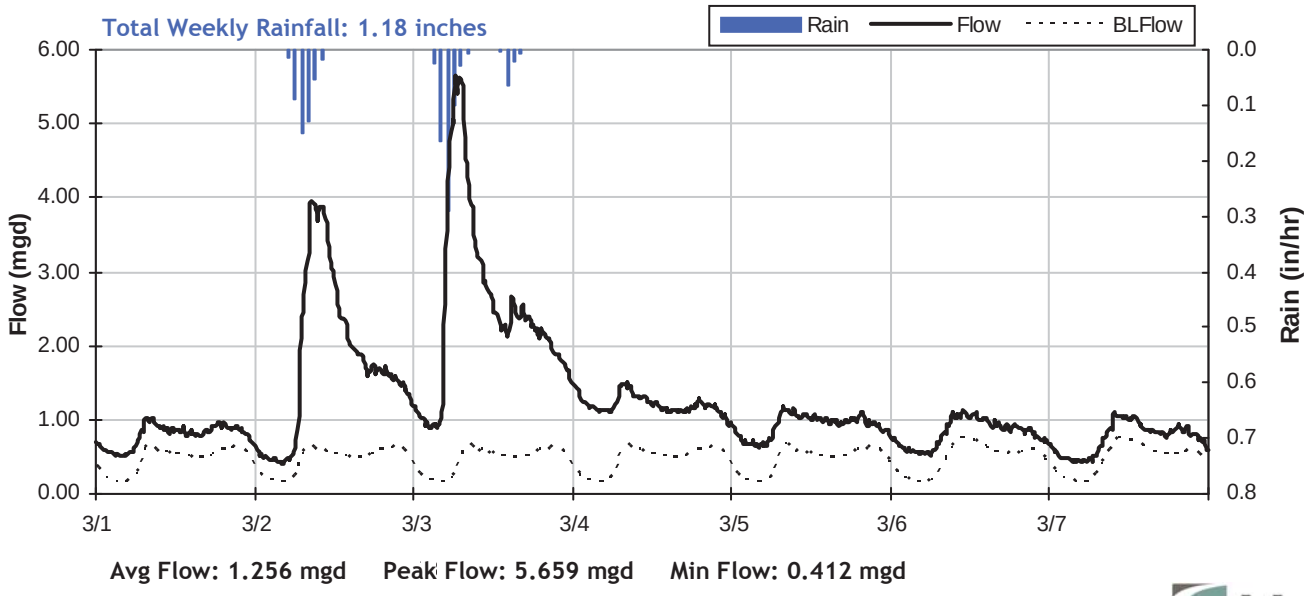
Avg Flow: 1.224 mgd Peak Flow: 5.341 mgd Min Flow: 0.266 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 8



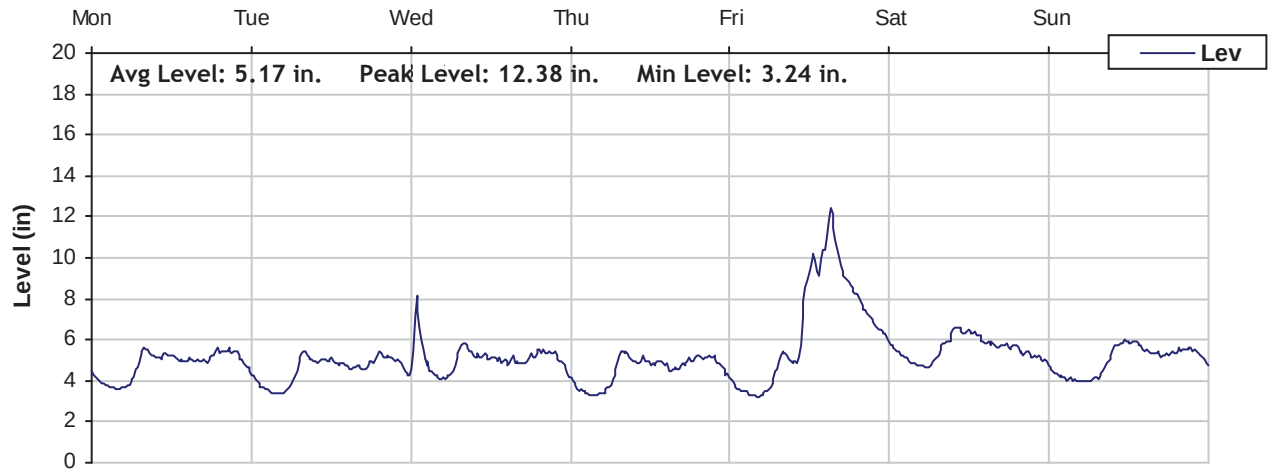


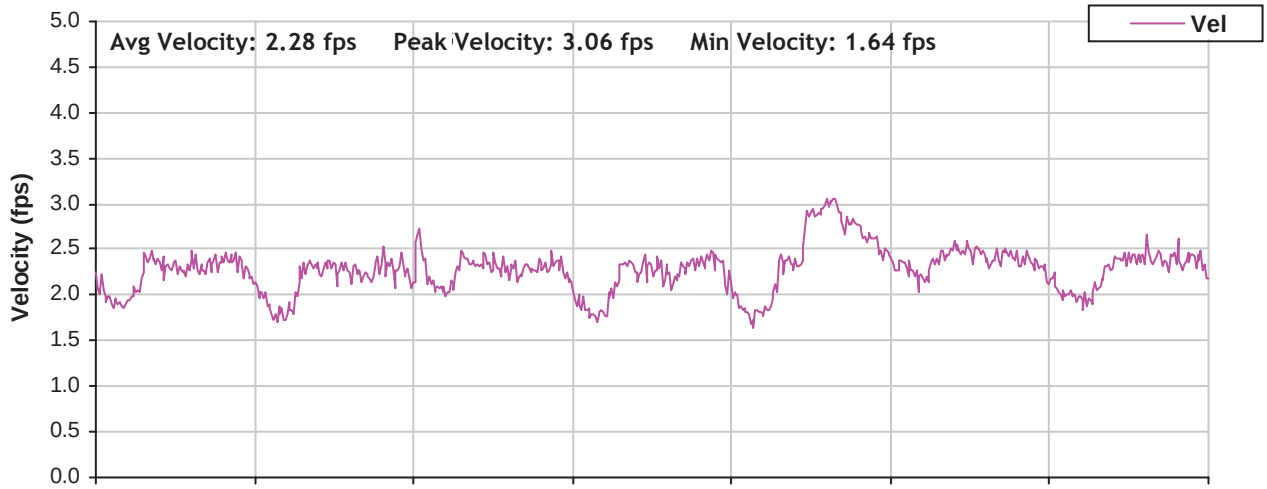


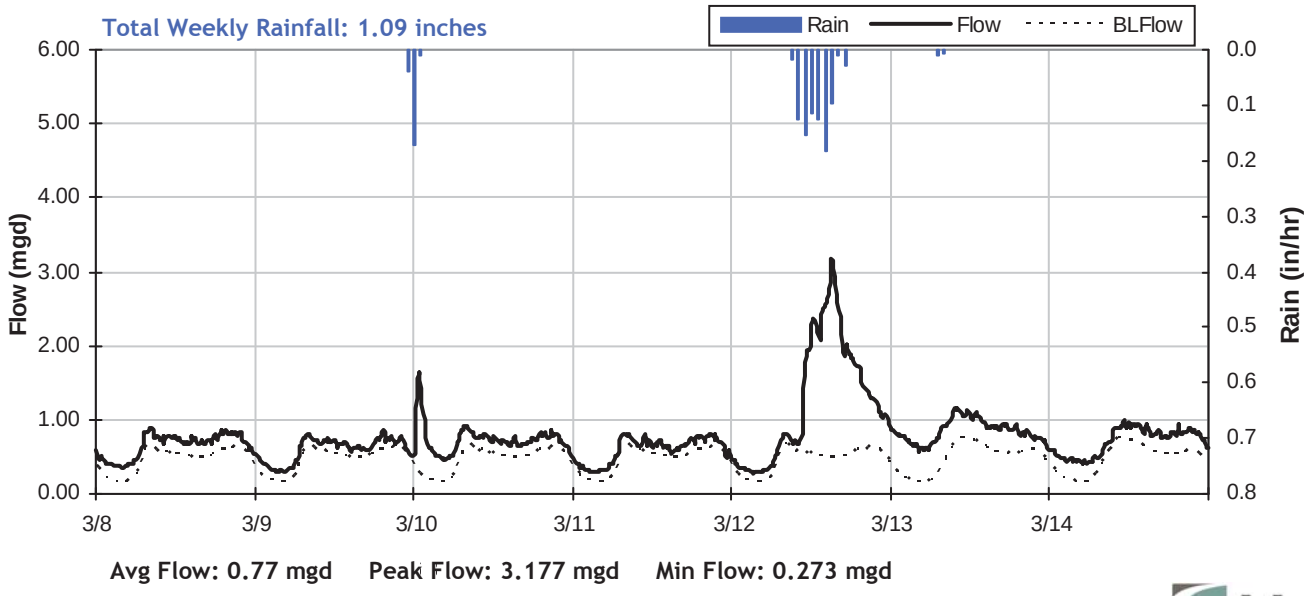
Avg Flow: 1.256 mgd Peak Flow: 5.659 mgd Min Flow: 0.412 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 8



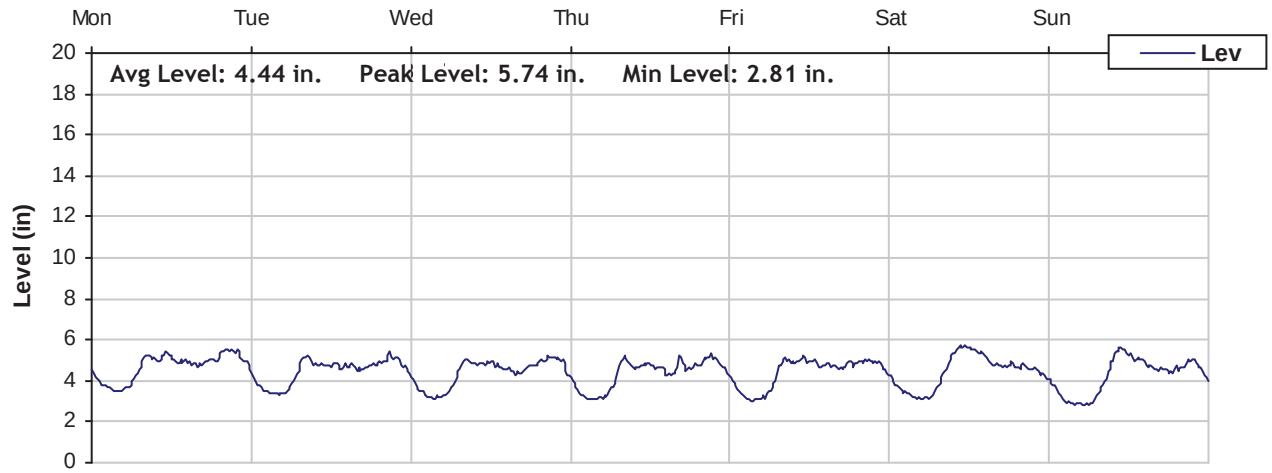


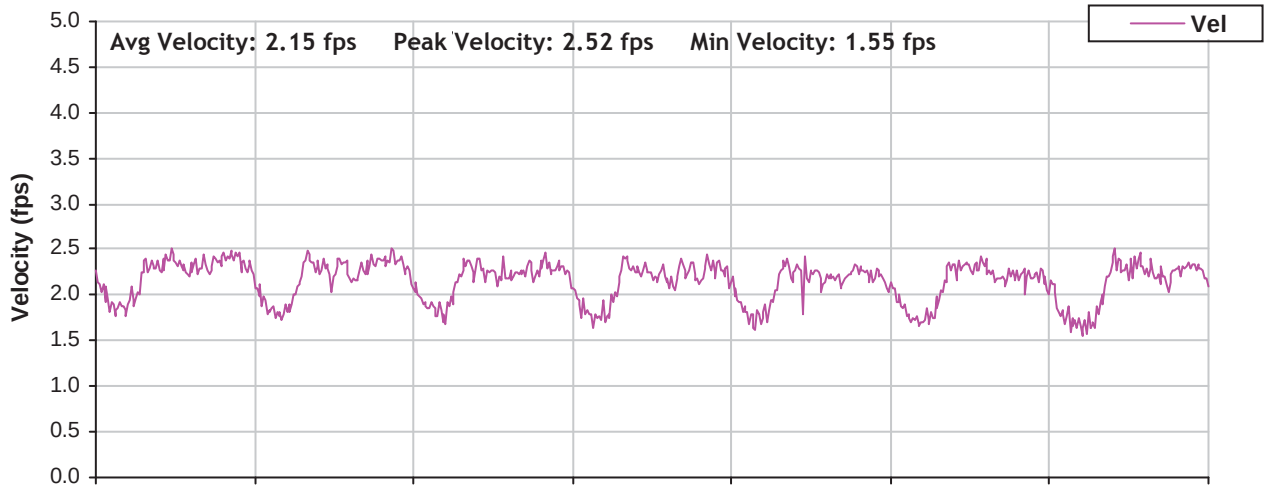


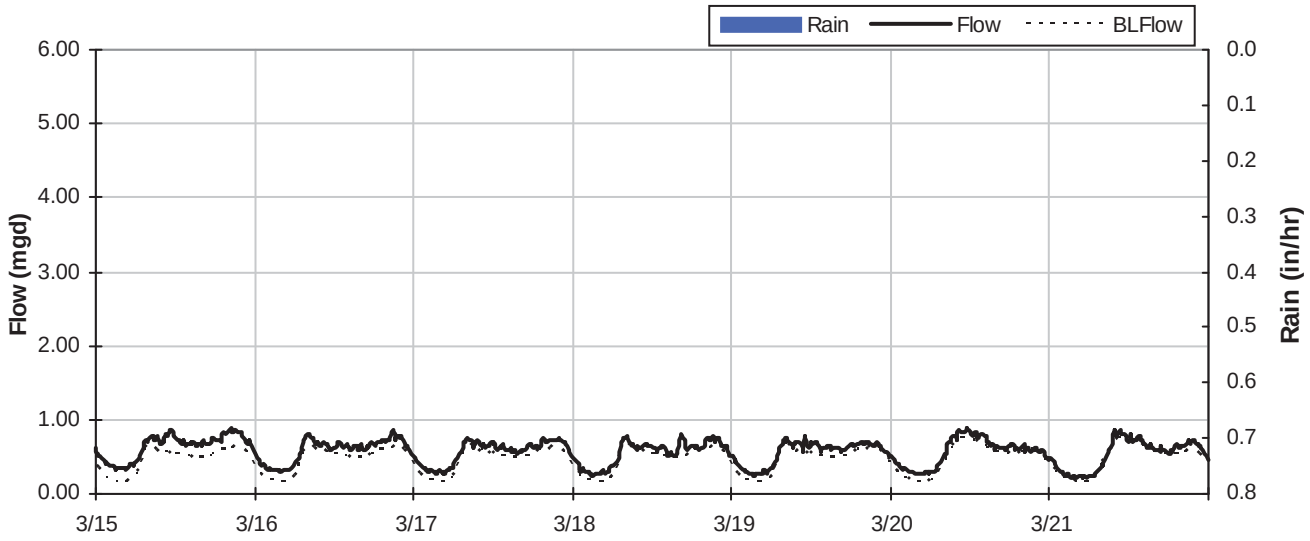
Avg Flow: 0.77 mgd Peak Flow: 3.177 mgd Min Flow: 0.273 mgd

Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

Monitoring Site:
Site 8



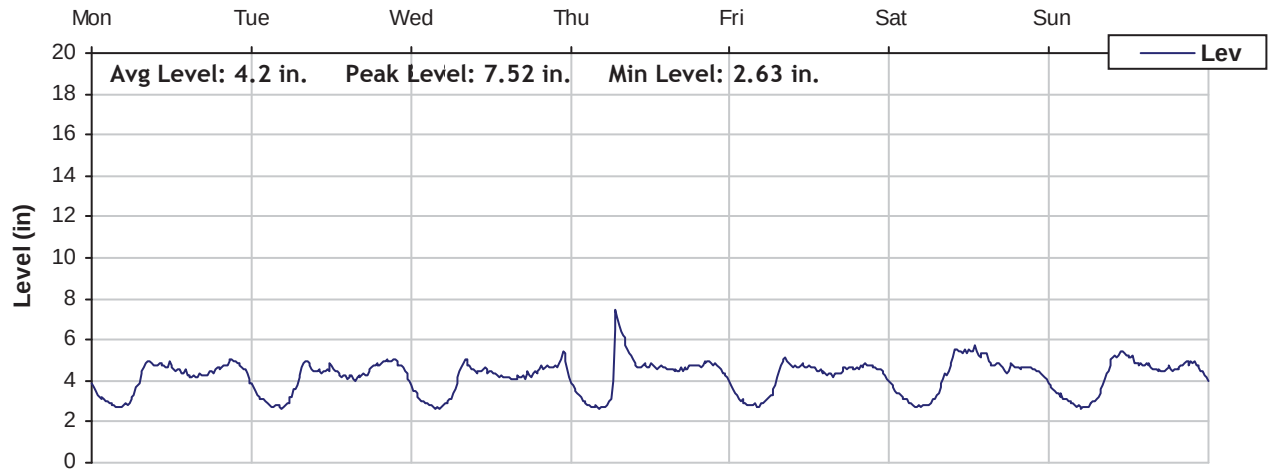


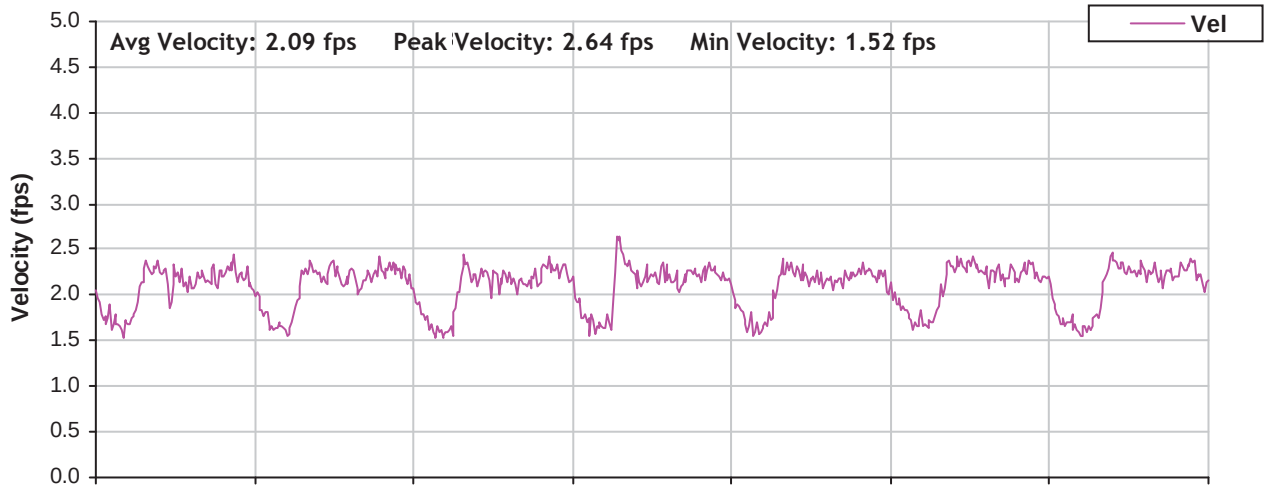


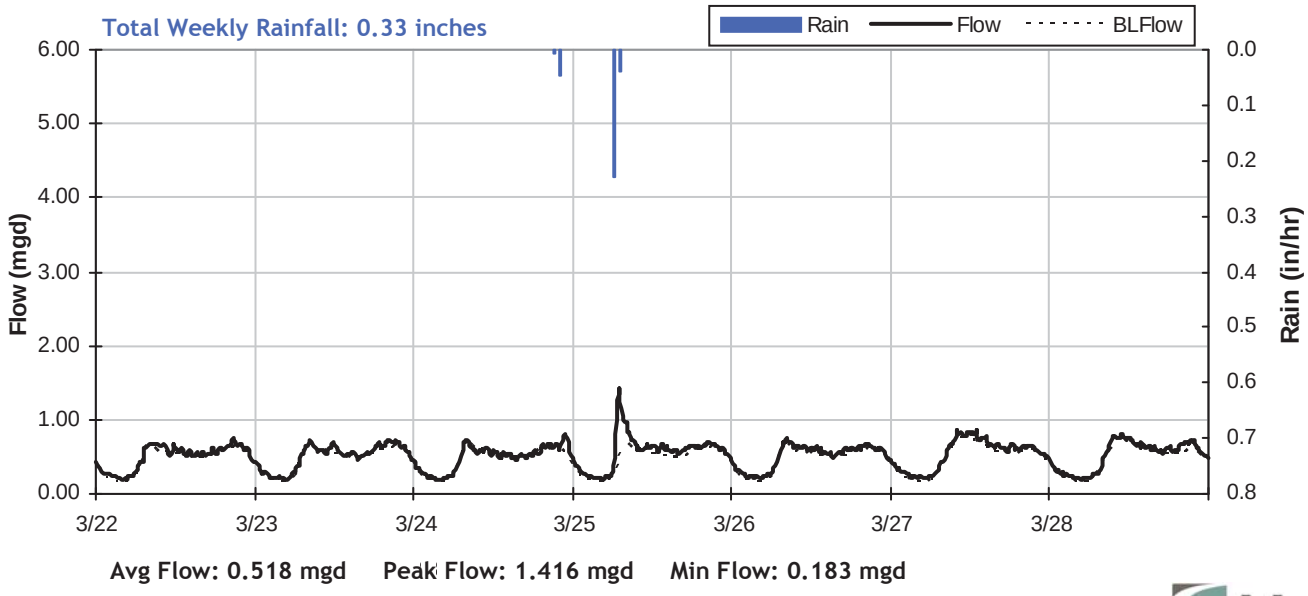
Avg Flow: 0.572 mgd Peak Flow: 0.879 mgd Min Flow: 0.214 mgd

Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 8



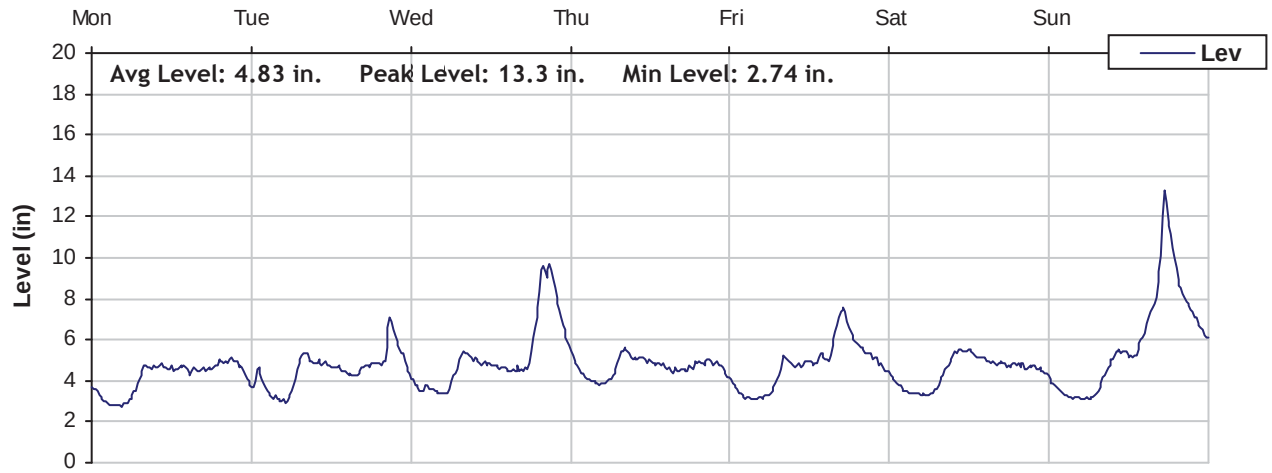


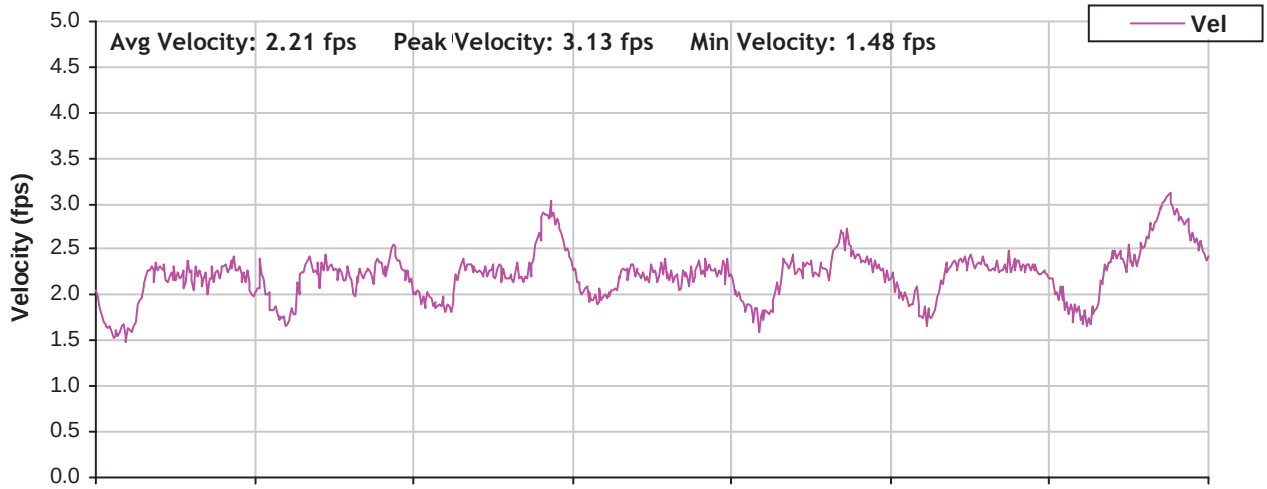


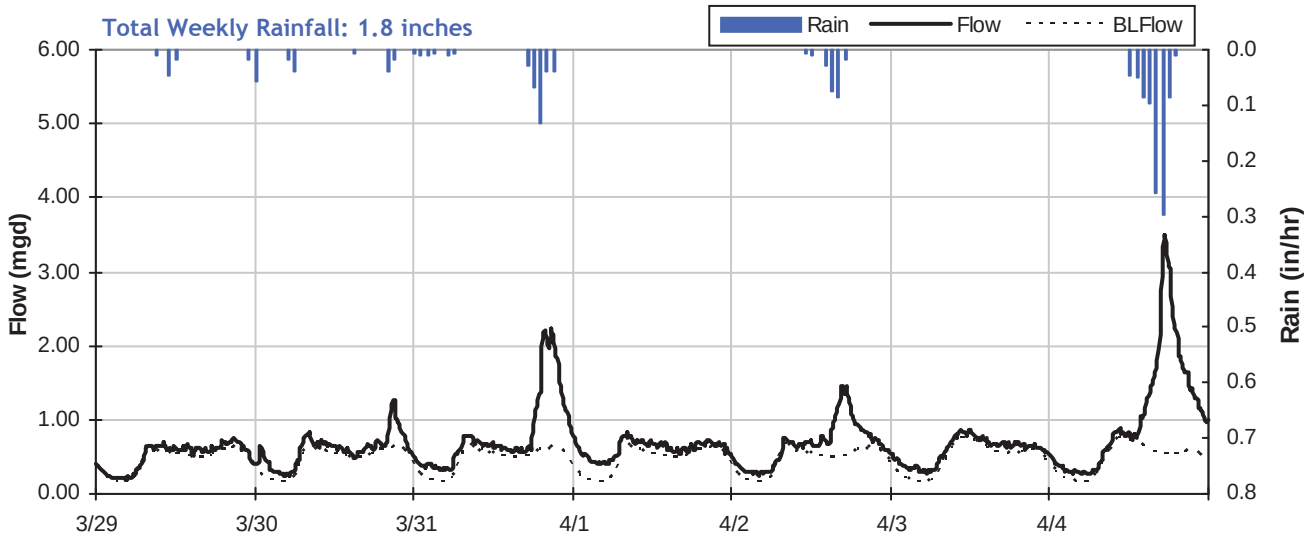
Avg Flow: 0.518 mgd Peak Flow: 1.416 mgd Min Flow: 0.183 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 8



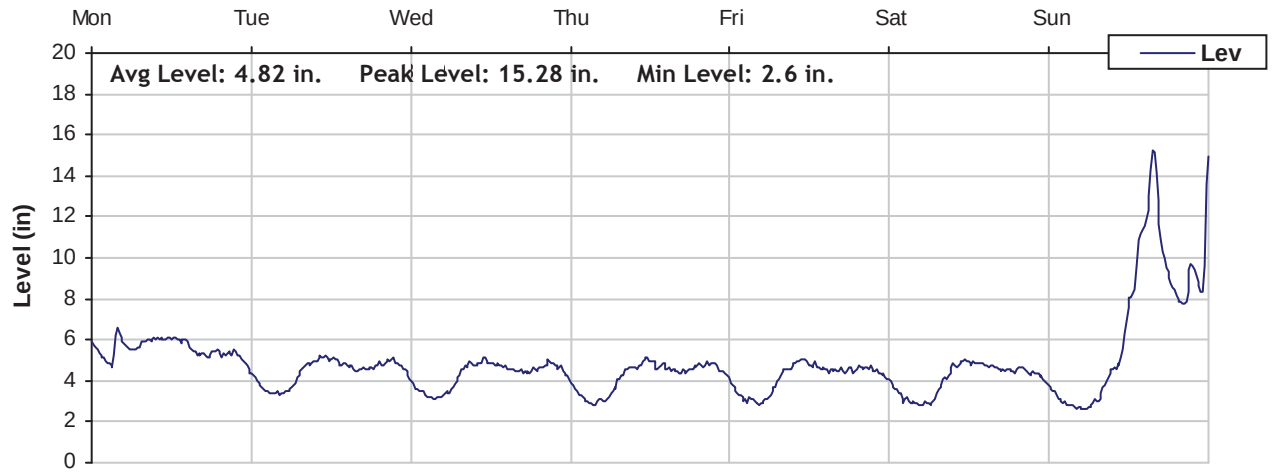


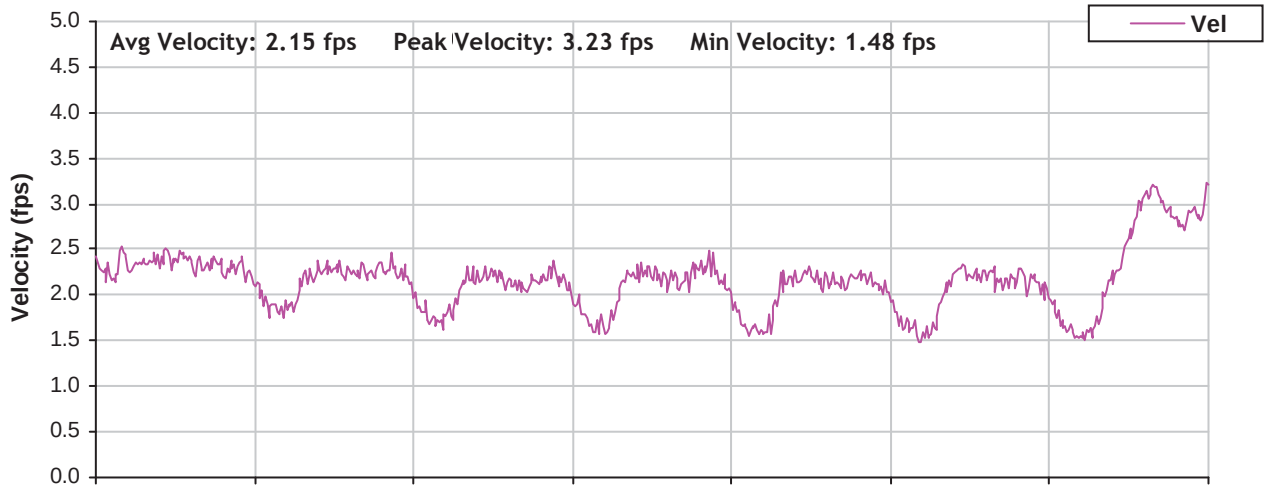


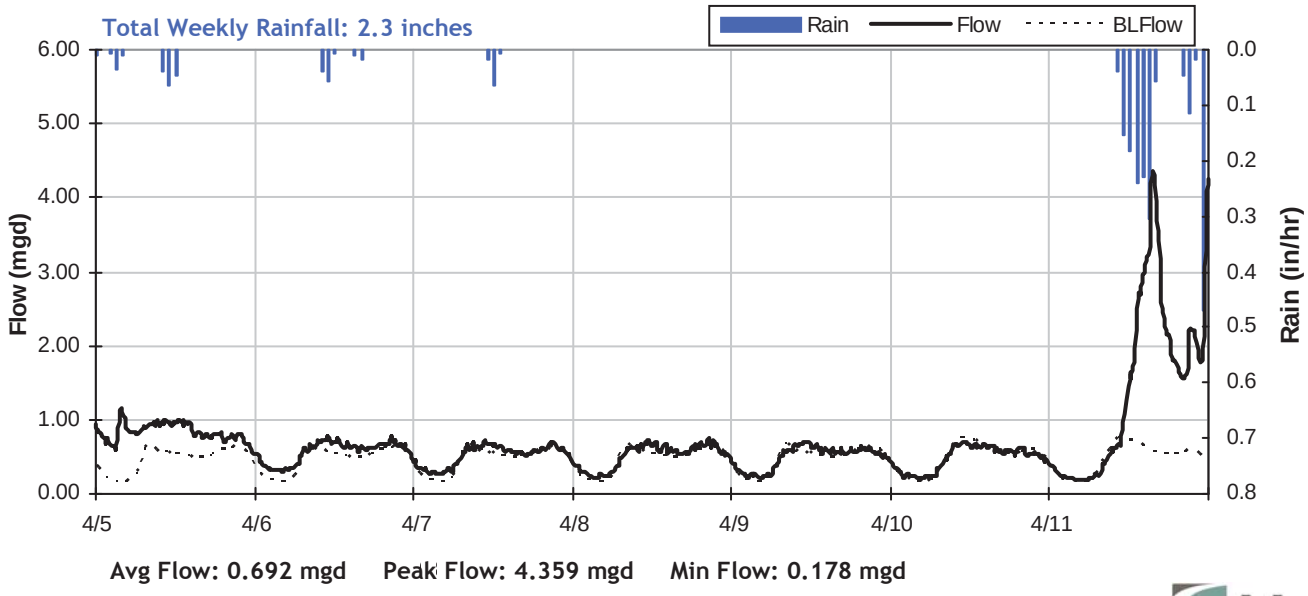
Avg Flow: 0.691 mgd Peak Flow: 3.51 mgd Min Flow: 0.19 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 8



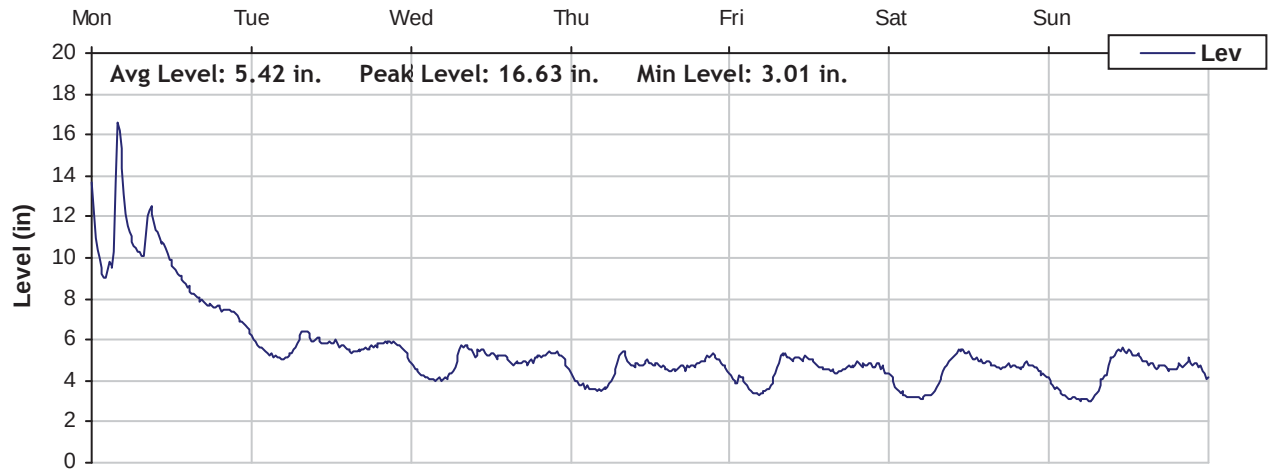


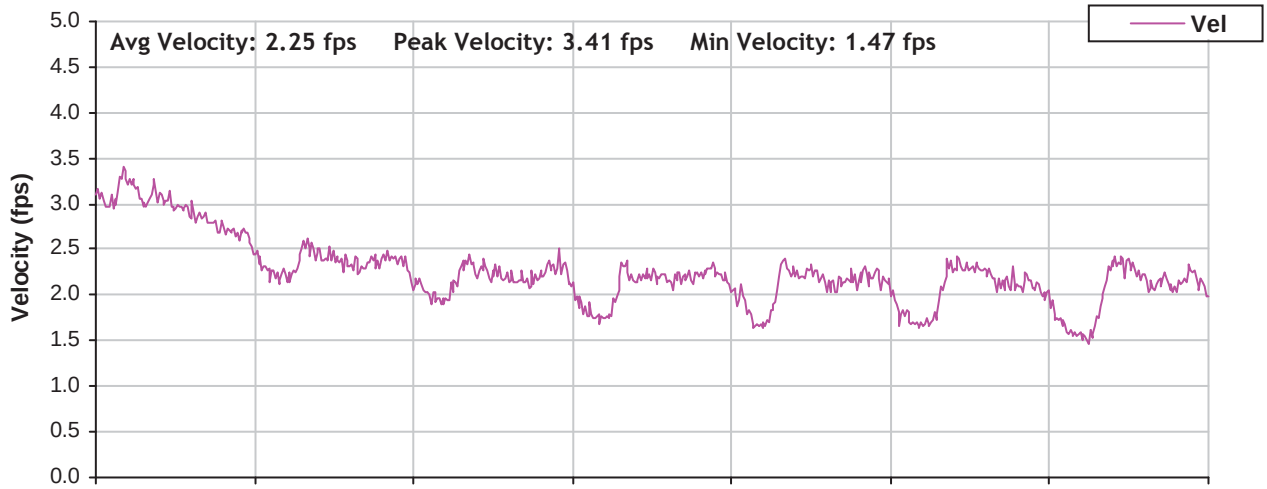


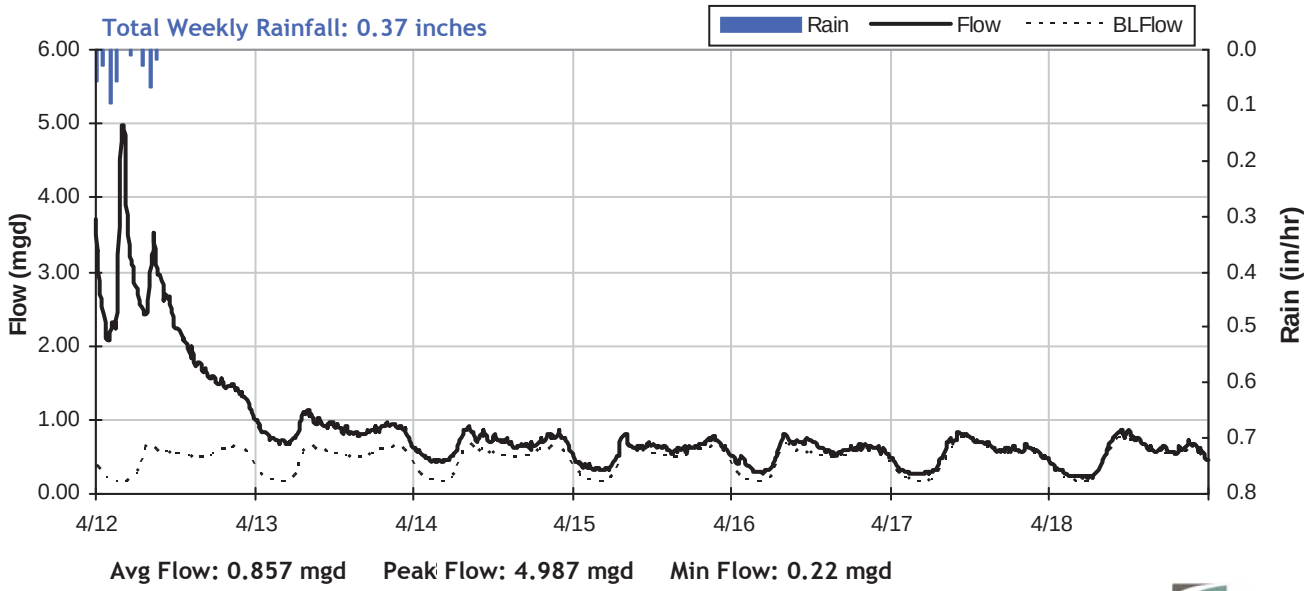
Avg Flow: 0.692 mgd Peak Flow: 4.359 mgd Min Flow: 0.178 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 8



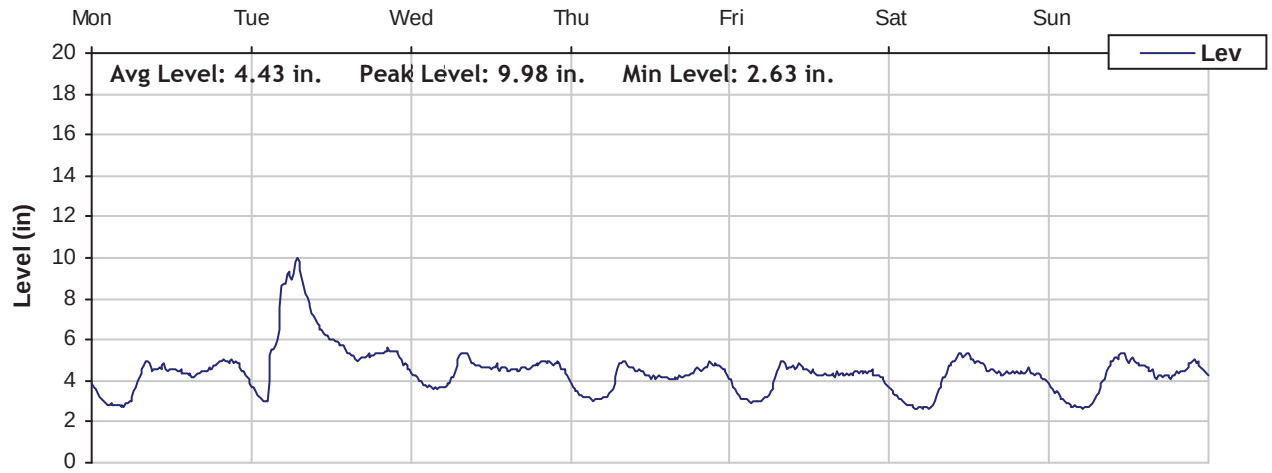


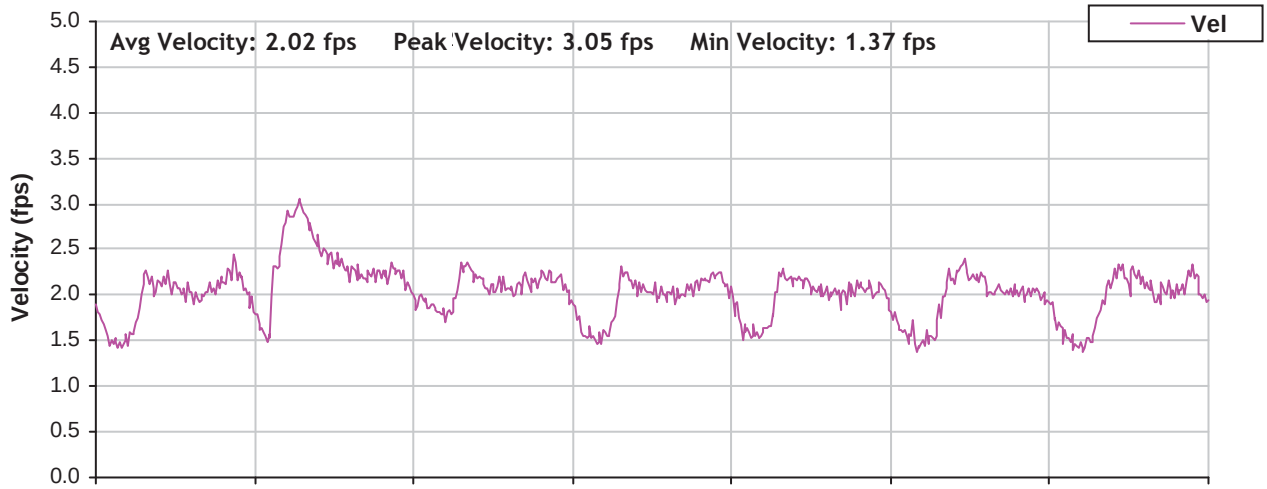


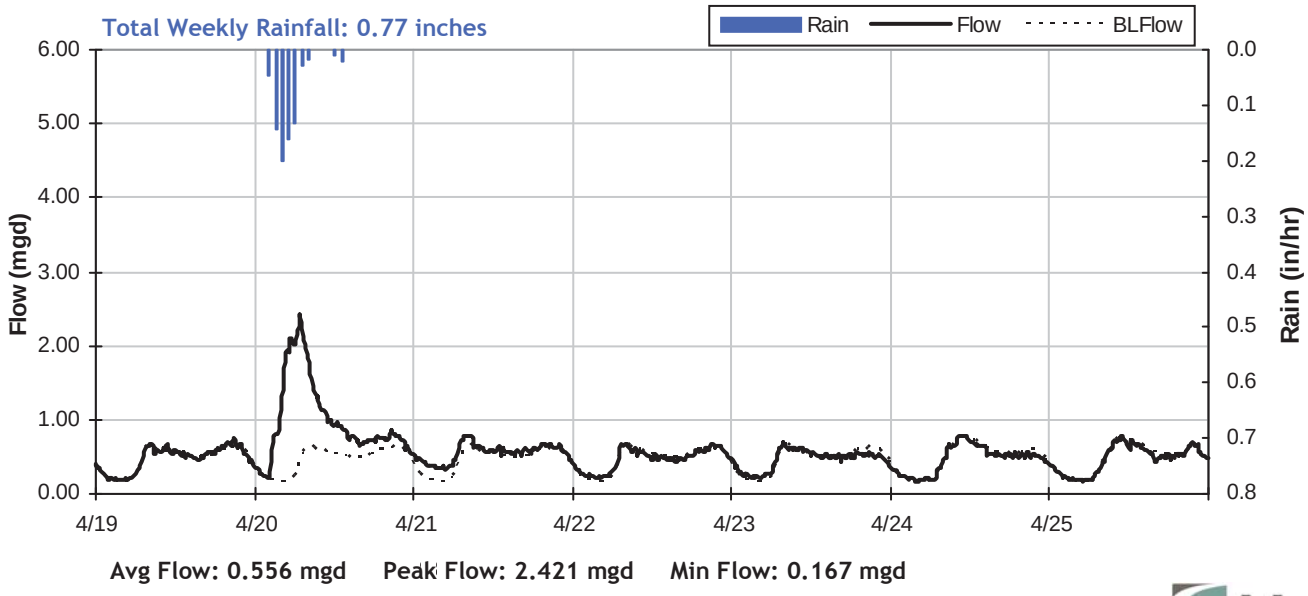
Avg Flow: 0.857 mgd Peak Flow: 4.987 mgd Min Flow: 0.22 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 8



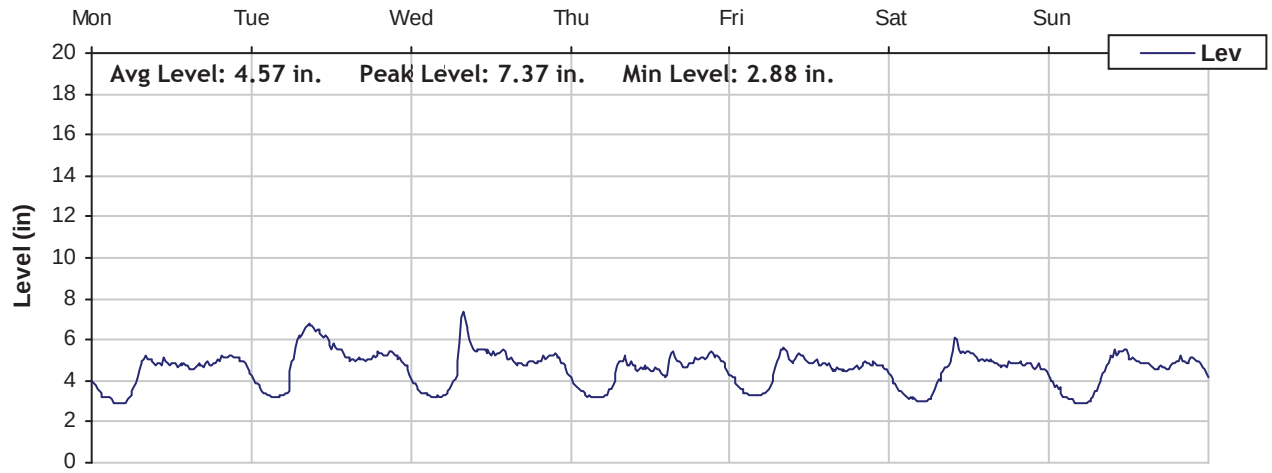


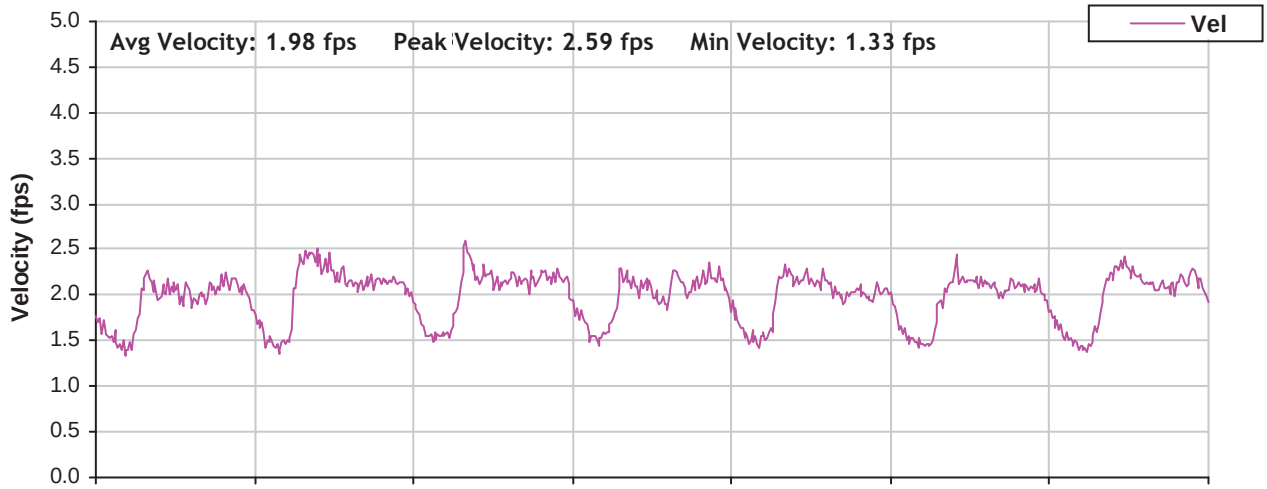


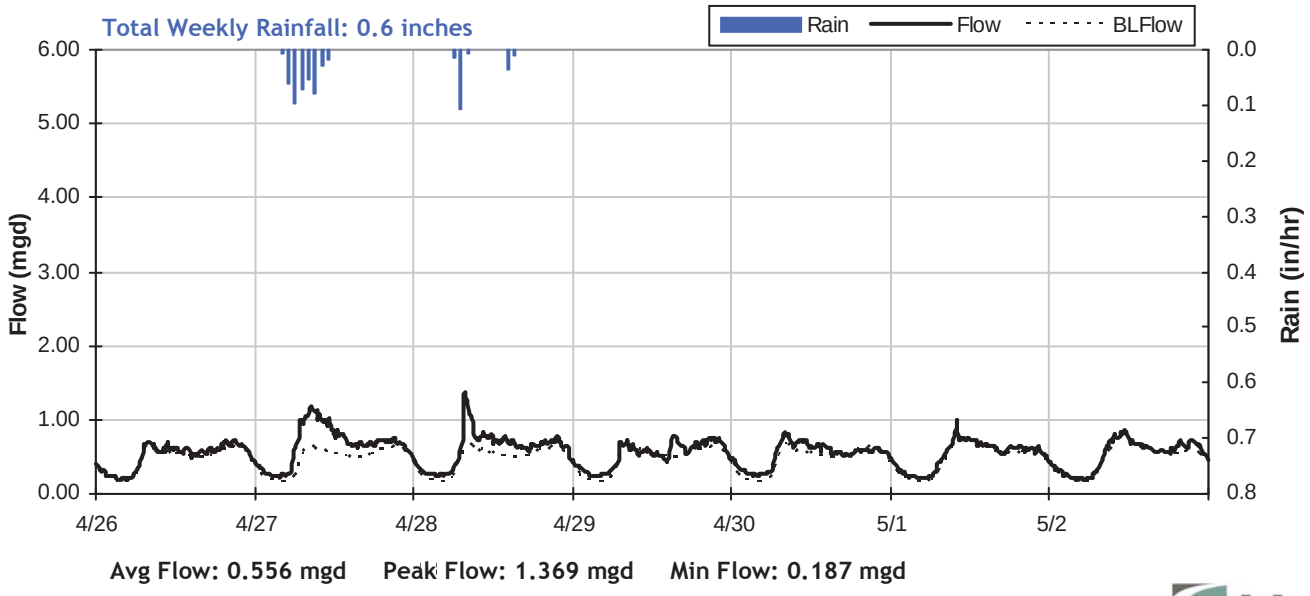
Avg Flow: 0.556 mgd Peak Flow: 2.421 mgd Min Flow: 0.167 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 8



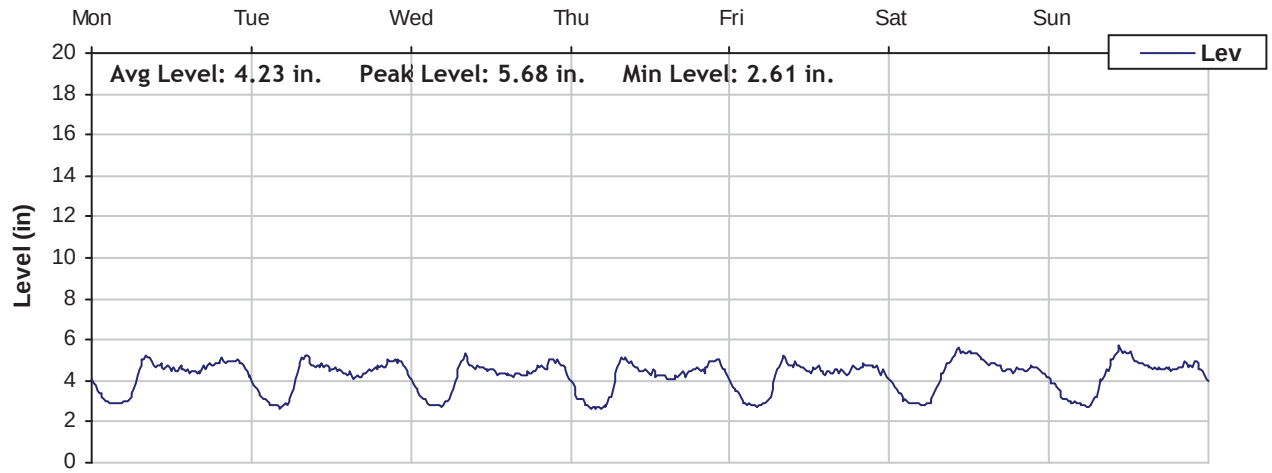


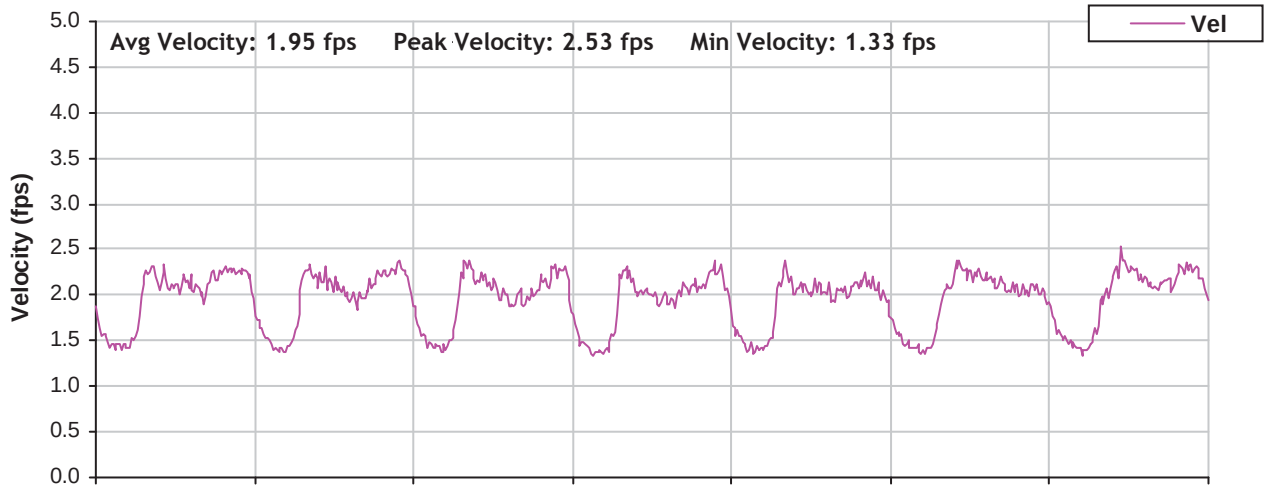


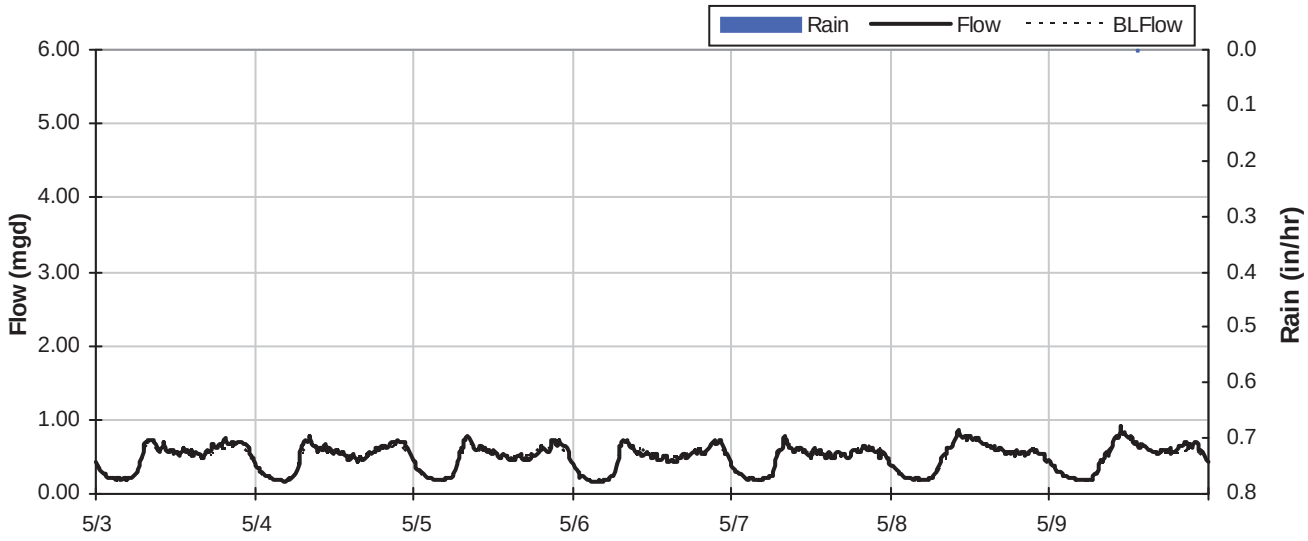
Avg Flow: 0.556 mgd Peak Flow: 1.369 mgd Min Flow: 0.187 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 8



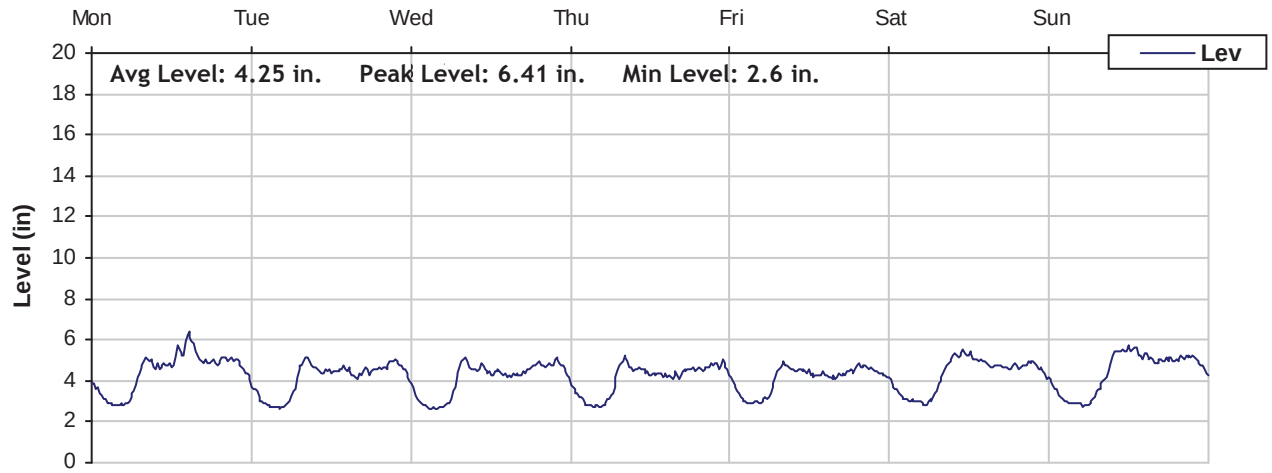


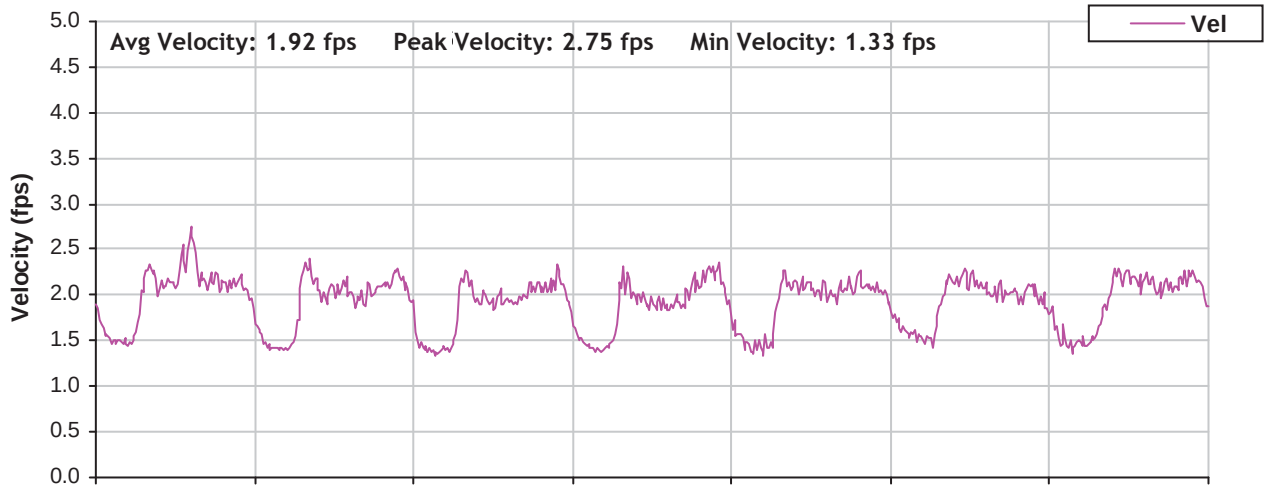


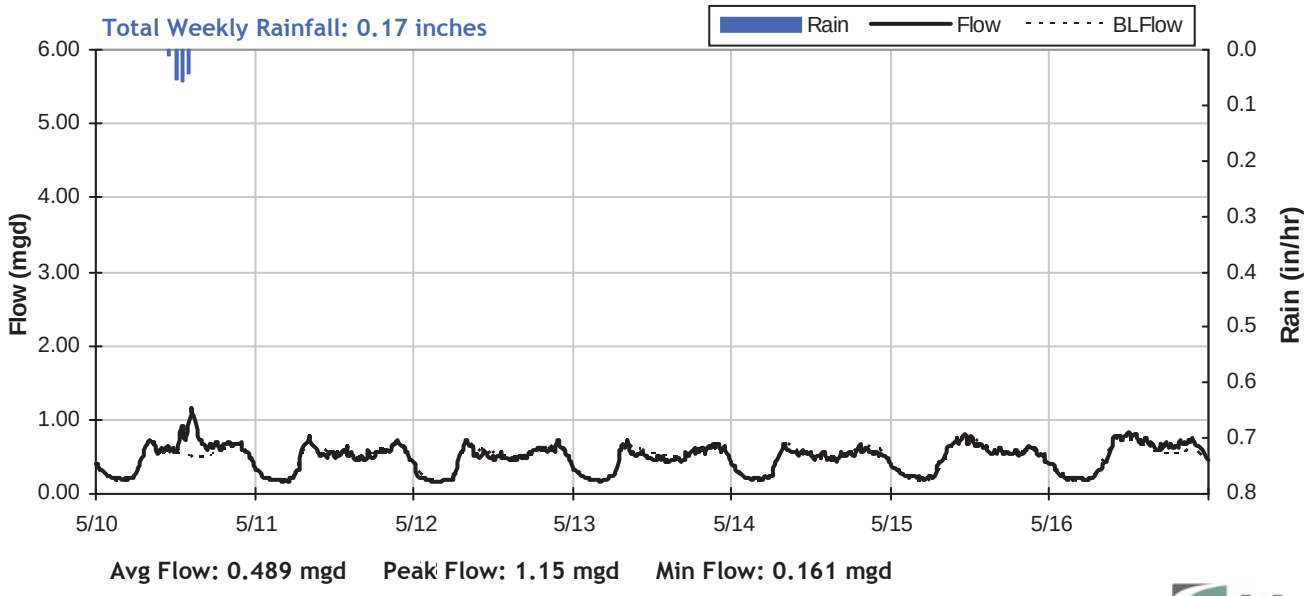
Avg Flow: 0.492 mgd Peak Flow: 0.918 mgd Min Flow: 0.164 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 8



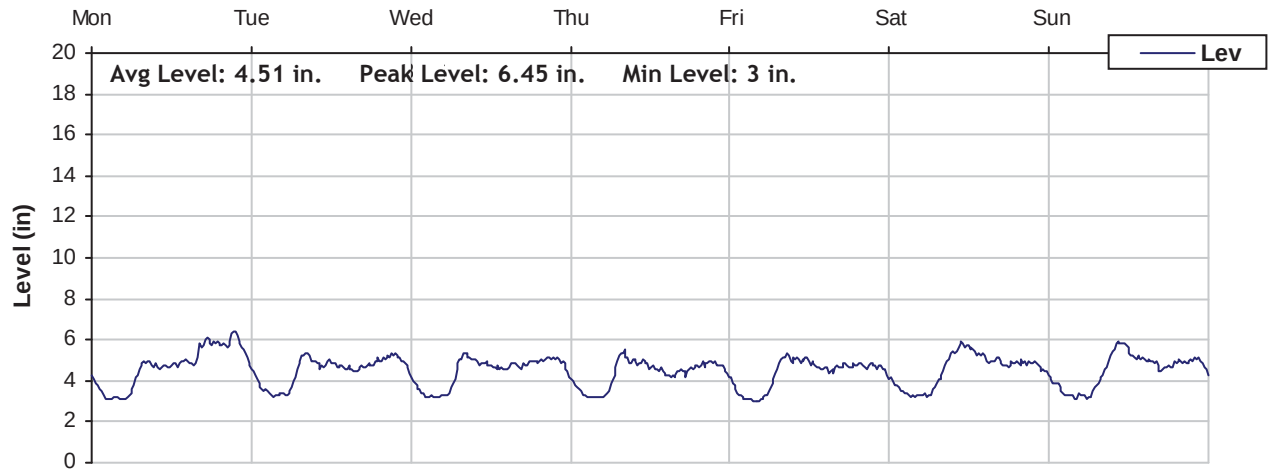


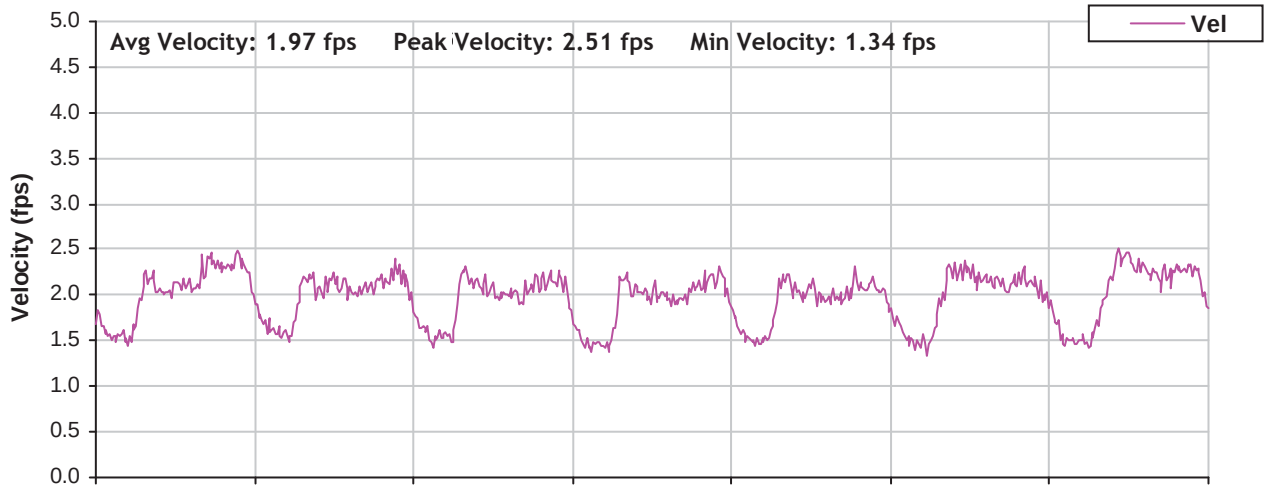


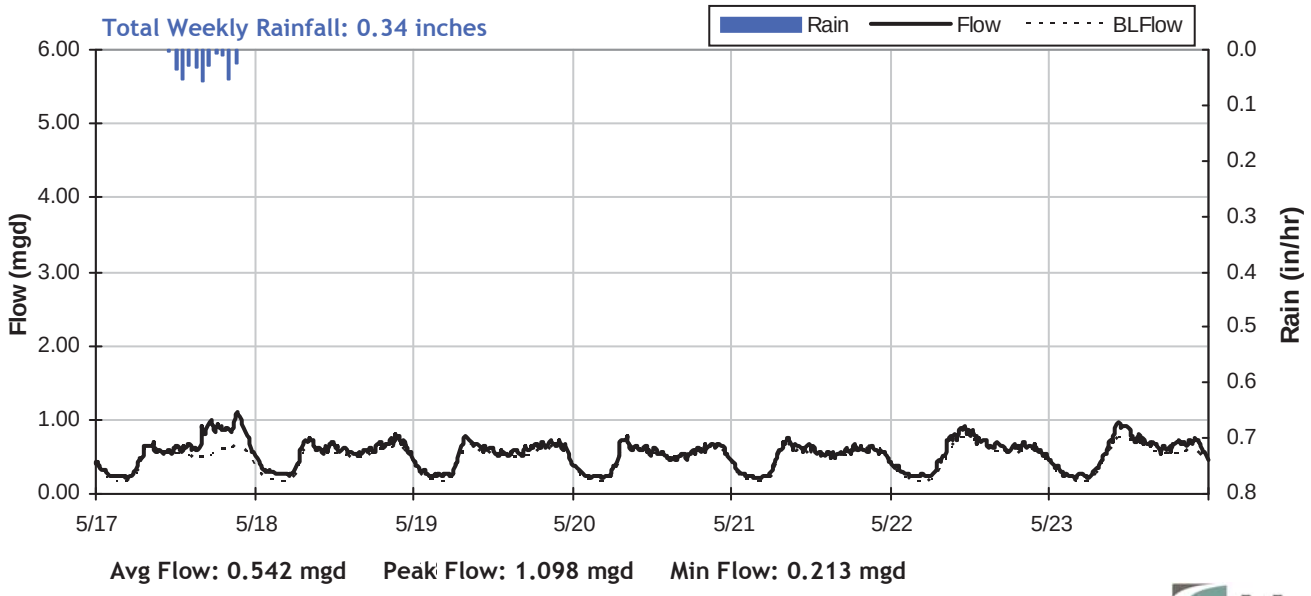
Avg Flow: 0.489 mgd Peak Flow: 1.15 mgd Min Flow: 0.161 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 8



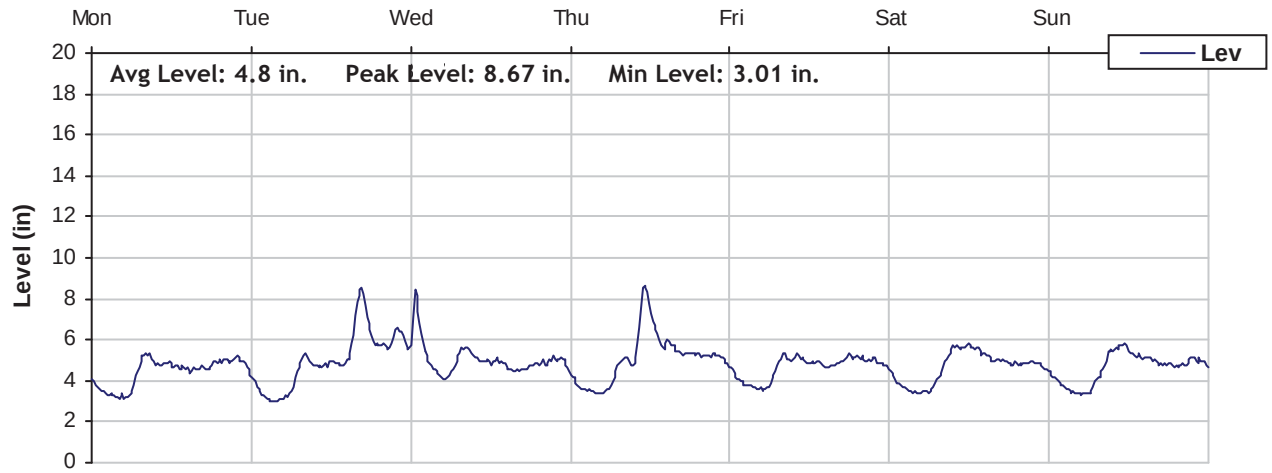


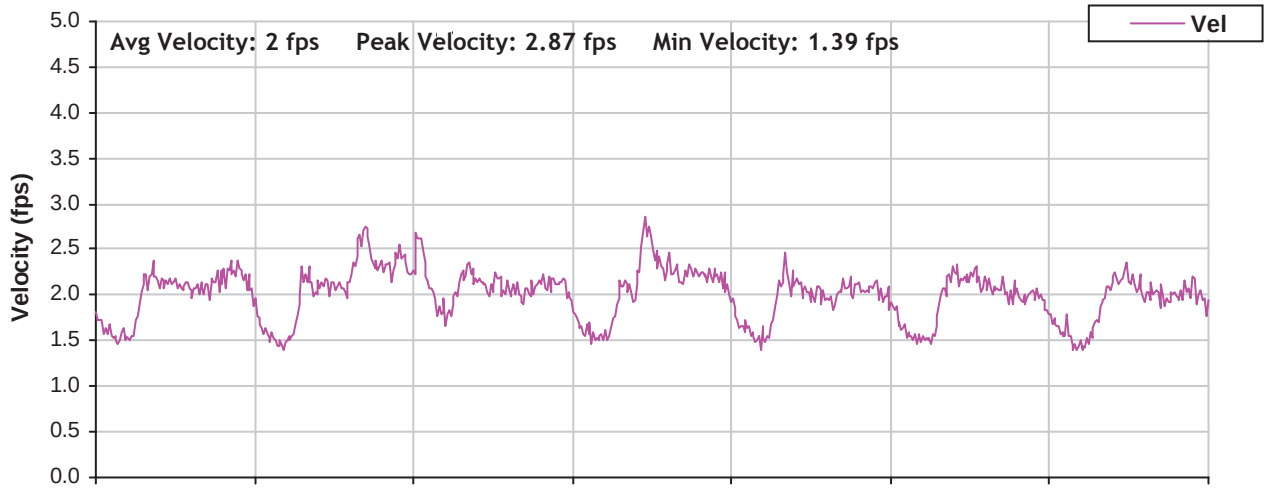


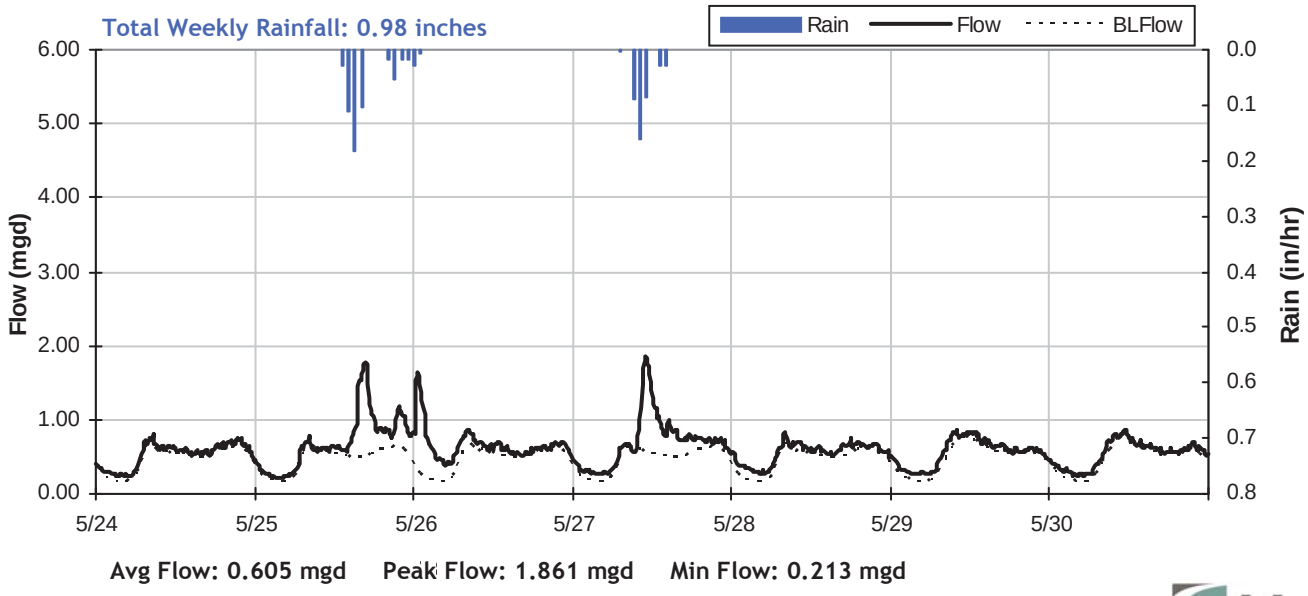
Avg Flow: 0.542 mgd Peak Flow: 1.098 mgd Min Flow: 0.213 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 8



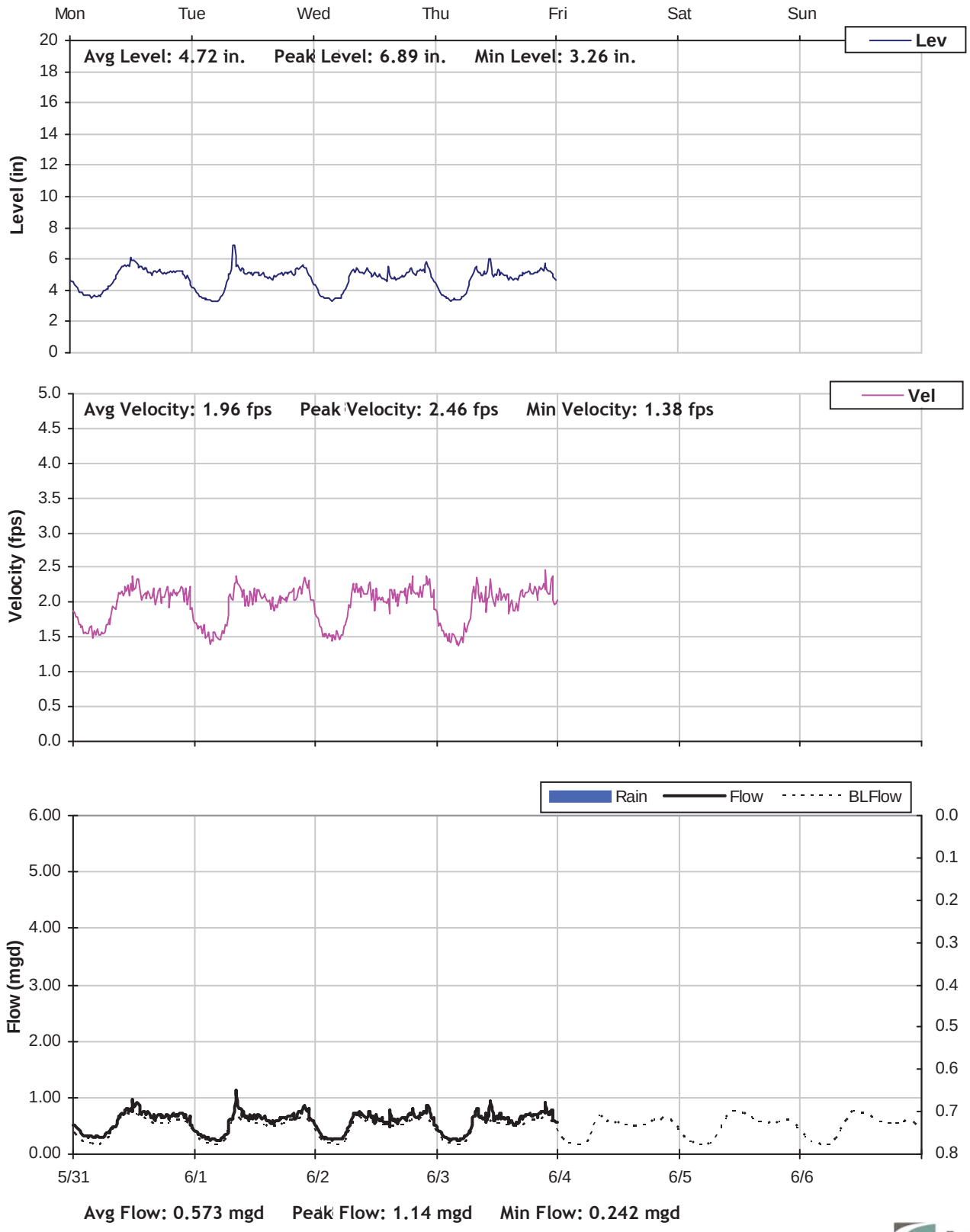




Avg Flow: 0.605 mgd Peak Flow: 1.861 mgd Min Flow: 0.213 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 8



Temporary Flow Monitoring Study

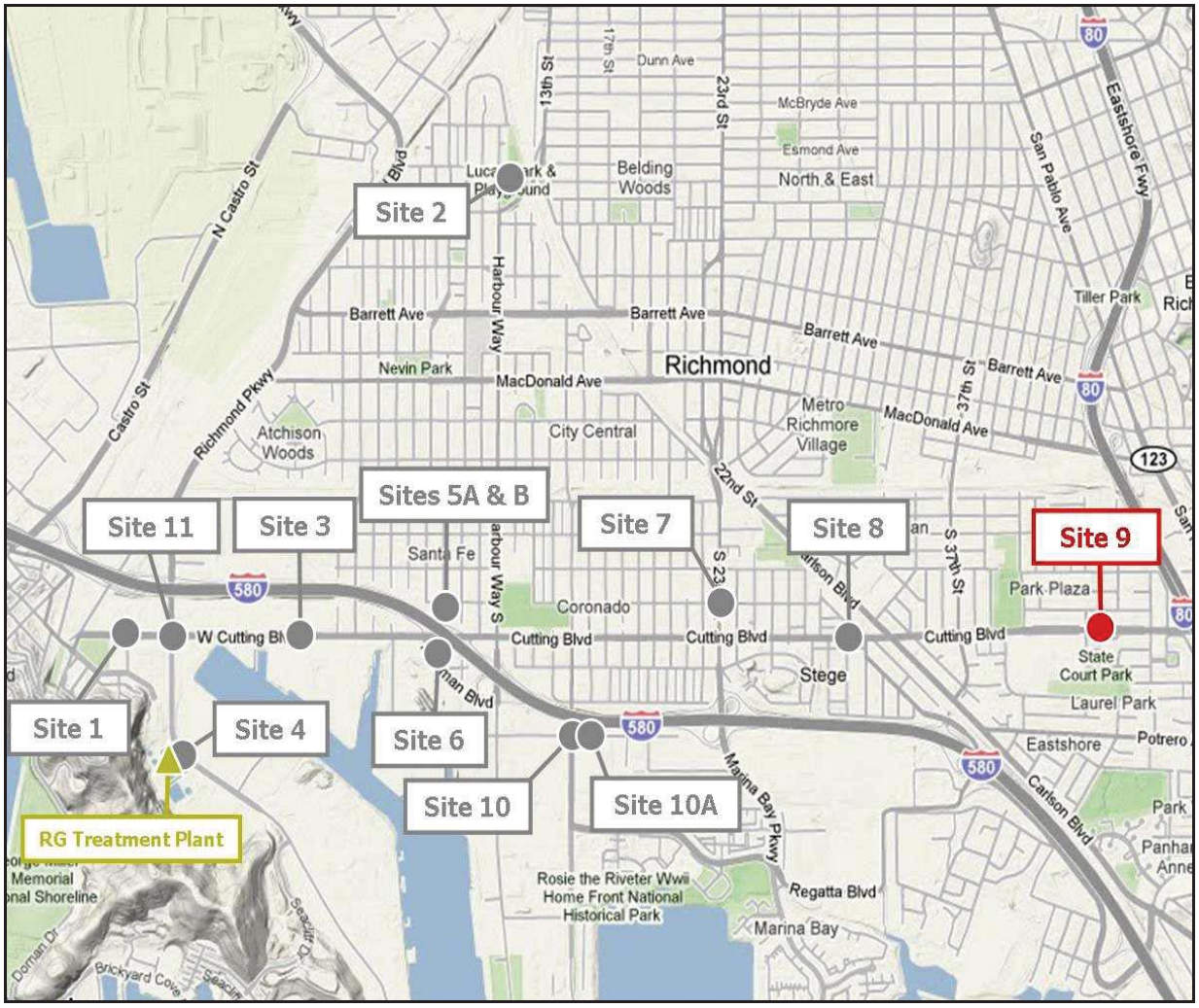
Sanitary Sewer Collection System

Monitoring Site: Site 9

Location: Cutting Boulevard between S 45th Street and S 49th Street

Size/Type Line: 21-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 9

Location: Cutting Boulevard between S 45th Street and S 49th Street

Latitude: 37.9256°

Longitude: -122.3255°

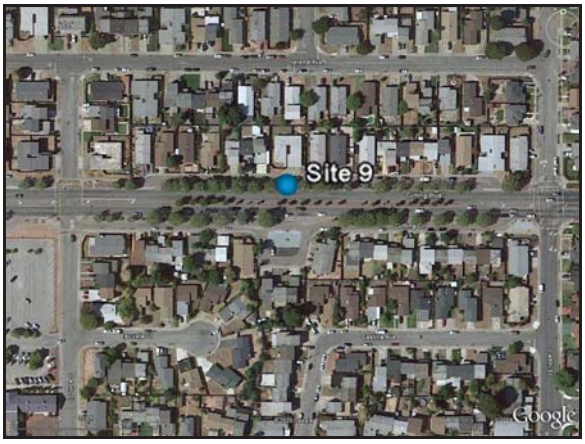
Rim Elevation: 46 *feet above sea level*

Diameter: 21 *inches*

Average Dry Weather Flow: 0.411 *mgd*

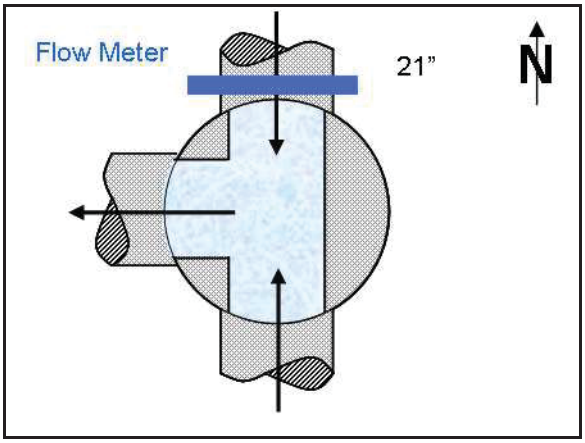
Peak Measured Flow: 5.550 *mgd*

Satellite Photo



Sanitary Map

Flow Sketch

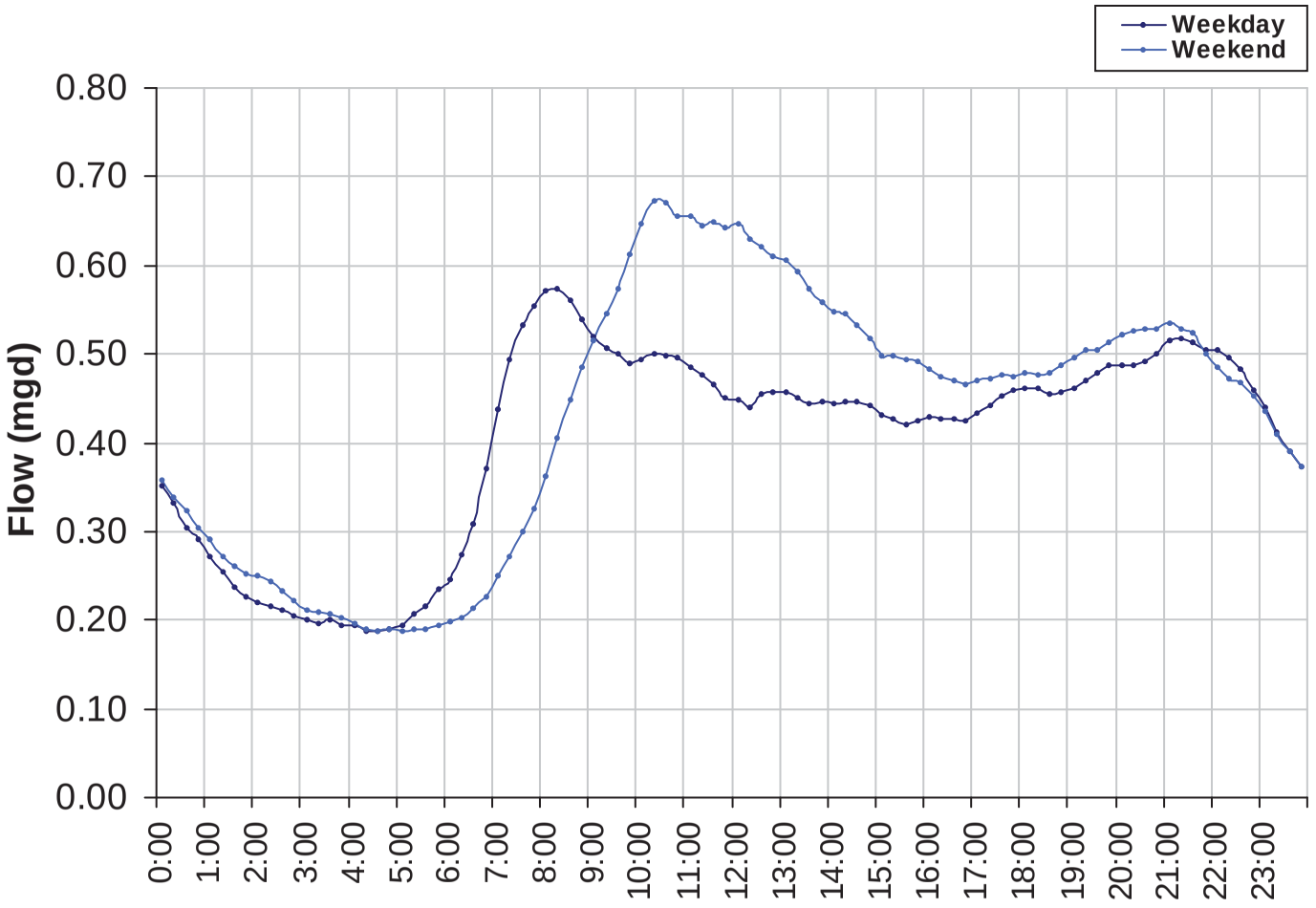


Street View Photo

Plan View Photo

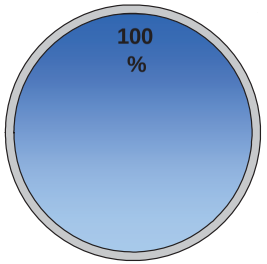
Average Dry Weather Flow

Monitoring Site:
Site 9



Peak Measured Flow:

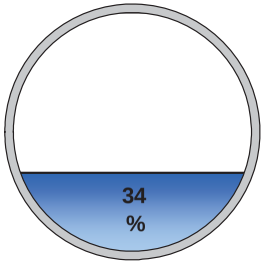
5.55 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

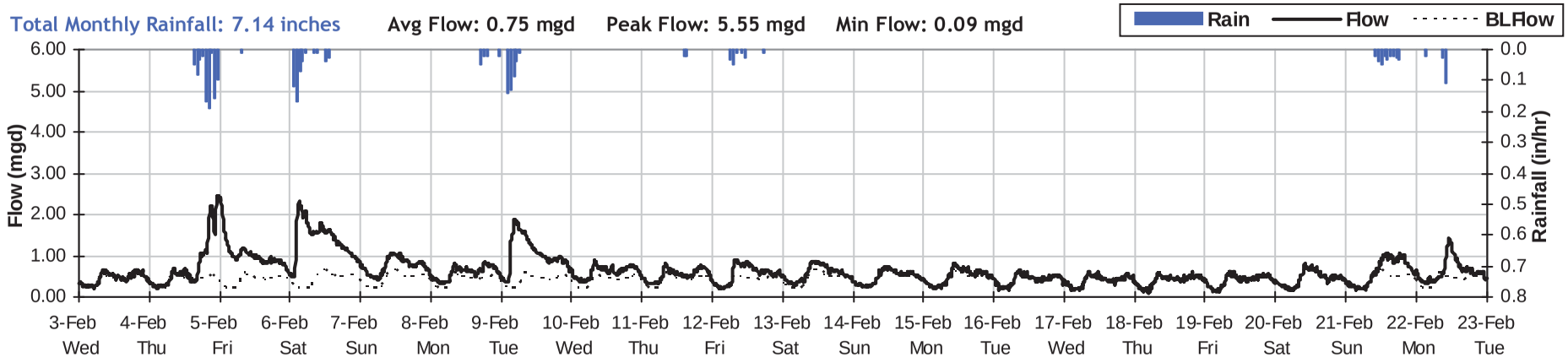
0.41 *mgd*

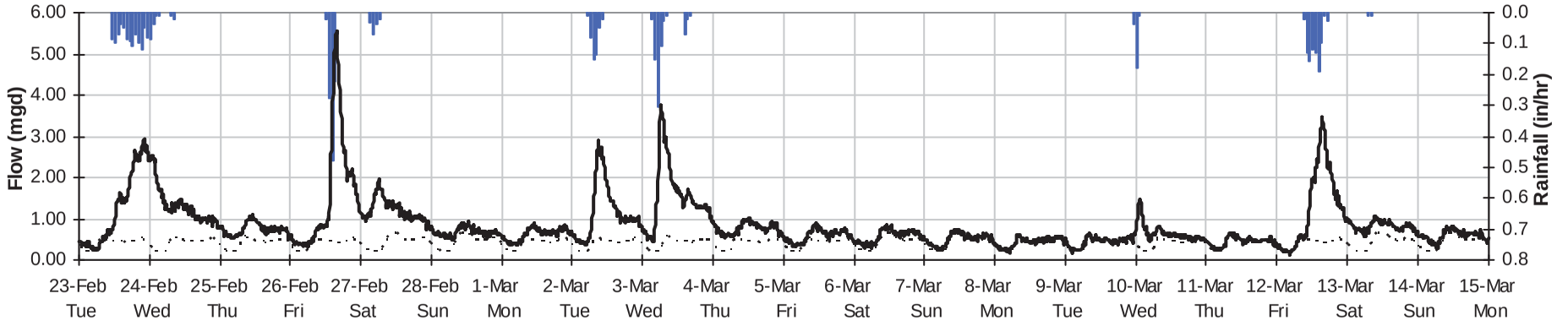


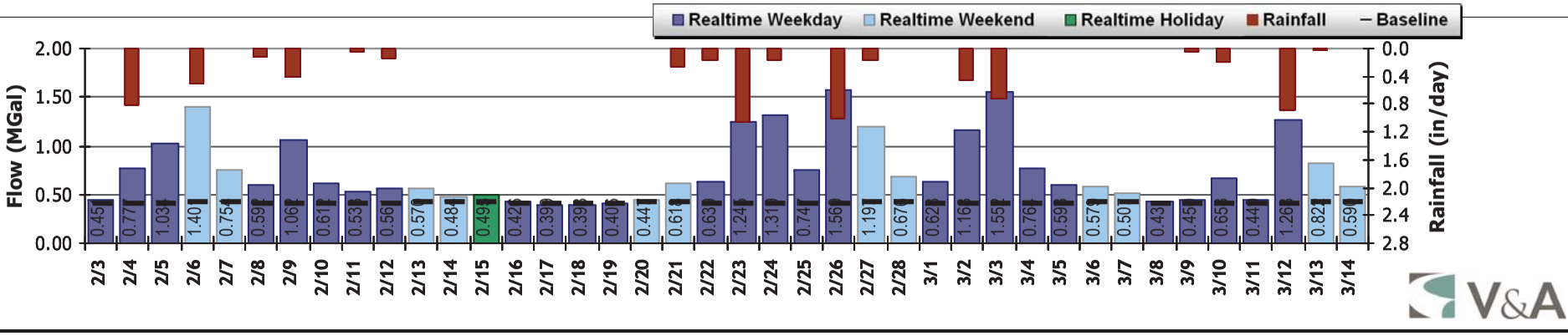
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 9

Total Monthly Rainfall: 7.14 inches Avg Flow: 0.75 mgd Peak Flow: 5.55 mgd Min Flow: 0.09 mgd





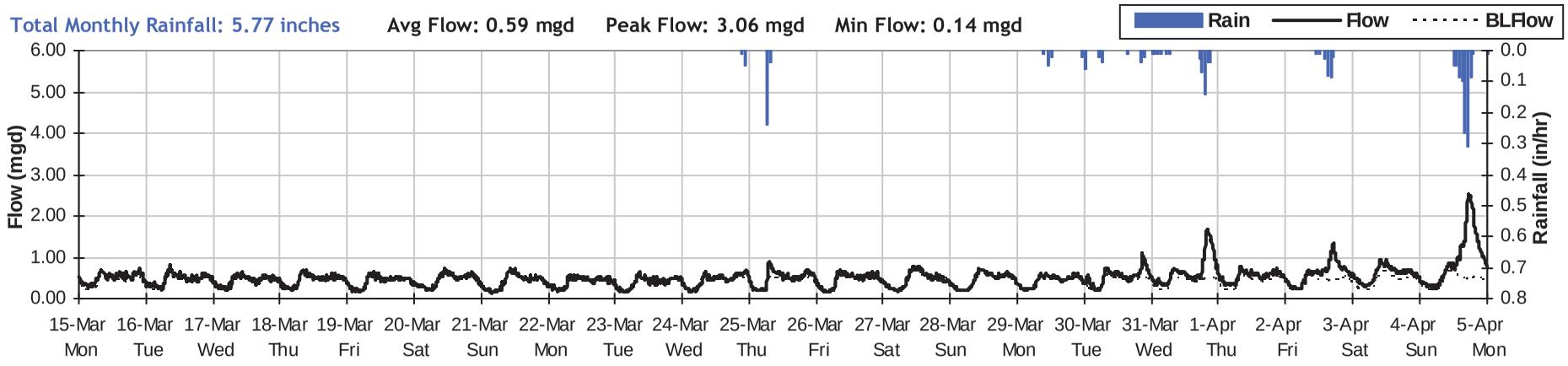


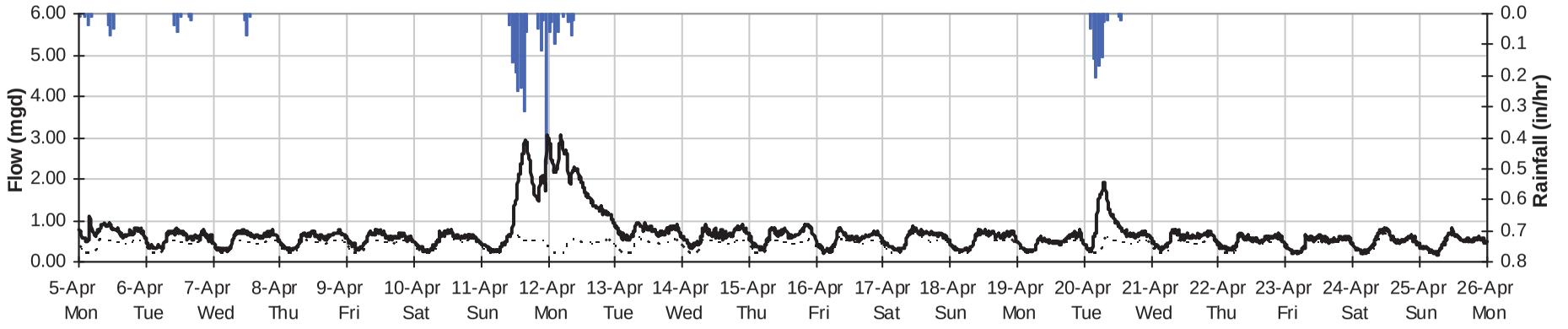
V&A

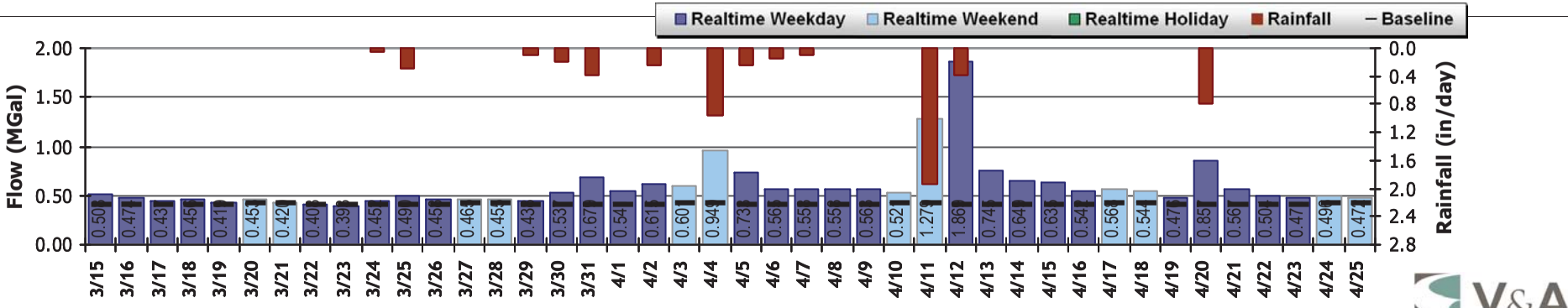
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 9

Total Monthly Rainfall: 5.77 inches Avg Flow: 0.59 mgd Peak Flow: 3.06 mgd Min Flow: 0.14 mgd





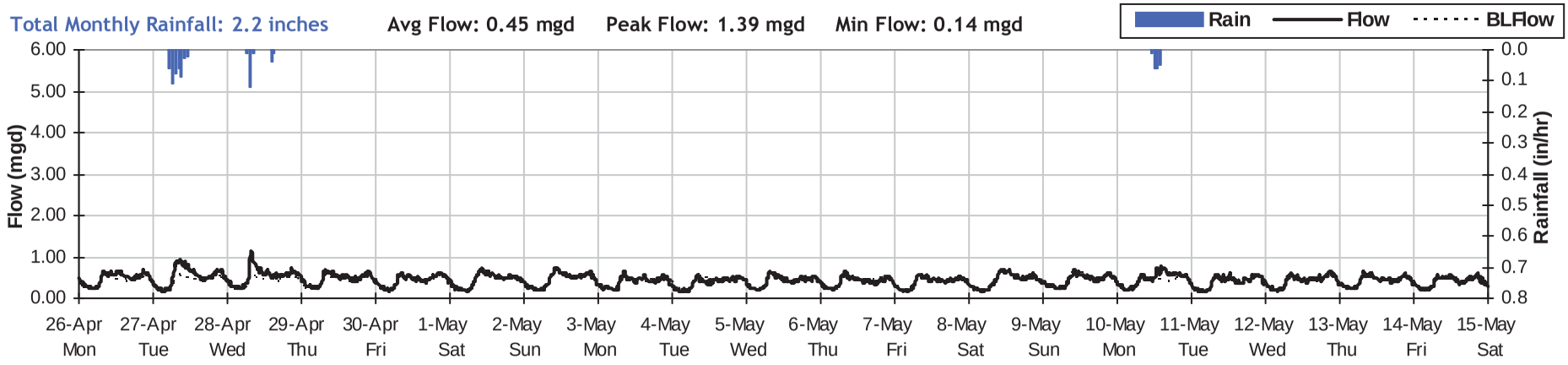


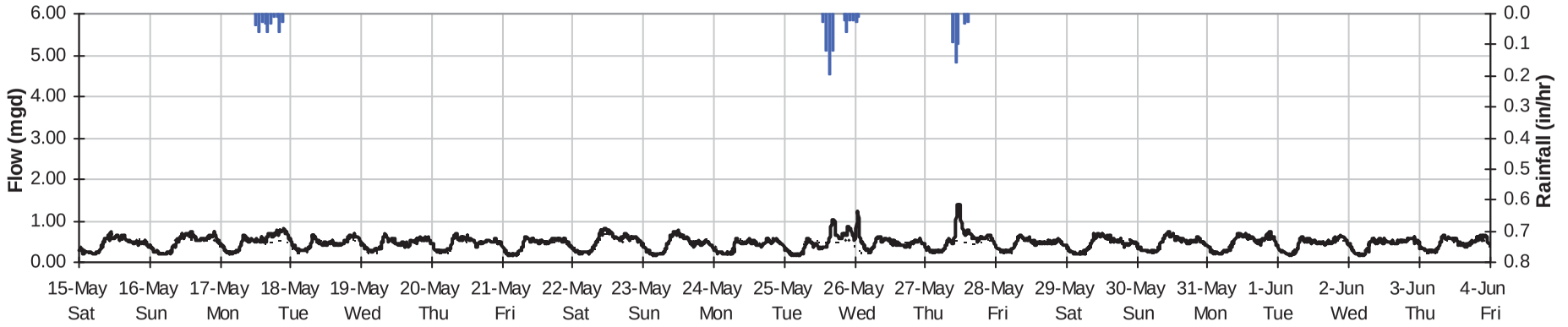
V&A

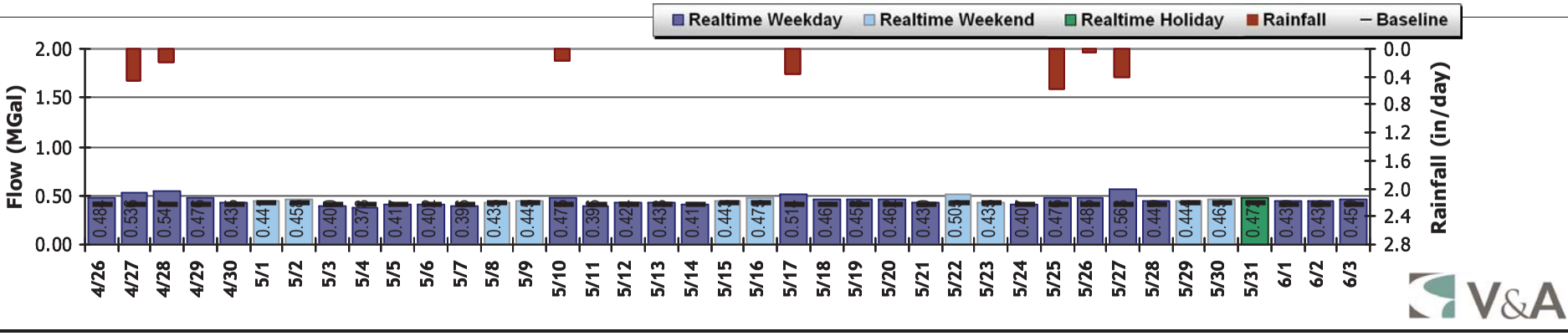
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 9

Total Monthly Rainfall: 2.2 inches Avg Flow: 0.45 mgd Peak Flow: 1.39 mgd Min Flow: 0.14 mgd





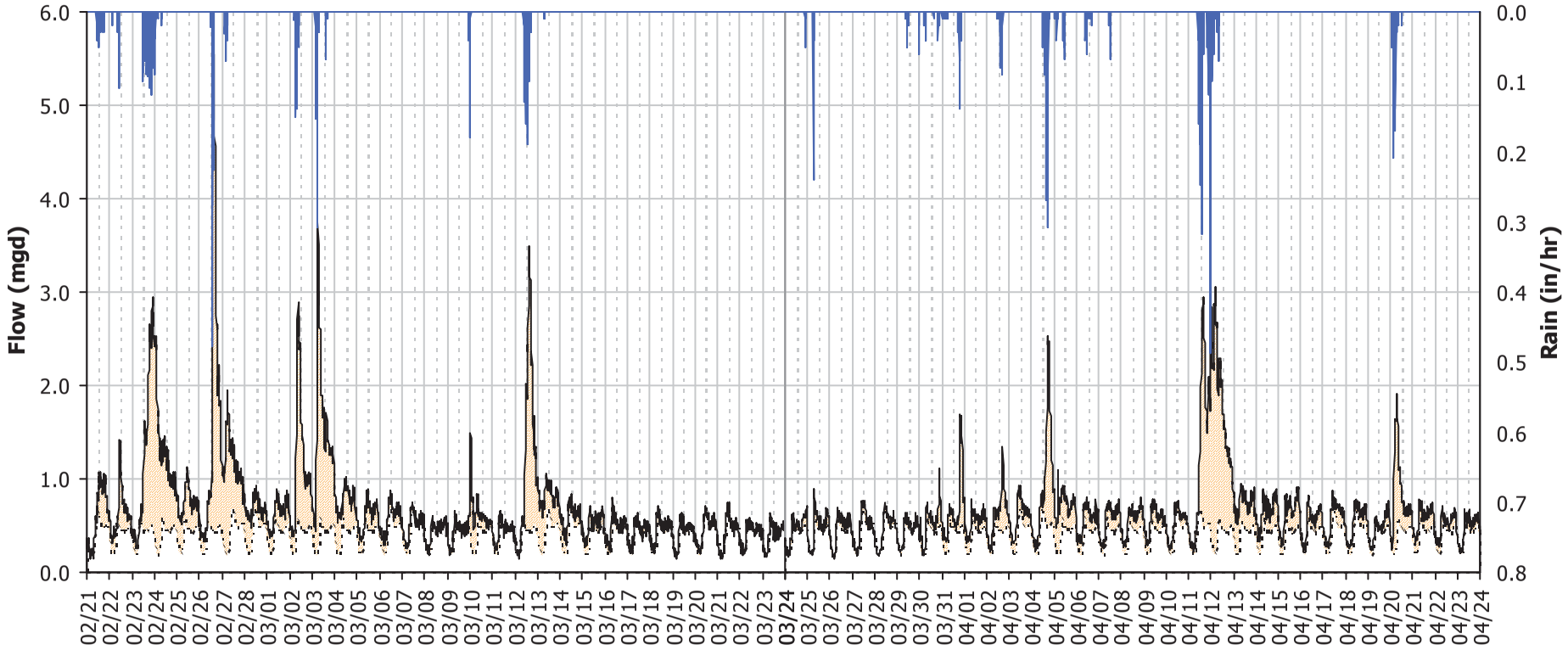


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 9

Multiple Events Detail I/I Graph



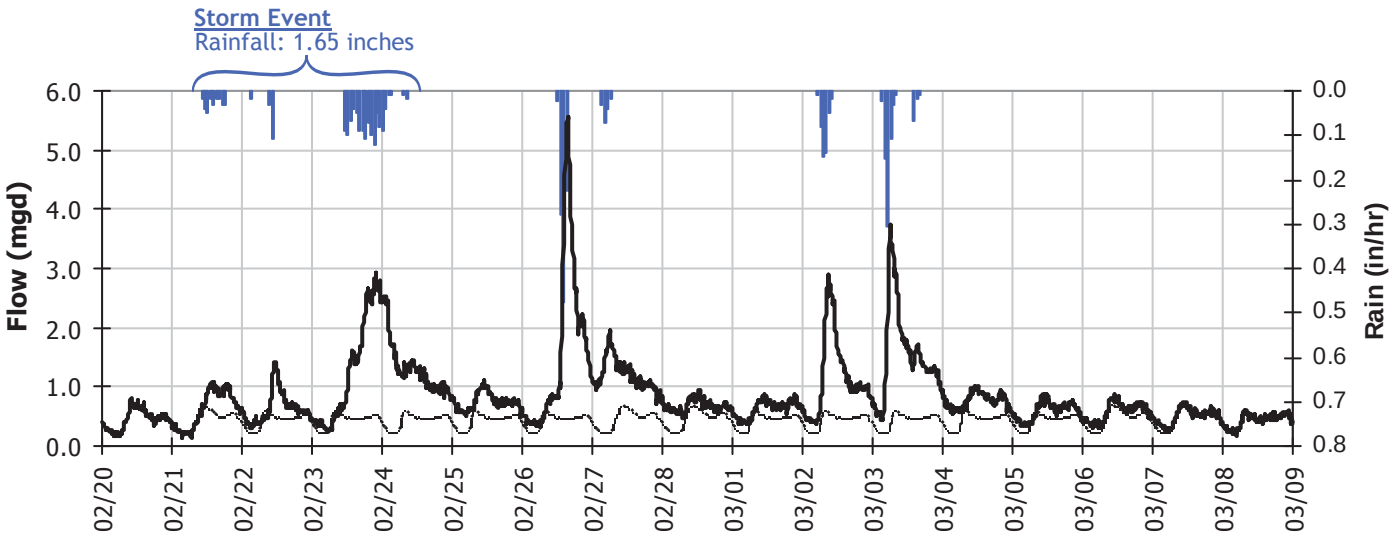
Multiple Events I/I Analysis

Rainfall:	10.90	*inches*	**Baseline Flow:**	0.41	*mgd*
Peak Flow:	5.55	*mgd*	**PF:**	13.50	
Peak I/I Rate:	5.13	*mgd*	**Pk I/I:ADWF:**	12.47	
Peak Level:	93.54	*inches*	**d/D Ratio:**	4.45	
Total I/I:	16,854,000	*gallons*	**R-Value:**	10.7%	
			I/I per ADWF:	3.8	*per in-rain*

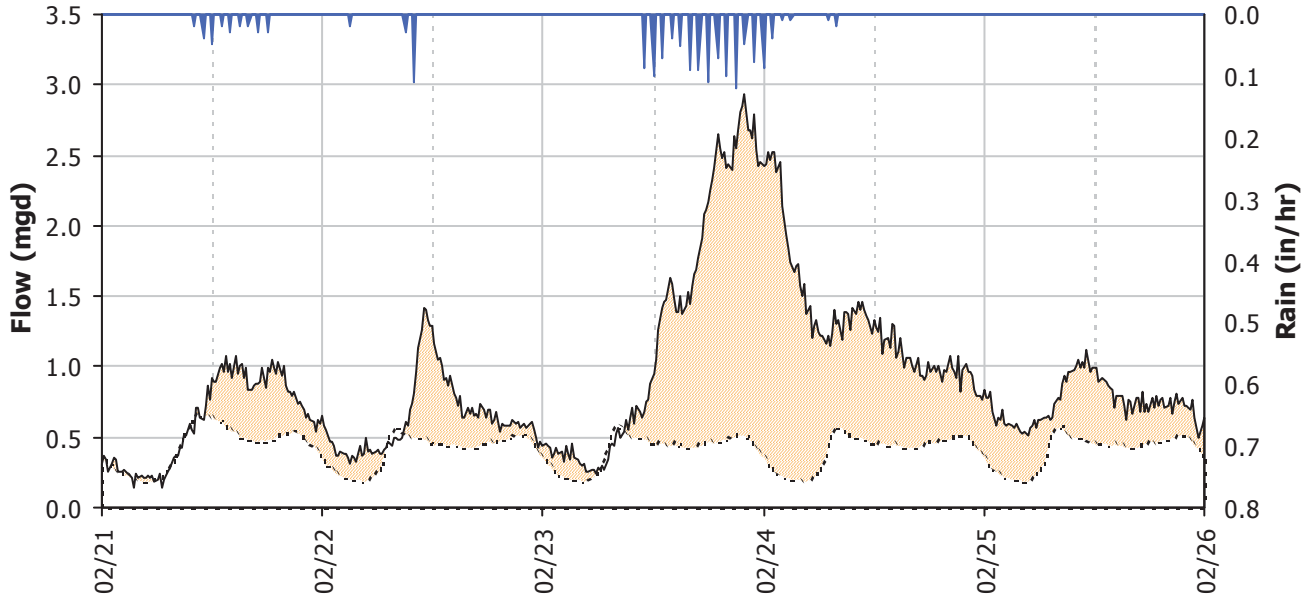
I/I Summary
Event 1

Monitoring Site:
Site 9

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

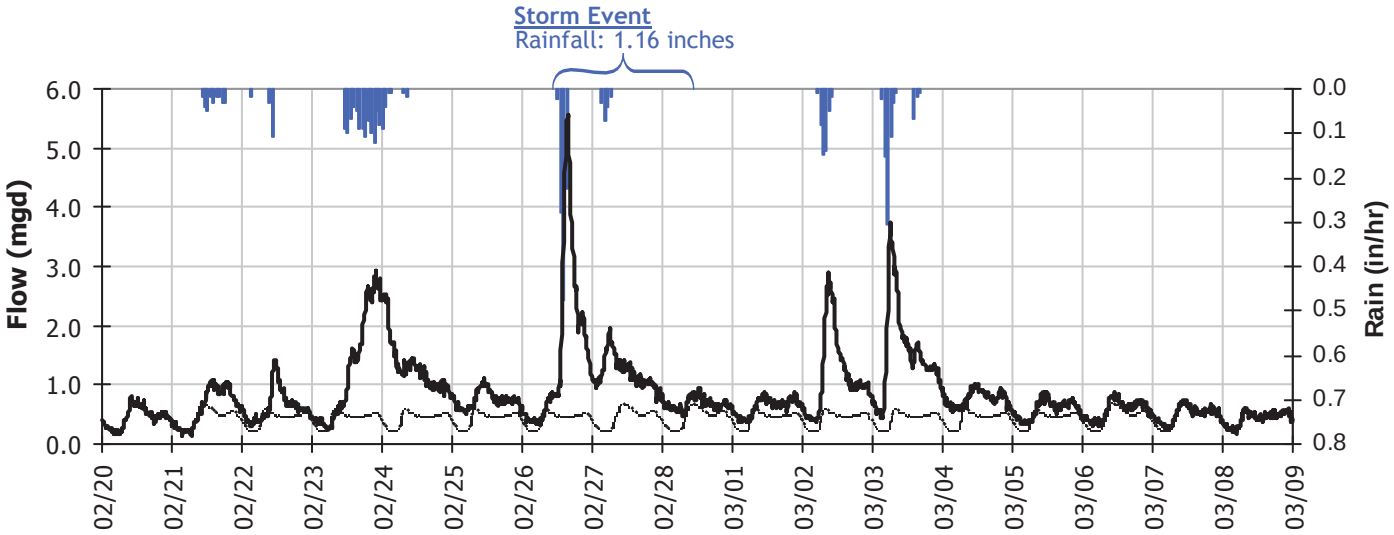
Rainfall:	1.65	*inches*		
Baseline Flow:	0.41	*mgd*		
Peak Flow:	2.94	*mgd*	**PF:**	7.14
Peak I/I Rate:	2.43	*mgd*	**Pk I/I:ADWF:**	5.92
Peak Level:	14.63	*inches*	**d/D Ratio:**	0.70
Total I/I:	2,526,000	*gallons*	**R-Value:**	10.6%
			I/I per ADWF:	3.72 *per in-rain*

Average Infiltration Rate on 2/25 (% of ADWF): 85.0%

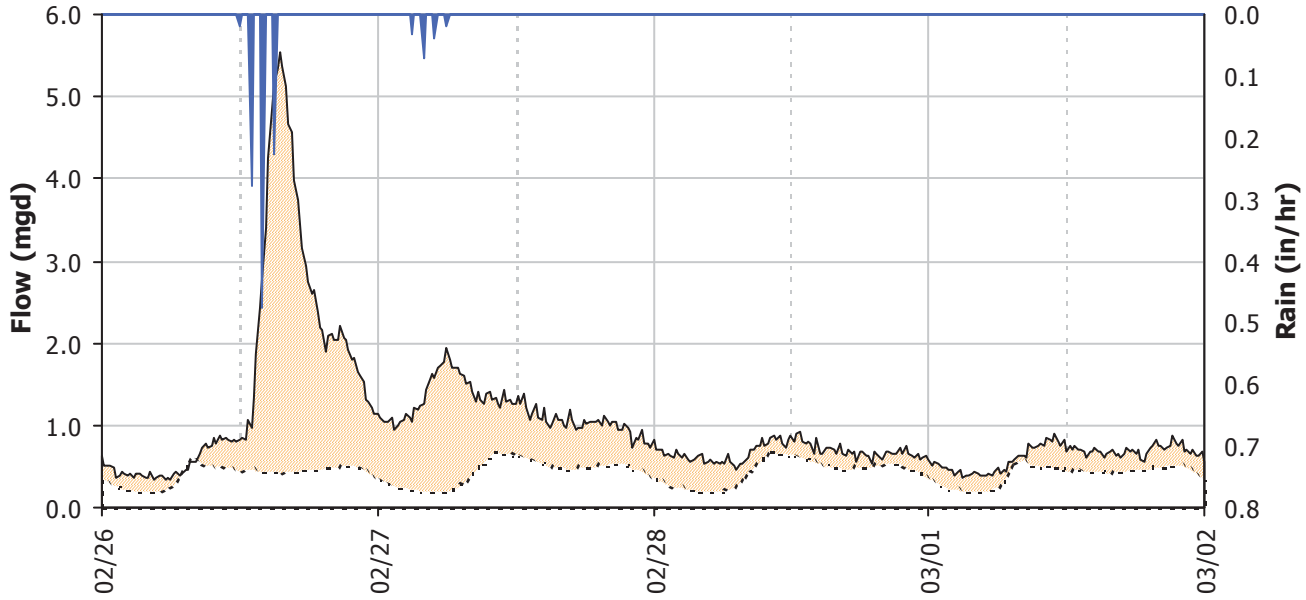
V&A

	I/I Summary Event 2	**Monitoring Site:** Site 9

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



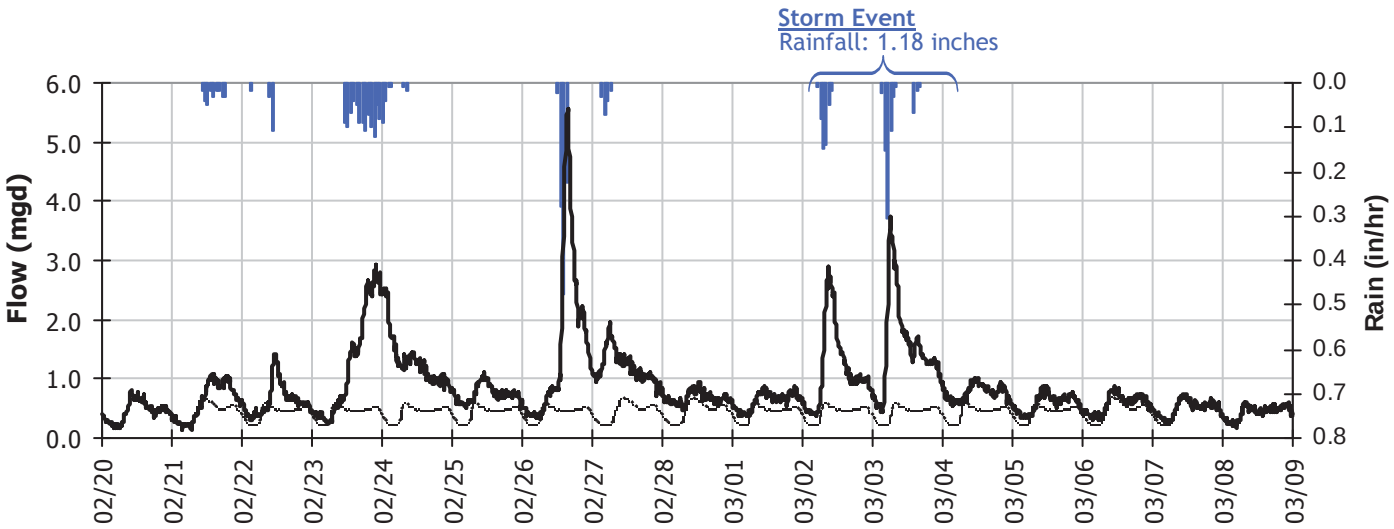
Storm Event #2 I/I Analysis

Rainfall:	1.16	*inches*		
Baseline Flow:	0.41	*mgd*		
Peak Flow:	5.55	*mgd*	**PF:**	13.50
Peak I/I Rate:	5.13	*mgd*	**Pk I/I:ADWF:**	12.47
Peak Level:	93.54	*inches*	**d/D Ratio:**	4.45
Total I/I:	2,406,000	*gallons*	**R-Value:**	14.3%
			I/I per ADWF:	5.04 *per in-rain*

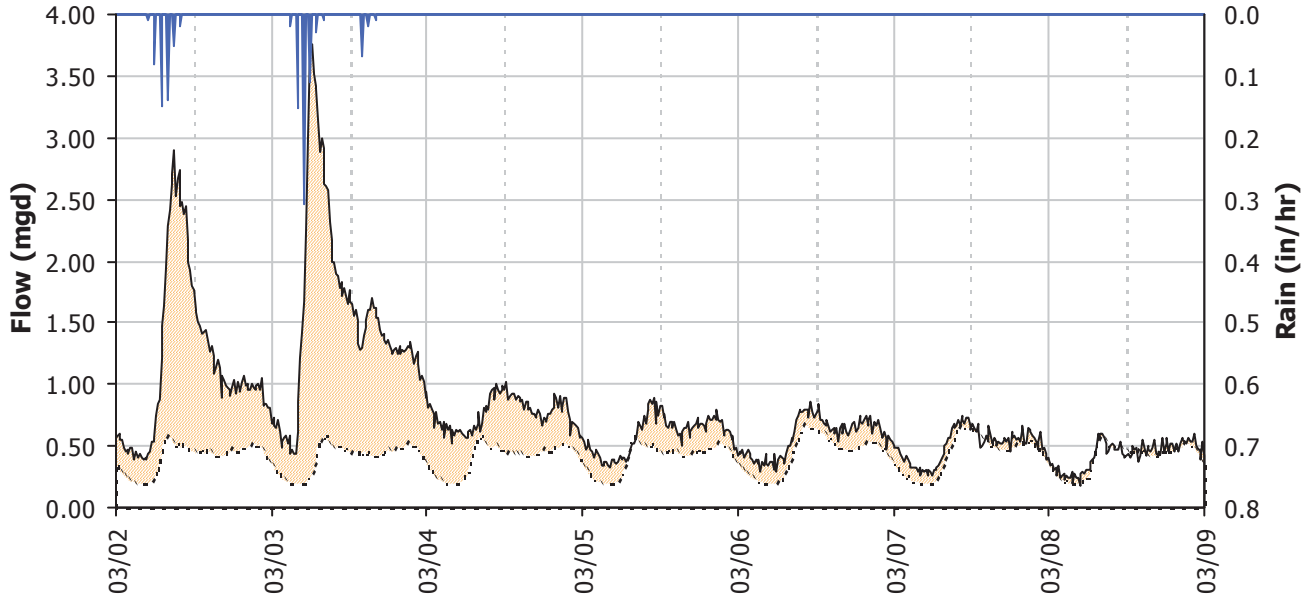
Average Infiltration Rate on 3/1 (% of ADWF): 55.5%

	I/I Summary Event 3	**Monitoring Site:** Site 9

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



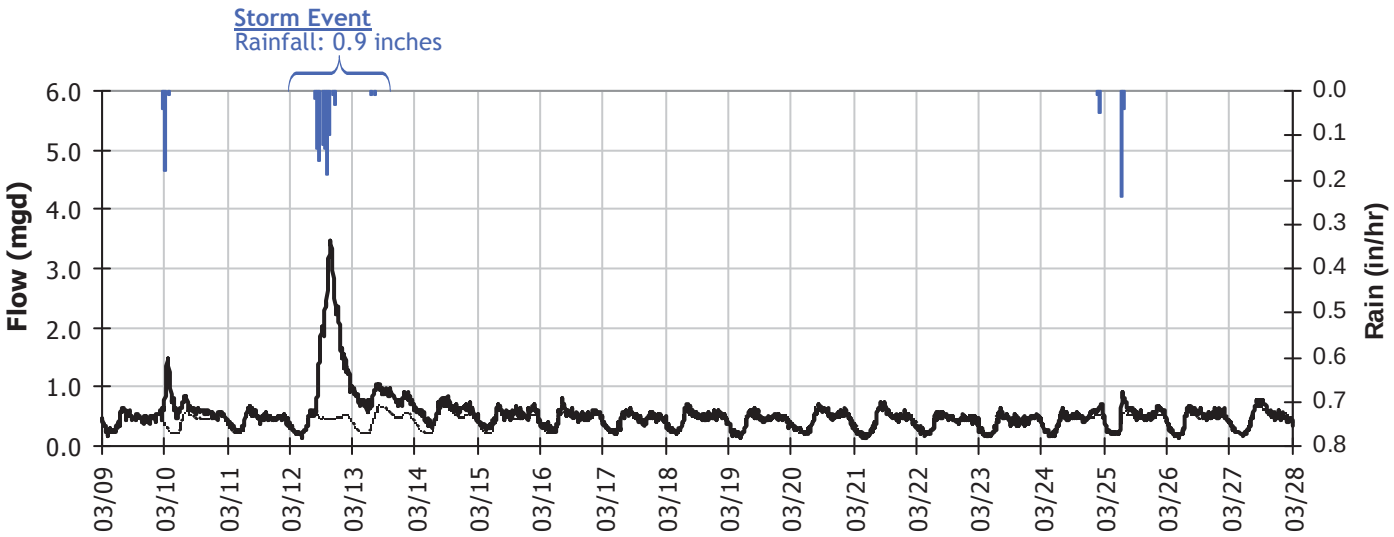
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	0.41	*mgd*		
Peak Flow:	3.75	*mgd*	**PF:**	9.12
Peak I/I Rate:	3.48	*mgd*	**Pk I/I:ADWF:**	8.45
Peak Level:	16.69	*inches*	**d/D Ratio:**	0.79
Total I/I:	2,719,000	*gallons*	**R-Value:**	15.9%
			I/I per ADWF:	5.60 *per in-rain*

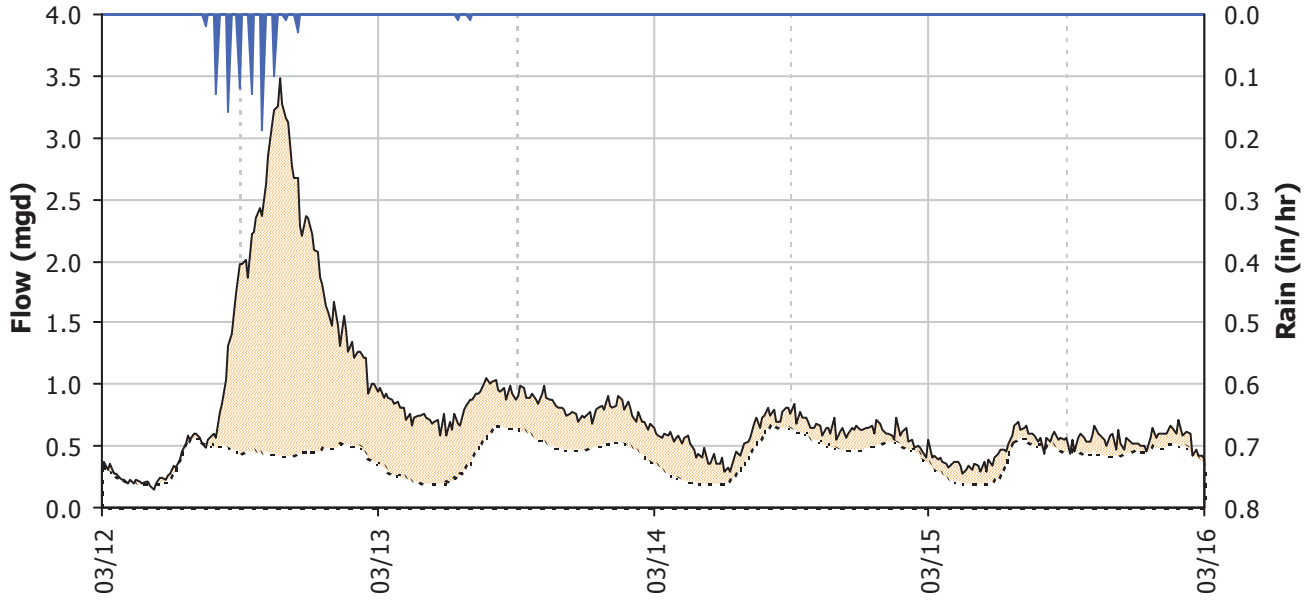
Average Infiltration Rate on 3/5 (% of ADWF): 46.6%

	I/I Summary Event 4	**Monitoring Site:** Site 9

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



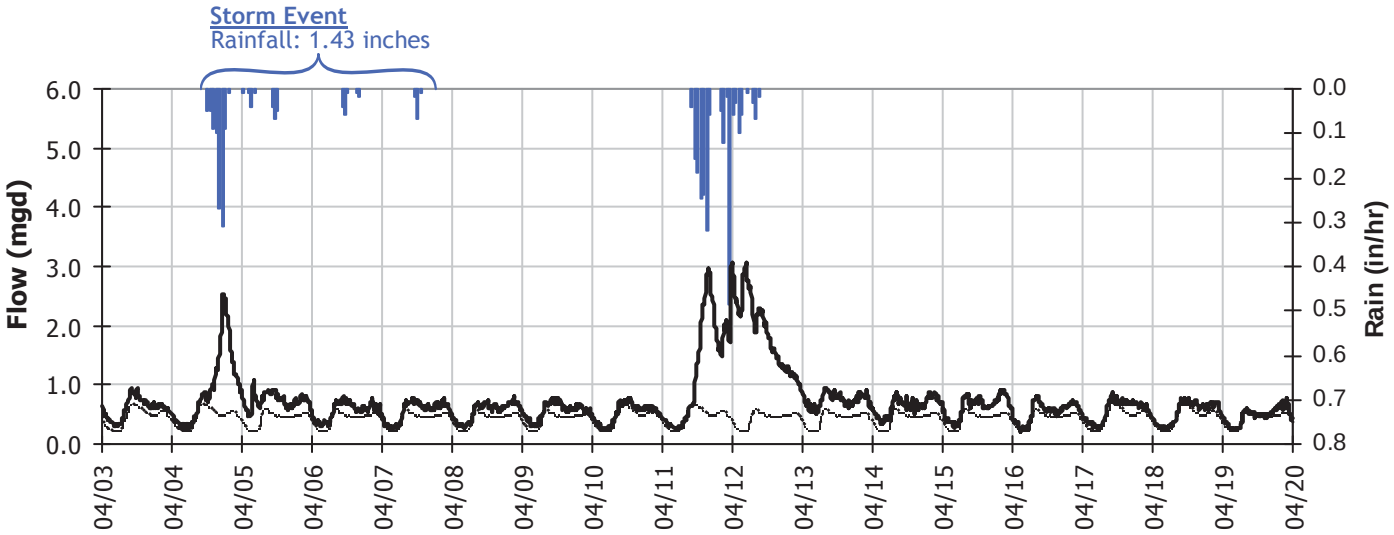
Storm Event #1 I/I Analysis

Rainfall:	0.90	*inches*		
Baseline Flow:	0.41	*mgd*		
Peak Flow:	3.48	*mgd*	**PF:**	8.48
Peak I/I Rate:	3.06	*mgd*	**Pk I/I:ADWF:**	7.45
Peak Level:	15.34	*inches*	**d/D Ratio:**	0.73
Total I/I:	1,522,000	*gallons*	**R-Value:**	11.6%
			I/I per ADWF:	4.10 *per in-rain*

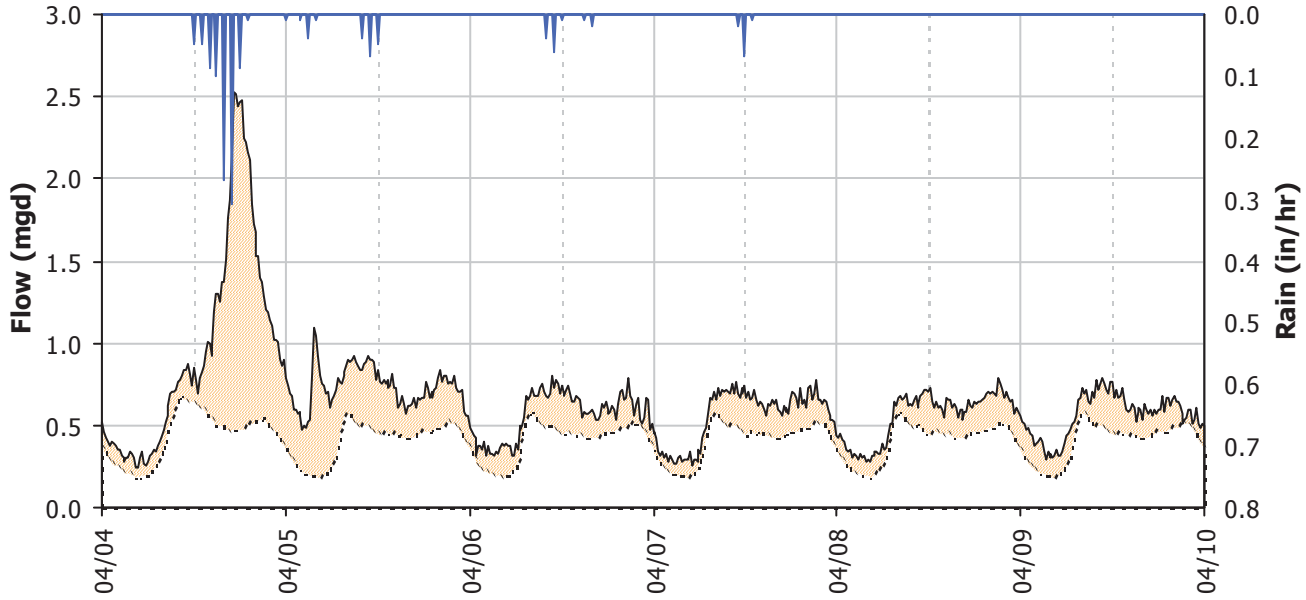
Average Infiltration Rate on 3/14 (% of ADWF): 37.4%

	I/I Summary Event 5	**Monitoring Site:** Site 9

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



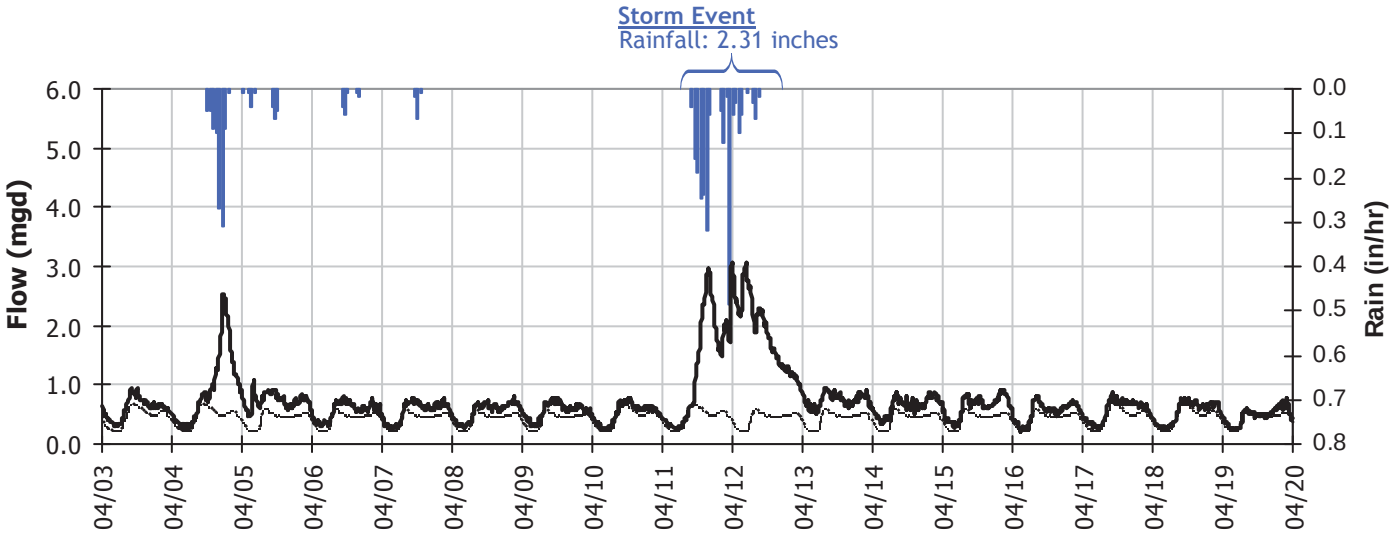
Storm Event #5 I/I Analysis

Rainfall:	1.43	*inches*		
Baseline Flow:	0.41	*mgd*		
Peak Flow:	2.53	*mgd*	**PF:**	6.15
Peak I/I Rate:	2.06	*mgd*	**Pk I/I:ADWF:**	5.00
Peak Level:	13.20	*inches*	**d/D Ratio:**	0.63
Total I/I:	1,480,000	*gallons*	**R-Value:**	7.2%
			I/I per ADWF:	2.52 *per in-rain*

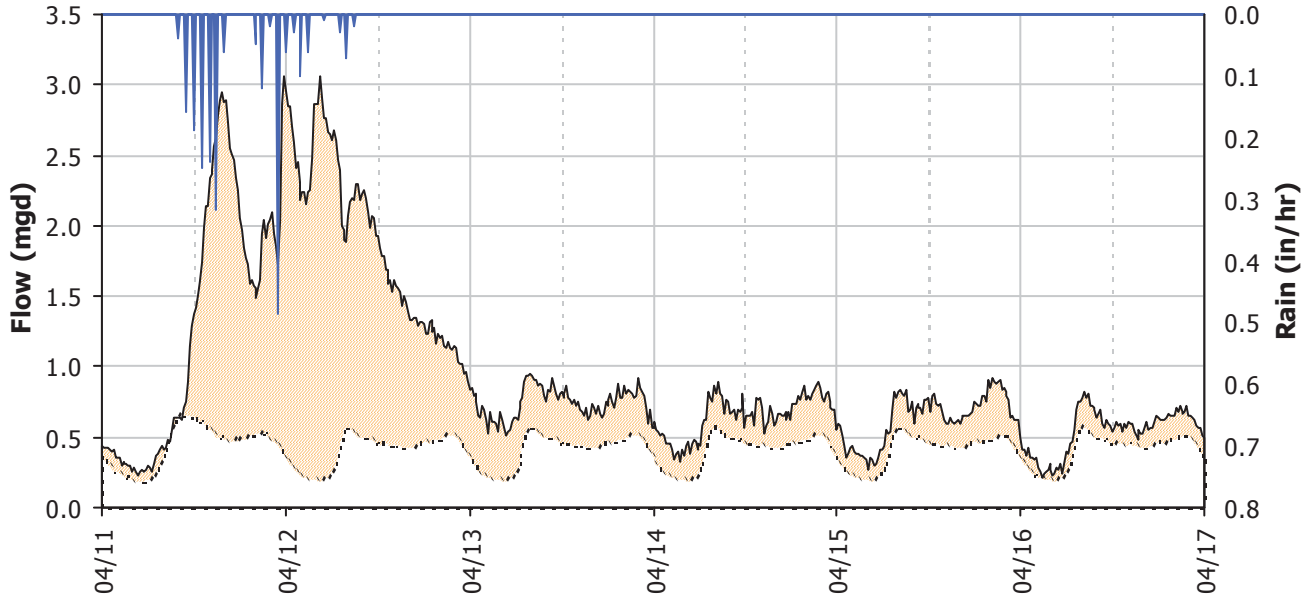
Average Infiltration Rate on 4/8 (% of ADWF): 38.5%

	I/I Summary Event 6	**Monitoring Site:** Site 9

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



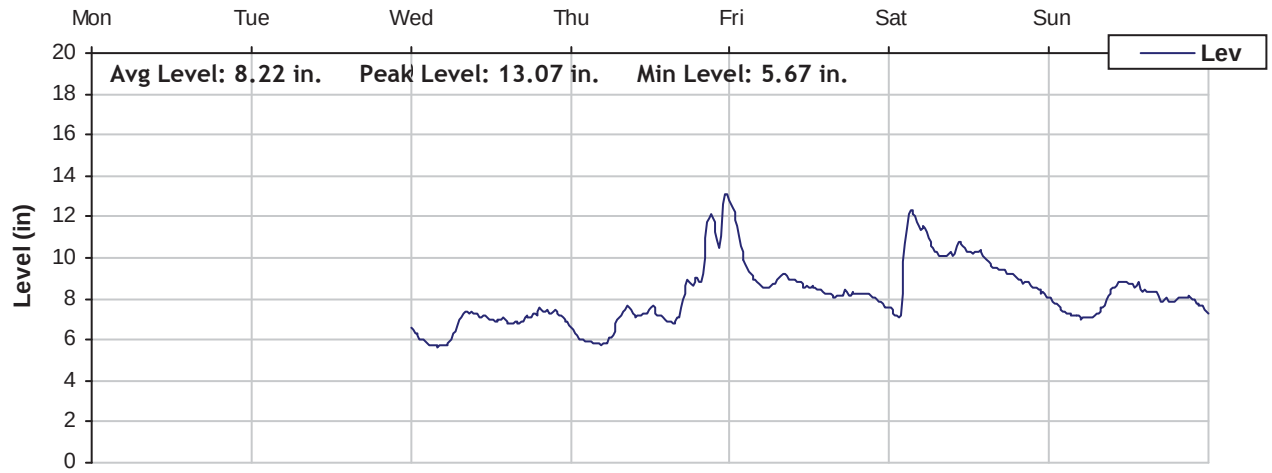
Storm Event #6 I/I Analysis

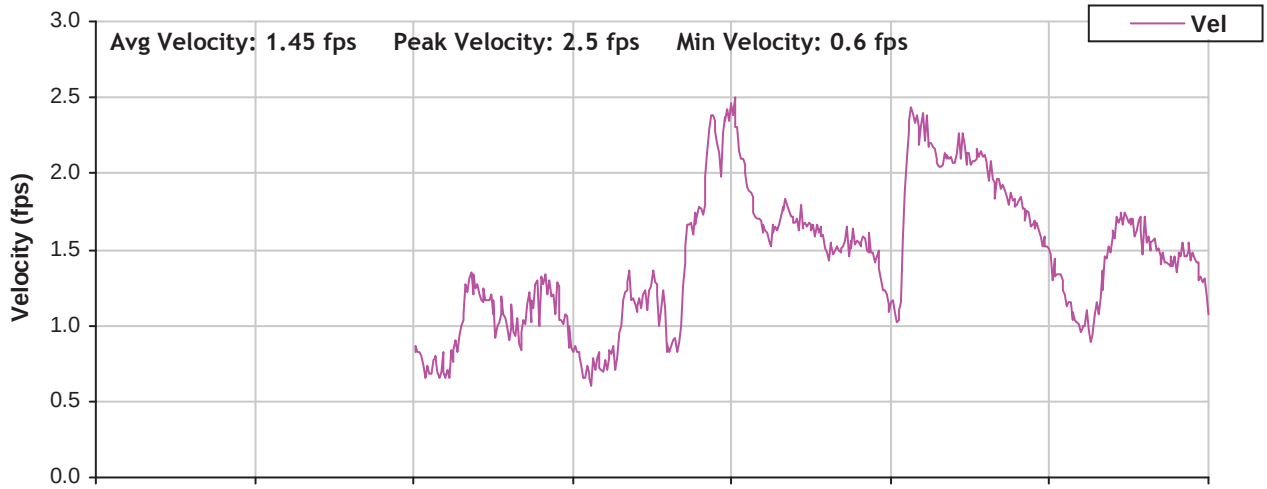
Rainfall:	2.31	*inches*		
Baseline Flow:	0.41	*mgd*		
Peak Flow:	3.06	*mgd*	**PF:**	7.44
Peak I/I Rate:	2.87	*mgd*	**Pk I/I:ADWF:**	6.98
Peak Level:	14.55	*inches*	**d/D Ratio:**	0.69
Total I/I:	3,272,000	*gallons*	**R-Value:**	9.8%
			I/I per ADWF:	3.45 *per in-rain*

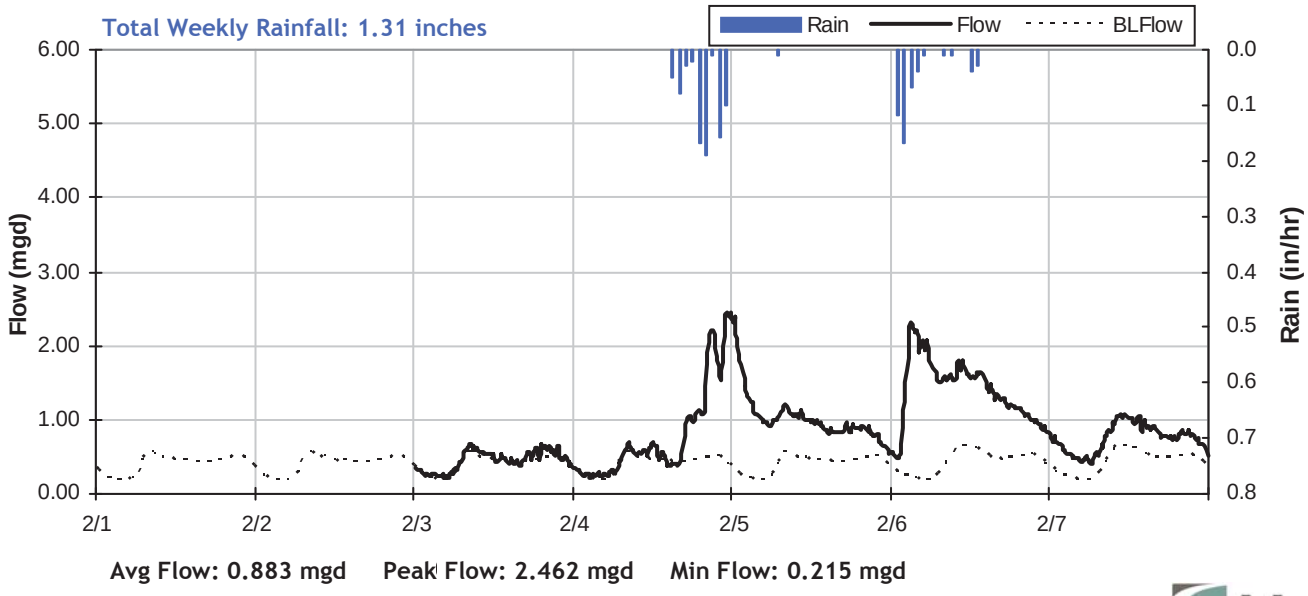
Average Infiltration Rate on 4/14 (% of ADWF): 60.8%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 9

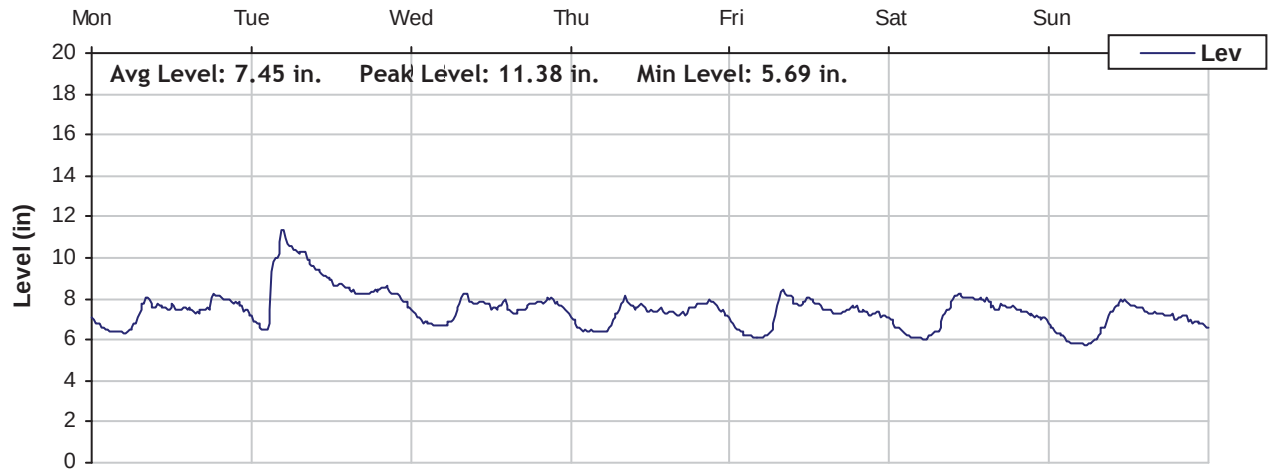


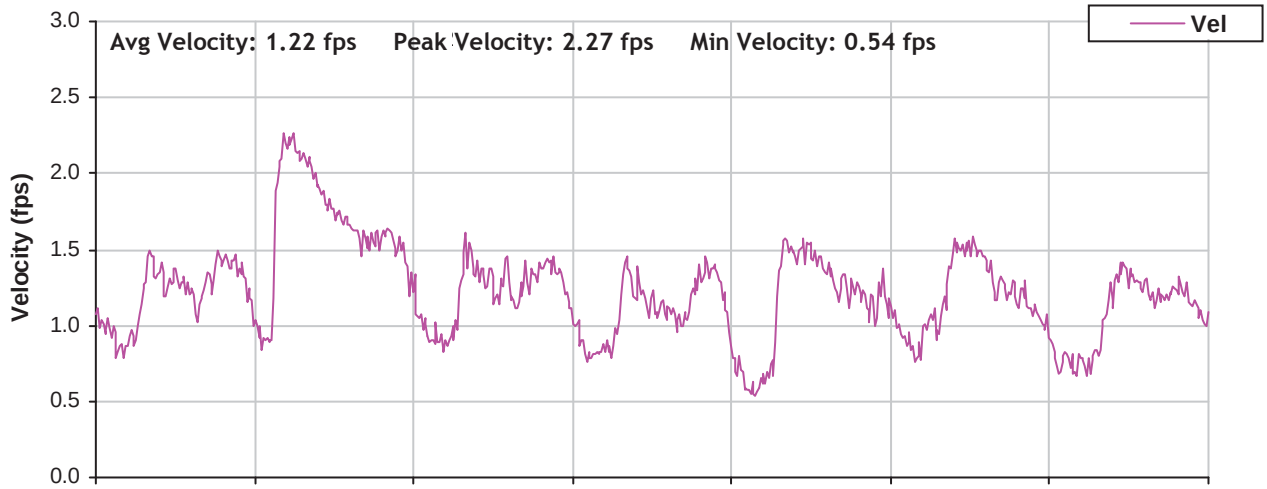


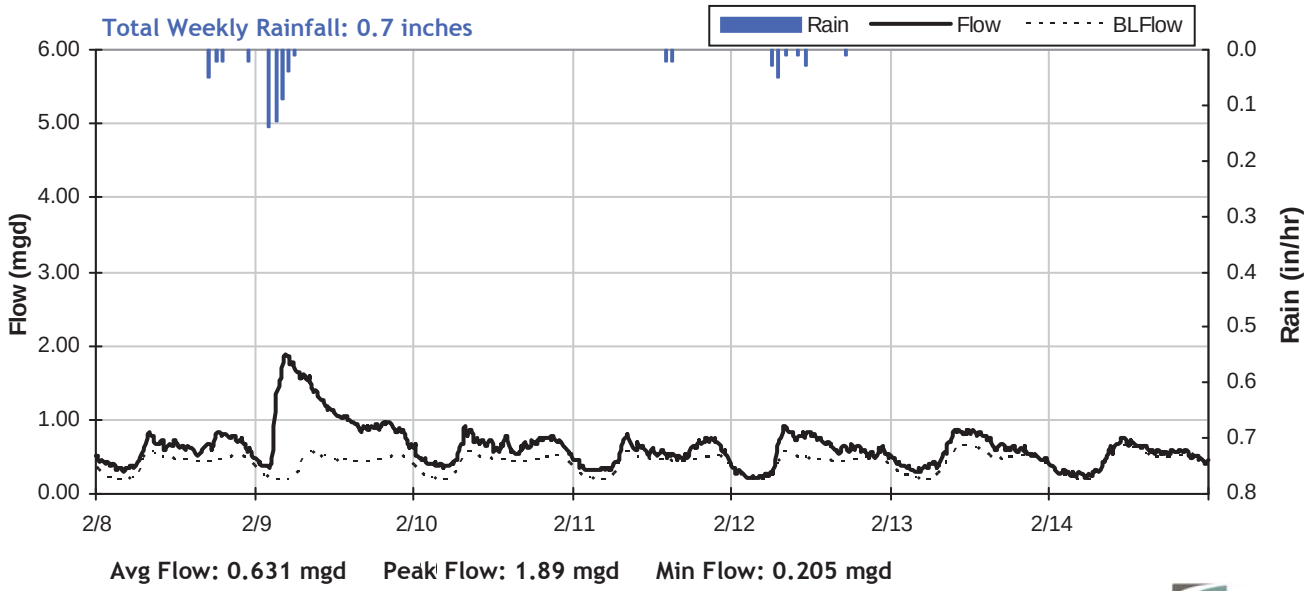


Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 9

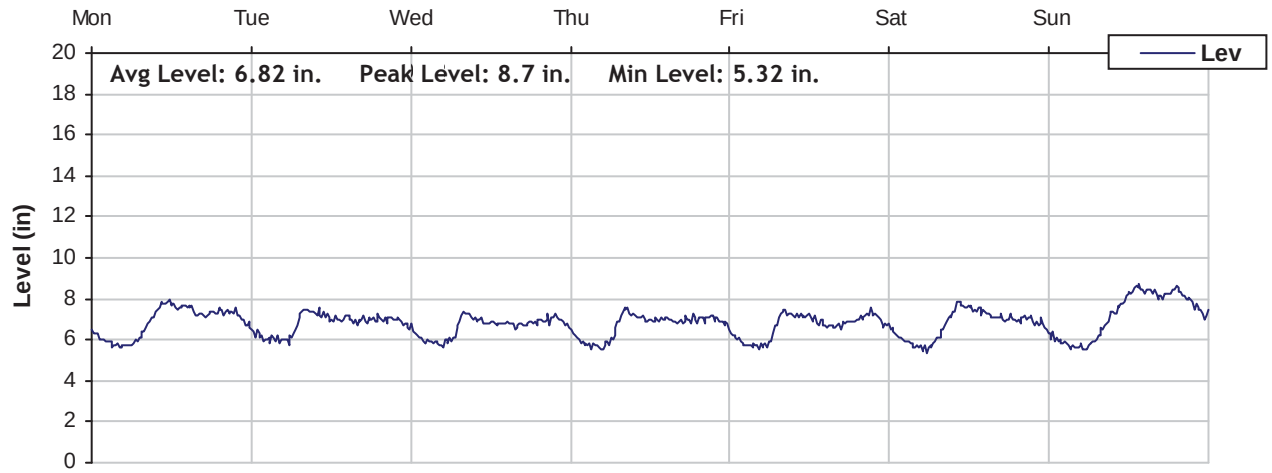


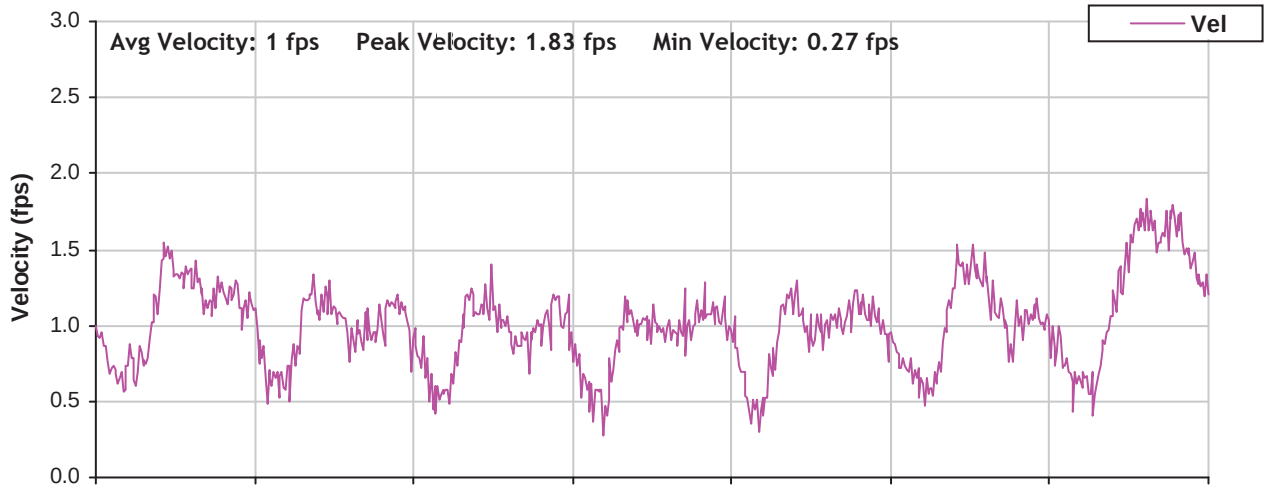


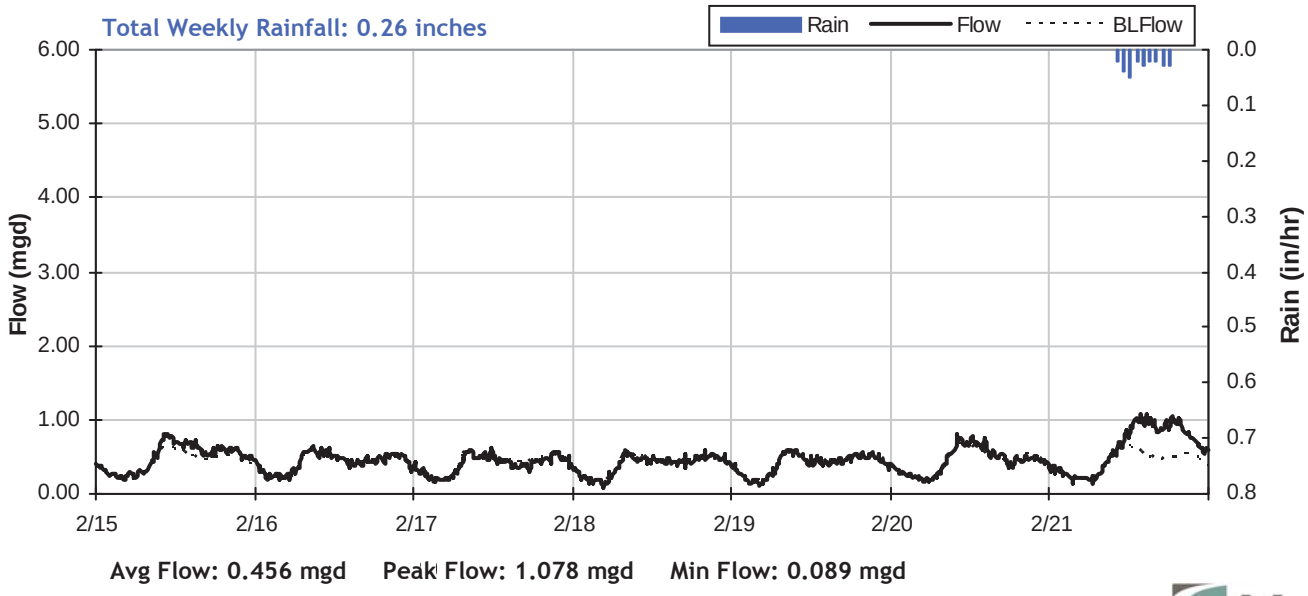


Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 9



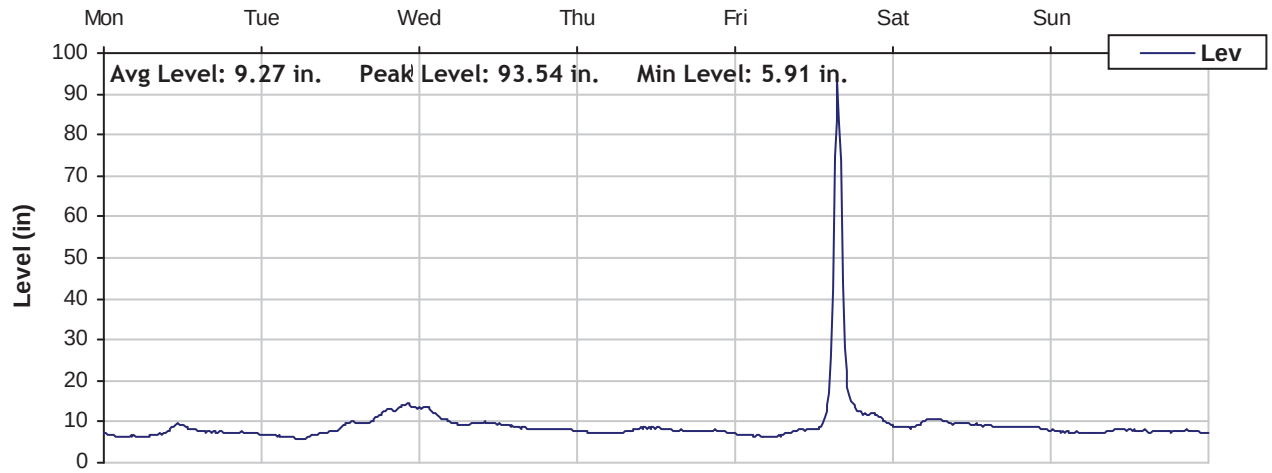


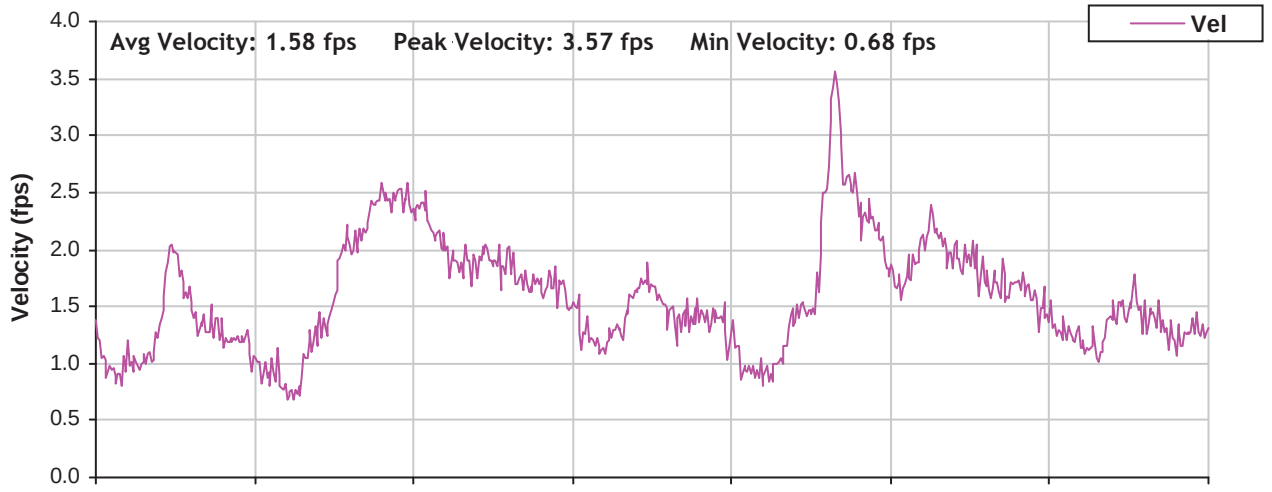


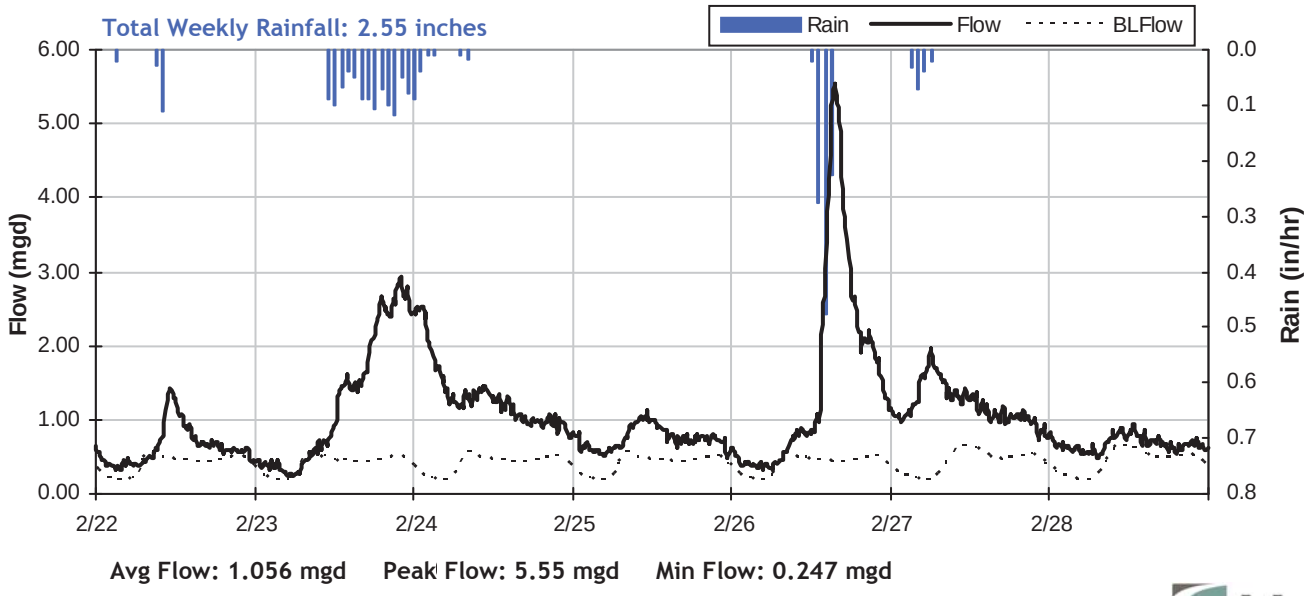
Avg Flow: 0.456 mgd Peak Flow: 1.078 mgd Min Flow: 0.089 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 9



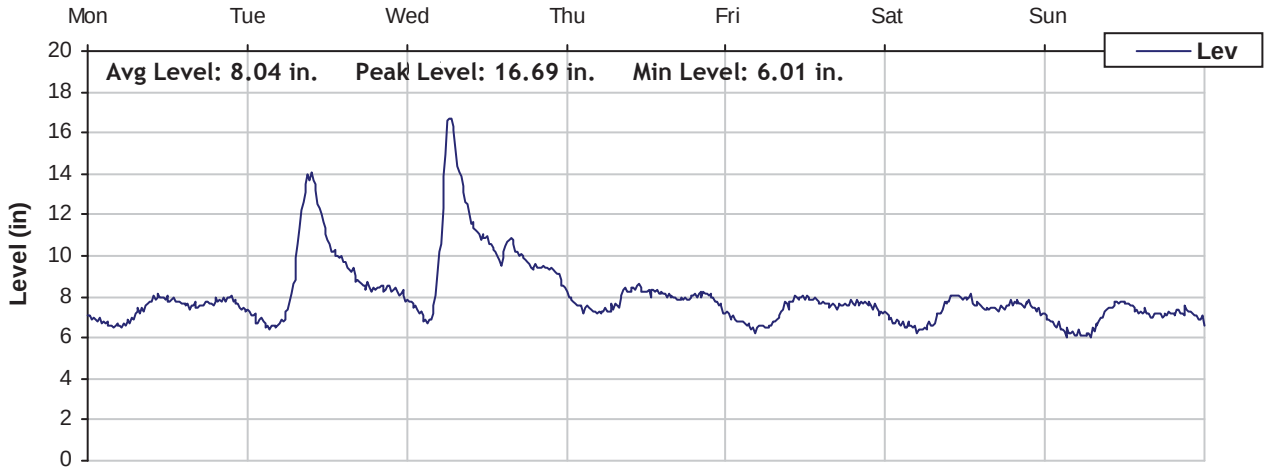


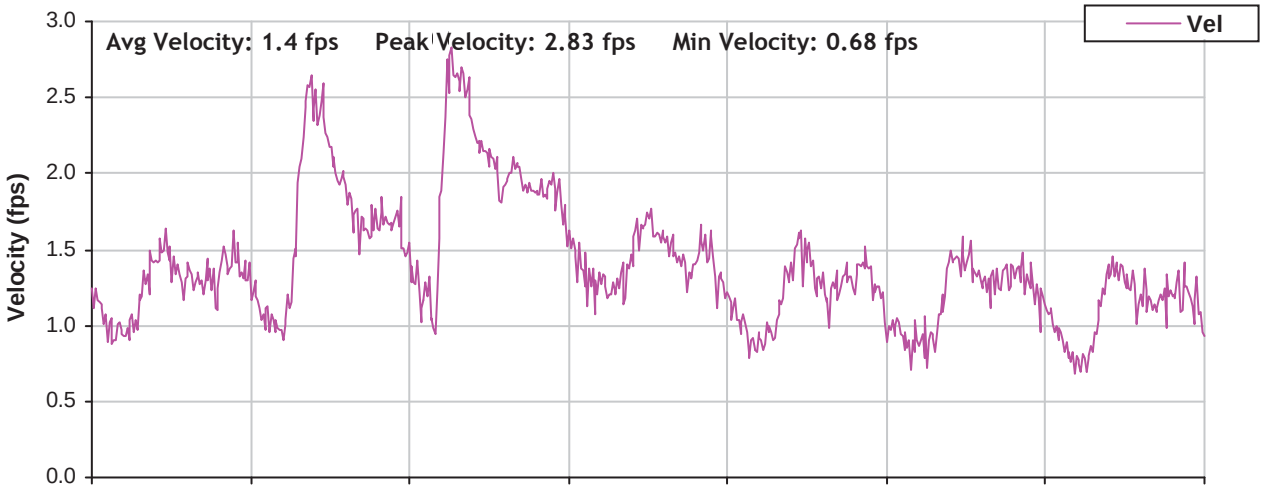


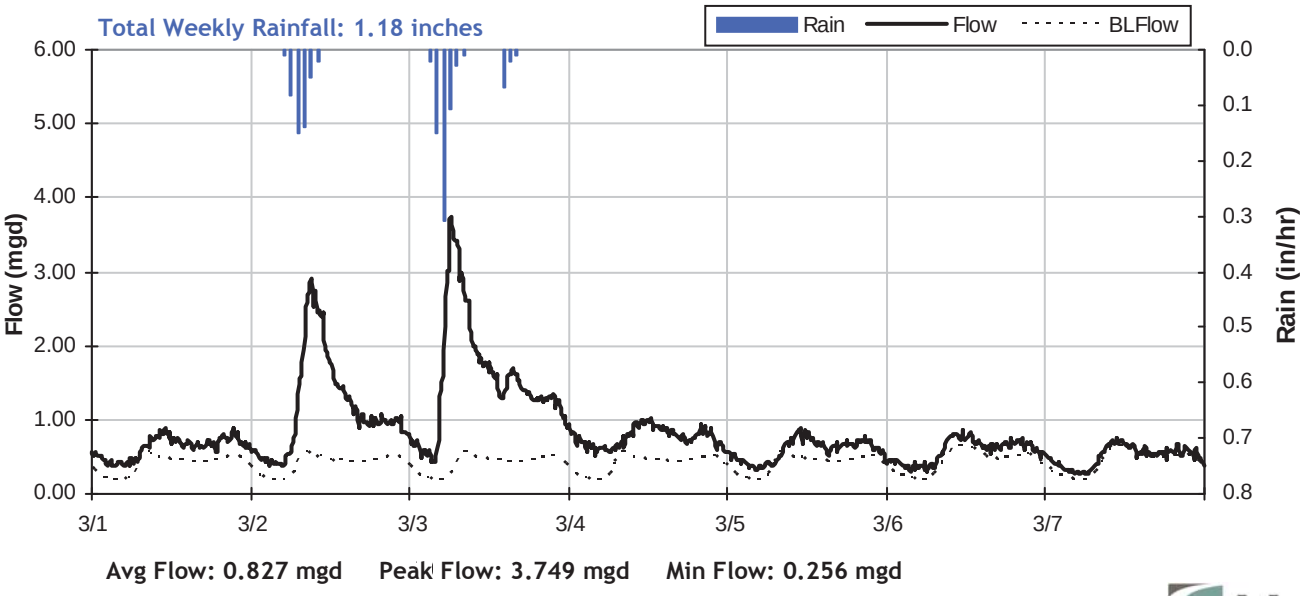
Avg Flow: 1.056 mgd Peak Flow: 5.55 mgd Min Flow: 0.247 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 9

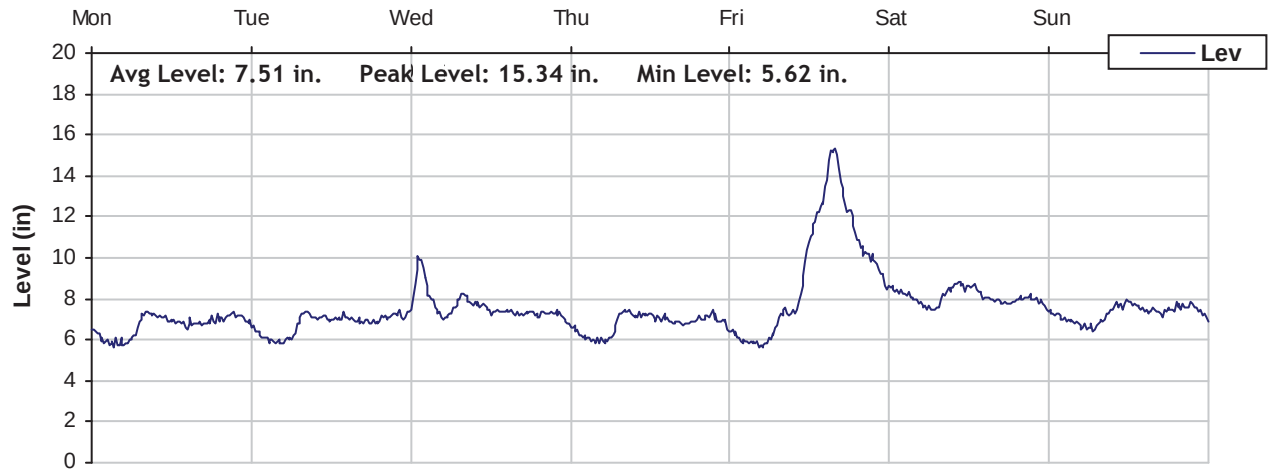


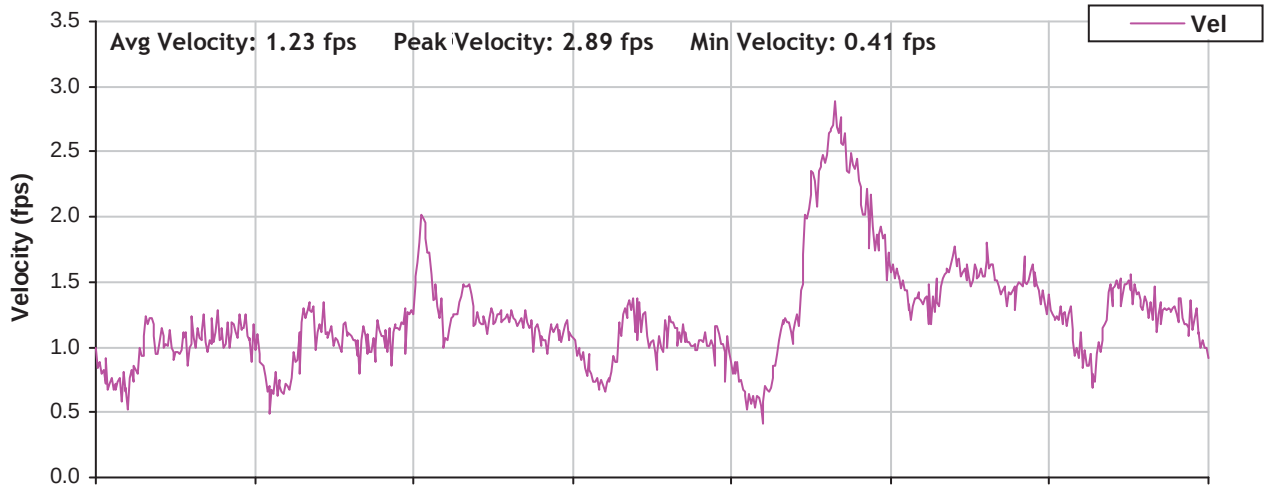


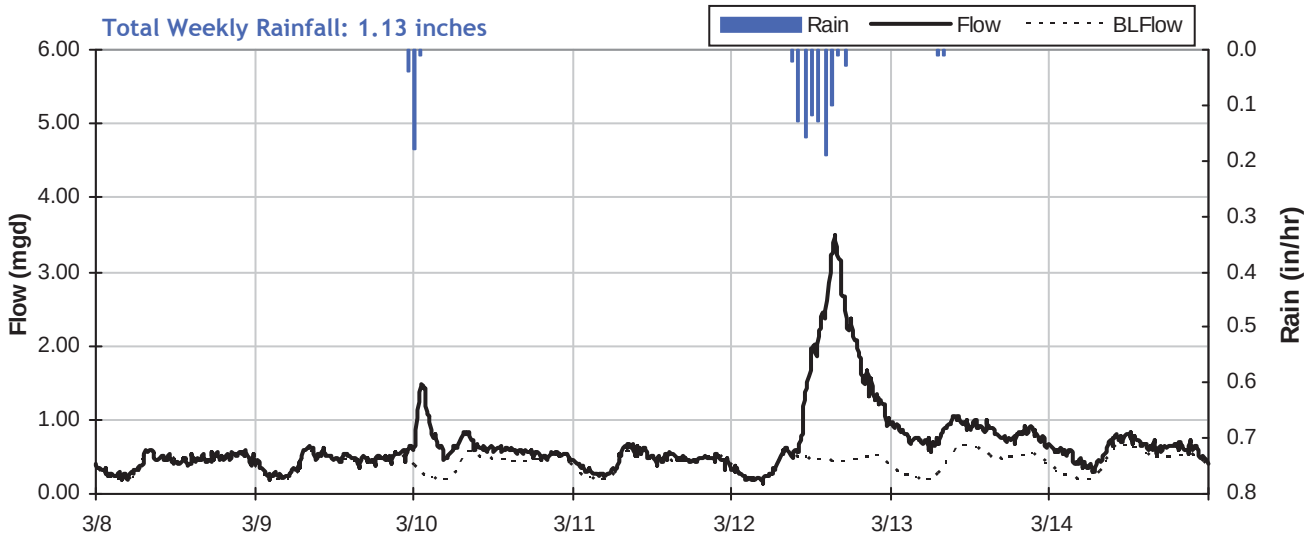


Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 9



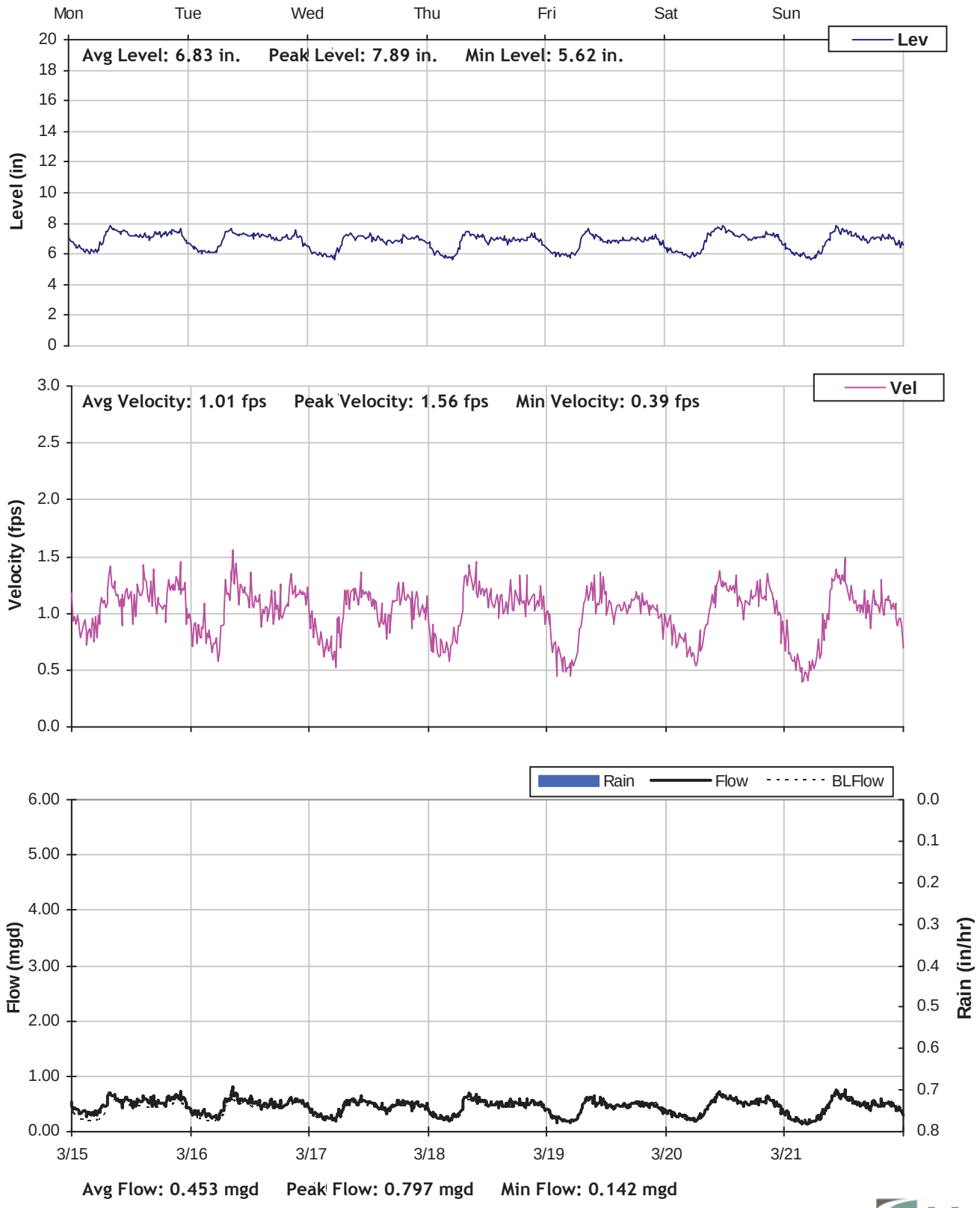




Avg Flow: 0.667 mgd Peak Flow: 3.485 mgd Min Flow: 0.14 mgd

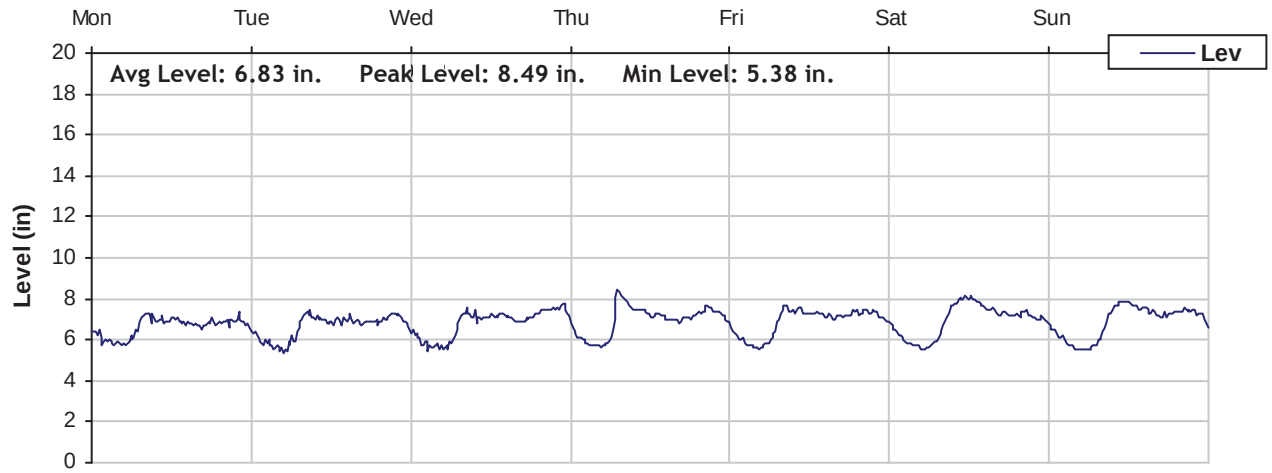
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

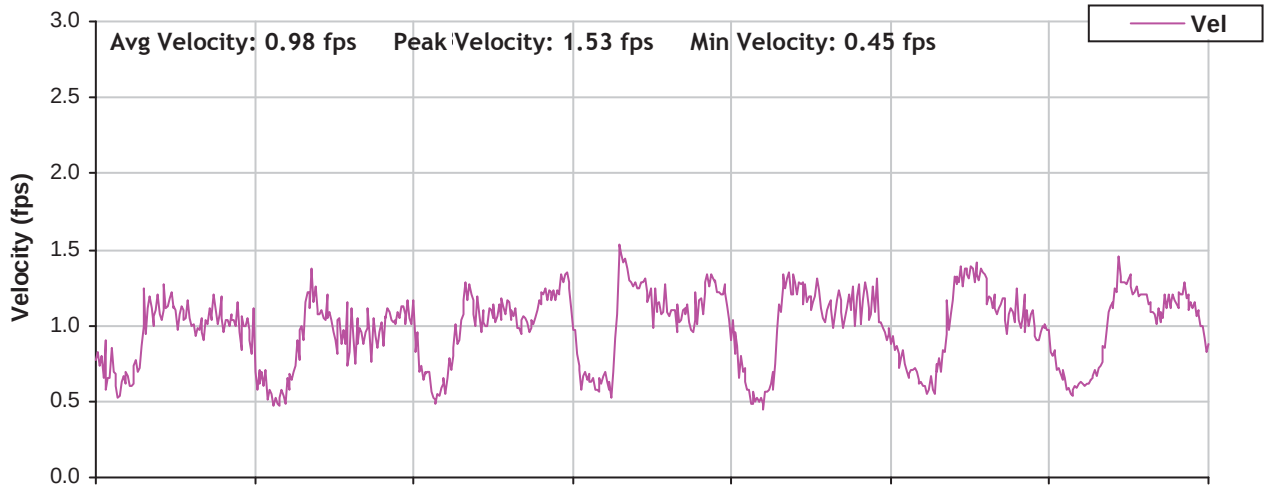
Monitoring Site:
Site 9

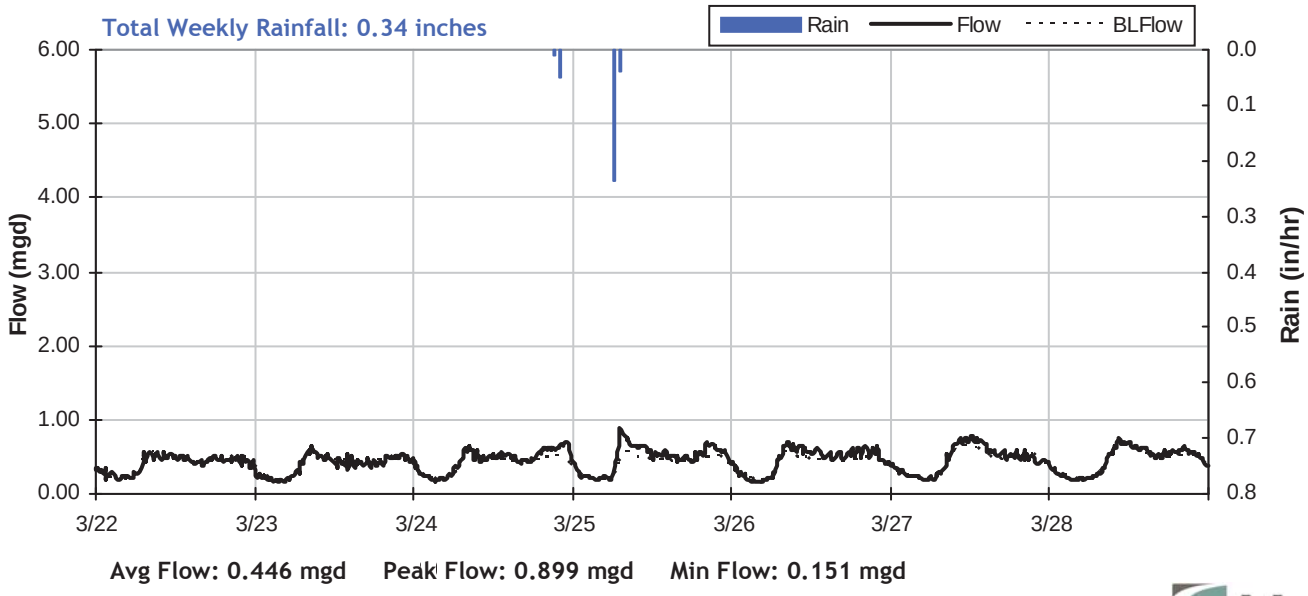


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 9



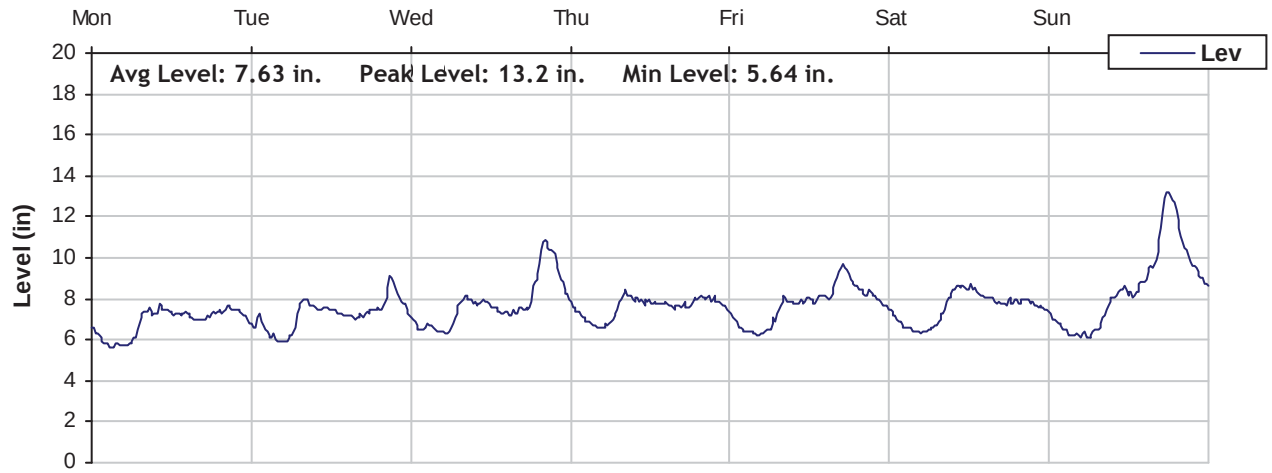


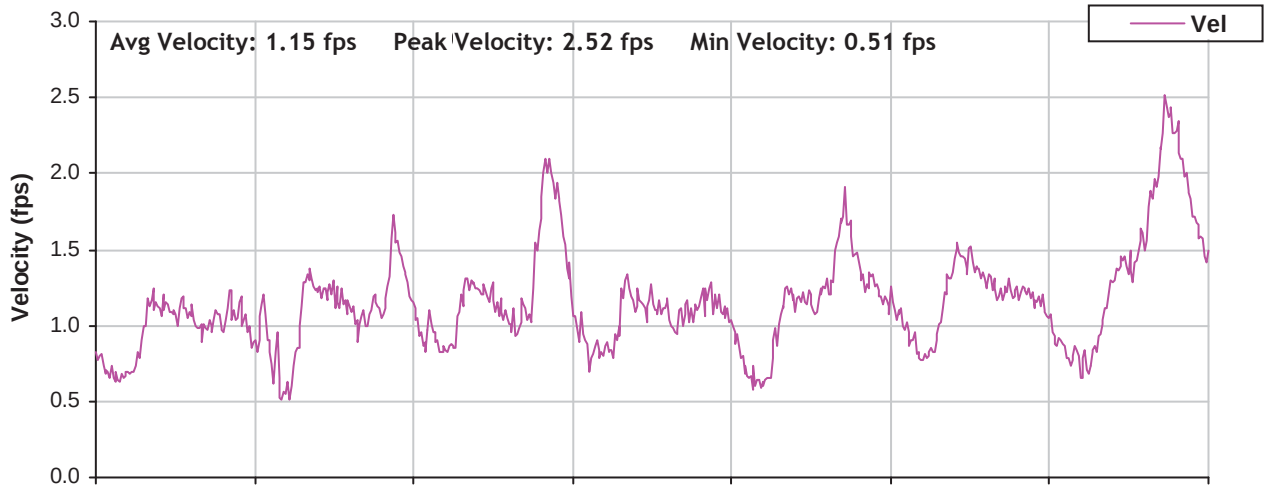


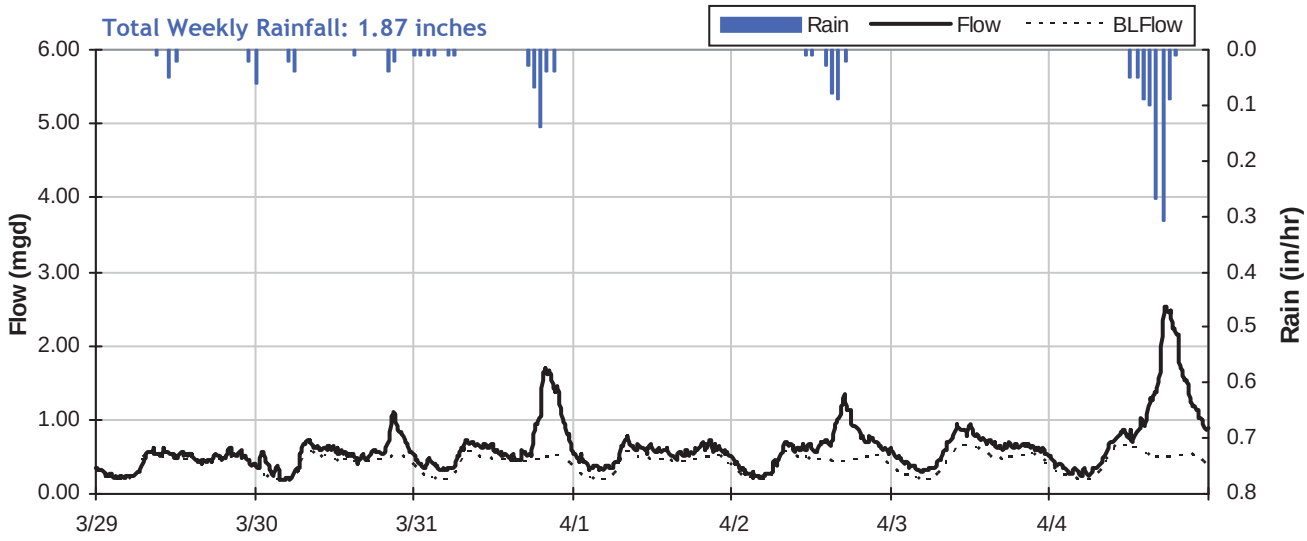
Avg Flow: 0.446 mgd Peak Flow: 0.899 mgd Min Flow: 0.151 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 9



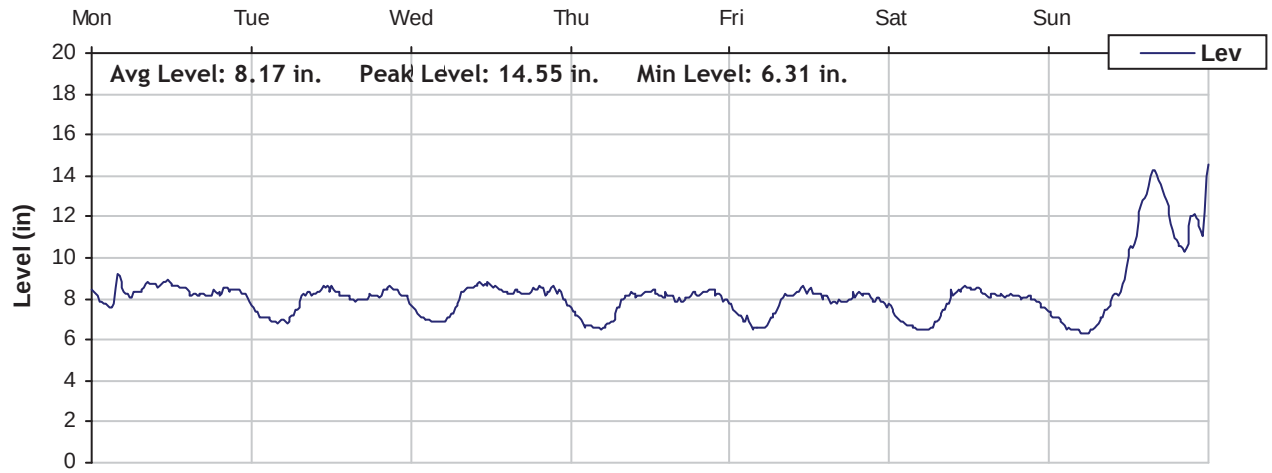


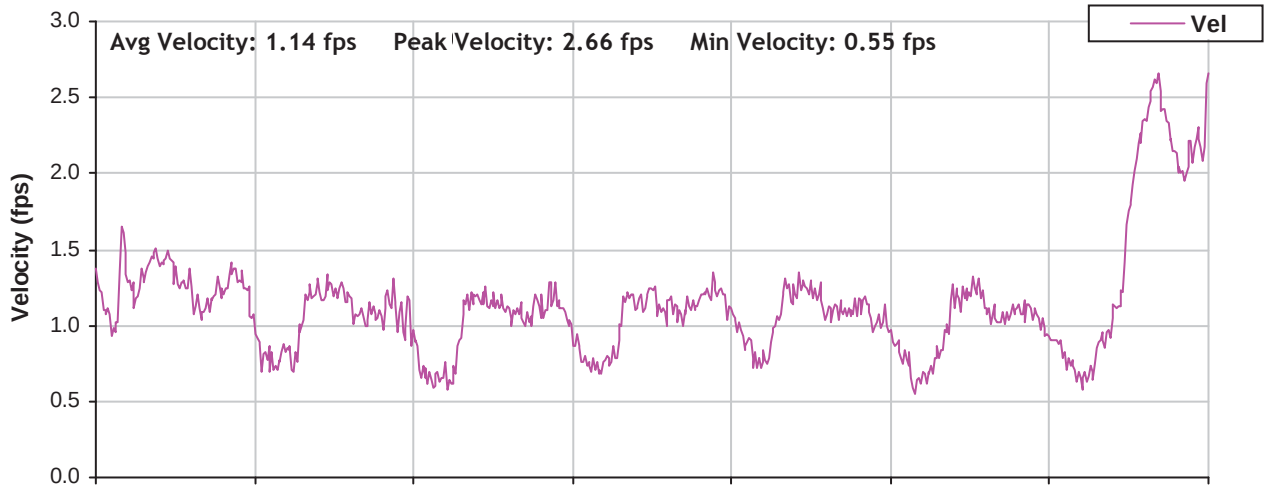


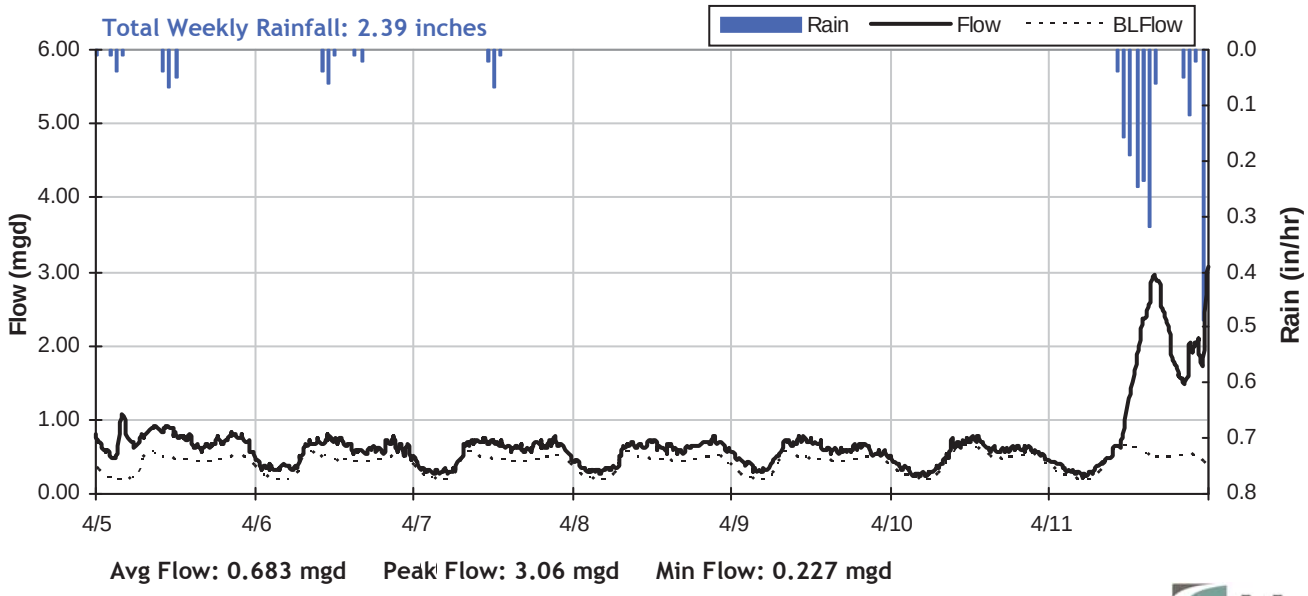
Avg Flow: 0.623 mgd Peak Flow: 2.529 mgd Min Flow: 0.186 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 9



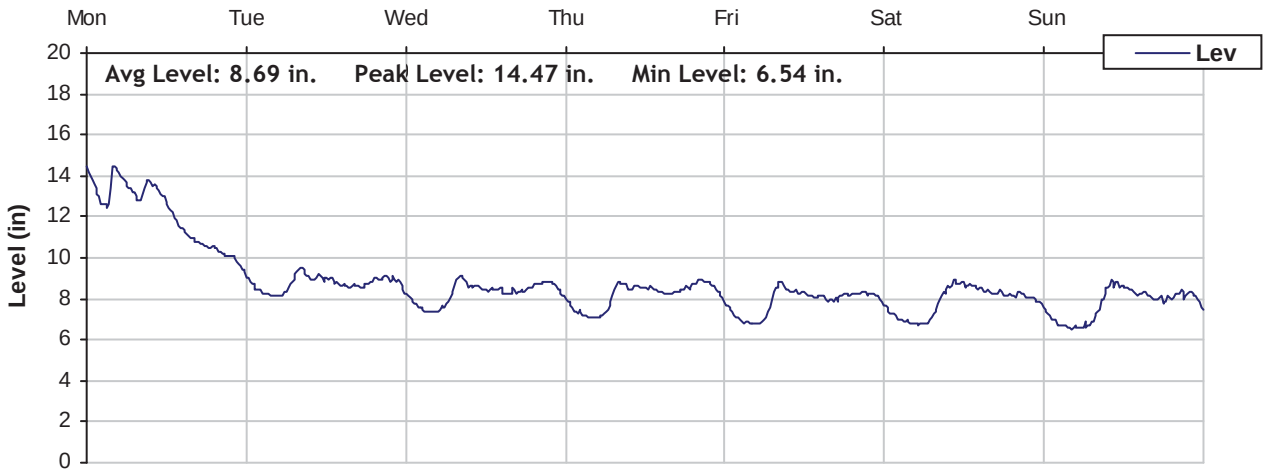


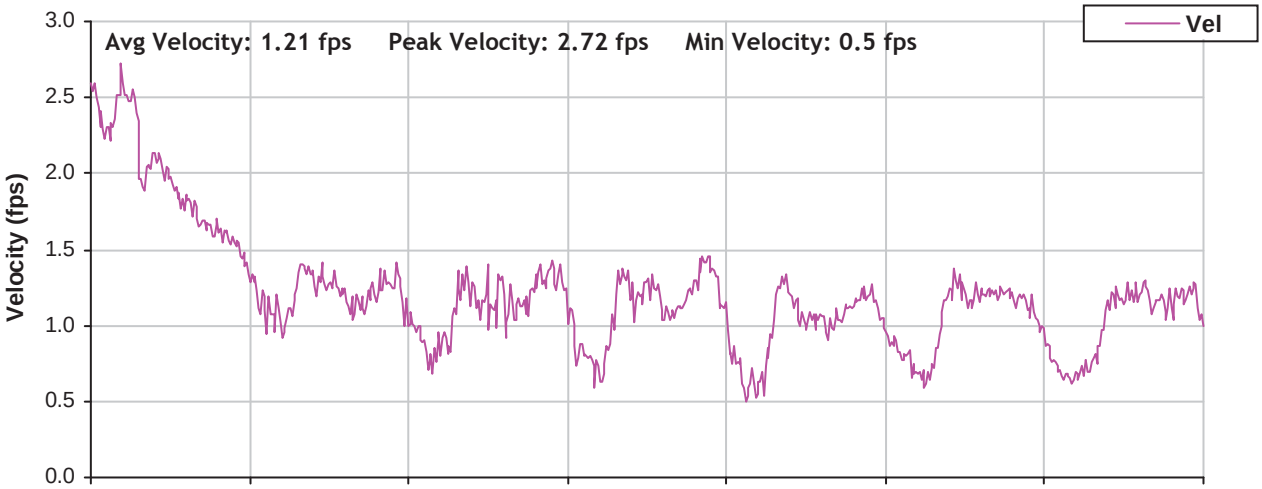


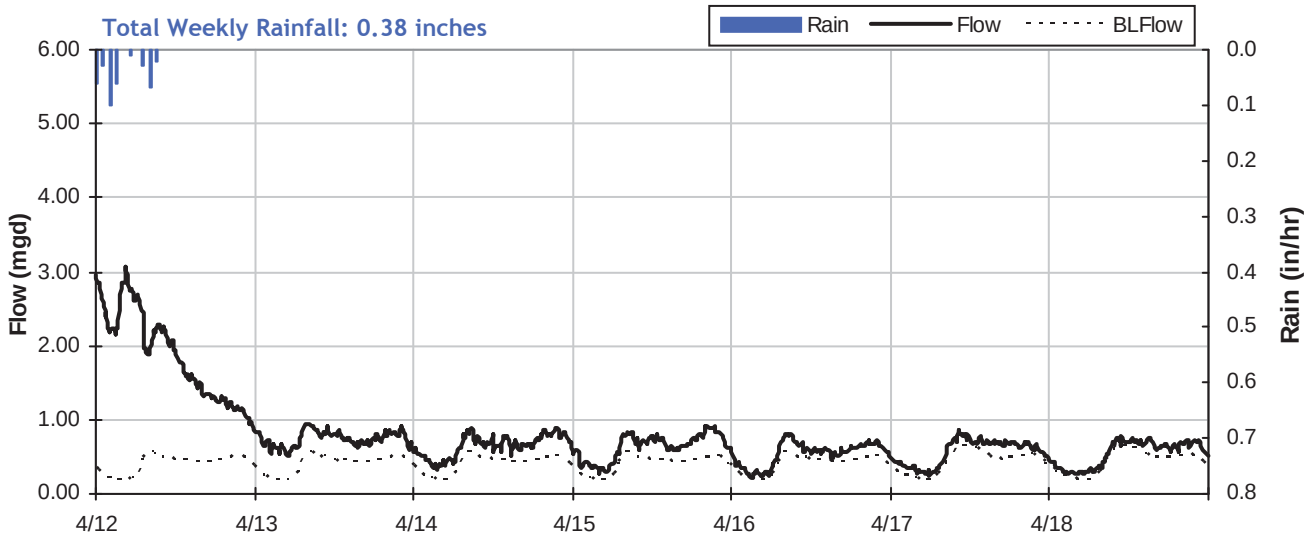
Avg Flow: 0.683 mgd Peak Flow: 3.06 mgd Min Flow: 0.227 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 9



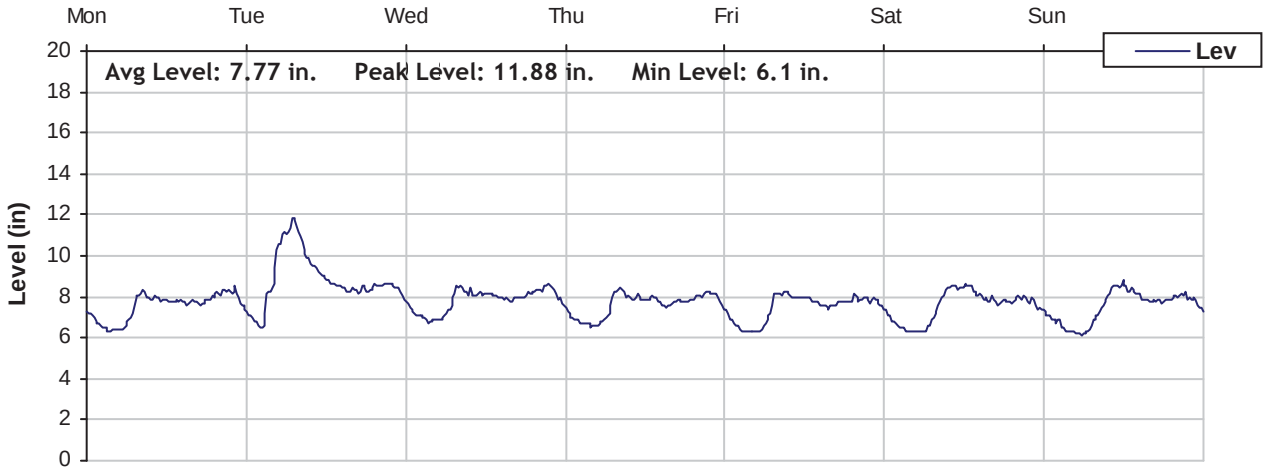


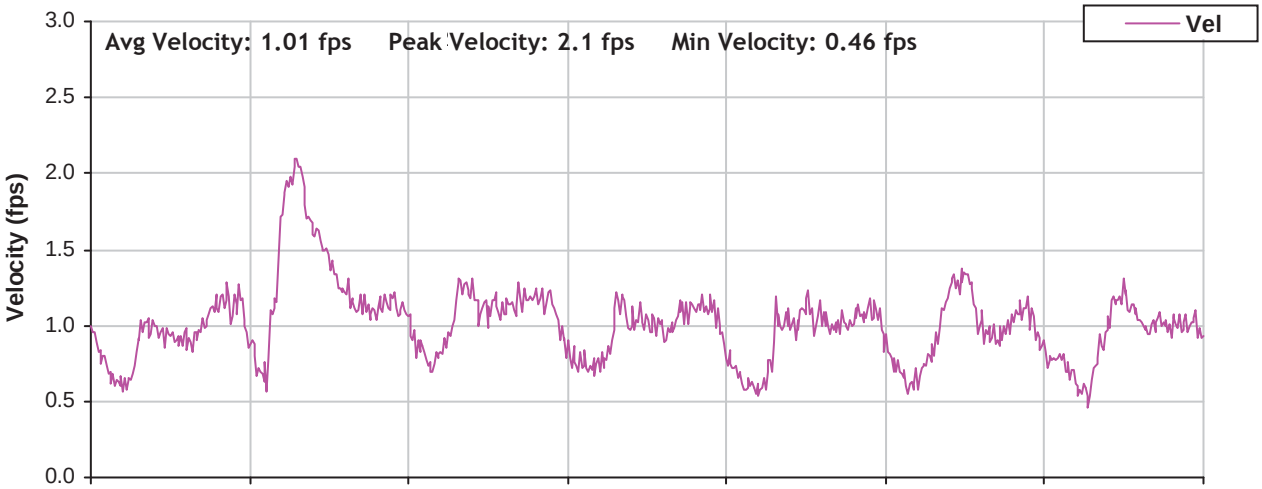


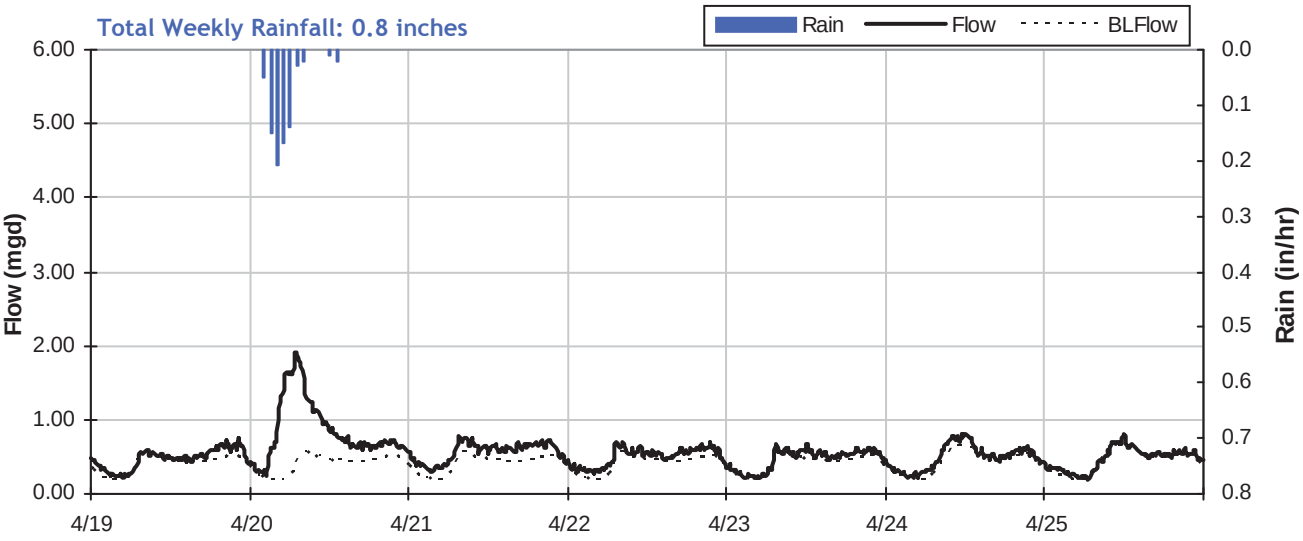
Avg Flow: 0.793 mgd Peak Flow: 3.055 mgd Min Flow: 0.218 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 9



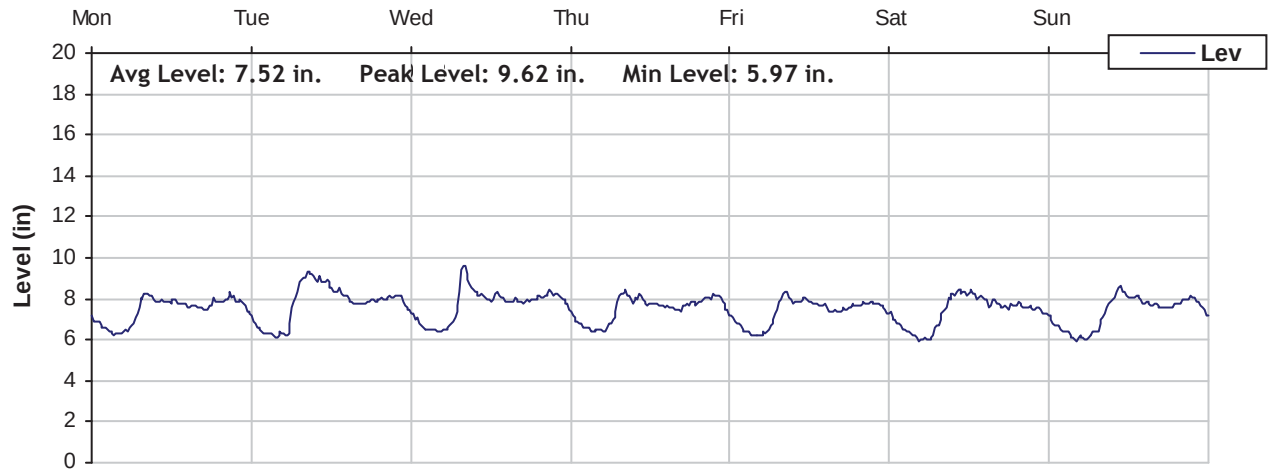


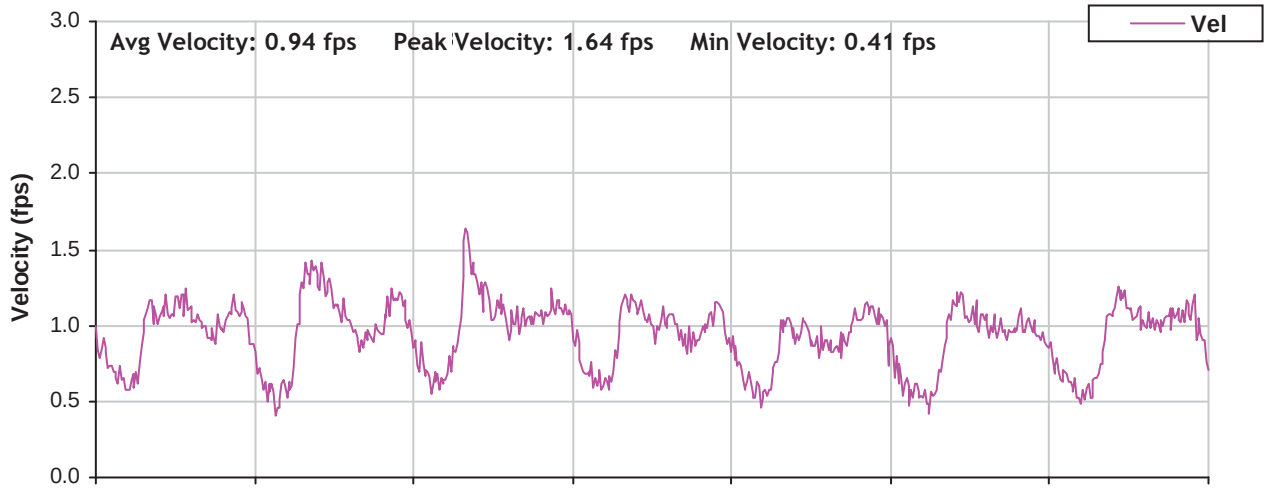


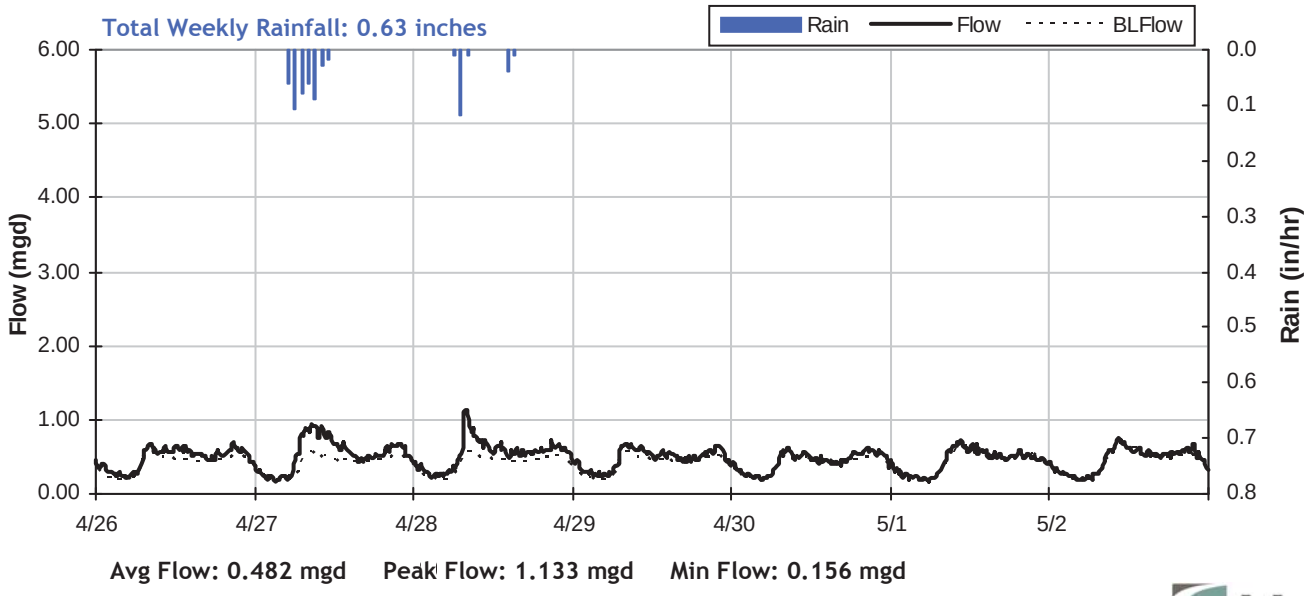
Avg Flow: 0.549 mgd Peak Flow: 1.905 mgd Min Flow: 0.18 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 9



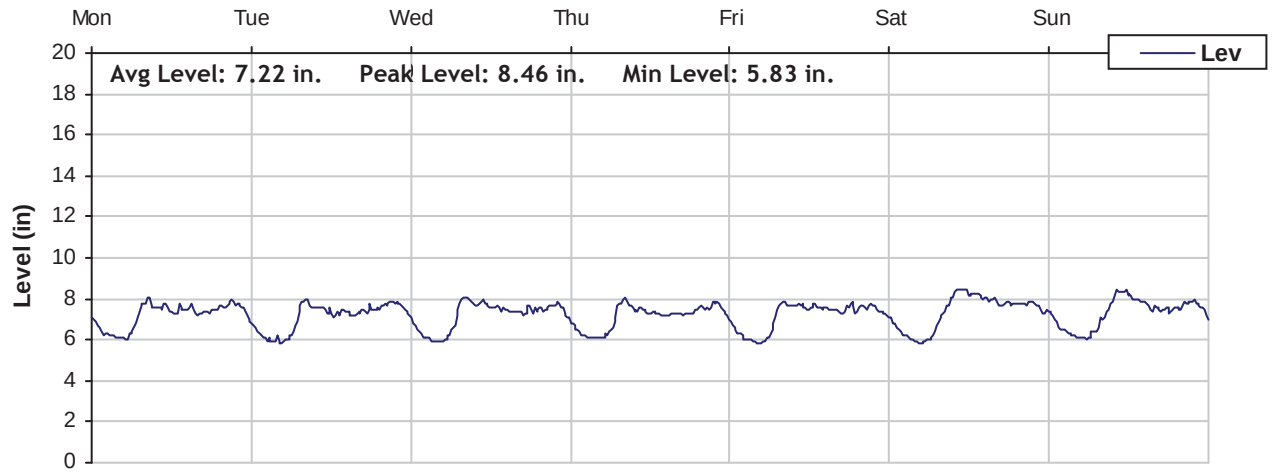


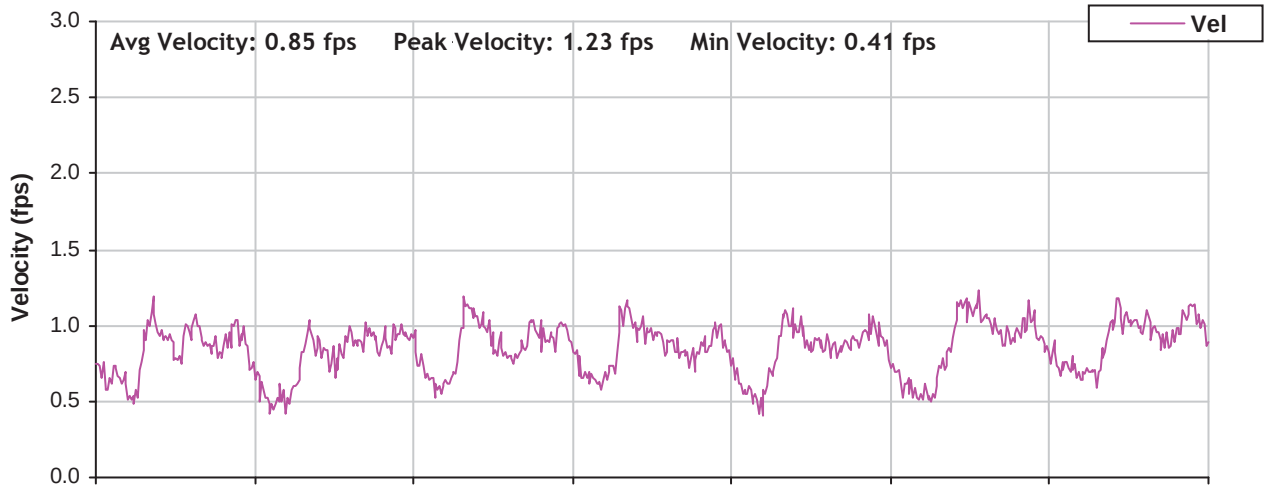


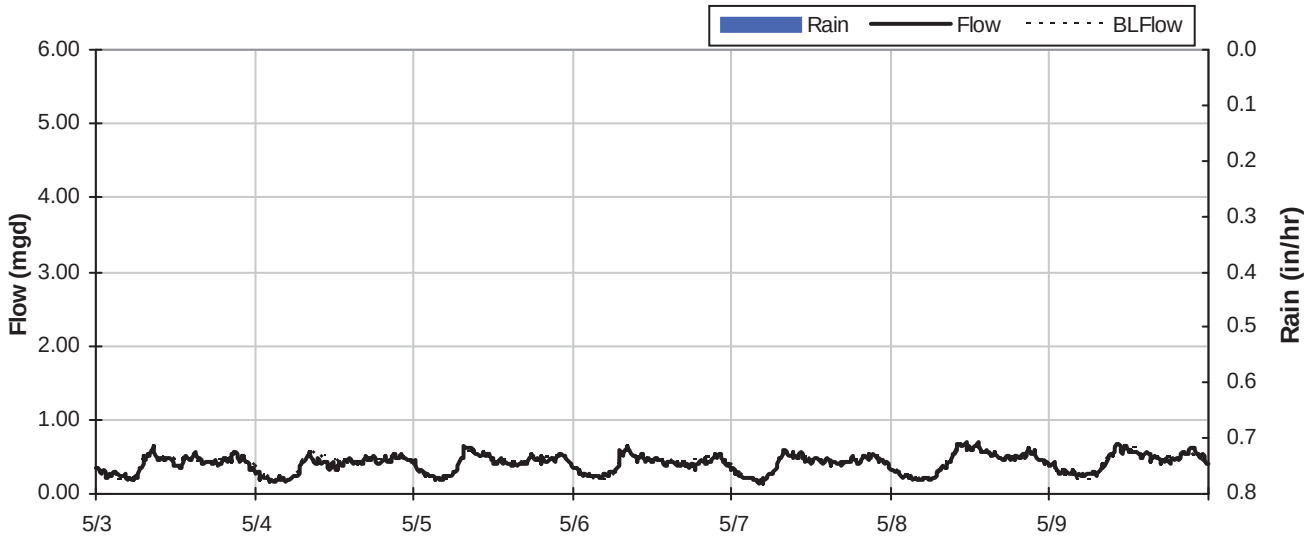
Avg Flow: 0.482 mgd Peak Flow: 1.133 mgd Min Flow: 0.156 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 9



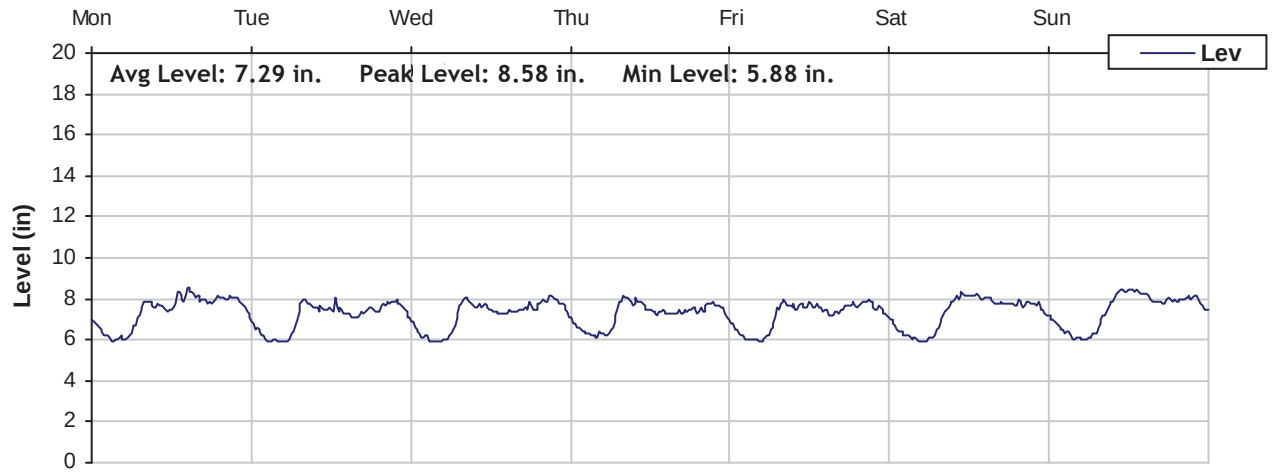


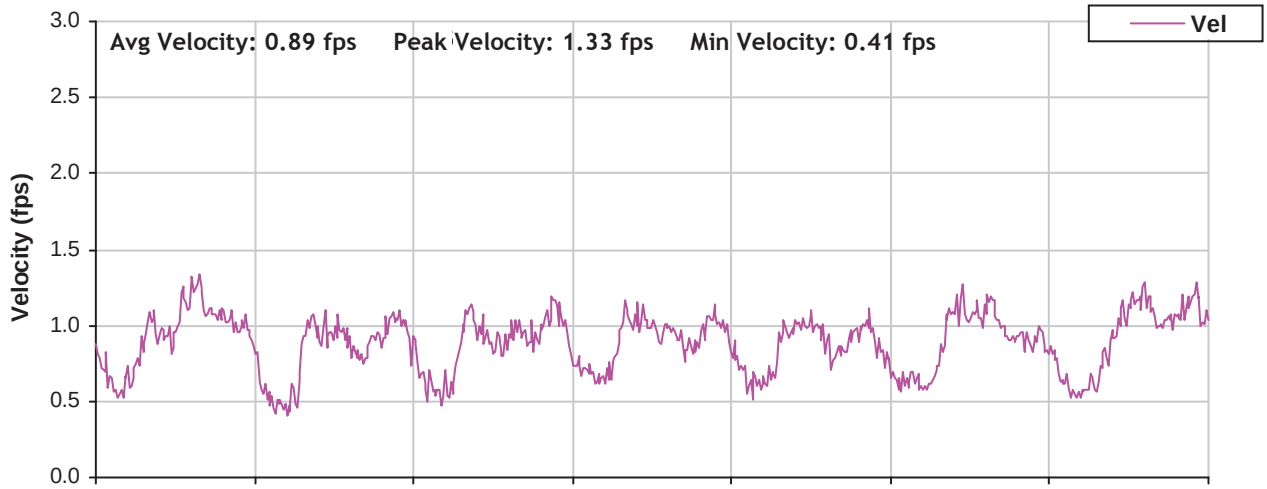


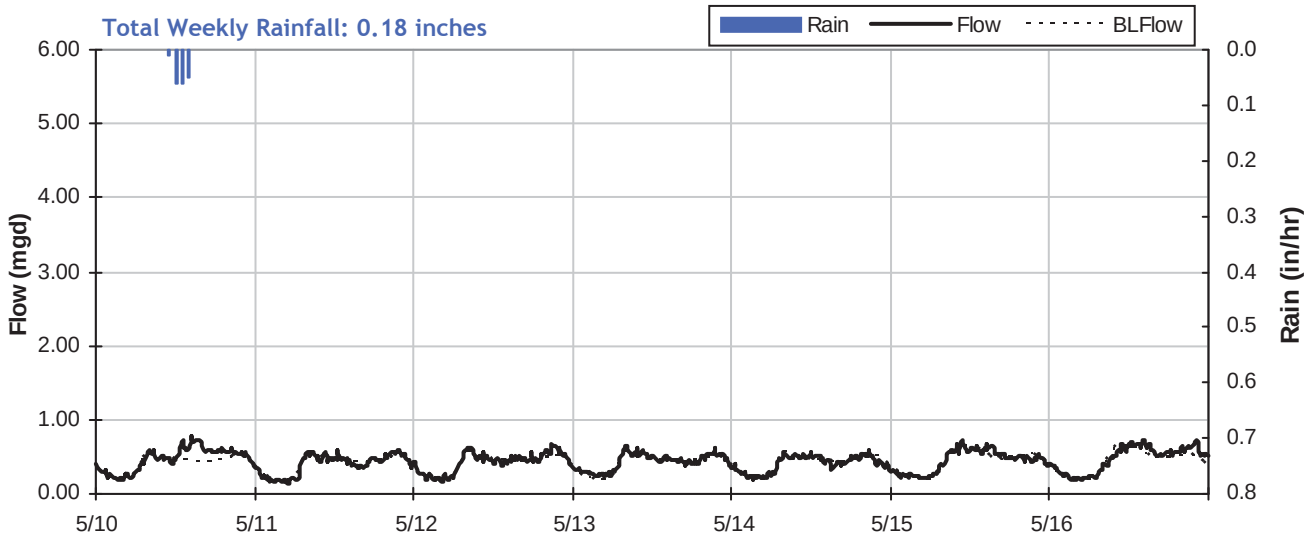
Avg Flow: 0.41 mgd Peak Flow: 0.701 mgd Min Flow: 0.146 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 9



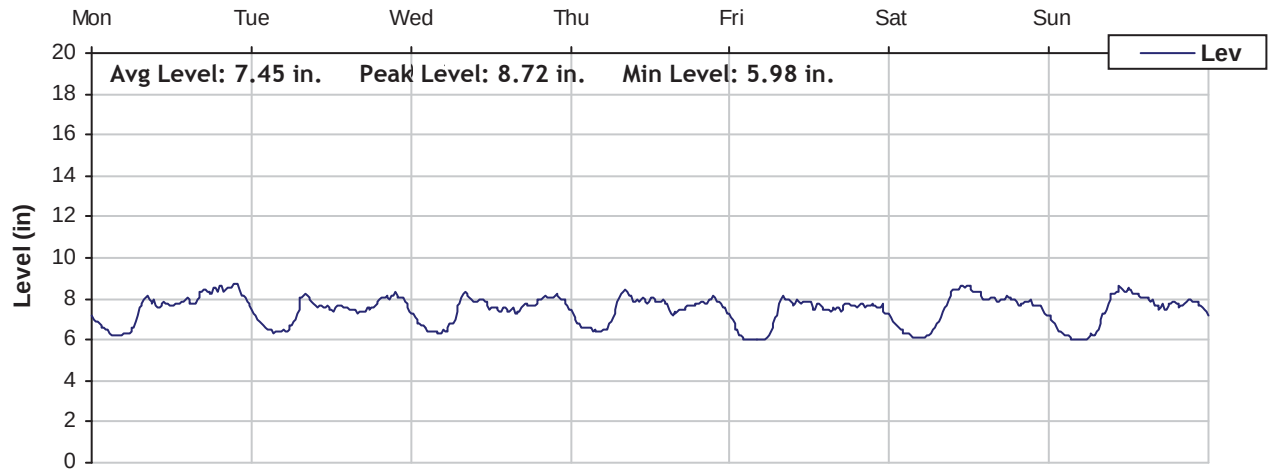


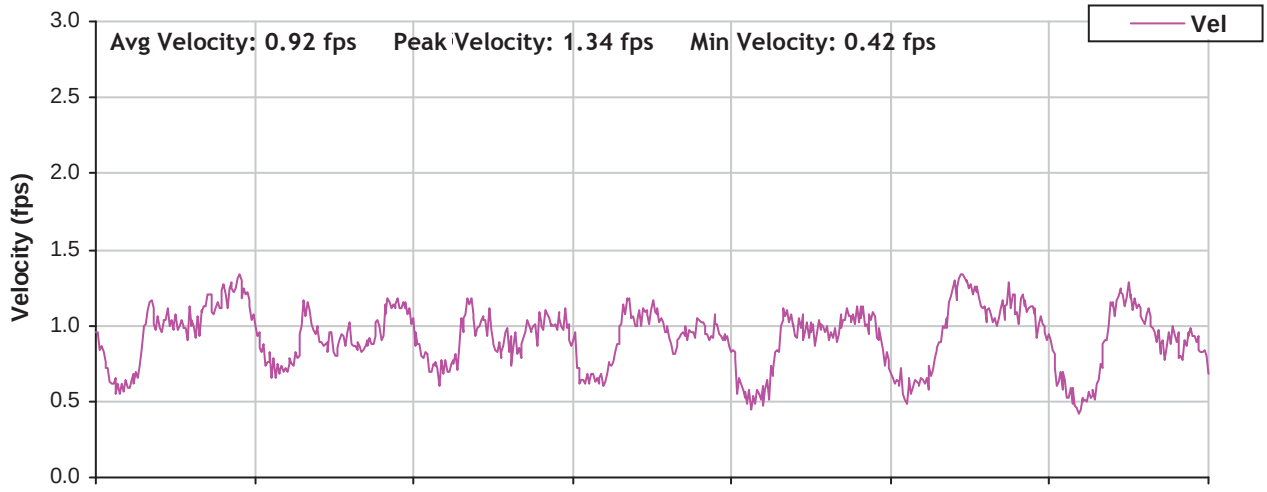


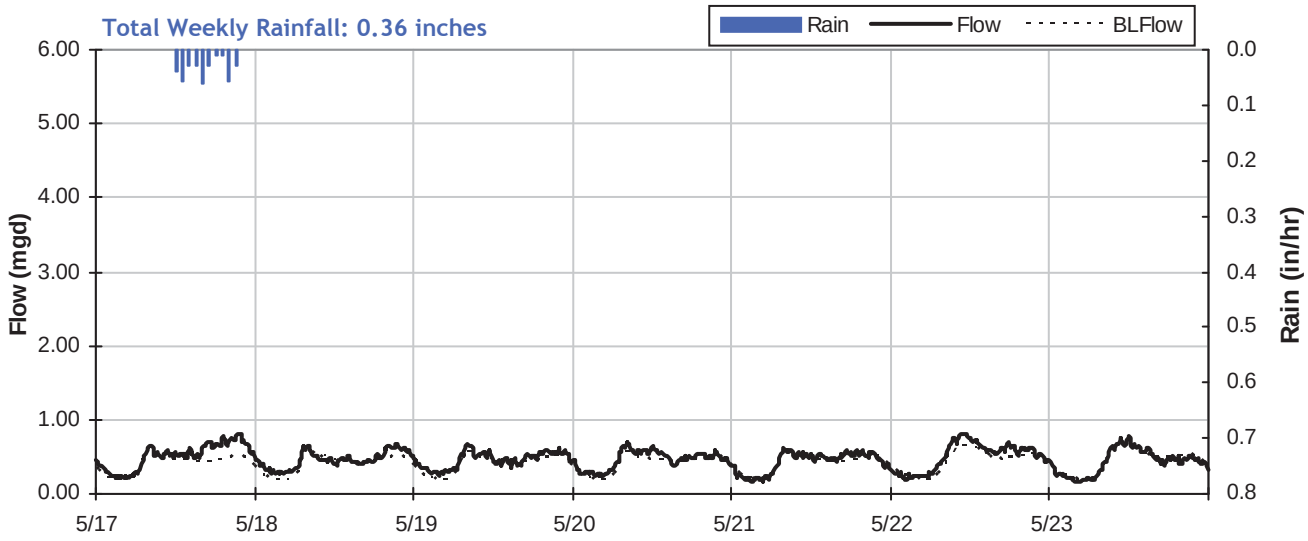
Avg Flow: 0.437 mgd Peak Flow: 0.787 mgd Min Flow: 0.146 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 9



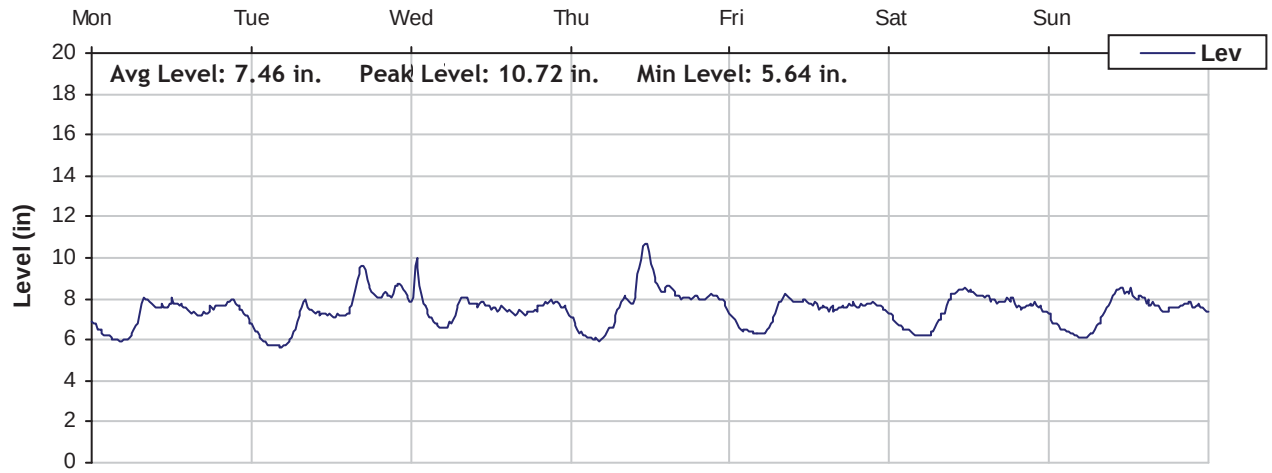


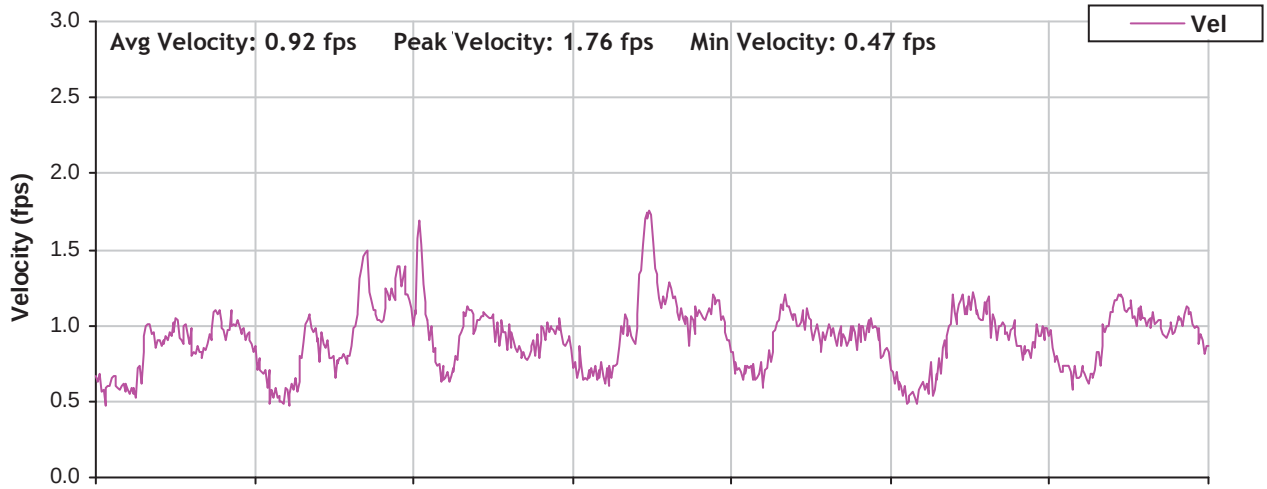


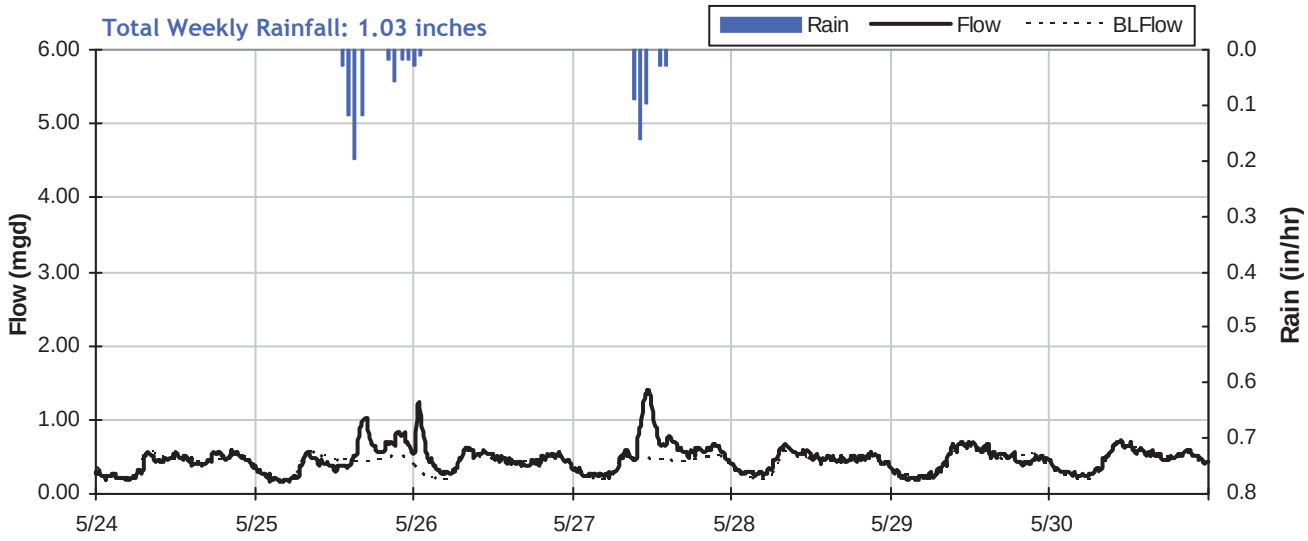
Avg Flow: 0.466 mgd Peak Flow: 0.813 mgd Min Flow: 0.155 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 9



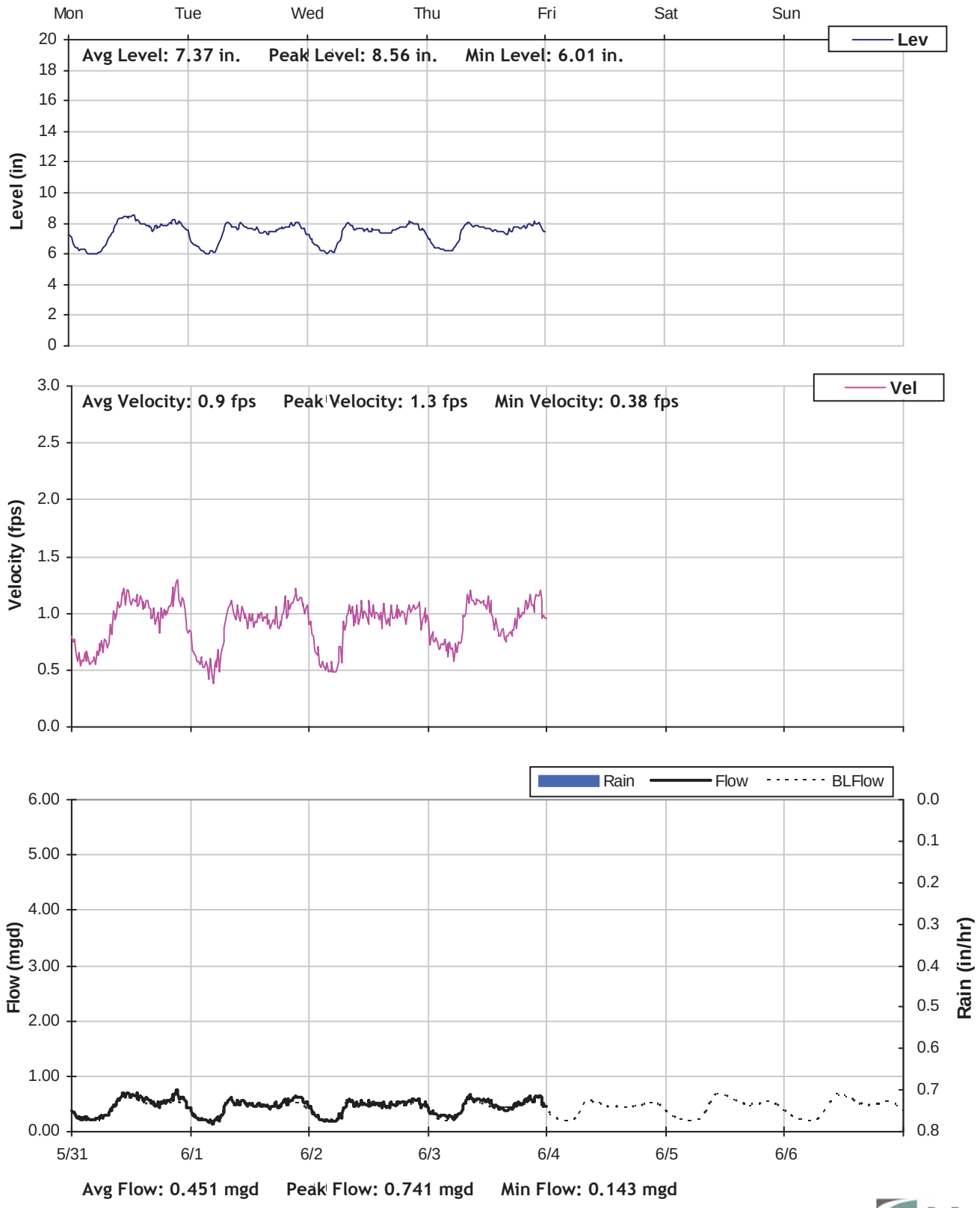




Avg Flow: 0.47 mgd Peak Flow: 1.389 mgd Min Flow: 0.162 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 9



Temporary Flow Monitoring Study

Sanitary Sewer Collection System

Monitoring Site: Site 10

Location: Intersection of Wright Avenue and S Marina Way; west cross walk

Size/Type Line: 36-inch Sanitary Sewer Pipe

Data Summary Report

Site Information Report

Monitoring Site: Site 10

Location: Intersection of Wright Avenue and S Marina Way; west cross walk

Latitude: 37.9212°

Longitude: -122.3560°

Rim Elevation: 13 *feet above sea level*

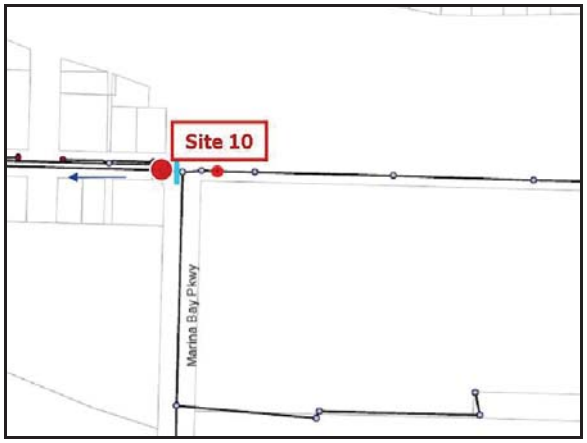
Diameter: 36 *inches*

Average Dry Weather Flow: 1.685 *mgd*

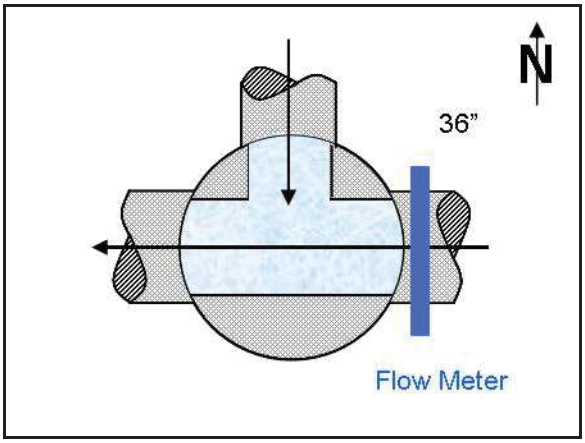
Peak Measured Flow: 11.010 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

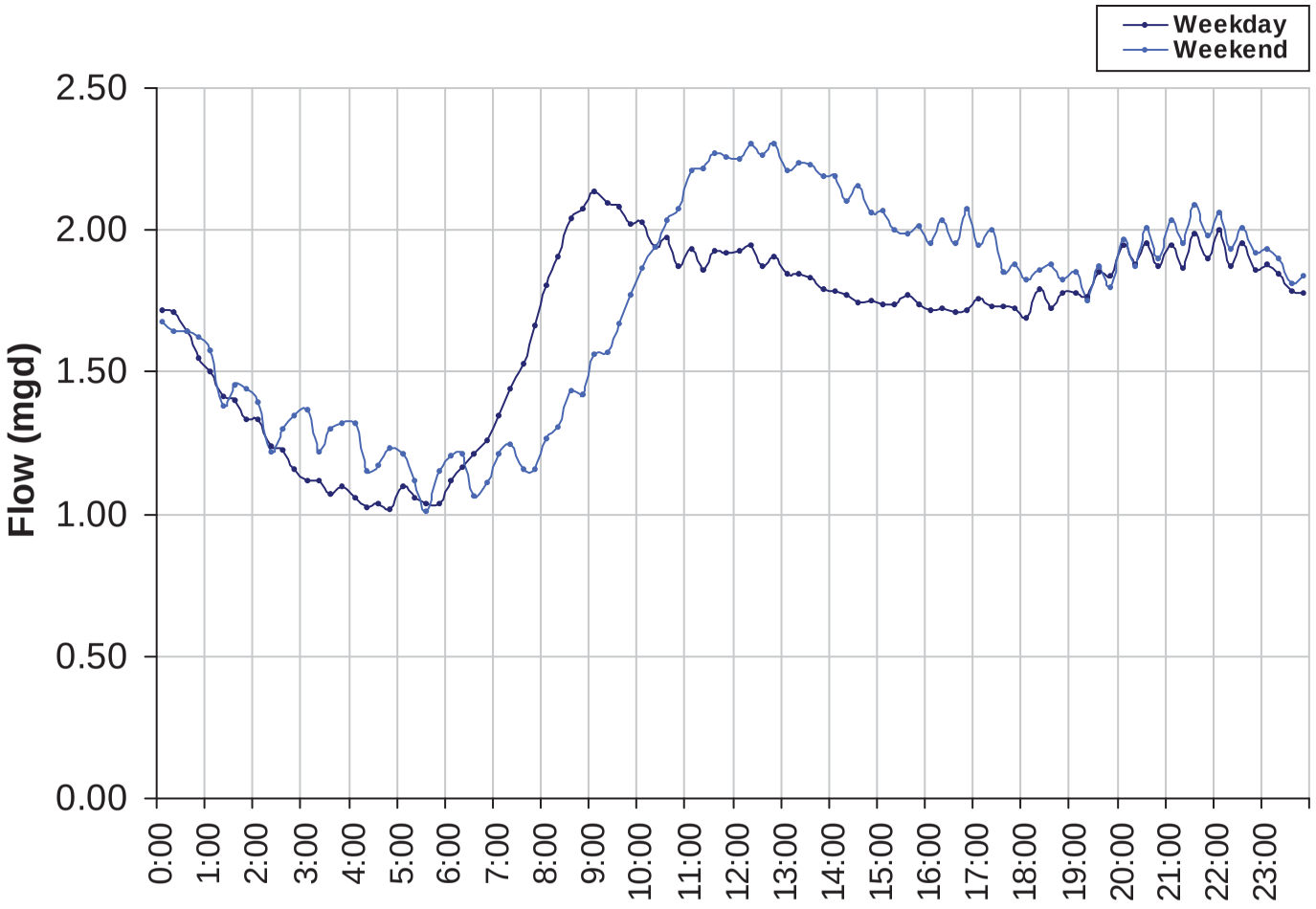


Street View Photo

Plan View Photo

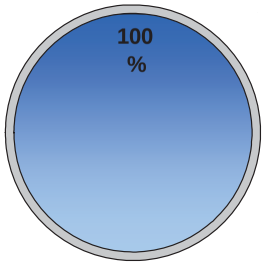
Average Dry Weather Flow

Monitoring Site:
Site 10



Peak Measured Flow:

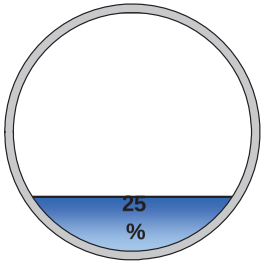
11.01 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

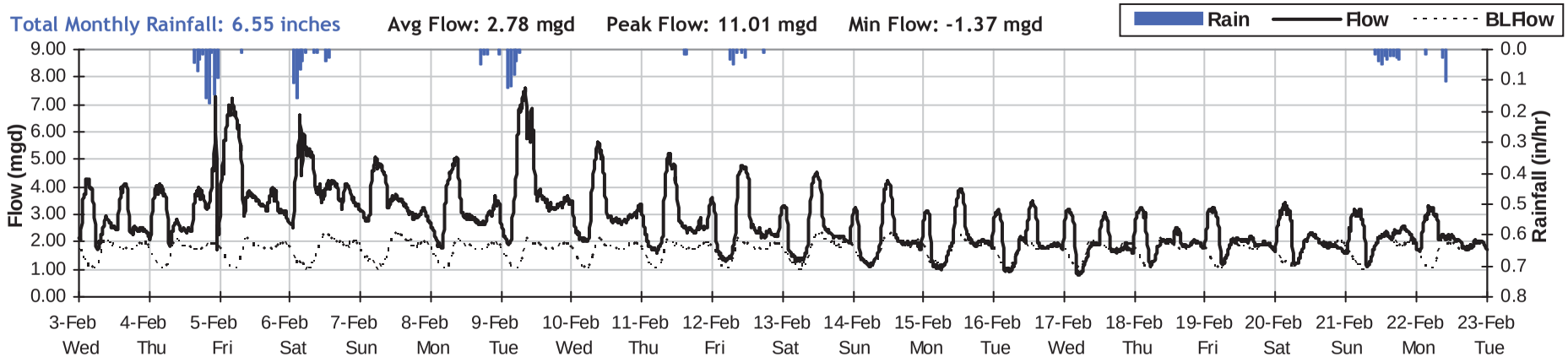
1.69 *mgd*

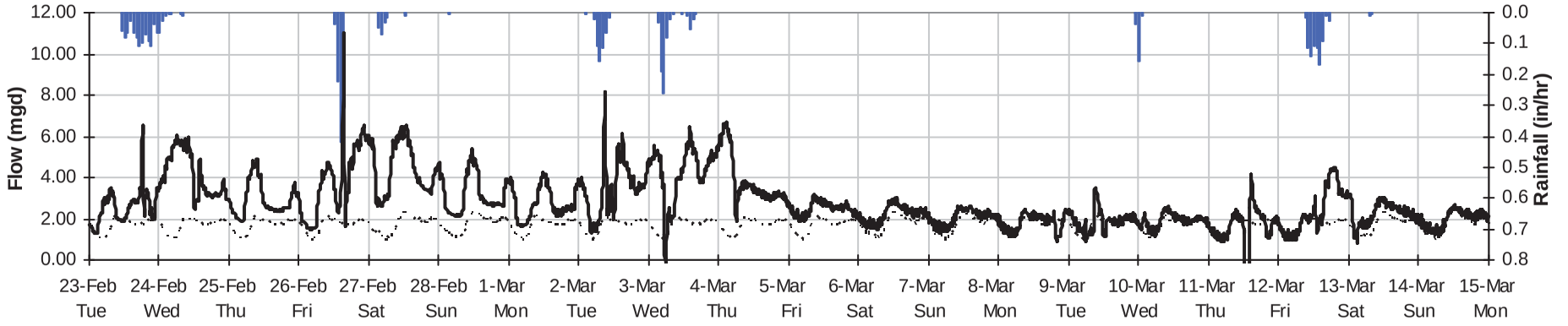


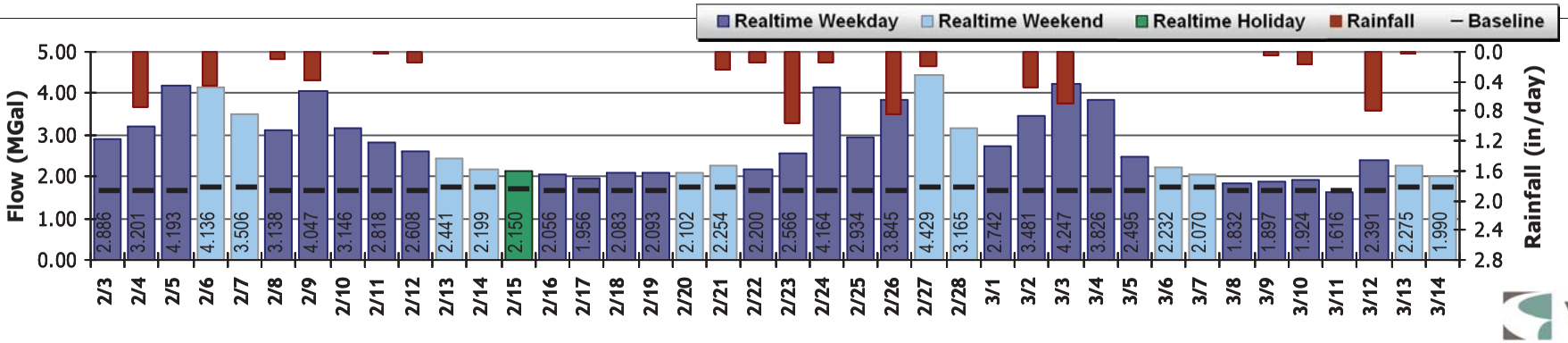
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 10

Total Monthly Rainfall: 6.55 inches Avg Flow: 2.78 mgd Peak Flow: 11.01 mgd Min Flow: -1.37 mgd



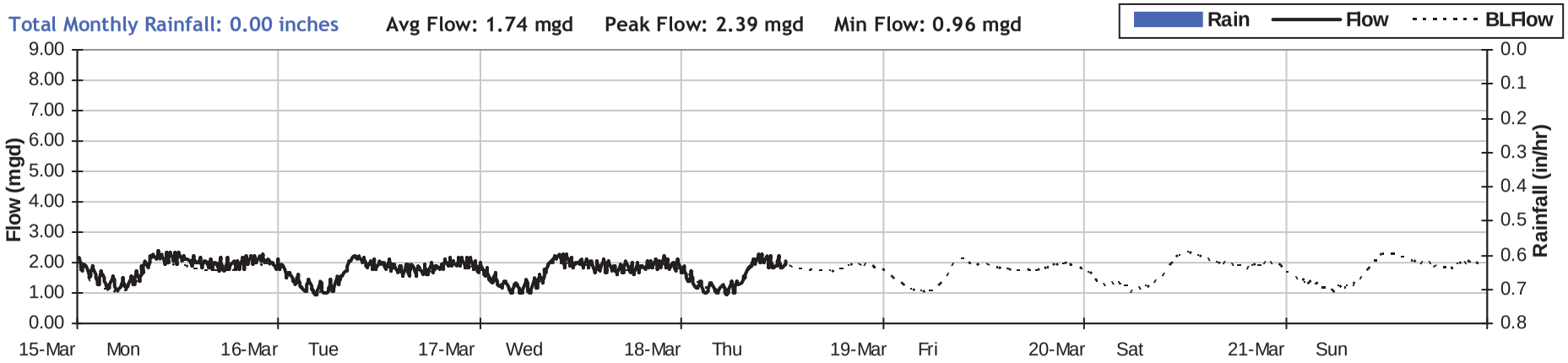


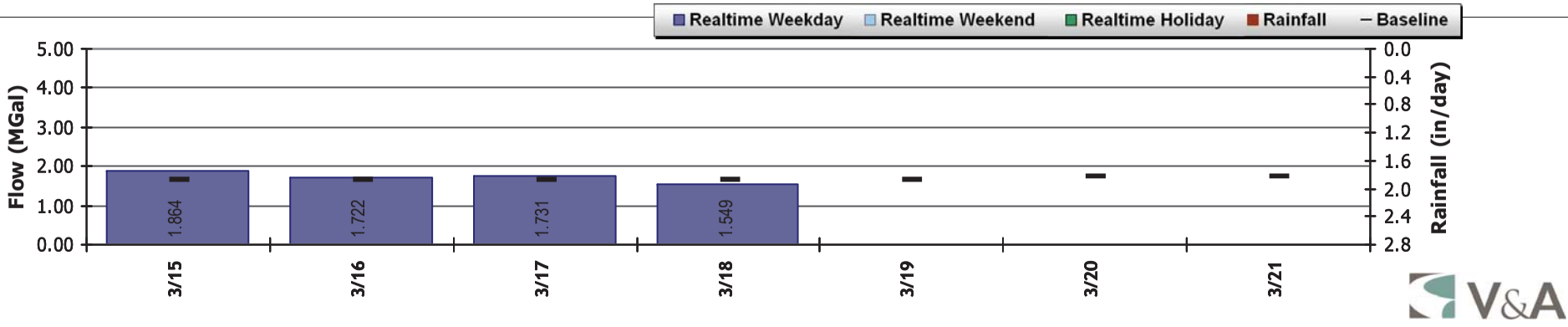


Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 10

Total Monthly Rainfall: 0.00 inches Avg Flow: 1.74 mgd Peak Flow: 2.39 mgd Min Flow: 0.96 mgd



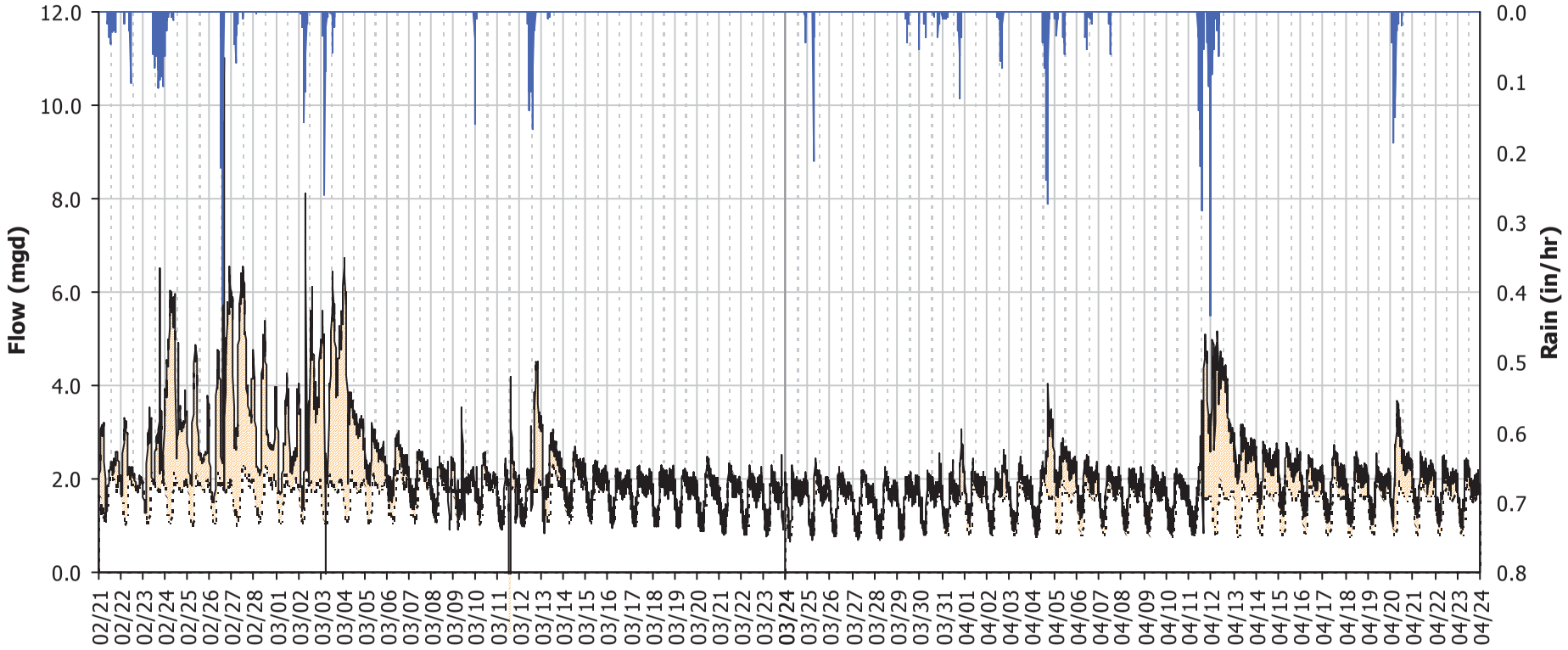


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
10+10A

Multiple Events Detail I/I Graph

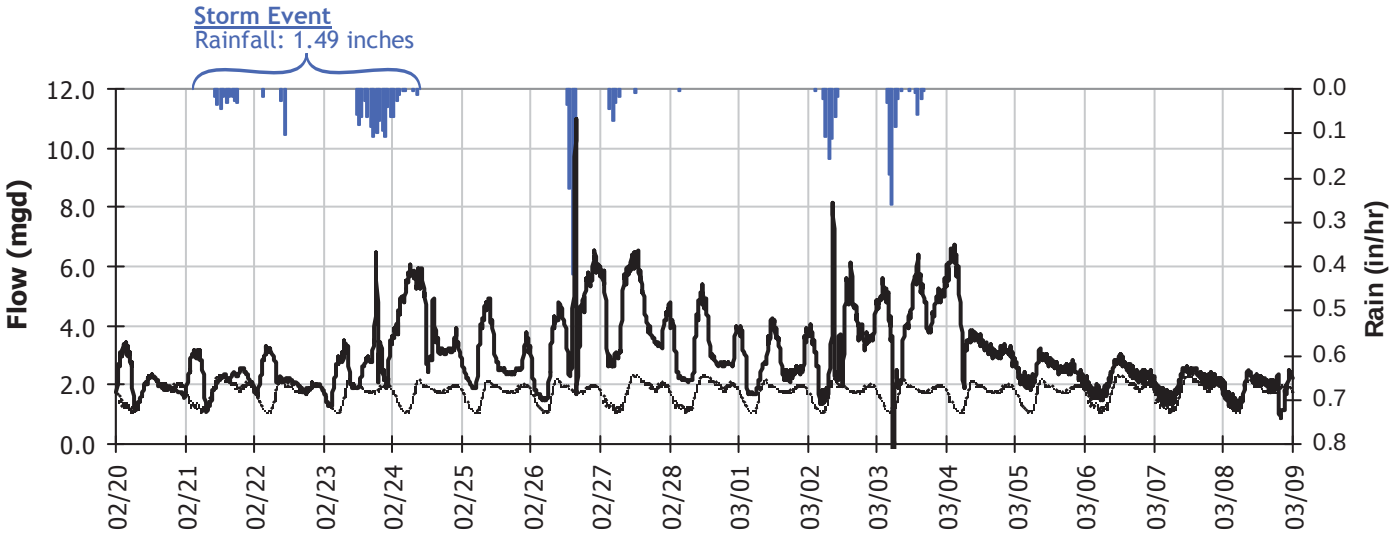


Multiple Events I/I Analysis

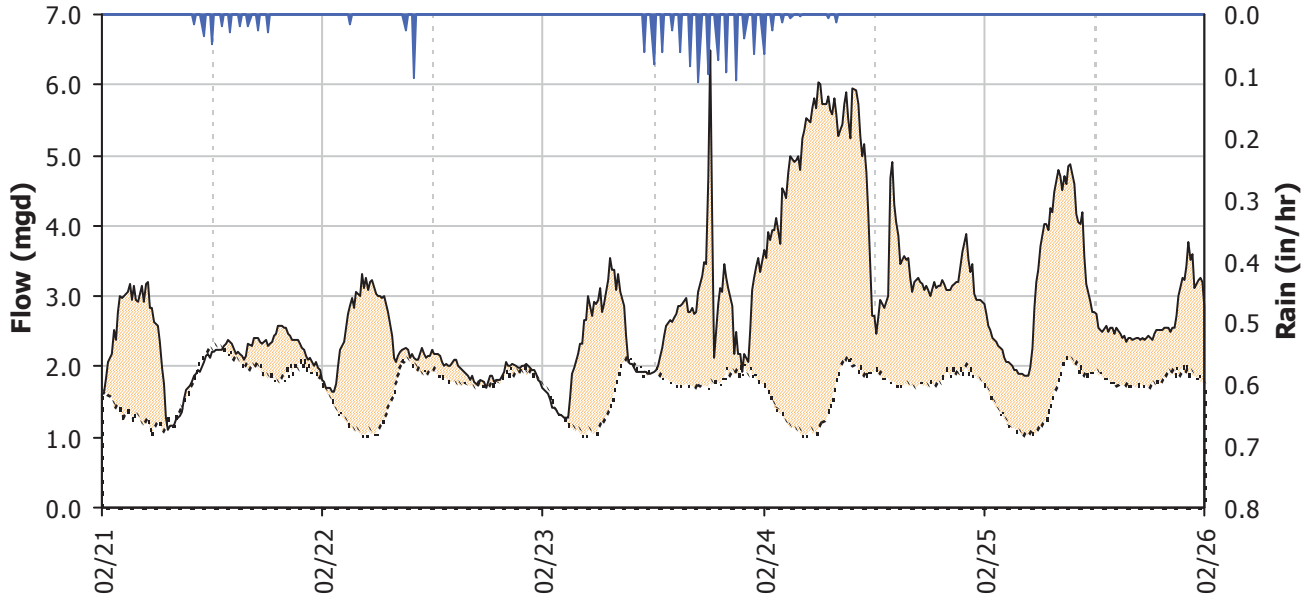
Rainfall:	9.83	*inches*	**Baseline Flow:**	1.46	*mgd*
Peak Flow:	11.01	*mgd*	**PF:**	7.56	
Peak I/I Rate:	9.27	*mgd*	**Pk I/I:ADWF:**	6.37	
Peak Level:	94.10	*inches*	**d/D Ratio:**		
Total I/I:	38,154,000	*gallons*	**R-Value:**	11.9%	
			I/I per ADWF:	2.7	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 10

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

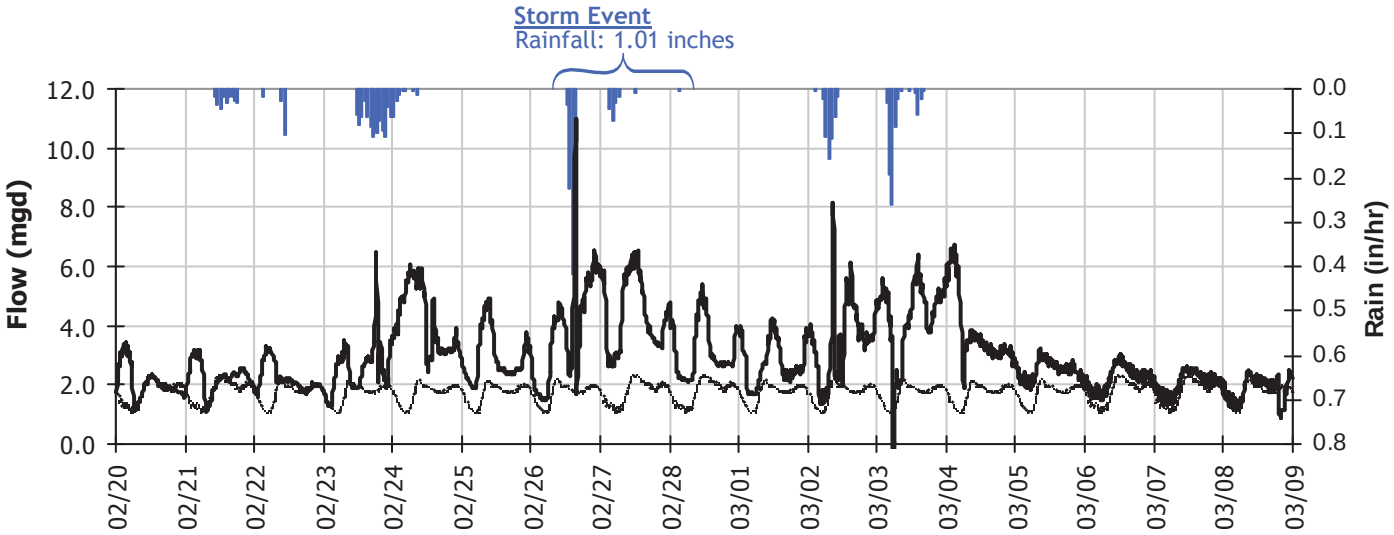
Rainfall:	1.49	*inches*		
Baseline Flow:	1.69	*mgd*		
Peak Flow:	6.49	*mgd*	**PF:**	3.85
Peak I/I Rate:	4.93	*mgd*	**Pk I/I:ADWF:**	2.92
Peak Level:	84.65	*inches*	**d/D Ratio:**	2.35
Total I/I:	5,736,000	*gallons*	**R-Value:**	11.8%
			I/I per ADWF:	2.29 *per in-rain*

Average Infiltration Rate on 2/25 (% of ADWF): 76.2%

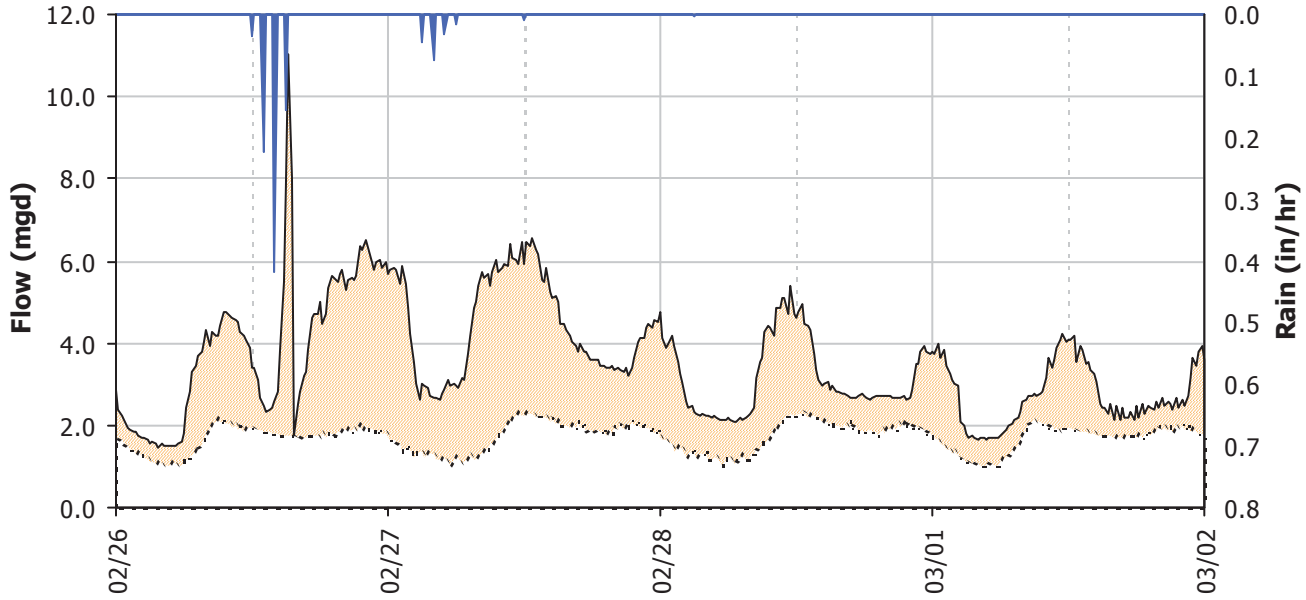
V&A

	I/I Summary Event 2	**Monitoring Site:** Site 10

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



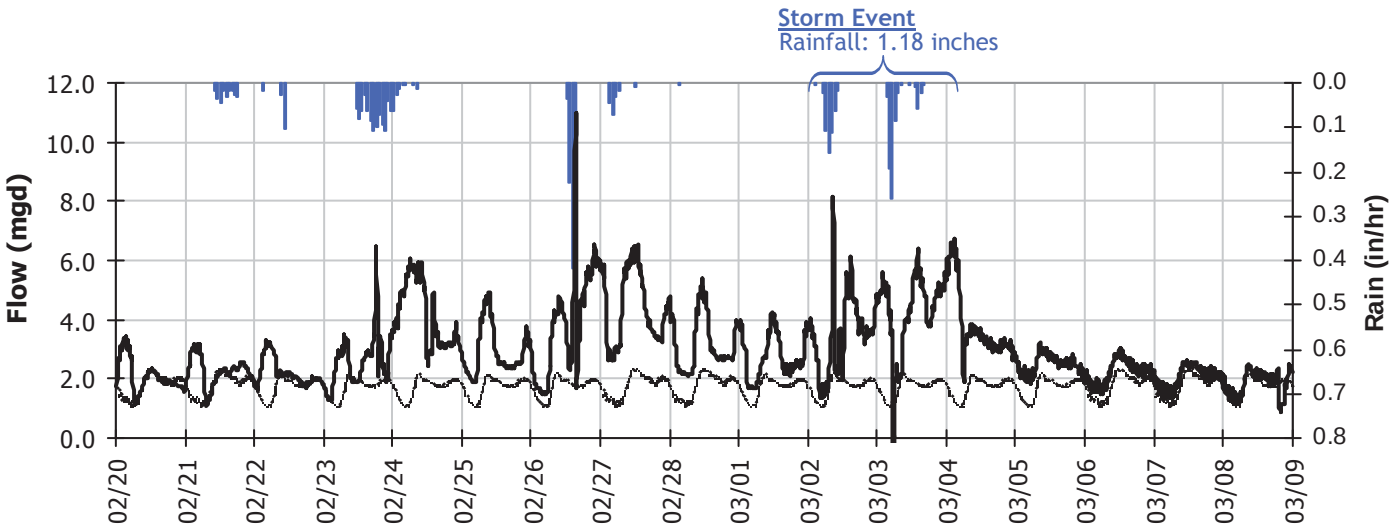
Storm Event #2 I/I Analysis

Rainfall:	1.01	*inches*		
Baseline Flow:	1.69	*mgd*		
Peak Flow:	11.01	*mgd*	**PF:**	6.53
Peak I/I Rate:	9.27	*mgd*	**Pk I/I:ADWF:**	5.50
Peak Level:	78.55	*inches*	**d/D Ratio:**	2.18
Total I/I:	7,398,000	*gallons*	**R-Value:**	22.3%
			I/I per ADWF:	4.33 *per in-rain*

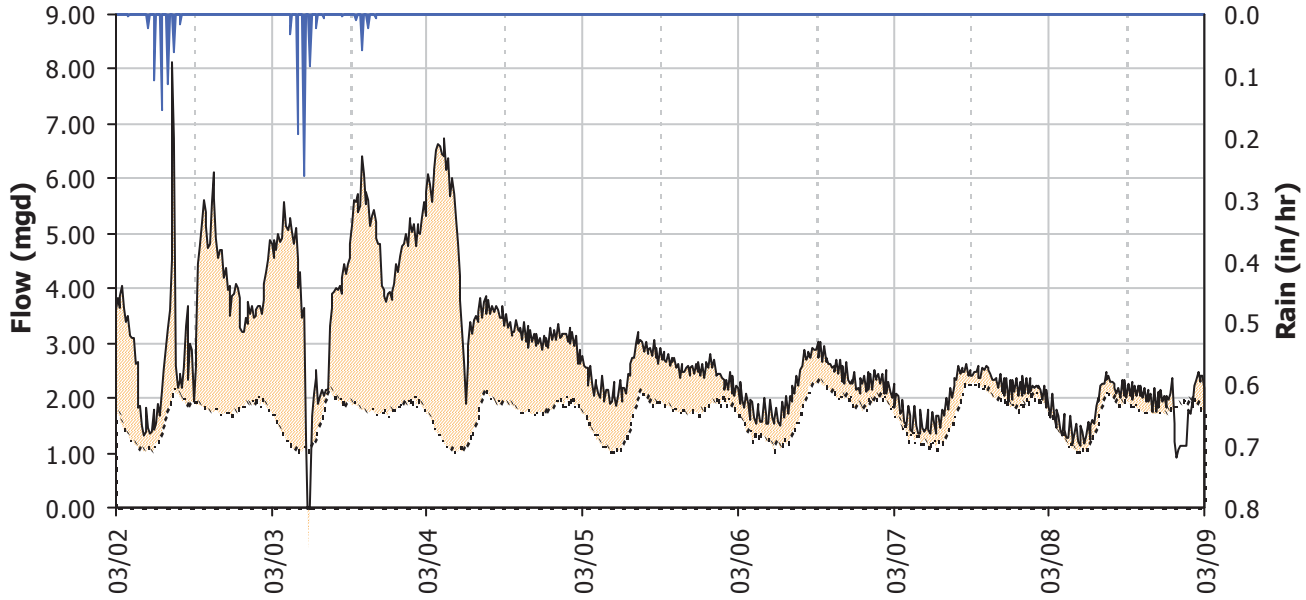
Average Infiltration Rate on 3/1 (% of ADWF): 65.2%

	I/I Summary Event 3	**Monitoring Site:** Site 10

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



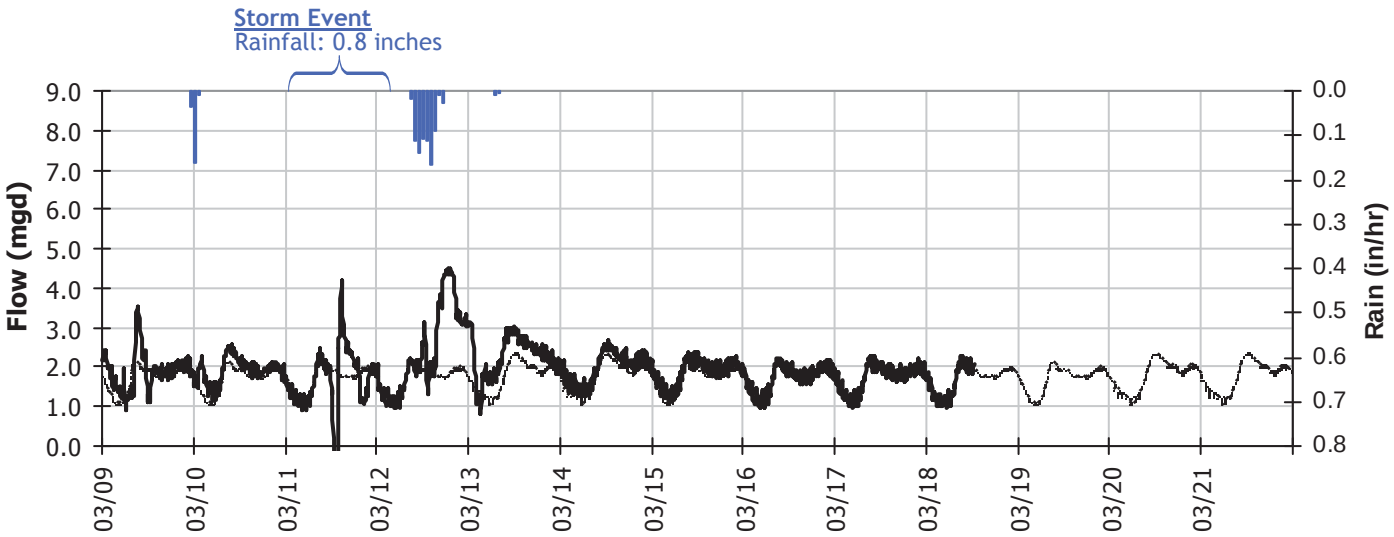
Storm Event #3 I/I Analysis

Rainfall:	1.18	*inches*		
Baseline Flow:	1.69	*mgd*		
Peak Flow:	8.11	*mgd*	**PF:**	4.81
Peak I/I Rate:	6.03	*mgd*	**Pk I/I:ADWF:**	3.58
Peak Level:	94.10	*inches*	**d/D Ratio:**	2.61
Total I/I:	8,392,000	*gallons*	**R-Value:**	21.7%
			I/I per ADWF:	4.21 *per in-rain*

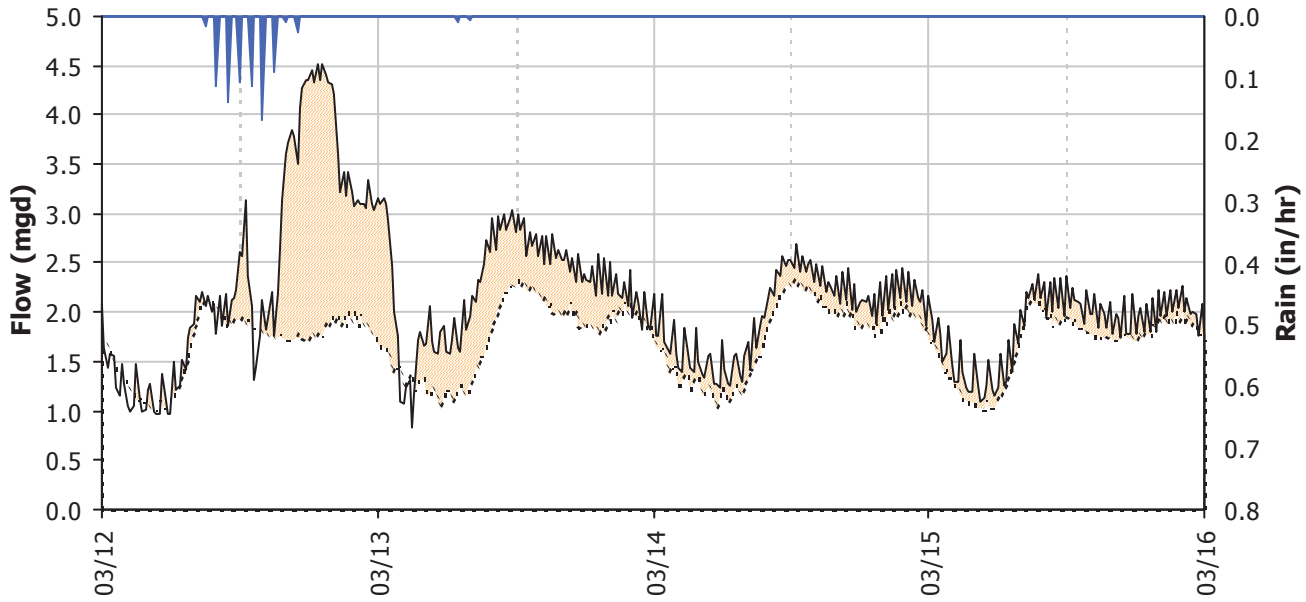
Average Infiltration Rate on 3/5 (% of ADWF): 49.7%

	I/I Summary Event 4	**Monitoring Site:** Site 10

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



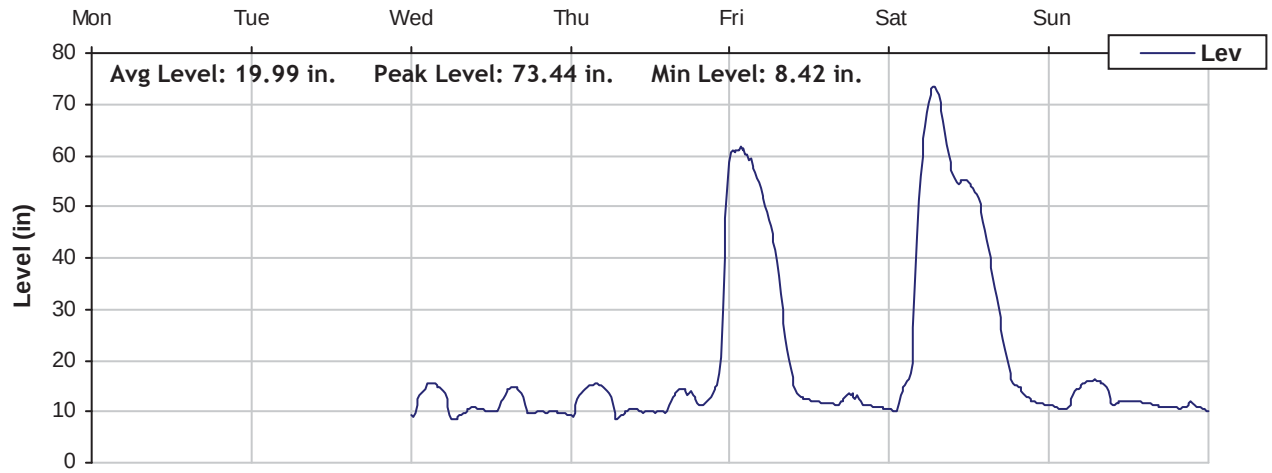
Storm Event #1 I/I Analysis

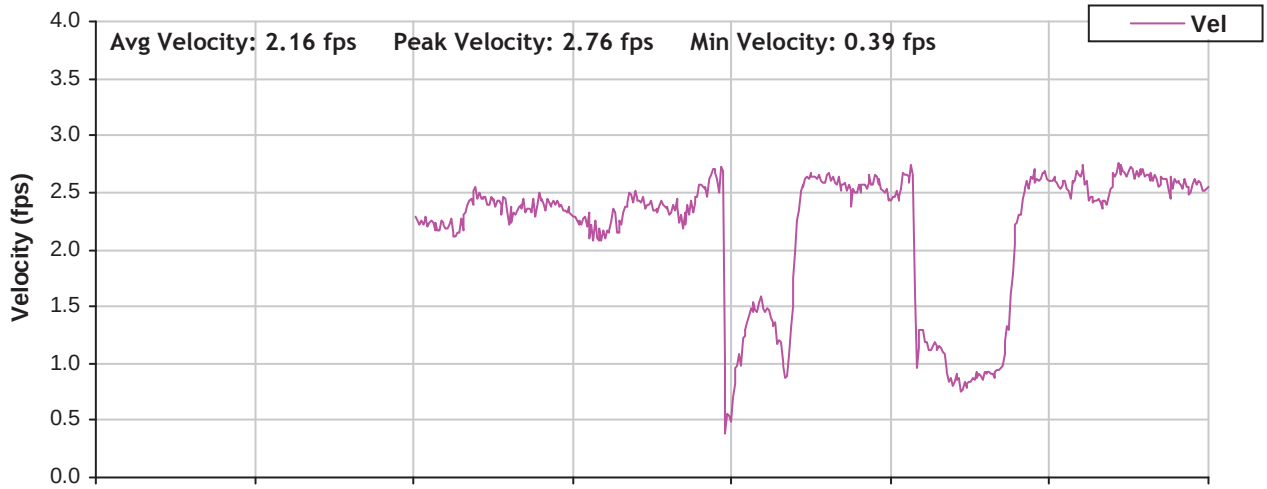
Rainfall:	0.80	*inches*		
Baseline Flow:	1.69	*mgd*		
Peak Flow:	4.52	*mgd*	**PF:**	2.68
Peak I/I Rate:	2.75	*mgd*	**Pk I/I:ADWF:**	1.63
Peak Level:	72.13	*inches*	**d/D Ratio:**	2.00
Total I/I:	1,719,000	*gallons*	**R-Value:**	6.6%
			I/I per ADWF:	1.27 *per in-rain*

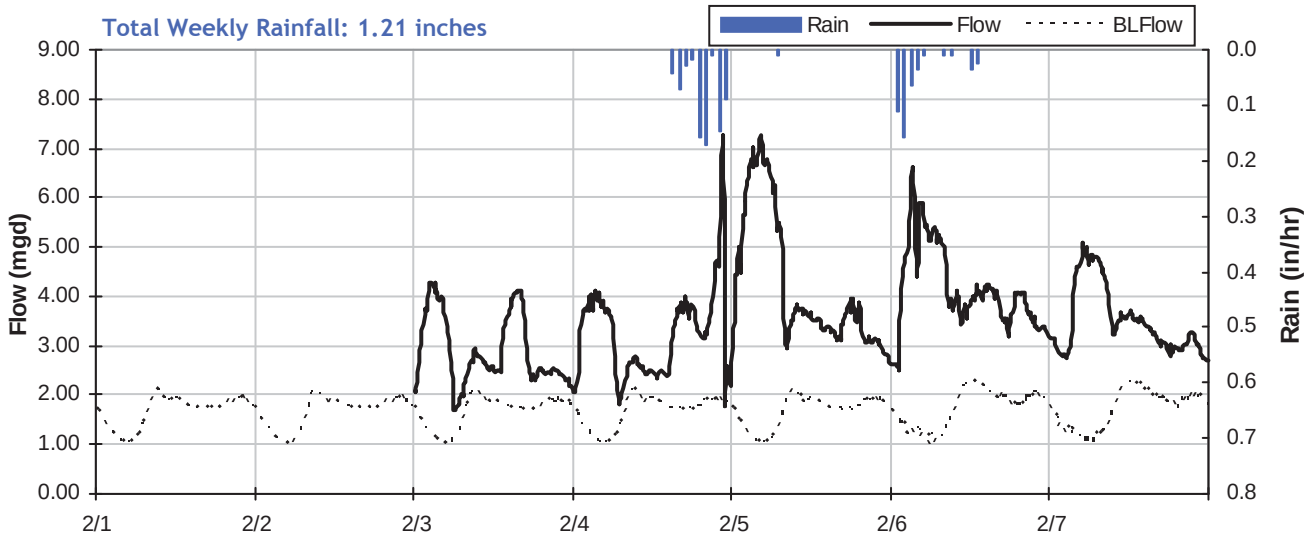
Average Infiltration Rate on 3/14 (% of ADWF): 14.7%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 10



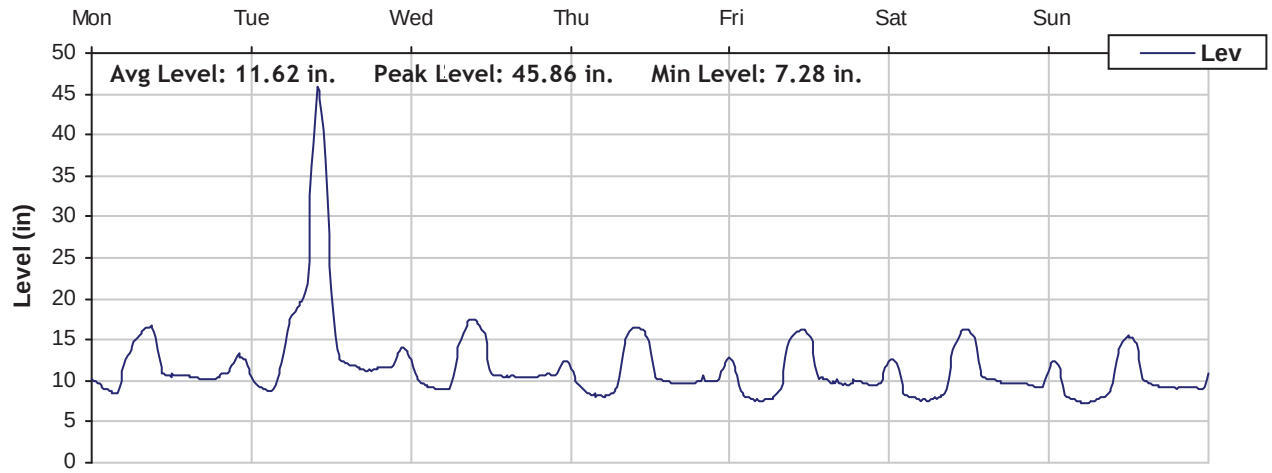


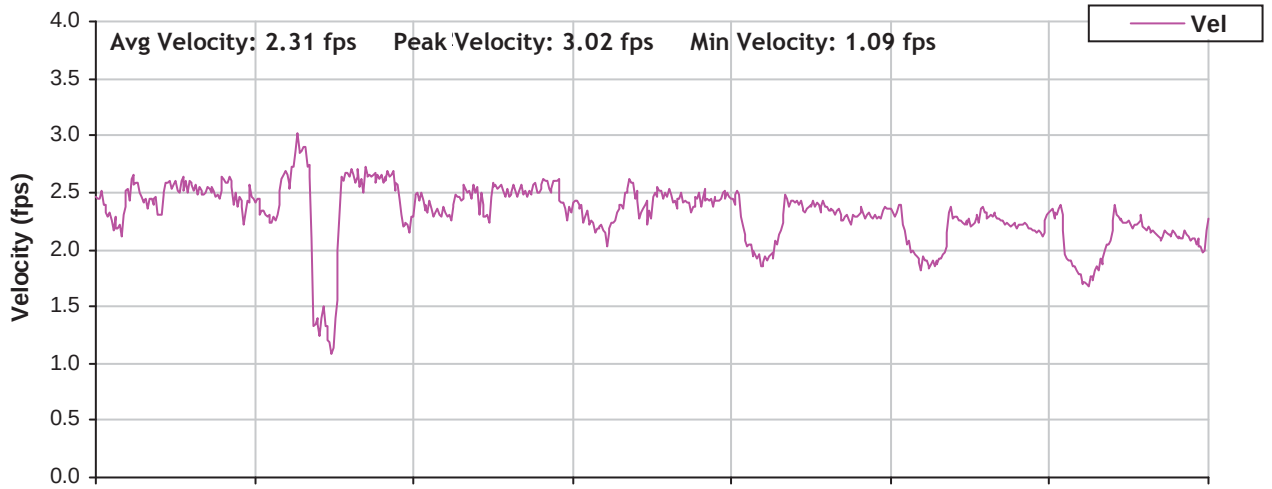


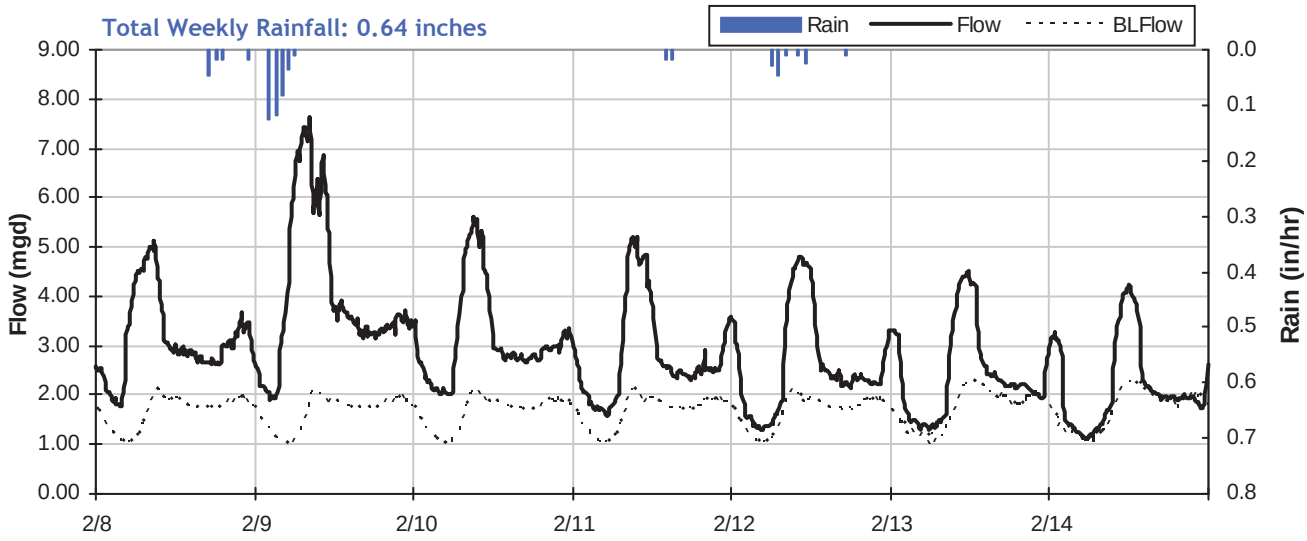
Avg Flow: 3.584 mgd Peak Flow: 7.249 mgd Min Flow: 1.712 mgd

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 10



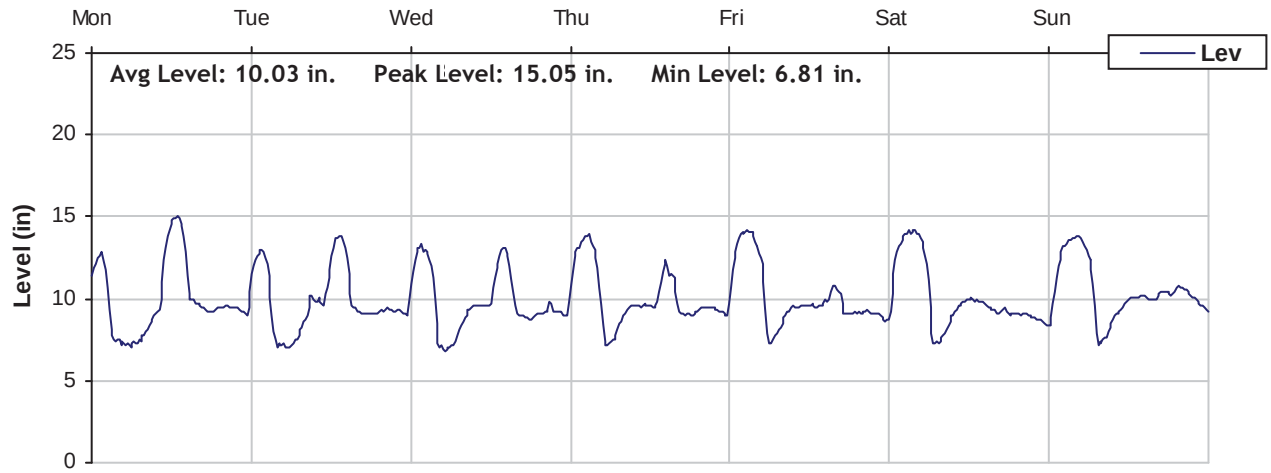


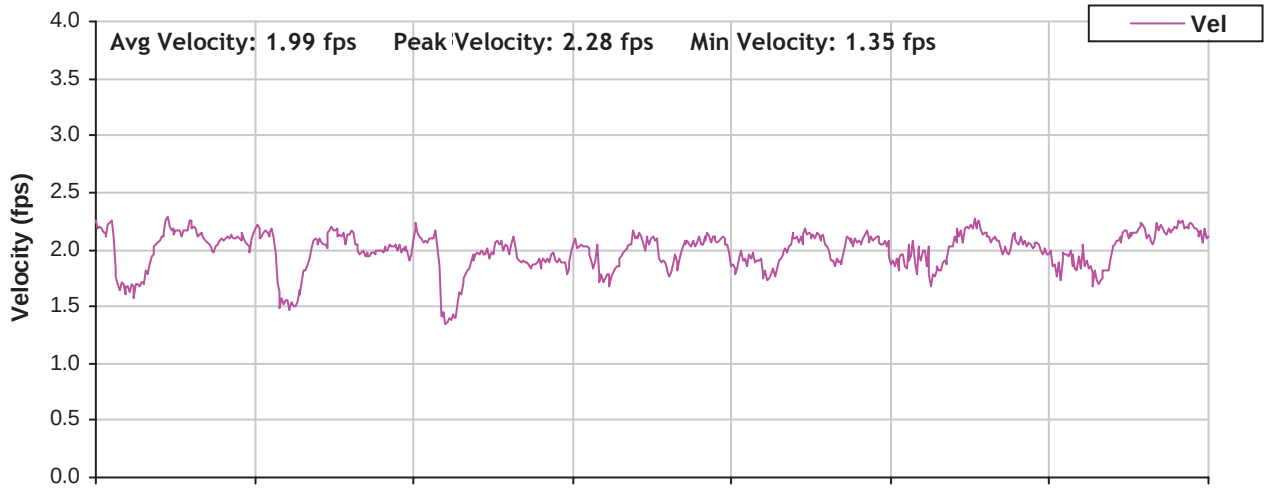


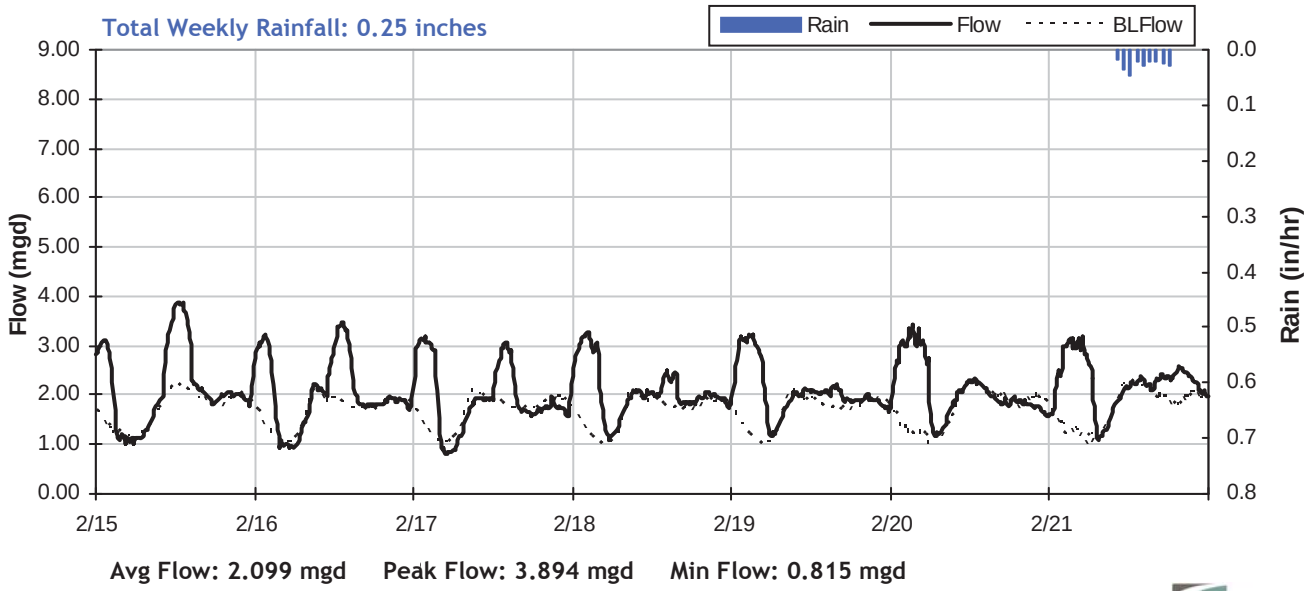
Avg Flow: 2.914 mgd Peak Flow: 7.617 mgd Min Flow: 1.124 mgd

Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 10



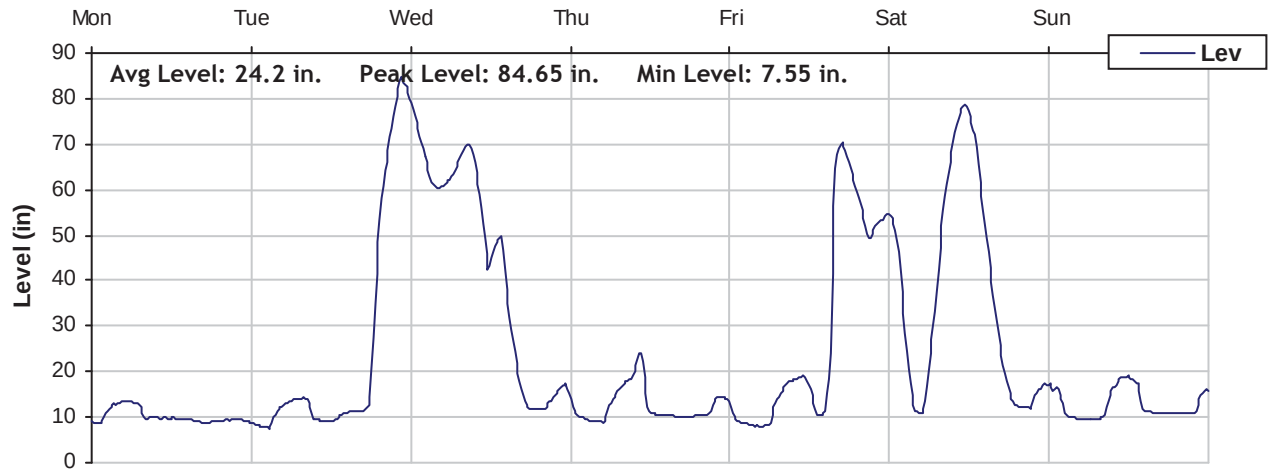


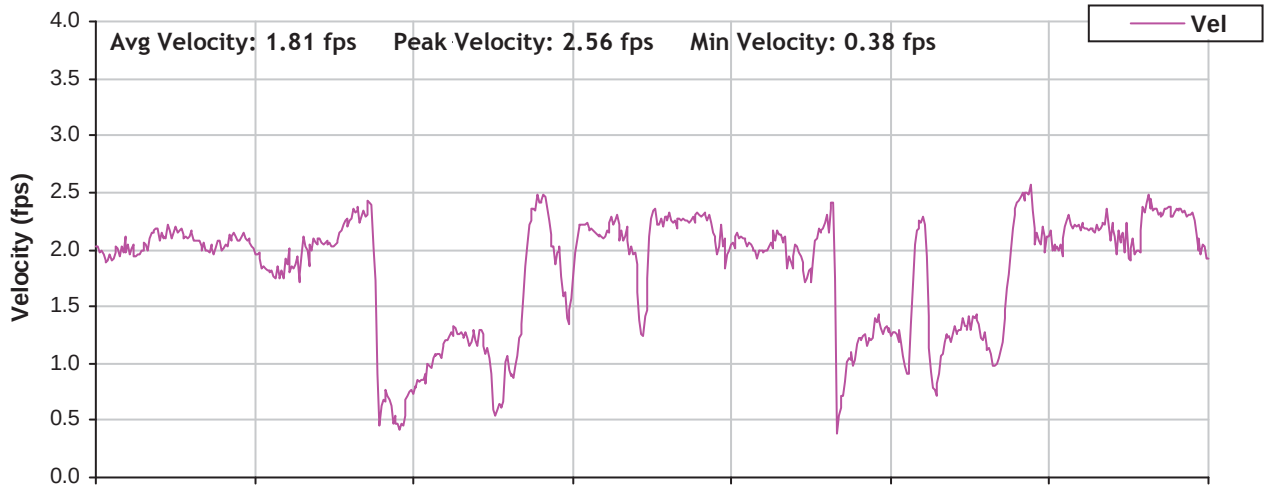


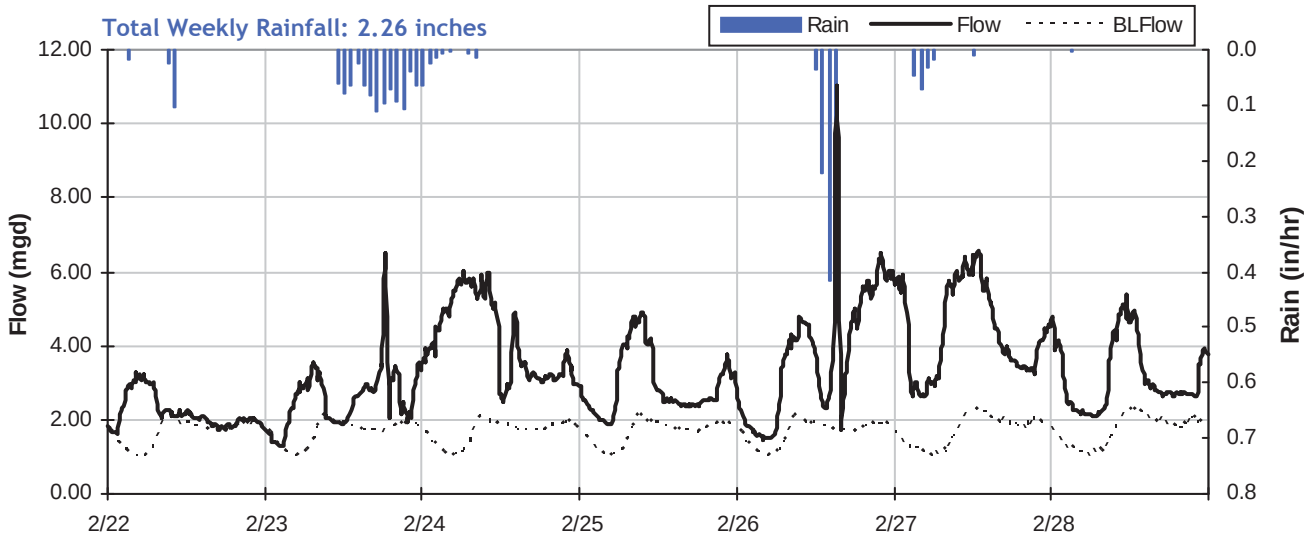
Avg Flow: 2.099 mgd Peak Flow: 3.894 mgd Min Flow: 0.815 mgd

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 10



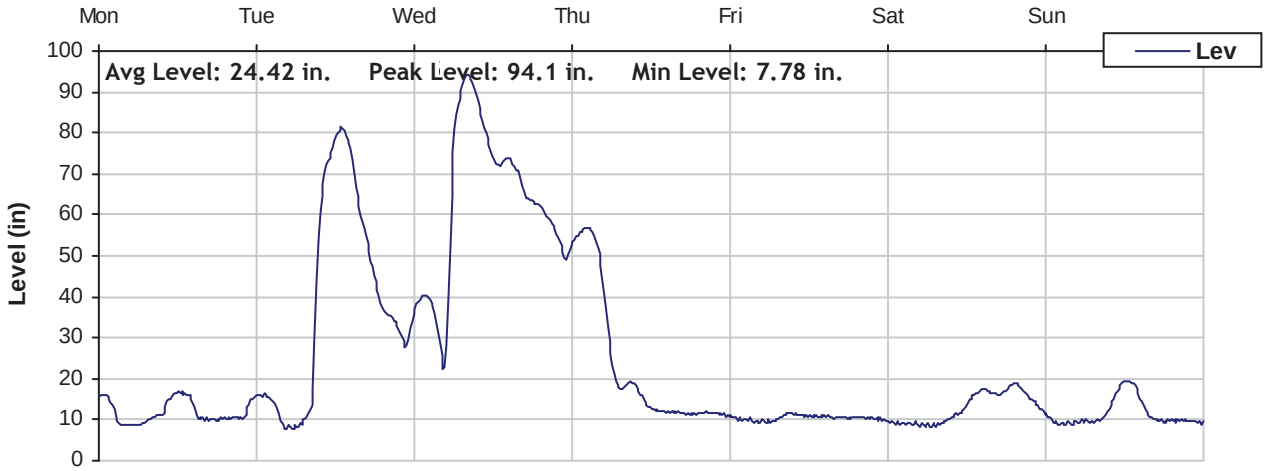


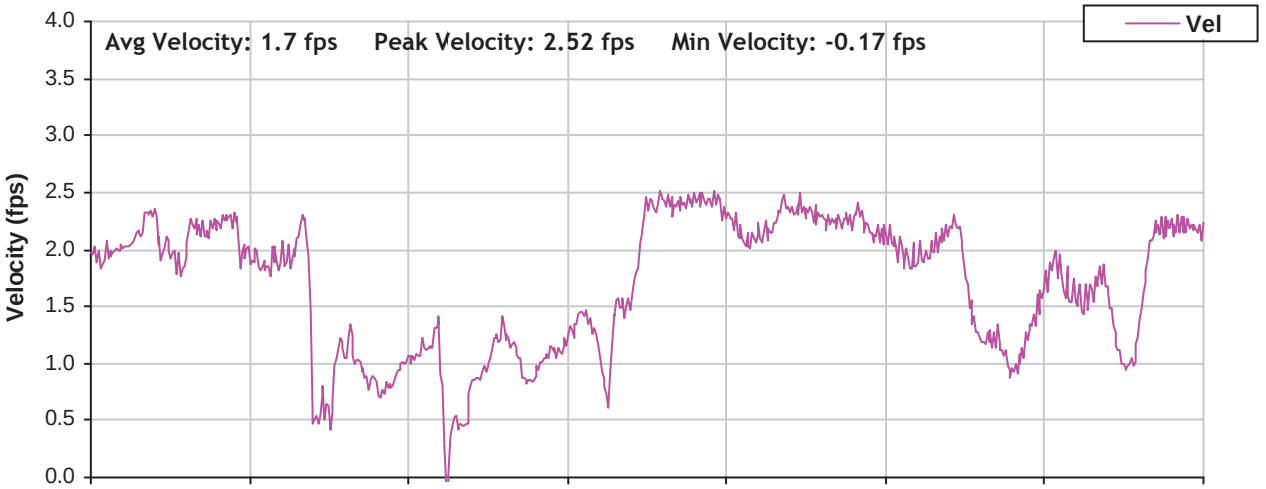


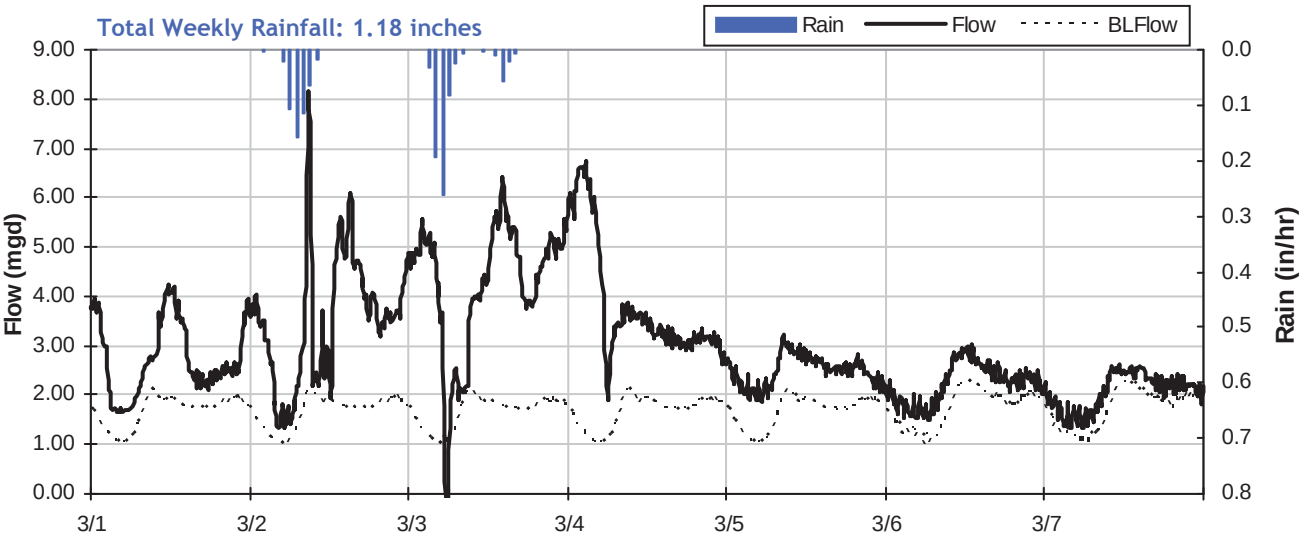
Avg Flow: 3.329 mgd Peak Flow: 11.01 mgd Min Flow: 1.266 mgd

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 10



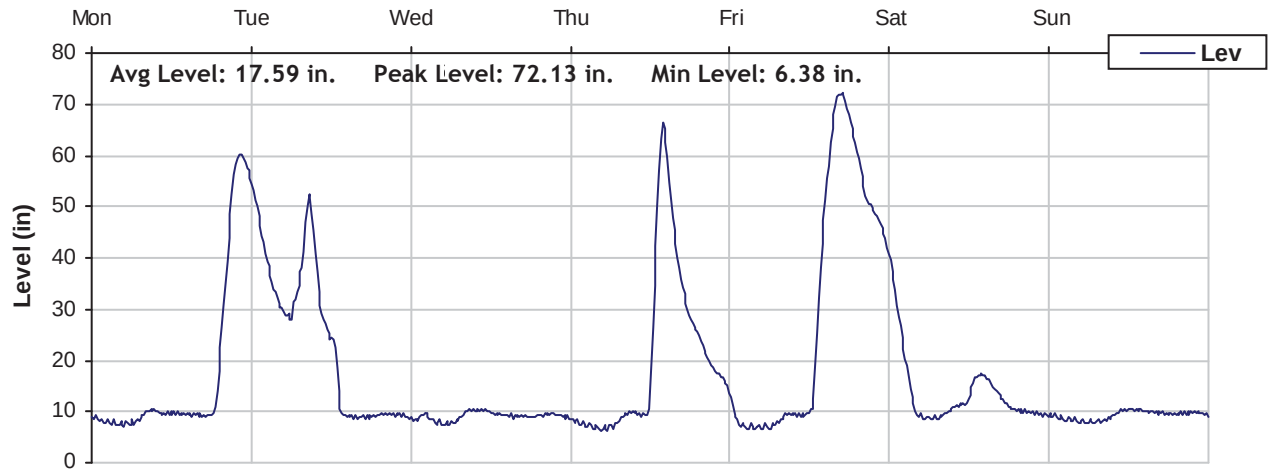


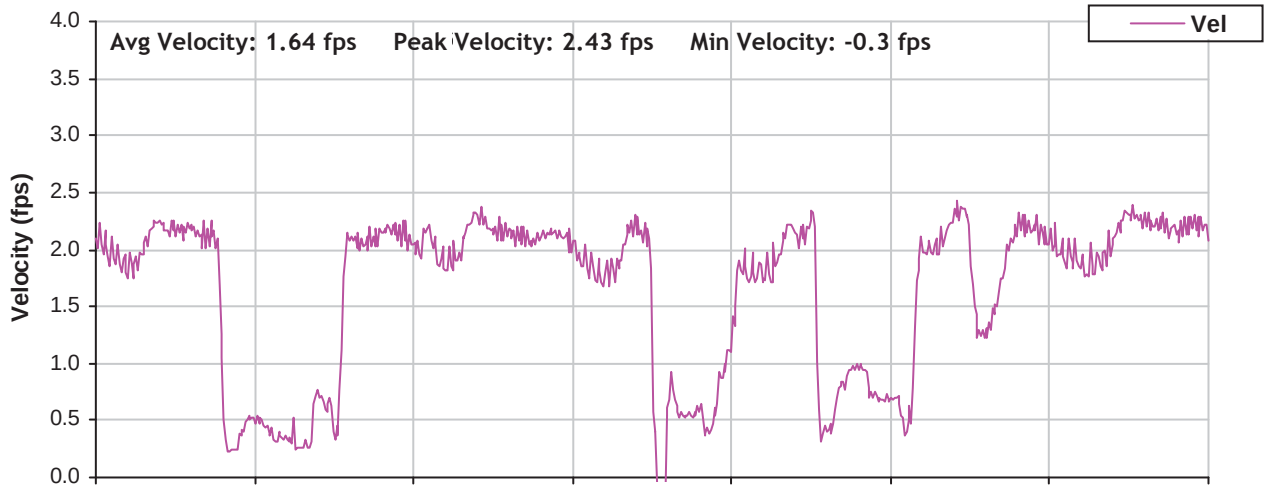


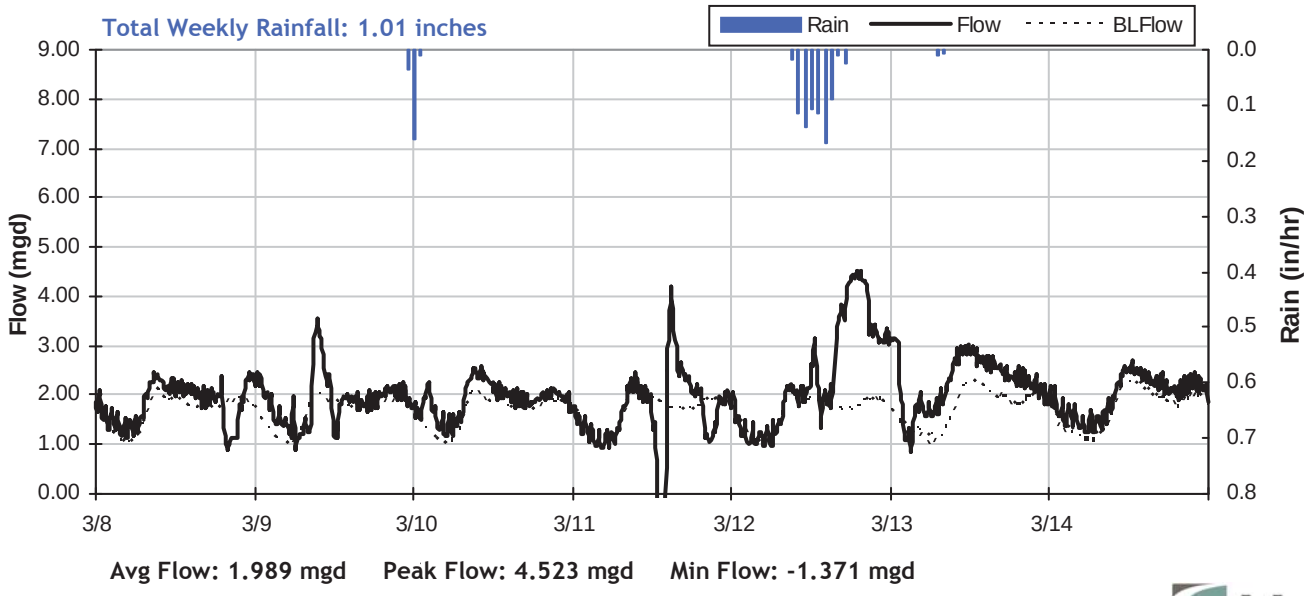
Avg Flow: 3.013 mgd Peak Flow: 8.107 mgd Min Flow: -0.777 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 10



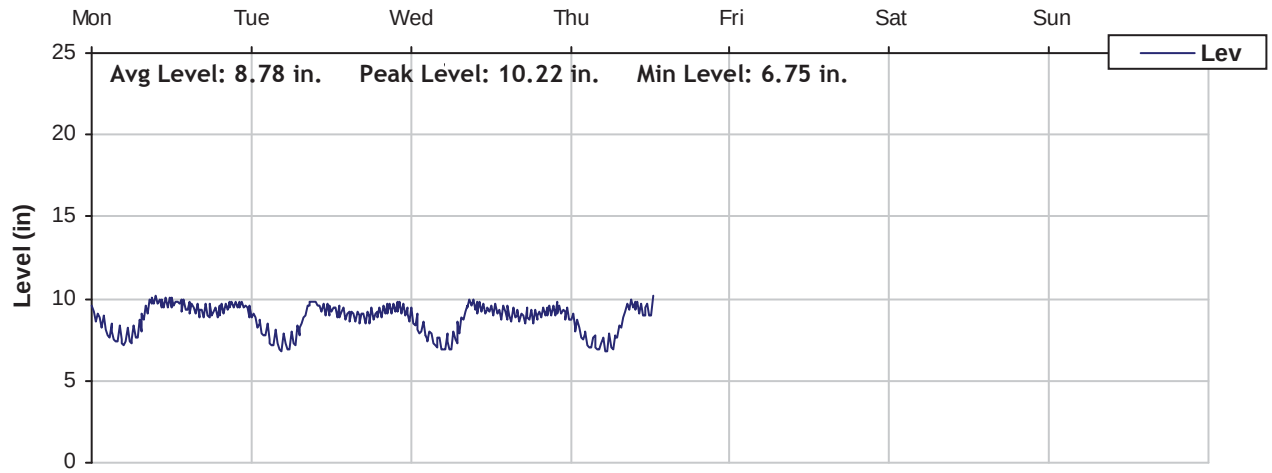


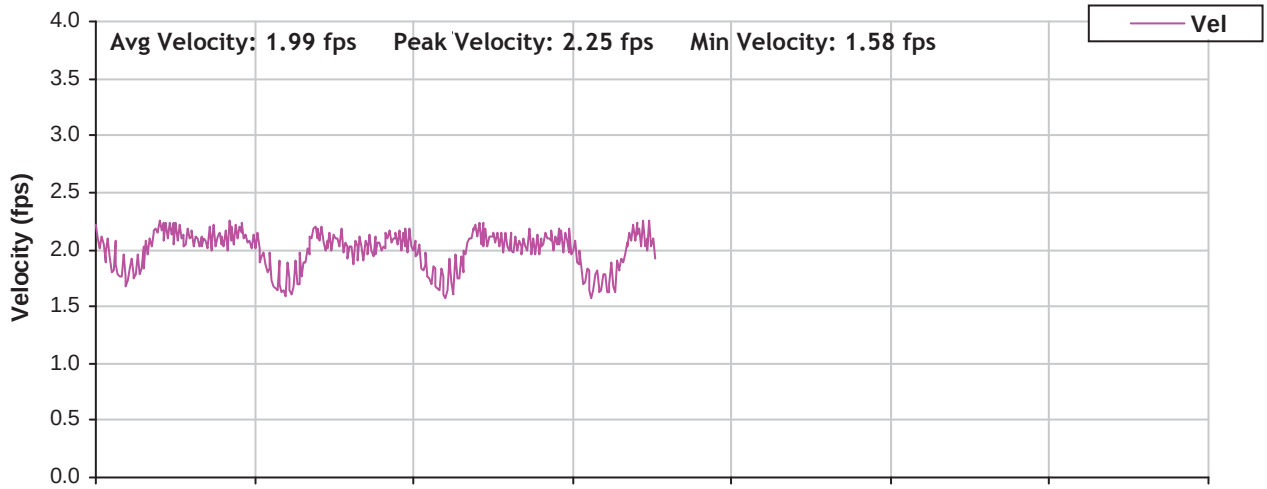


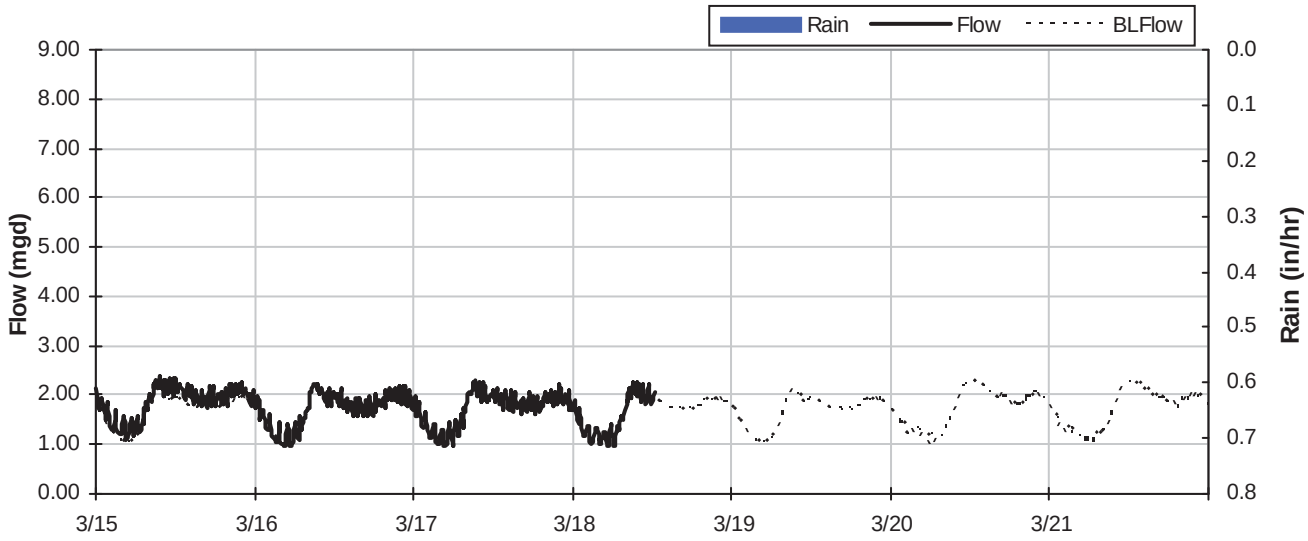
Avg Flow: 1.989 mgd Peak Flow: 4.523 mgd Min Flow: -1.371 mgd

Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

Monitoring Site:
Site 10







Avg Flow: 1.739 mgd Peak Flow: 2.388 mgd Min Flow: 0.963 mgd

Temporary Flow Monitoring Study

Sanitary Sewer Collection System

Monitoring Site: Site 10A

Location: Wright Avenue; east of the intersection of Wright Avenue and S Marina Way

Size/Type Line: 36-inch Sanitary Sewer Pipe

Data Summary Report

Site Information Report

Monitoring Site: Site 10A

Location: Wright Avenue; east of the intersection of Wright Avenue and S

Latitude: 37.9211°

Longitude: -122.3552°

Rim Elevation: 9 *feet above sea level*

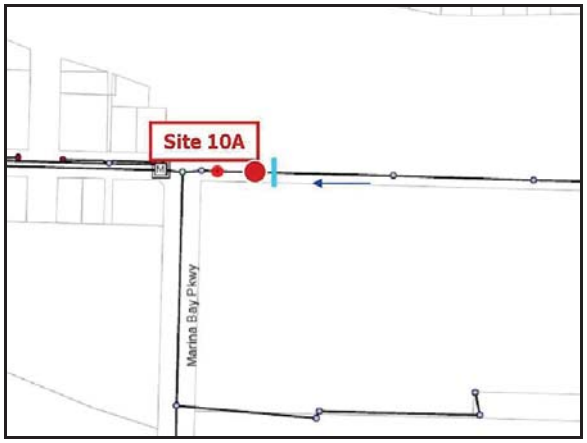
Diameter: 36 *inches*

Average Dry Weather Flow: 1.456 *mgd*

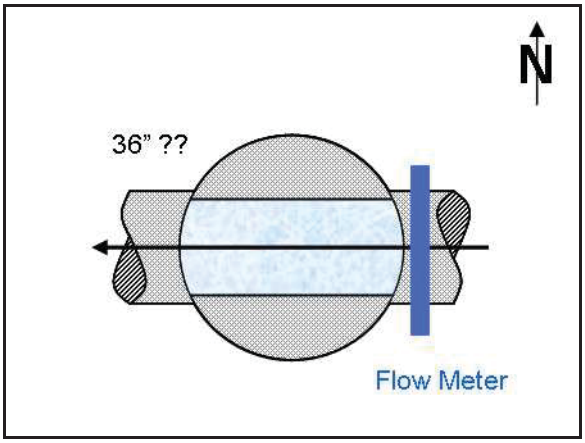
Peak Measured Flow: 5.154 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

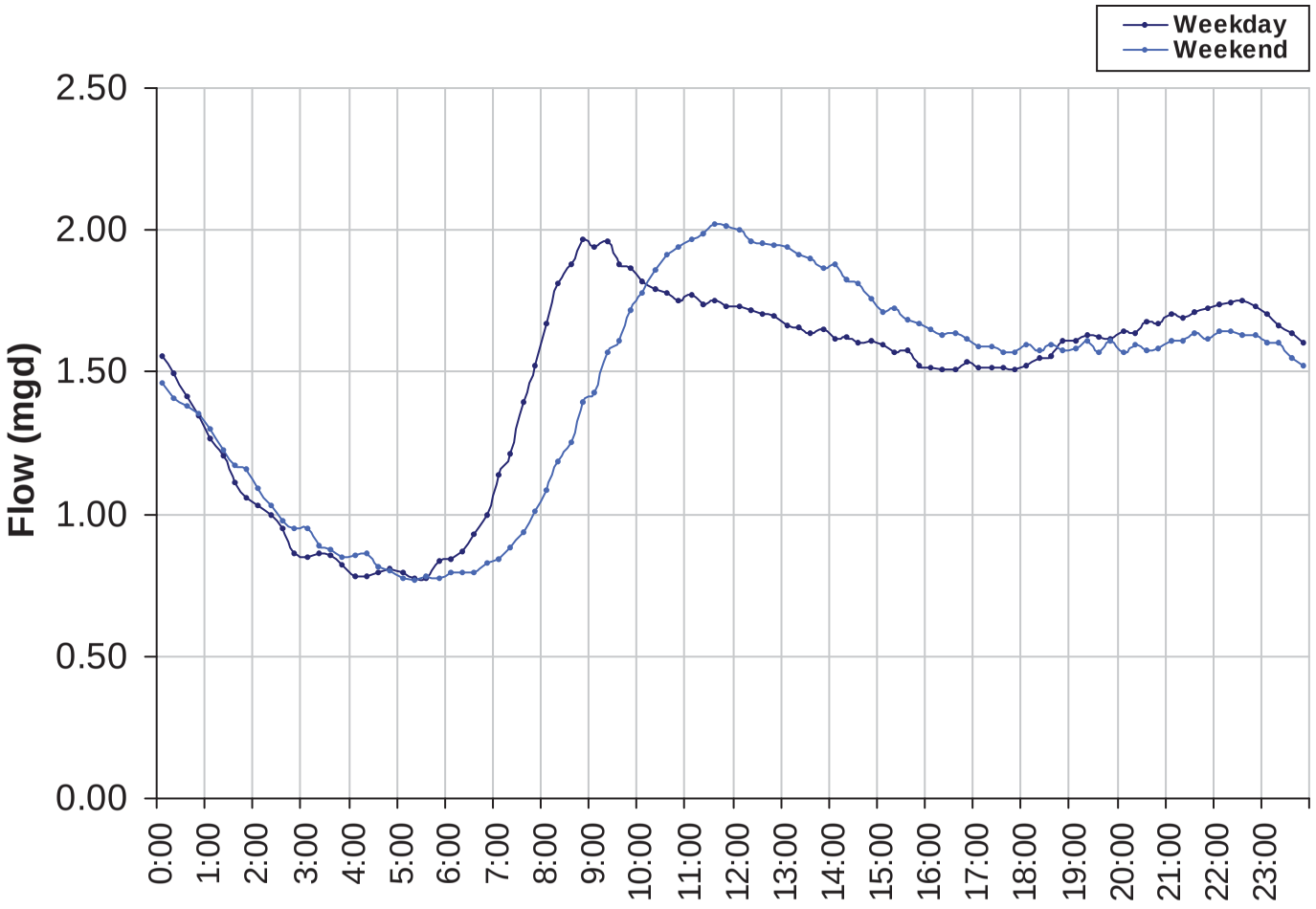


Street View Photo

Plan View Photo

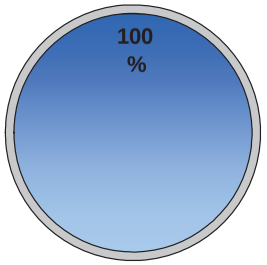
Average Dry Weather Flow

Monitoring Site:
Site 10A



Peak Measured Flow:

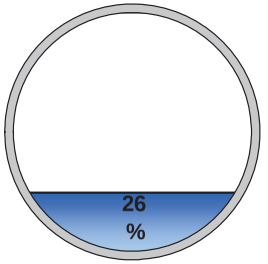
5.15 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

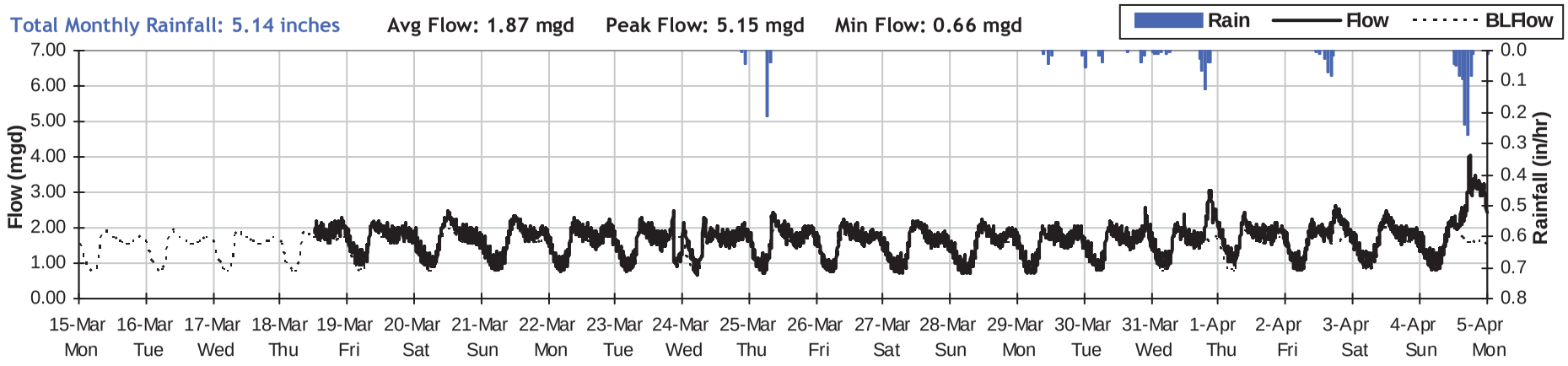
1.46 *mgd*

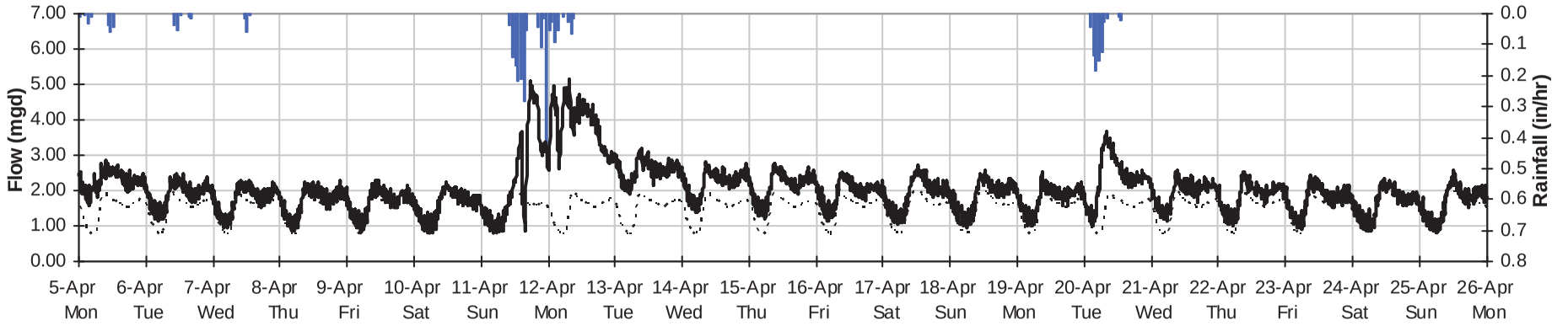


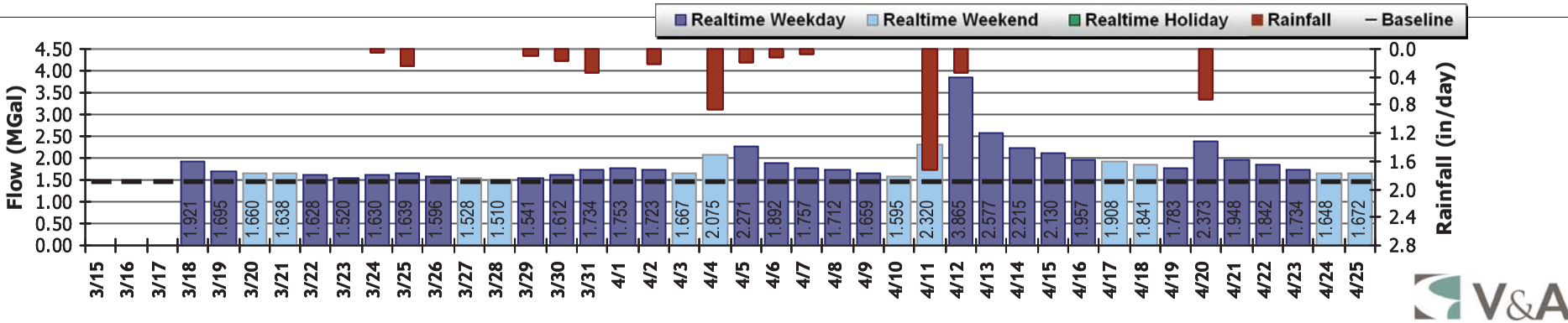
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 10A

Total Monthly Rainfall: 5.14 inches Avg Flow: 1.87 mgd Peak Flow: 5.15 mgd Min Flow: 0.66 mgd





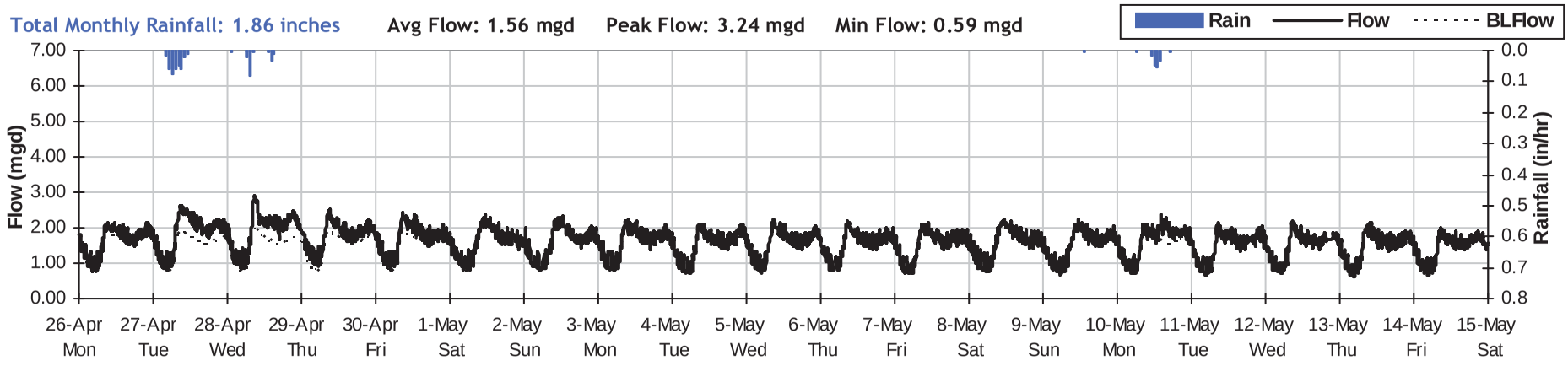


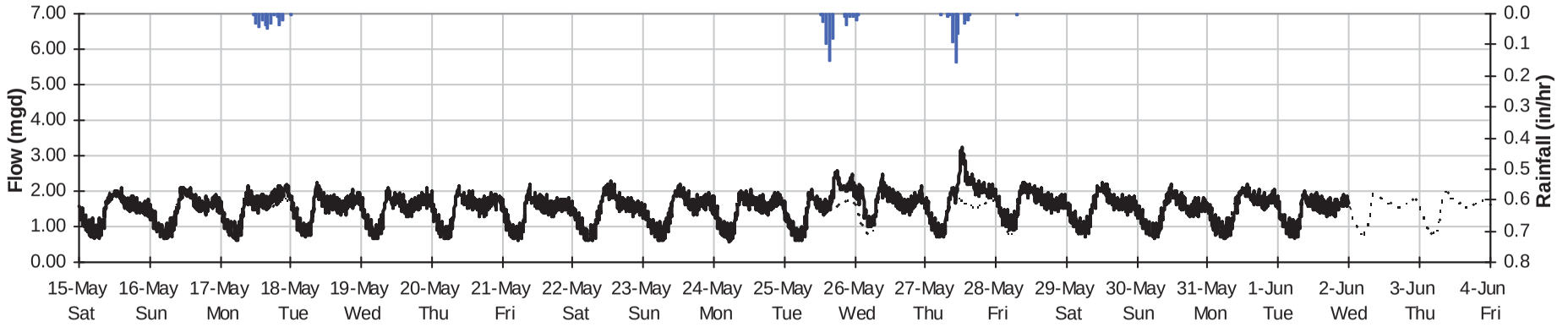
V&A

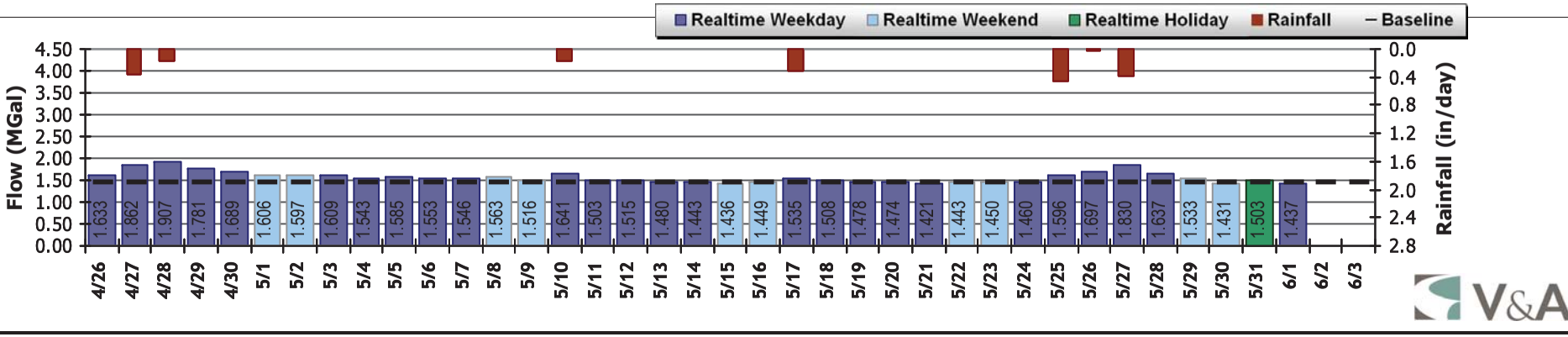
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 10A

Total Monthly Rainfall: 1.86 inches Avg Flow: 1.56 mgd Peak Flow: 3.24 mgd Min Flow: 0.59 mgd





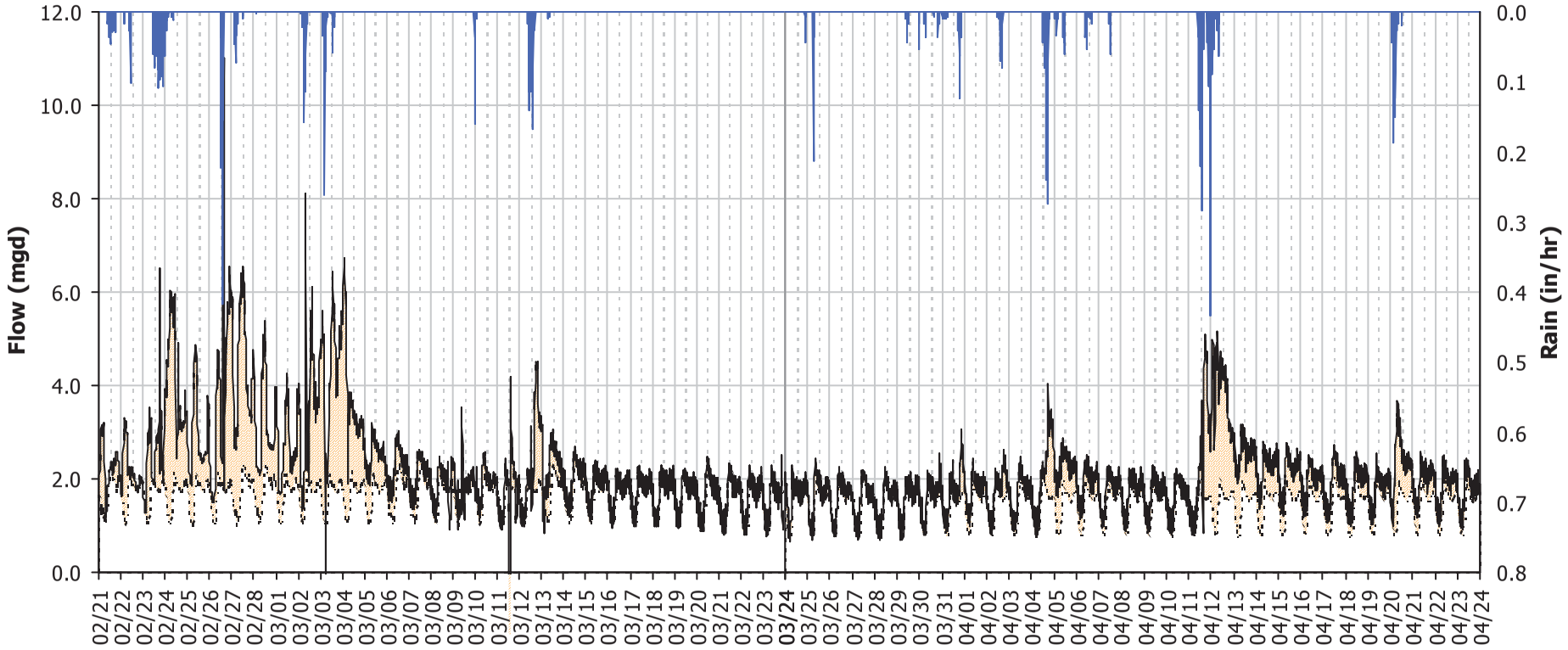


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
10+10A

Multiple Events Detail I/I Graph



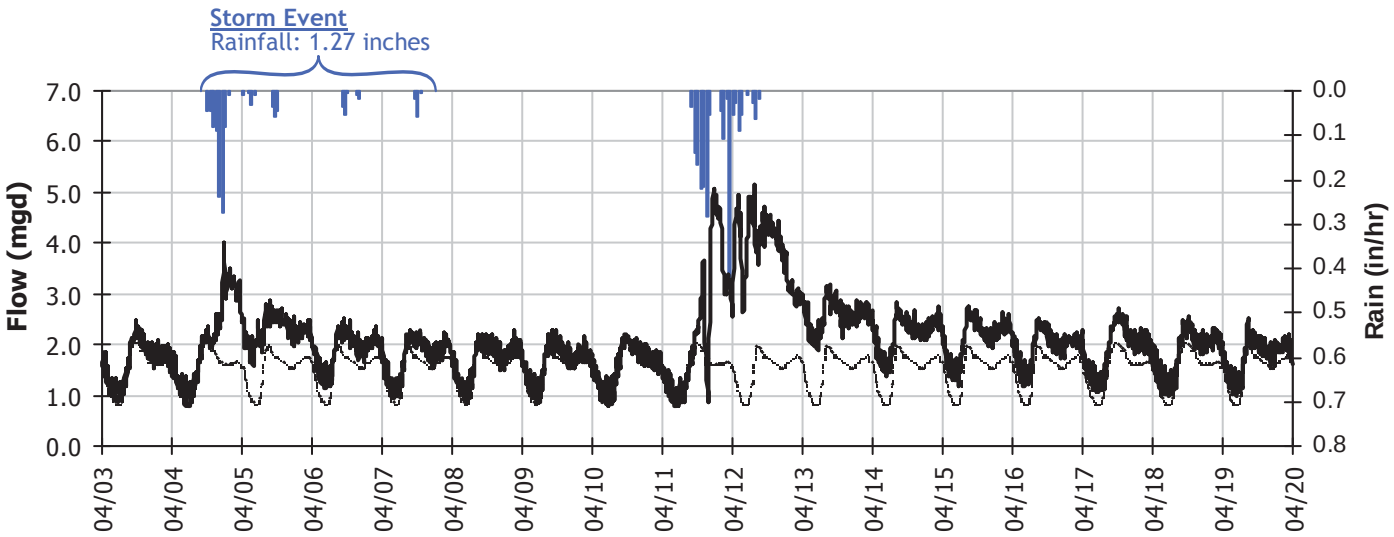
Multiple Events I/I Analysis

Rainfall:	9.83	*inches*	**Baseline Flow:**	1.46	*mgd*
Peak Flow:	11.01	*mgd*	**PF:**	7.56	
Peak I/I Rate:	9.27	*mgd*	**Pk I/I:ADWF:**	6.37	
Peak Level:	94.10	*inches*	**d/D Ratio:**		
Total I/I:	38,154,000	*gallons*	**R-Value:**	11.9%	
			I/I per ADWF:	2.7	*per in-rain*

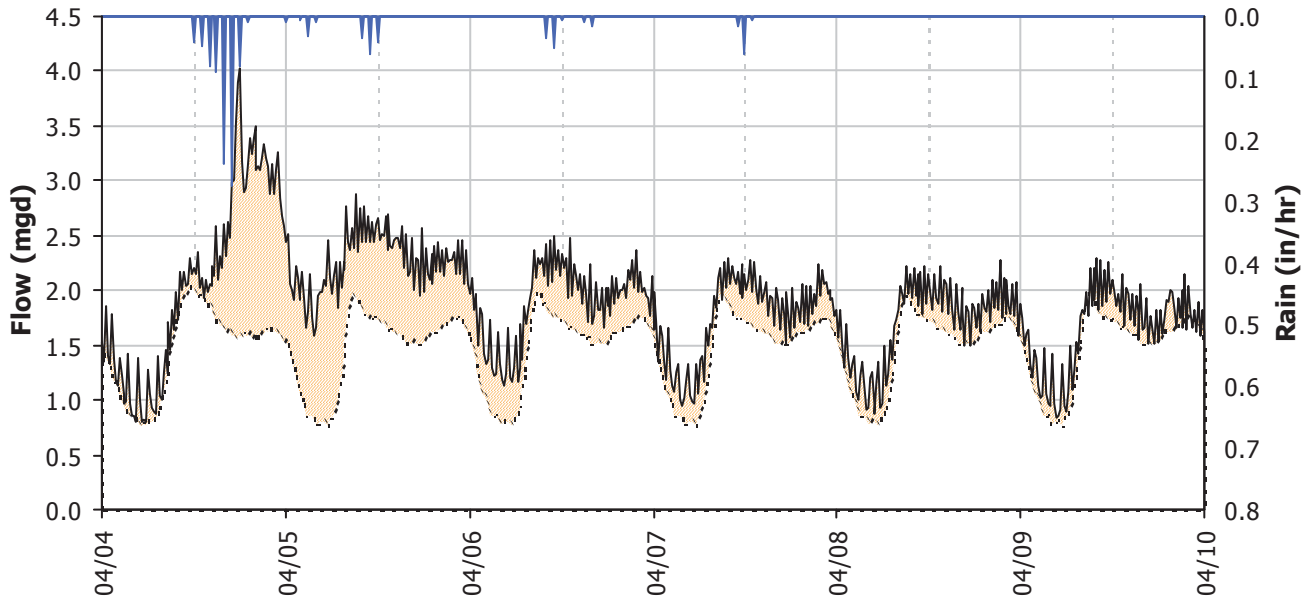
I/I Summary
Event 5

Monitoring Site:
Site 10A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #5 I/I Analysis

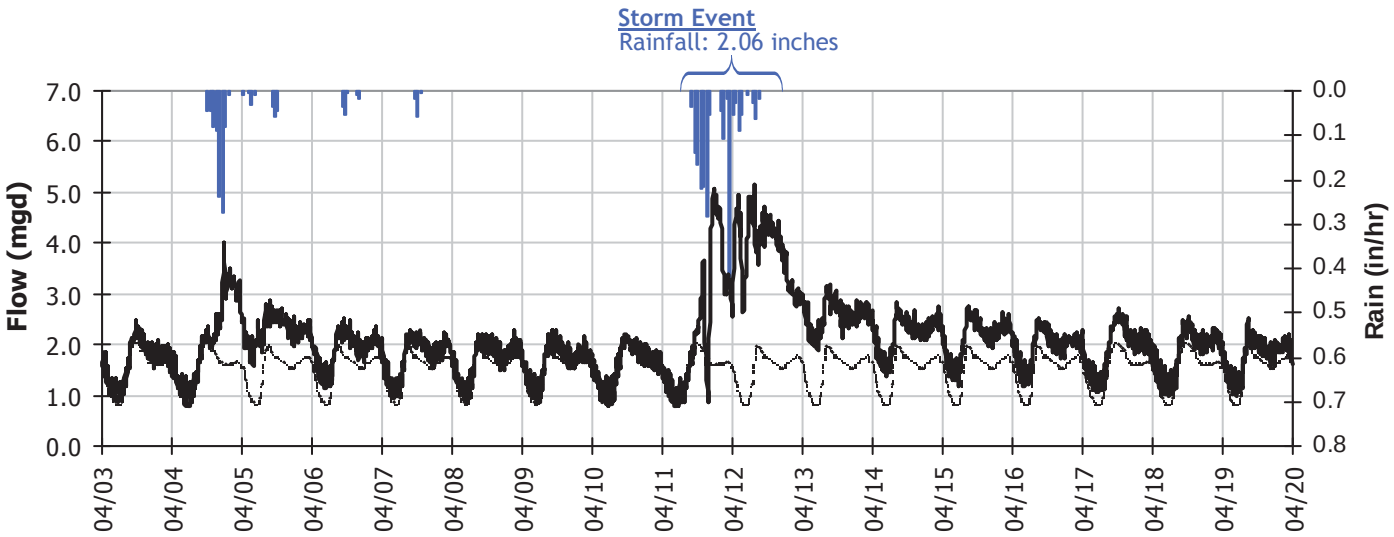
Rainfall:	1.27	*inches*		
Baseline Flow:	1.46	*mgd*		
Peak Flow:	4.03	*mgd*	**PF:**	2.77
Peak I/I Rate:	2.44	*mgd*	**Pk I/I:ADWF:**	1.67
Peak Level:	49.29	*inches*	**d/D Ratio:**	1.37
Total I/I:	2,621,000	*gallons*	**R-Value:**	7.0%
			I/I per ADWF:	1.42 *per in-rain*

Average Infiltration Rate on 4/8 (% of ADWF): 17.3%

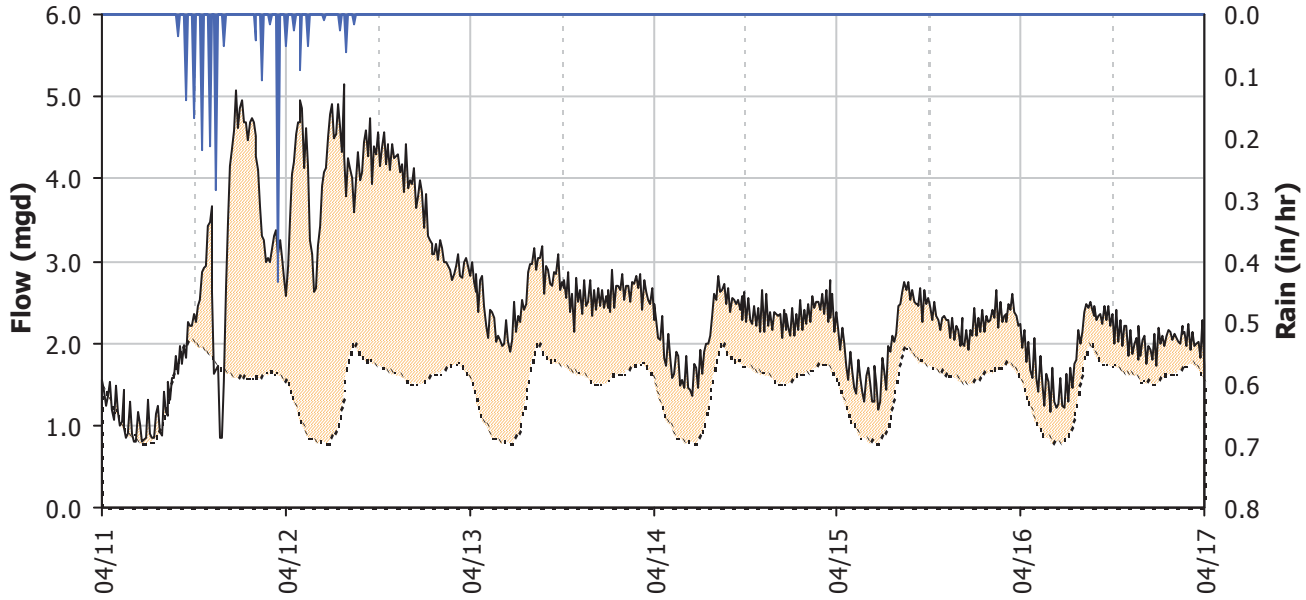
I/I Summary
Event 6

Monitoring Site:
Site 10A

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



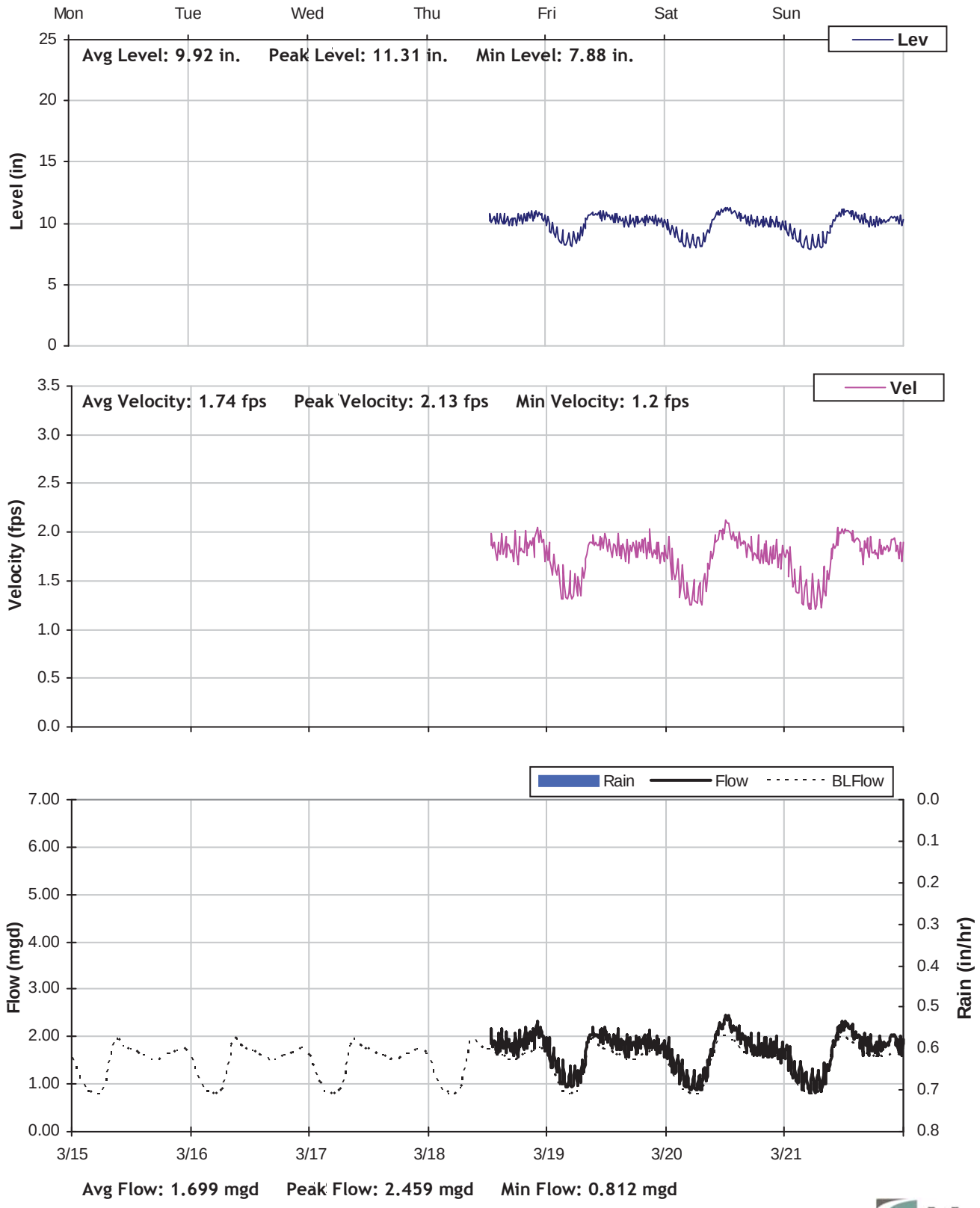
Storm Event #6 I/I Analysis

Rainfall:	2.06	*inches*		
Baseline Flow:	1.46	*mgd*		
Peak Flow:	5.15	*mgd*	**PF:**	3.54
Peak I/I Rate:	4.06	*mgd*	**Pk I/I:ADWF:**	2.79
Peak Level:	89.20	*inches*	**d/D Ratio:**	2.48
Total I/I:	6,321,000	*gallons*	**R-Value:**	10.4%
			I/I per ADWF:	2.11 *per in-rain*

Average Infiltration Rate on 4/14 (% of ADWF): 51.7%

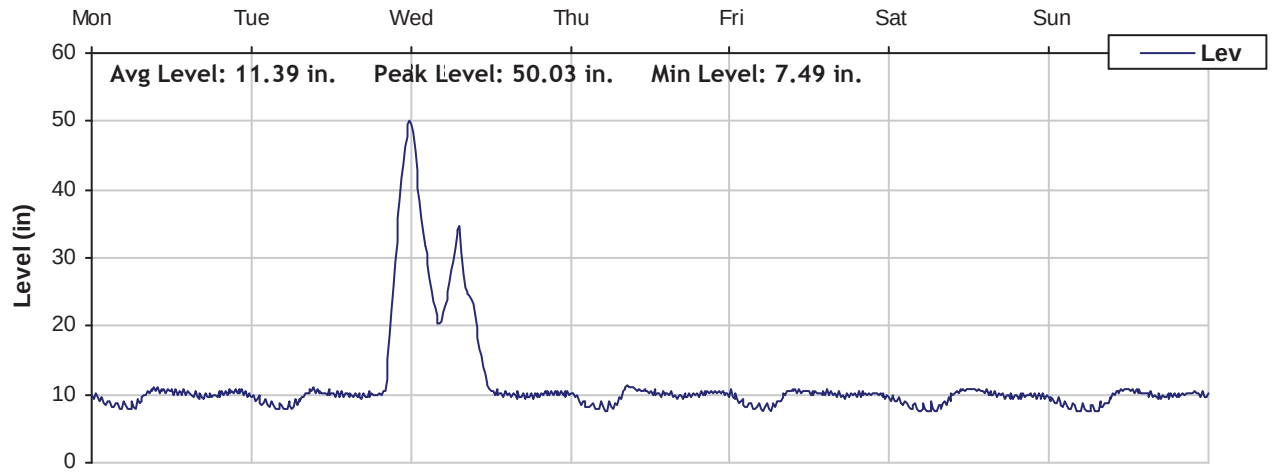
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

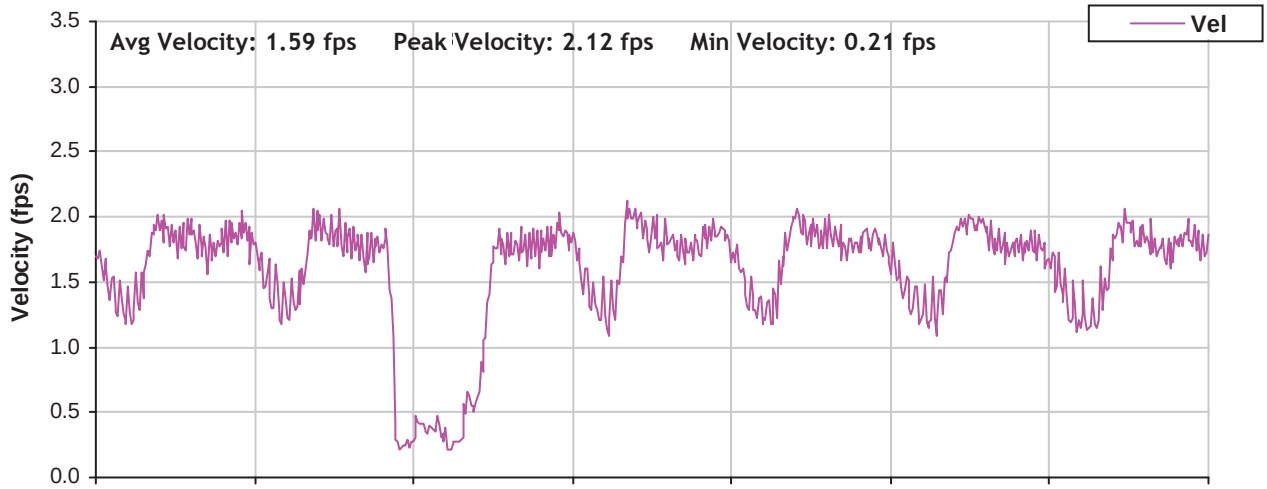
Monitoring Site:
Site 10A

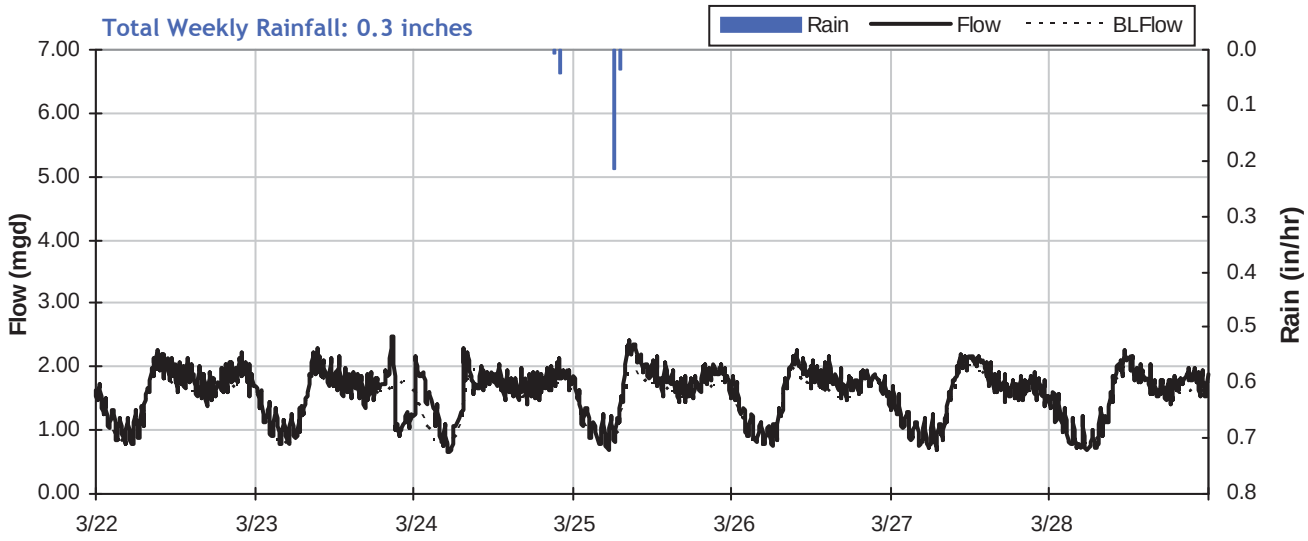


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 10A



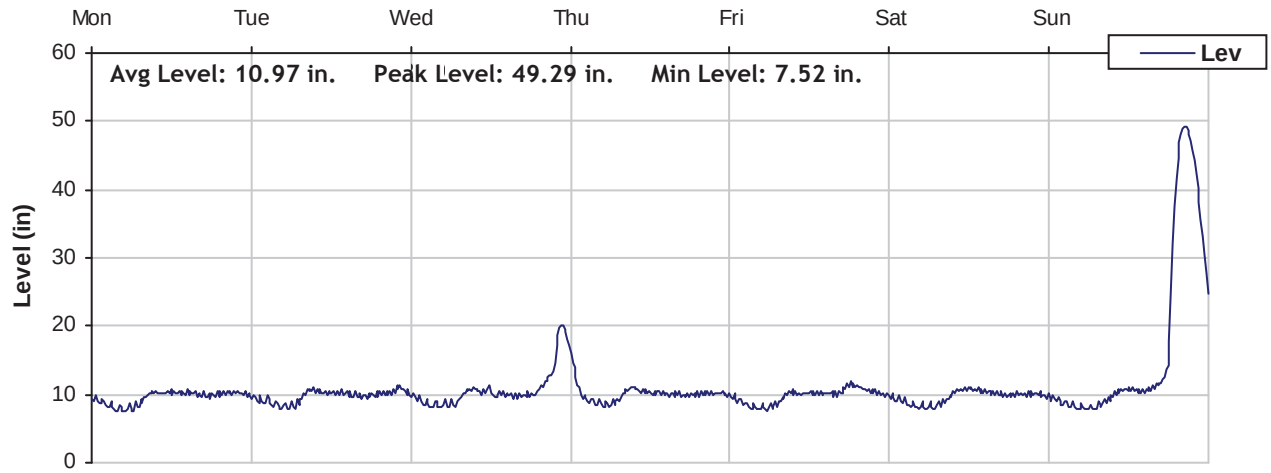


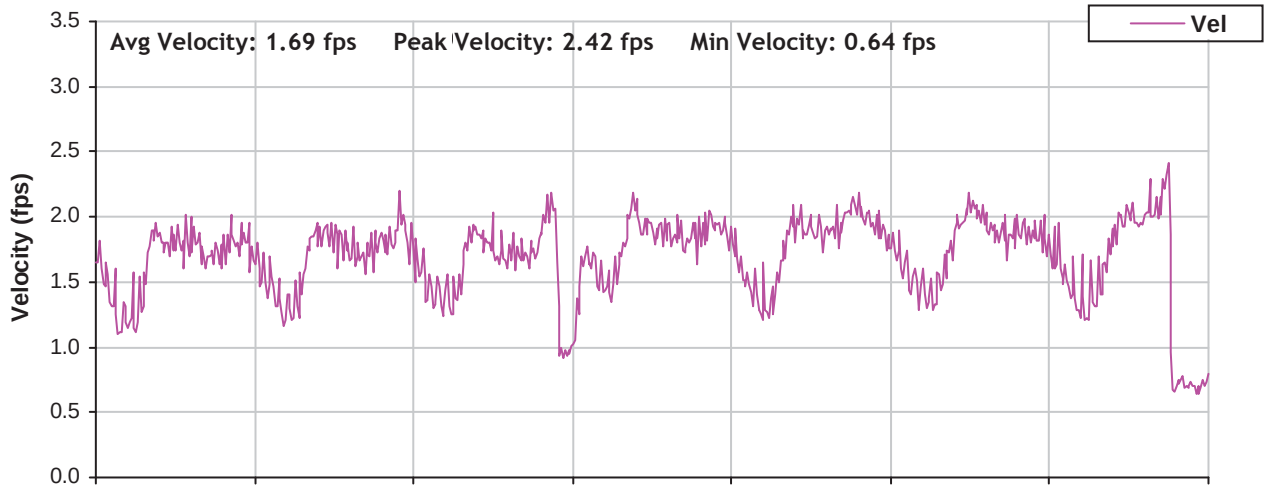


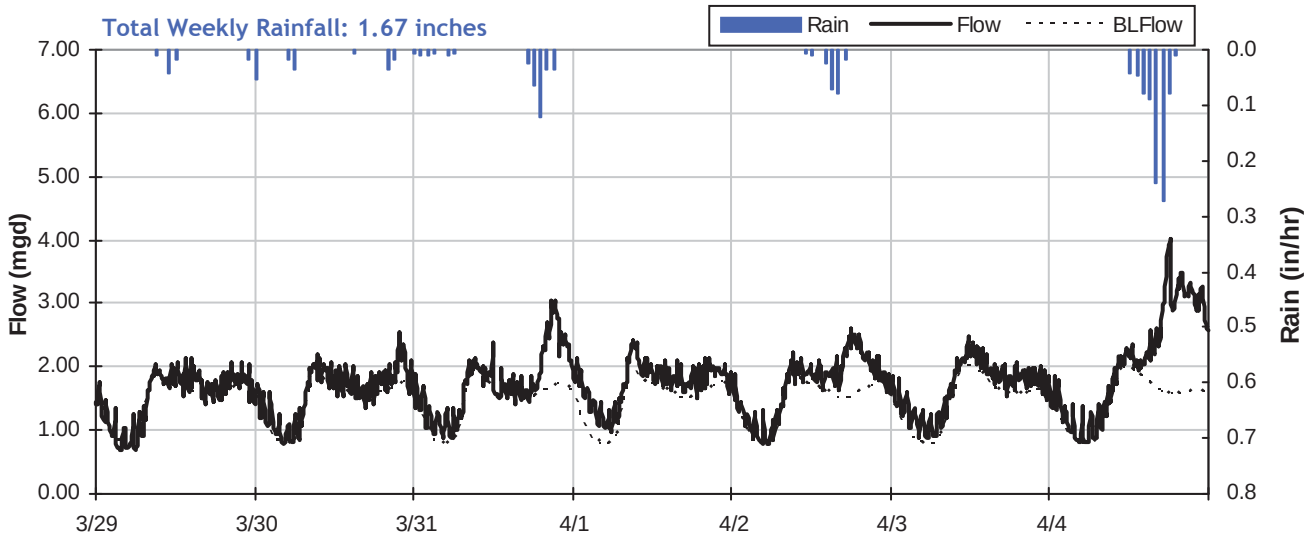
Avg Flow: 1.579 mgd Peak Flow: 2.492 mgd Min Flow: 0.659 mgd

Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 10A



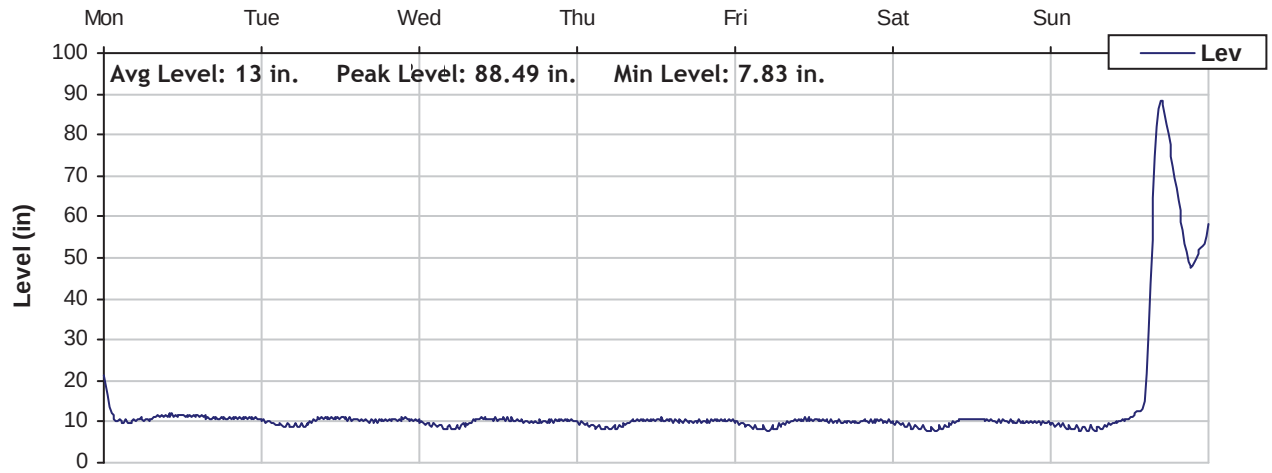


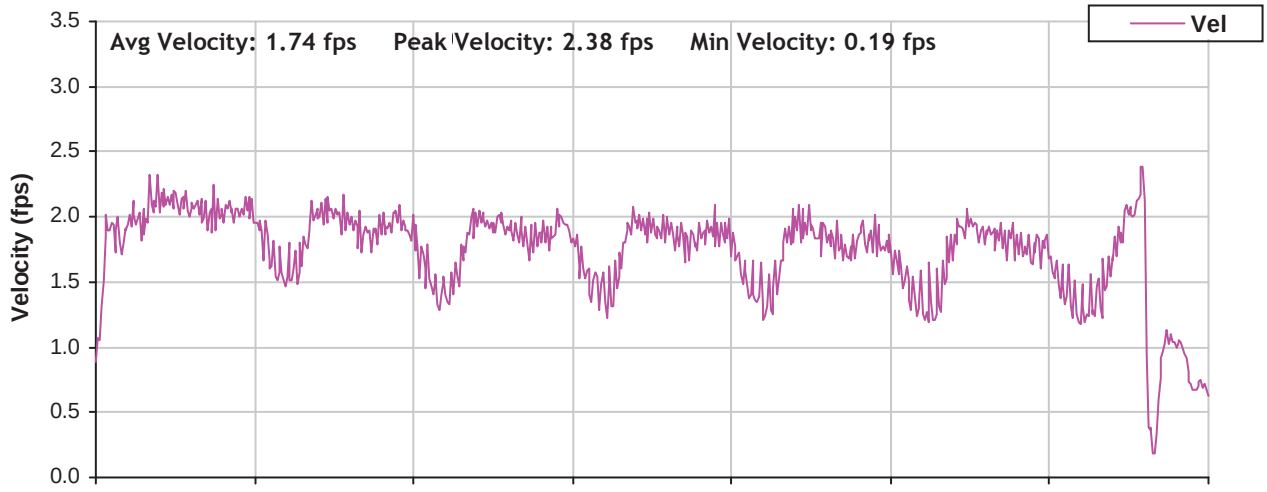


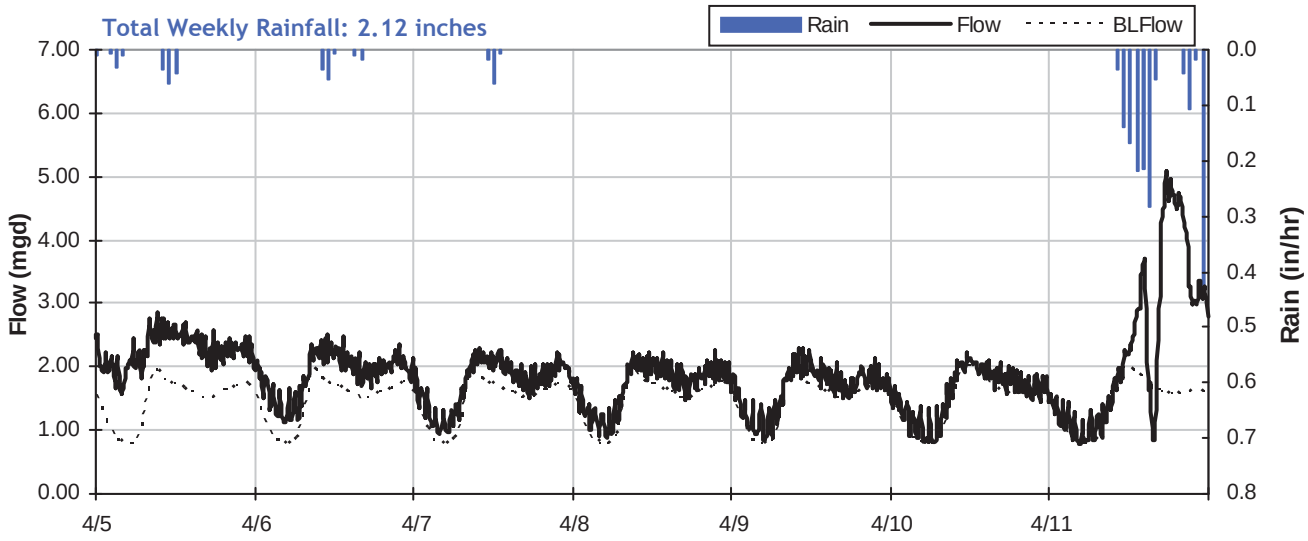
Avg Flow: 1.729 mgd Peak Flow: 4.031 mgd Min Flow: 0.697 mgd

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 10A



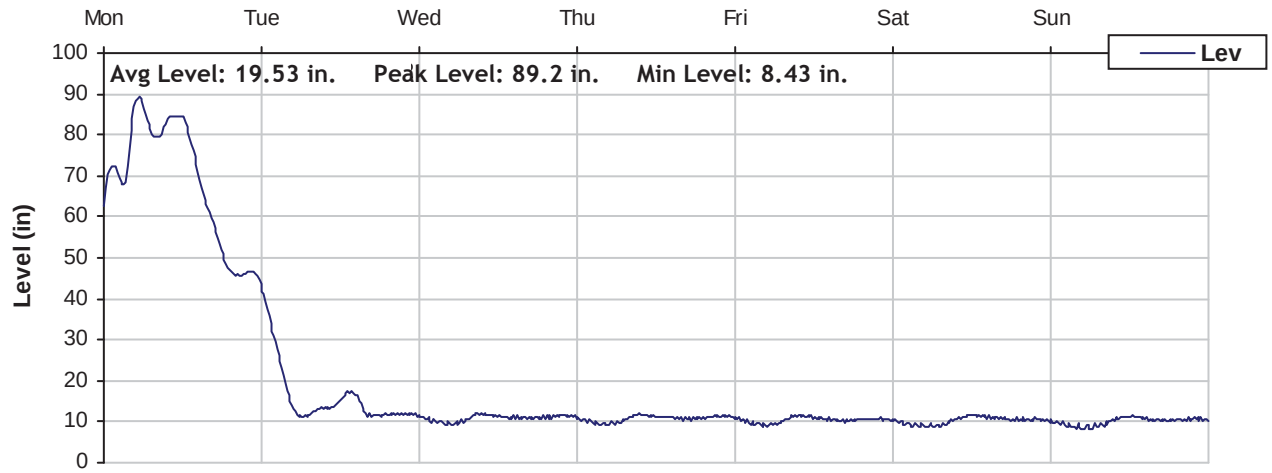


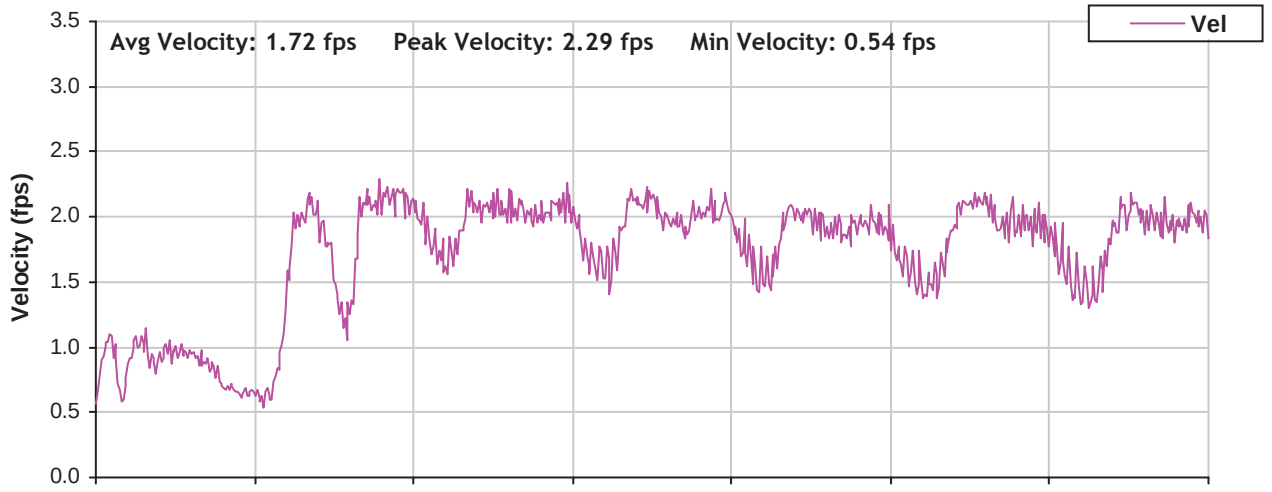


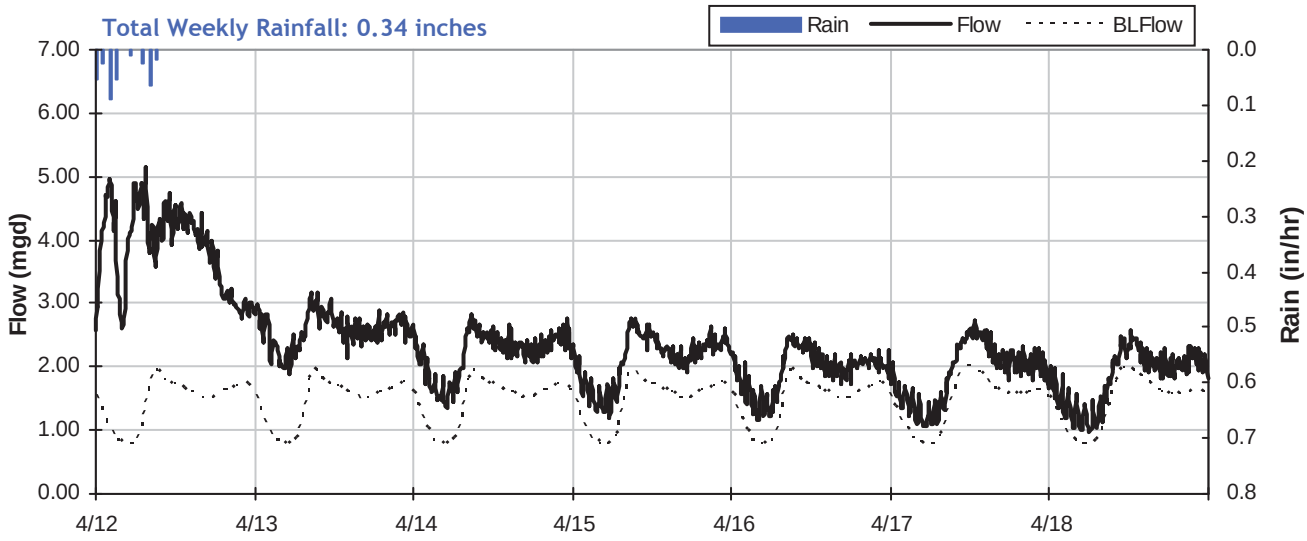
Avg Flow: 1.887 mgd Peak Flow: 5.075 mgd Min Flow: 0.797 mgd

Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 10A



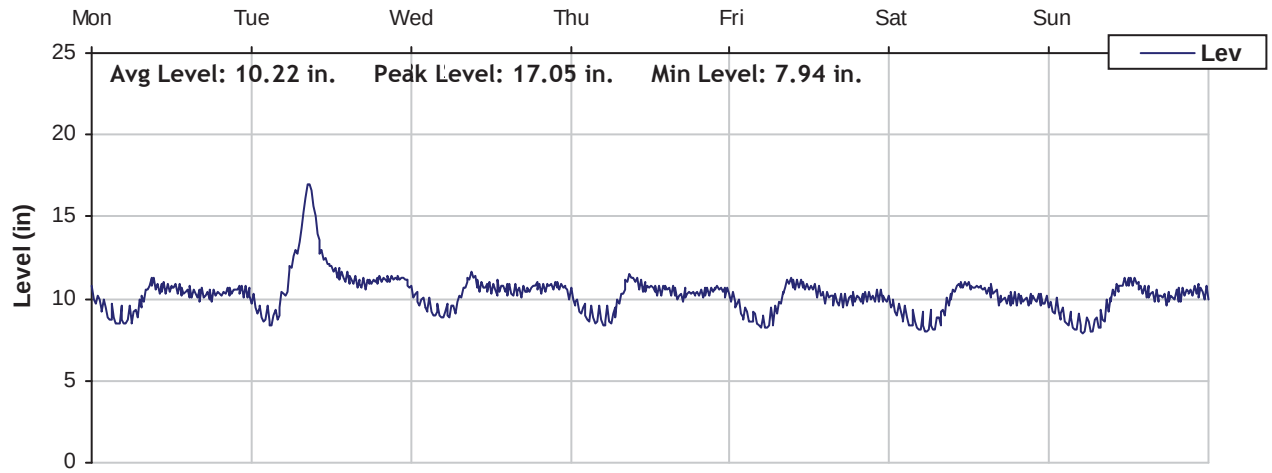


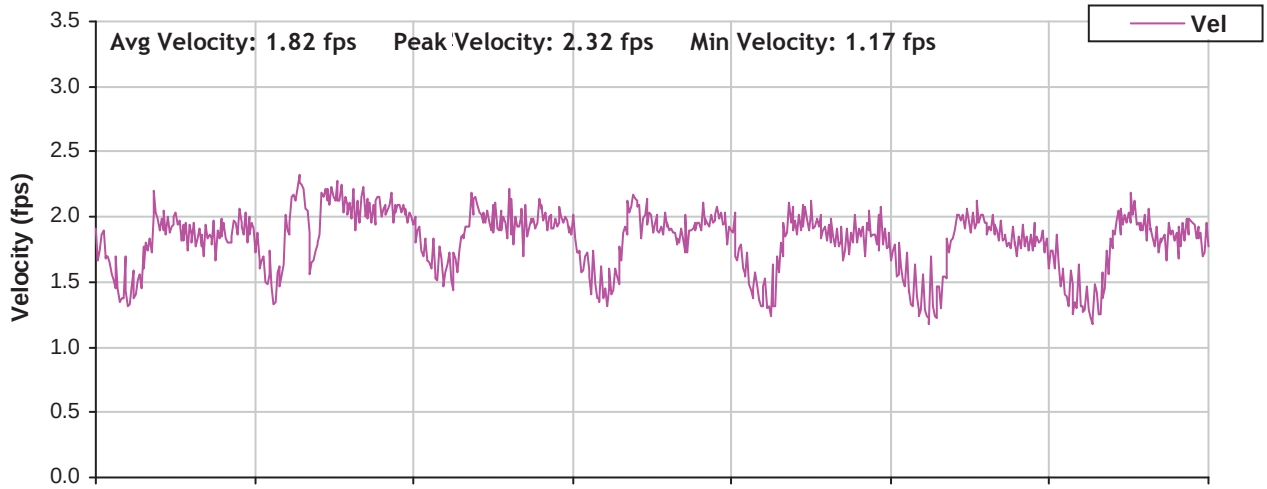


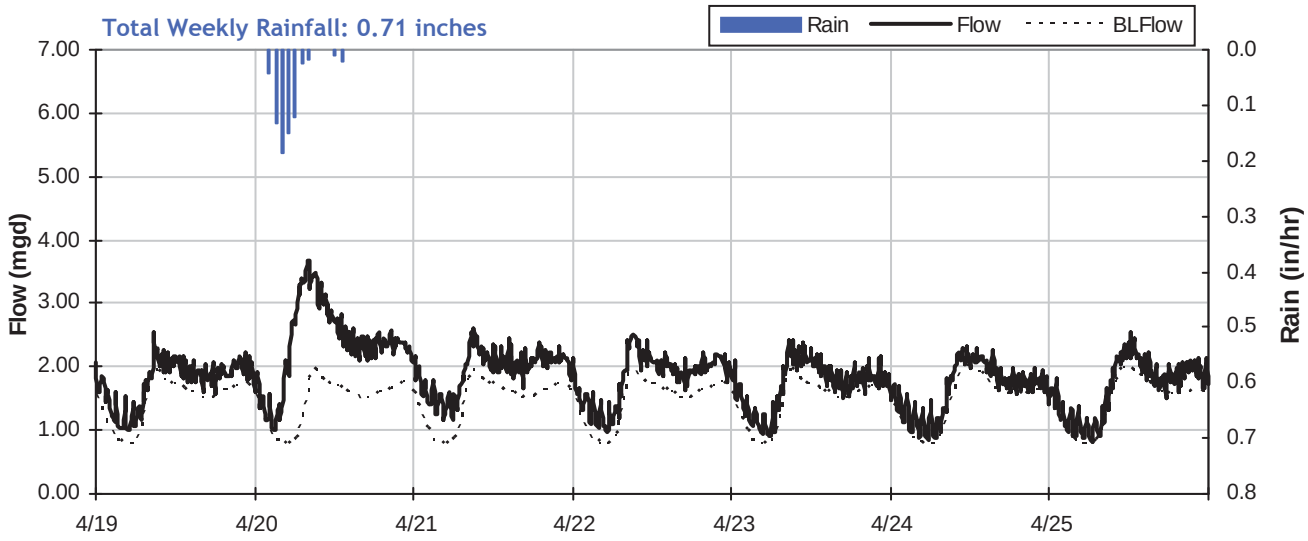
Avg Flow: 2.356 mgd Peak Flow: 5.154 mgd Min Flow: 0.975 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 10A



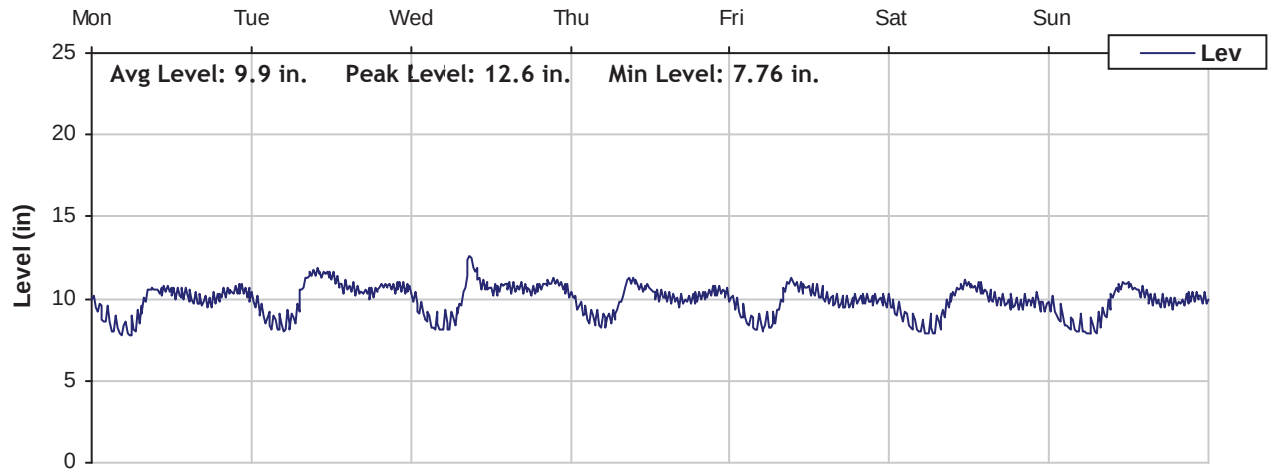


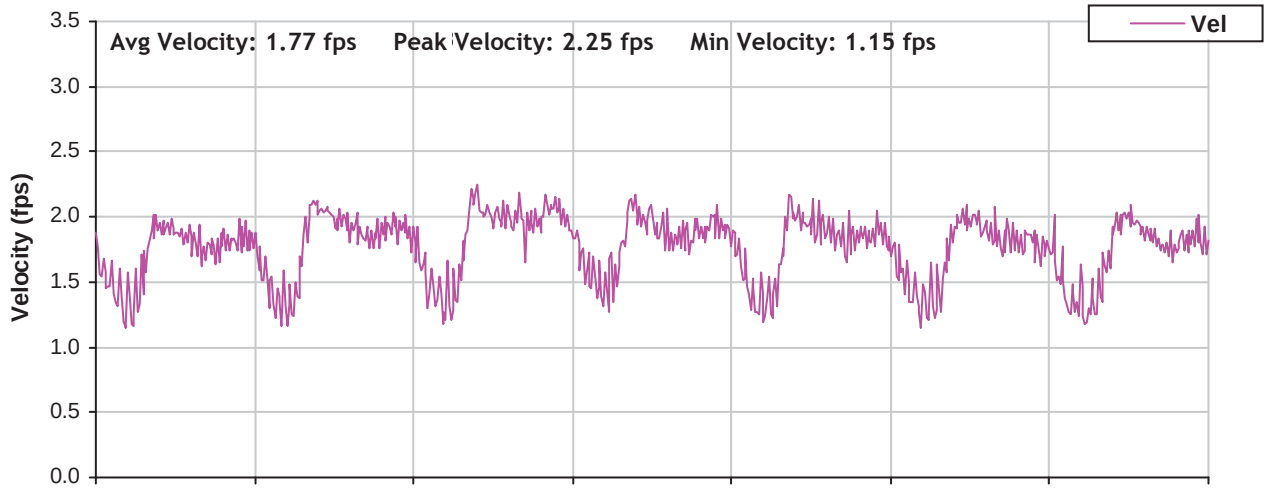


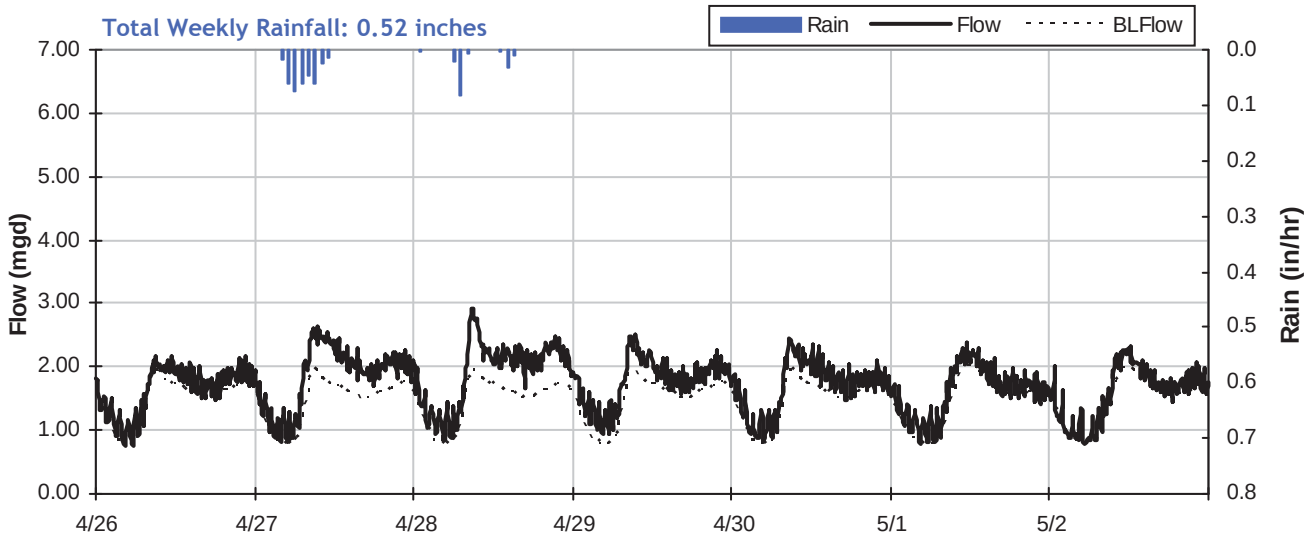
Avg Flow: 1.857 mgd Peak Flow: 3.676 mgd Min Flow: 0.81 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 10A



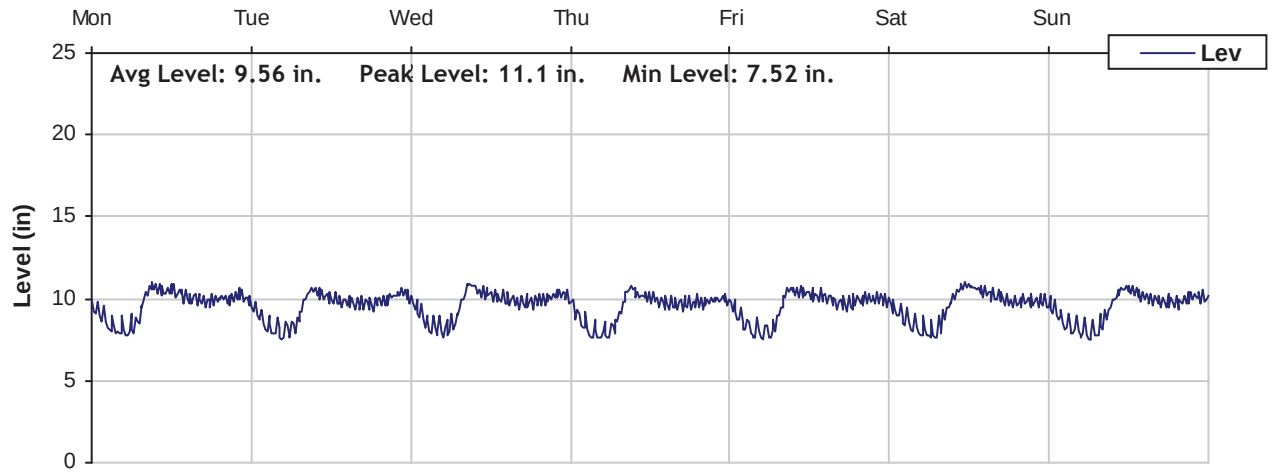


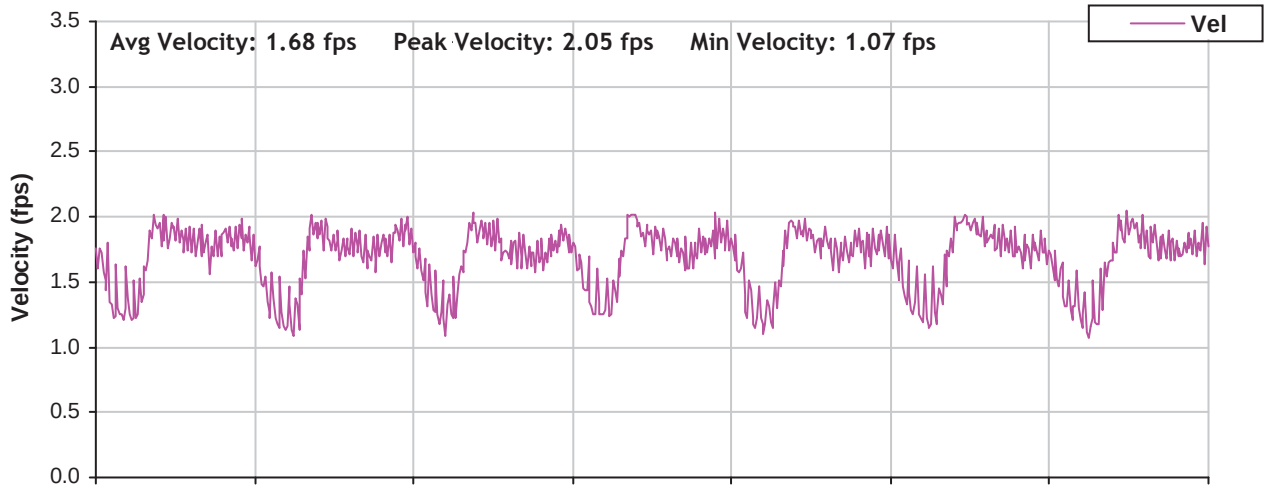


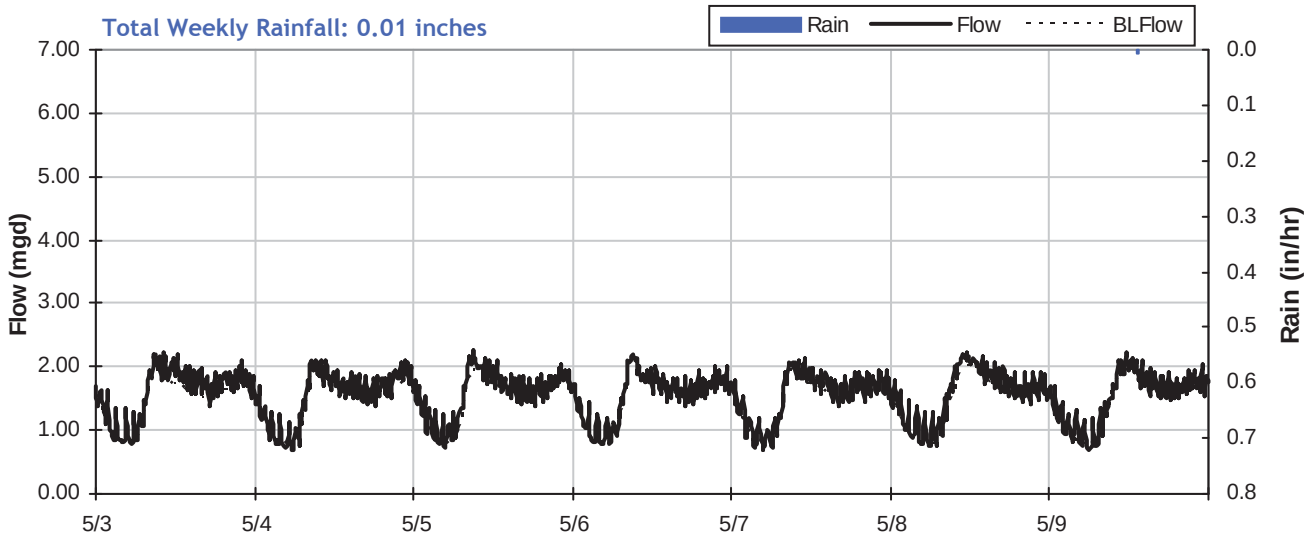
Avg Flow: 1.725 mgd Peak Flow: 2.912 mgd Min Flow: 0.759 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 10A



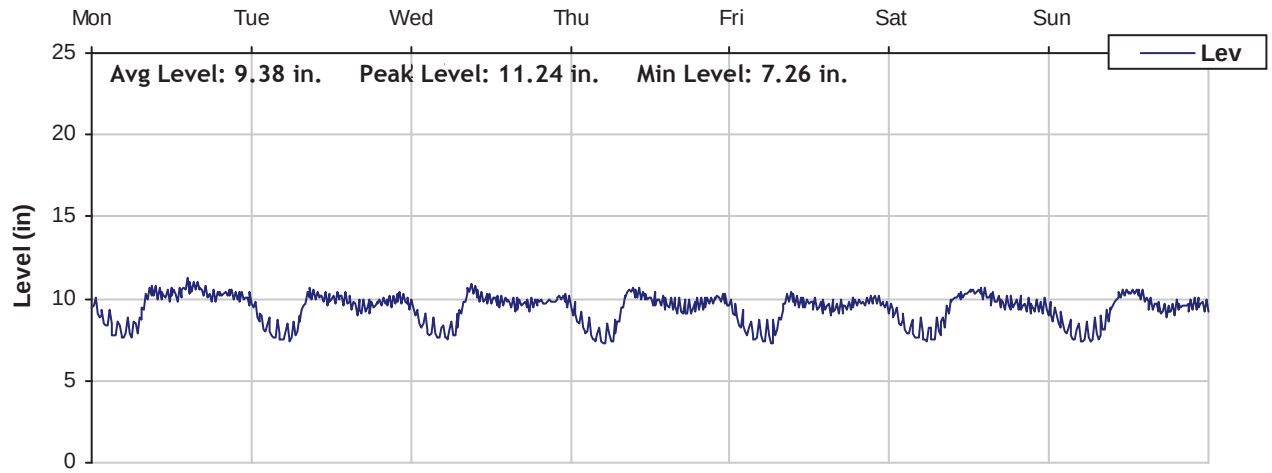


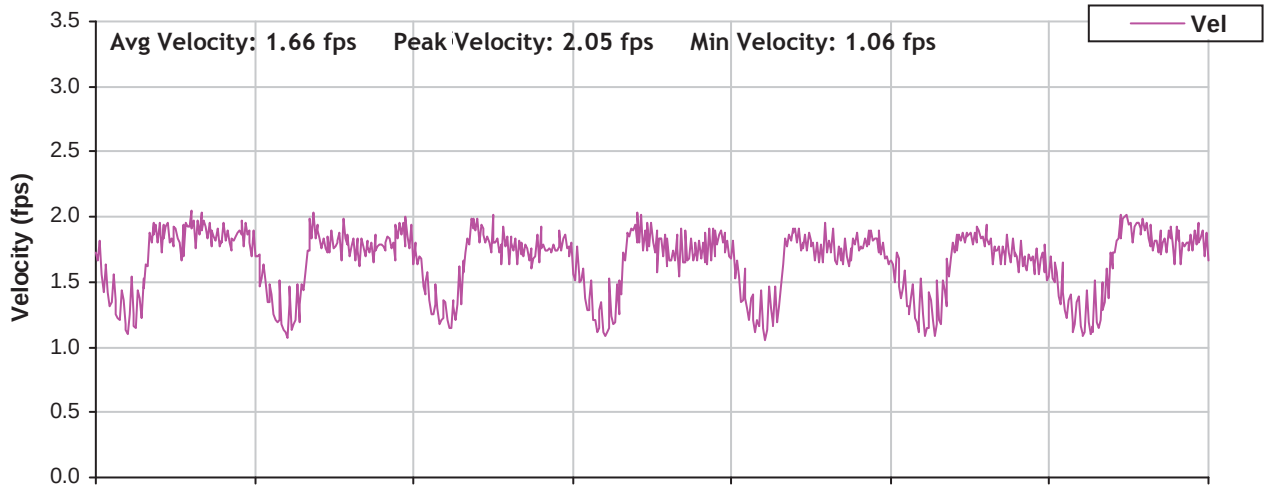


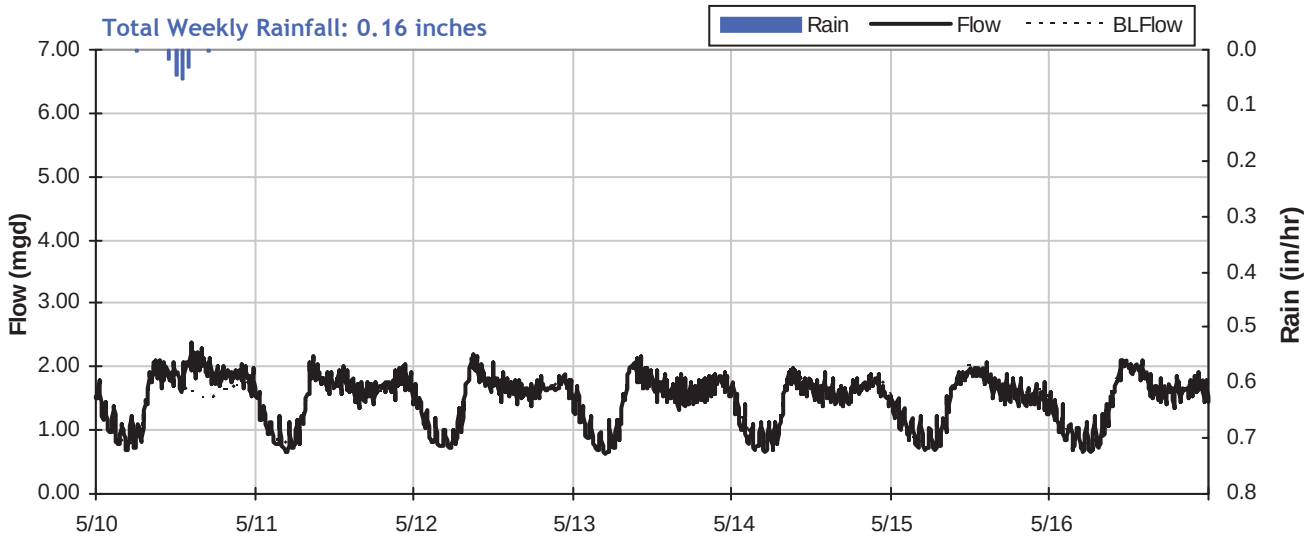
Avg Flow: 1.559 mgd Peak Flow: 2.249 mgd Min Flow: 0.68 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 10A



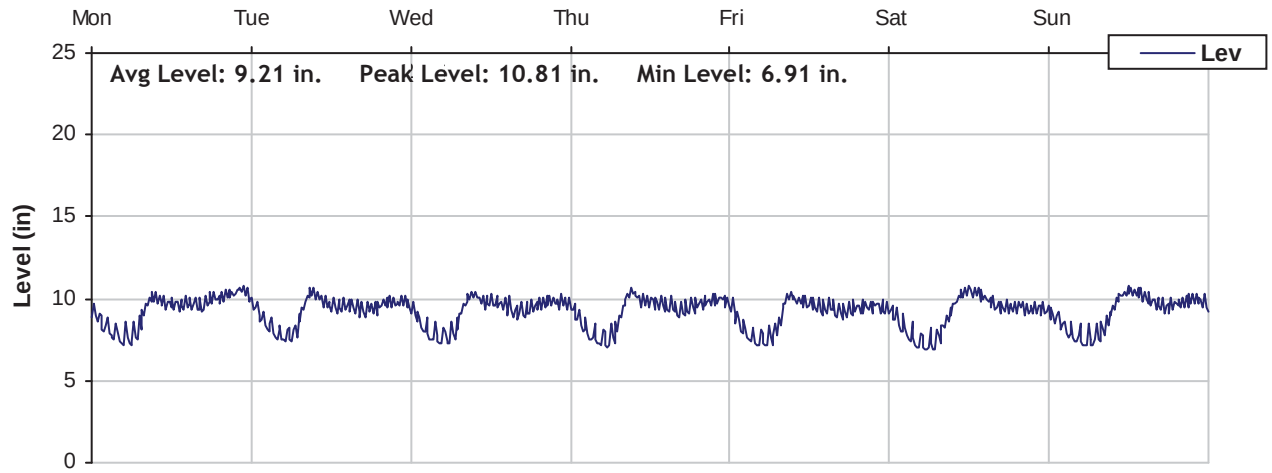


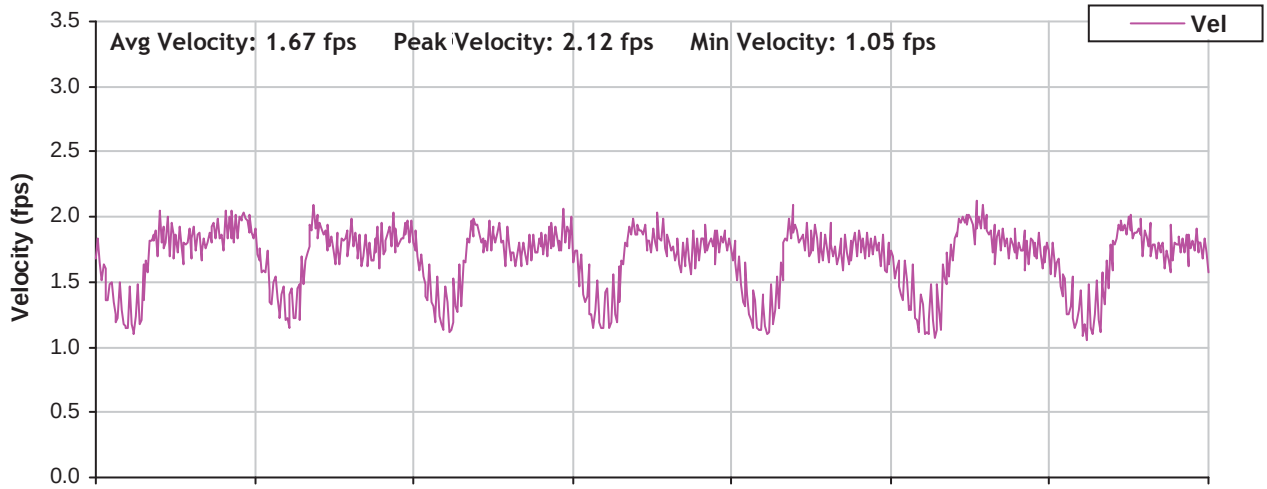


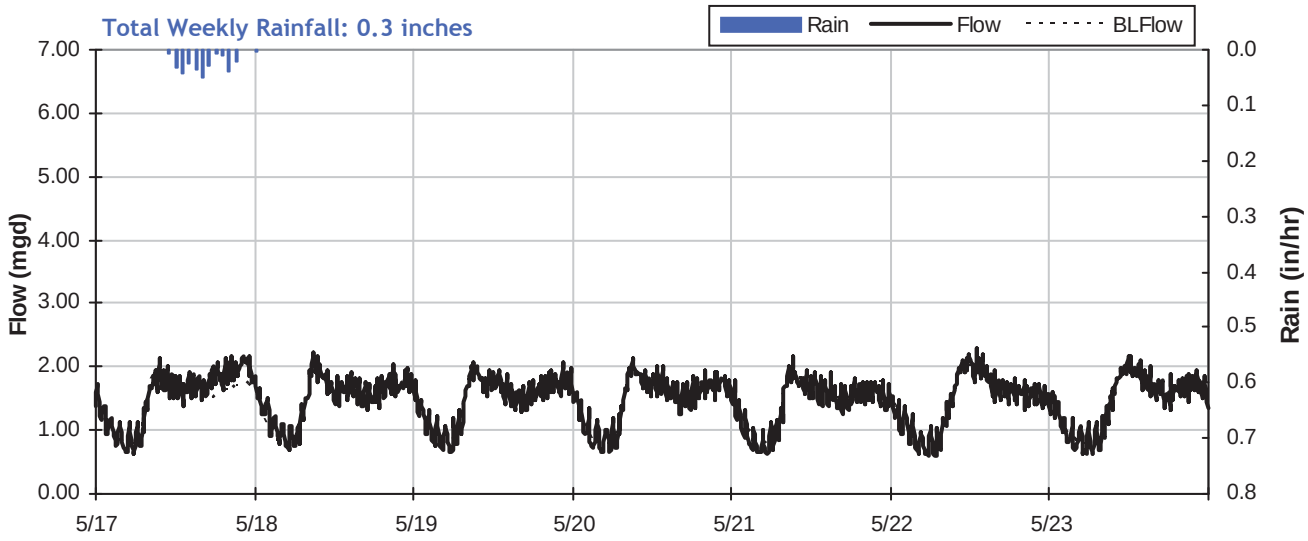
Avg Flow: 1.495 mgd Peak Flow: 2.37 mgd Min Flow: 0.639 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 10A



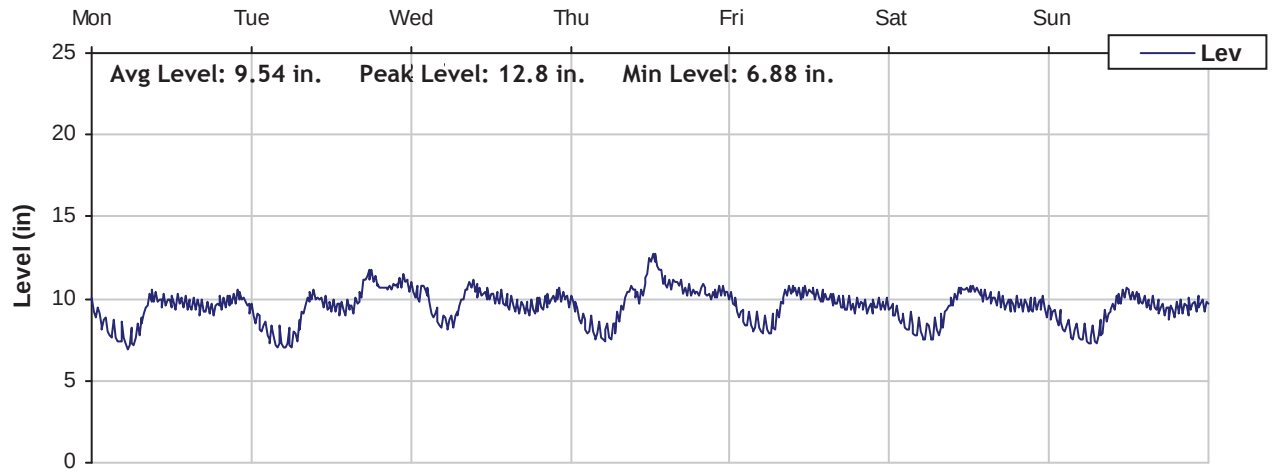


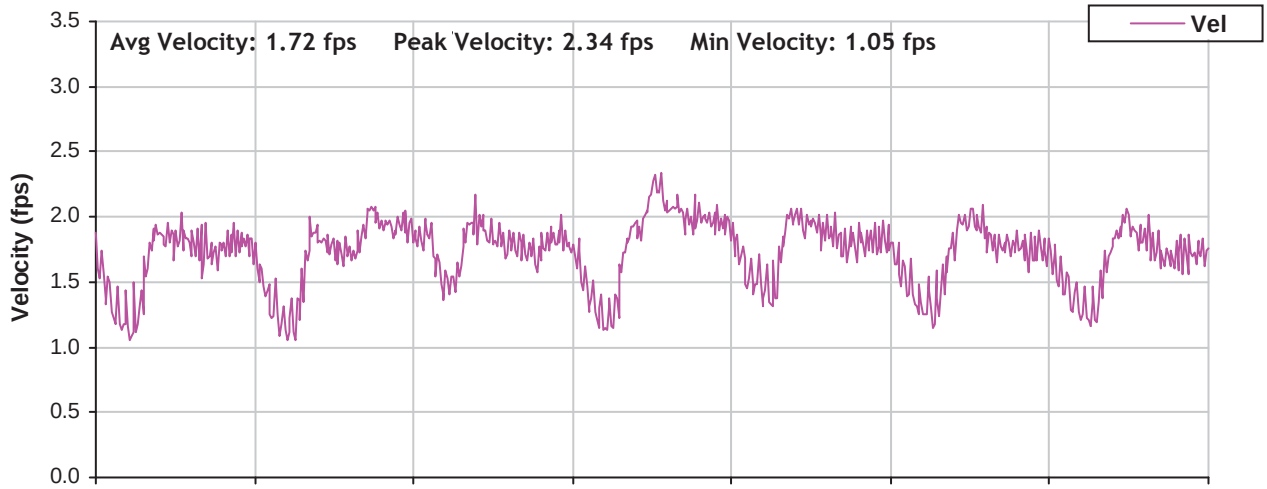


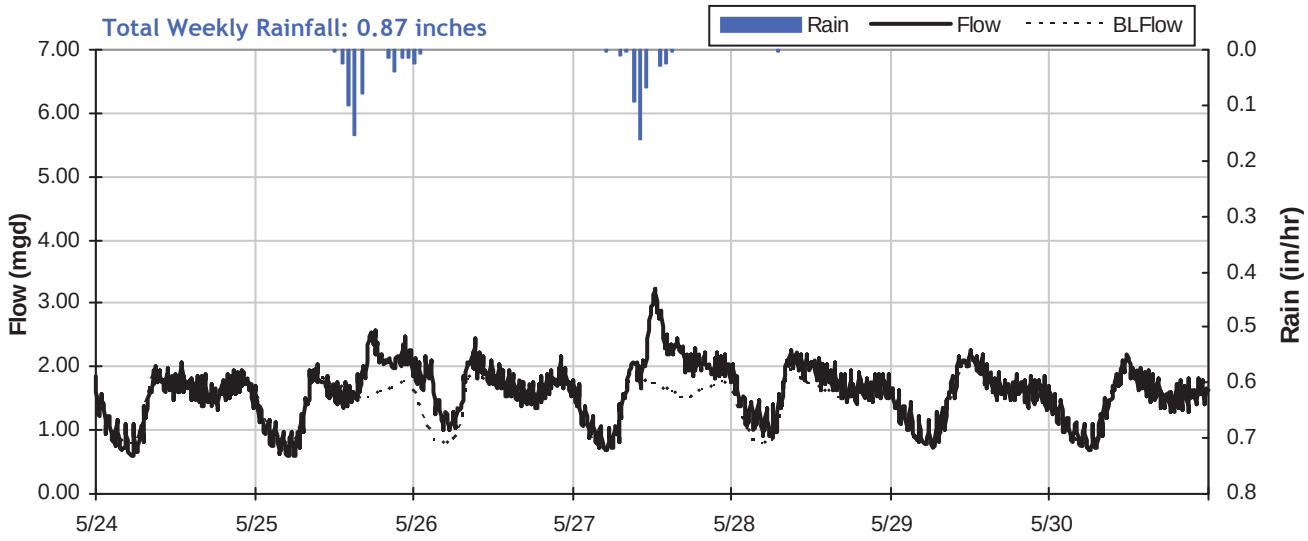
Avg Flow: 1.472 mgd Peak Flow: 2.29 mgd Min Flow: 0.597 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 10A



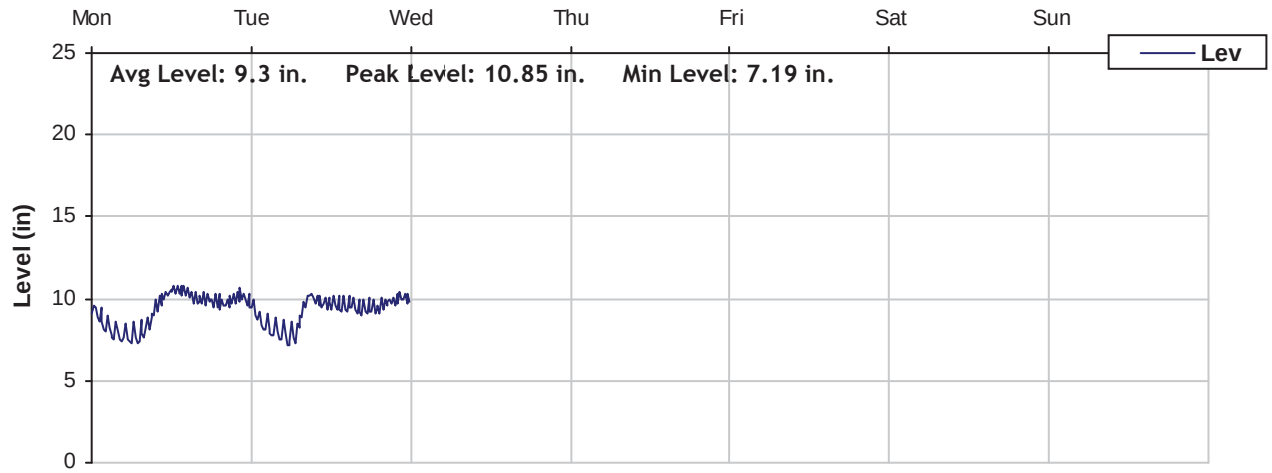


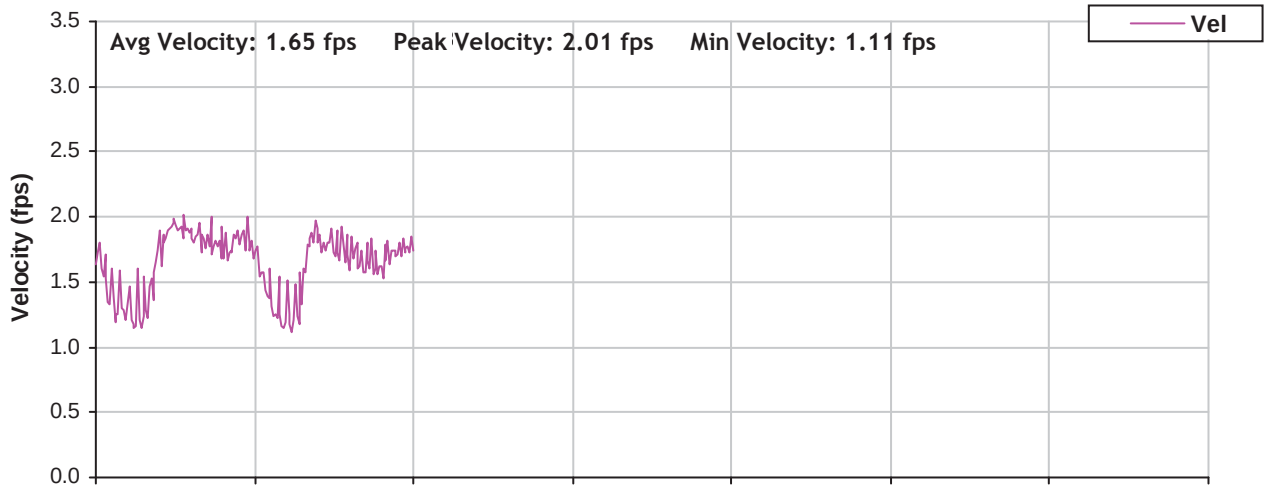


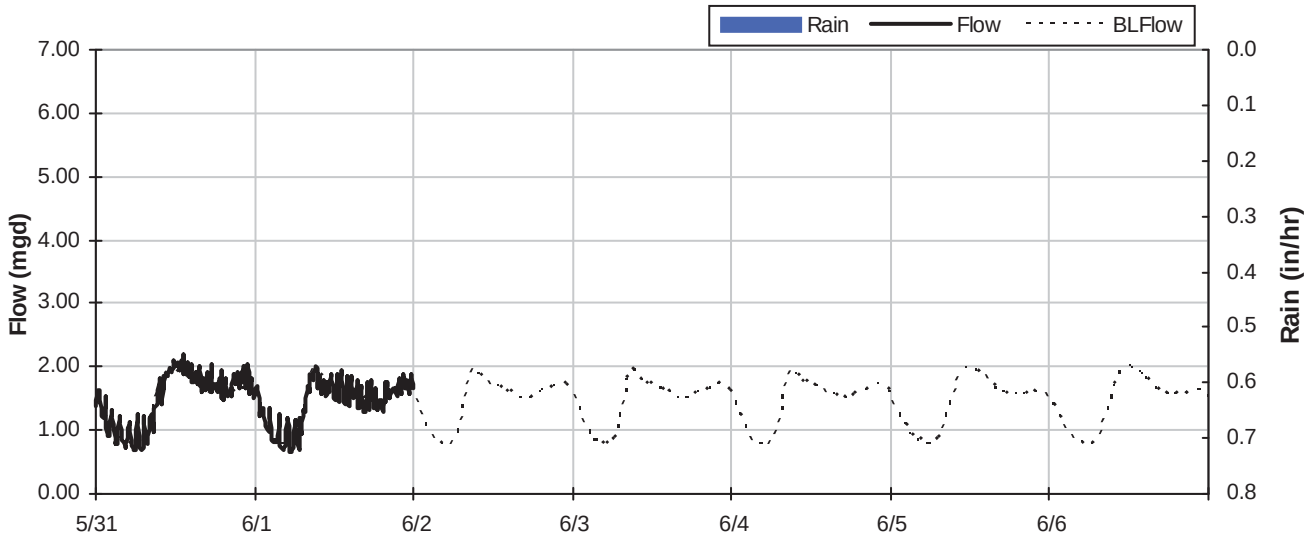
Avg Flow: 1.598 mgd Peak Flow: 3.236 mgd Min Flow: 0.591 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 10A







Avg Flow: 1.47 mgd Peak Flow: 2.2 mgd Min Flow: 0.645 mgd

Temporary Flow Monitoring Study

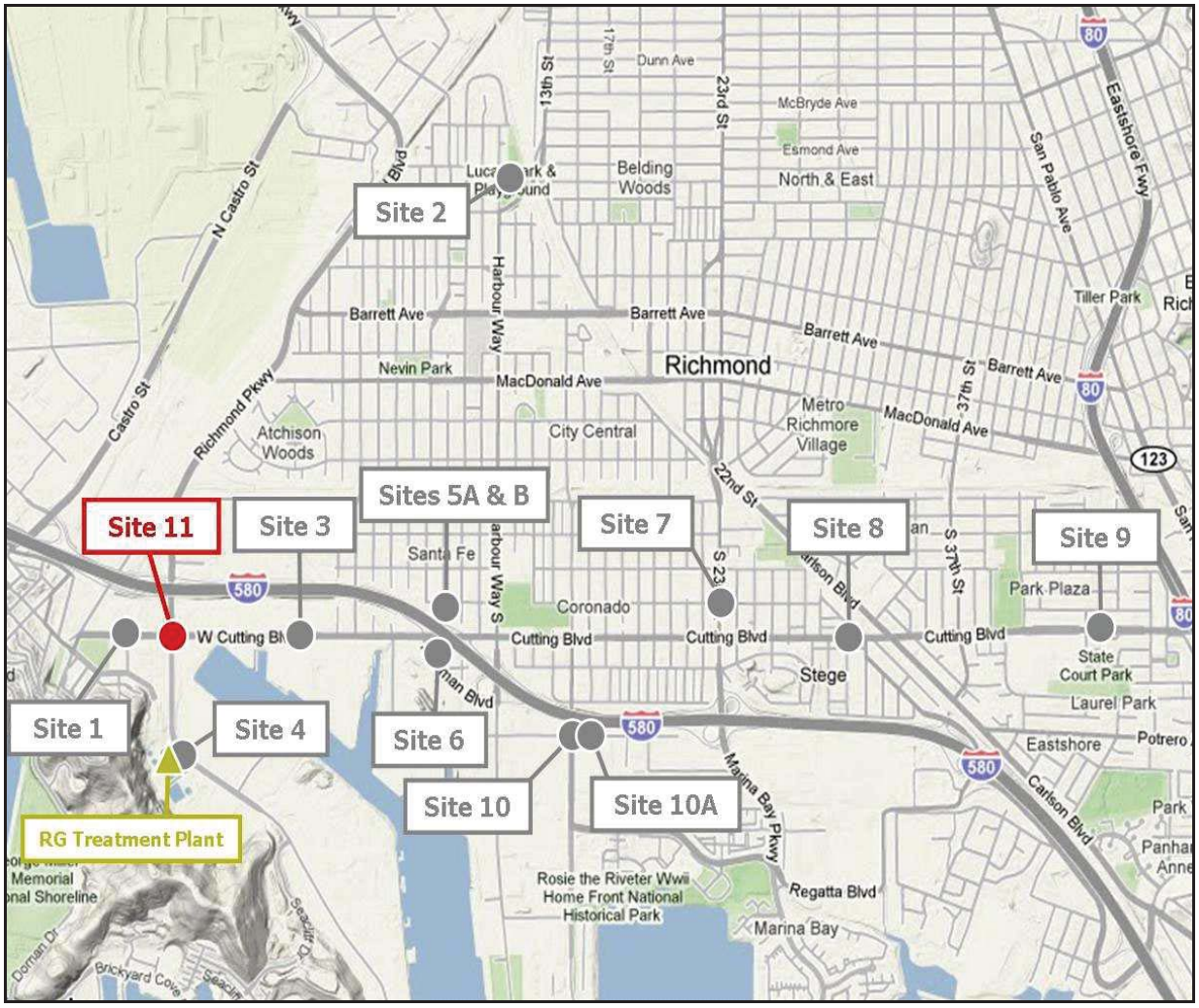
Sanitary Sewer Collection System

Monitoring Site: Site 11

Location: Intersection of W Cutting Boulevard and Canal Boulevard; west cross walk

Size/Type Line: 66-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 11

Location: Intersection of W Cutting Boulevard and Canal Boulevard; west cross walk

Latitude: 37.9253°

Longitude: -122.3784°

Rim Elevation: 9 *feet above sea level*

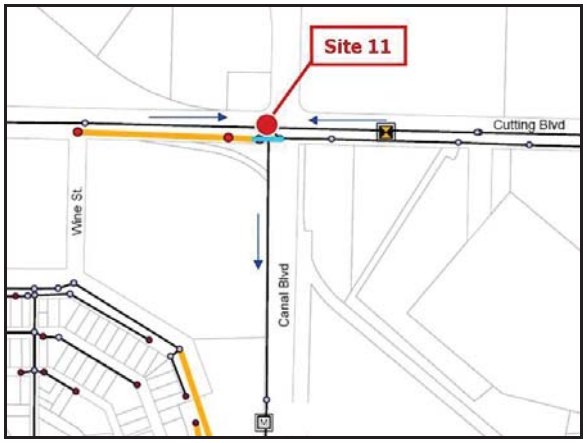
Diameter: 66 *inches*

Average Dry Weather Flow: 6.244 *mgd*

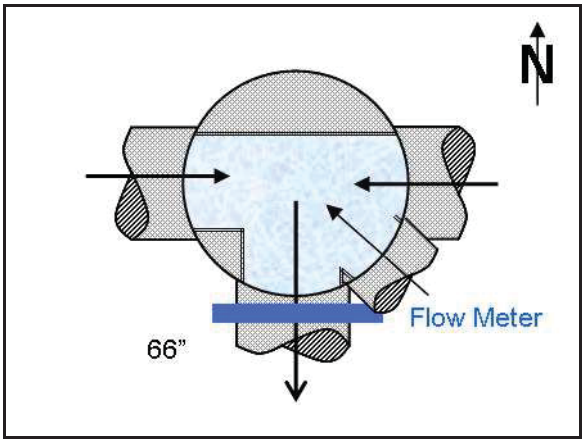
Peak Measured Flow: 31.765 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

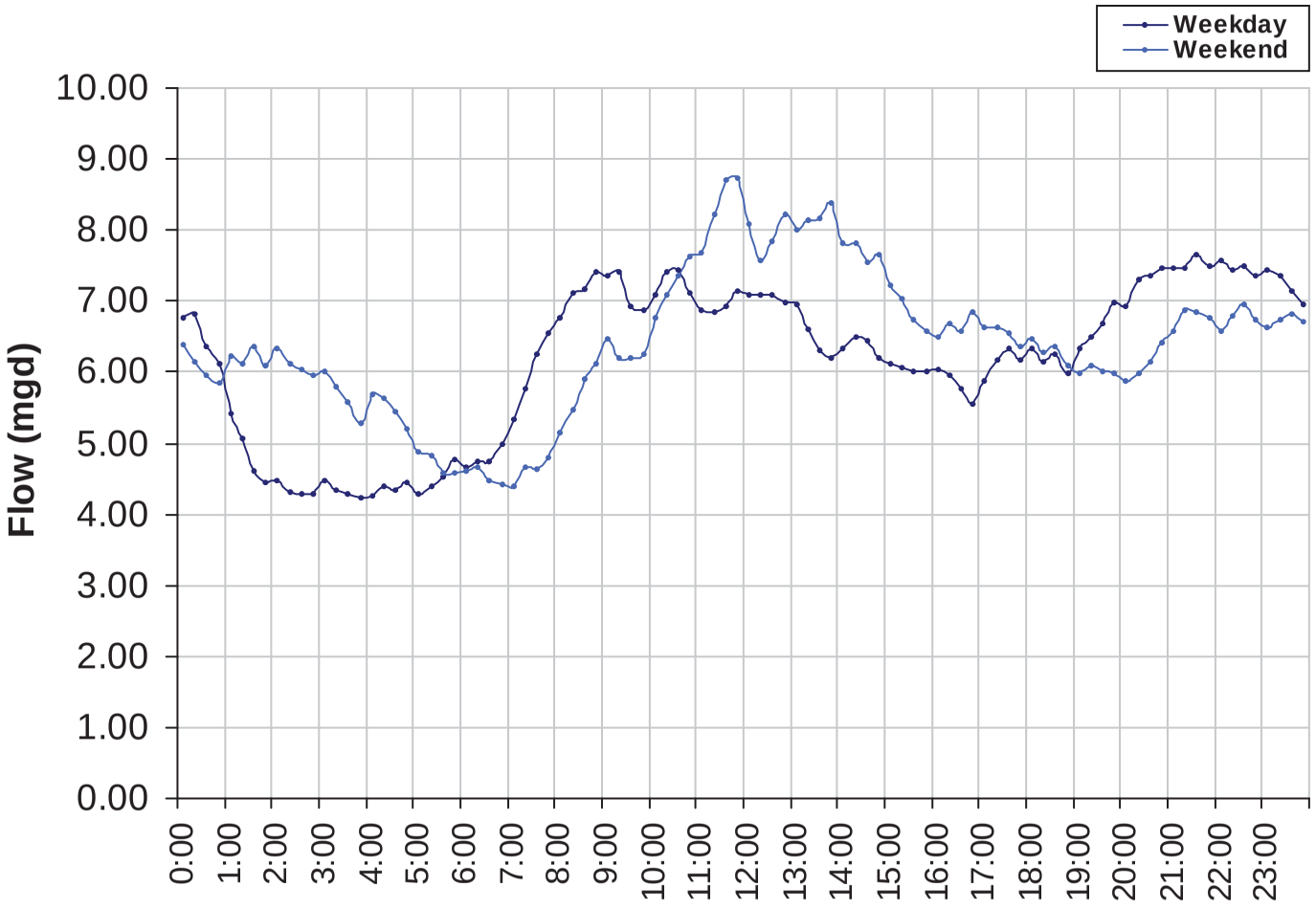


Street View Photo

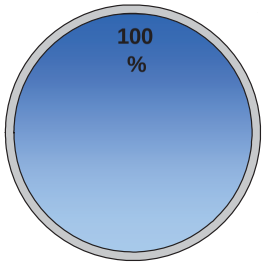
Plan View Photo

Average Dry Weather Flow

Monitoring Site:
Site 11

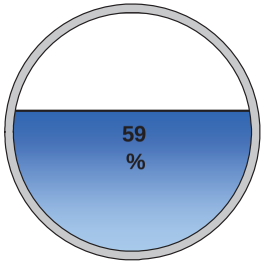


Peak Measured Flow:
31.76 *mgd*



Peak measured flow shown in weekly graphs on following pages

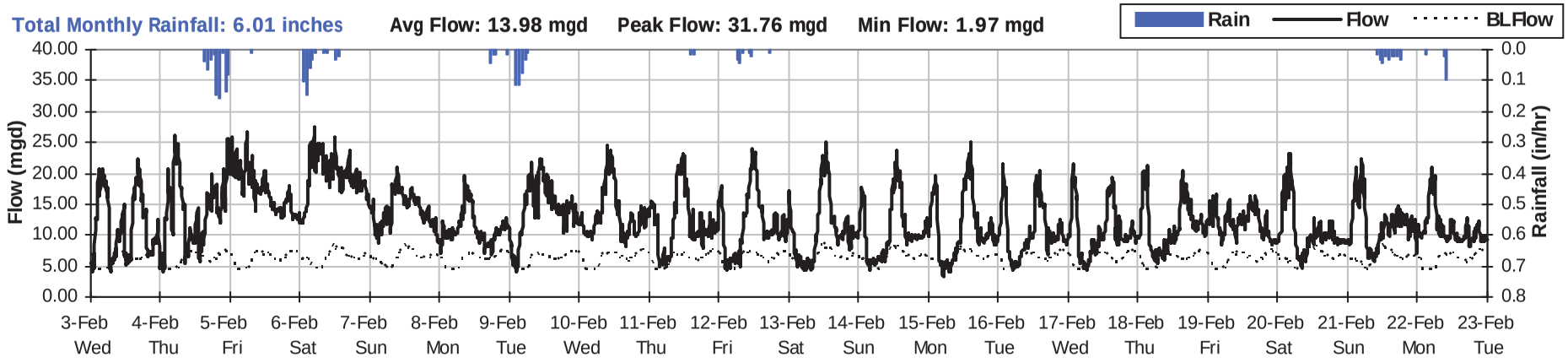
Average Dry Weather Flow:
6.24 *mgd*

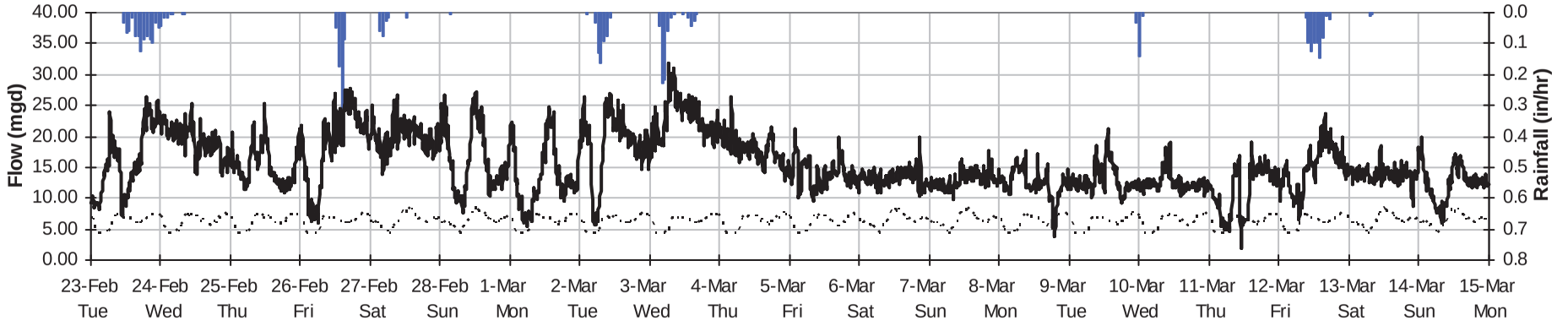


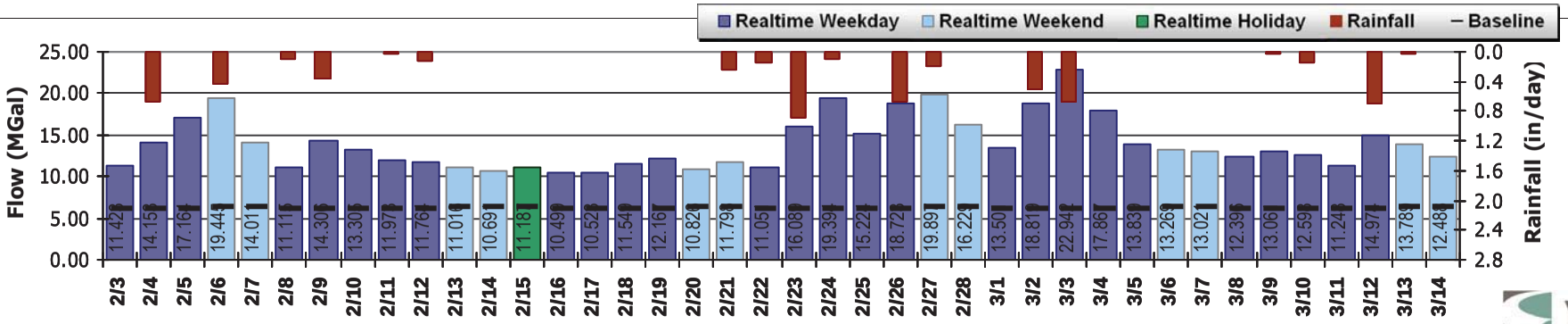
Period Flow Summary
February 3 to March 15, 2010

Monitoring Site:
Site 11

Total Monthly Rainfall: 6.01 inches **Avg Flow: 13.98 mgd** **Peak Flow: 31.76 mgd** **Min Flow: 1.97 mgd**





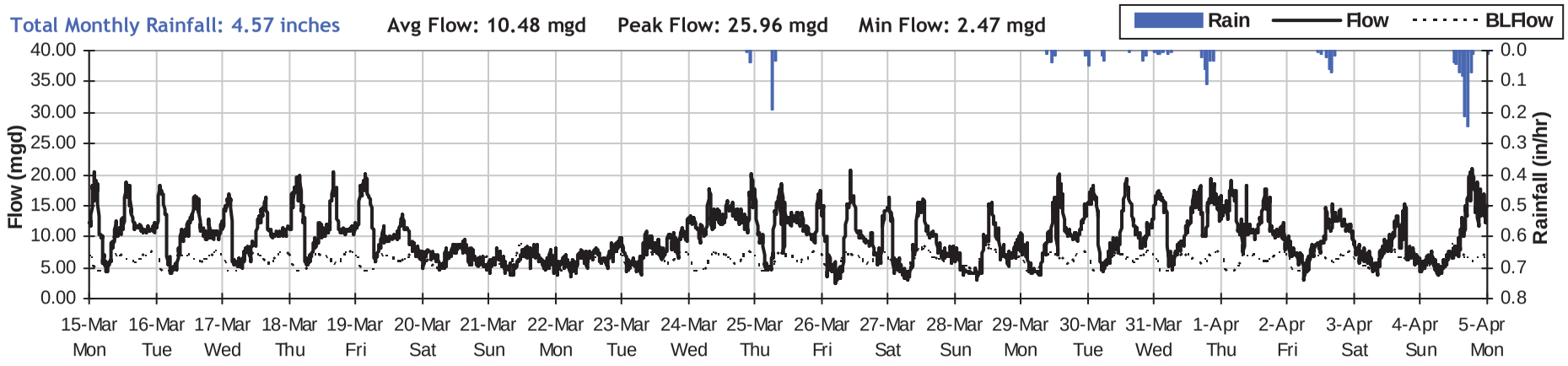


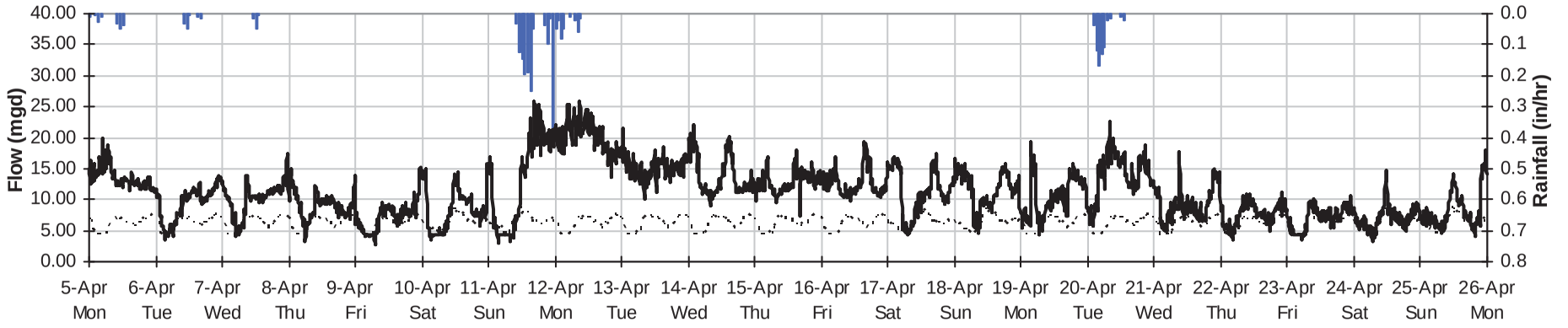
V&A

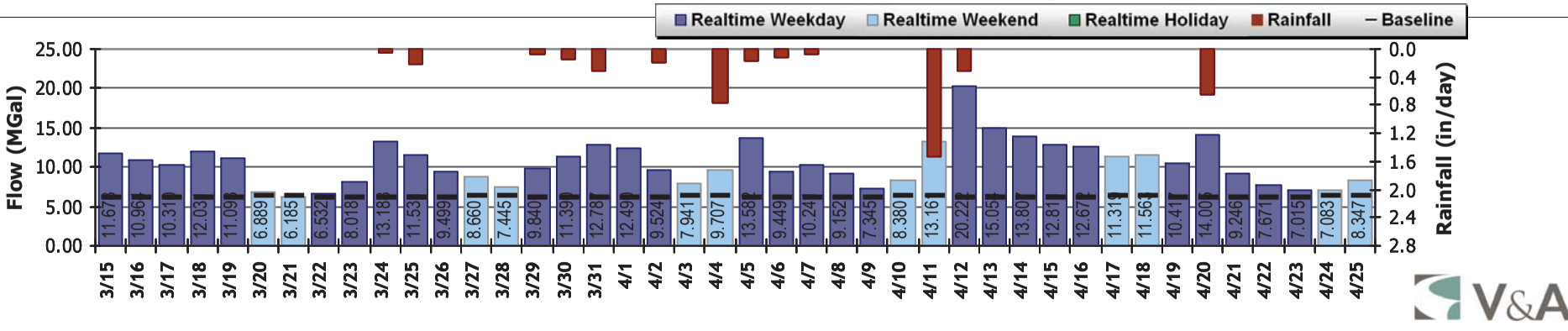
Period Flow Summary
March 15 to April 26, 2010

Monitoring Site:
Site 11

Total Monthly Rainfall: 4.57 inches Avg Flow: 10.48 mgd Peak Flow: 25.96 mgd Min Flow: 2.47 mgd



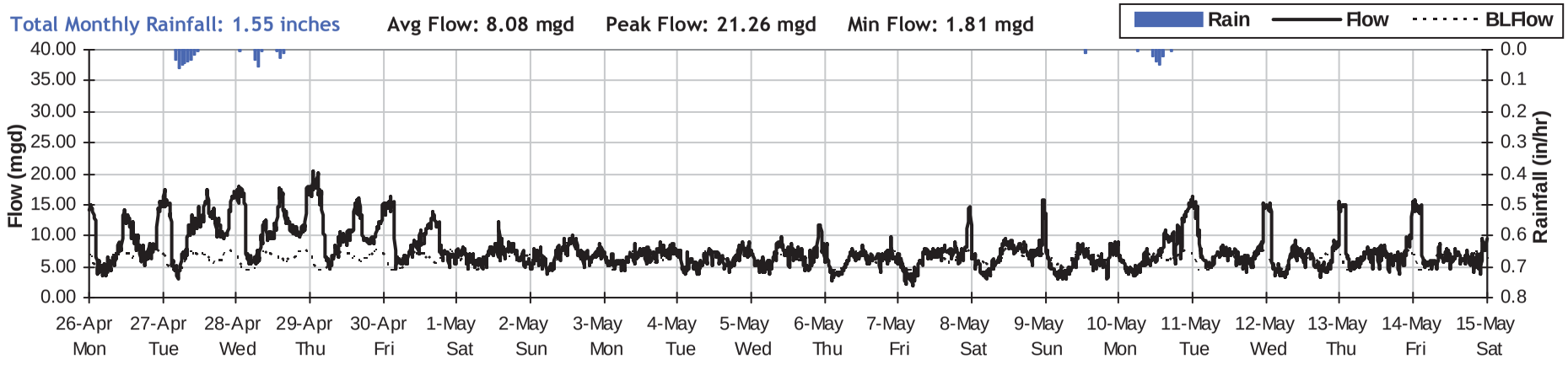


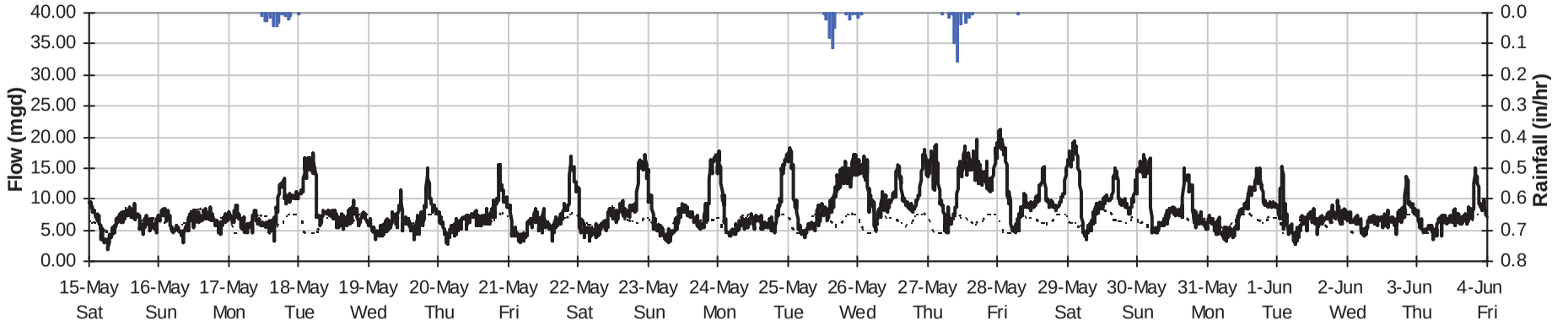


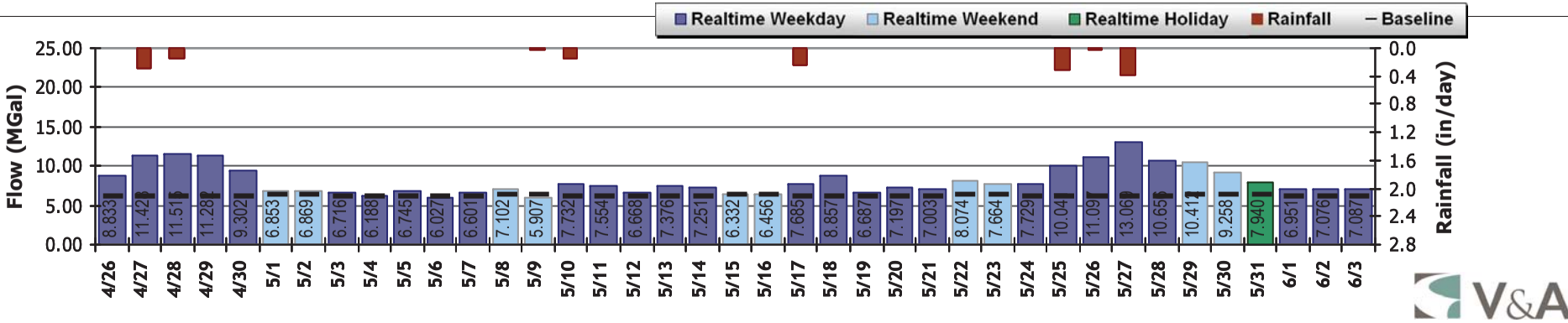
Period Flow Summary
April 26 to June 3, 2010

Monitoring Site:
Site 11

Total Monthly Rainfall: 1.55 inches Avg Flow: 8.08 mgd Peak Flow: 21.26 mgd Min Flow: 1.81 mgd





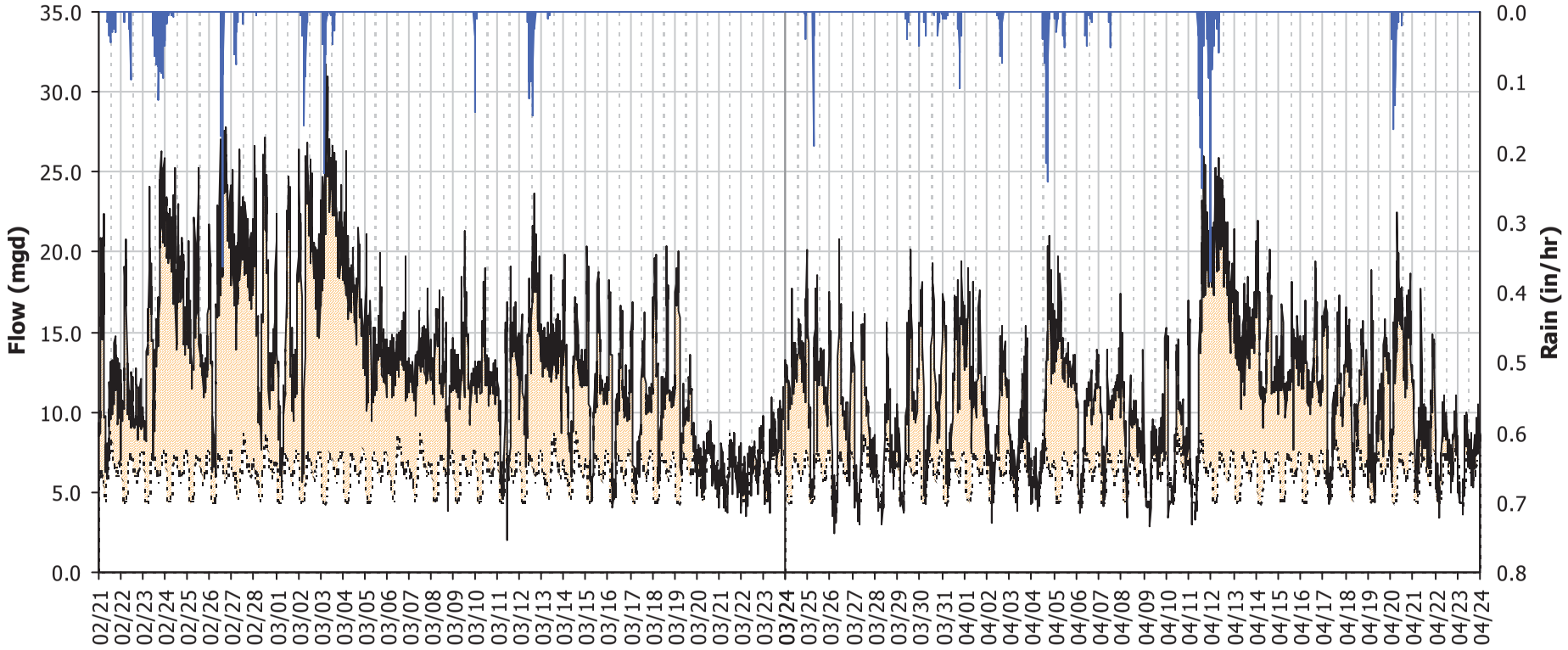


V&A

I/I Summary
Multiple Rainfall Events

Monitoring Site:
Site 11

Multiple Events Detail I/I Graph

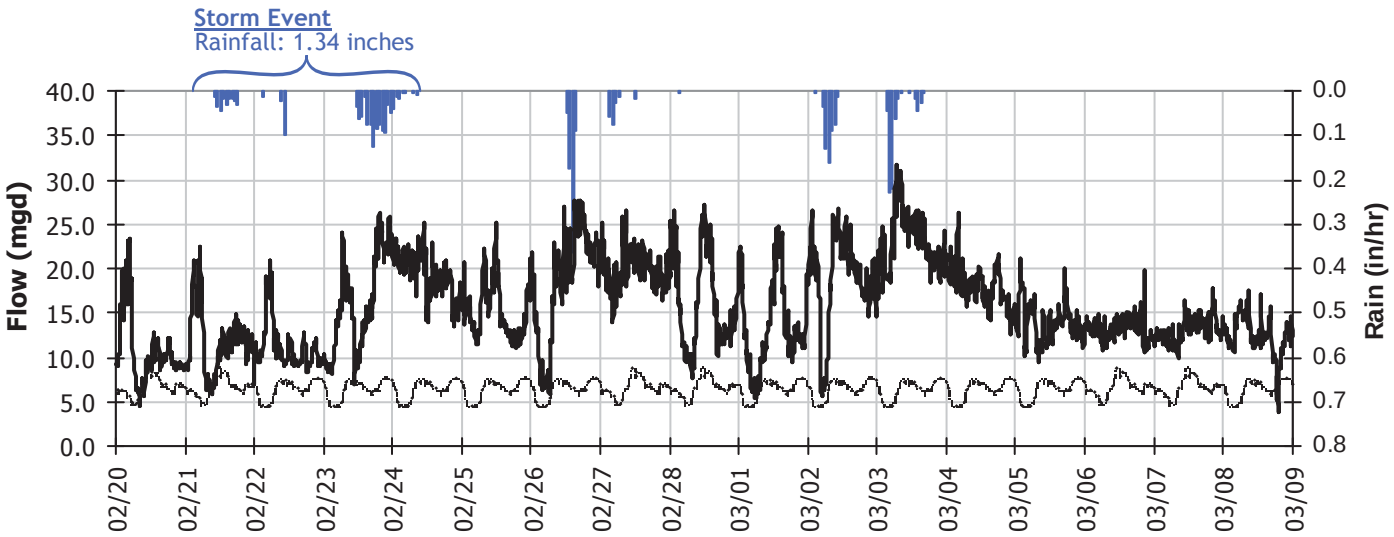


Multiple Events I/I Analysis

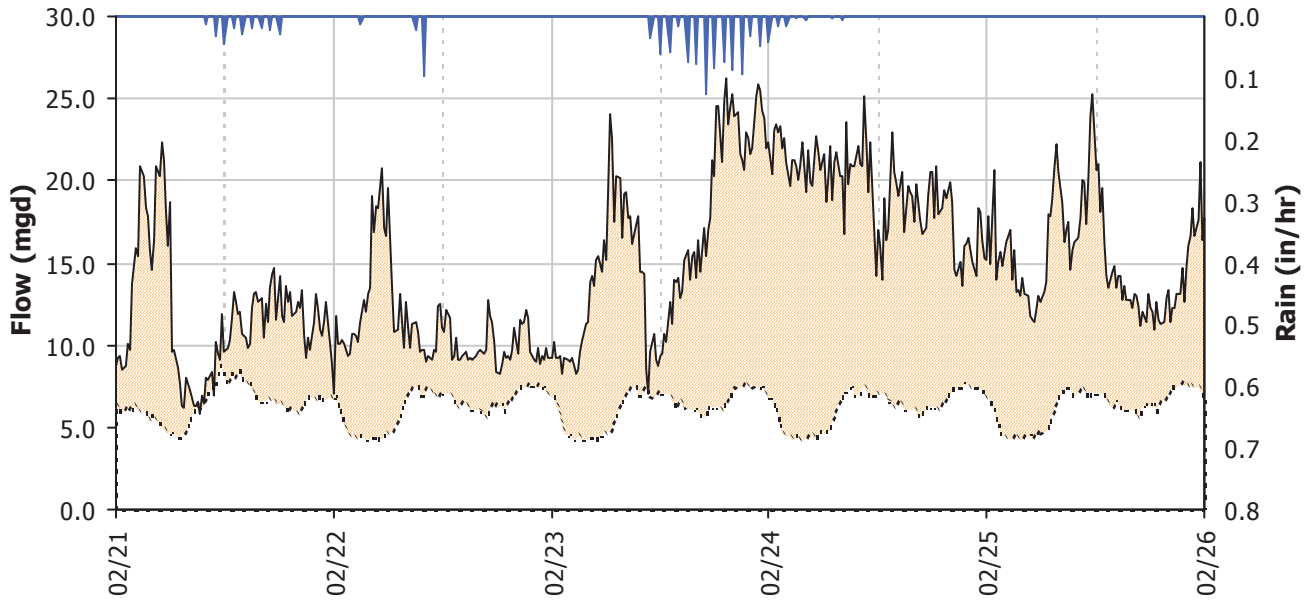
Rainfall:	8.87	*inches*	**Baseline Flow:**	6.24	*mgd*
Peak Flow:	31.76	*mgd*	**PF:**	5.09	
Peak I/I Rate:	27.02	*mgd*	**Pk I/I:ADWF:**	4.33	
Peak Level:	162.25	*inches*	**d/D Ratio:**	2.46	
Total I/I:	370,074,000	*gallons*	**R-Value:**	26.7%	
			I/I per ADWF:	6.7	*per in-rain*

	I/I Summary Event 1	**Monitoring Site:** Site 11

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #1 I/I Analysis

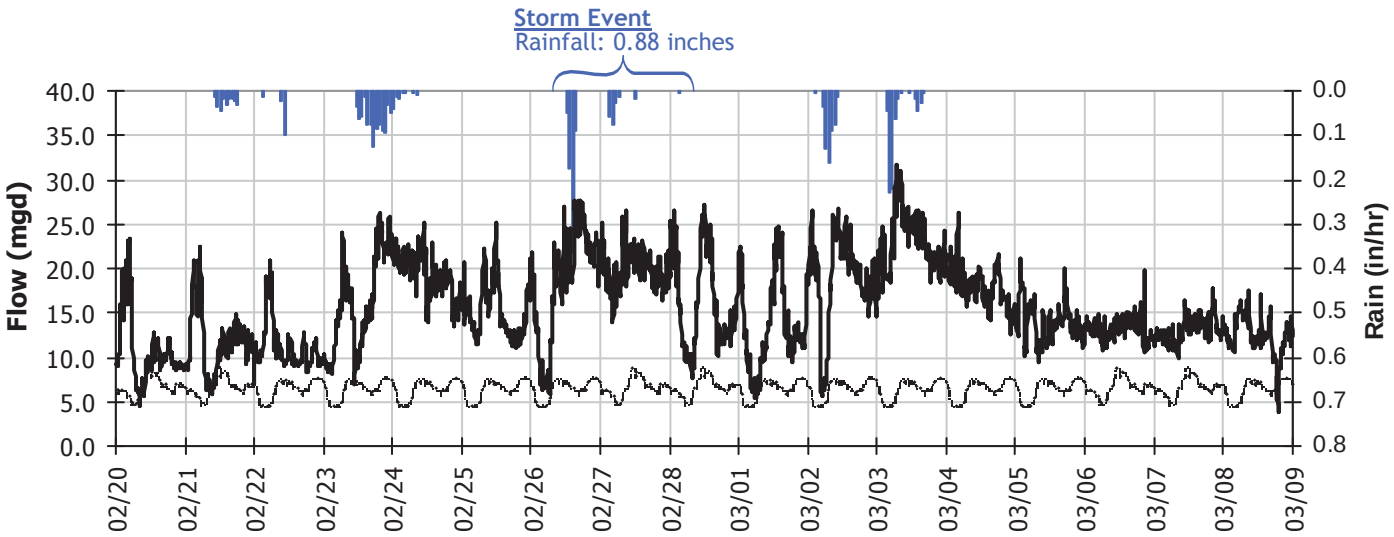
Rainfall:	1.34	*inches*		
Baseline Flow:	6.24	*mgd*		
Peak Flow:	26.28	*mgd*	**PF:**	4.21
Peak I/I Rate:	19.79	*mgd*	**Pk I/I:ADWF:**	3.17
Peak Level:	154.56	*inches*	**d/D Ratio:**	2.34
Total I/I:	42,541,000	*gallons*	**R-Value:**	20.3%
			I/I per ADWF:	5.08 *per in-rain*

Average Infiltration Rate on 2/25 (% of ADWF): 146.4%

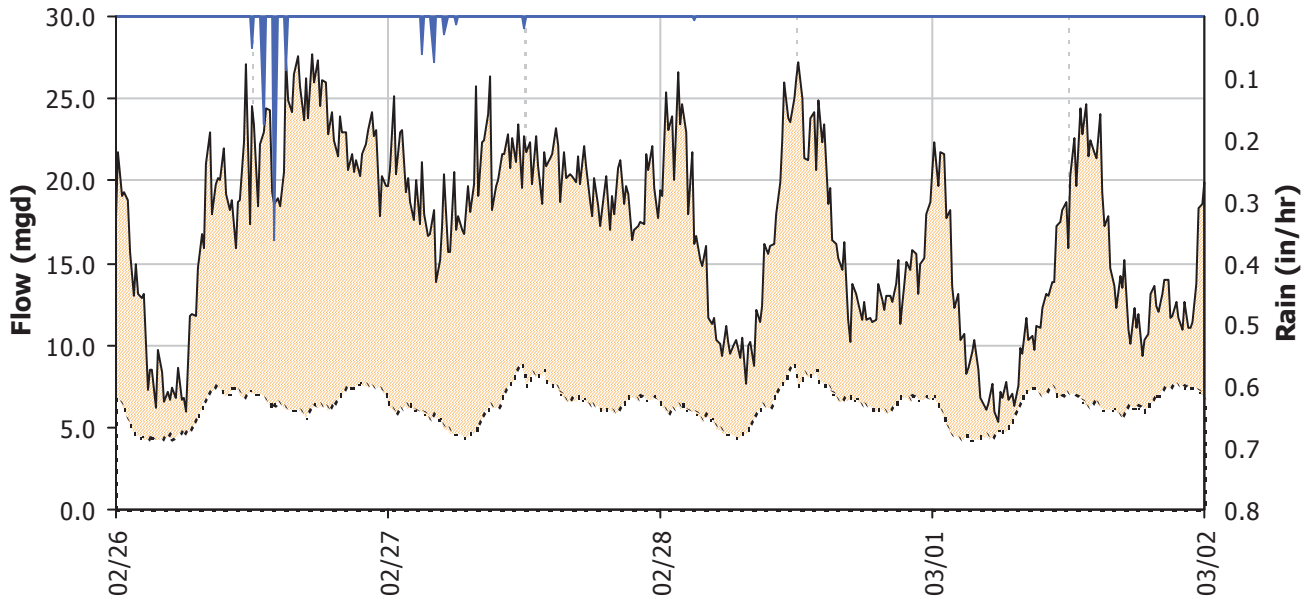
V&A

	I/I Summary Event 2	**Monitoring Site:** Site 11

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #2 I/I Analysis

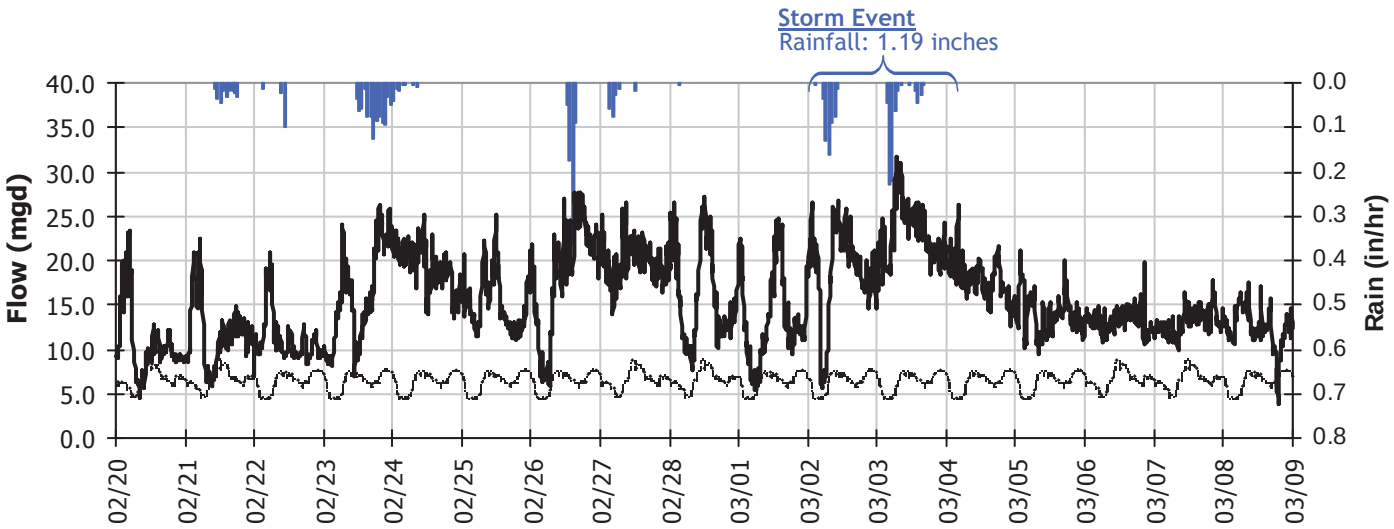
Rainfall:	0.88	*inches*		
Baseline Flow:	6.24	*mgd*		
Peak Flow:	27.75	*mgd*	**PF:**	4.44
Peak I/I Rate:	21.58	*mgd*	**Pk I/I:ADWF:**	3.46
Peak Level:	133.41	*inches*	**d/D Ratio:**	2.02
Total I/I:	43,329,000	*gallons*	**R-Value:**	31.5%
			I/I per ADWF:	7.87 *per in-rain*

Average Infiltration Rate on 3/1 (% of ADWF): 119.2%

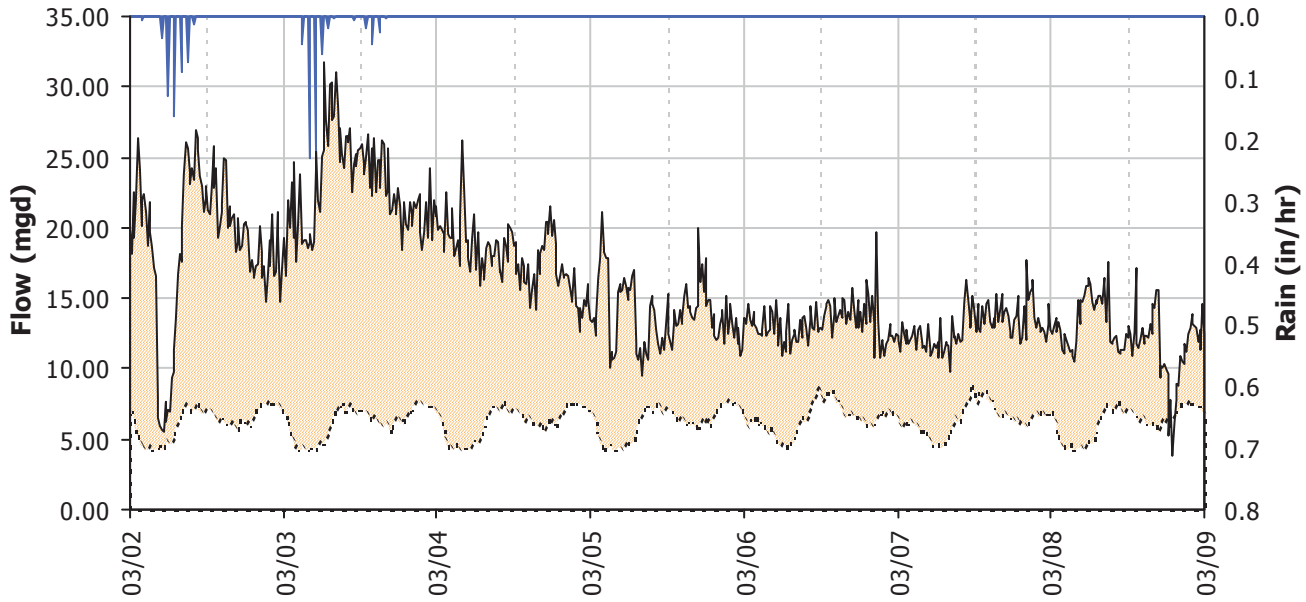
V&A

	I/I Summary Event 3	**Monitoring Site:** Site 11

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



Storm Event #3 I/I Analysis

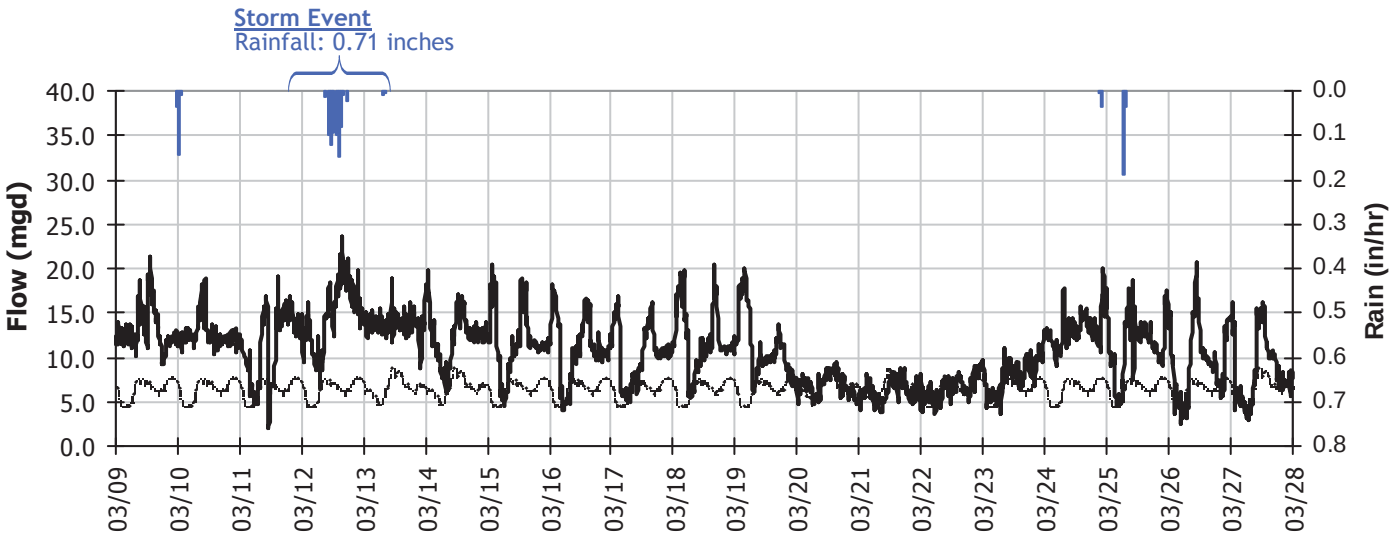
Rainfall:	1.19	*inches*		
Baseline Flow:	6.24	*mgd*		
Peak Flow:	31.76	*mgd*	**PF:**	5.09
Peak I/I Rate:	27.02	*mgd*	**Pk I/I:ADWF:**	4.33
Peak Level:	155.71	*inches*	**d/D Ratio:**	2.36
Total I/I:	68,503,000	*gallons*	**R-Value:**	37.0%
			I/I per ADWF:	9.25 *per in-rain*

Average Infiltration Rate on 3/5 (% of ADWF): 123.7%

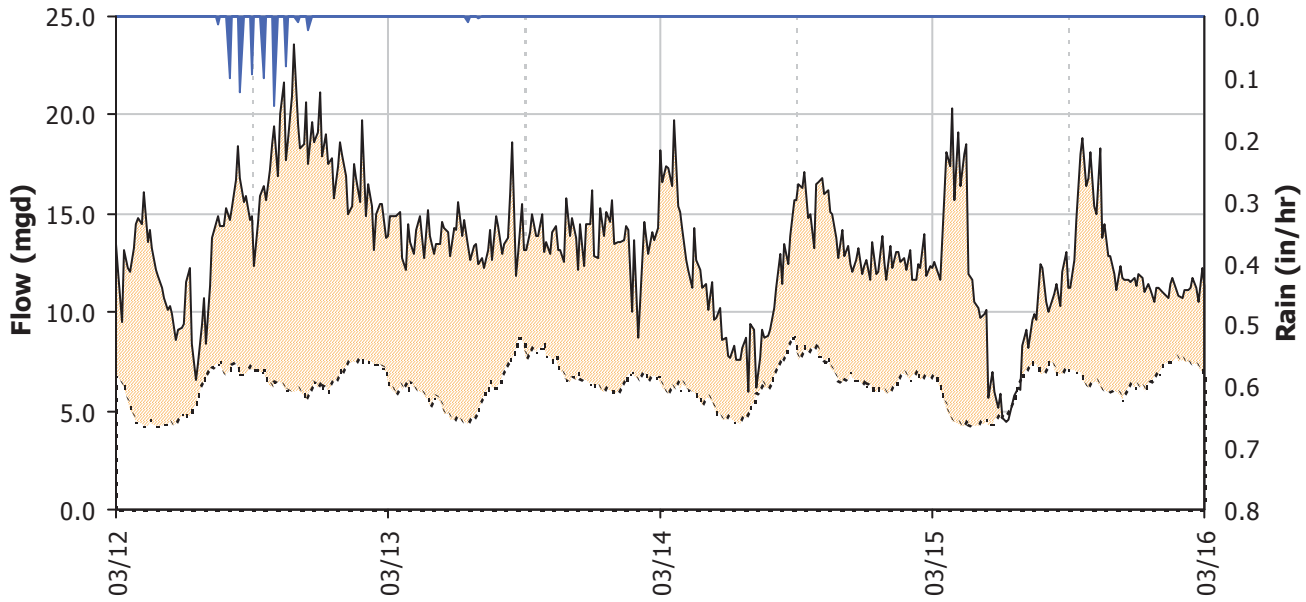
V&A

	I/I Summary Event 4	**Monitoring Site:** Site 11

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



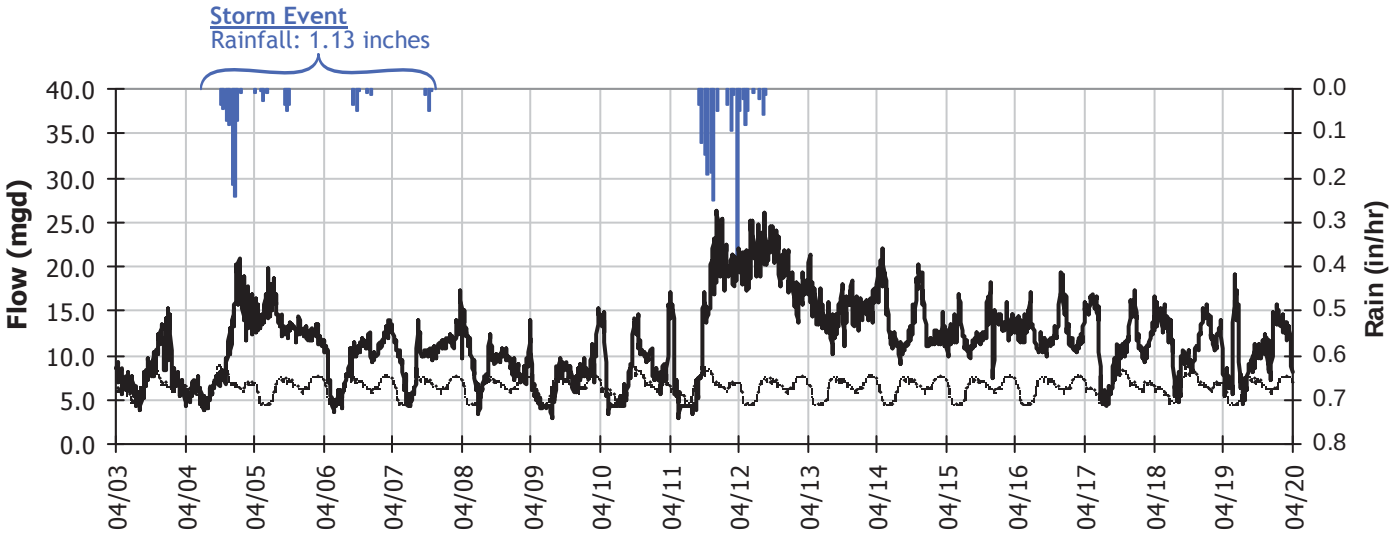
Storm Event #1 I/I Analysis

Rainfall:	0.71	*inches*		
Baseline Flow:	6.24	*mgd*		
Peak Flow:	23.63	*mgd*	**PF:**	3.78
Peak I/I Rate:	17.61	*mgd*	**Pk I/I:ADWF:**	2.82
Peak Level:	140.83	*inches*	**d/D Ratio:**	2.13
Total I/I:	27,818,000	*gallons*	**R-Value:**	25.2%
			I/I per ADWF:	6.29 *per in-rain*

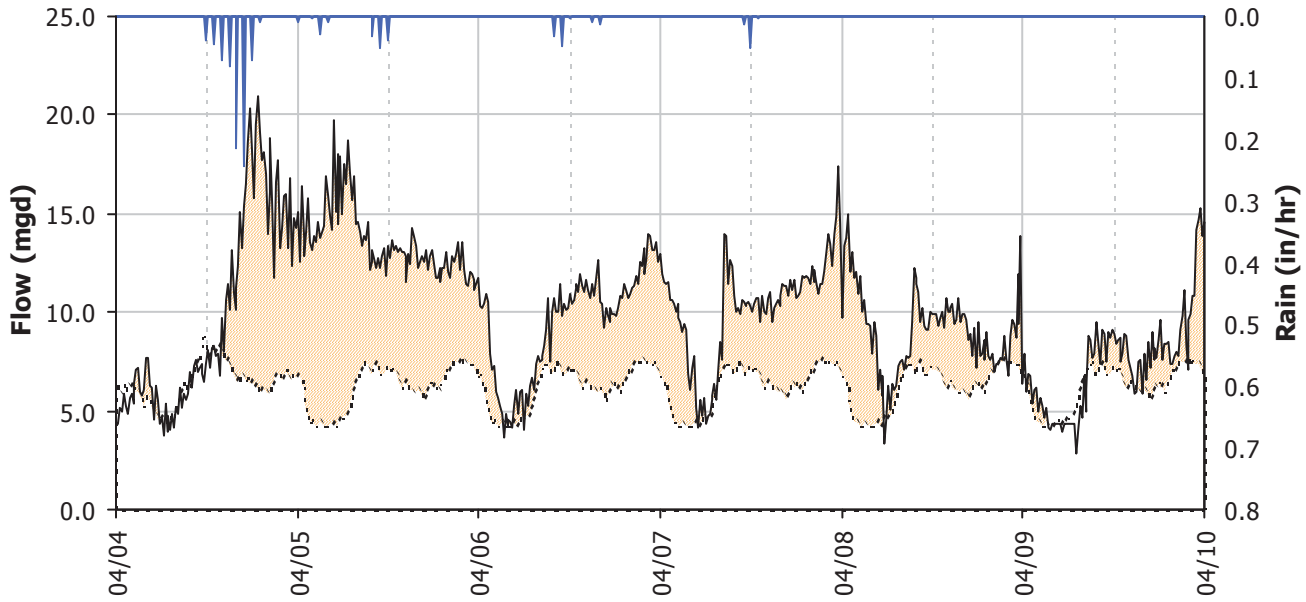
Average Infiltration Rate on 3/14 (% of ADWF): 95.1%

	I/I Summary Event 5	**Monitoring Site:** Site 11

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



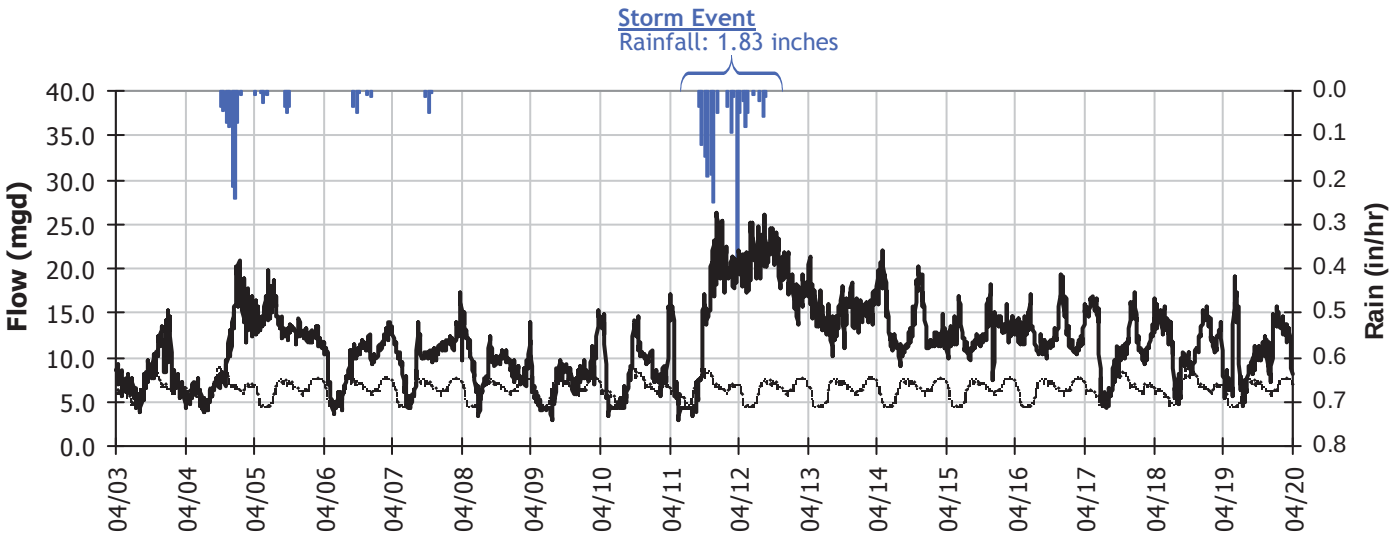
Storm Event #5 I/I Analysis

Rainfall:	1.13	*inches*		
Baseline Flow:	6.24	*mgd*		
Peak Flow:	20.95	*mgd*	**PF:**	3.36
Peak I/I Rate:	15.29	*mgd*	**Pk I/I:ADWF:**	2.45
Peak Level:	121.11	*inches*	**d/D Ratio:**	1.84
Total I/I:	22,249,000	*gallons*	**R-Value:**	12.7%
			I/I per ADWF:	3.16 *per in-rain*

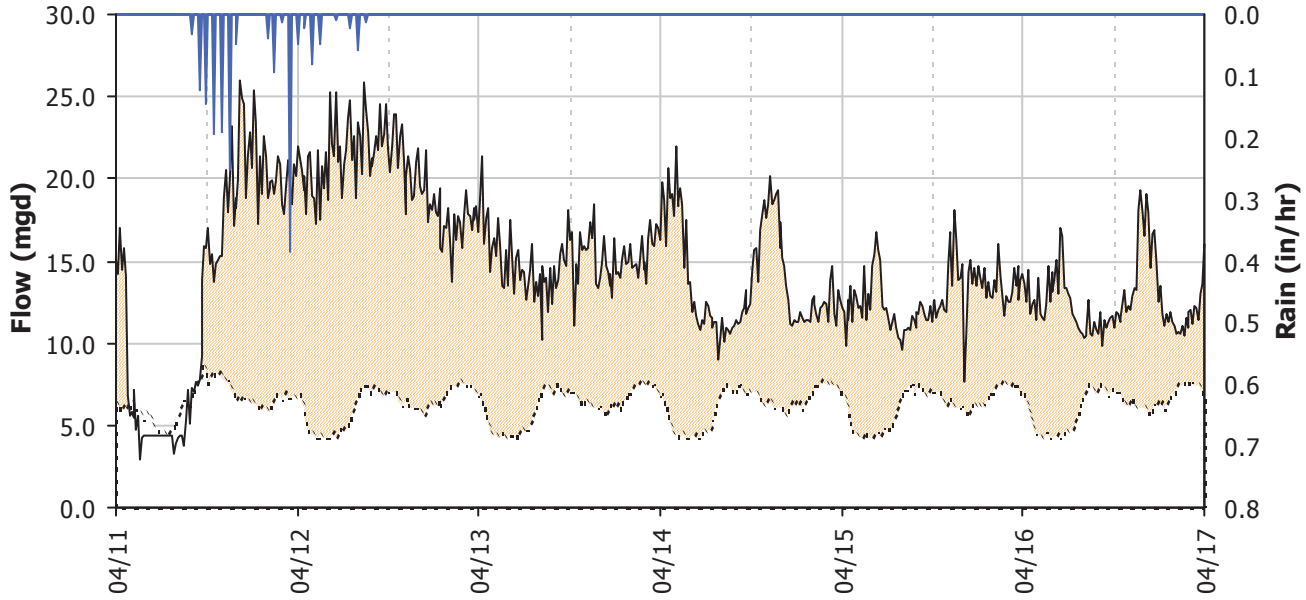
Average Infiltration Rate on 4/8 (% of ADWF): 47.4%

	I/I Summary Event 6	**Monitoring Site:** Site 11

Baseline and Realtime Flows over Monitoring Period



Detail I/I Graph



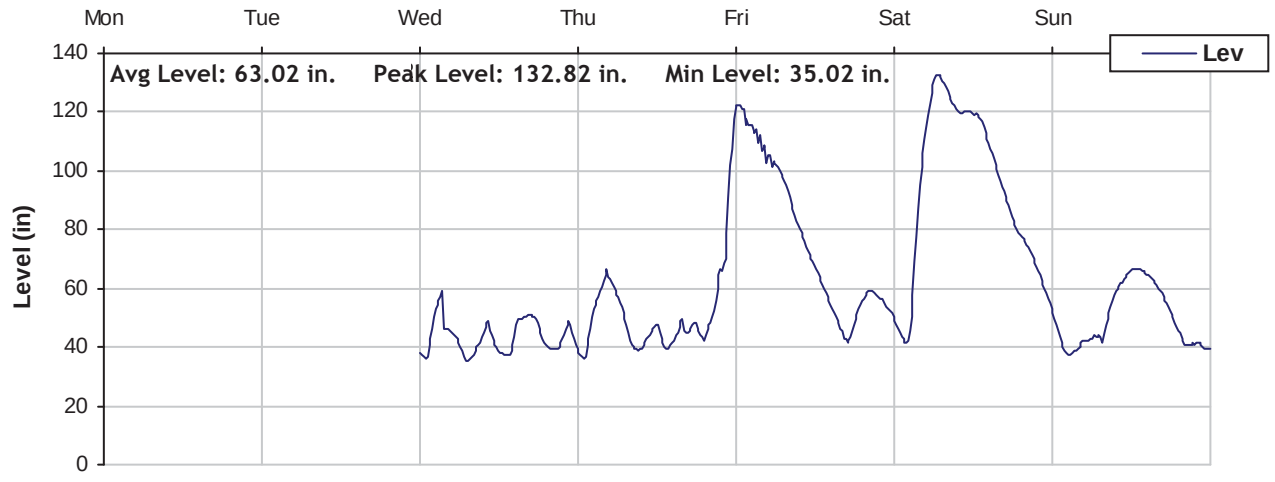
Storm Event #6 I/I Analysis

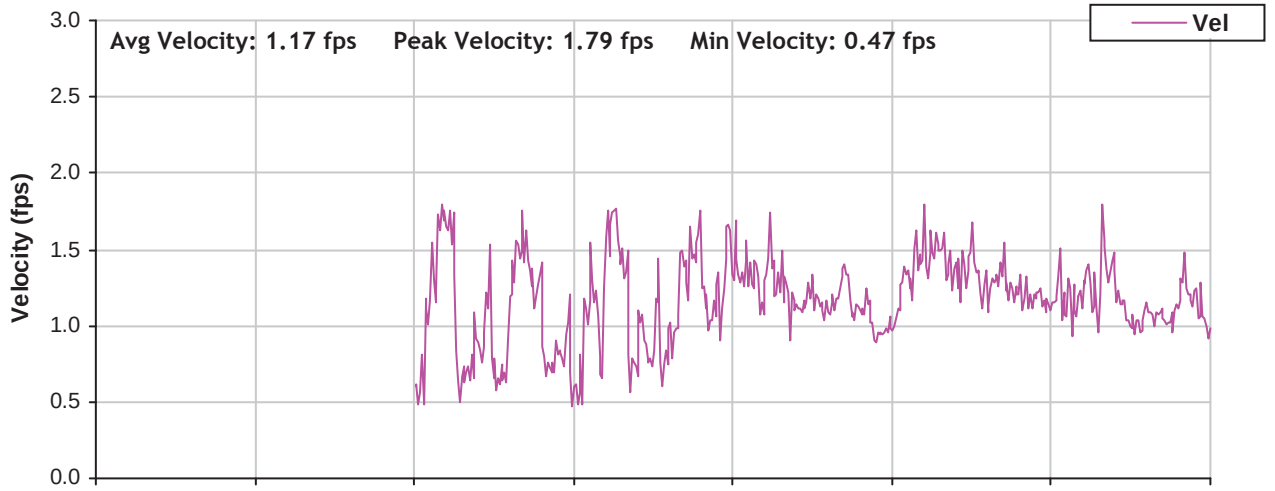
Rainfall:	1.83	*inches*		
Baseline Flow:	6.24	*mgd*		
Peak Flow:	25.96	*mgd*	**PF:**	4.16
Peak I/I Rate:	20.96	*mgd*	**Pk I/I:ADWF:**	3.36
Peak Level:	162.25	*inches*	**d/D Ratio:**	2.46
Total I/I:	50,514,000	*gallons*	**R-Value:**	17.7%
			I/I per ADWF:	4.42 *per in-rain*

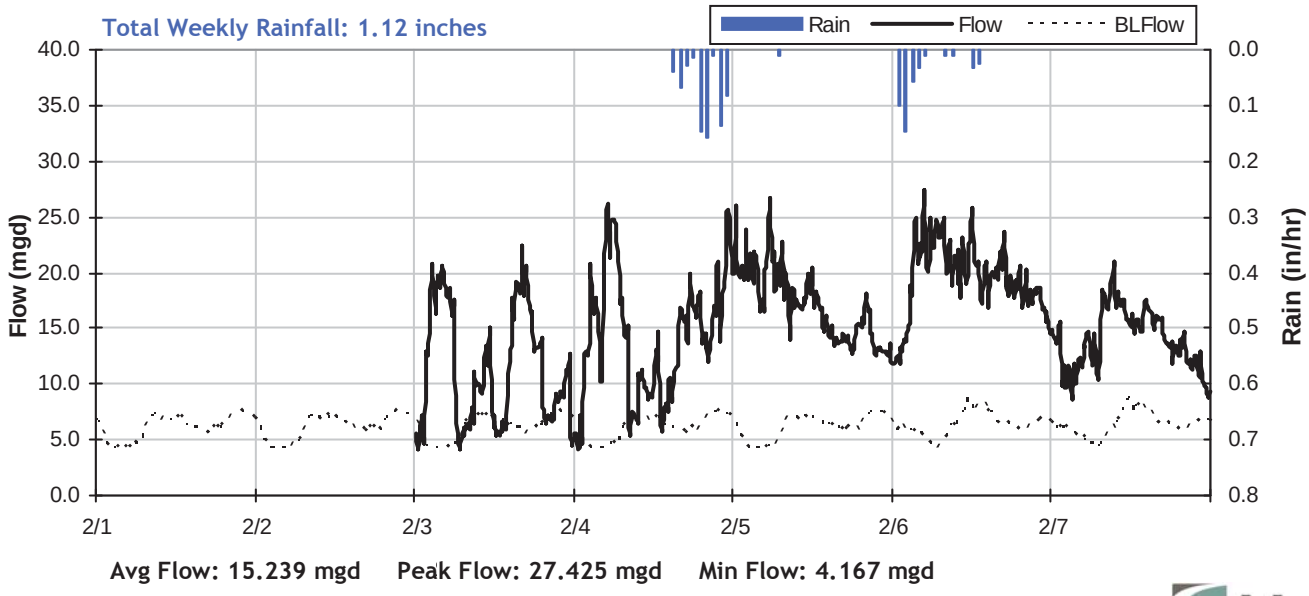
Average Infiltration Rate on 4/14 (% of ADWF): 122.8%

Level, Velocity and Flow
From 2/1/2010 to 2/8/2010

Monitoring Site:
Site 11



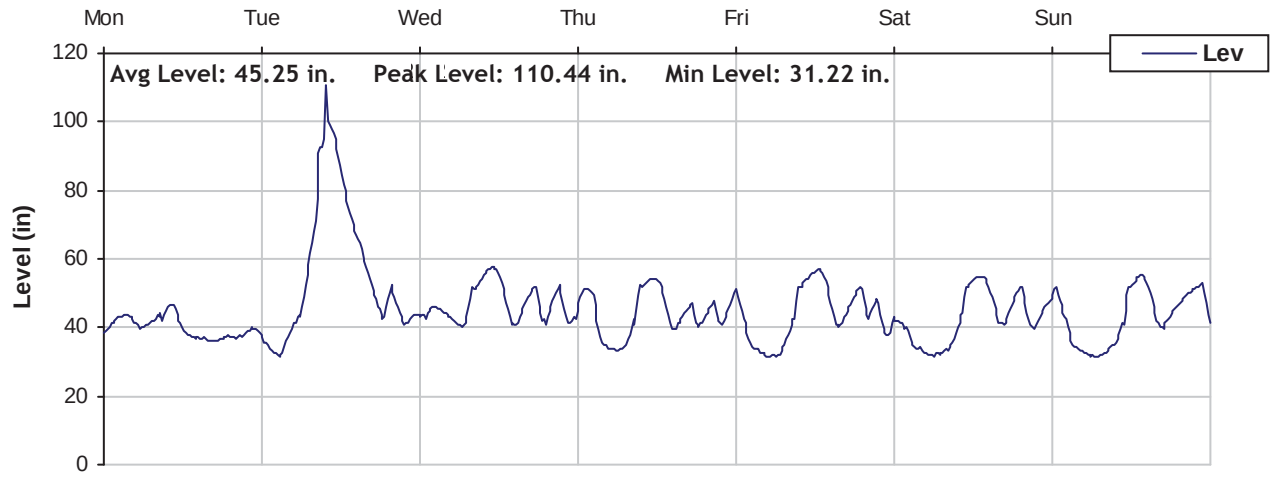


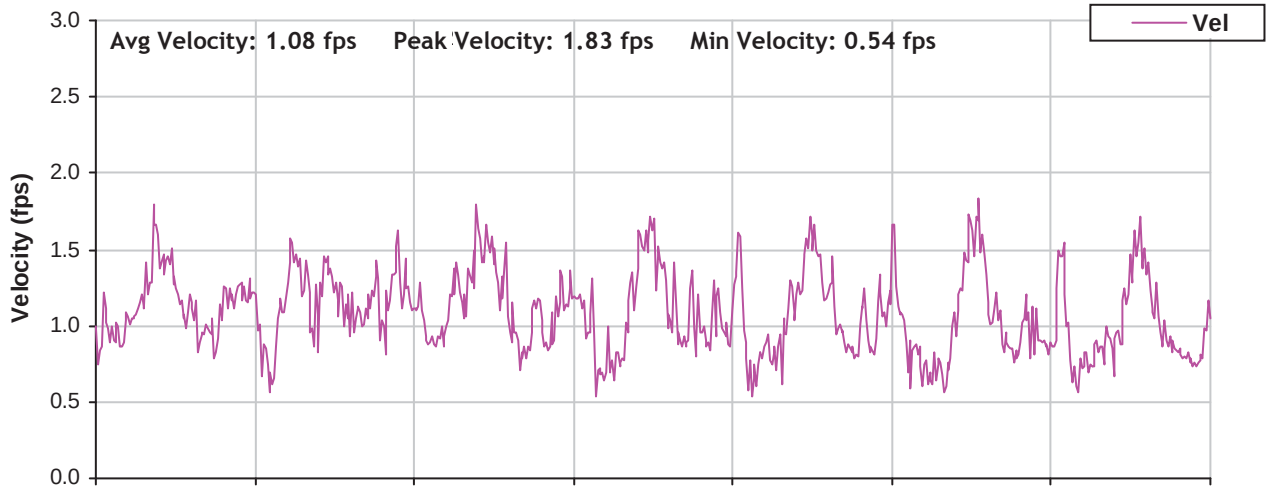


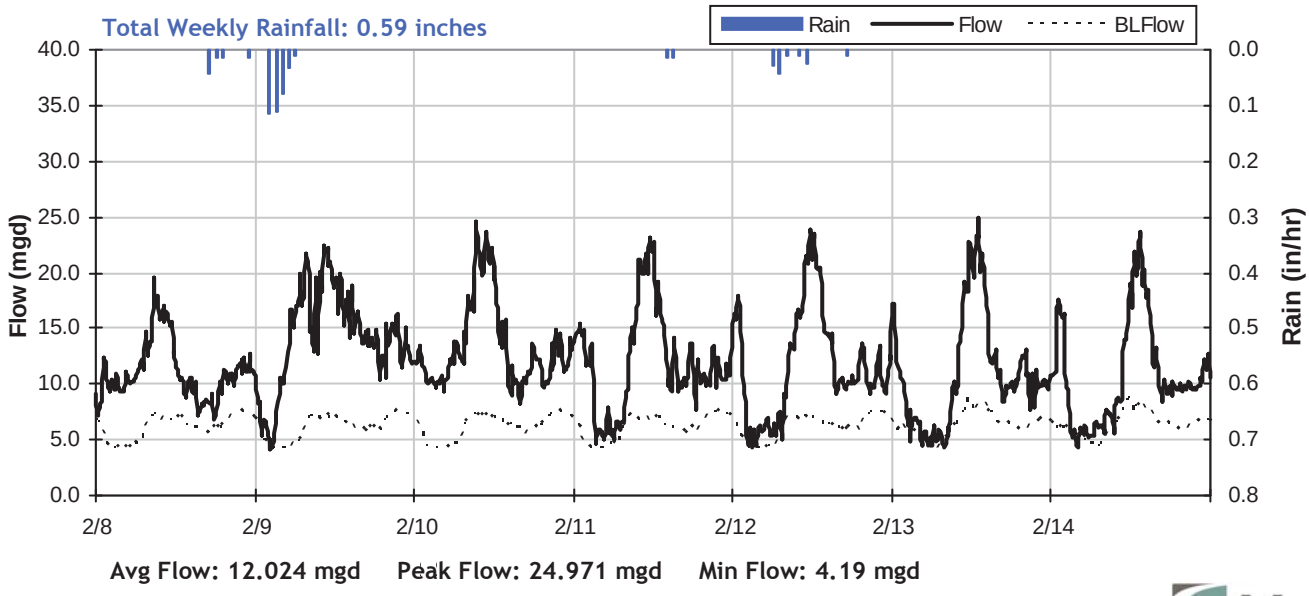
Avg Flow: 15.239 mgd Peak Flow: 27.425 mgd Min Flow: 4.167 mgd

Level, Velocity and Flow
From 2/8/2010 to 2/15/2010

Monitoring Site:
Site 11



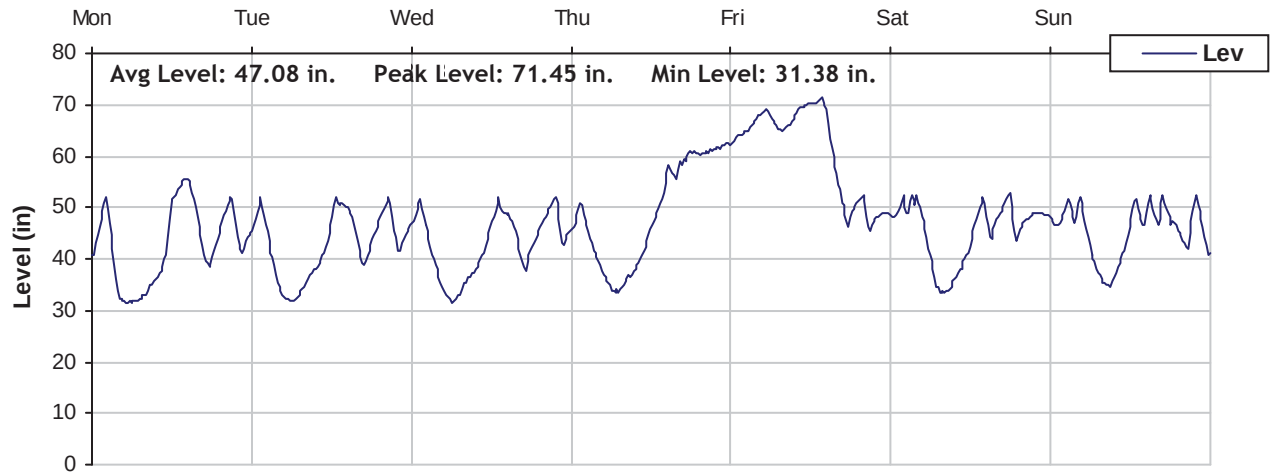


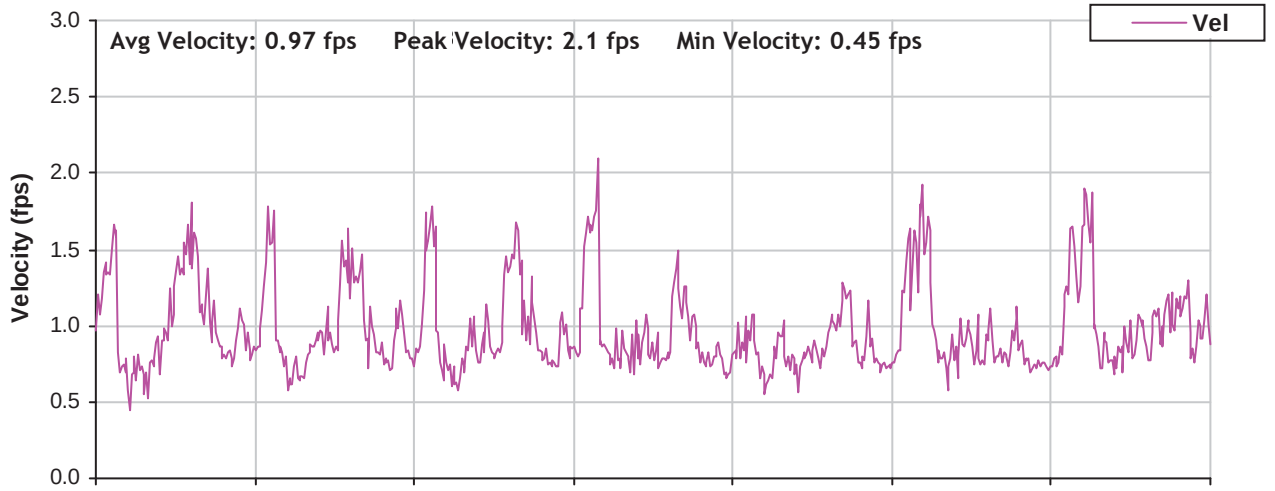


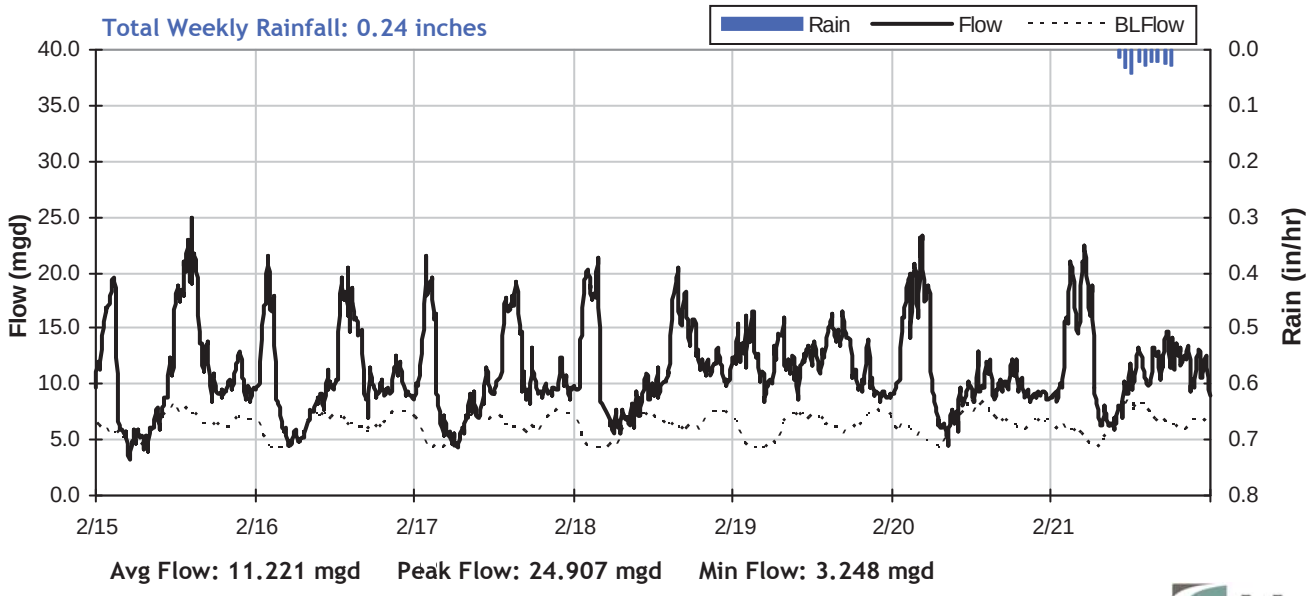
V&A

Level, Velocity and Flow
From 2/15/2010 to 2/22/2010

Monitoring Site:
Site 11



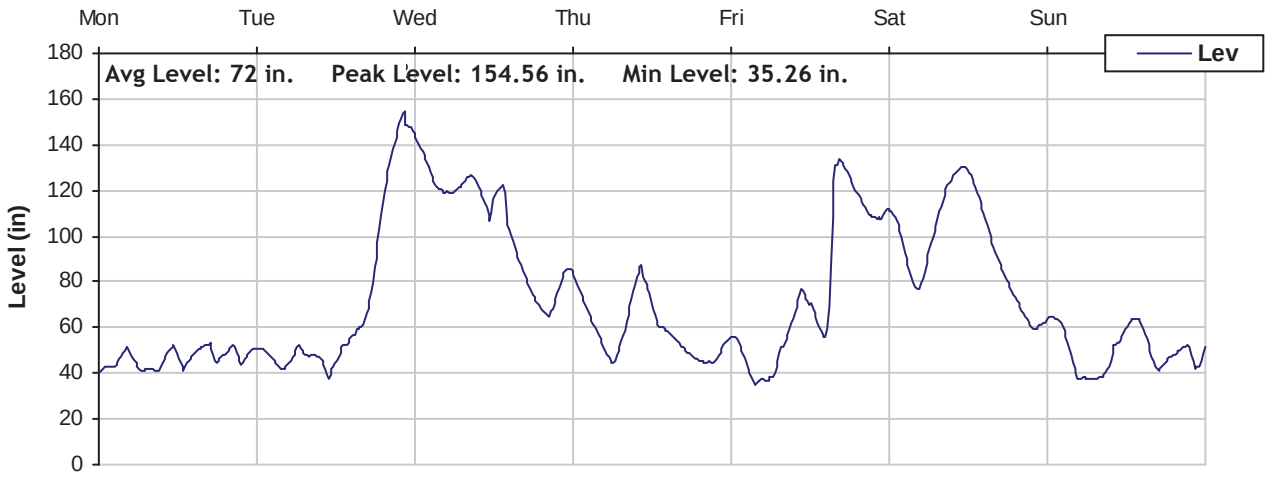


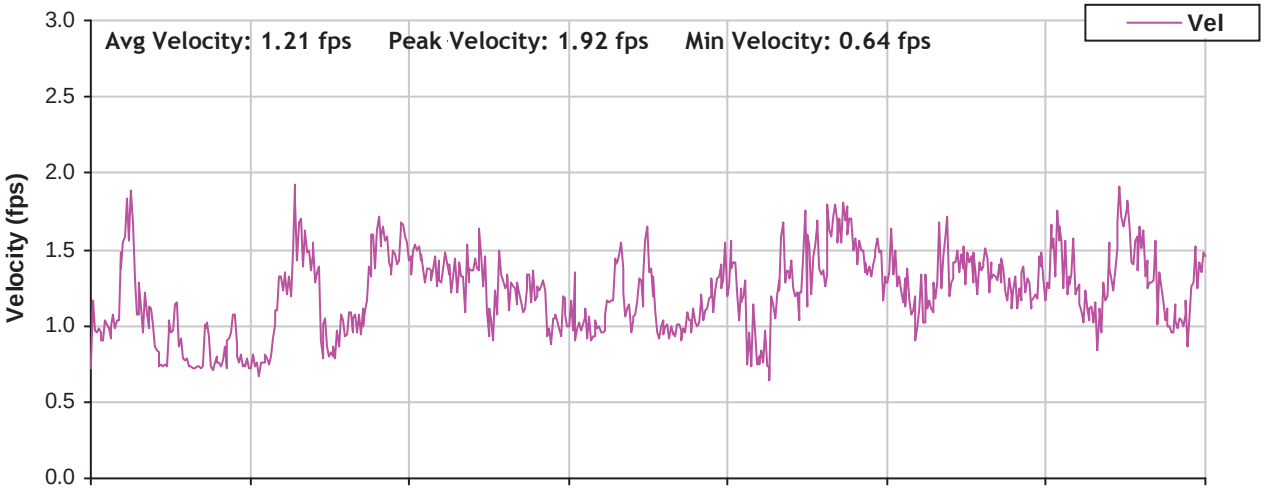


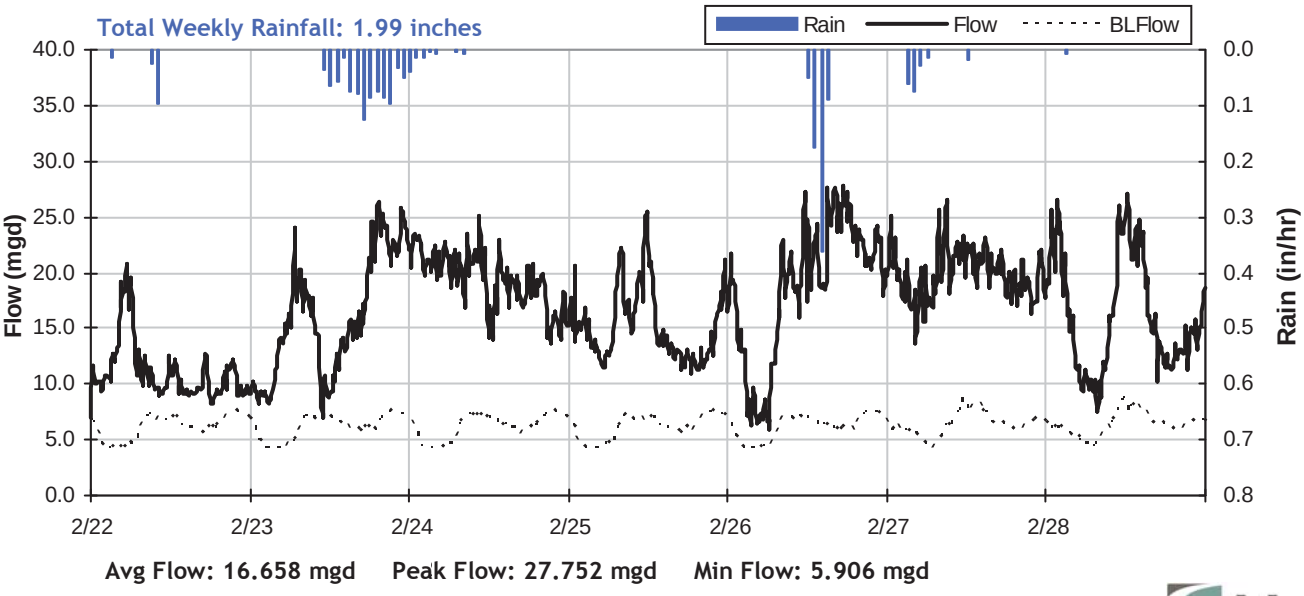
V&A

Level, Velocity and Flow
From 2/22/2010 to 3/1/2010

Monitoring Site:
Site 11





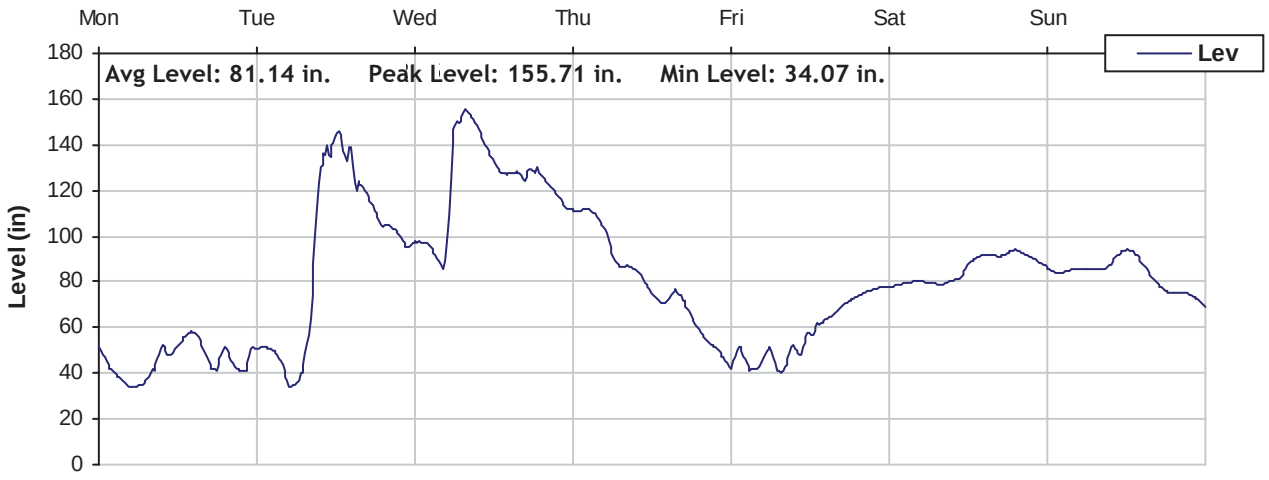


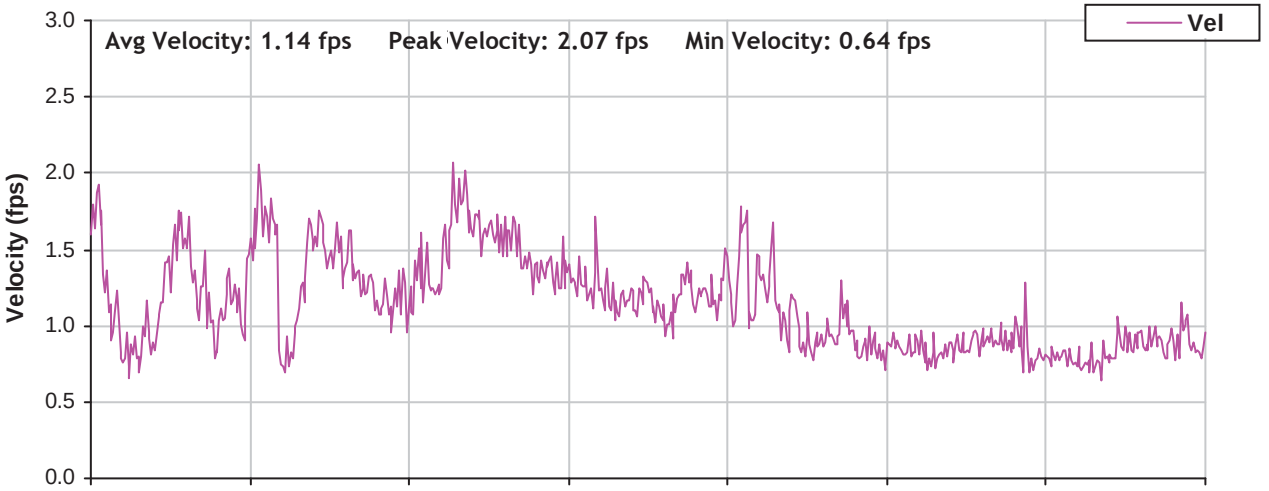
Avg Flow: 16.658 mgd Peak Flow: 27.752 mgd Min Flow: 5.906 mgd

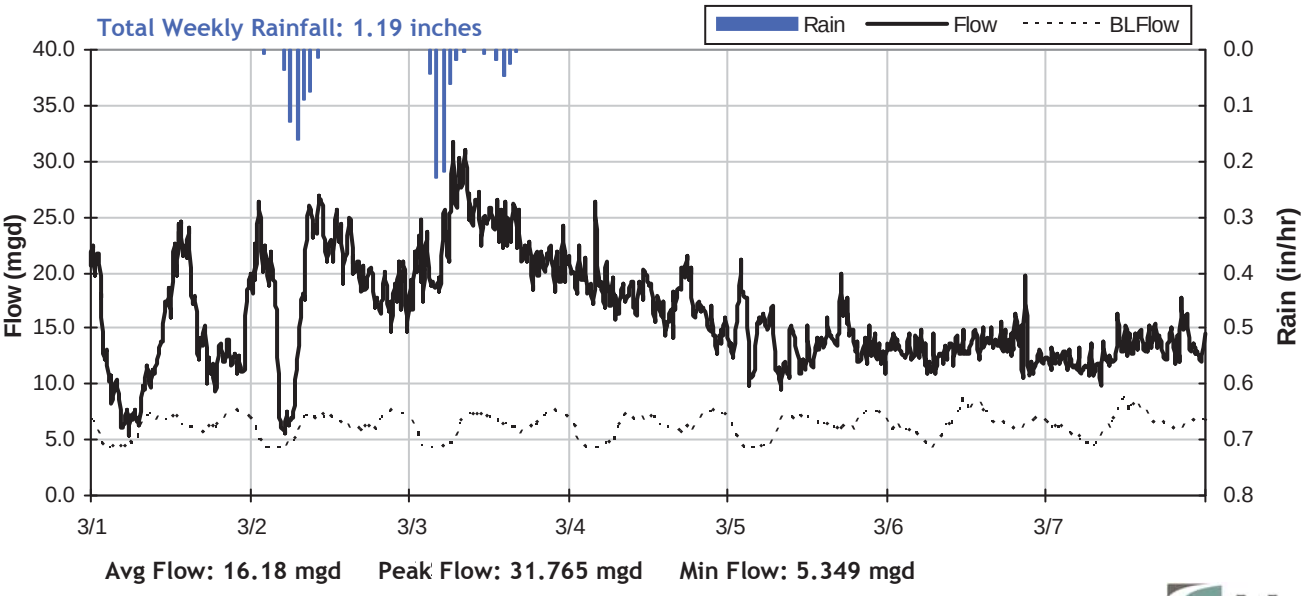
V&A

Level, Velocity and Flow
From 3/1/2010 to 3/8/2010

Monitoring Site:
Site 11



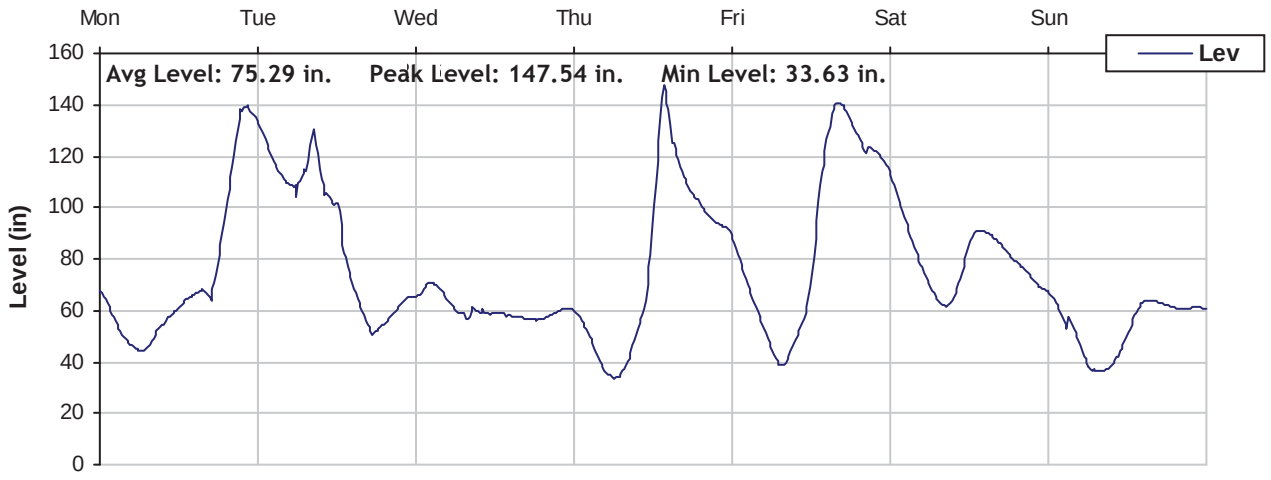


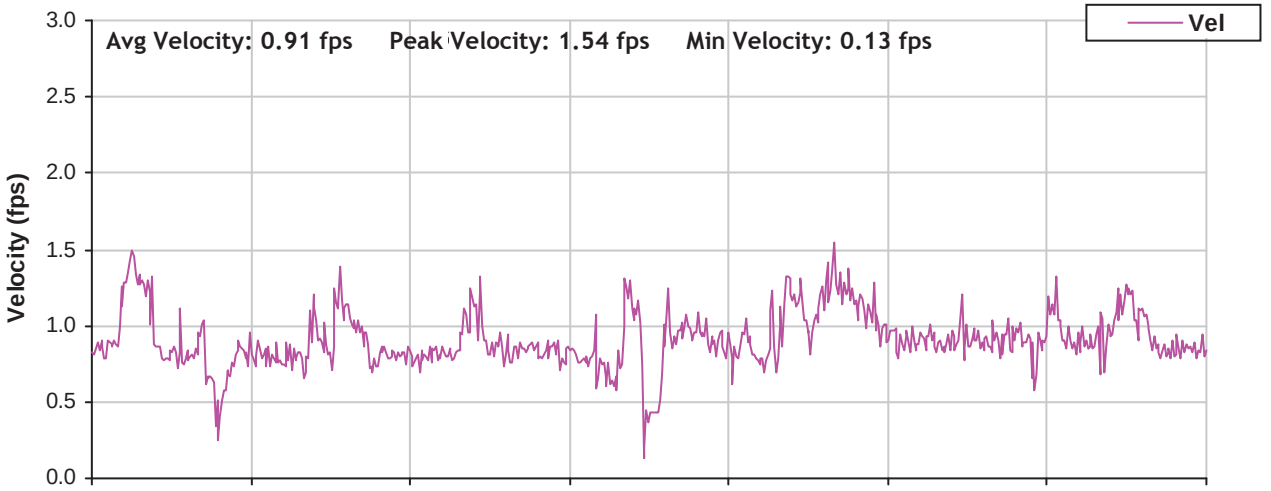


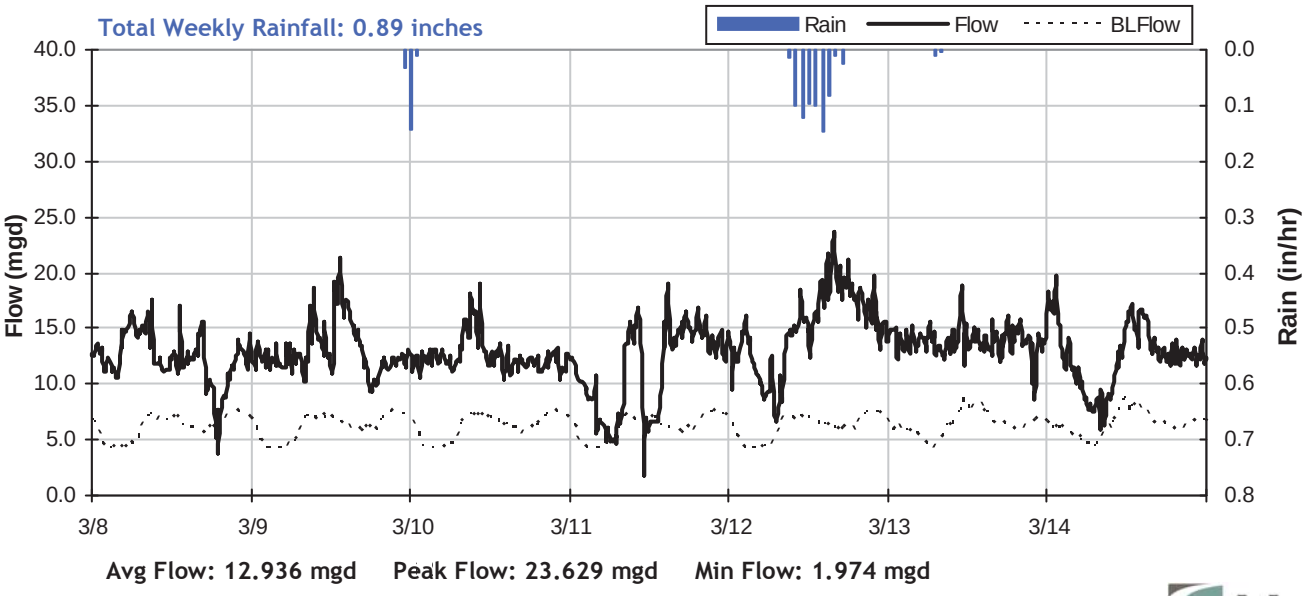
Avg Flow: 16.18 mgd Peak Flow: 31.765 mgd Min Flow: 5.349 mgd

Level, Velocity and Flow
From 3/8/2010 to 3/15/2010

Monitoring Site:
Site 11



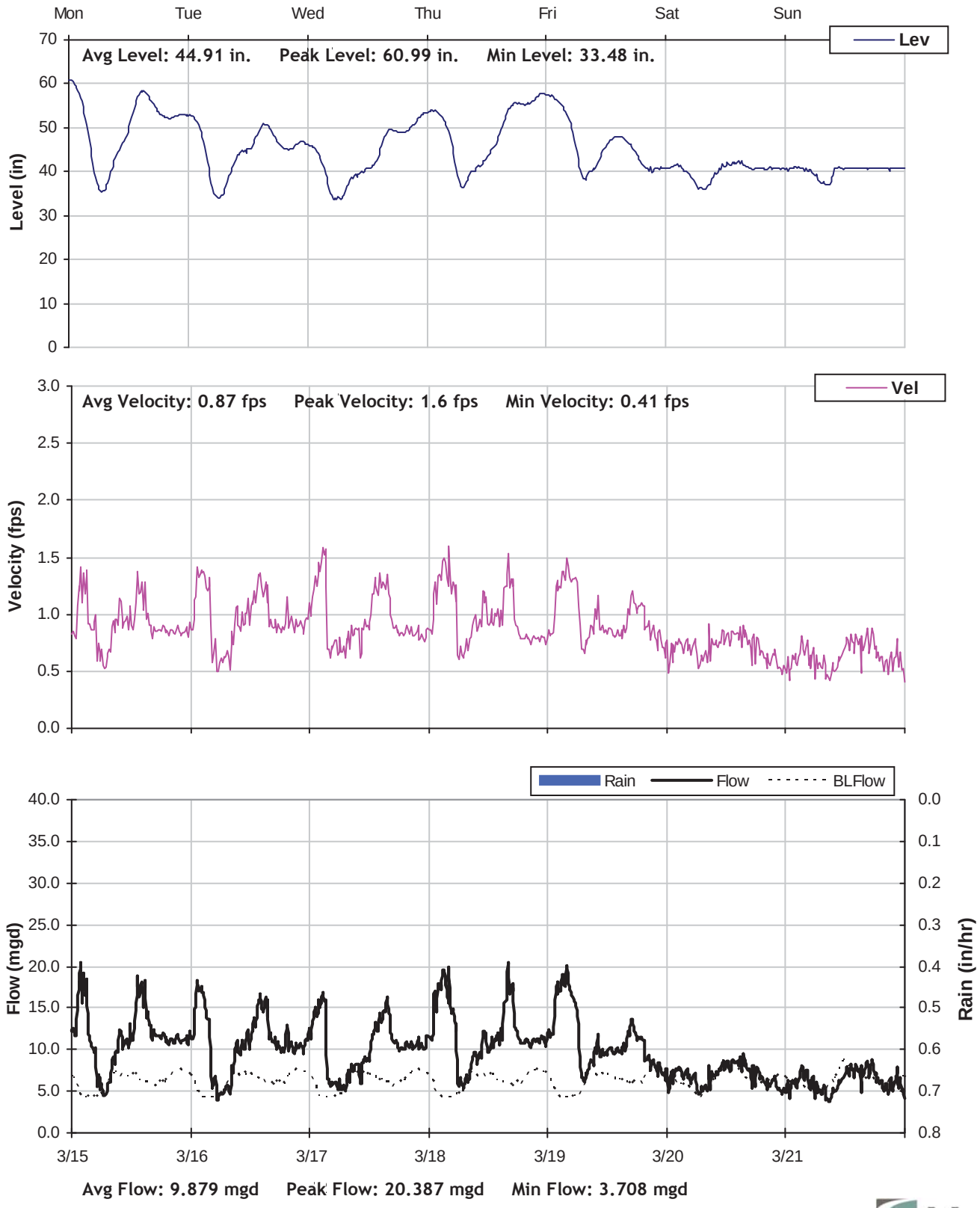




Avg Flow: 12.936 mgd Peak Flow: 23.629 mgd Min Flow: 1.974 mgd

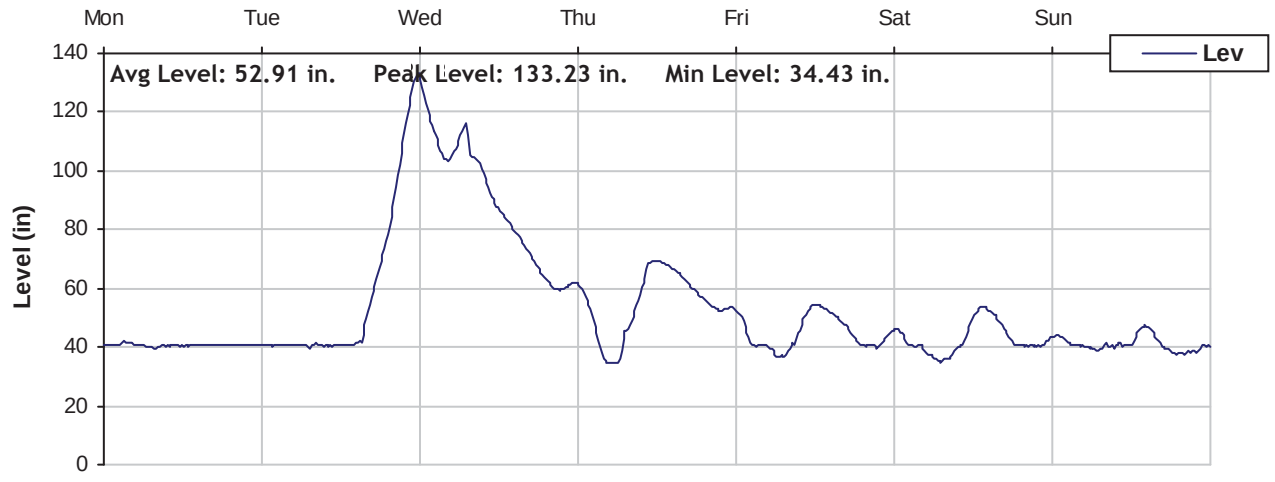
Level, Velocity and Flow
From 3/15/2010 to 3/22/2010

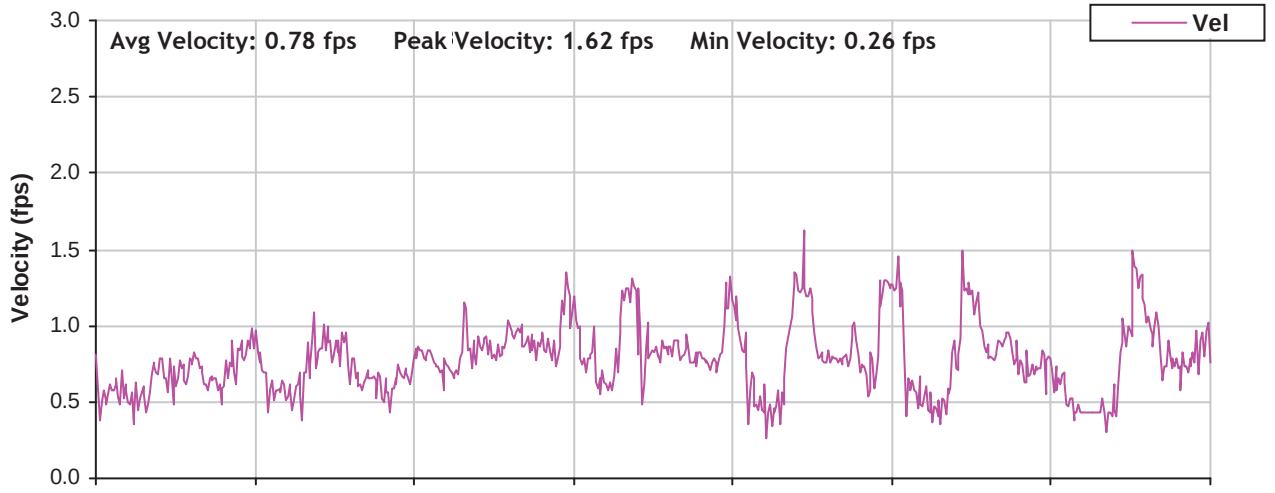
Monitoring Site:
Site 11

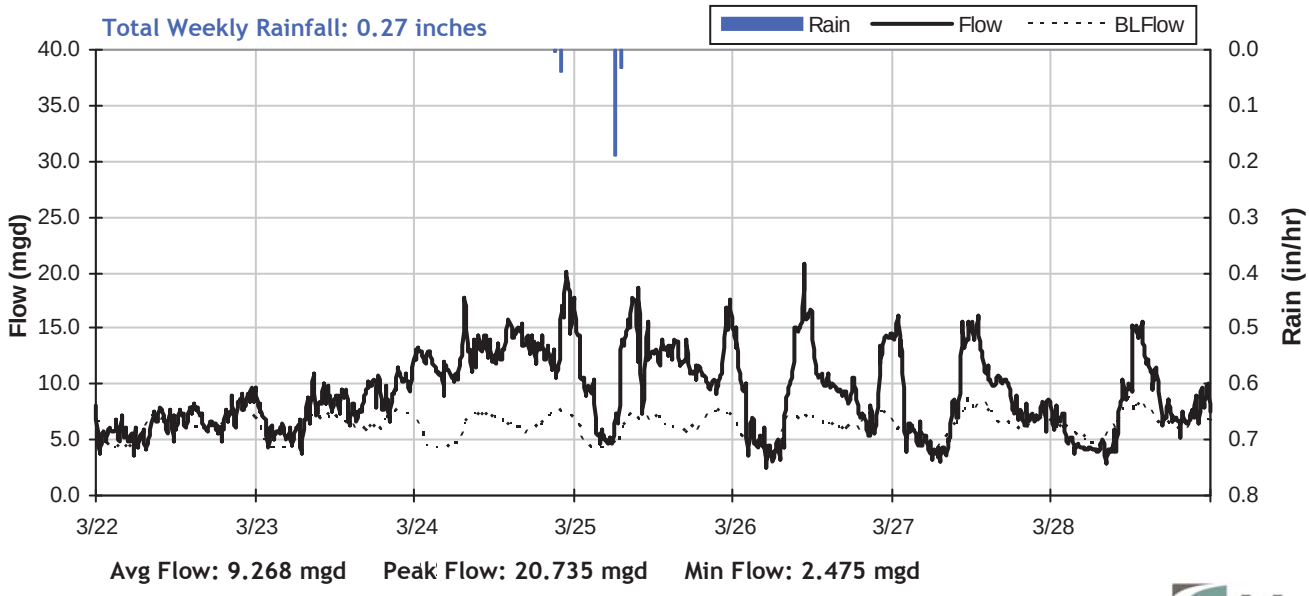


Level, Velocity and Flow
From 3/22/2010 to 3/29/2010

Monitoring Site:
Site 11

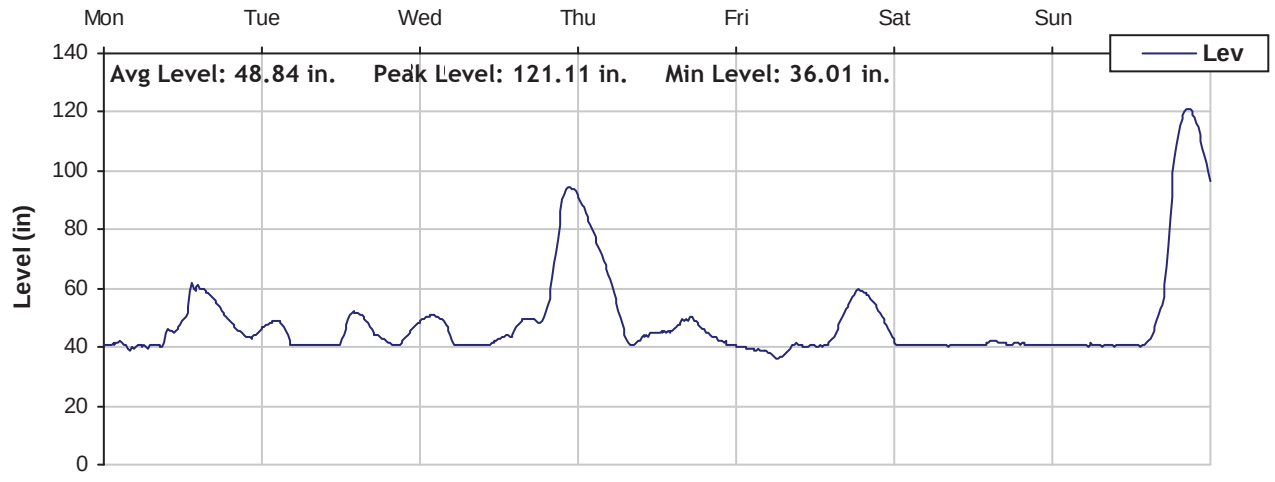


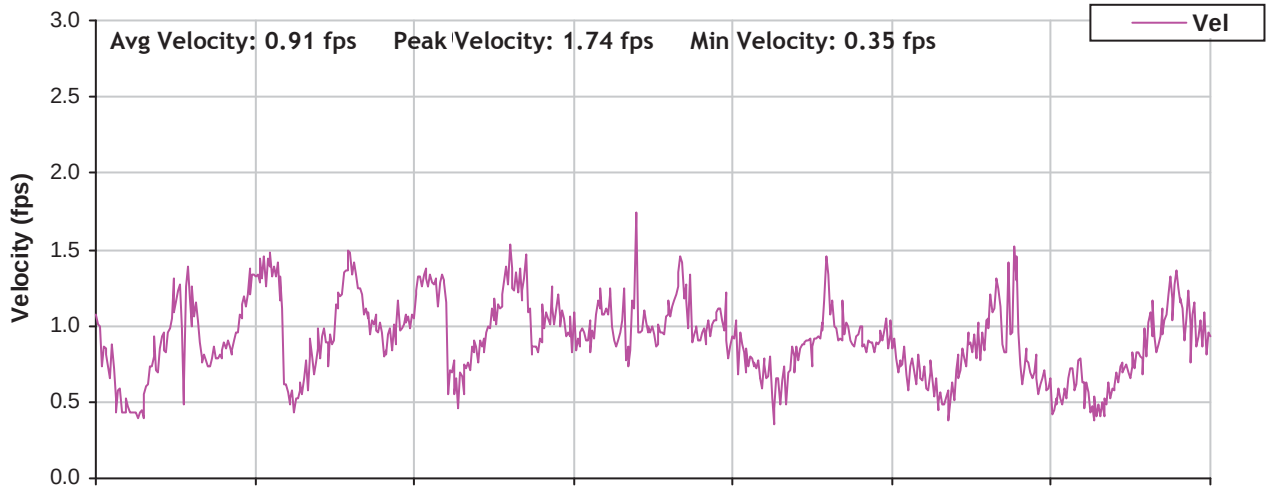


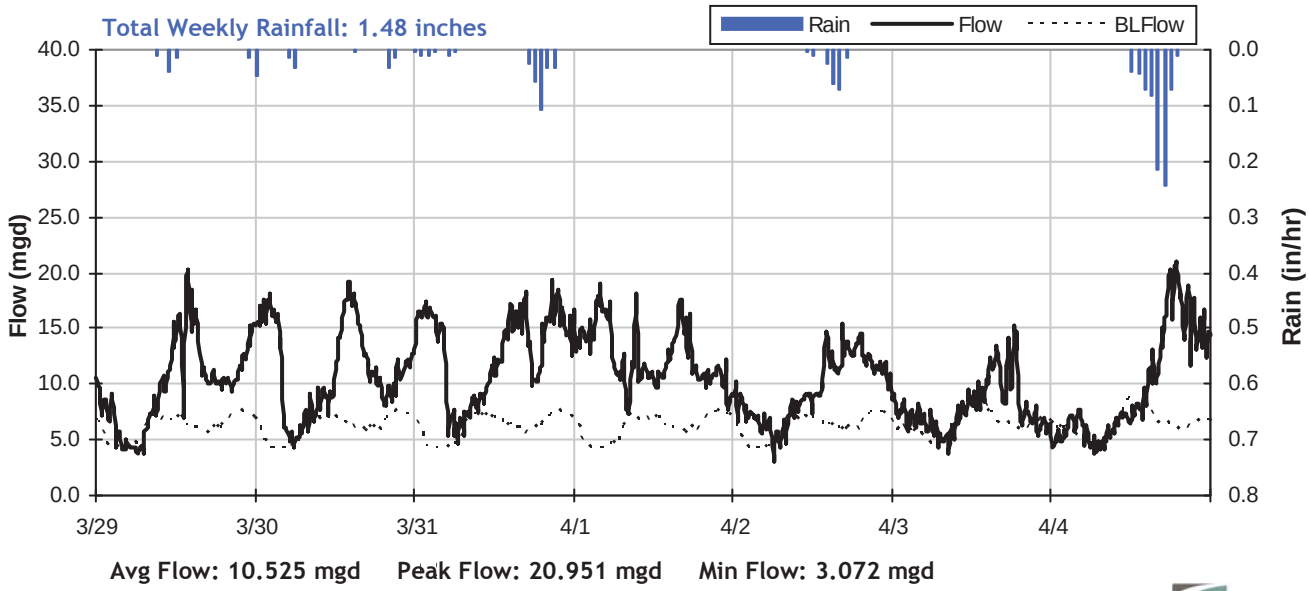


Level, Velocity and Flow
From 3/29/2010 to 4/5/2010

Monitoring Site:
Site 11





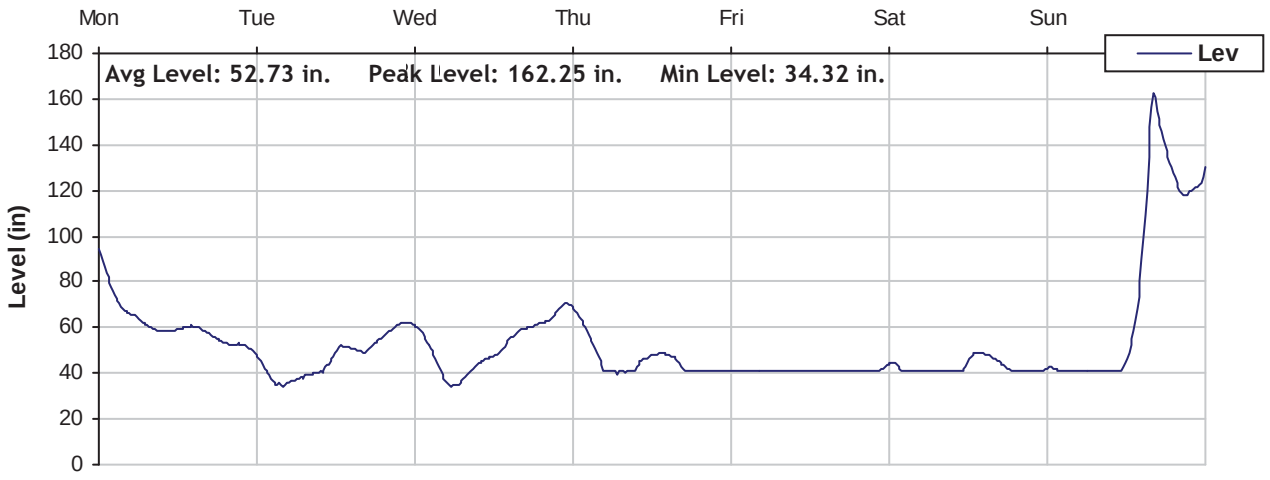


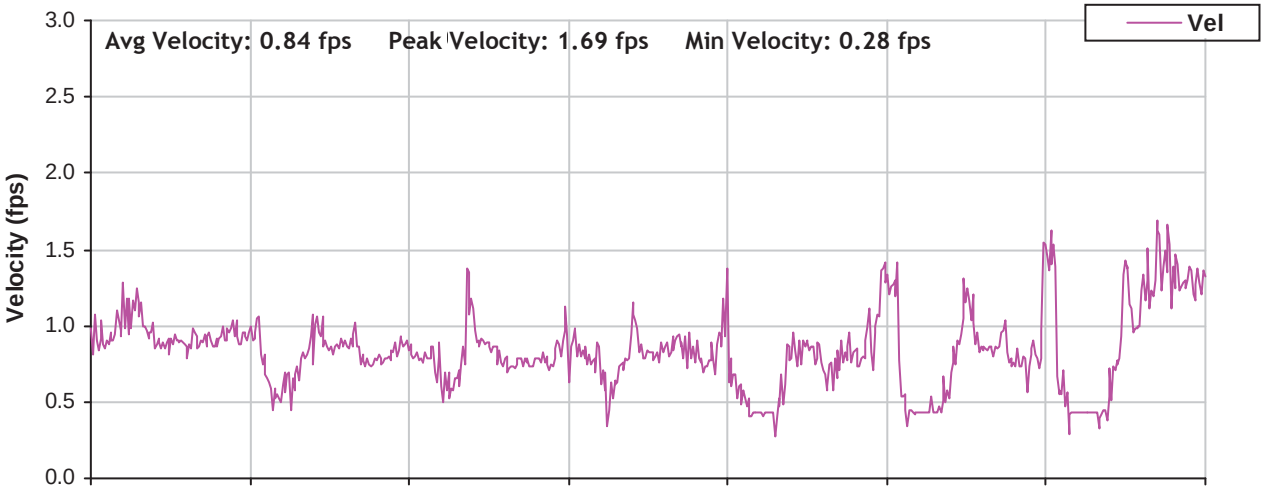
Avg Flow: 10.525 mgd Peak Flow: 20.951 mgd Min Flow: 3.072 mgd

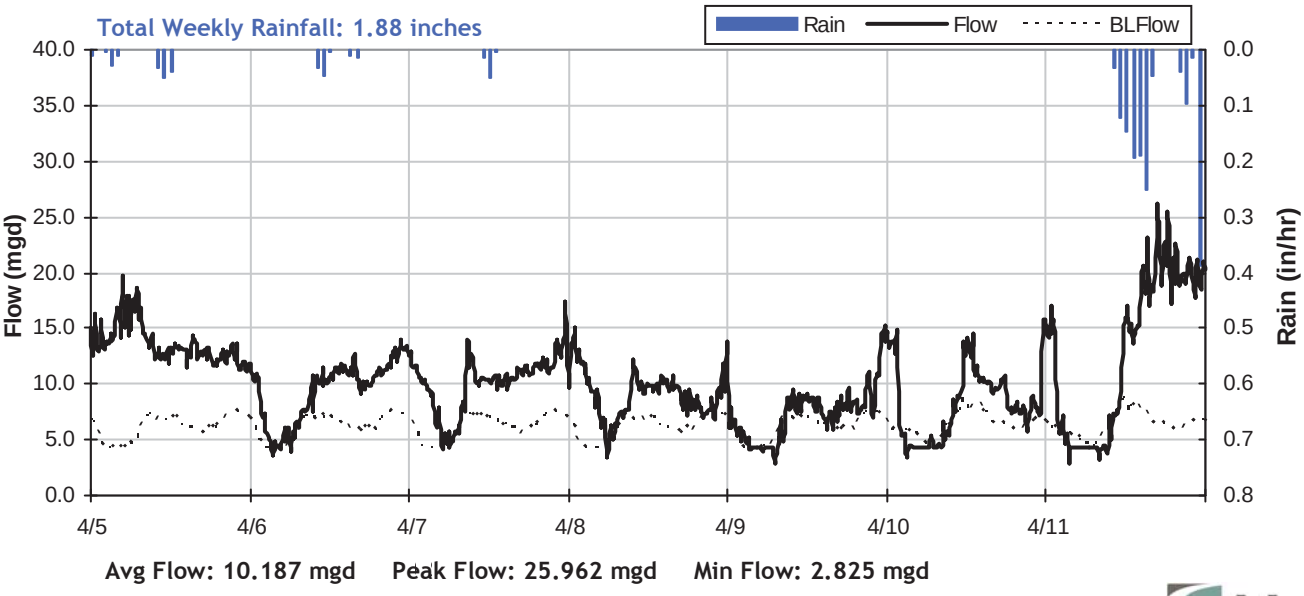
V&A

Level, Velocity and Flow
From 4/5/2010 to 4/12/2010

Monitoring Site:
Site 11

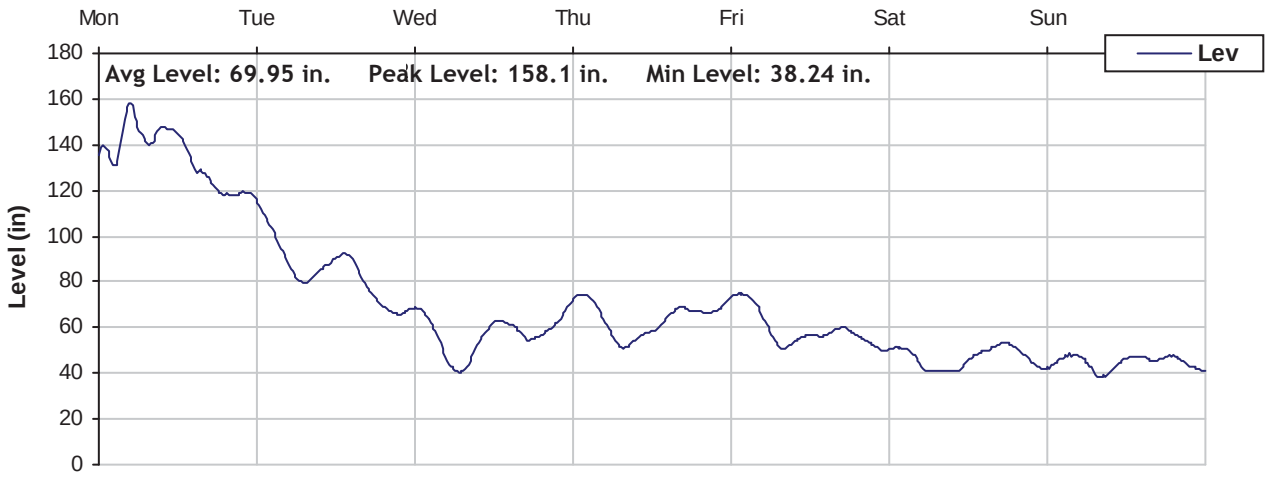


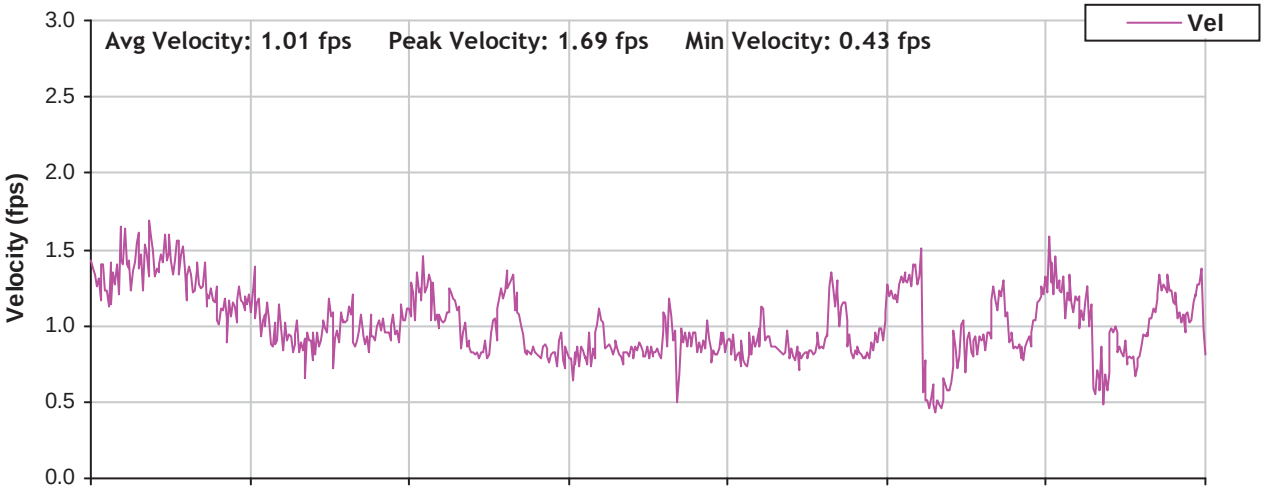


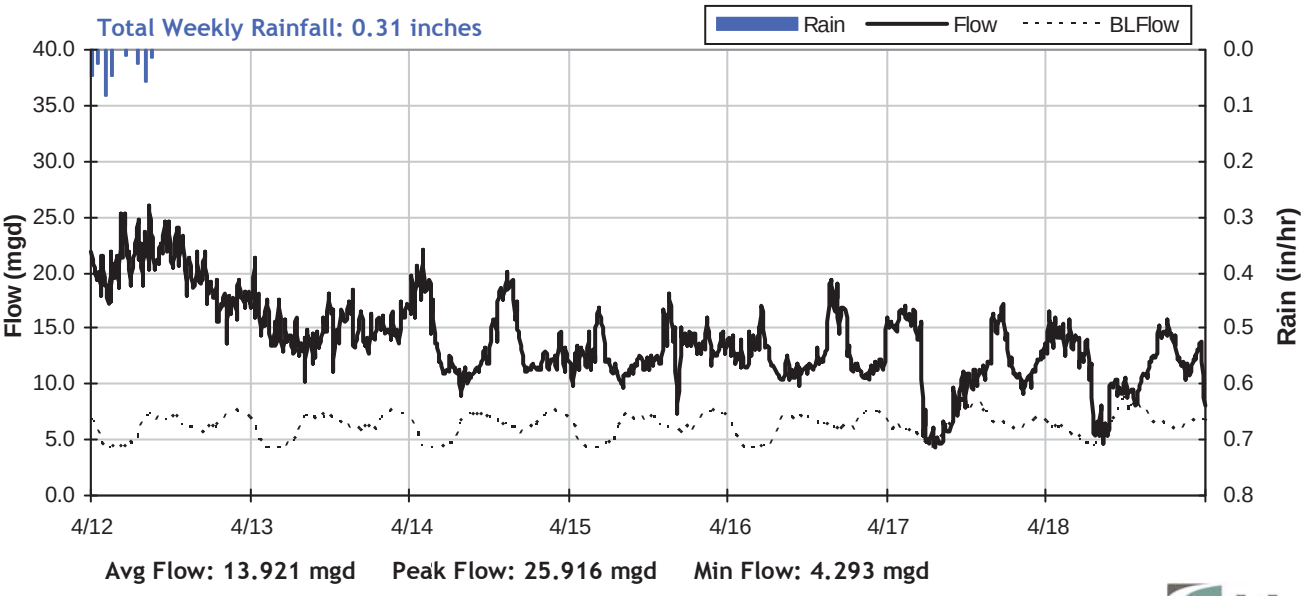


Level, Velocity and Flow
From 4/12/2010 to 4/19/2010

Monitoring Site:
Site 11



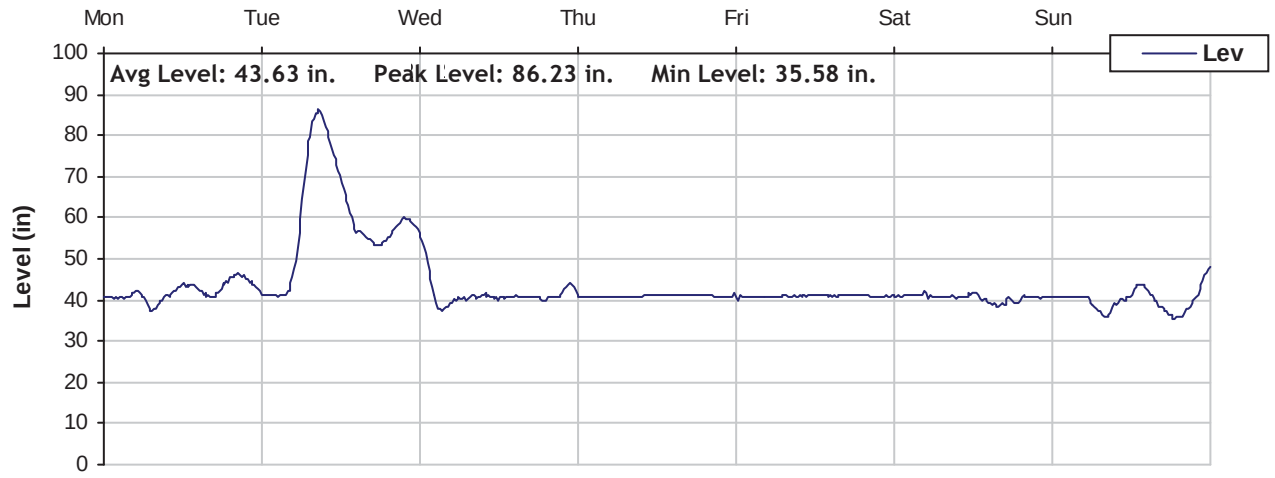


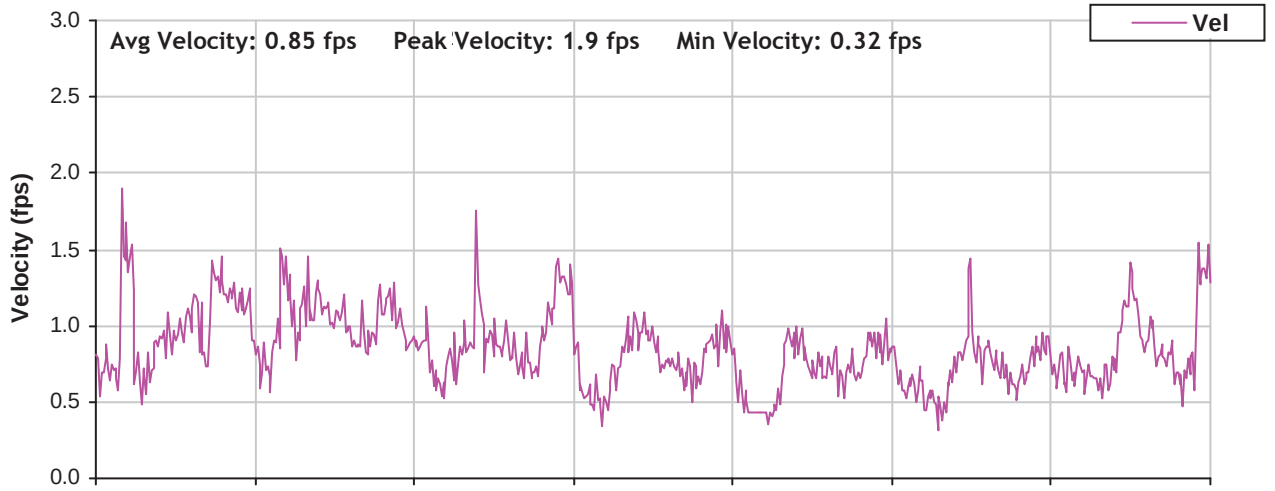


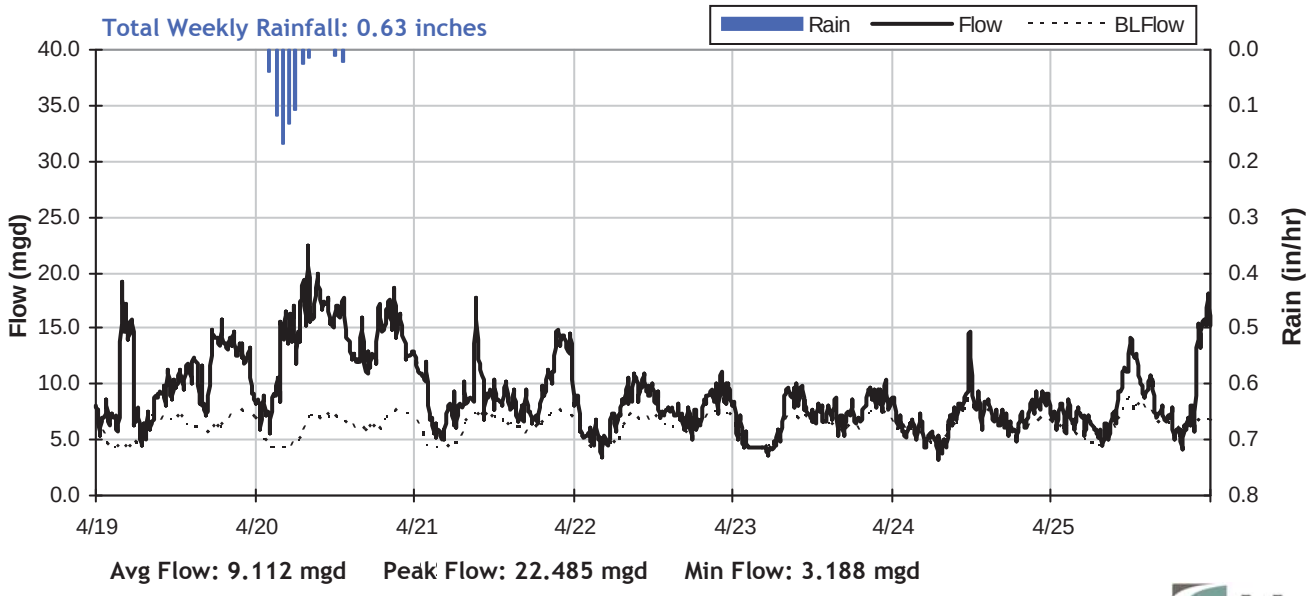
Avg Flow: 13.921 mgd Peak Flow: 25.916 mgd Min Flow: 4.293 mgd

Level, Velocity and Flow
From 4/19/2010 to 4/26/2010

Monitoring Site:
Site 11



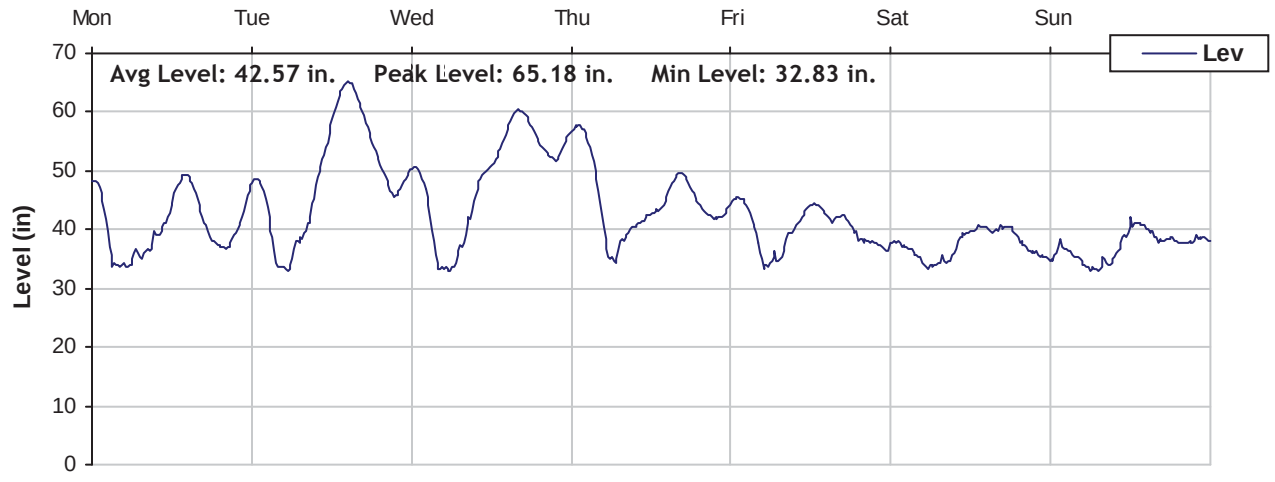


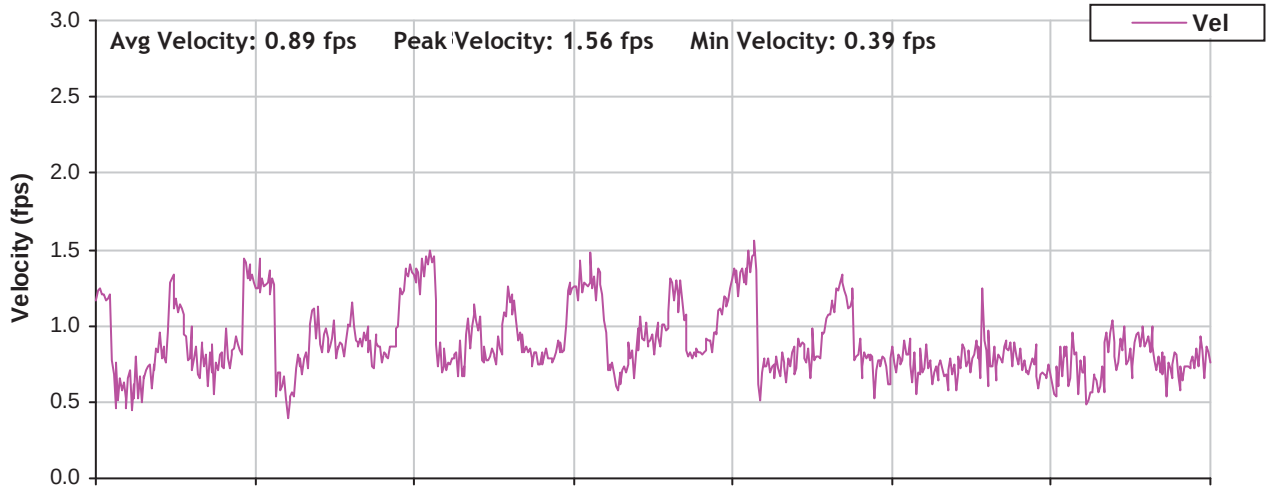


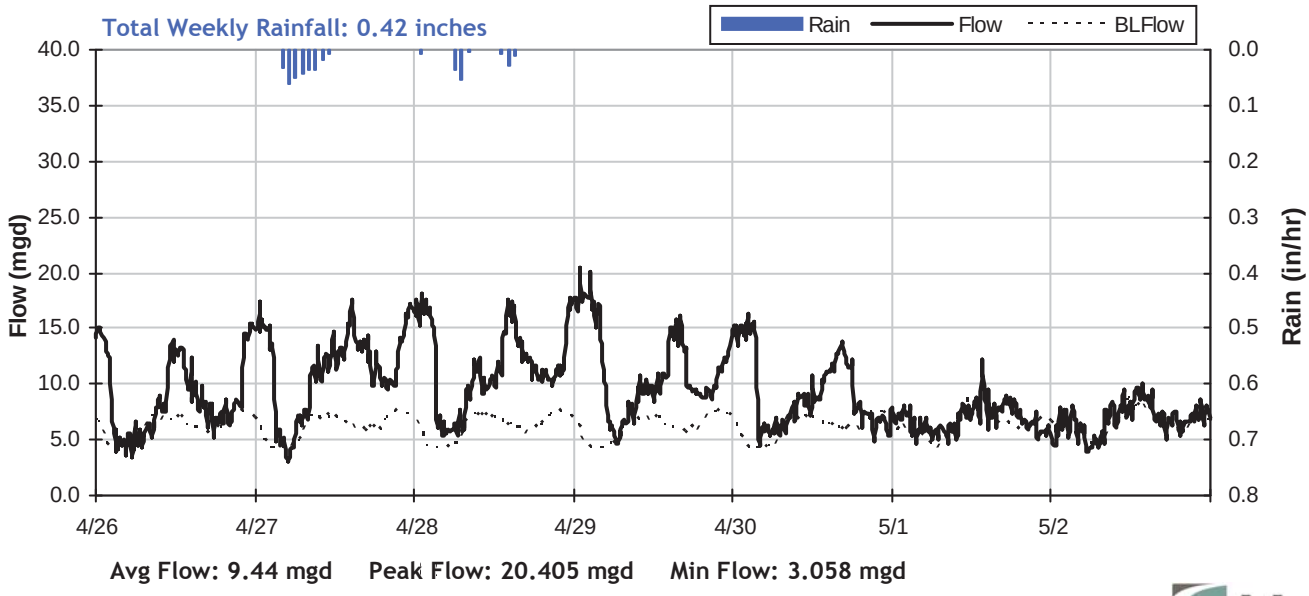
Avg Flow: 9.112 mgd Peak Flow: 22.485 mgd Min Flow: 3.188 mgd

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 11



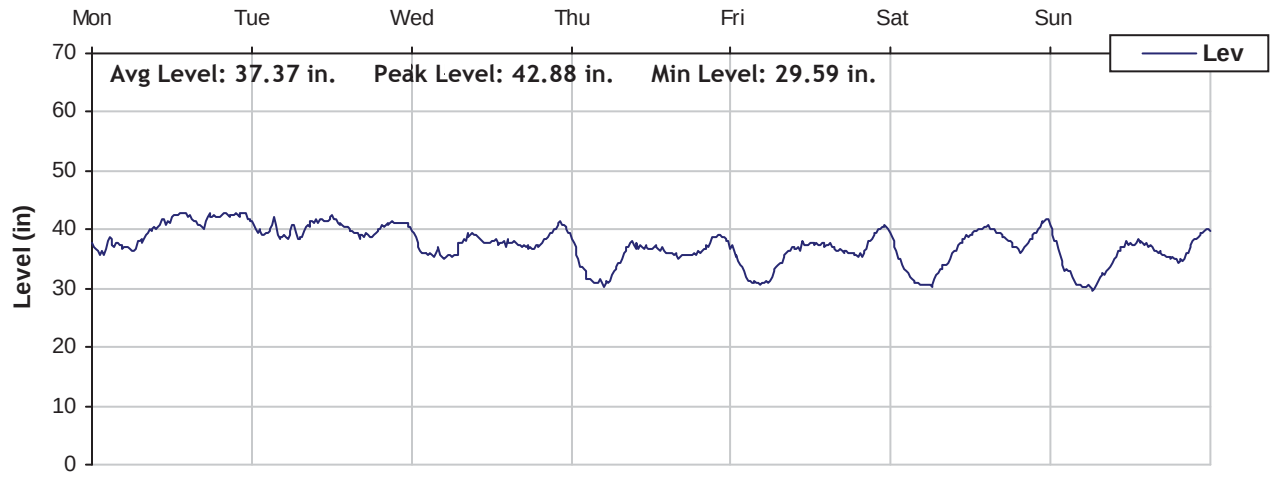


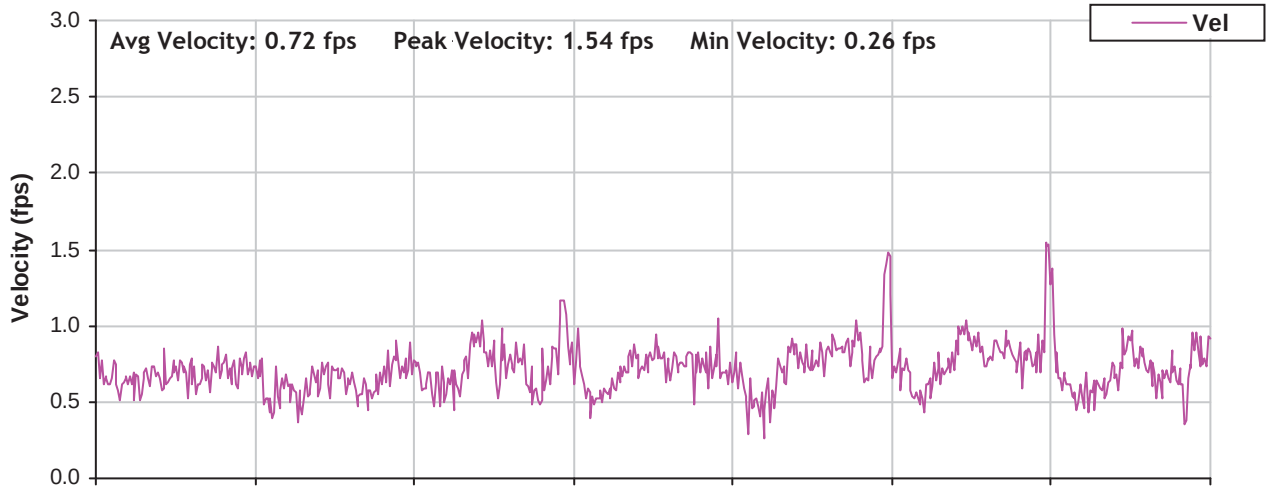


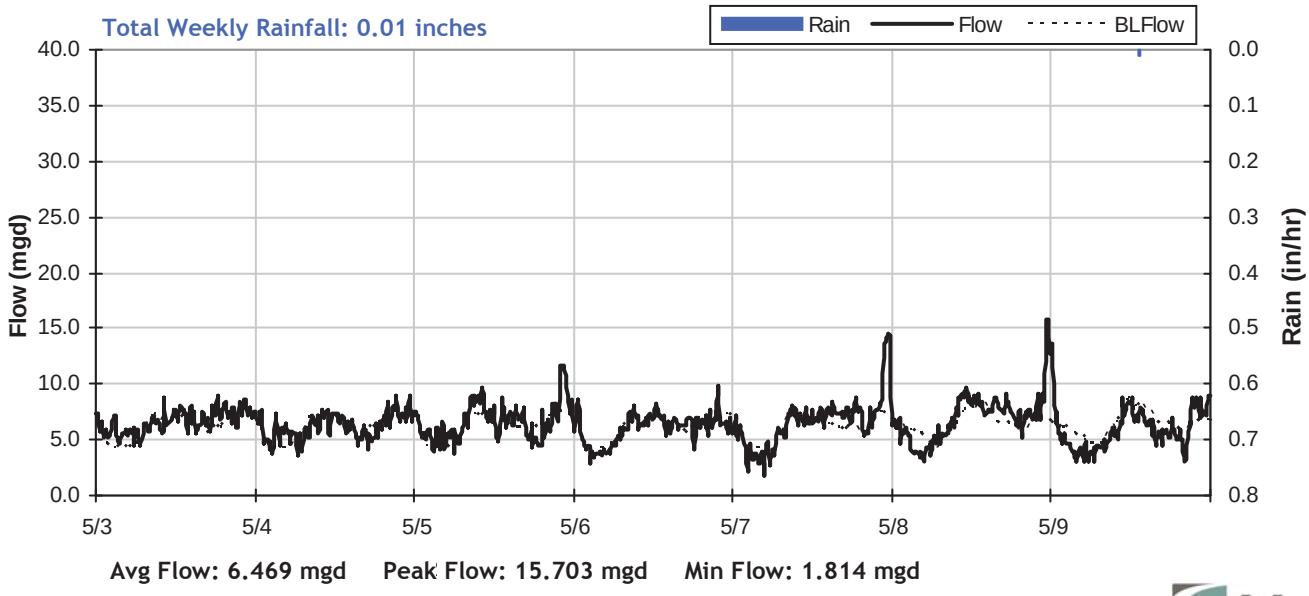
Avg Flow: 9.44 mgd Peak Flow: 20.405 mgd Min Flow: 3.058 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 11





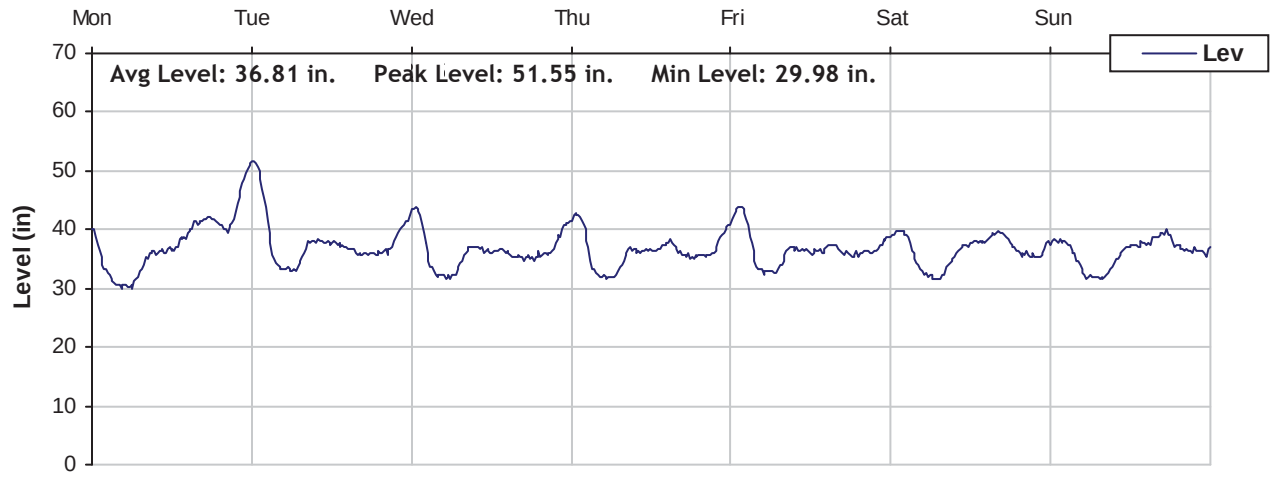


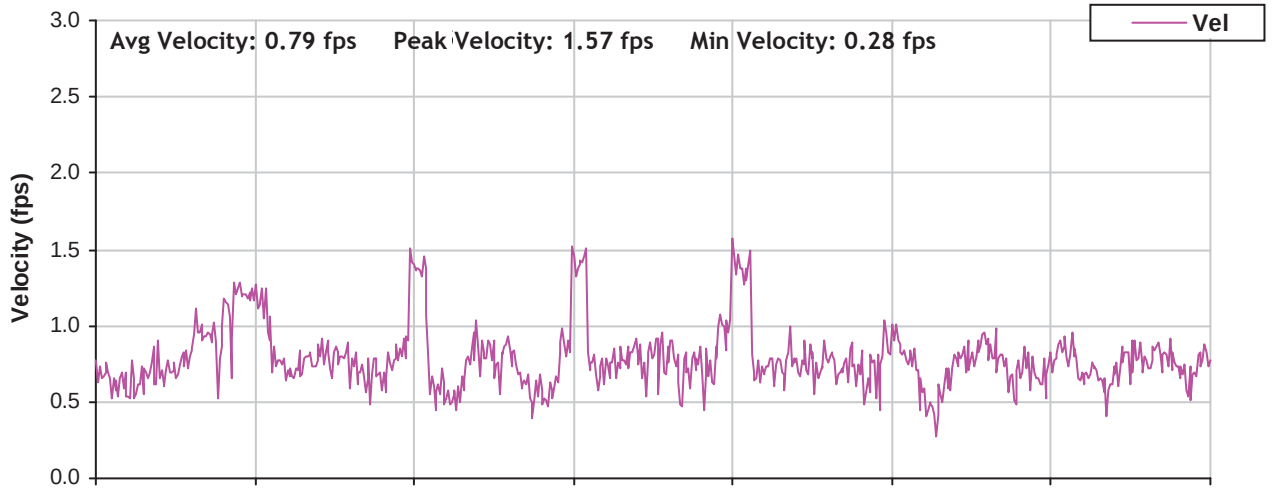
Avg Flow: 6.469 mgd Peak Flow: 15.703 mgd Min Flow: 1.814 mgd

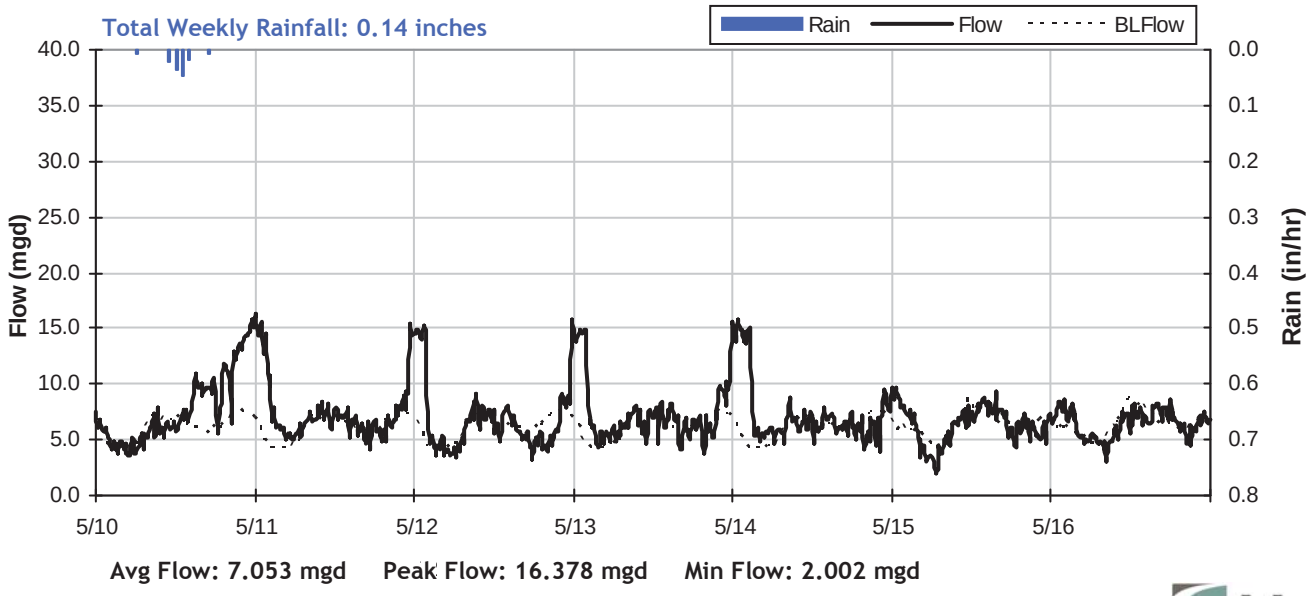
V&A

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 11

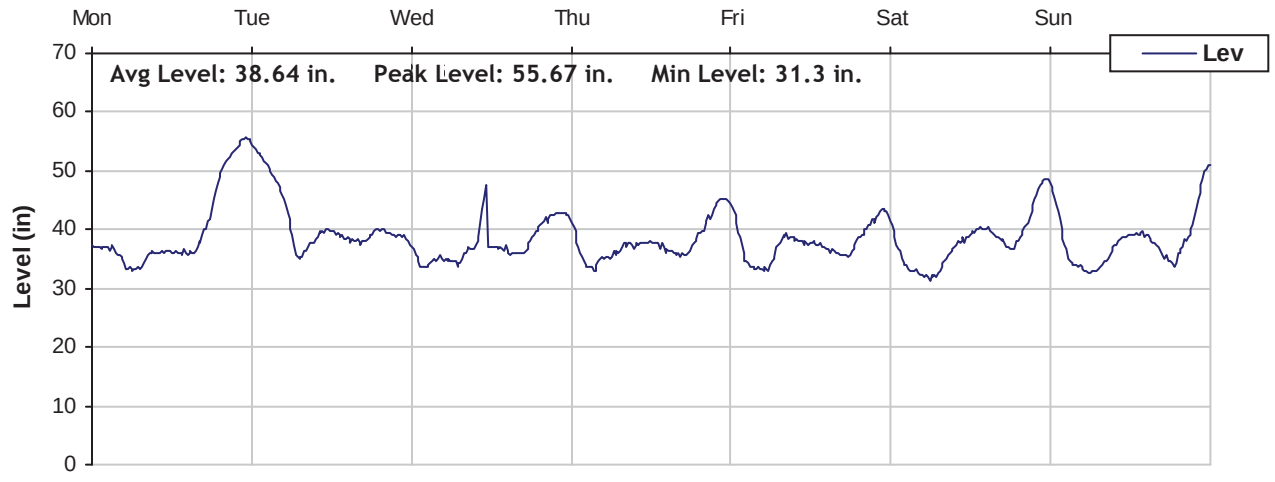


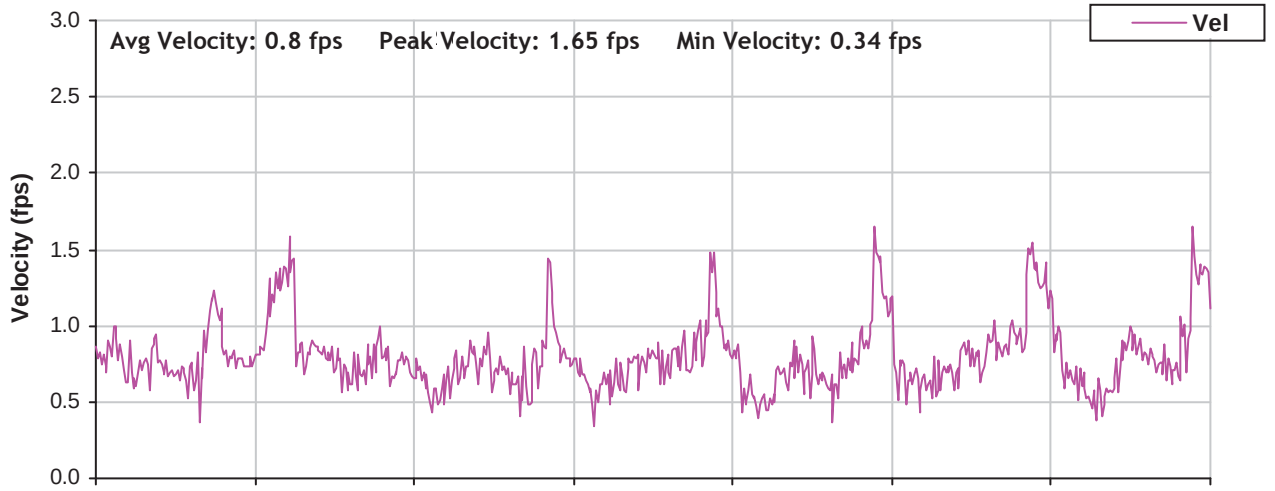


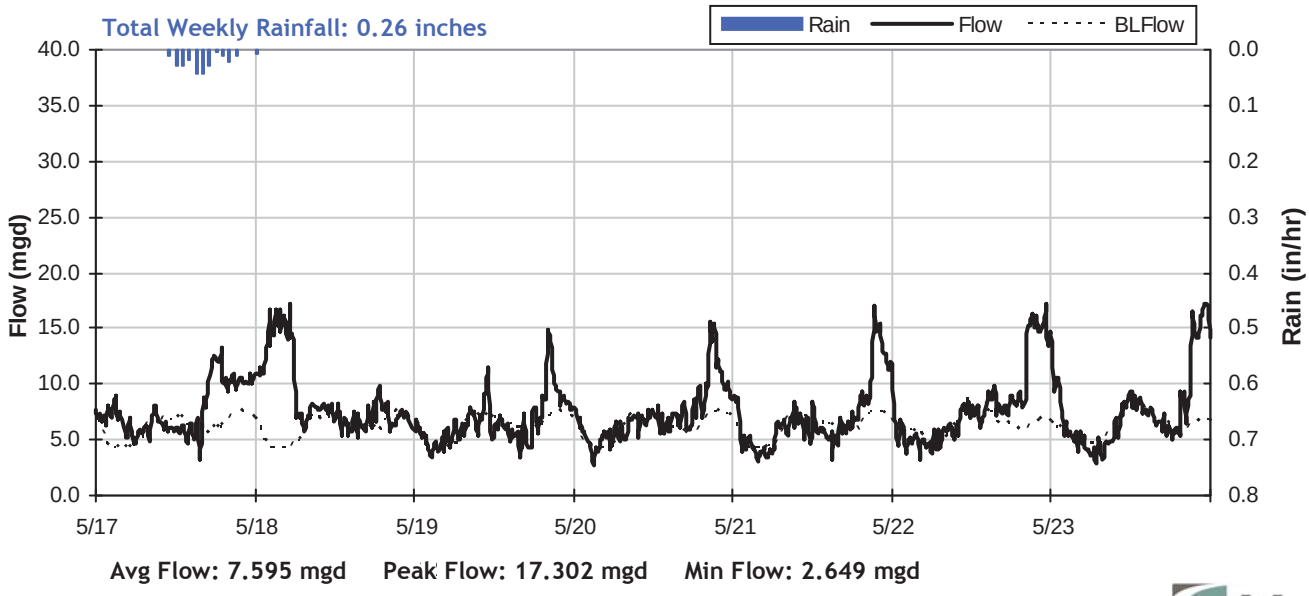


Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 11



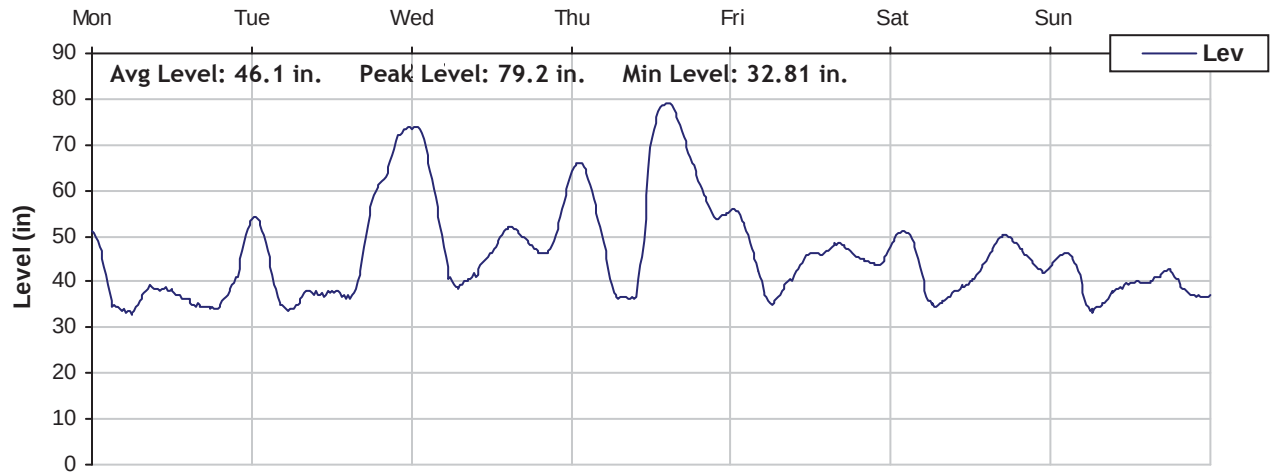


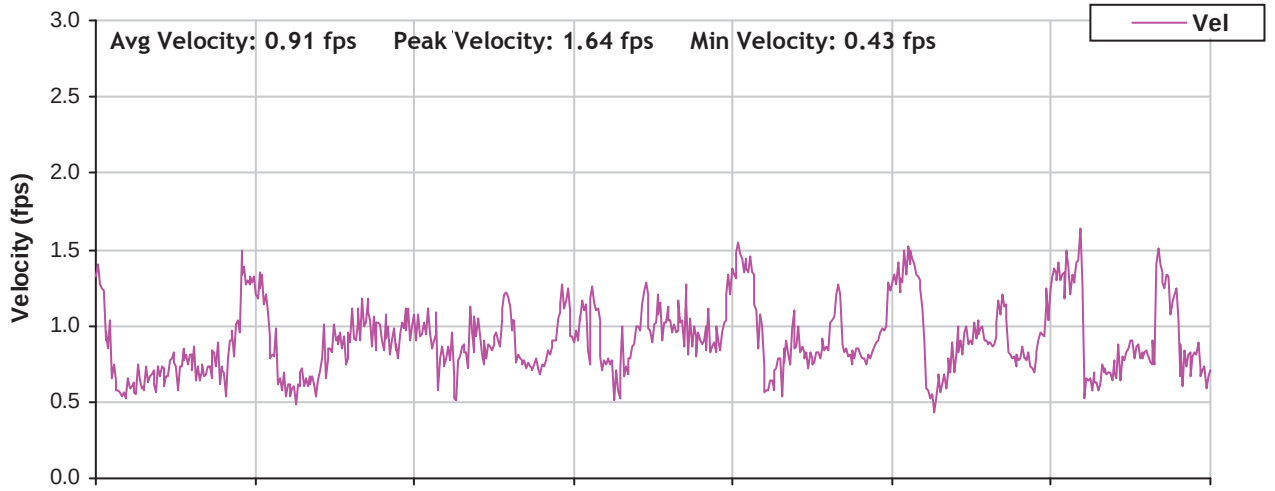


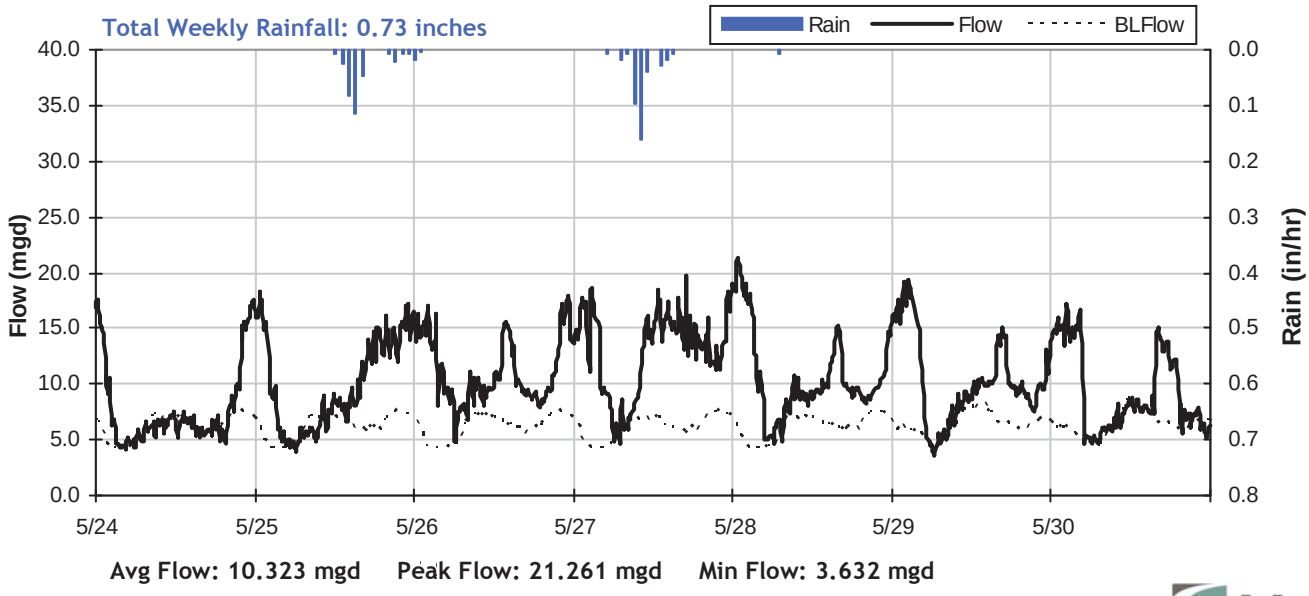
Avg Flow: 7.595 mgd Peak Flow: 17.302 mgd Min Flow: 2.649 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 11



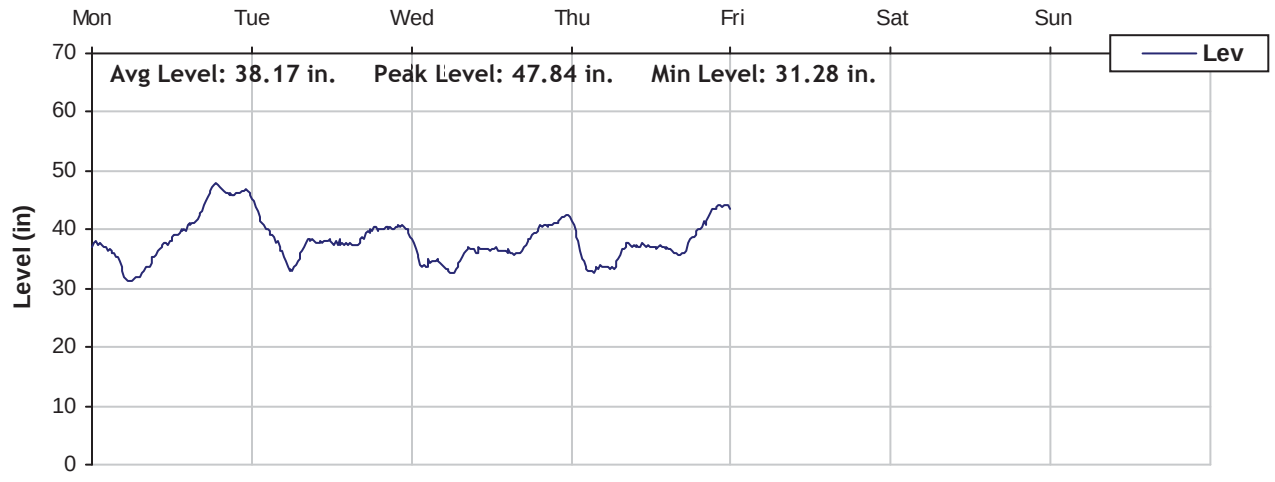


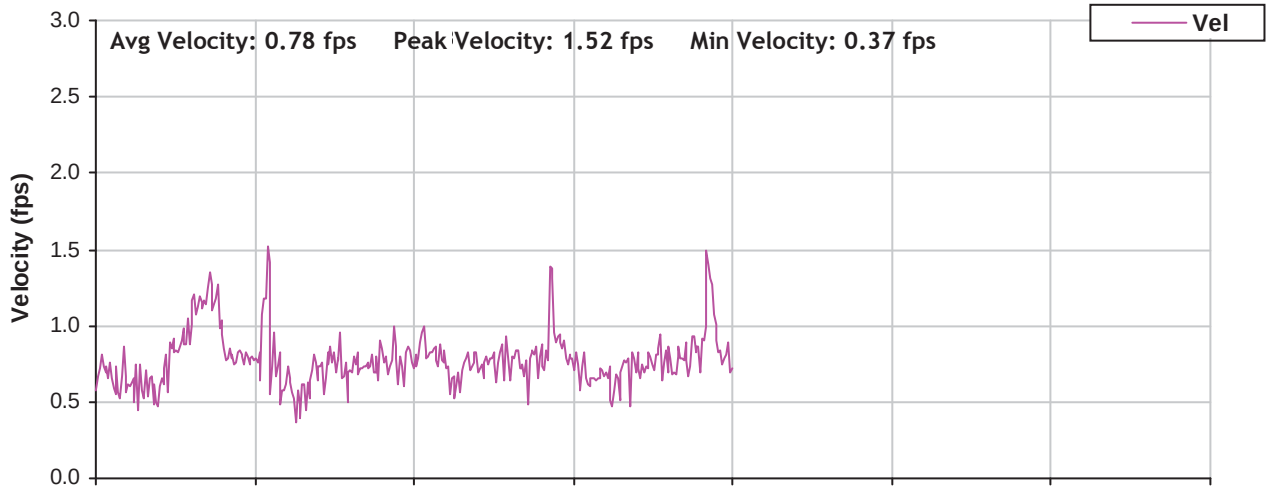


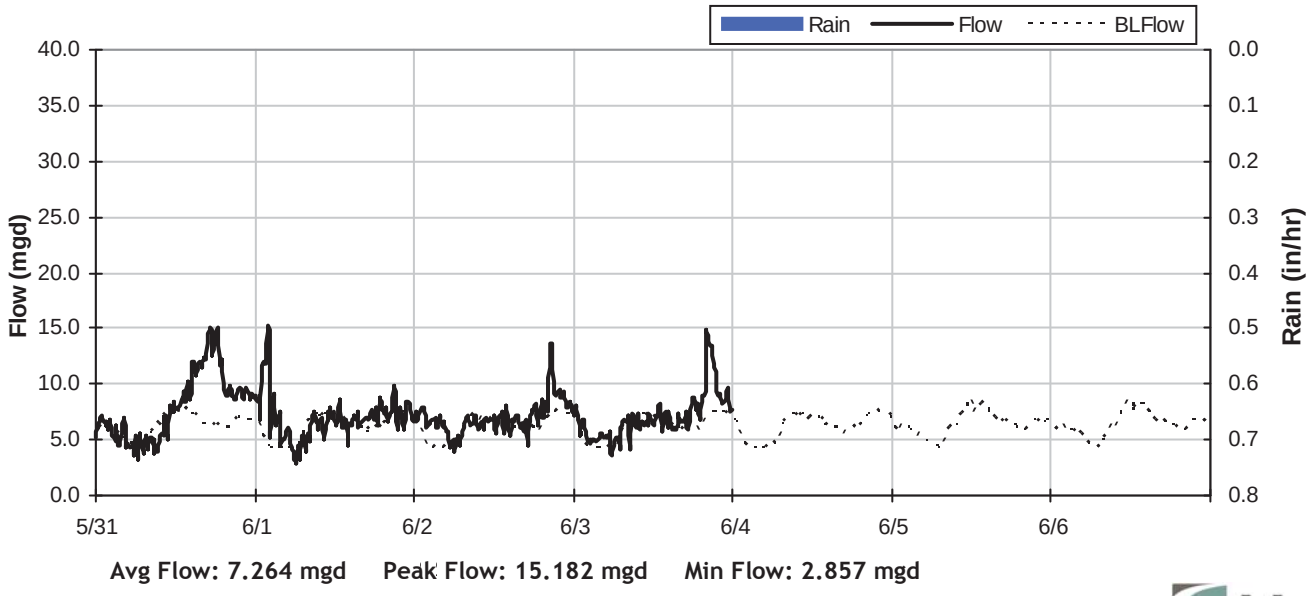
Avg Flow: 10.323 mgd Peak Flow: 21.261 mgd Min Flow: 3.632 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

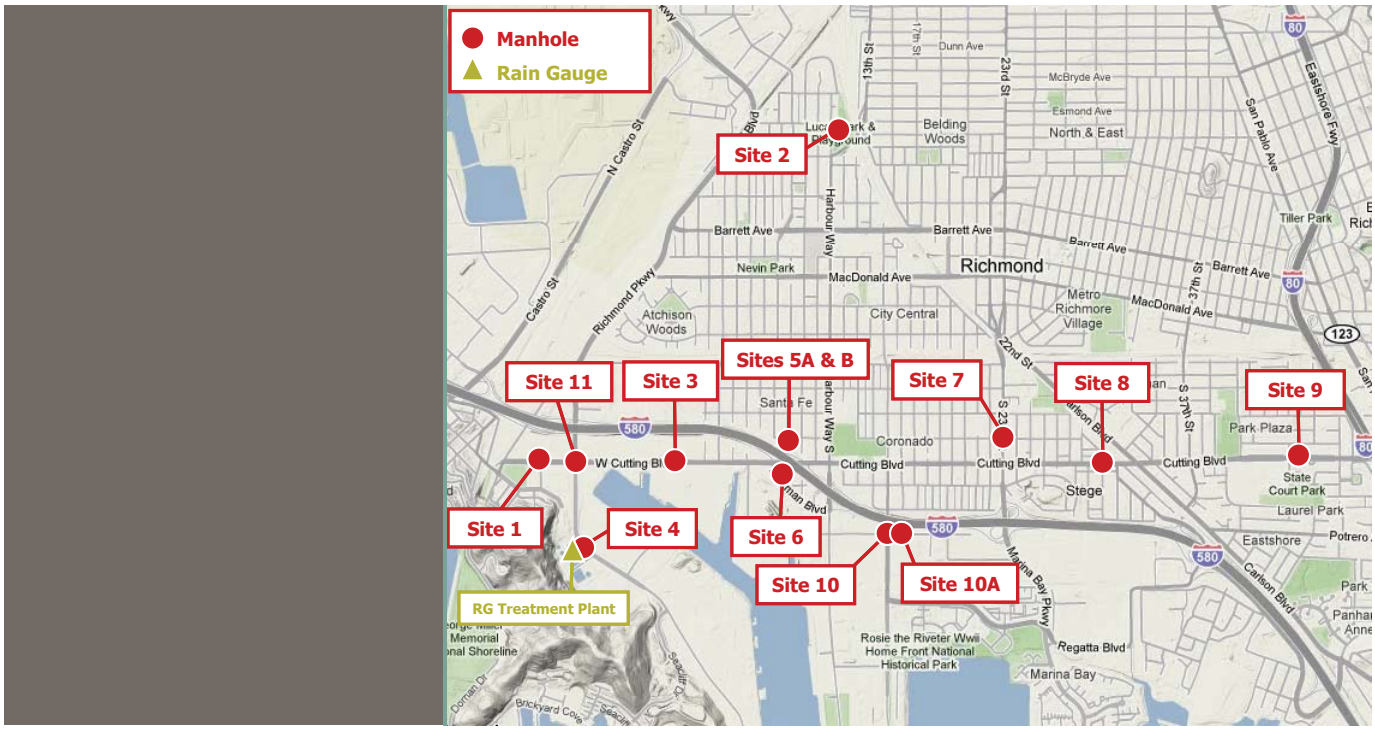
Monitoring Site:
Site 11







Avg Flow: 7.264 mgd Peak Flow: 15.182 mgd Min Flow: 2.857 mgd



Oakland
155 Grand Avenue, Suite 700
Oakland, CA 94612
510.903.6600 **Tel**
510.903.6601 **Fax**

San Diego
8291 Aero Place, Suite 110
San Diego, CA 92123
858.576.0226 **Tel**
858.576.0004 **Fax**

Seattle
14900 Interurban Avenue, Suite 268
Seattle, WA 96818
206.674.4560 **Tel**
206.674.4561 **Fax**

Houston
8220 Jones Road, Suite 500
Houston, TX 77065
713.840.6490 **Tel**
713.840.6491 **Fax**

vaengineering.com

FLOW MONITORING STUDY OF FIVE TIDAL SITES

Veolia City of Richmond

September 2010

V&A

FLOW MONITORING STUDY
OF
FIVE TIDAL LOCATIONS

Veolia City of Richmond

Prepared for

Prepared by

September 2010

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
INTRODUCTION 3
METHODS AND PROCEDURES 5
Confined Space Entry 5
Flow Meter Installation 6
RAINFALL RESULTS 7
FLOW MONITORING RESULTS SUMMARY 8
Site Notes 8
Average Dry Weather Flows 10
Pipeline Capacity Analysis 11
RECOMMENDATIONS 13

TABLES

Table 1. Flow Monitoring and I&I Results Summary 1
Table 2. List of Flow Monitoring and Rainfall Monitoring Sites 3
Table 3. Dry Weather Flow Summary 10
Table 4. Capacity Analysis Summary 11

FIGURES

Figure 1. Flow and Tide Levels at Site 2A 2
Figure 2. Flow and Rain Monitoring Locations 4
Figure 3. Typical Flow Meter Installation 6
Figure 4. Rainfall Activity over Flow Monitoring Period – Rain Gauge 1 7
Figure 5. Rainfall Accumulation Plot 7
Figure 6. Flow and Tide Levels at Site 2A 8
Figure 7. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site 12

APPENDIX

Appendix A: Flow Monitoring Sites: Data, Graphs, Information

EXECUTIVE SUMMARY

Flow Monitoring Results

V&A has completed sanitary sewer flow monitoring and rainfall monitoring within the City of Richmond, California (City). Flow and rainfall monitoring occurred over a 1½-month period from May 1 to June 23, 2010, at five open-channel flow monitoring sites. Table 1 summarizes the results for the flow monitoring sites.

Table 1.
Flow Monitoring and I&I Results Summary

Monitoring Site	Diameter (in)	ADWF (mgd)[1]	Peak Flow (mgd)	Peaking Factor[2]	Peak Level (in)	d/D Ratio[3]	Surcharged Level above Pipe Crown (in)
Site 1A	42	0.82	2.44	2.98	55.21	1.31	13.2
Site 2A	18	0.031	1.58	50.3	41.02	2.28	23.0
Site 3A	30	1.11	2.87	2.58	13.37	0.45	N/A
Site 4A	24	0.65	1.70	2.60	9.36	0.39	N/A
Site 4B	24	0.46	1.15	2.52	8.46	0.35	N/A

1. ADWF – Average Dry Weather Flow
2. Peaking Factor – Maximum Flow / ADWF
3. d/D – depth of flow / Diameter of Pipe

The following capacity analysis results are noted:

- **Capacity (Peaking Factor):** Only Site 2A had a peaking factor over 3, a common threshold value used for pipe design. This value was excessively high due to the "backflow-then-flushing" events that occurred late in the flow monitoring period. The normal peaking factor experienced at this location was about 10.1. This value is still very high and is a result of the tidal infiltration occurring upstream from this site.
- **Capacity (d/D Ratio):** Sites 1A and 2A exceeded the common threshold value for the d/D ratio. The surcharge events present at this location are possibly the result of downstream plant operations as opposed to upstream capacity issues.

The following additional analysis items are noted:

- Site 2A had the only significant response to the tide (refer to Figure 1). It is estimated that over half (about 53%) of the flow through this is infiltration from tidal flow.

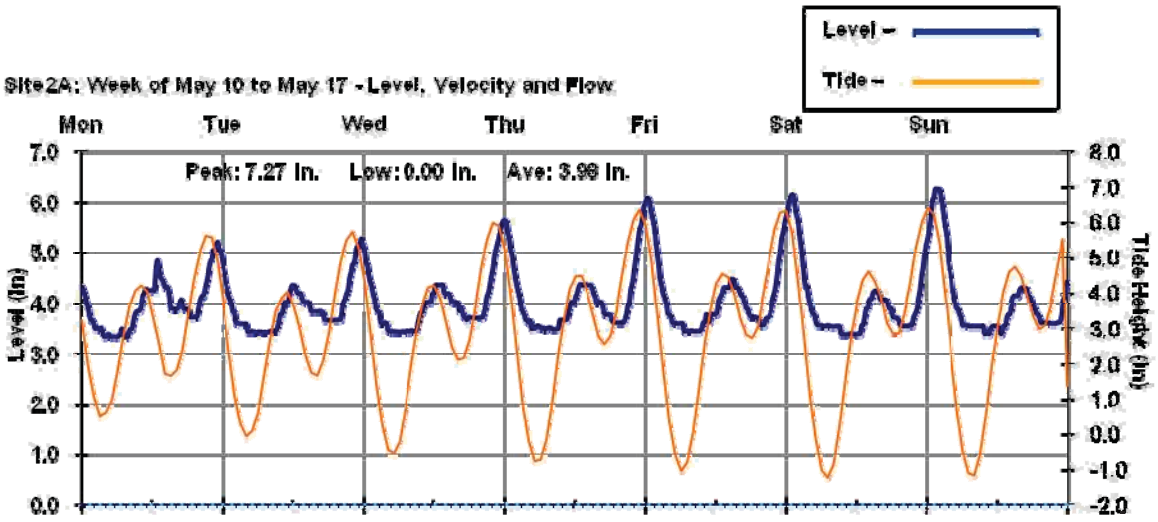


Figure 1. Flow and Tide Levels at Site 2A

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.
    b. If total 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.
2. **I&I Investigation Methods:** Potential I&I investigation methods include the following:
    a. Smoke testing to identify cross-connections and other inflow sources. Smoke testing to try to locate defective laterals.
    b. Mini-basin flow monitoring to better localize suspected I&I sources.
    c. Night-time reconnaissance work to (i) investigate and determine direct point sources of inflow and (ii) determine the areas or pipe reaches responsible for high levels of infiltration contribution.
    d. CCTV inspection to find defects in pipe segments between manholes.
3. **I&I Reduction Cost Effective Analysis:** The City should conduct a study to determine which is more cost-effective: (1) locating the sources of inflow/infiltration and systematically rehabilitating or replacing the faulty pipelines; or (2) continued treatment of the additional rainfall dependent I&I flow.

INTRODUCTION

V&A has completed sanitary sewer flow monitoring and rainfall monitoring within the City of Richmond, California (City). Flow monitoring occurred over a 1½-month period from May 1 to June 23, 2010 at five open channel flow monitoring sites. Rainfall data was used from two locations within the City. The flow monitoring sites and rain gauge sites (RG) are listed in Table 2 and illustrated in Figure 2. Detailed descriptions of the individual flow monitoring sites, including photographs, are included in *Appendix A*.

V&A was retained by Veolia through West Yost Associates to perform this project for the City as the City begins development of their sanitary sewer master plan (SSMP). These five locations were chosen specifically due to interest in tidal infiltration into the collection system.

Table 2.
List of Flow Monitoring and Rainfall Monitoring Sites

Monitoring Site	Diameter (in)	Location
Site 1A	42	Off N. Castro St., inside Chevron fuel terminal
Site 2A	18	Intersection of Wright Ave. and S. Harbour Way
Site 3A	30	Alongside railroad tracks north of S. 27th St., north of Pierson Ave.
Site 4A	24	Seaver Ave., before entrance to University of California Field Station
Site 4B	24	Meade St., at intersection with Seaver Ave.
RG 1	-	Located at City of Richmond Treatment Plant
RG 2	-	Poinsett Ave, east of Jordan Ave.

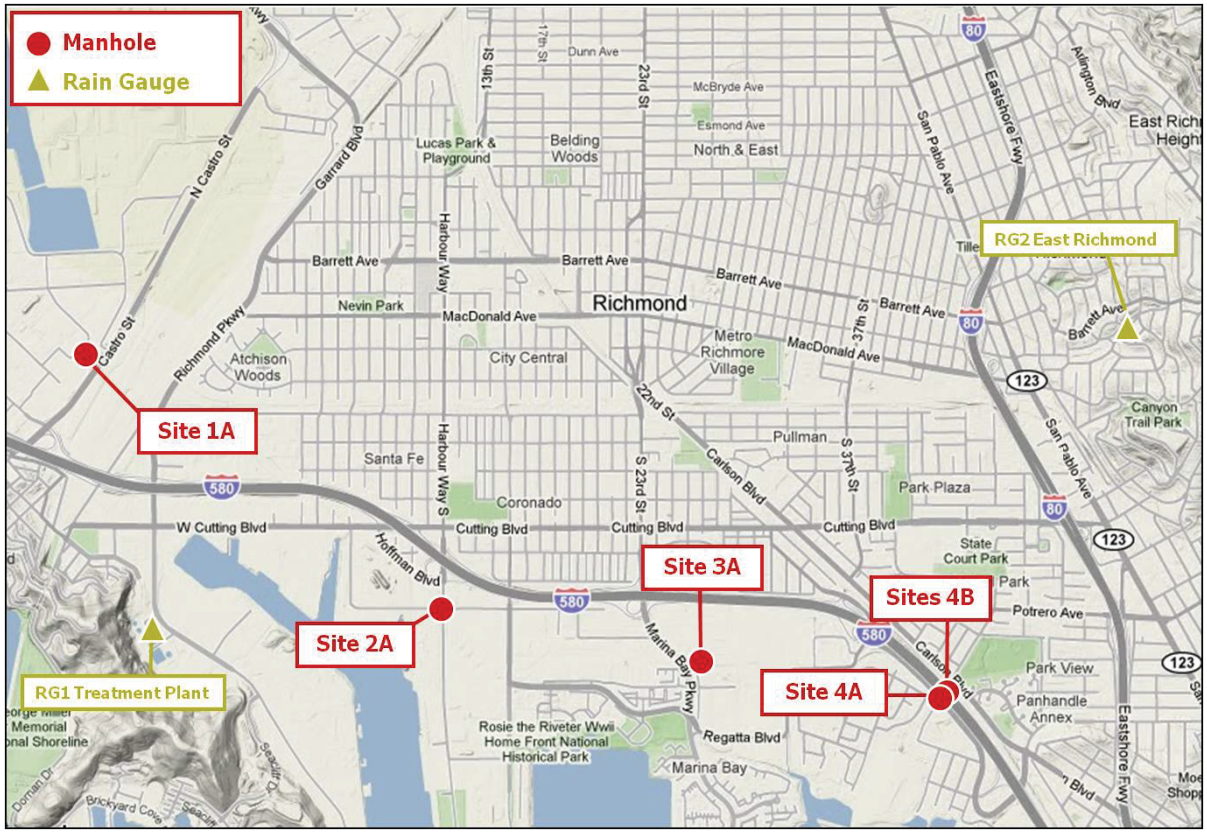


Figure 2. Flow and Rain Monitoring Locations

METHODS AND PROCEDURES

Confined Space Entry

A confined space (Photo 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. Title 8, Section 5157 of the California Code of Regulations provides the guidelines and rules for working in these environments. In general, the atmosphere must be constantly monitored for sufficient levels of oxygen (19.5 to 23.0%), and the absence of Hydrogen Sulfide (H_2S) gas, Carbon Monoxide (CO) gas and 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/she is equipped with the necessary personal protective equipment needed to perform the job safely, including a personal 4-gas monitor (Photo 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 entrant(s) to monitor the atmosphere on another 4-gas monitor and maintaining records of all Entrants, if there is more than one. The Supervisor develops the safe work plan for the job at hand prior to entering.

Photo 1. Confined Space Entry

Photo 2. Typical Personal 4-Gas Monitor

Flow Meter Installation

Five Sigma 910 flow meters were installed by V&A in the sewer lines shown in Figure 2. Sigma meters use a pressure transducer to collect depth readings and ultrasonic Doppler sensors on the probe to determine the average fluid velocity. Figure 3 shows a sketch of a typical flow meter installation.

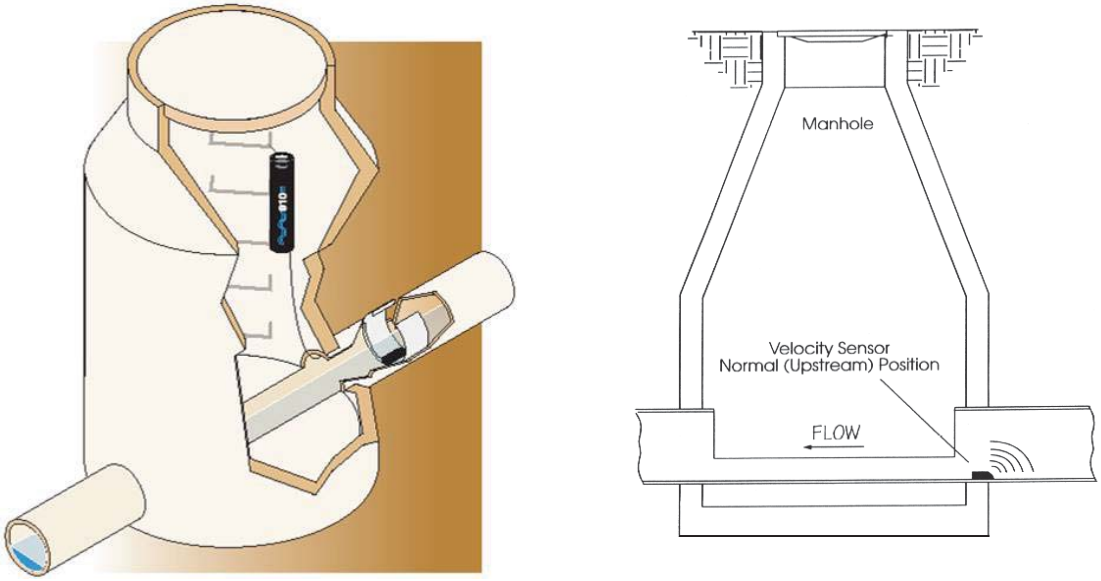


Figure 3. Typical Flow Meter Installation

Continuous depth and velocity readings were recorded by the flow meters in 5-minute increments and downloaded into a computer spreadsheet program where the data could be analyzed and made report ready. Manual level and velocity readings were taken in the field during the flow meter installation and again when the flow meters were removed. These readings were compared to the readings of the flow meters to ensure proper calibration and accuracy.

RAINFALL RESULTS

One rain gauge was installed by V&A at the City of Richmond treatment plant. The second rain gauge was located in East Richmond. Figure 4 graphically displays the rainfall events recorded over the flow monitoring period (RG1 data illustrated). Figure 5 shows the rain accumulation from the rain gauges, as well as the historical average rainfall[1] in the City over the duration of this study. Rainfall totals for Rain Gauges 1 and 2 were at approximately 100% and 185%, respectively, of normal levels during this time period.

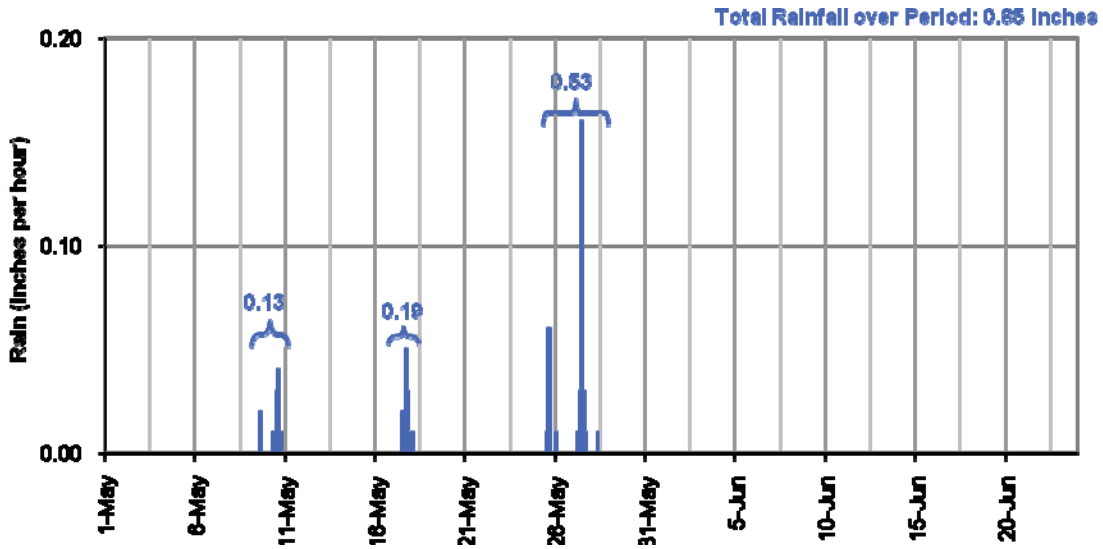


Figure 4. Rainfall Activity over Flow Monitoring Period – Rain Gauge 1

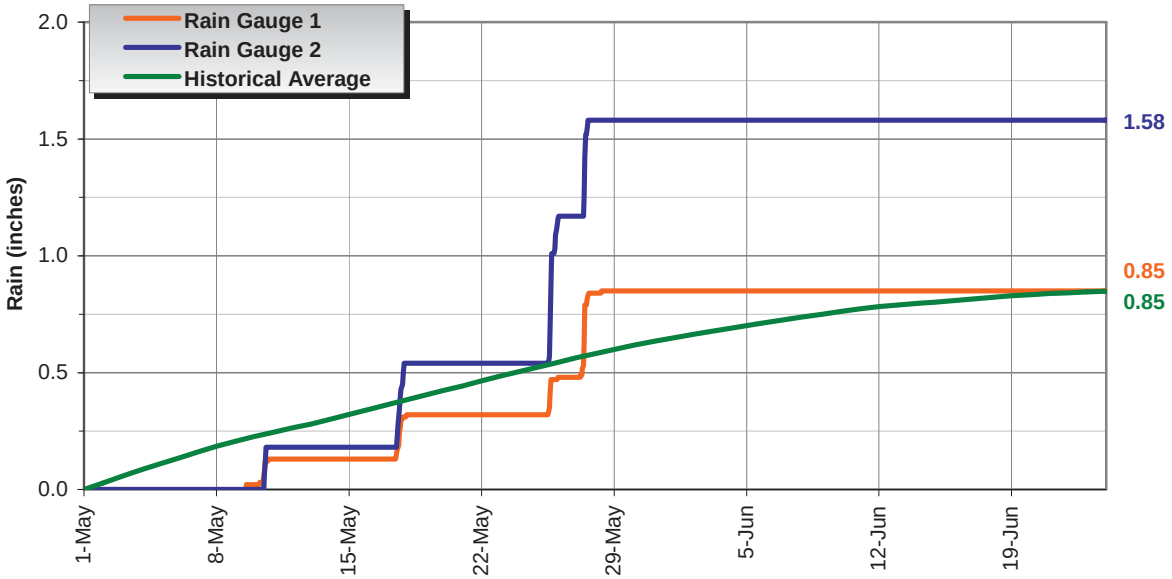


Figure 5. Rainfall Accumulation Plot

[1] Weighted historical data taken from the Western Regional Climate Center (WRCC): Site 1http://www.wrcc.dri.edu/summary/climsmnca.html

FLOW MONITORING RESULTS SUMMARY

Site Notes

Site 1A

There are periodic "constant" flow events that occur upstream from Site 1A. These events start and end quickly, last for about 10 hours and flow at a generally constant rate of approximately 0.7 million gallons per day (in addition to the normal flow through Site 1A). Refer to May 7, 2010 for an example of this event. The constant flow rate may indicate a pump being turned on.

On May 19, 2010 at approximately 7:45am, a similar jump in flow occurred (an increase of approximately 0.75 mgd) but the flow did not return to normal levels until June 7, 8, 2010.

From June 12 to June 19, 2010, the flow levels increased significantly; the flow monitoring location was in a surcharged condition about half of each day during this period. The flow velocities reported during this period were often measured at zero. The flow meters utilized for this project are not capable of capturing extremely slow velocities. It is unknown during this period of increased flow levels if the flow velocities were actually zero, indicating stagnant flow, or if the flow was still moving through the pipeline but at velocities too slow to register with the flow monitoring equipment.

Site 2A

Of the five sites monitored during this study, only Site 2A had a significant response to tide levels (refer to Figure 6). It is estimated that over half (about 53%) of this location's flow is attributable to tidal infiltration. Photo 3 shows a source of infiltration in the monitoring manhole.

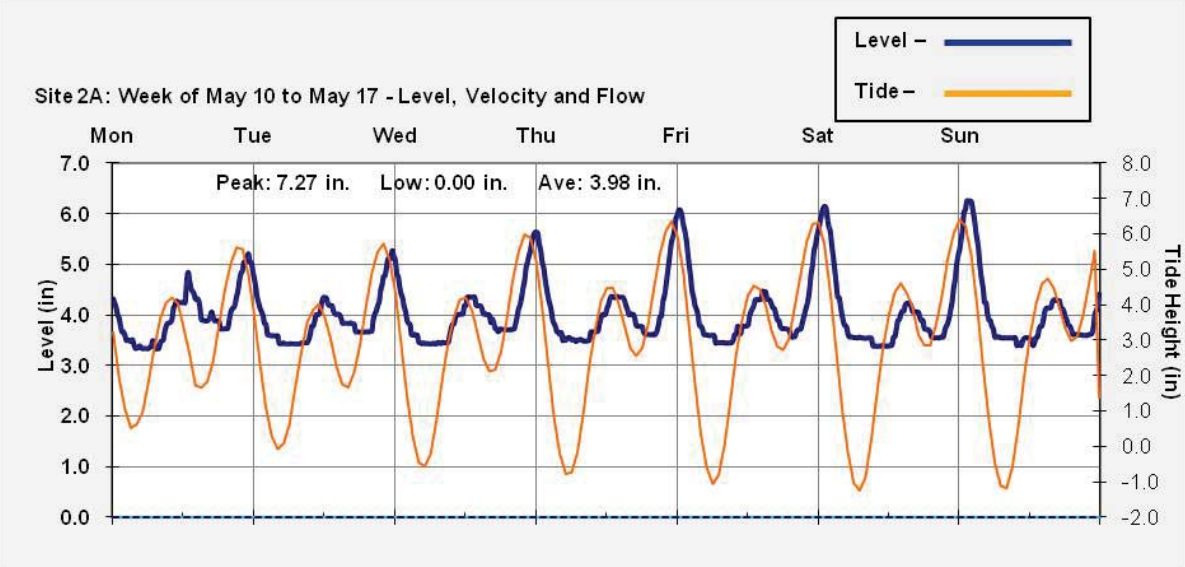


Figure 6. Flow and Tide Levels at Site 2A

Photo 3. Infiltration at Site 2A (Pipe Outlet)

The backflow conditions observed in Site 1A were also observed in Site 2A. It appears as though there was reverse flow through Site 2A during this surcharged condition.

Note: Flow data was lost from Site 2A from May 25 through June 16, 2010, due to a meter malfunction.

Site 3A

The flows through Site 3A did not show a measurable tidal response. There was a noticeable response to rainfall events. There were no unusual events or conditions to report for this site.

Sites 4A and 4B

Sites 4A and 4B were measuring parallel lines downstream from a junction structure. The hydraulic split of flows from the junction structure changed over the course of the flow monitoring period; however, the sum of flows through Sites 4A and 4B was consistent.

Flows through Sites 4A and 4B did not show a measurable tidal response. There was a noticeable response to rainfall events. Other than the aforementioned upstream hydraulic split, there were no unusual events or conditions to report for these sites.

Average Dry Weather Flows

Weekday and weekend flow patterns vary and must be separated when determining average dry weather flows. For this project, the following days were least affected by rainfall and were used to estimate weekend and weekday average flows:

- Weekdays: May 12 – 14 and June 9 – 10, 2010
- Weekends: May 9, 15, and June 12 – 13, 2010

Table 3 lists the average dry weather flow (ADWF) recorded during this study for the flow monitoring sites. Detailed graphs of the flow monitoring data on a site-by-site basis are included in *Appendix A*.

Note: Due to the tidal influence affecting flows through Site 2A, V&A extracted the flow associated with the tidal influence when estimating the ADWF for Site 2A. Reporting the data in this manner calls attention to two items: (1) The ADWF reported for Site 2A may be less than any one day measured during the monitoring period. (2) Although direct tidal influence has been removed and accounted for, other indirect influences may not have been removed (for example, sustained infiltration into the system due to tidal saturation of soils). The ADWF reported for Site 2A is the best estimate of ADWF (since soils are assumed to be tidally saturated year round), but there as an greater degree of uncertainty in the accuracy of ADWF calculations for Site 2A.

Table 3.
Dry Weather Flow Summary

Location	Average Dry Weather Flow (mgd)		Weekend/ Weekday Ratio
	Weekday	Weekend	
Site 1A	0.814	0.835	1.03
Site 2A	0.034	0.026	0.78
Site 3A	1.101	1.142	1.04
Site 4A	0.647	0.665	1.03
Site 4B	0.457	0.460	1.01

Pipeline Capacity Analysis

Peaking Factor: Peaking Factor is defined as the Peak Measured Flow divided by the Average Dry Weather Flow. A peaking factor threshold value of 3.0 is commonly used for sanitary sewer design.

d/D Ratio: The d/D ratio is the peak measured depth of flow divided by the pipe diameter. A d/D ratio less than 0.75 is a common threshold value used for pipe design. A d/D ratio greater than 1.0 indicates a surcharged condition. The d/D ratio for each site was computed based on the peak measured depth of flow during the study.

Table 4 summarizes the peak recorded d/D ratios and Peaking Factors per site during the flow monitoring period. Figure 7 shows bar graphs of the capacity results and a bar graph of the d/D ratios.

Table 4.
Capacity Analysis Summary

Monitoring Site	Diameter (in)	ADWF (mgd)	Peak Flow (mgd)	Peaking Factor	Peak Level (in)	d/D Ratio	Surcharged Level above Pipe Crown (in)
Site 1A	42	0.82	2.44	2.98	55.21	1.31	13.2
Site 2A	18	0.031	1.58	50.3	41.02	2.28	23.0
Site 3A	30	1.11	2.87	2.58	13.37	0.45	N/A
Site 4A	24	0.65	1.70	2.60	9.36	0.39	N/A
Site 4B	24	0.46	1.15	2.52	8.46	0.35	N/A

The following capacity analysis results are noted:

- **Capacity (Peaking Factor):** Only Site 2A had a peaking factor over 3, a common threshold value used for pipe design. This value was excessively high due to the "backflow-then-flushing" events that occurred late in the flow monitoring period. The normal peaking factor experienced at this location was about 10.1. This value is still very high and is a result of the tidal infiltration occurring upstream from this site.
- **Capacity (d/D Ratio):** Sites 1A and 2A exceeded the common threshold value for the d/D ratio. The surcharge events present at this location are possibly the result of downstream plant operations as opposed to upstream capacity issues.

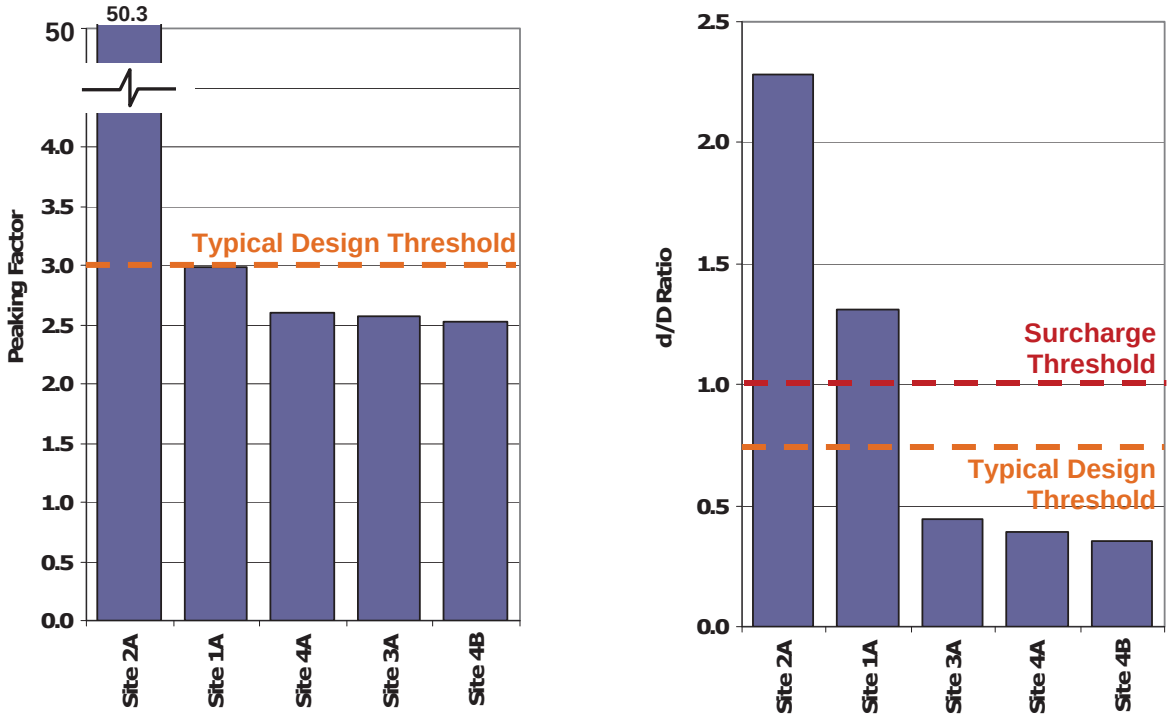


Figure 7. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site

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 the program can be prioritized to investigate and reduce sources of inflow within the basins with the greatest inflow problems.
    b. If total infiltration and general pipeline deterioration are of greater concern, then priority can be given to investigate and reduce sources of infiltration within the basins with the greatest infiltration problems.
2. **I&I Investigation Methods:** Potential I&I investigation methods include the following:
    a. Smoke testing to identify cross-connections and other inflow sources. Smoke testing to try to locate defective laterals.
    b. Mini-basin flow monitoring to better localize suspected I&I sources.
    c. Night-time reconnaissance work to (i) investigate and determine direct point sources of inflow and (ii) determine the areas or pipe reaches responsible for high levels of infiltration contribution.
    d. CCTV inspection to find defects in pipe segments between manholes.

I&I Reduction Cost Effective Analysis: The City should conduct a study to determine which is more cost-effective: (1) locating the sources of Inflow/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 SITES: DATA, GRAPHS, INFORMATION

Temporary Flow Monitoring Study

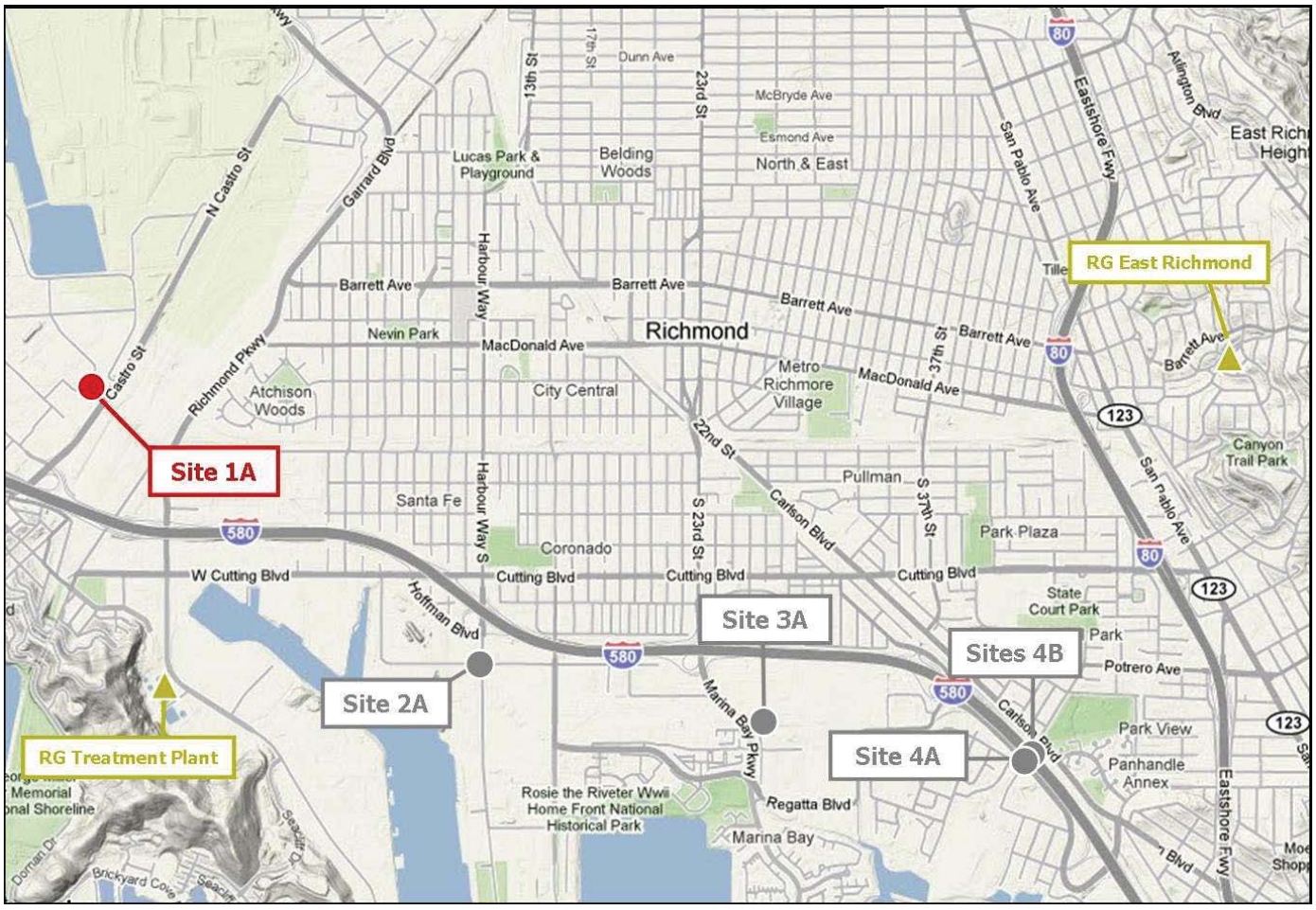
Sanitary Sewer Collection System

Monitoring Site: Site 1A

Location: Off N. Castro St., inside Chevron Gas Terminal

Size/Type Line: 42-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 1A

Location: Off N. Castro St., inside Chevron Gas Terminal

Latitude: 37.9253°

Longitude: -122.3806°

Rim Elevation: 8 *feet above sea level*

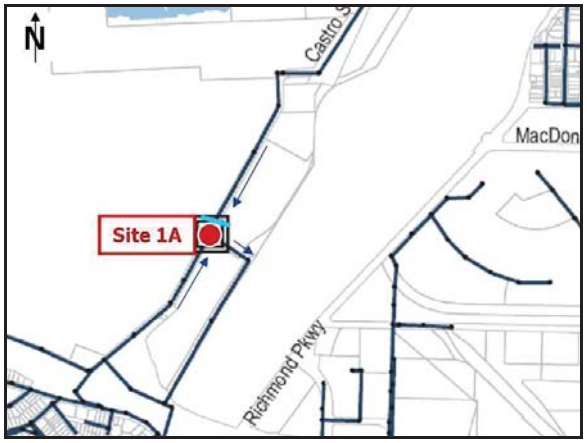
Diameter: 42 *inches*

Average Dry Weather Flow: 0.820 *mgd*

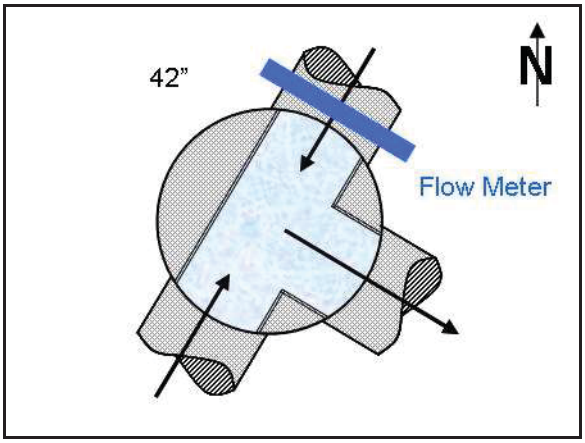
Peak Measured Flow: 2.442 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch

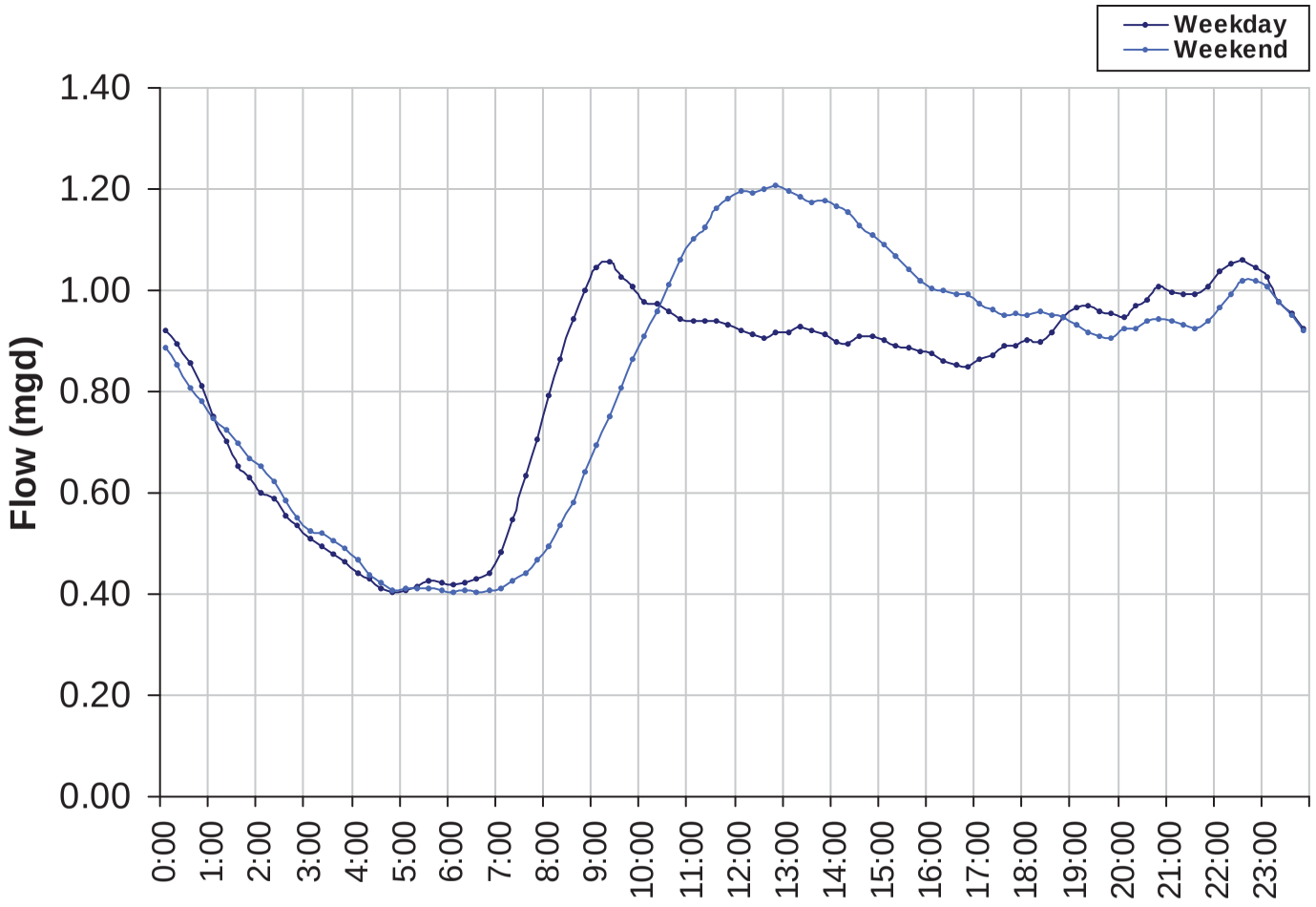


Street View Photo

Plan View Photo

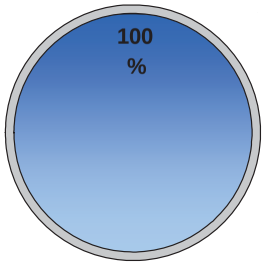
Average Dry Weather Flow

Monitoring Site:
Site 1A



Peak Measured Flow:

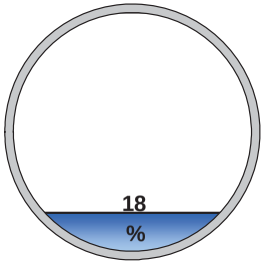
2.44 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

0.82 *mgd*

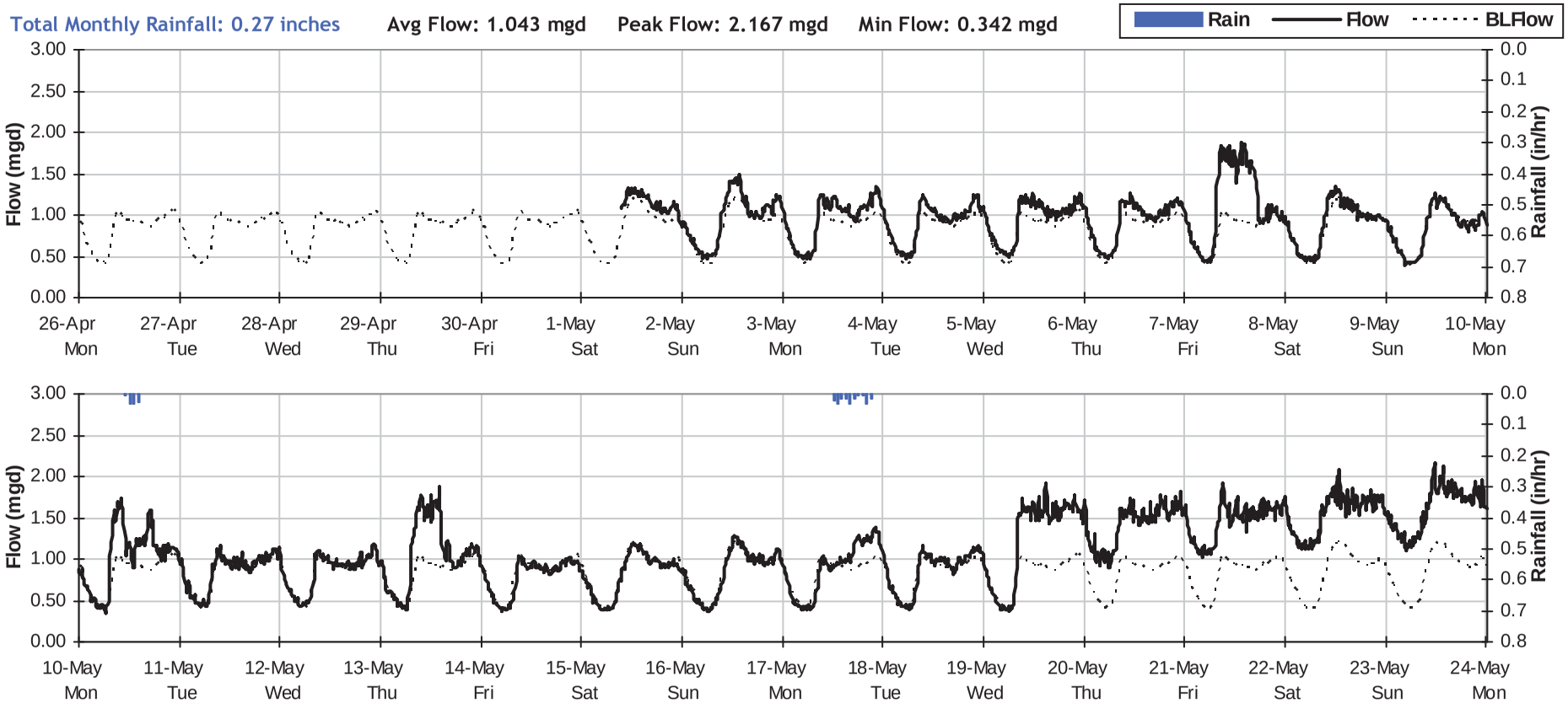


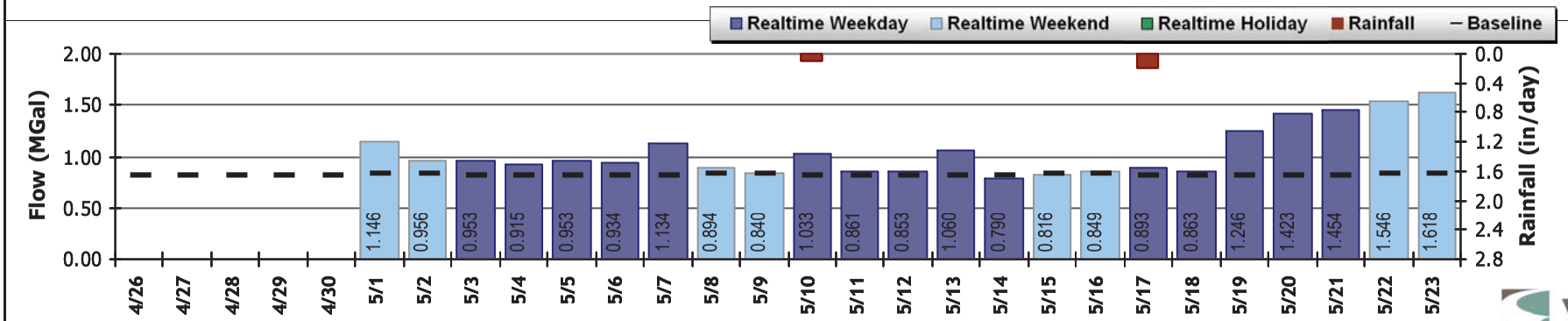
V&A

Period Flow Summary
April 26 to May 23, 2010

Monitoring Site:
Site 1A

Total Monthly Rainfall: 0.27 inches Avg Flow: 1.043 mgd Peak Flow: 2.167 mgd Min Flow: 0.342 mgd



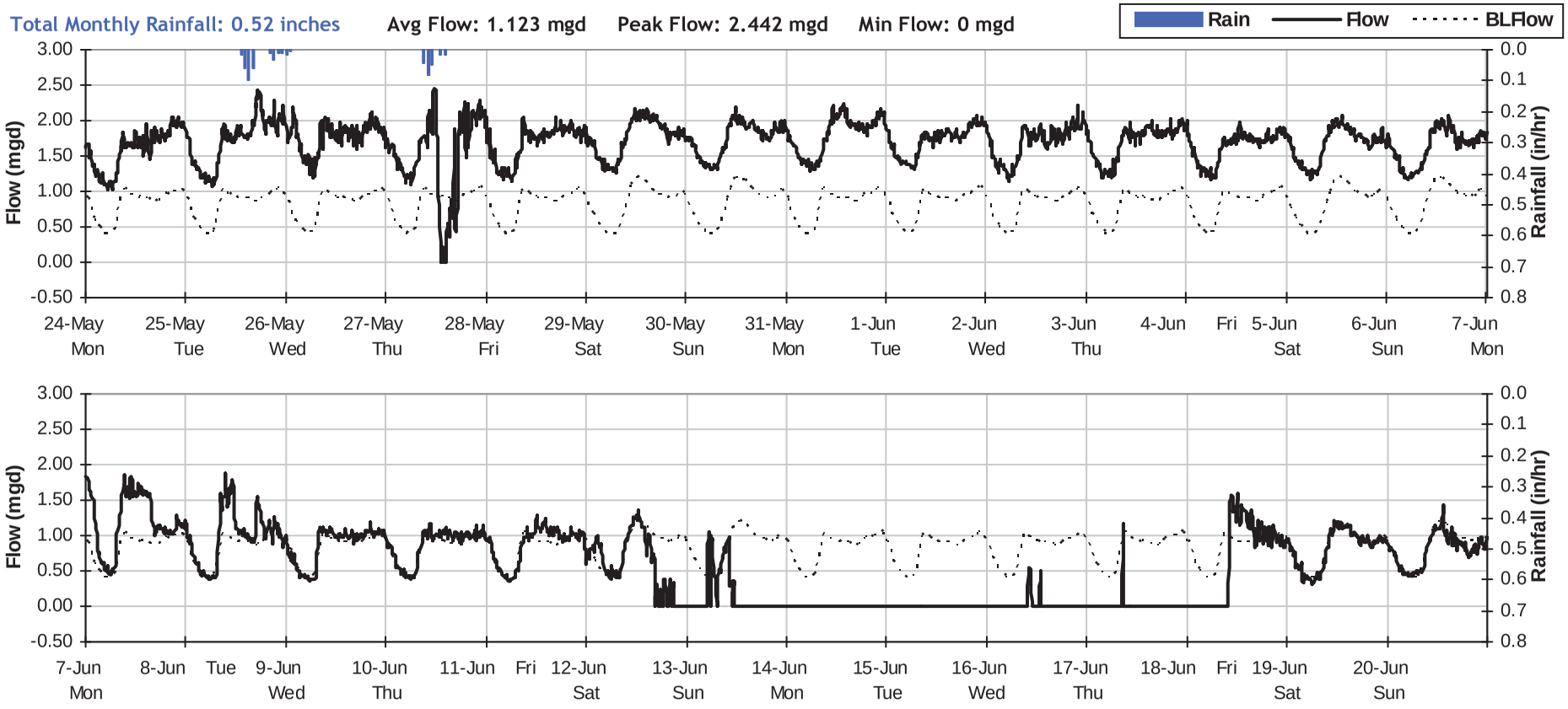


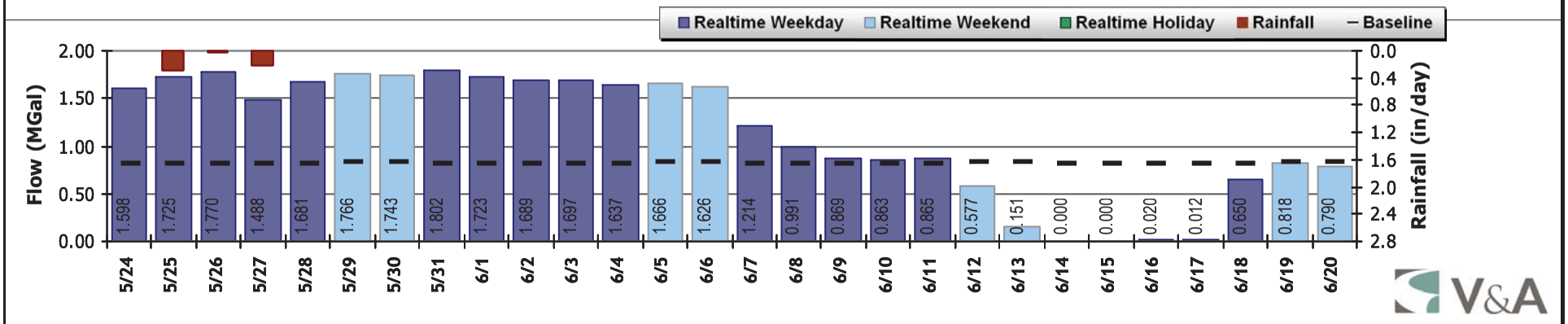
V&A

Period Flow Summary
May 24 to June 21, 2010

Monitoring Site:
Site 1A

Total Monthly Rainfall: 0.52 inches Avg Flow: 1.123 mgd Peak Flow: 2.442 mgd Min Flow: 0 mgd

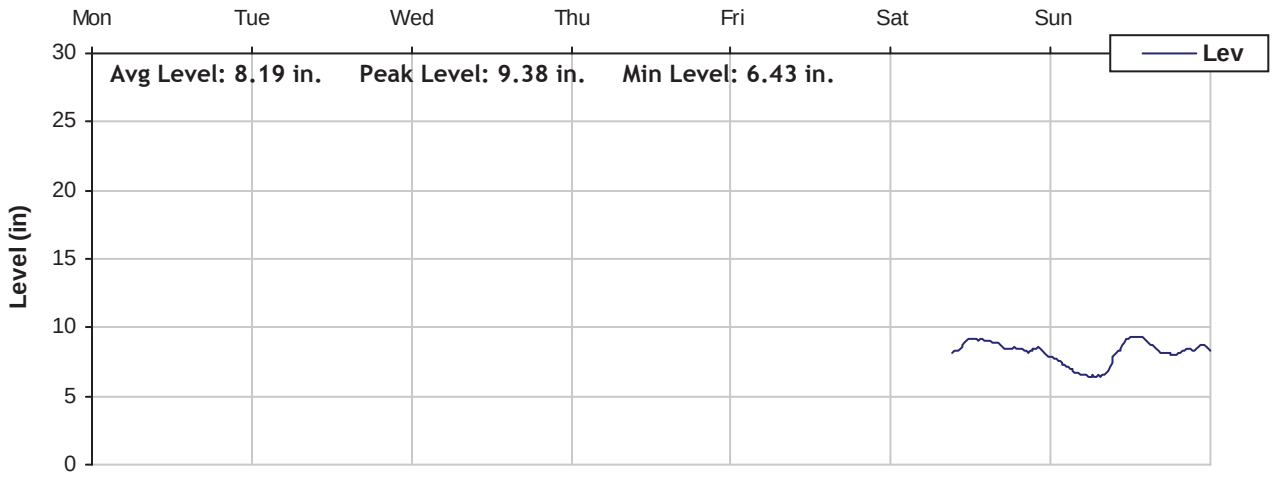


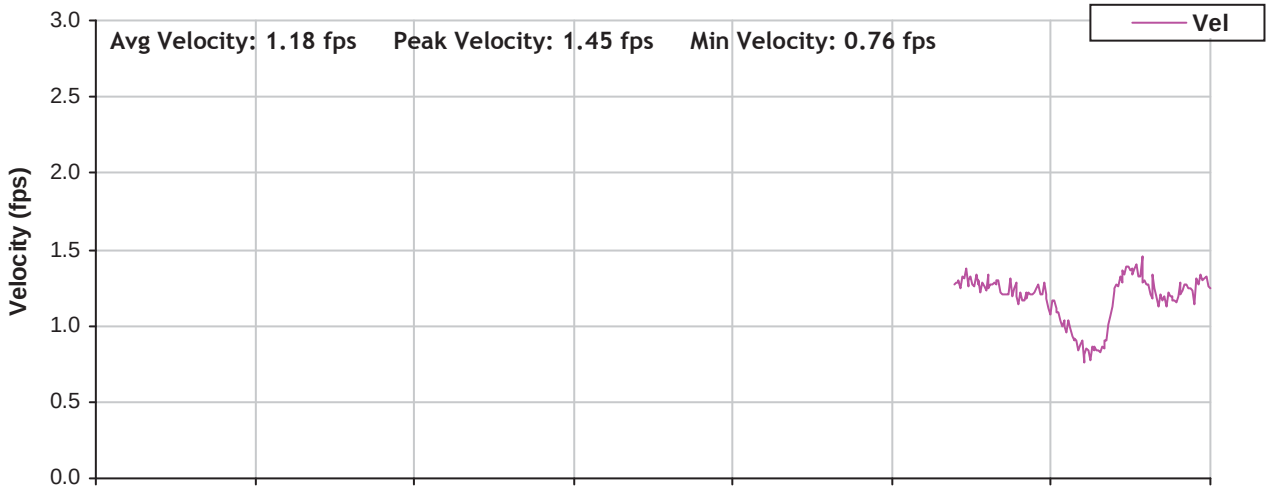


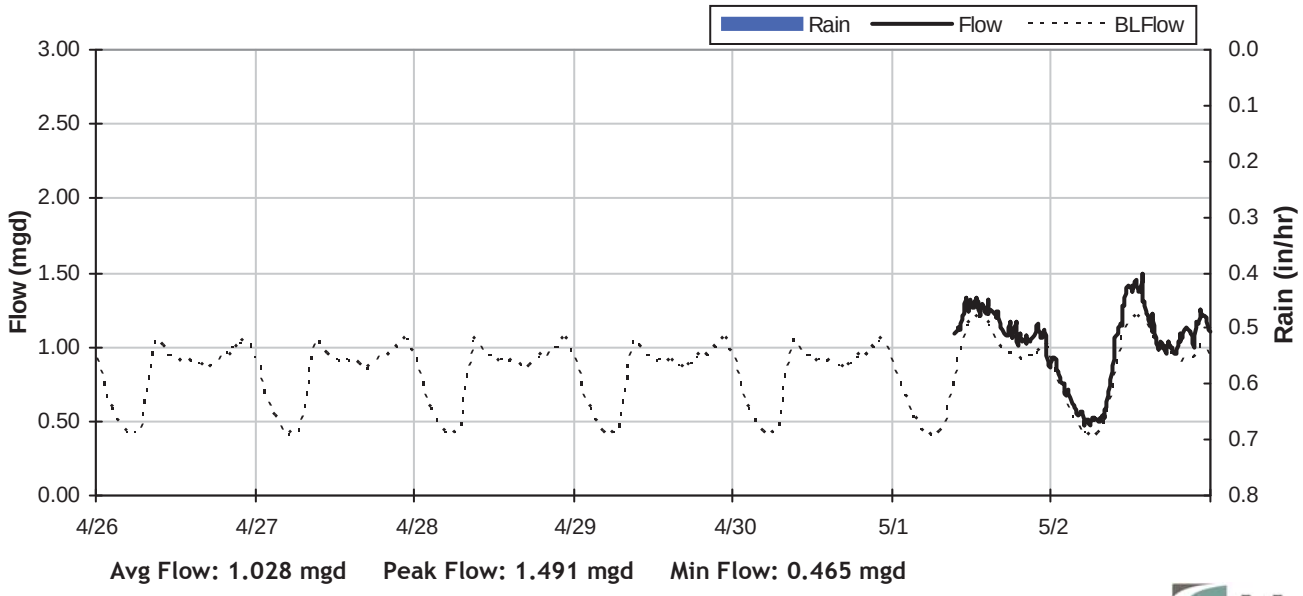
V&A

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 1A



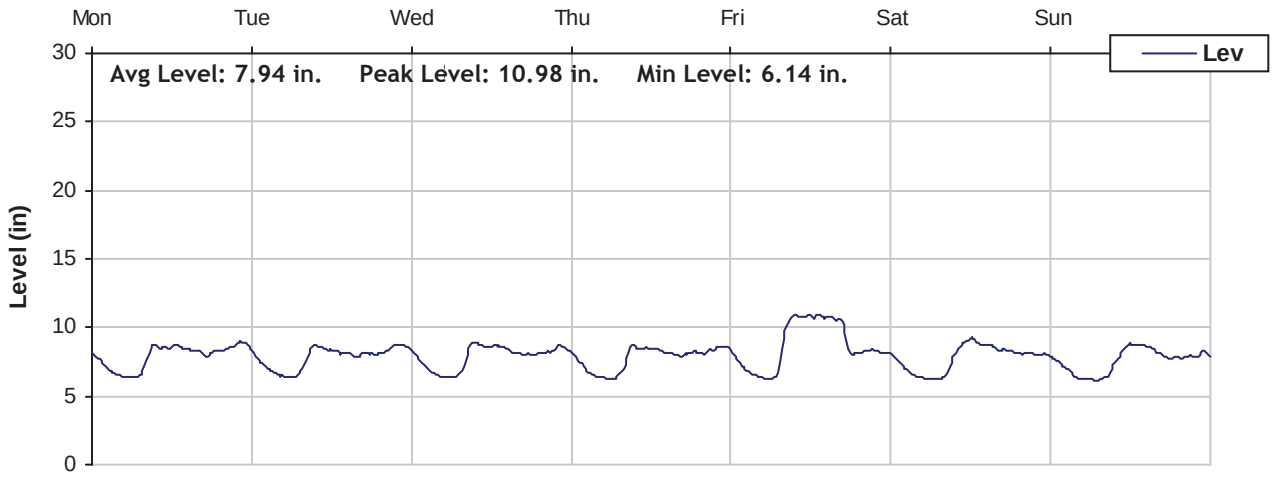


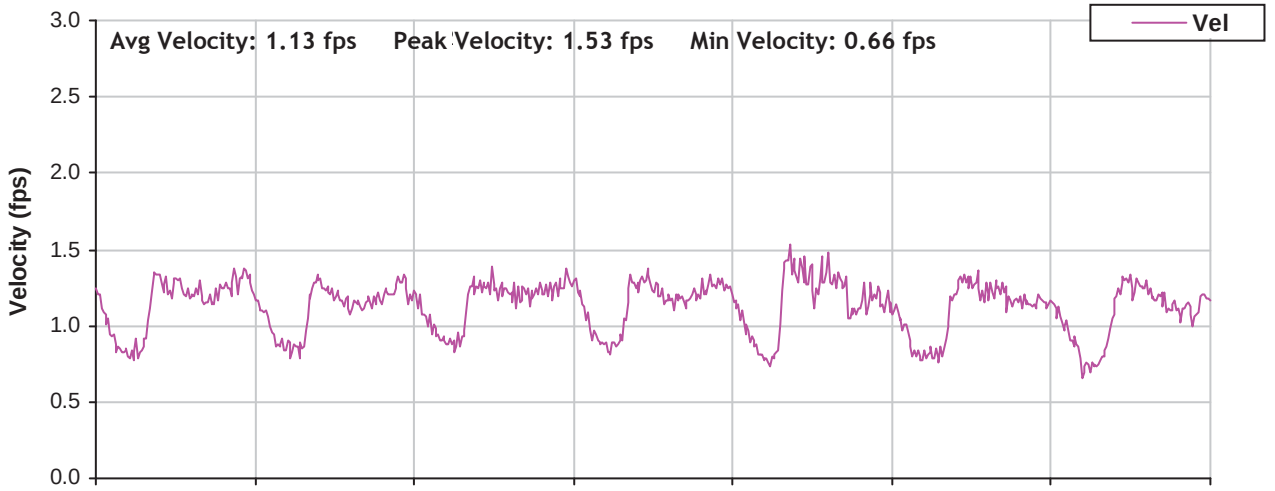


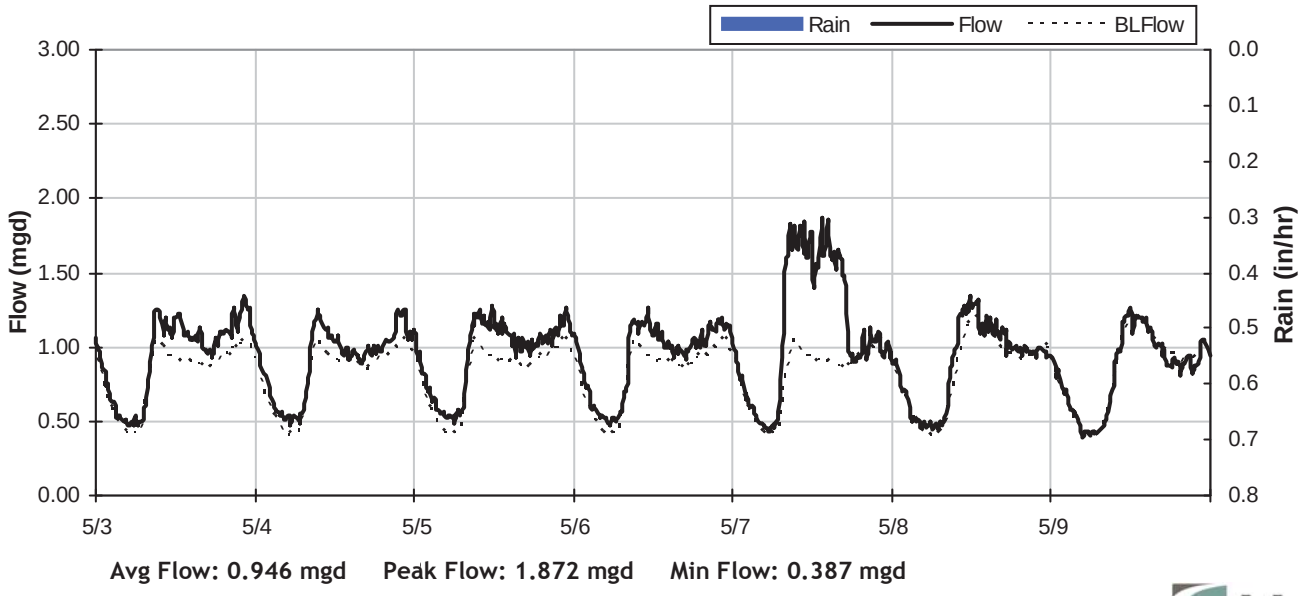
Avg Flow: 1.028 mgd Peak Flow: 1.491 mgd Min Flow: 0.465 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 1A



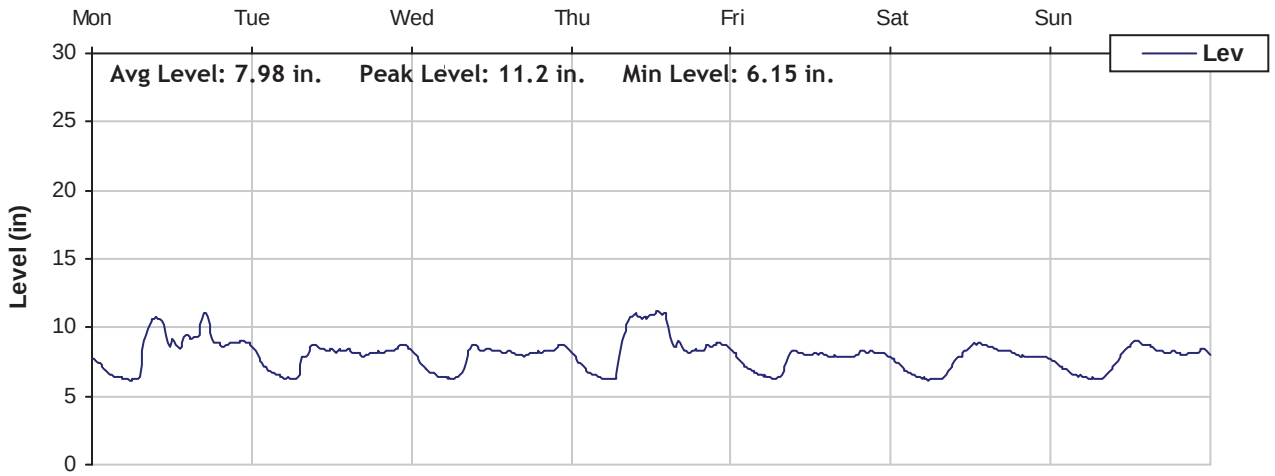


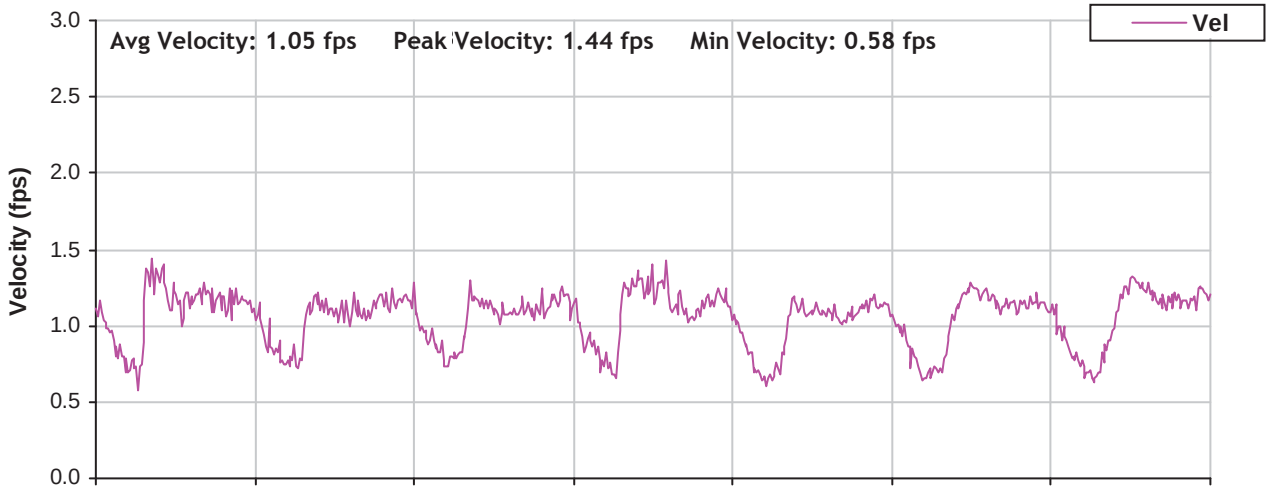


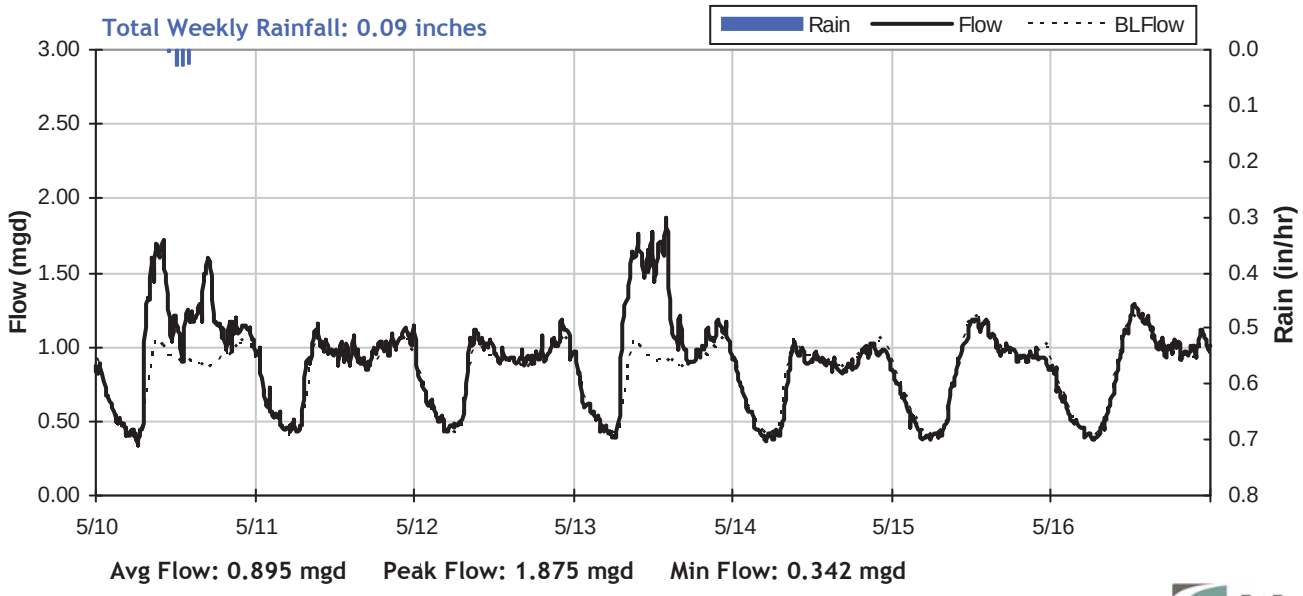
Avg Flow: 0.946 mgd Peak Flow: 1.872 mgd Min Flow: 0.387 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 1A

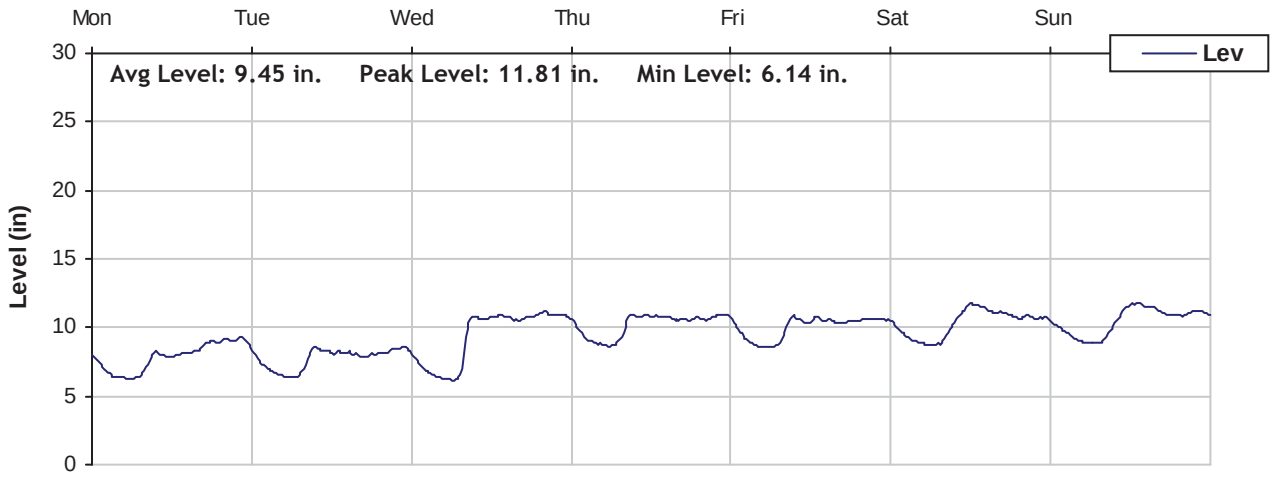


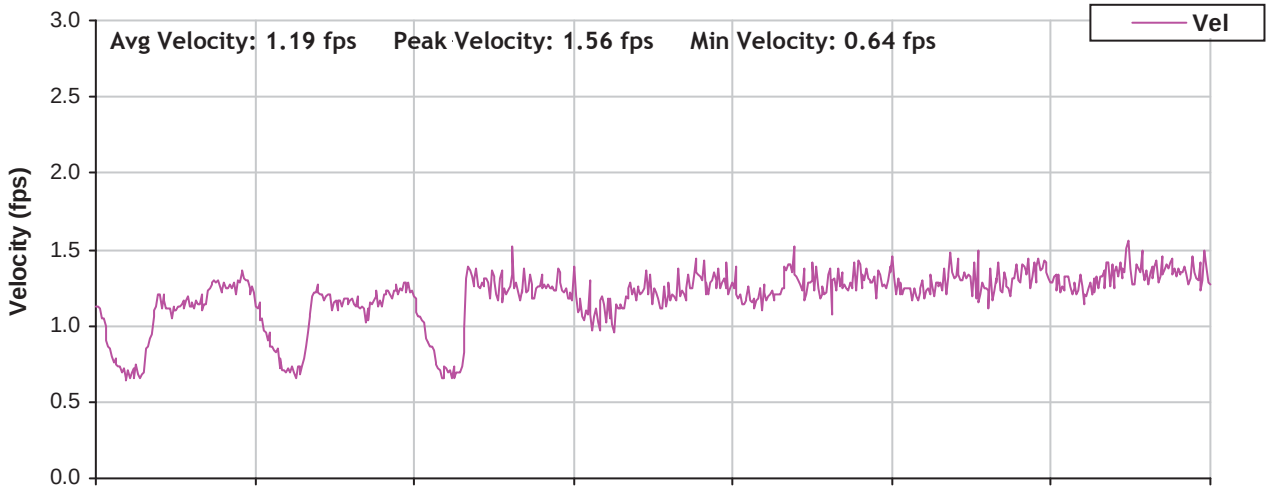


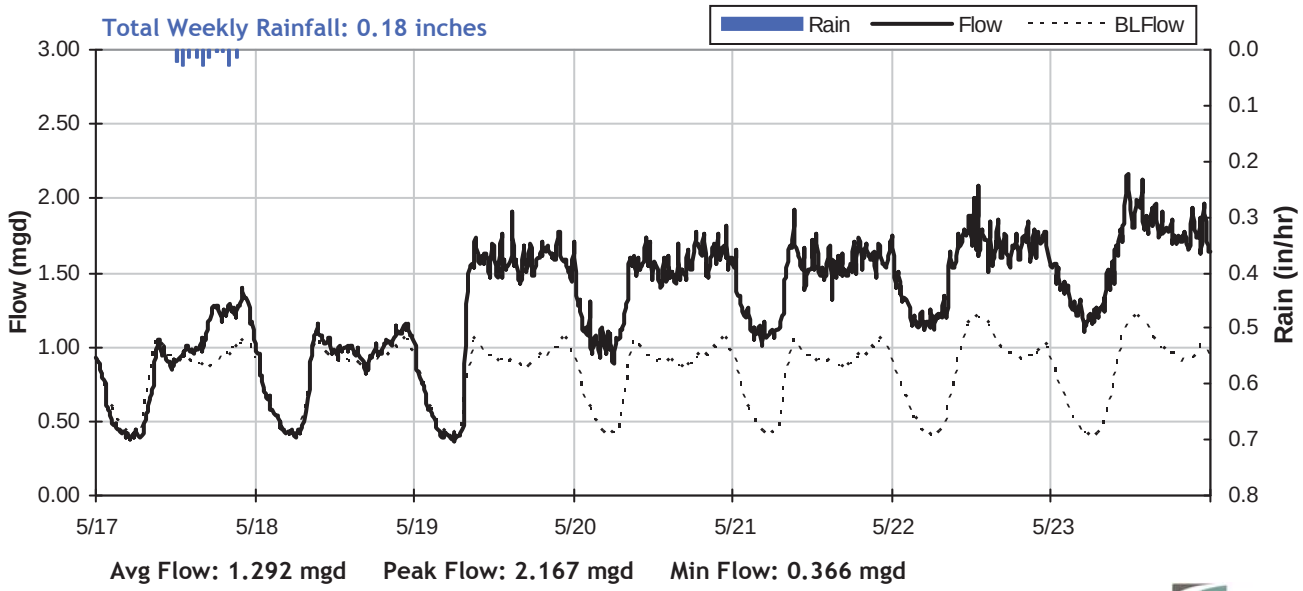


Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 1A



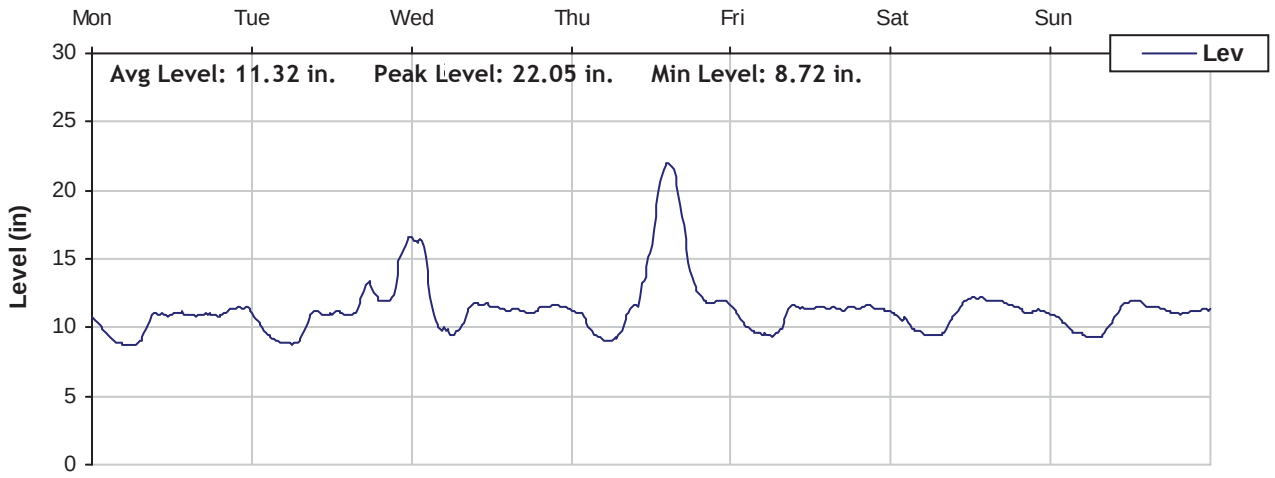


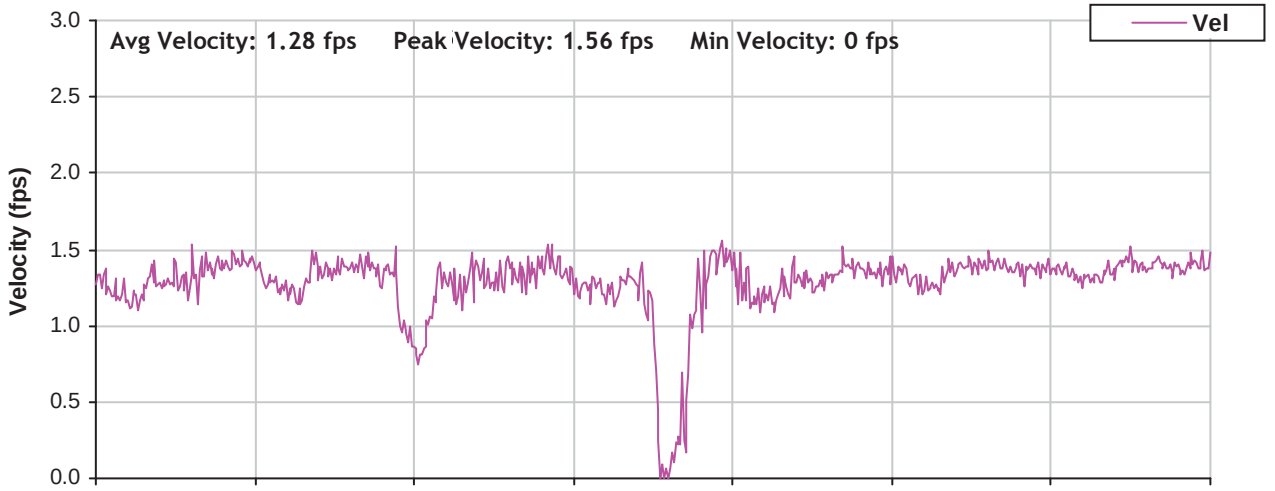


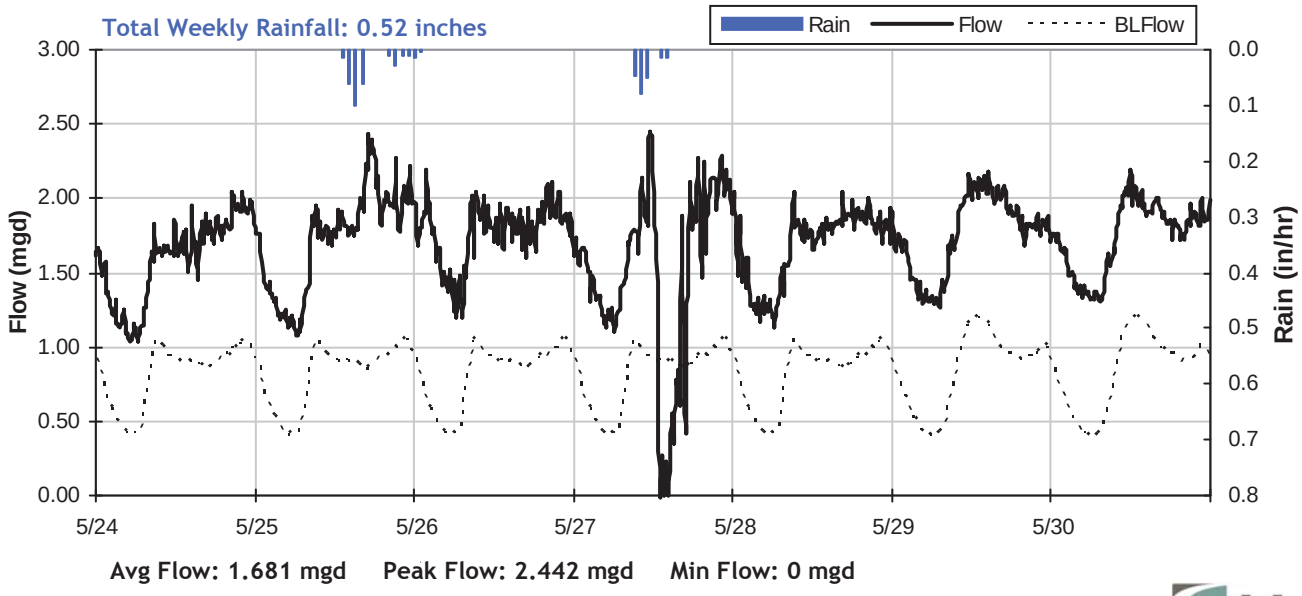
Avg Flow: 1.292 mgd Peak Flow: 2.167 mgd Min Flow: 0.366 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 1A



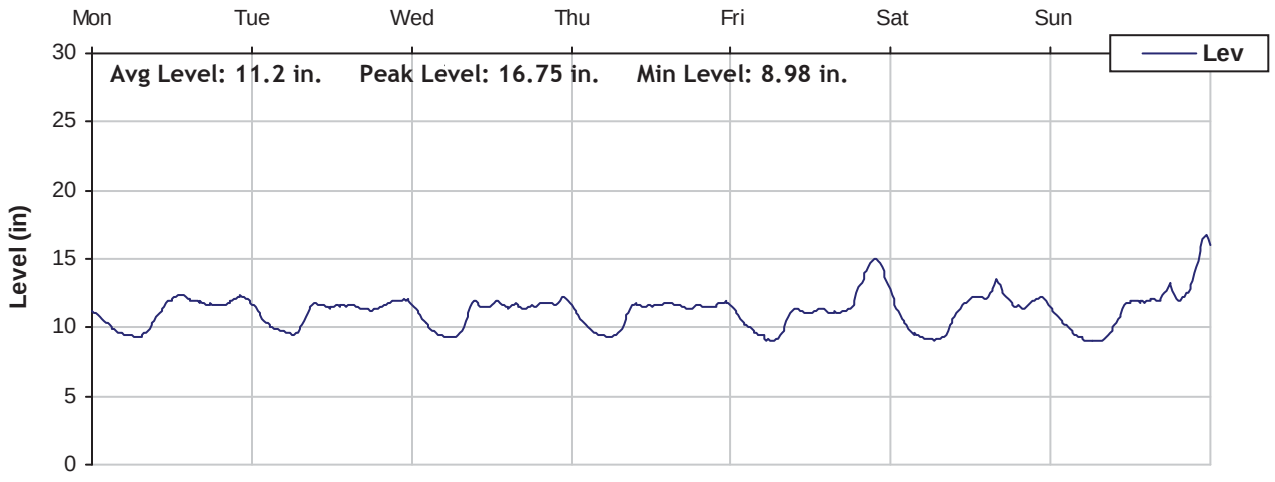


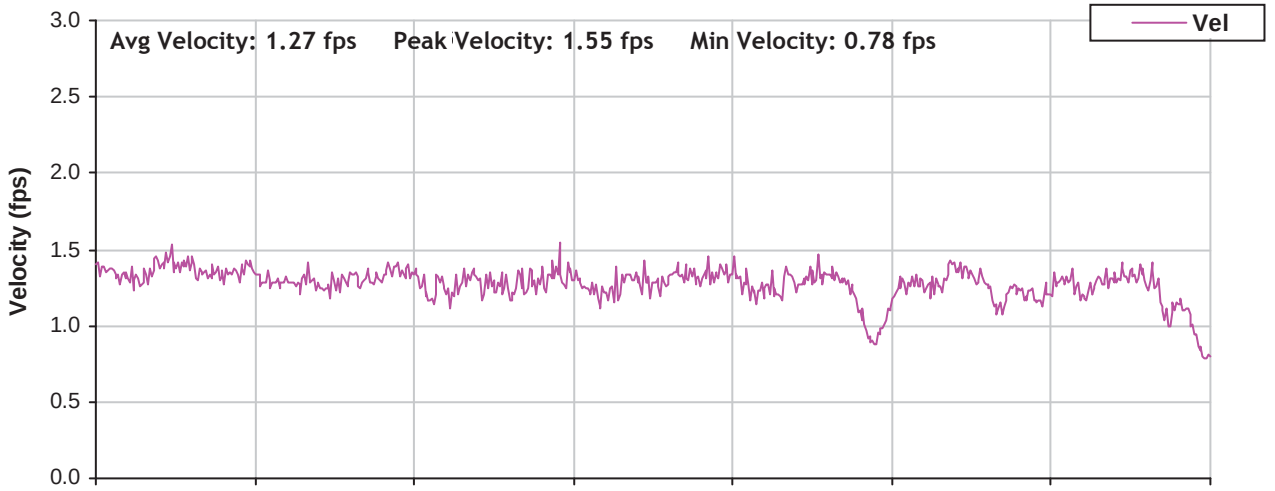


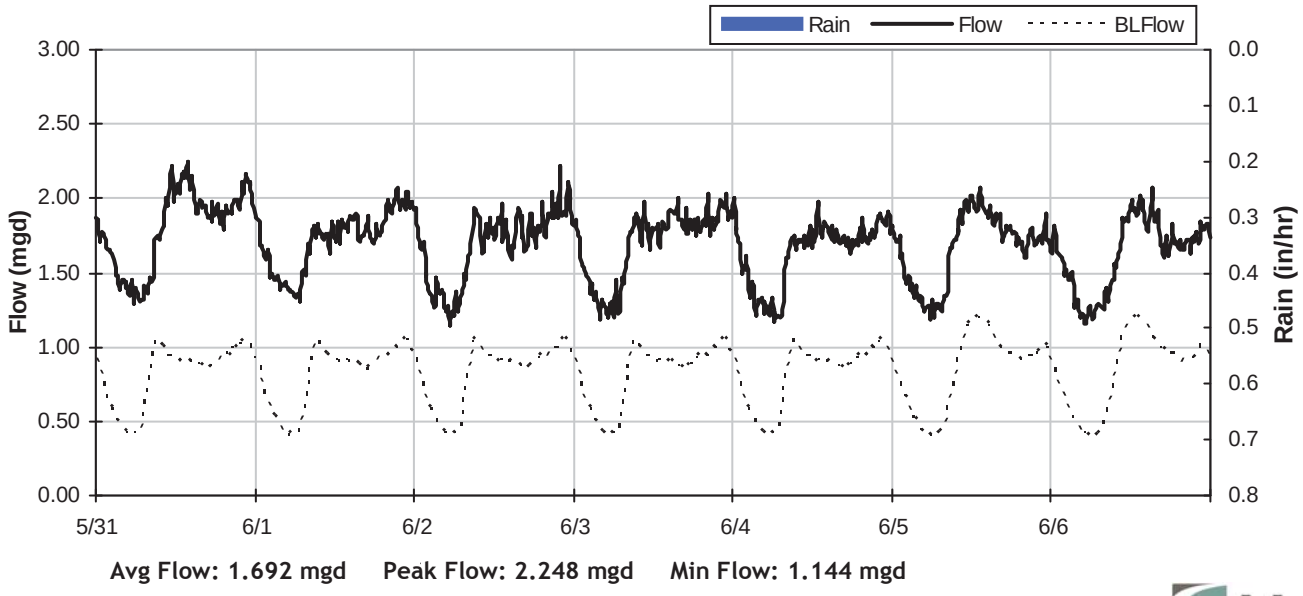
Avg Flow: 1.681 mgd Peak Flow: 2.442 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 1A



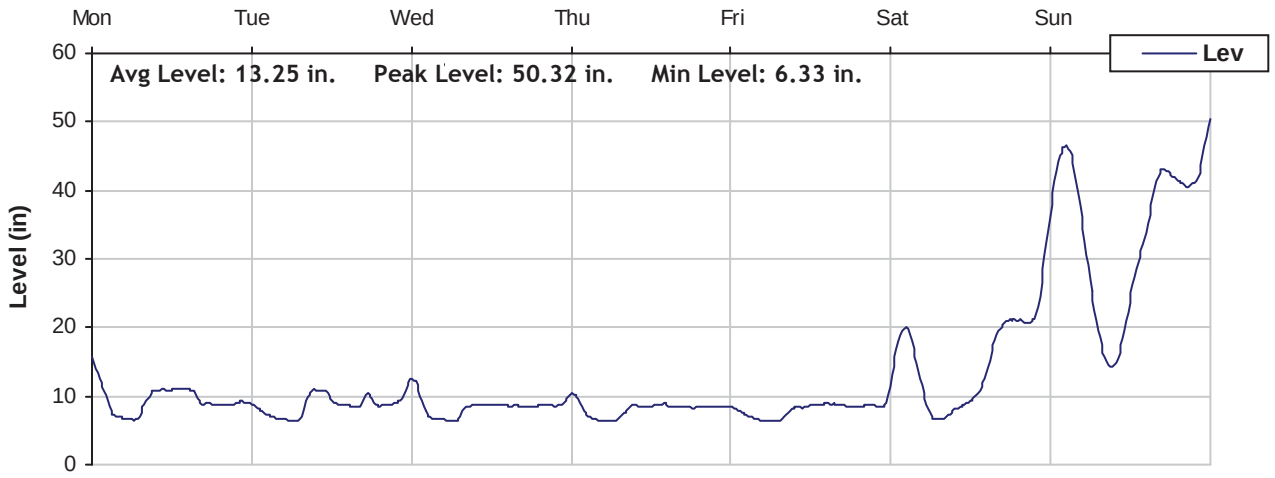


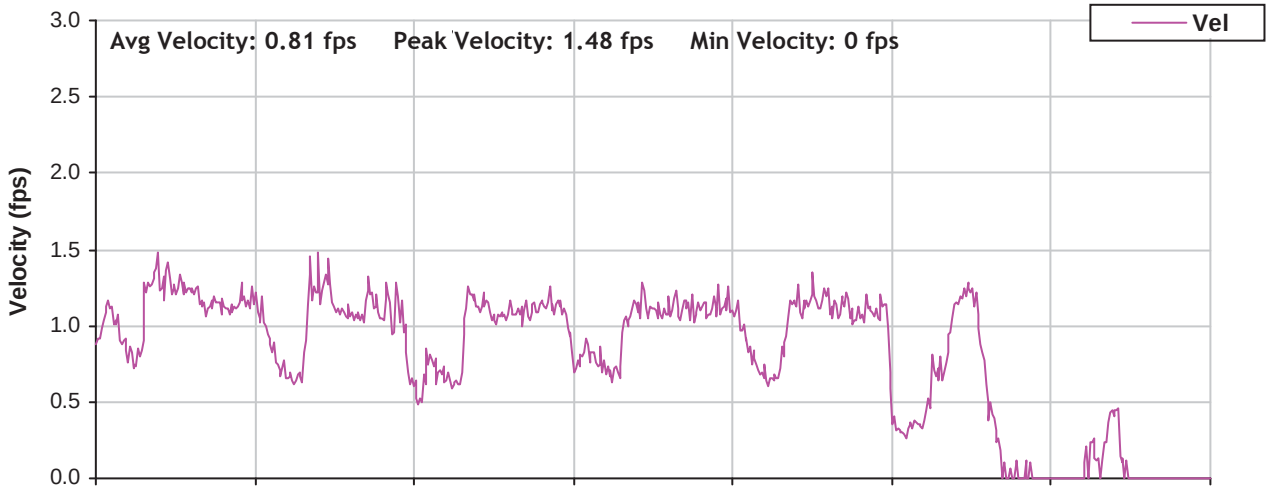


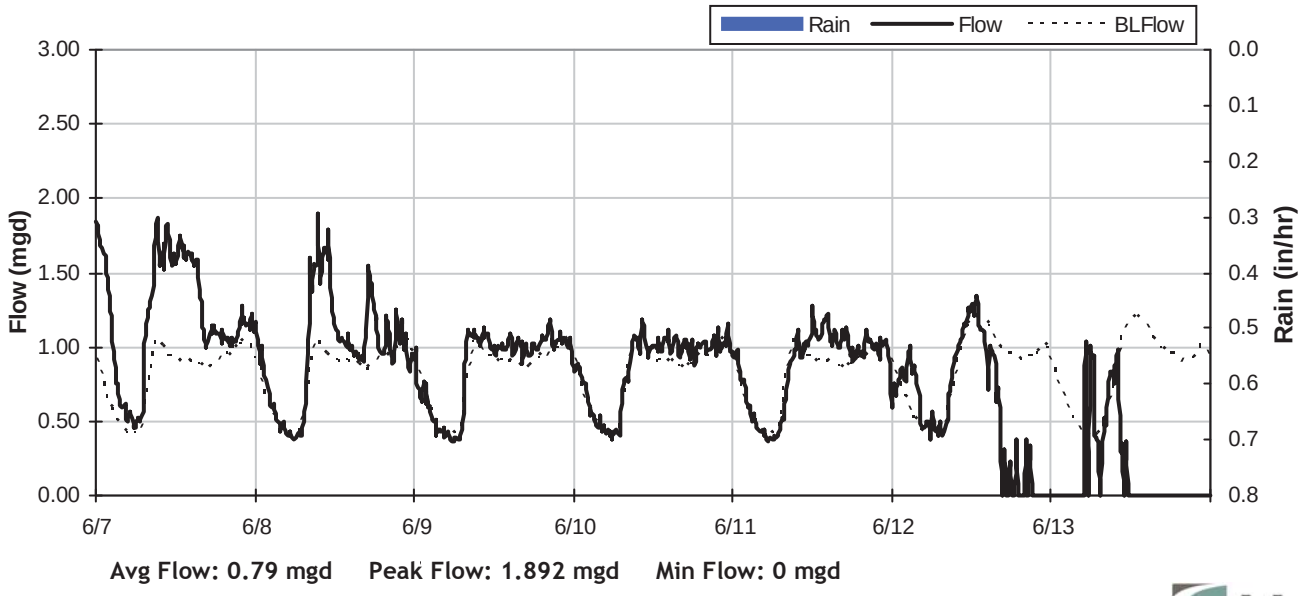
Avg Flow: 1.692 mgd Peak Flow: 2.248 mgd Min Flow: 1.144 mgd

Level, Velocity and Flow
From 6/7/2010 to 6/14/2010

Monitoring Site:
Site 1A



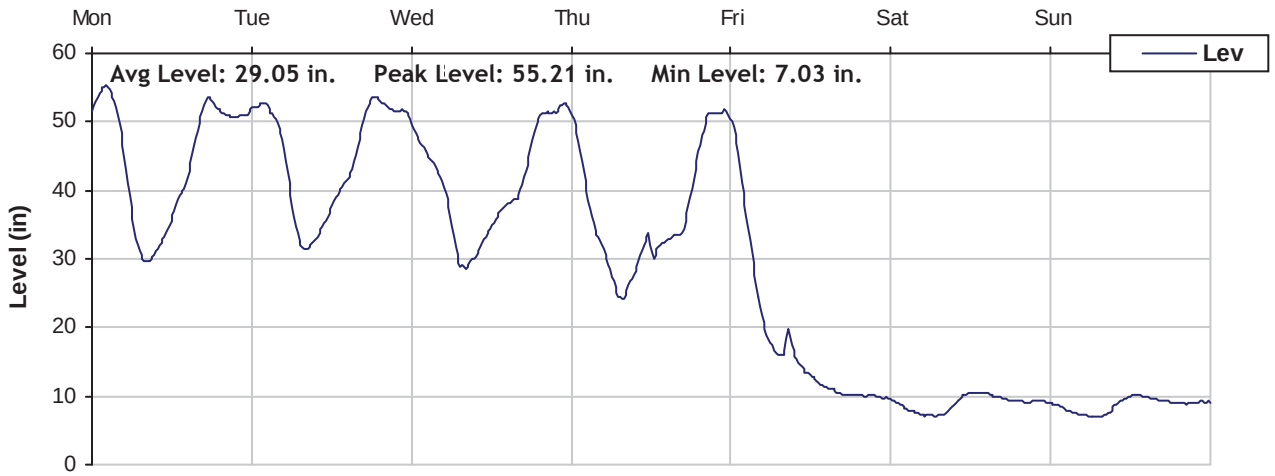


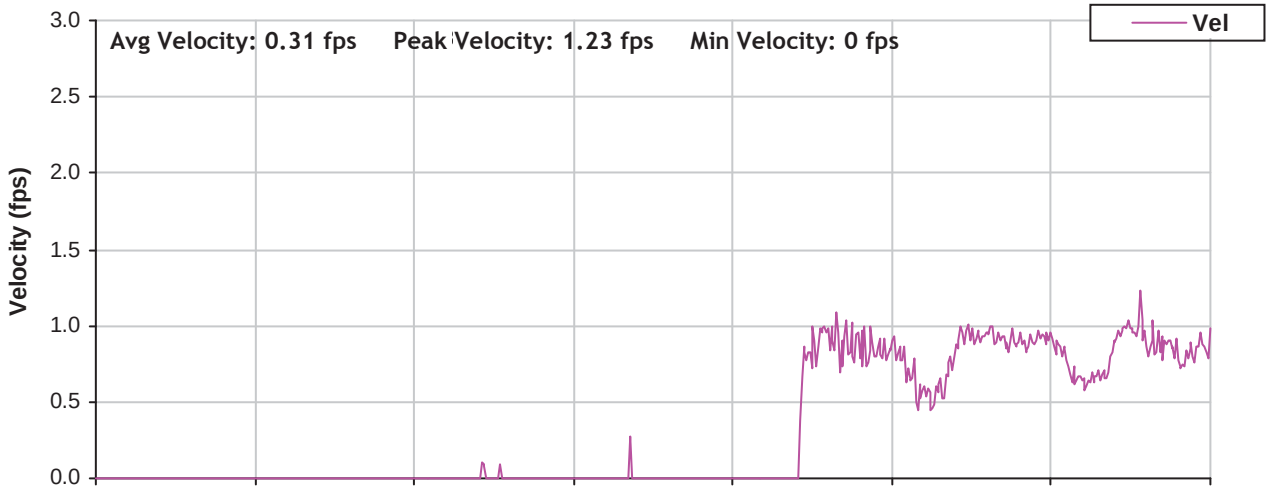


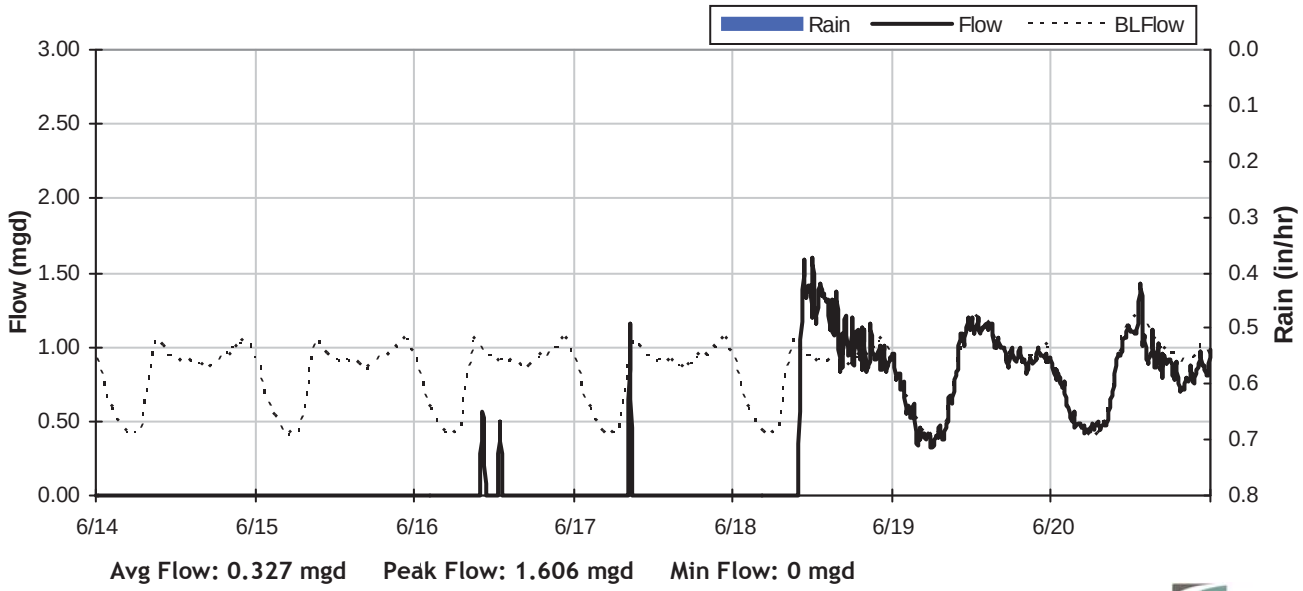
Avg Flow: 0.79 mgd Peak Flow: 1.892 mgd Min Flow: 0 mgd

Level, Velocity and Flow
From 6/14/2010 to 6/21/2010

Monitoring Site:
Site 1A







Avg Flow: 0.327 mgd Peak Flow: 1.606 mgd Min Flow: 0 mgd

Temporary Flow Monitoring Study

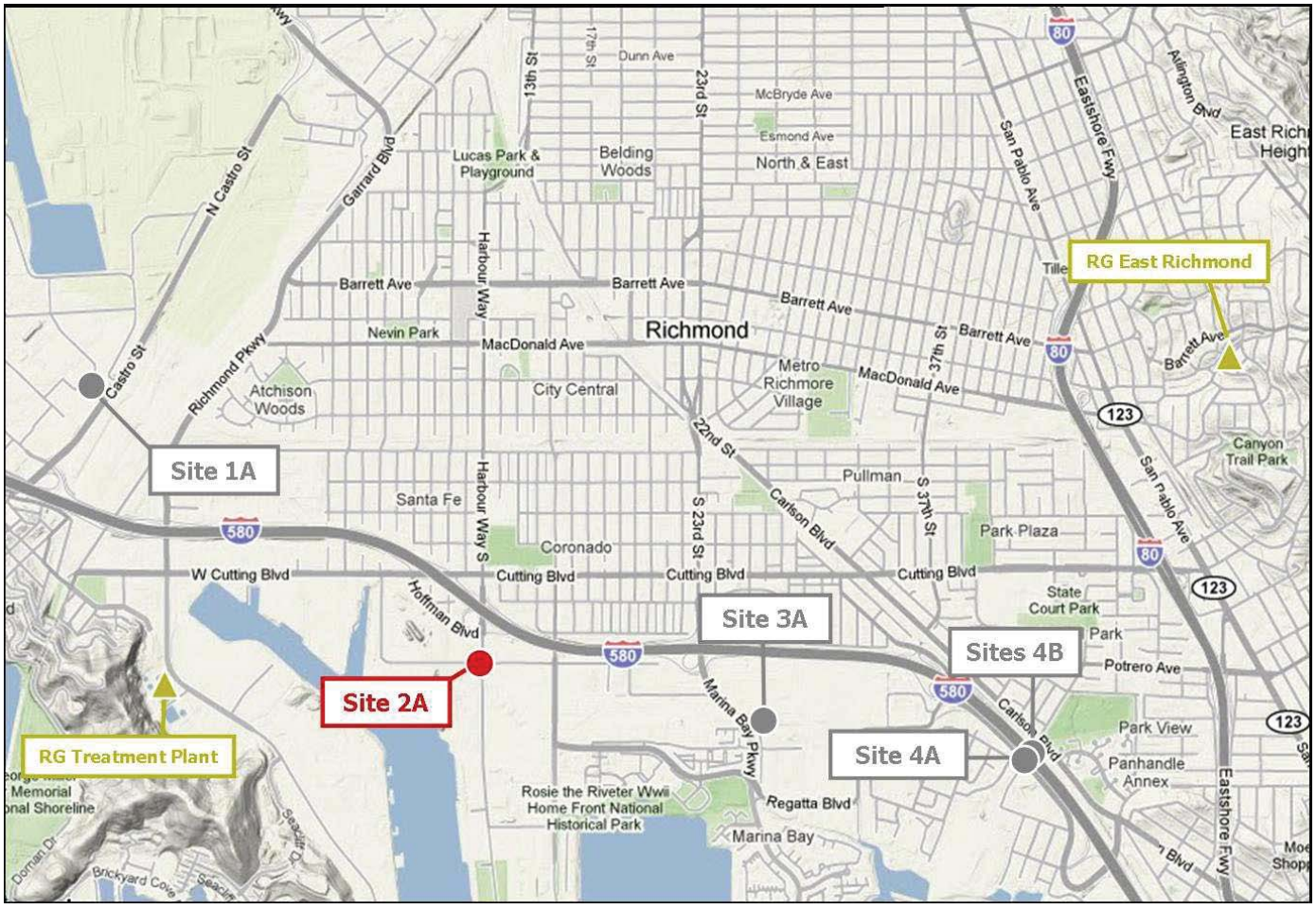
Sanitary Sewer Collection System

Monitoring Site: Site 2A

Location: Intersection of Wright Ave. and S. Harbour Way

Size/Type Line: 18-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 2A

Location: Intersection of Wright Ave. and S. Harbour Way

Latitude: 37.9444°

Longitude: -122.3599°

Rim Elevation: 31 *feet above sea level*

Diameter: 18 *inches*

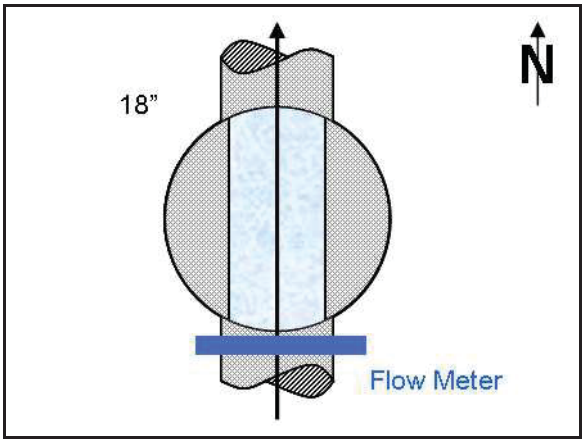
Average Dry Weather Flow: 0.031 *mgd*

Peak Measured Flow: 1.584 *mgd*

Satellite Photo

Sanitary Map

Flow Sketch

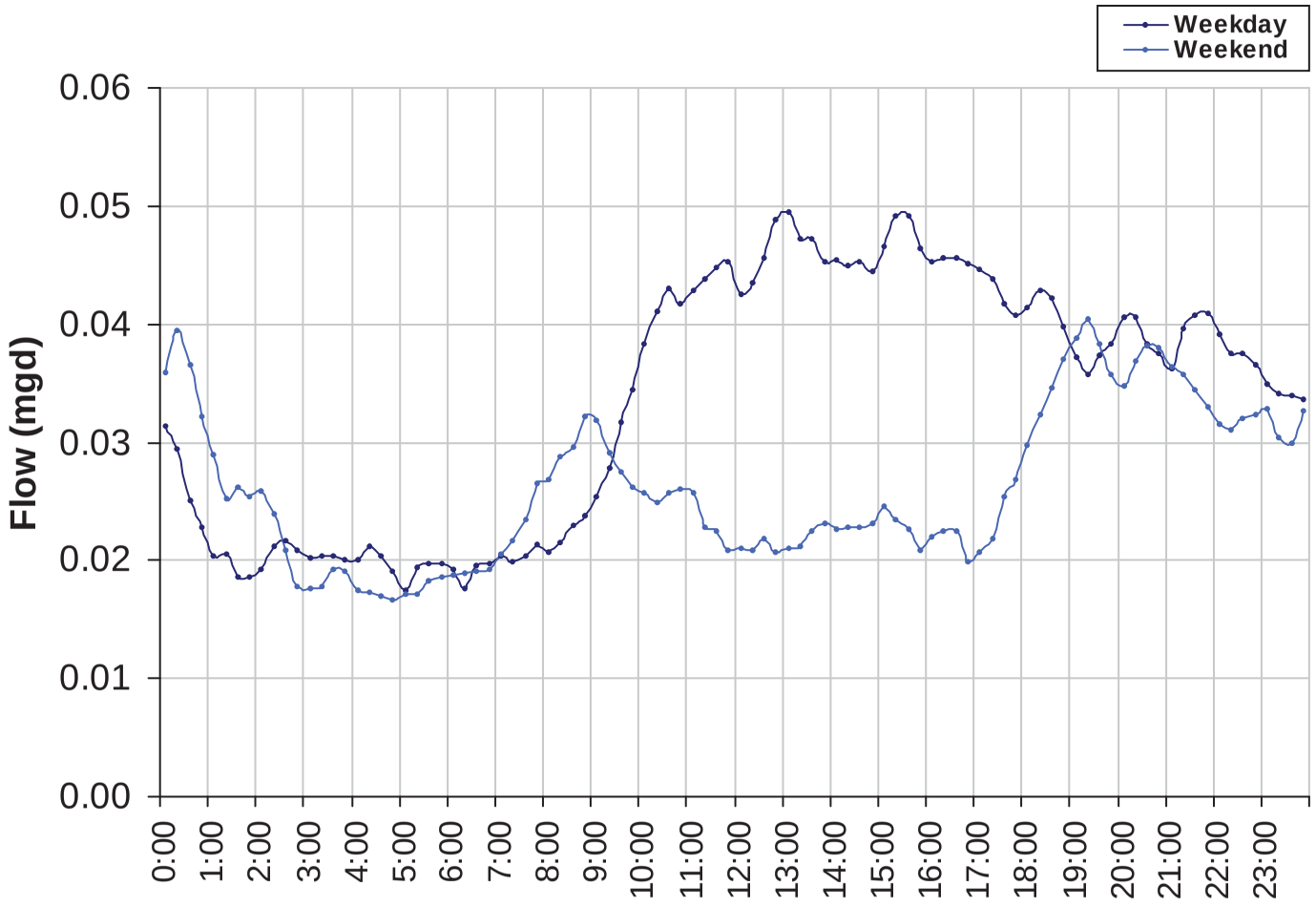


Street View Photo

Plan View Photo

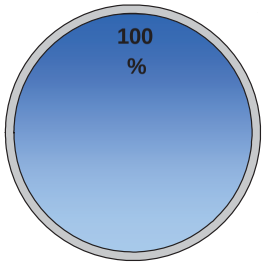
Average Dry Weather Flow

Monitoring Site:
Site 2A



Peak Measured Flow:

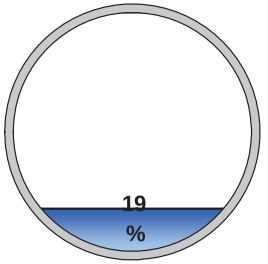
1.58 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

0.03 *mgd*

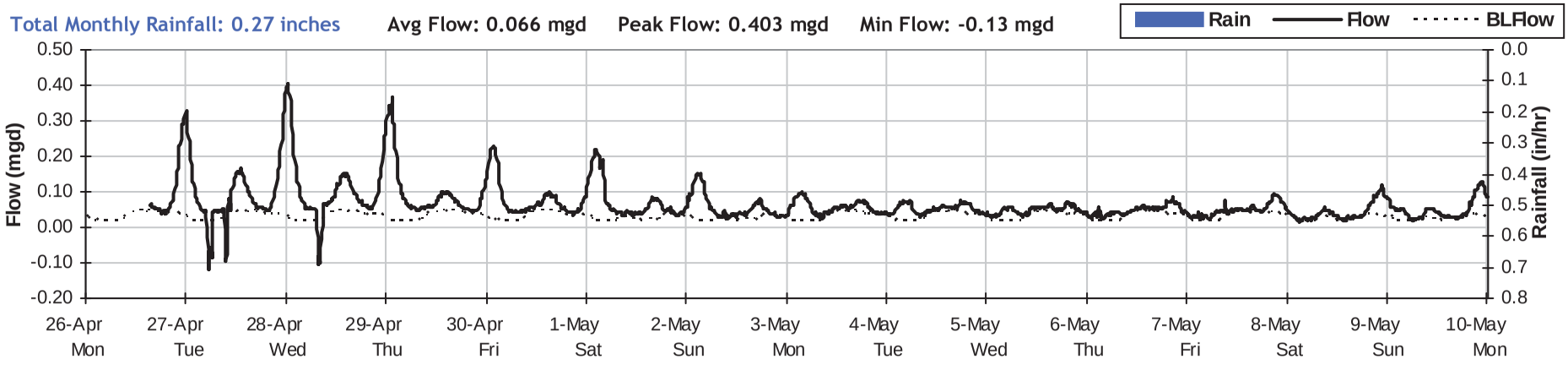


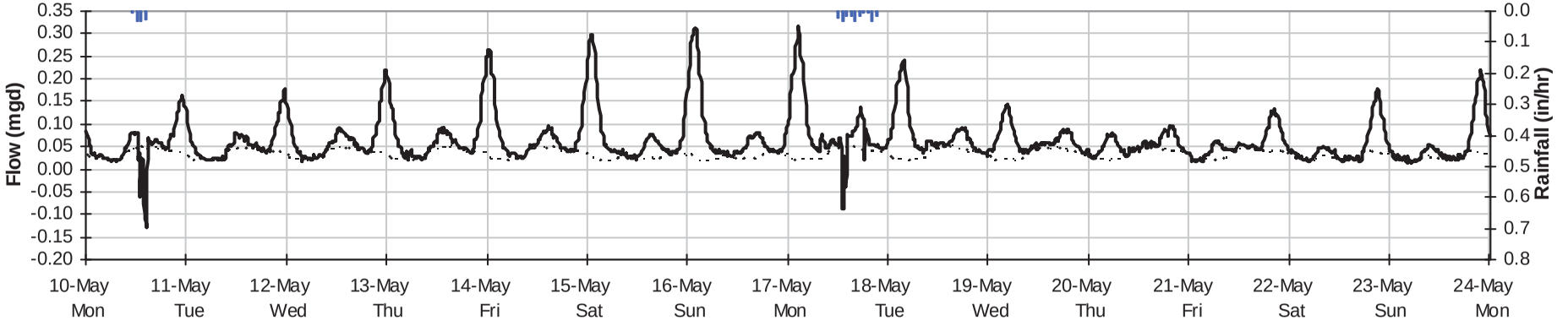
V&A

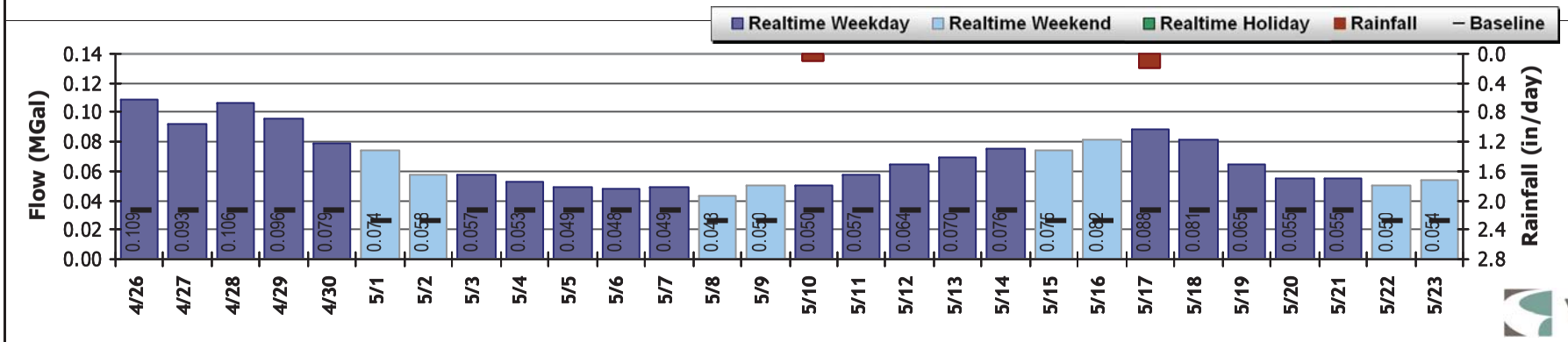
Period Flow Summary
April 26 to May 23, 2010

Monitoring Site:
Site 2A

Total Monthly Rainfall: 0.27 inches Avg Flow: 0.066 mgd Peak Flow: 0.403 mgd Min Flow: -0.13 mgd





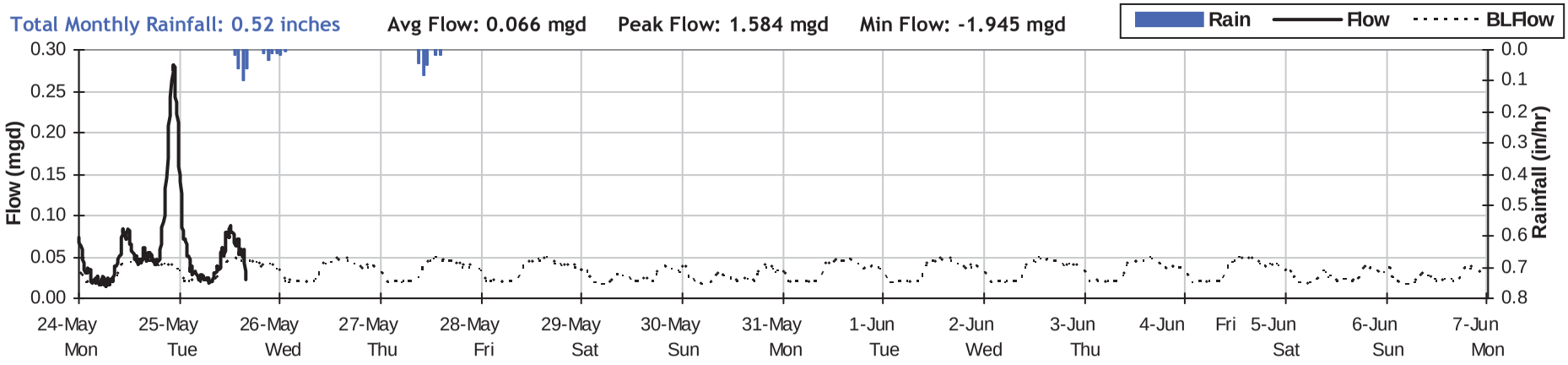


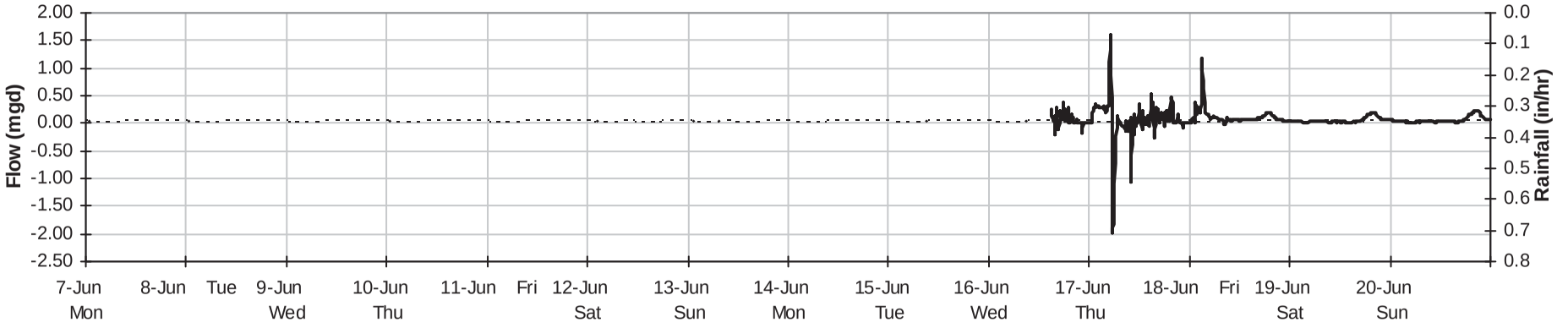
V&A

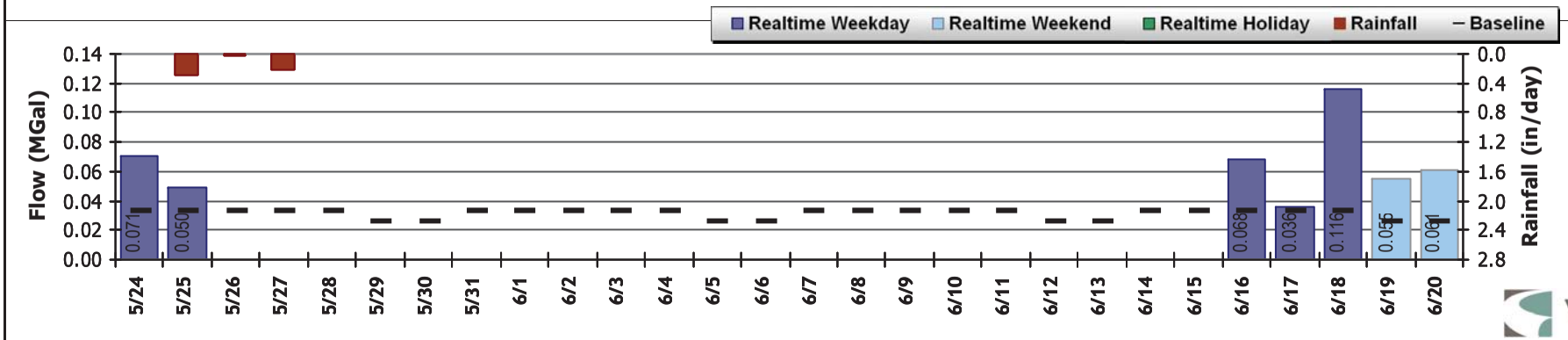
Period Flow Summary
May 24 to June 21, 2010

Monitoring Site:
Site 2A

Total Monthly Rainfall: 0.52 inches Avg Flow: 0.066 mgd Peak Flow: 1.584 mgd Min Flow: -1.945 mgd



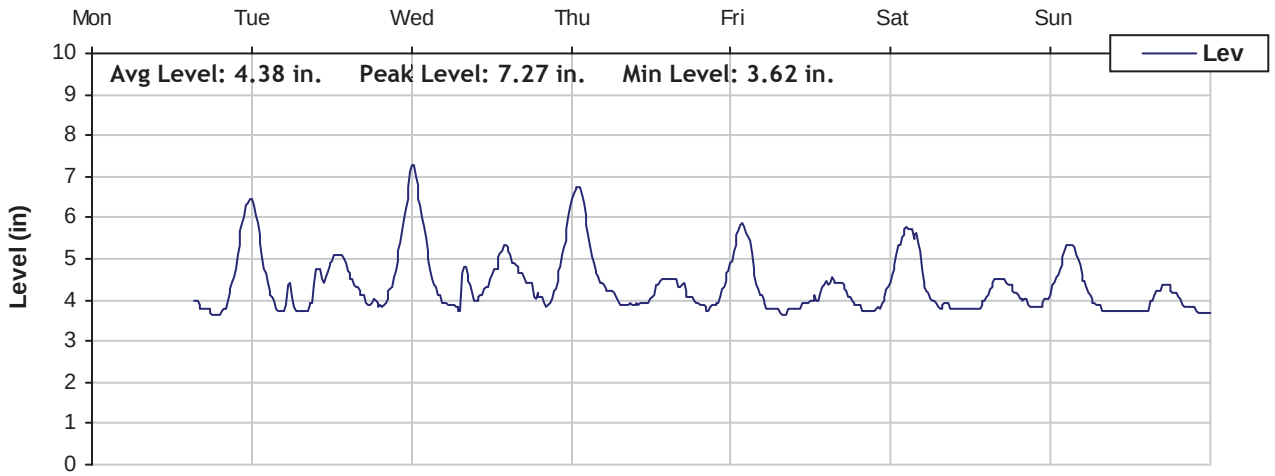


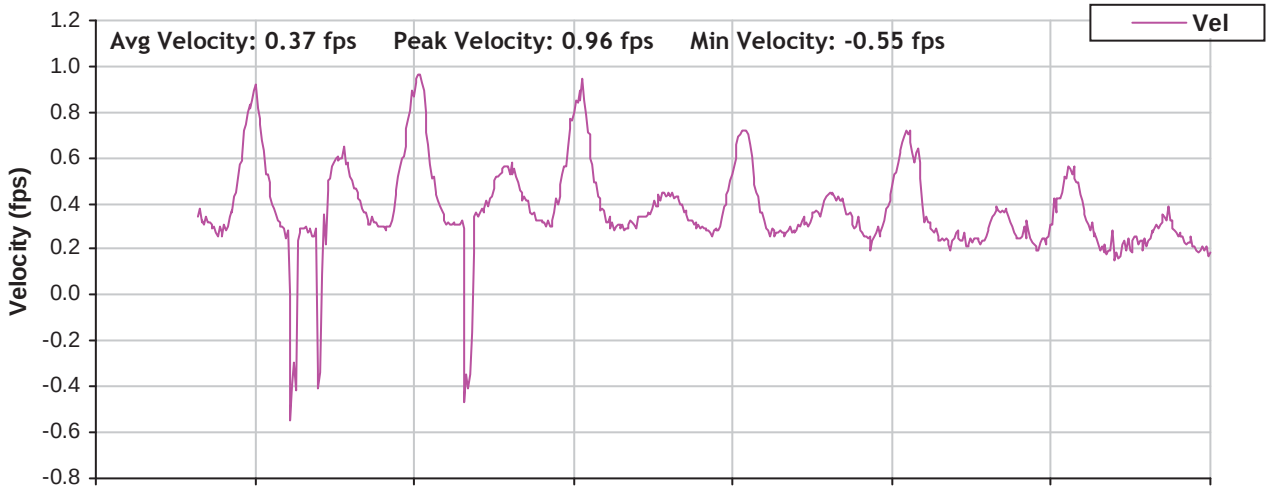


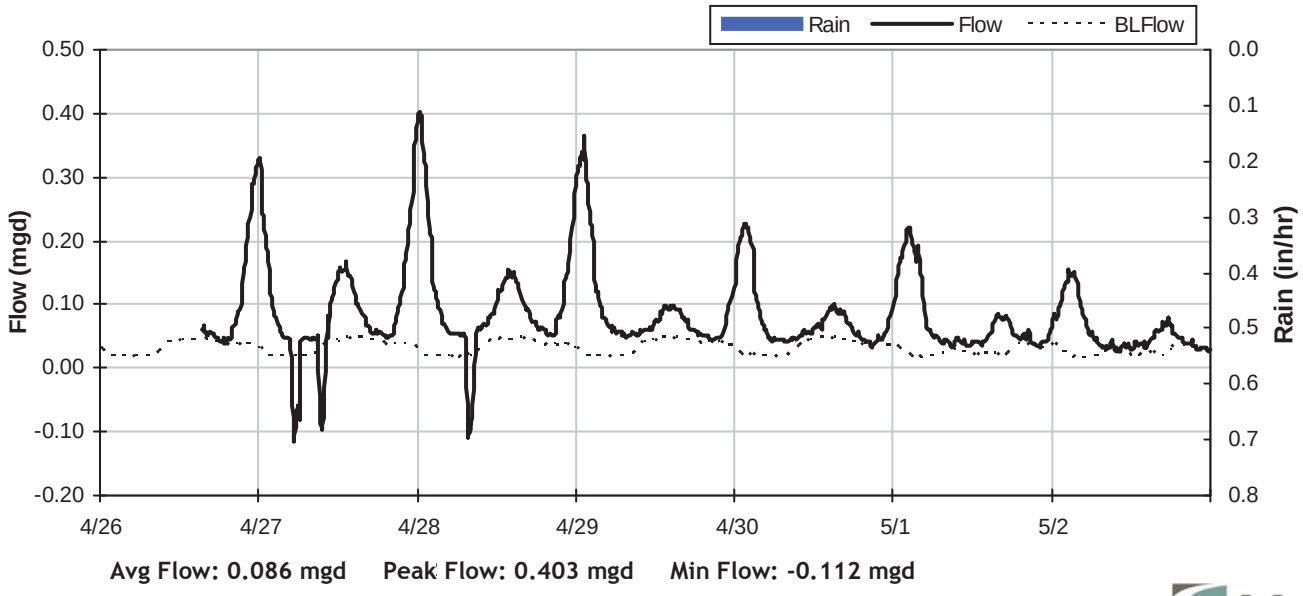
V&A

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 2A

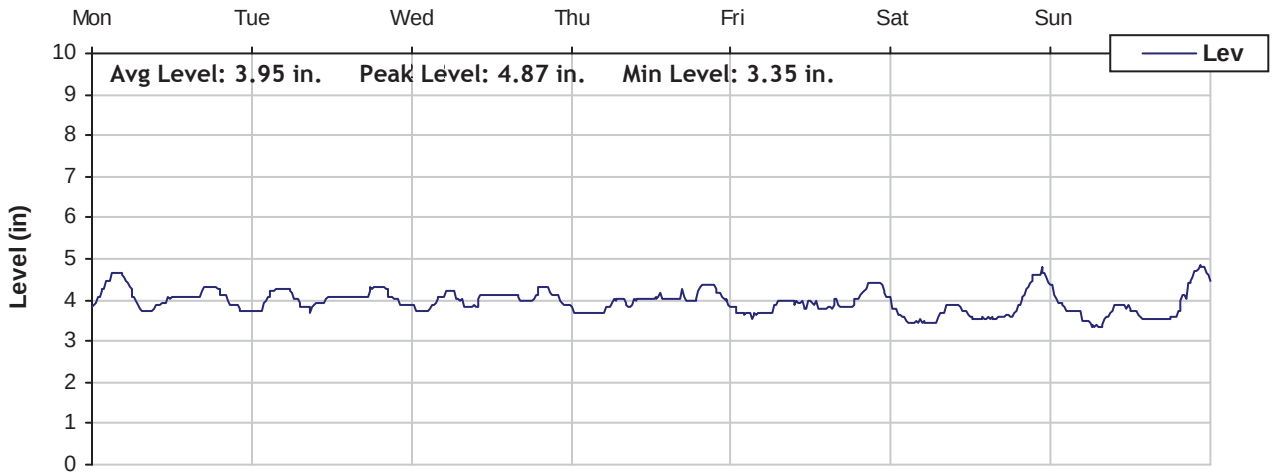


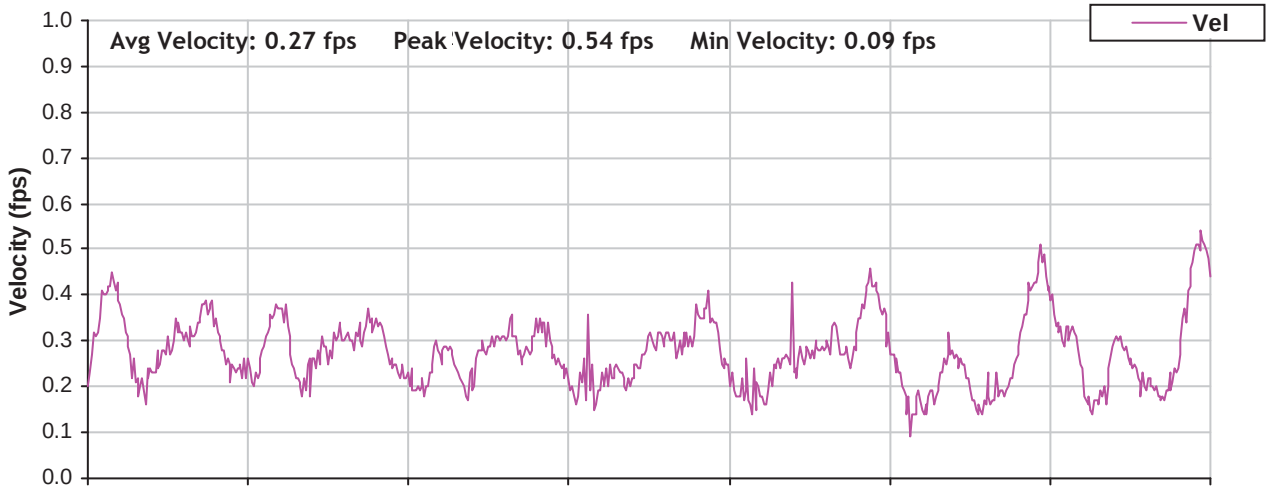


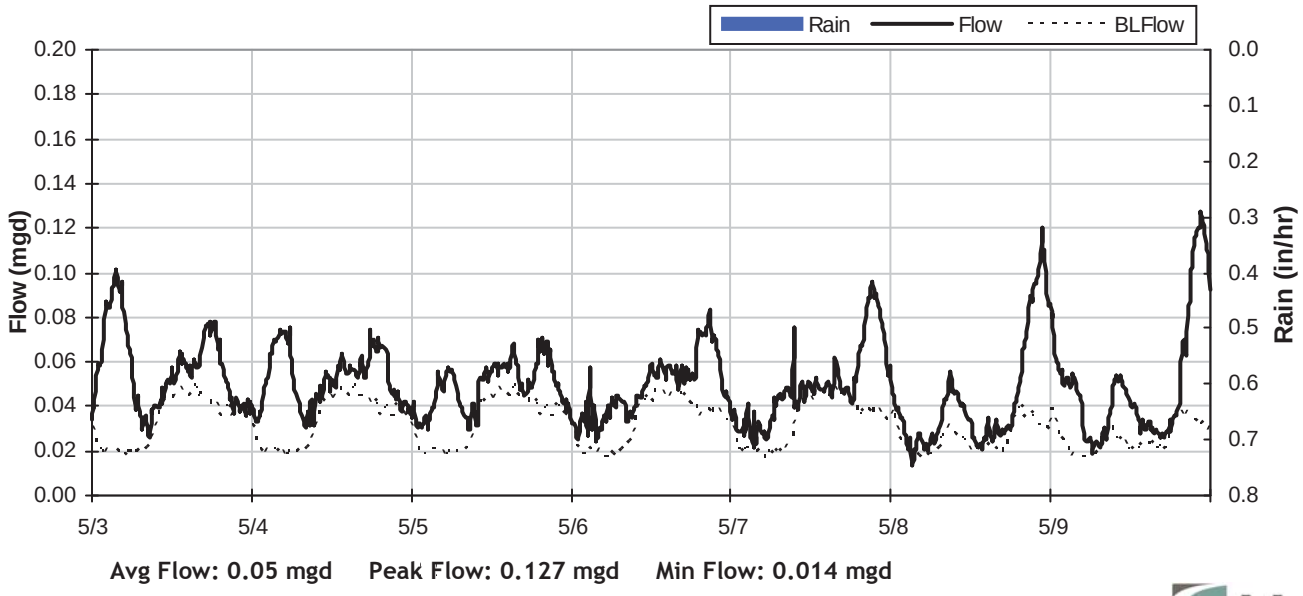


Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 2A



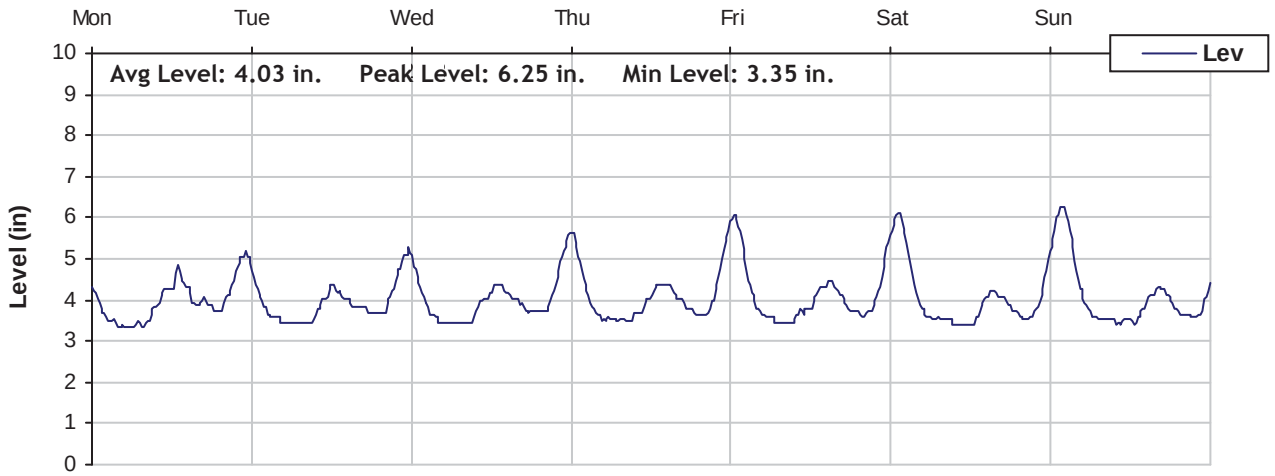


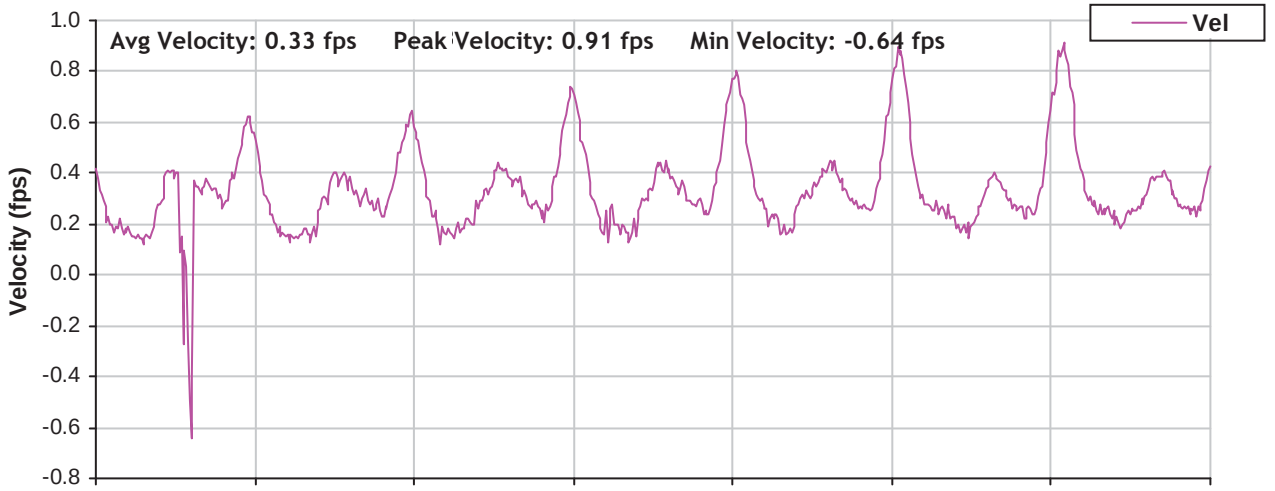


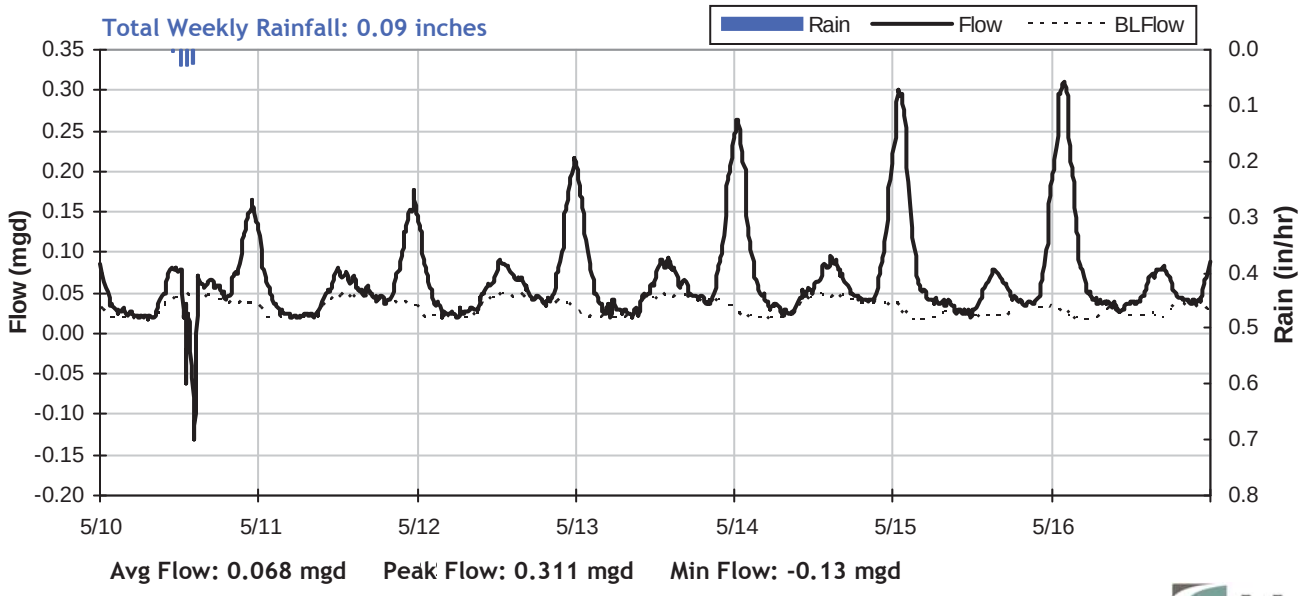
Avg Flow: 0.05 mgd Peak Flow: 0.127 mgd Min Flow: 0.014 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 2A



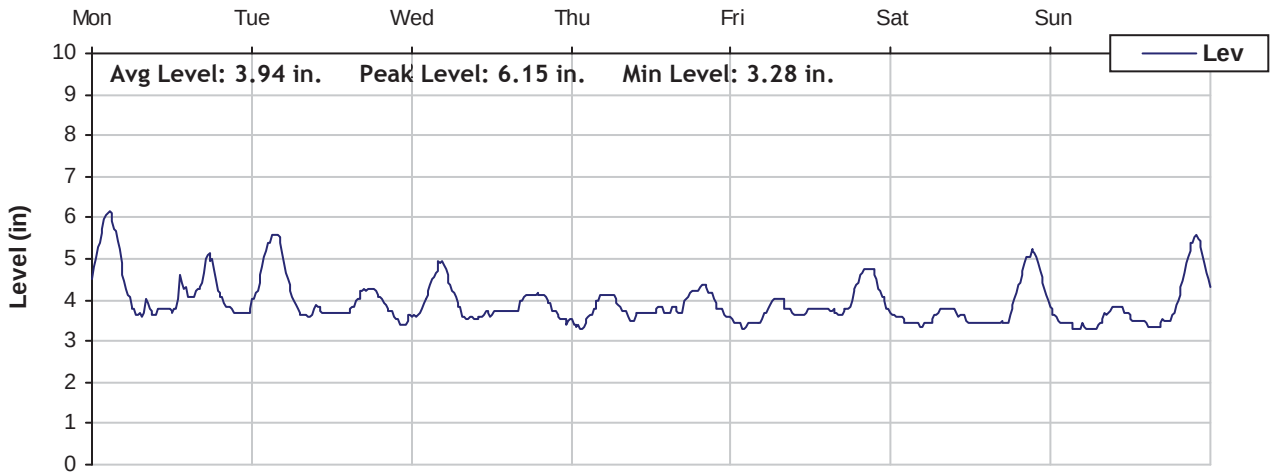


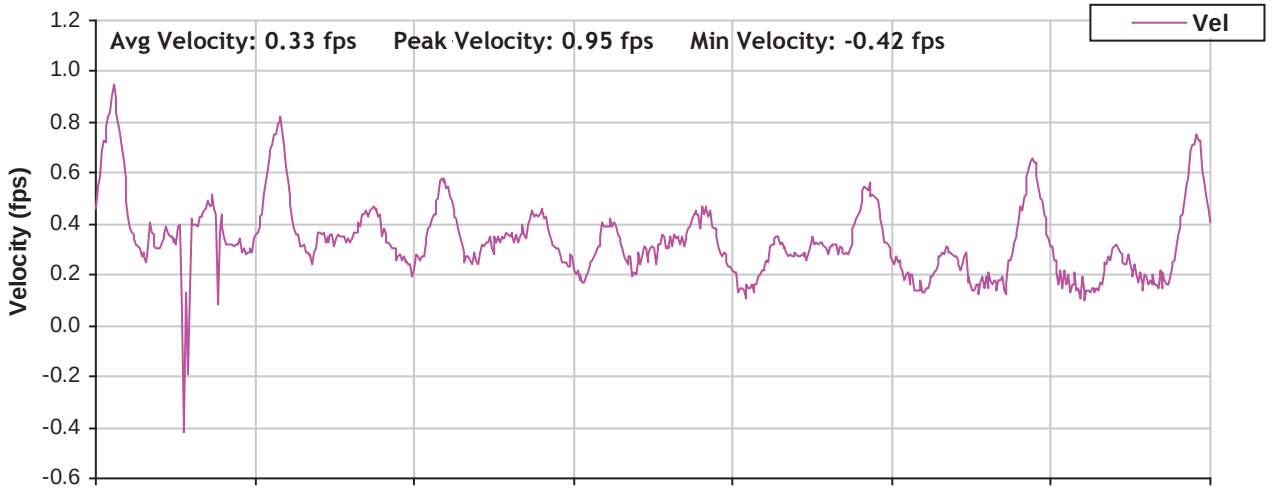


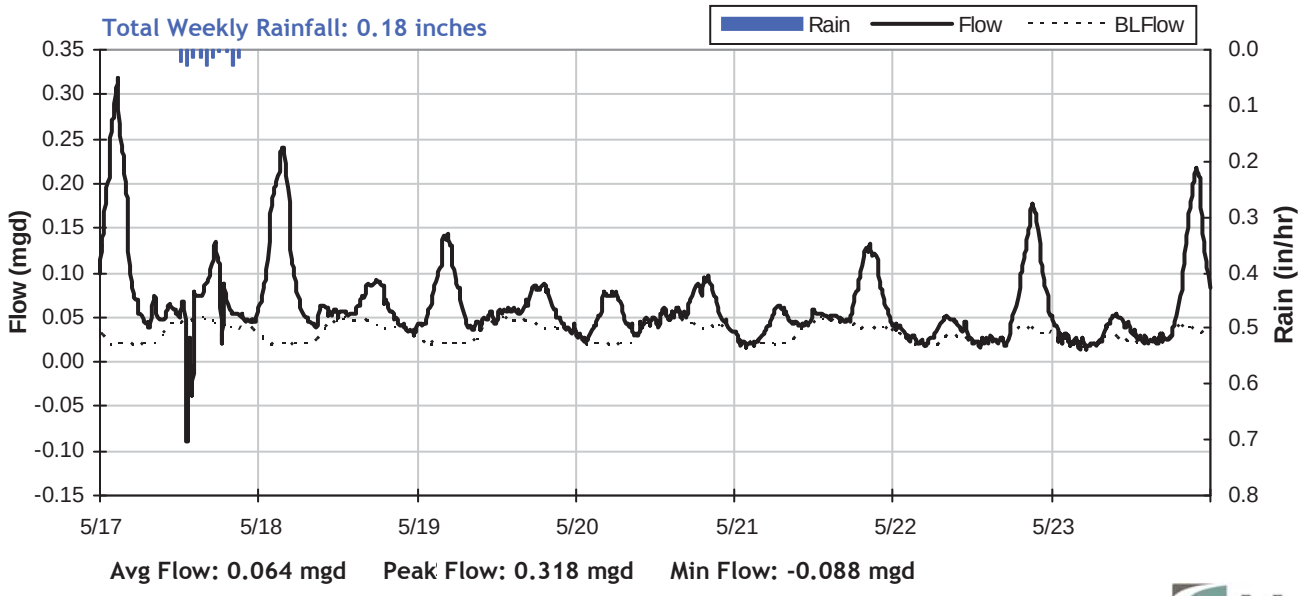
Avg Flow: 0.068 mgd Peak Flow: 0.311 mgd Min Flow: -0.13 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 2A

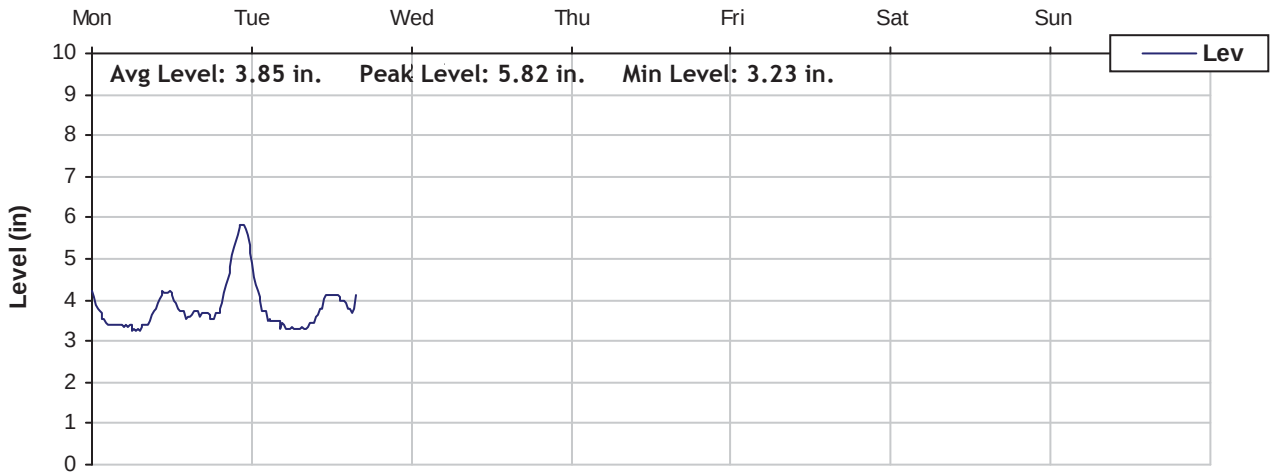


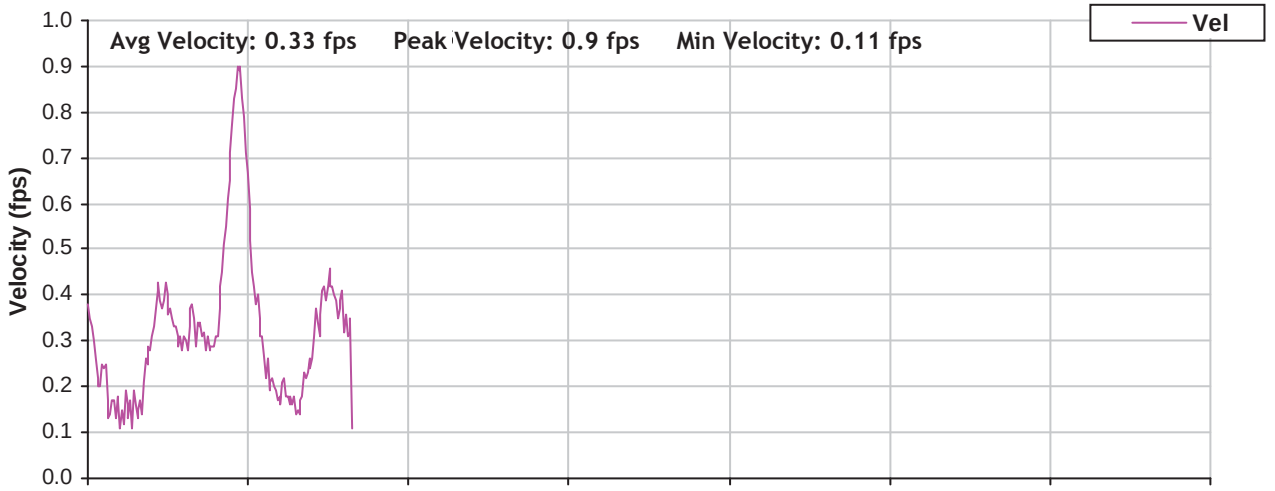


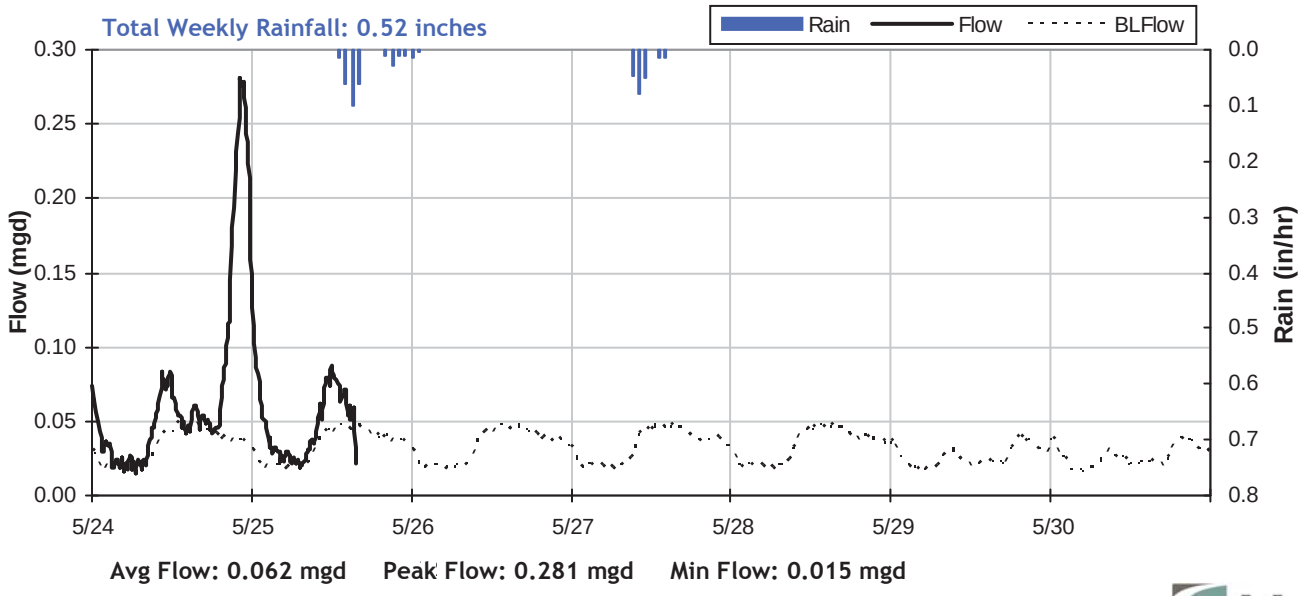


Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 2A

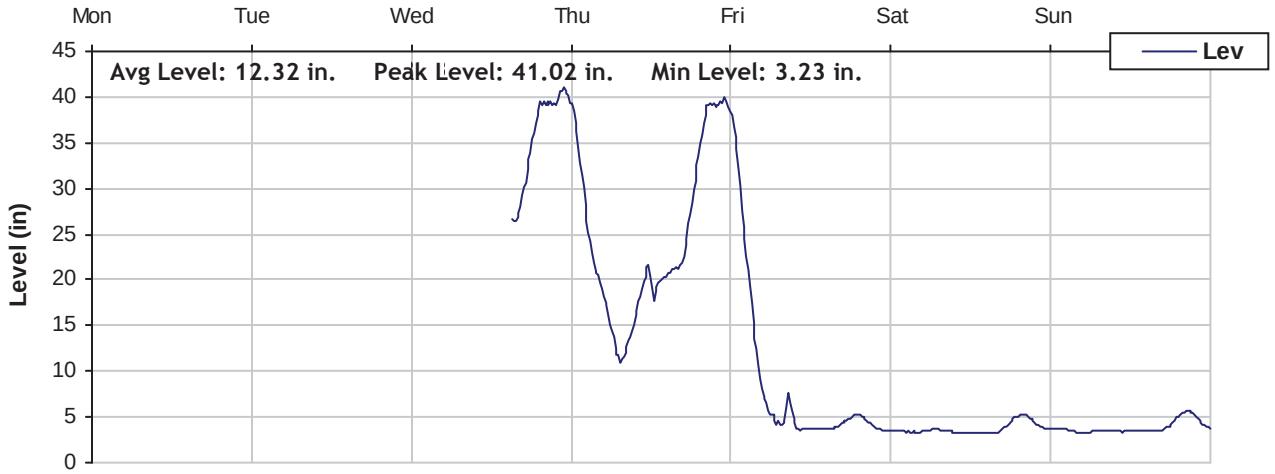


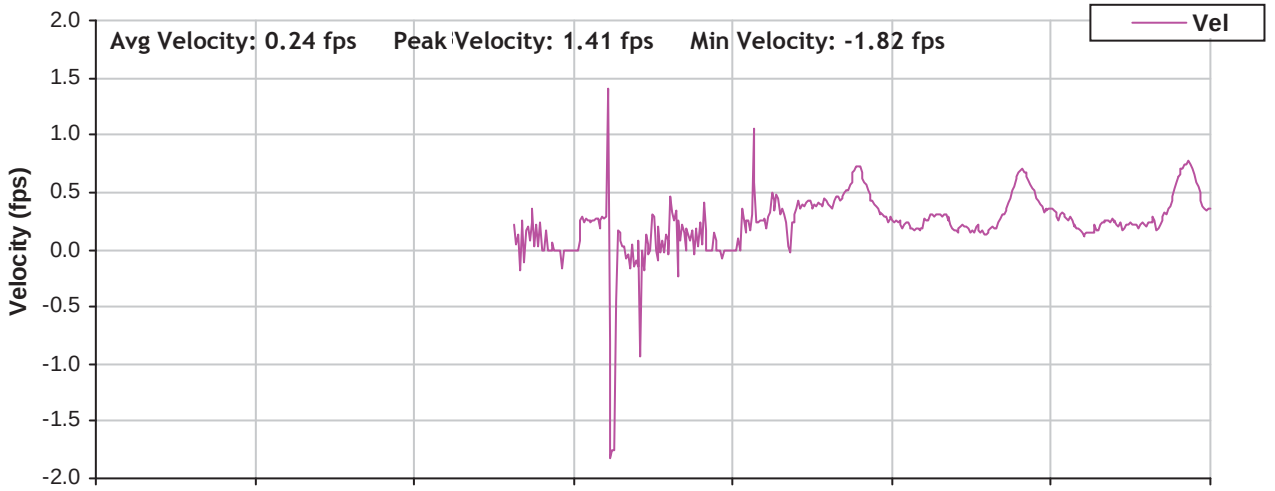


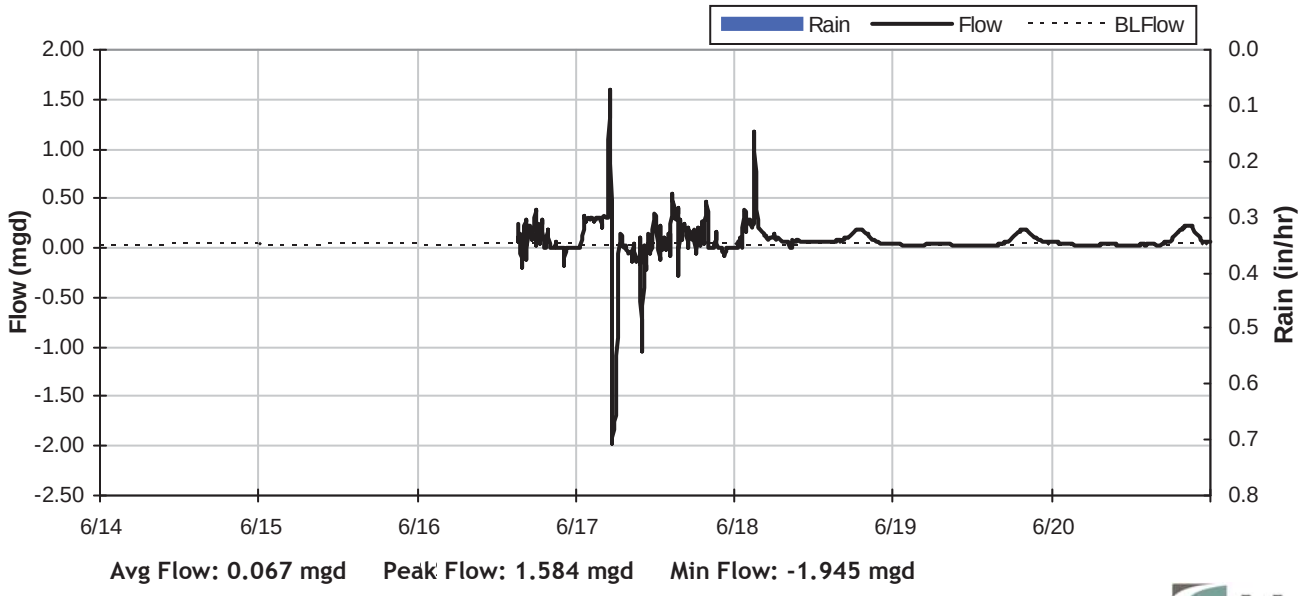


Level, Velocity and Flow
From 6/14/2010 to 6/21/2010

Monitoring Site:
Site 2A







Avg Flow: 0.067 mgd Peak Flow: 1.584 mgd Min Flow: -1.945 mgd

Temporary Flow Monitoring Study

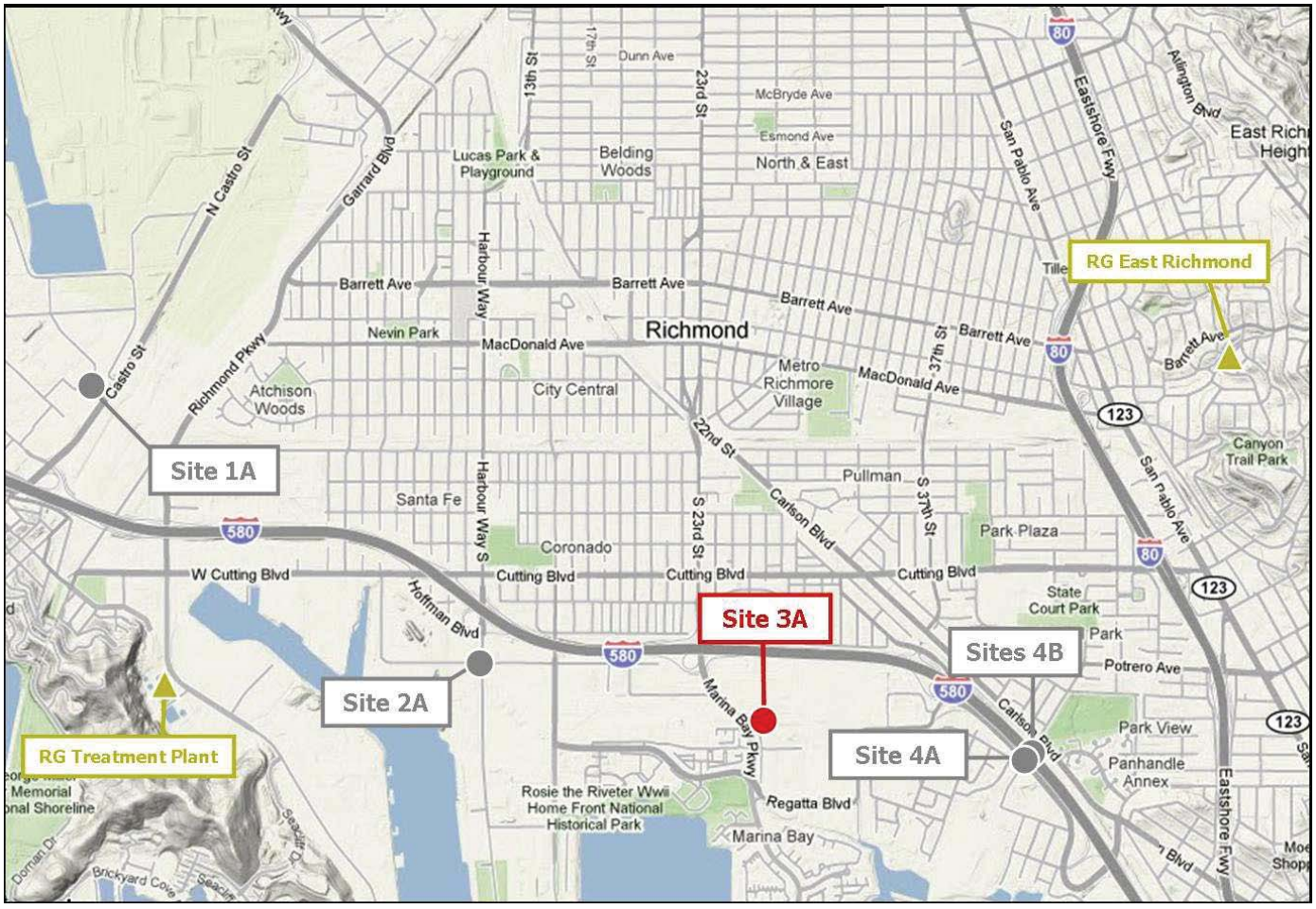
Sanitary Sewer Collection System

Monitoring Site: Site 3A

Location: Alongside railroad tracks north of S. 27th St., north or Pierson St.

Size/Type Line: 30-inch Sanitary Sewer Pipe

Data Summary Report



Site Information Report

Monitoring Site: Site 3A

Location: Alongside railroad tracks north of S. 27th St., north or Pierson St.

Latitude: 37.9253°

Longitude: -122.3711°

Rim Elevation: 10 *feet*

Diameter: 30 *inches*

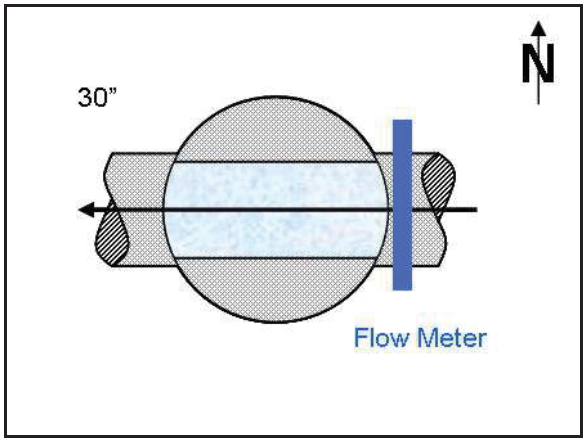
Average Dry Weather Flow: 1.113 *mgd*

Peak Measured Flow: 2.867 *mgd*

Satellite Photo

Sanitary Map

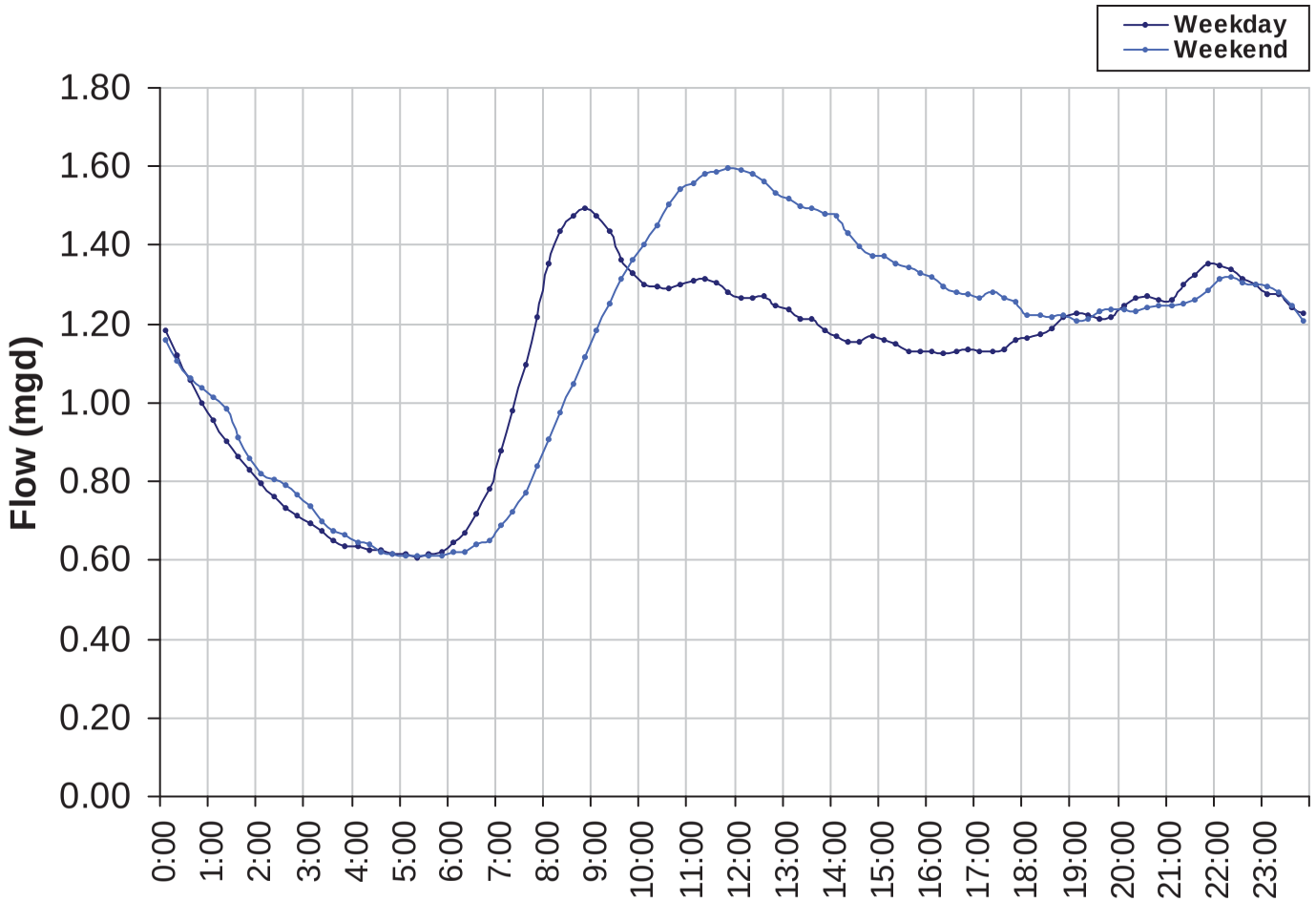
Flow Sketch



Street View Photo

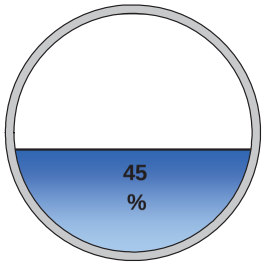
Average Dry Weather Flow

Monitoring Site:
Site 3A



Peak Measured Flow:

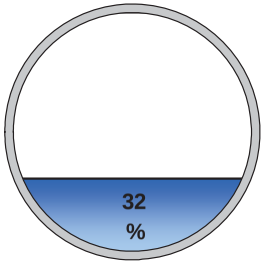
2.87 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

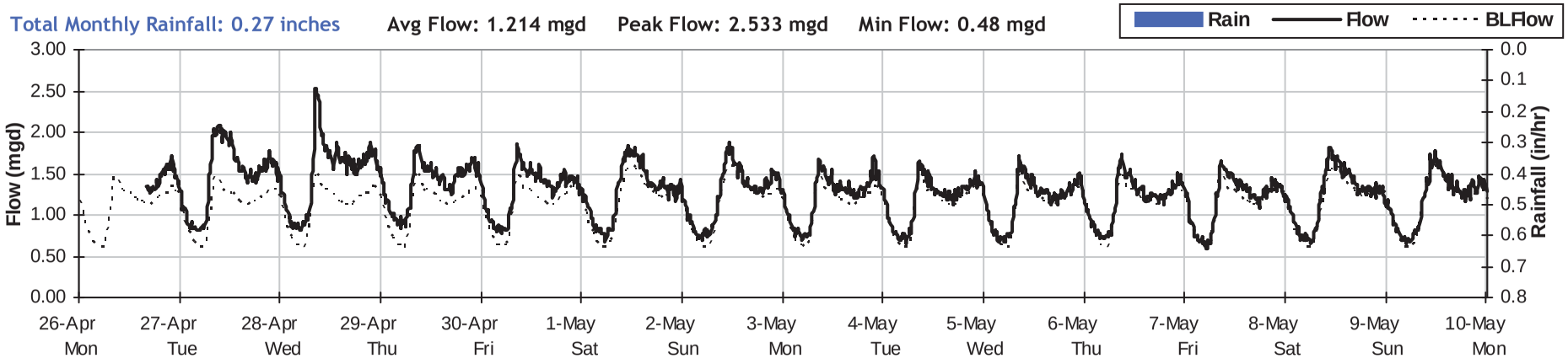
1.11 *mgd*

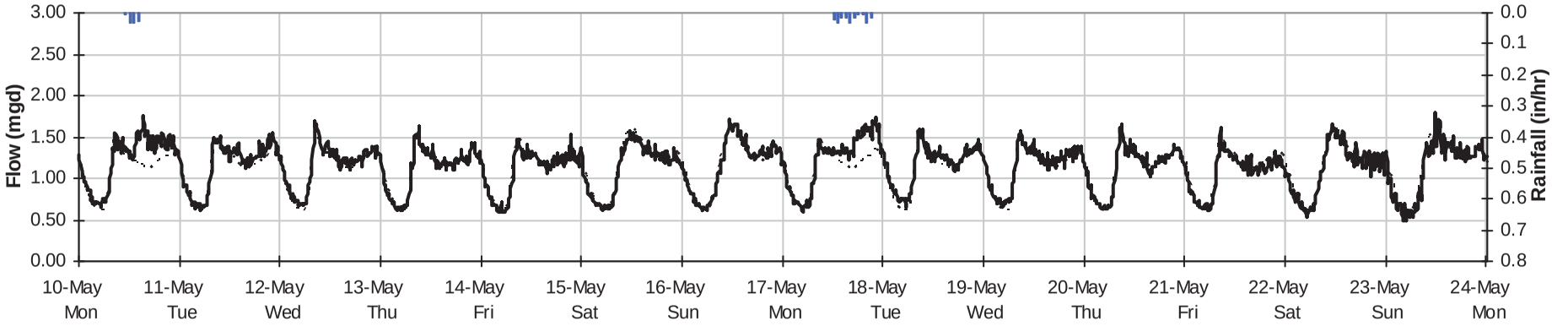


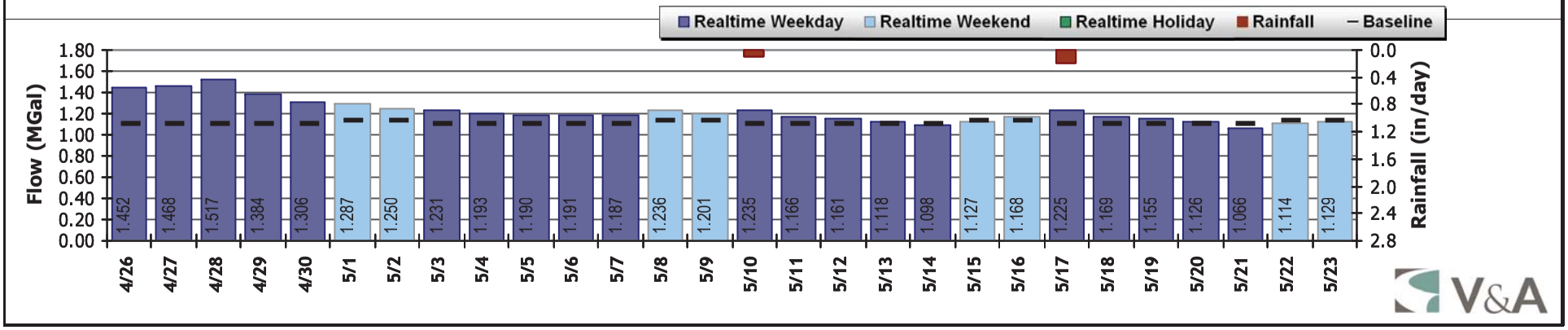
Period Flow Summary
April 26 to May 23, 2010

Monitoring Site:
Site 3A

Total Monthly Rainfall: 0.27 inches Avg Flow: 1.214 mgd Peak Flow: 2.533 mgd Min Flow: 0.48 mgd





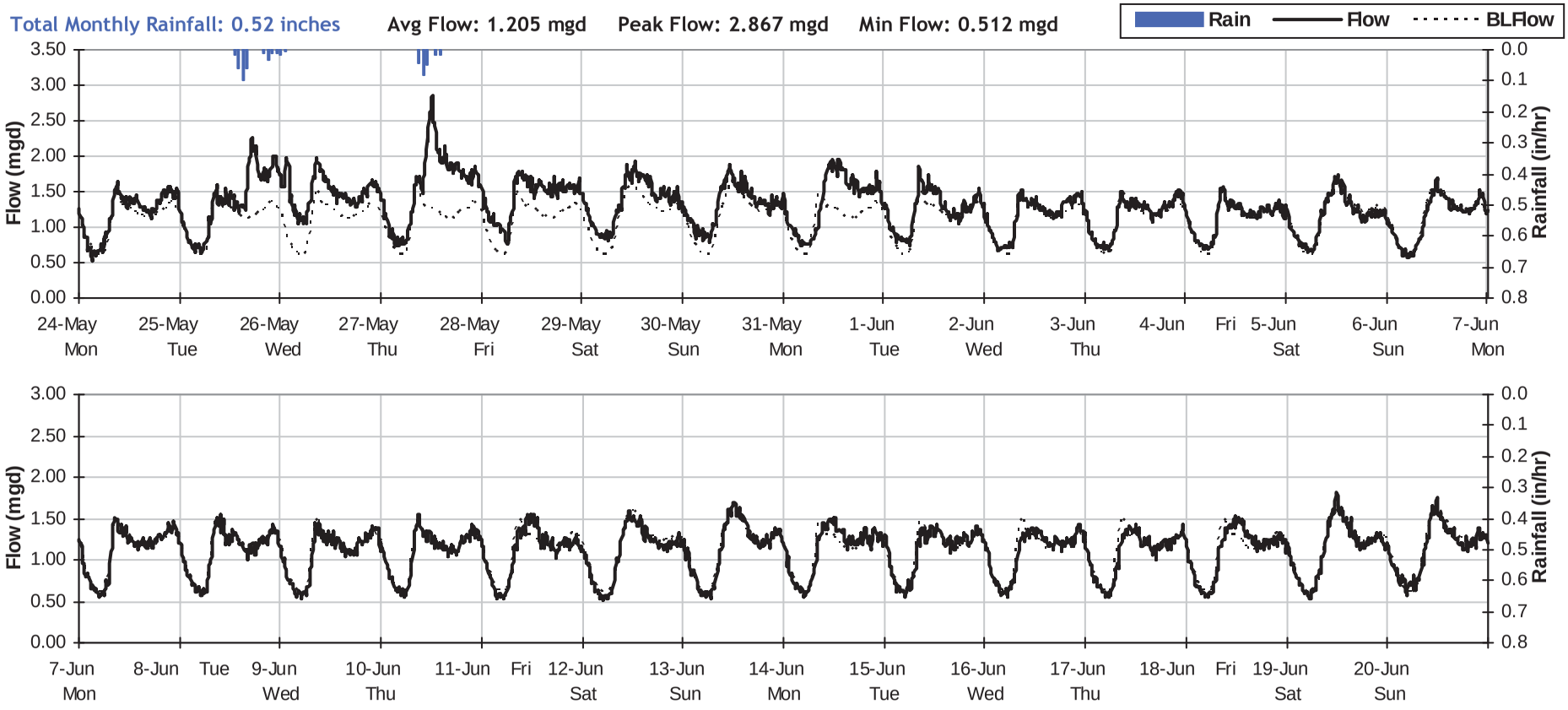


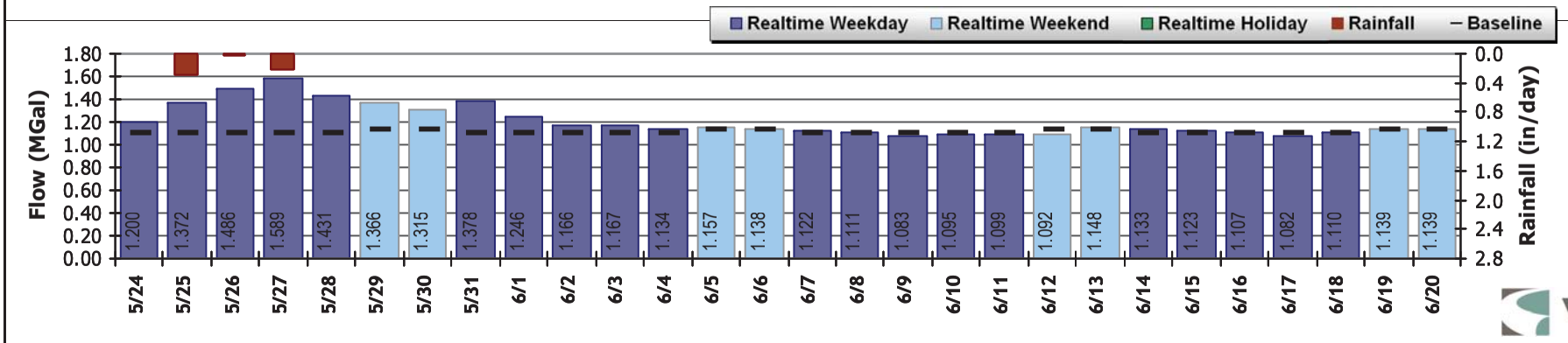
V&A

Period Flow Summary
May 24 to June 21, 2010

Monitoring Site:
Site 3A

Total Monthly Rainfall: 0.52 inches Avg Flow: 1.205 mgd Peak Flow: 2.867 mgd Min Flow: 0.512 mgd

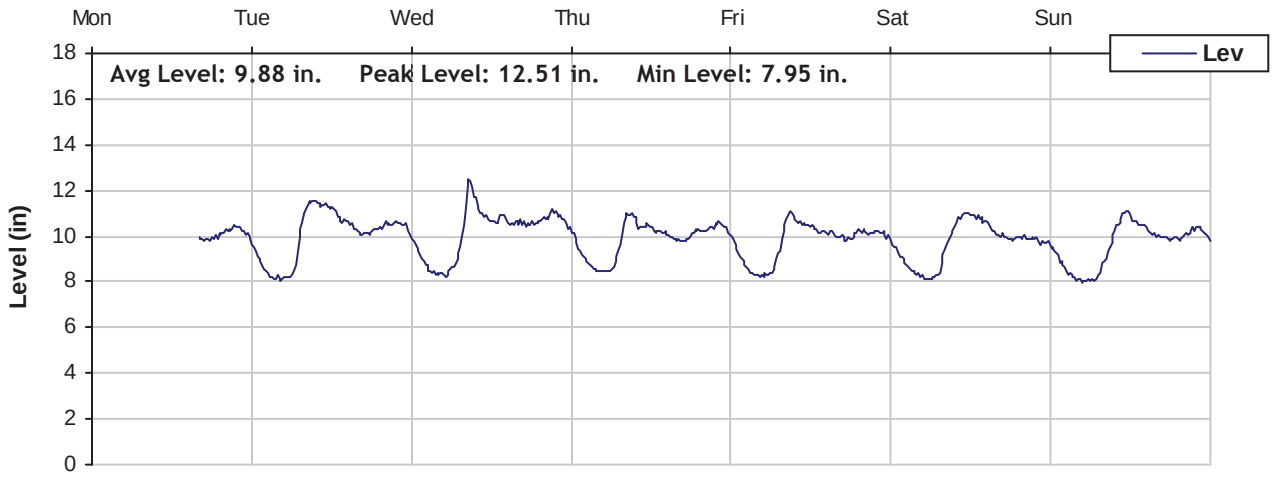


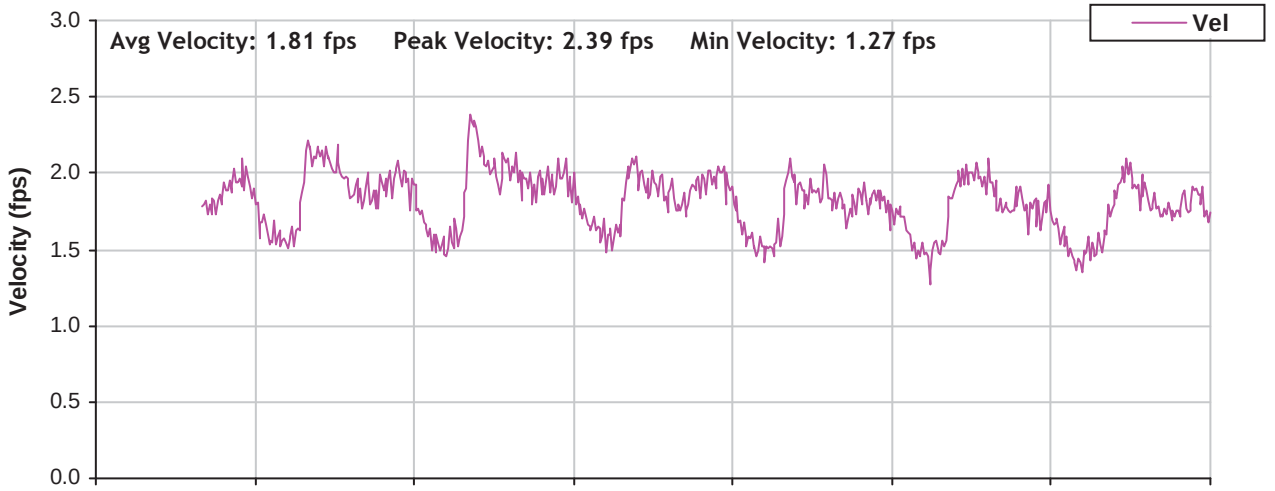


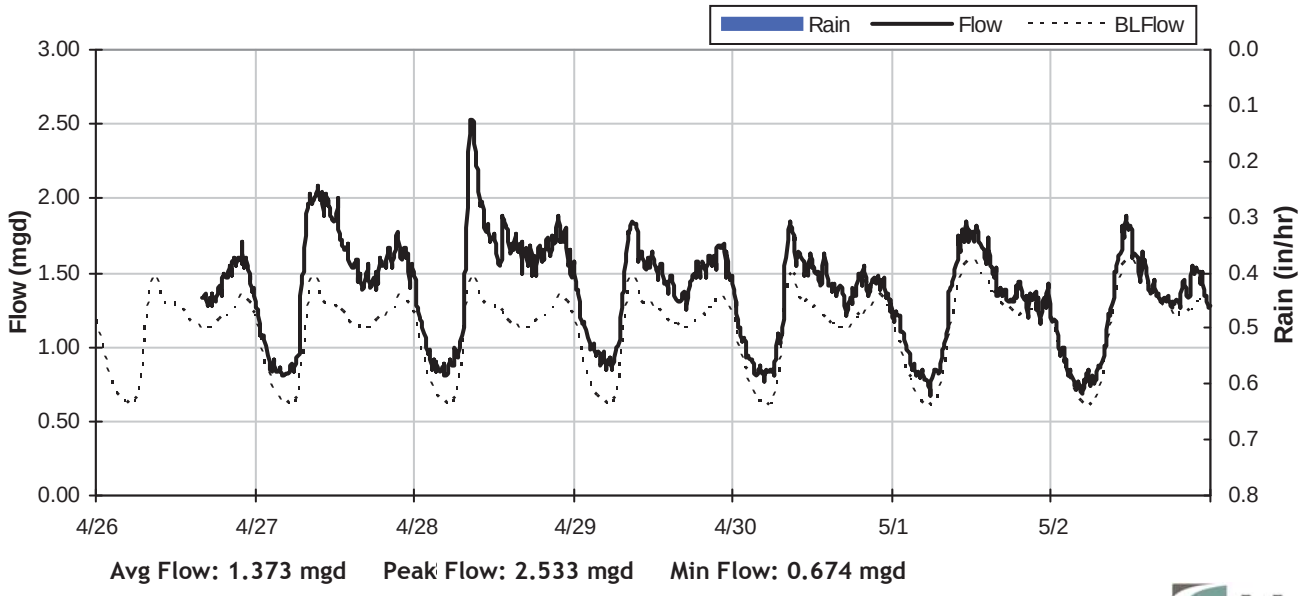
V&A

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 3A







Avg Flow: 1.373 mgd Peak Flow: 2.533 mgd Min Flow: 0.674 mgd

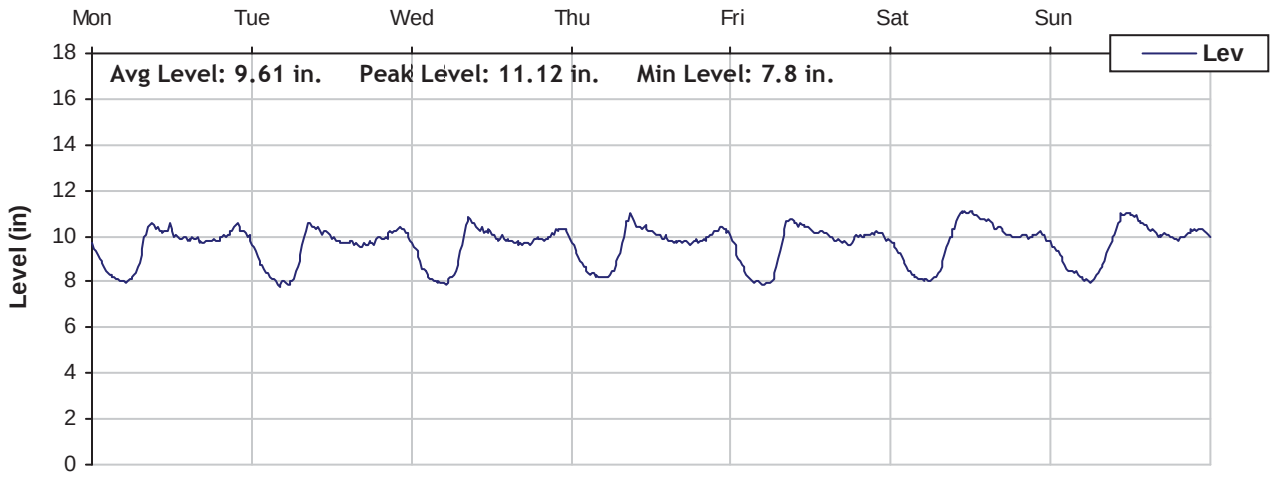
V&A

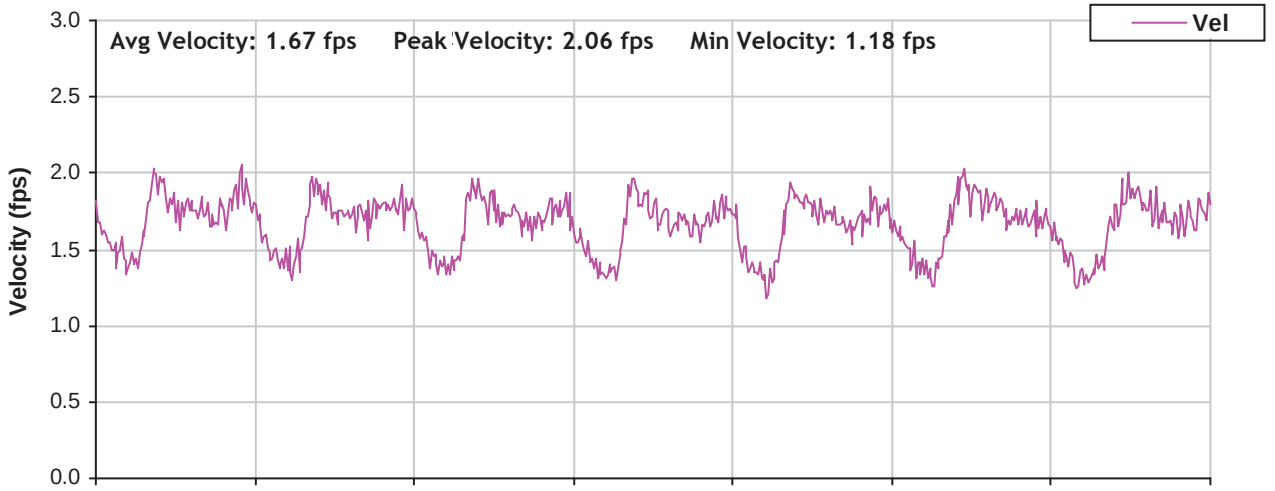
Level, Velocity and Flow

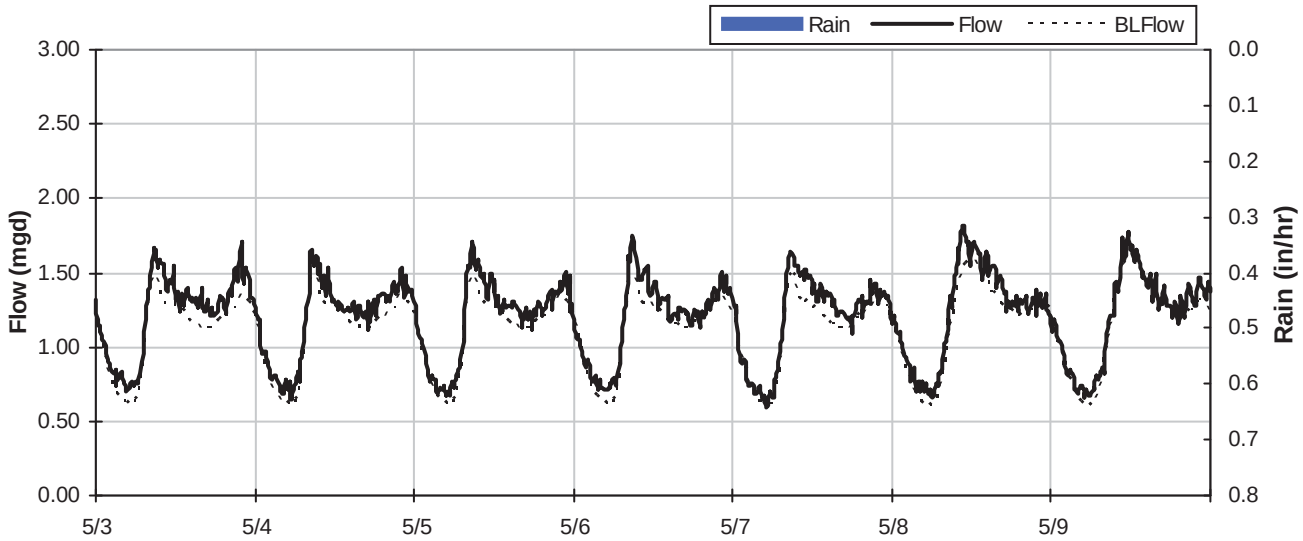
From 5/3/2010 to 5/10/2010

Monitoring Site:

Site 3A



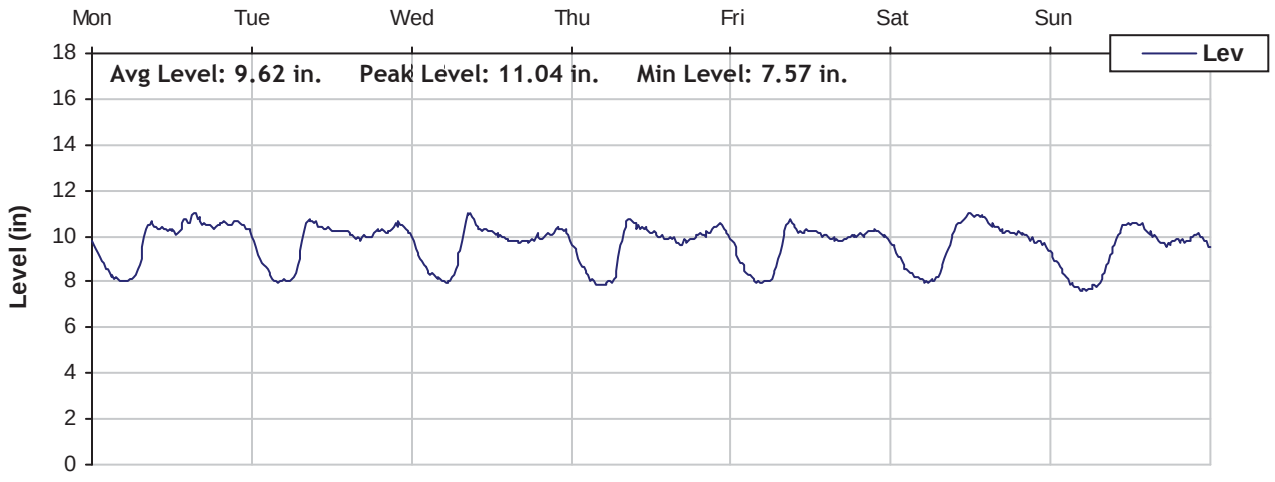


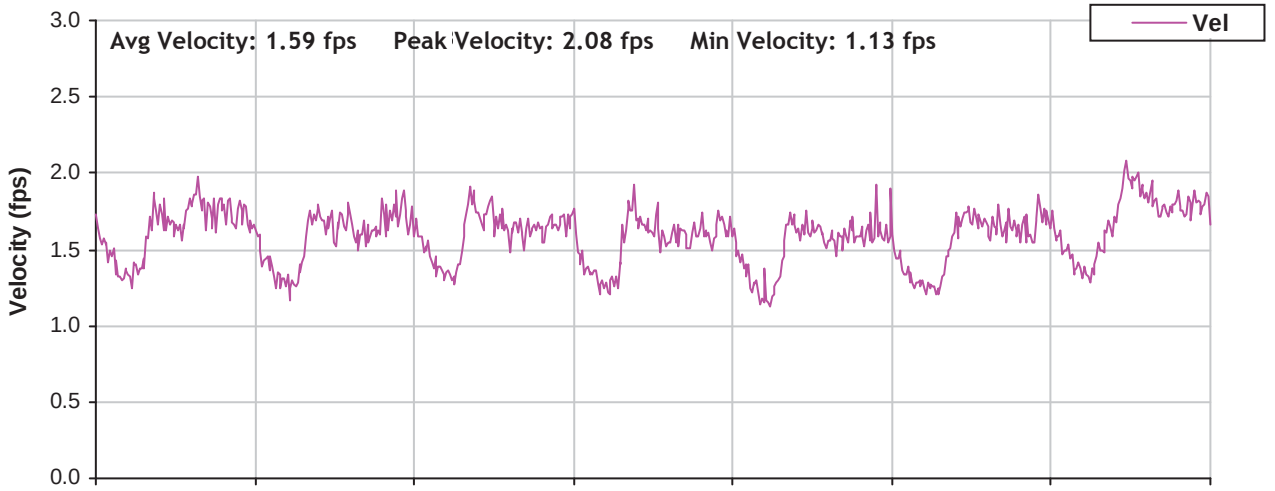


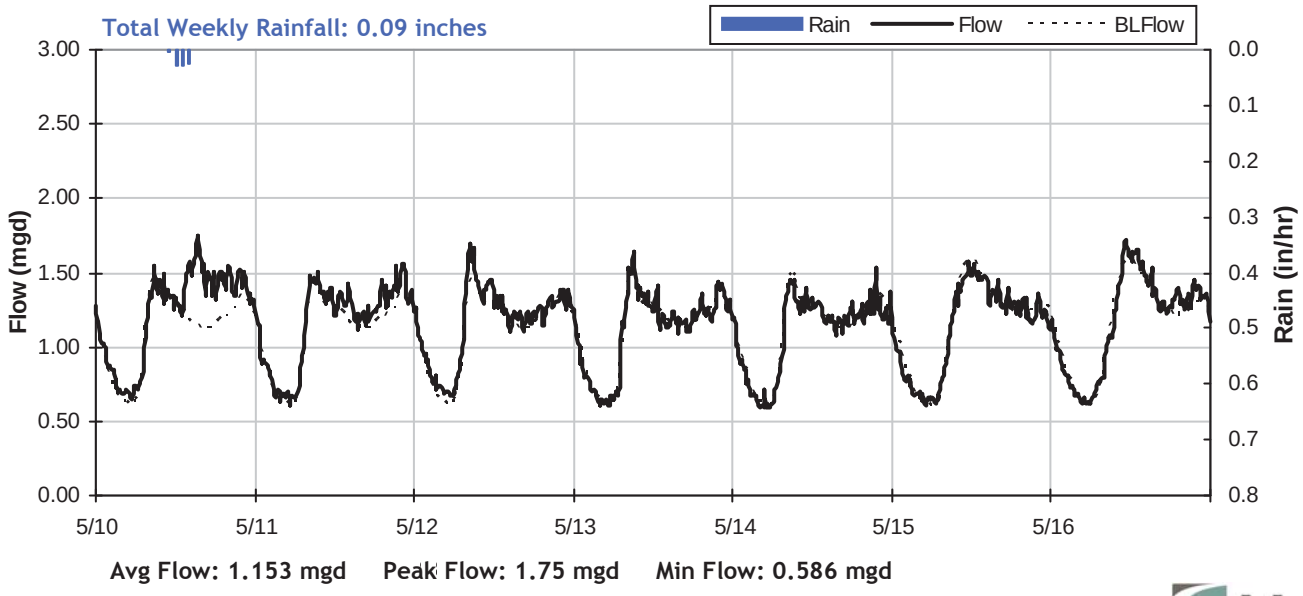
Avg Flow: 1.204 mgd Peak Flow: 1.811 mgd Min Flow: 0.593 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 3A

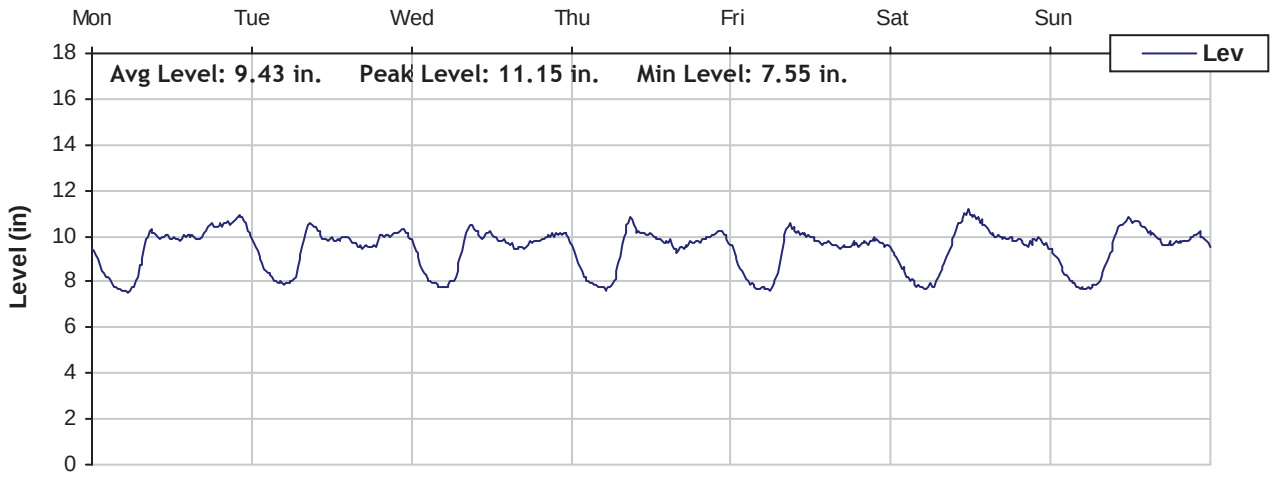


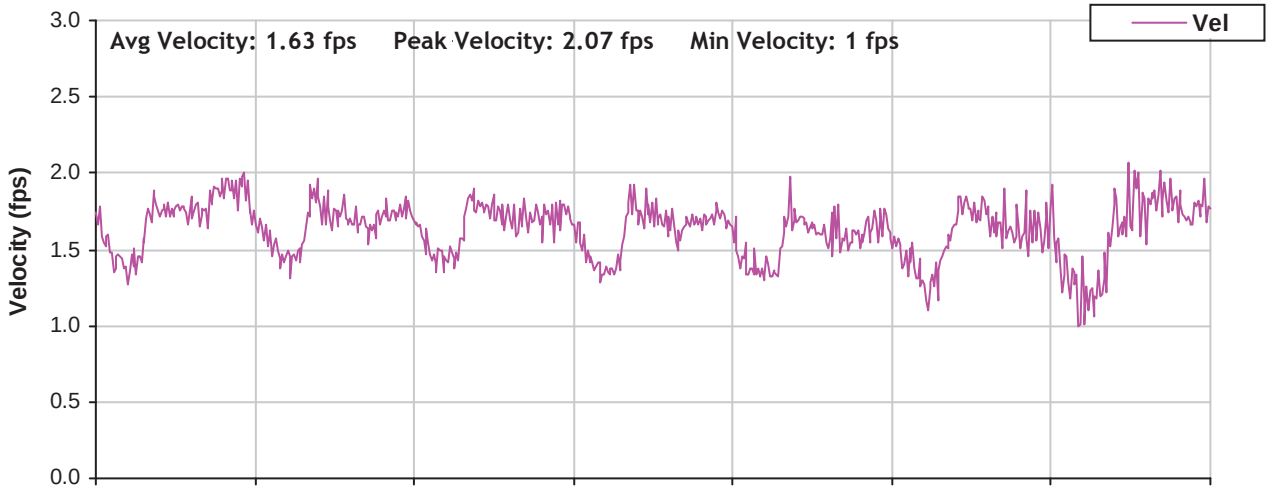


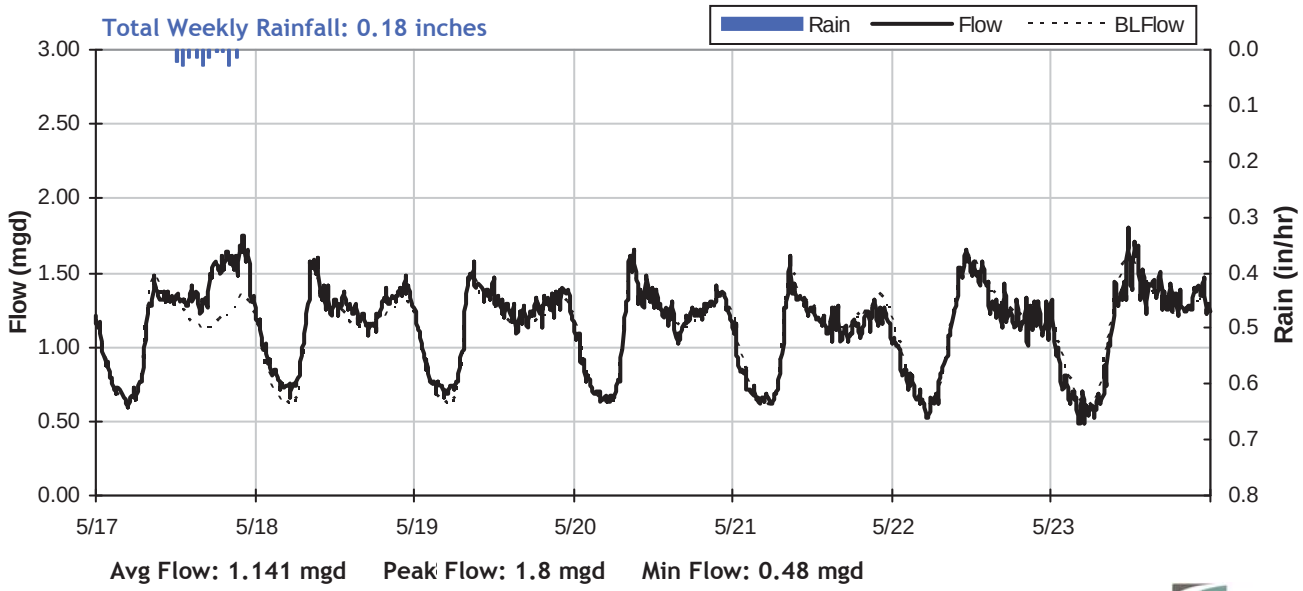


Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 3A



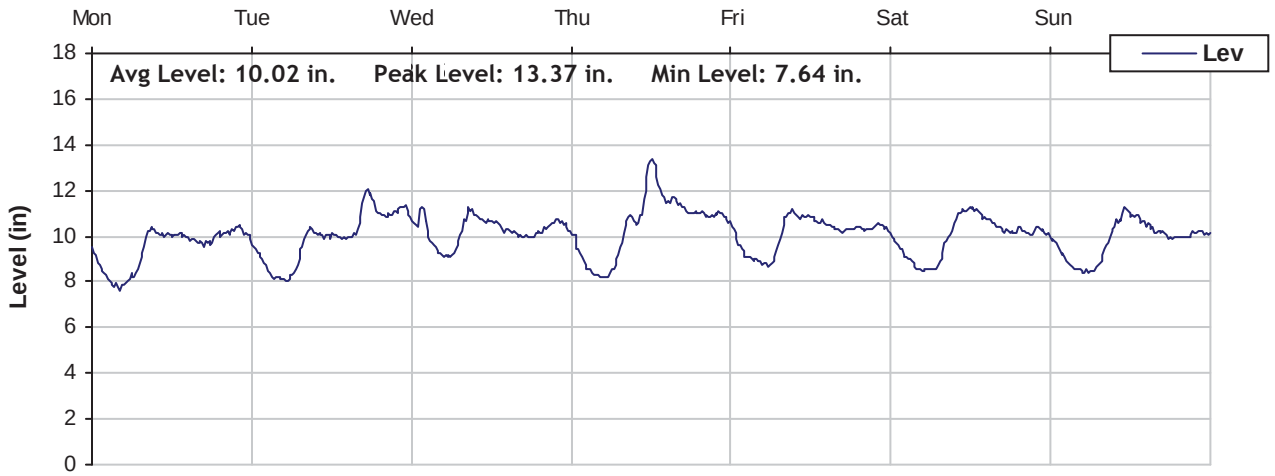


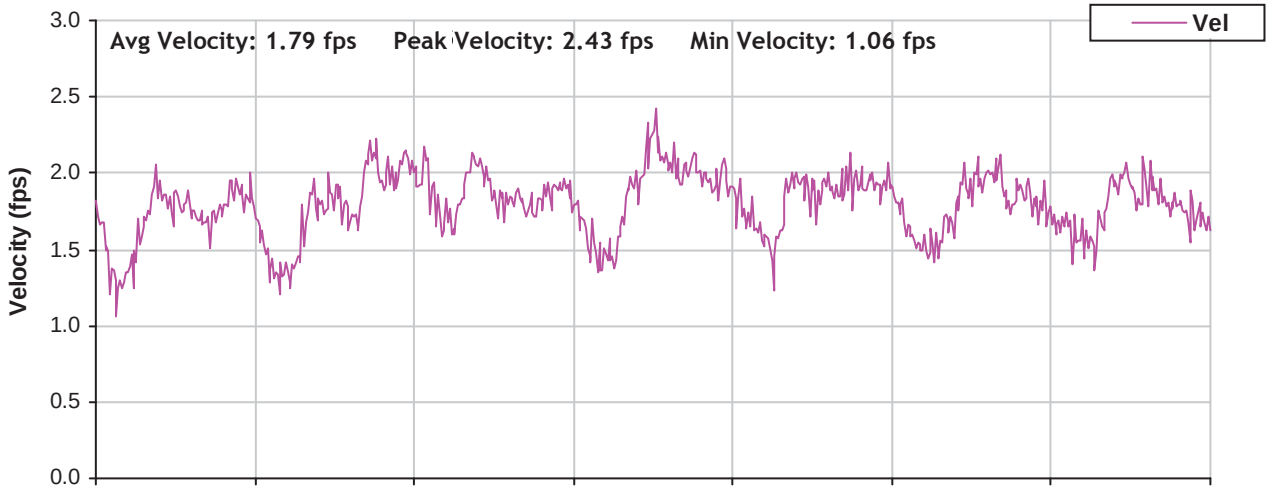


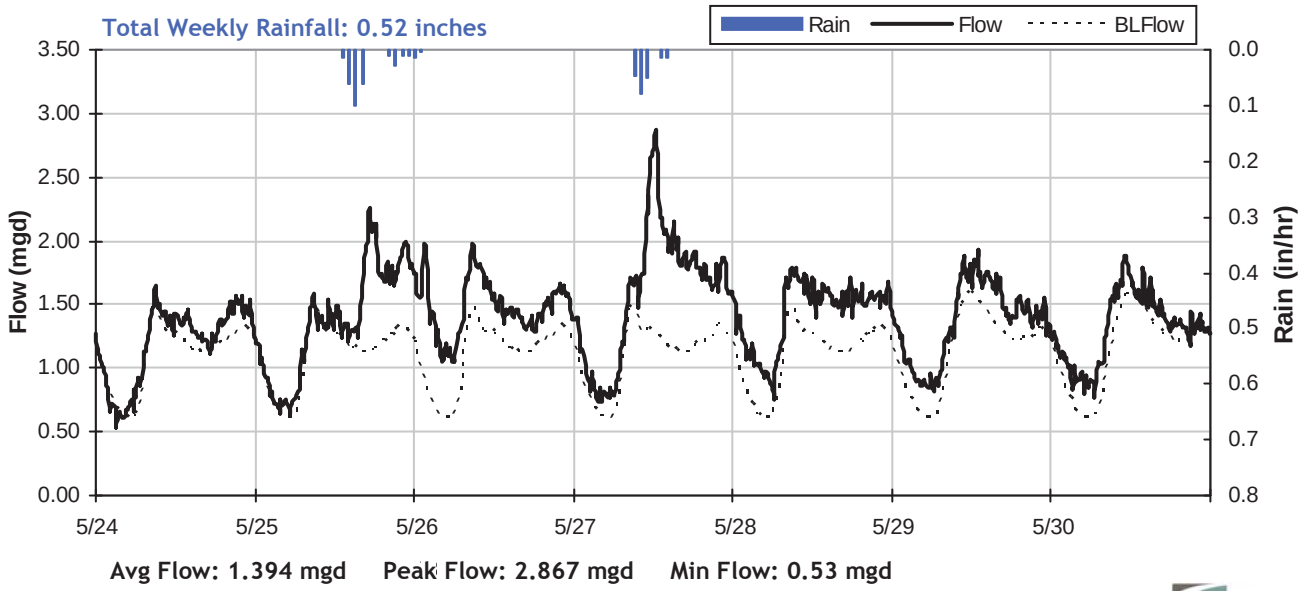
Avg Flow: 1.141 mgd Peak Flow: 1.8 mgd Min Flow: 0.48 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 3A

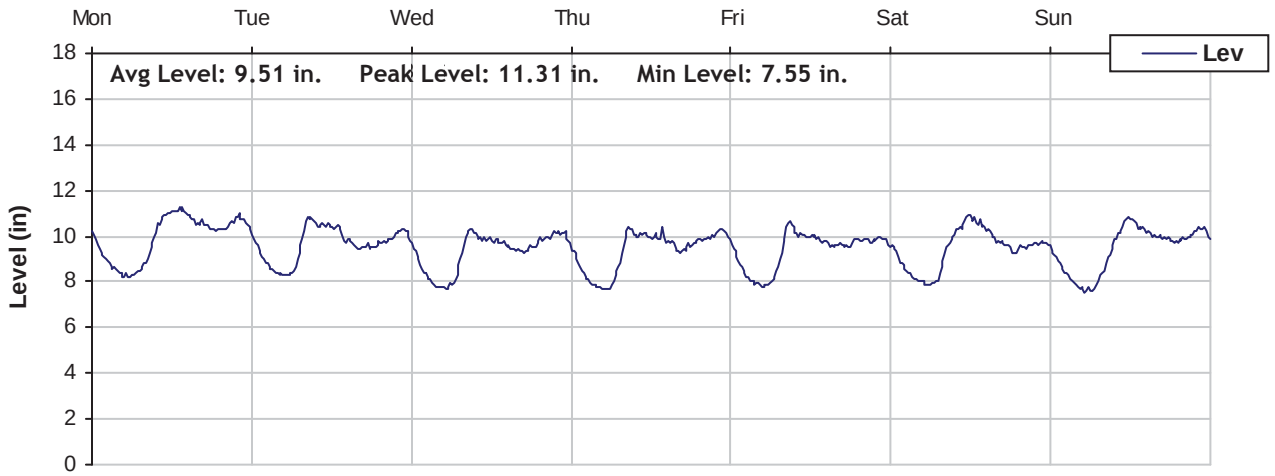


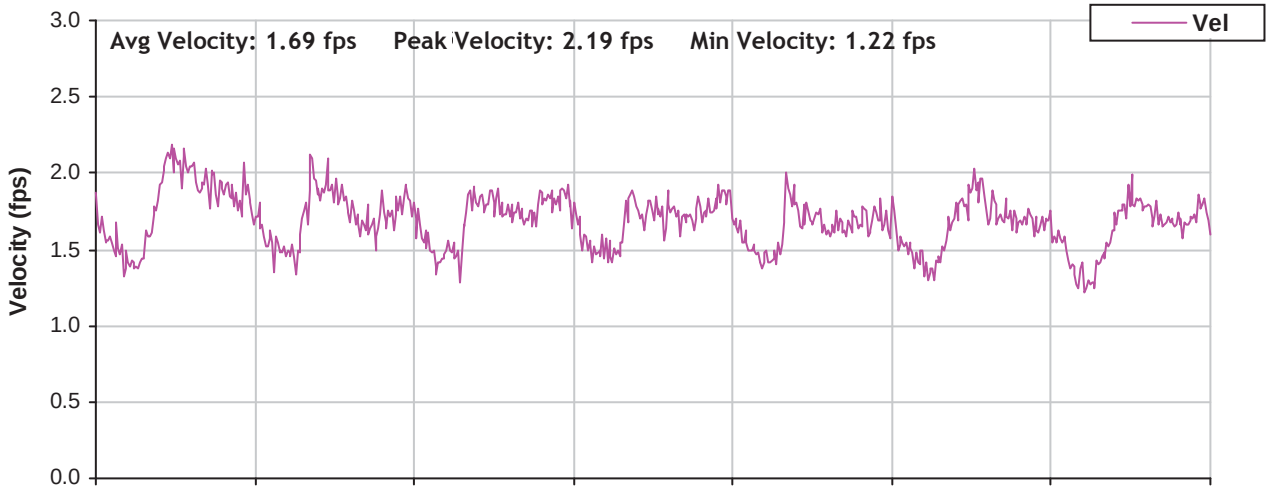


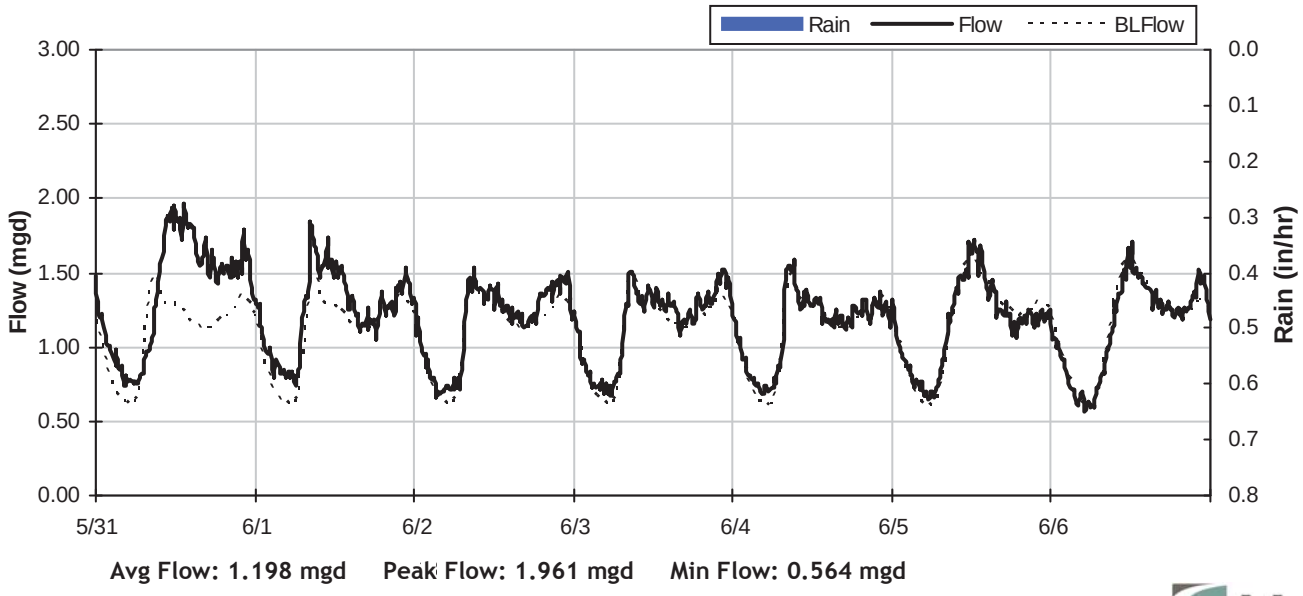


Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 3A



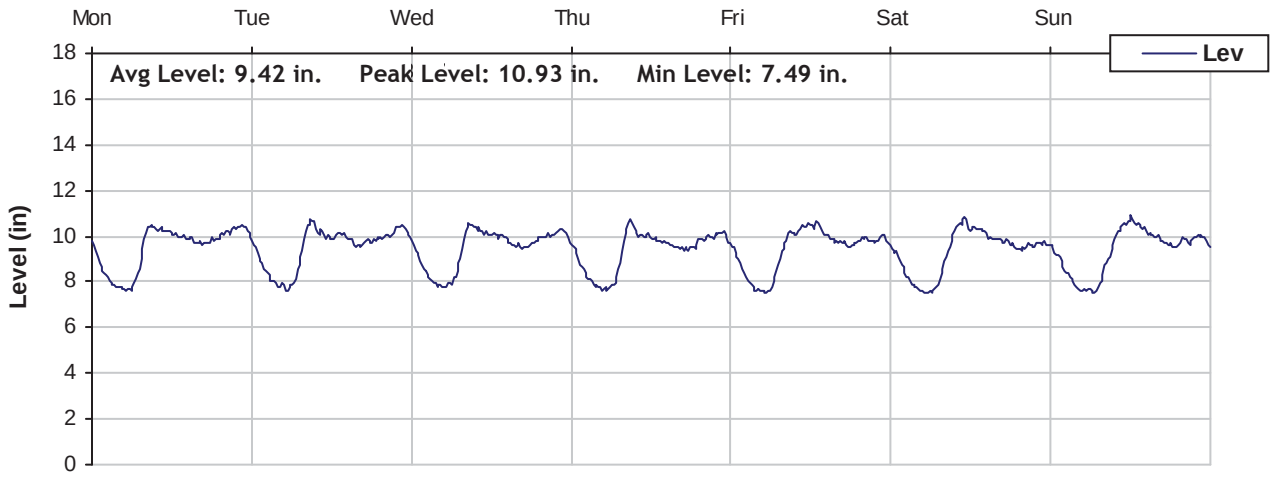


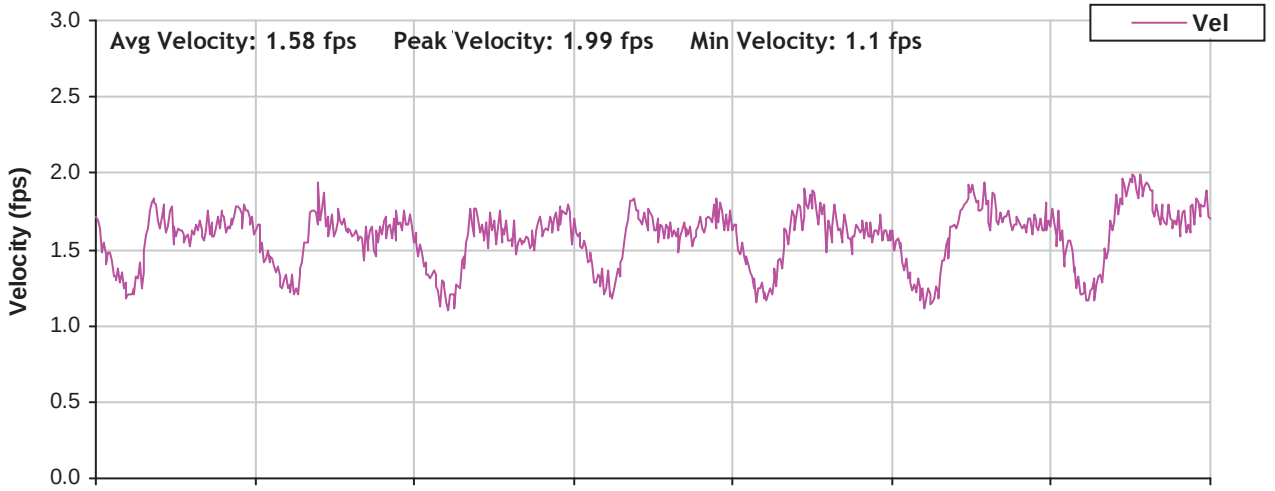


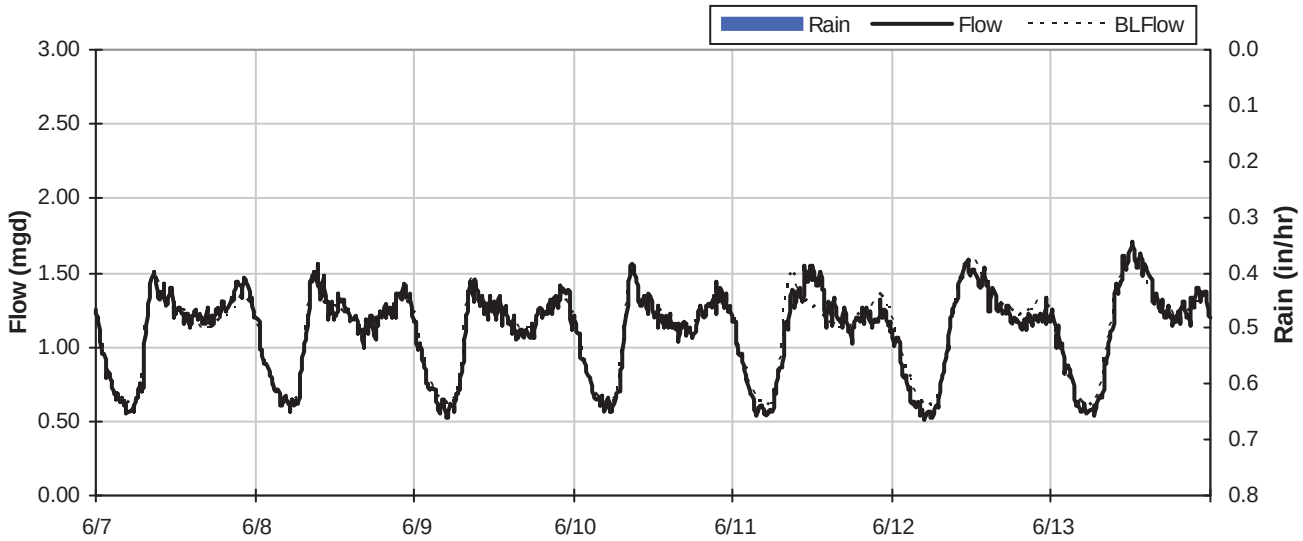
Avg Flow: 1.198 mgd Peak Flow: 1.961 mgd Min Flow: 0.564 mgd

Level, Velocity and Flow
From 6/7/2010 to 6/14/2010

Monitoring Site:
Site 3A



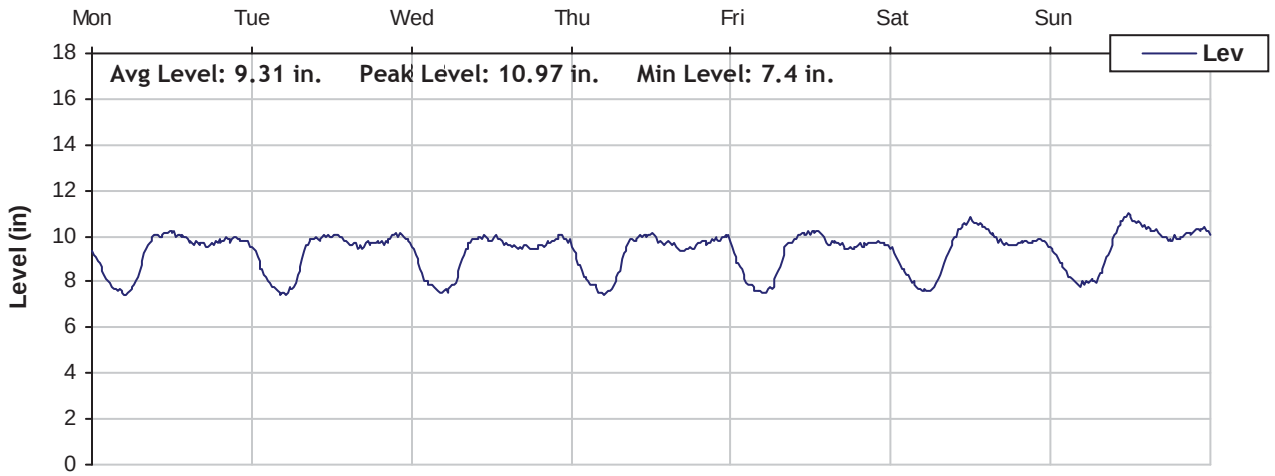


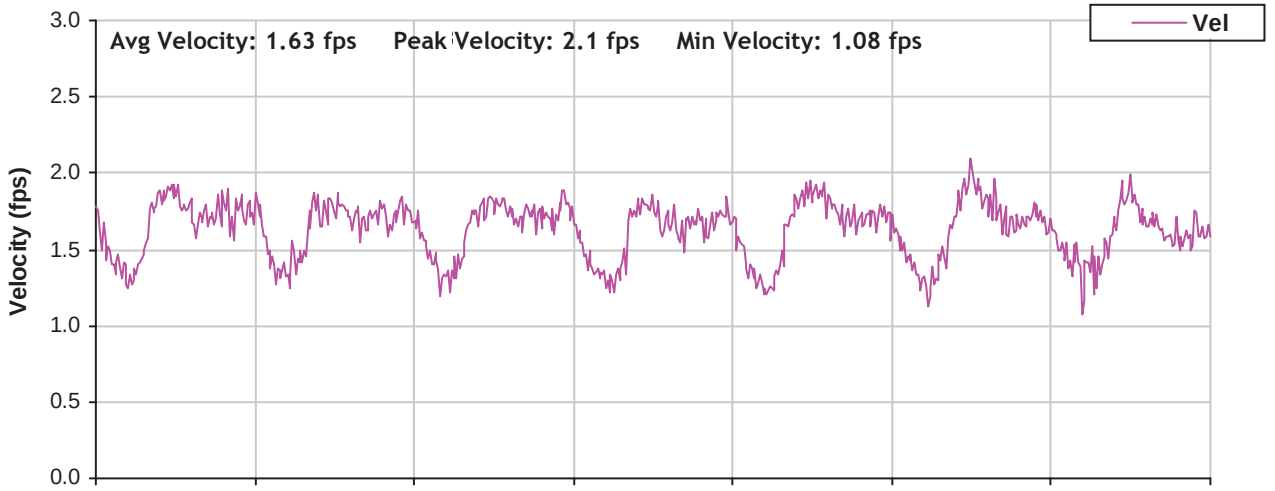


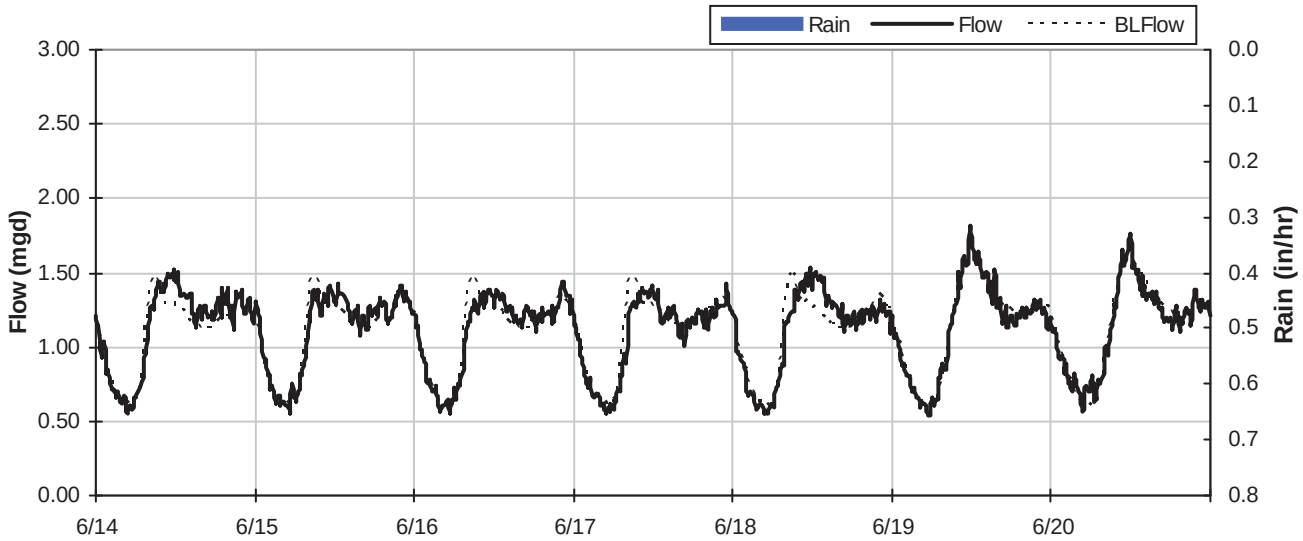
Avg Flow: 1.107 mgd Peak Flow: 1.704 mgd Min Flow: 0.512 mgd

Level, Velocity and Flow
From 6/14/2010 to 6/21/2010

Monitoring Site:
Site 3A







Avg Flow: 1.119 mgd Peak Flow: 1.815 mgd Min Flow: 0.534 mgd

Temporary Flow Monitoring Study

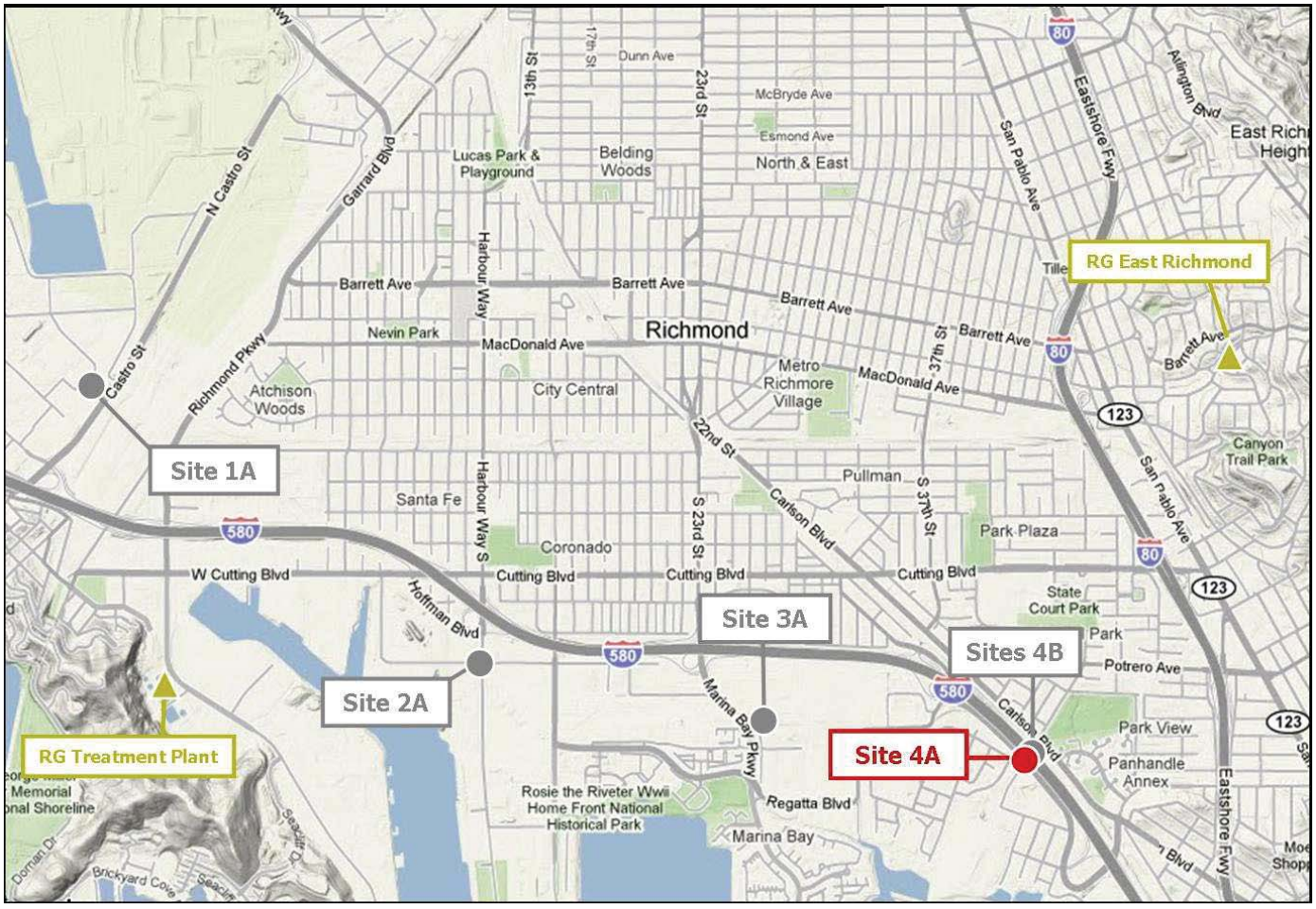
Sanitary Sewer Collection System

Monitoring Site: Site 4A

Location: Seaver Ave., before entrance to University of California Field Station

Size/Type Line: 24-inch Sanitary Sewer Pipe

Data Summary Report



V&A

Site Information Report

Monitoring Site: Site 4A

Location: Seaver Ave., before entrance to University of California Field Station

Latitude: 37.9203°

Longitude: -122.3772°

Rim Elevation: 15 *feet above sea level*

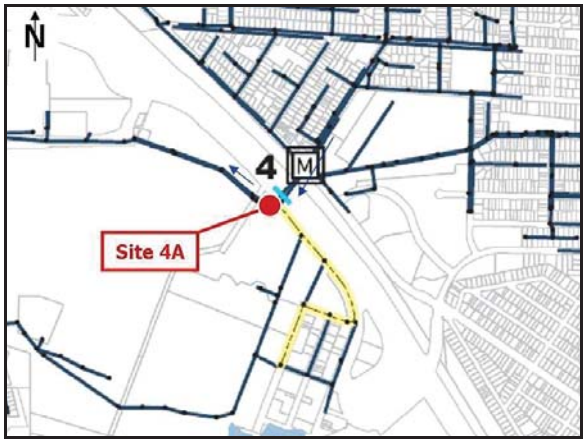
Diameter: 24 *inches*

Average Dry Weather Flow: 0.652 *mgd*

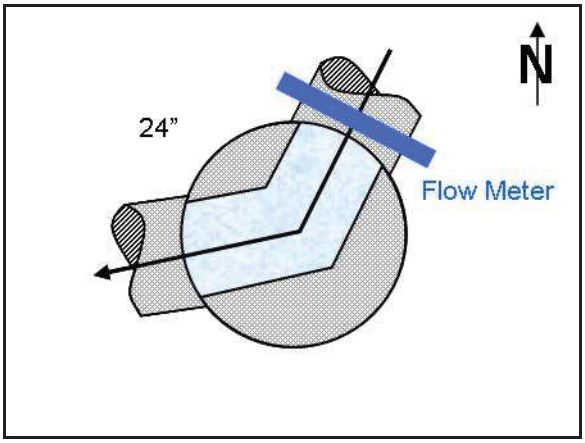
Peak Measured Flow: 1.697 *mgd*

Satellite Photo

Sanitary Map



Flow Sketch



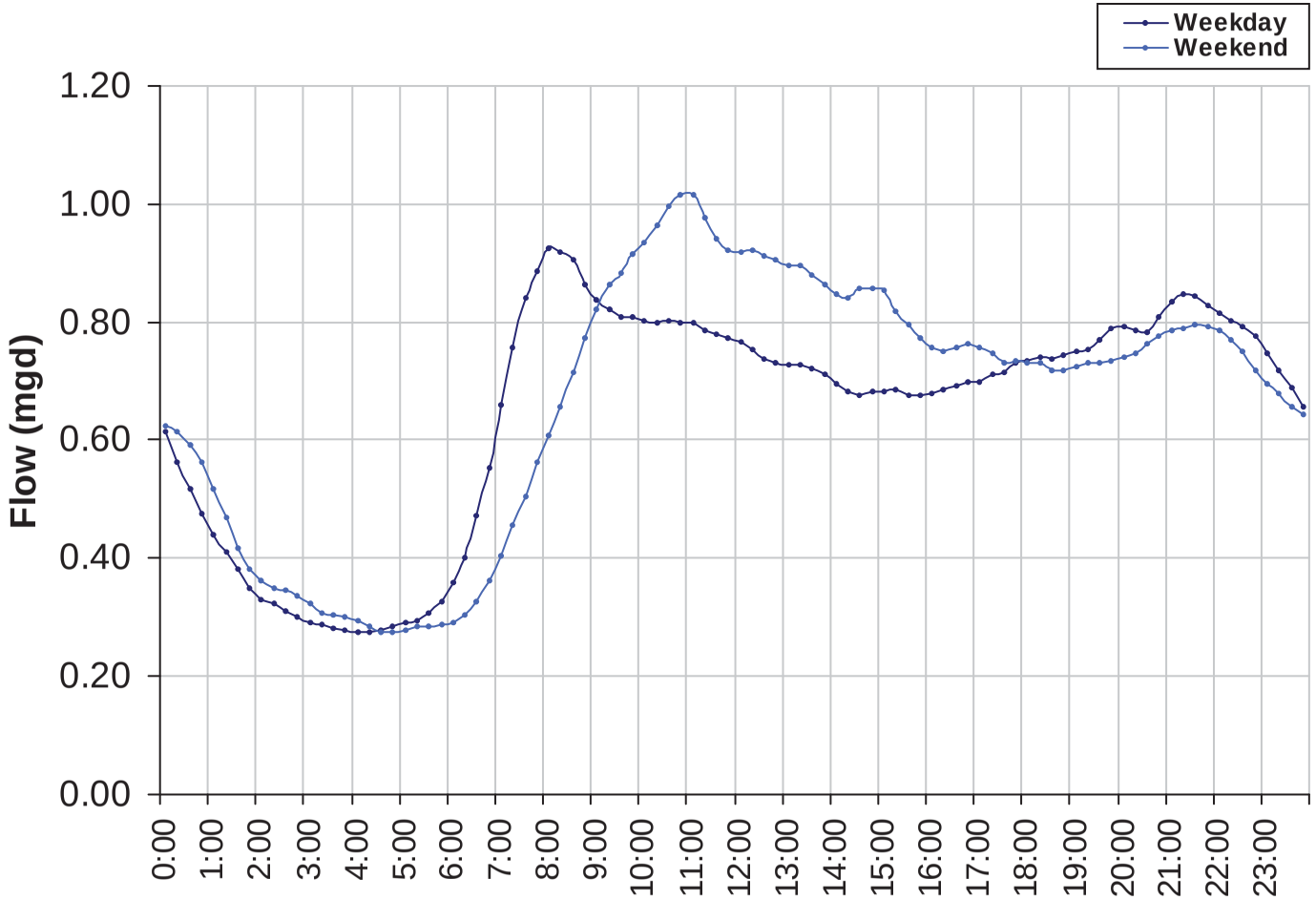
Street View Photo

Plan View Photo

V&A

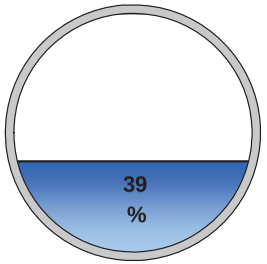
Average Dry Weather Flow

Monitoring Site:
Site 4A



Peak Measured Flow:

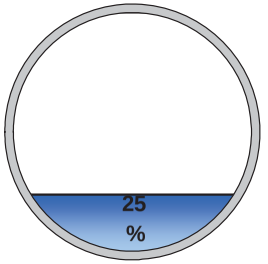
1.70 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

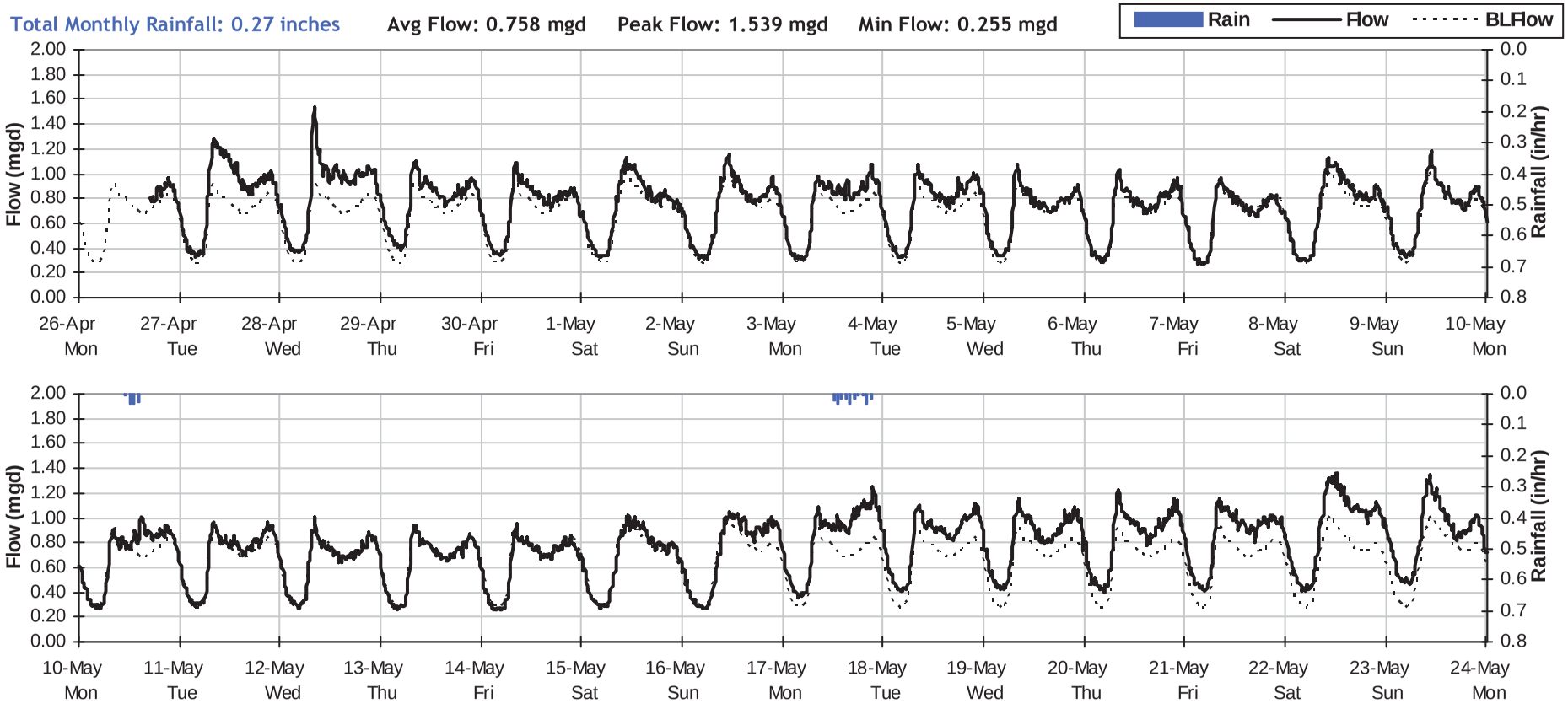
0.65 *mgd*

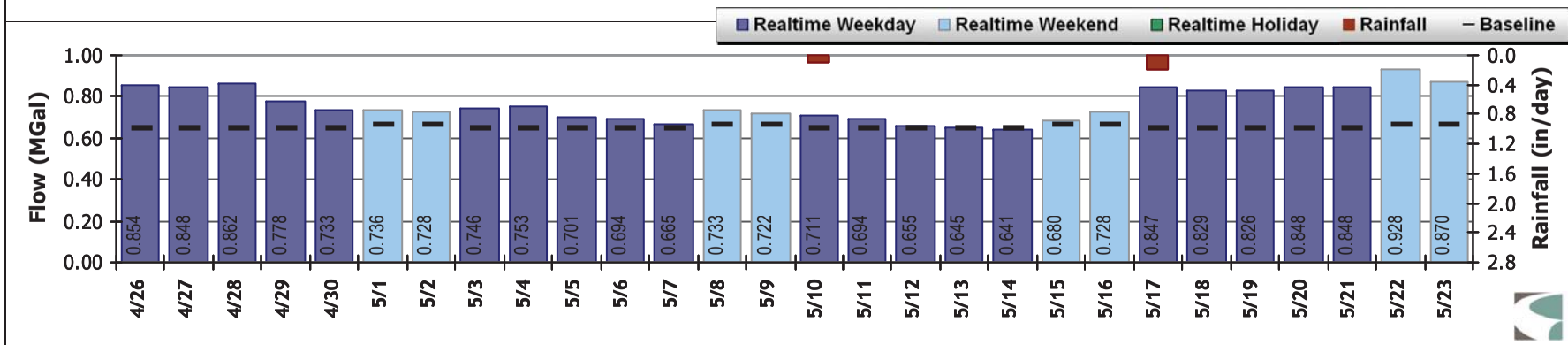


Period Flow Summary
April 26 to May 23, 2010

Monitoring Site:
Site 4A

Total Monthly Rainfall: 0.27 inches Avg Flow: 0.758 mgd Peak Flow: 1.539 mgd Min Flow: 0.255 mgd



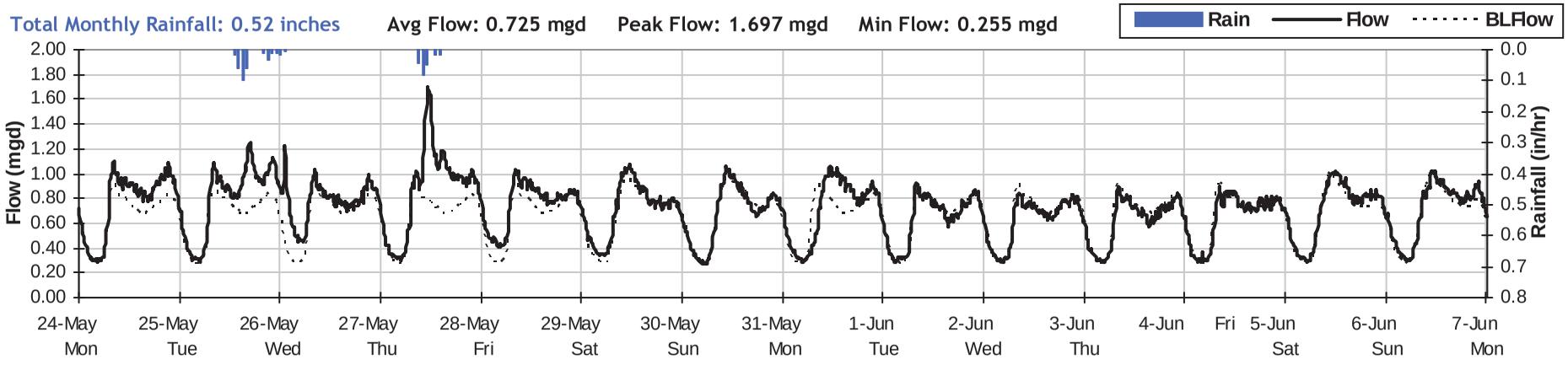


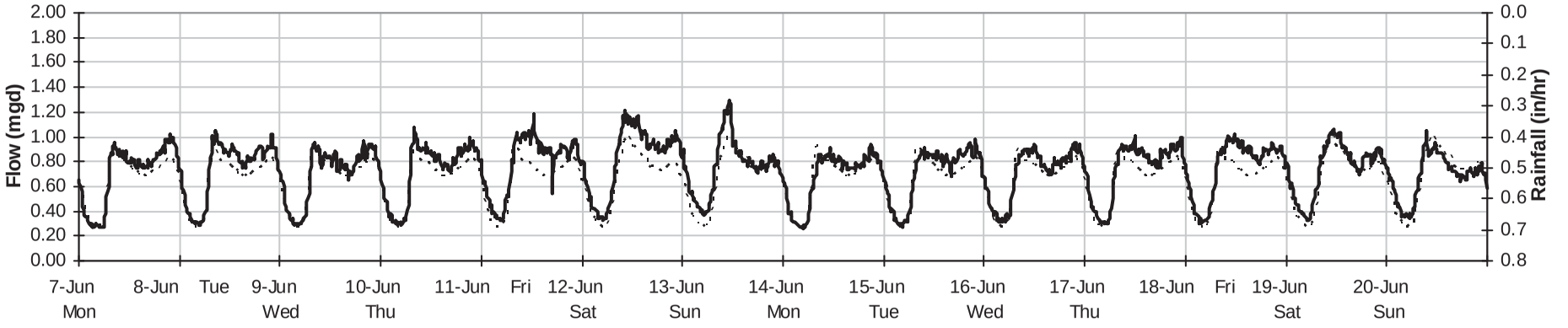
V&A

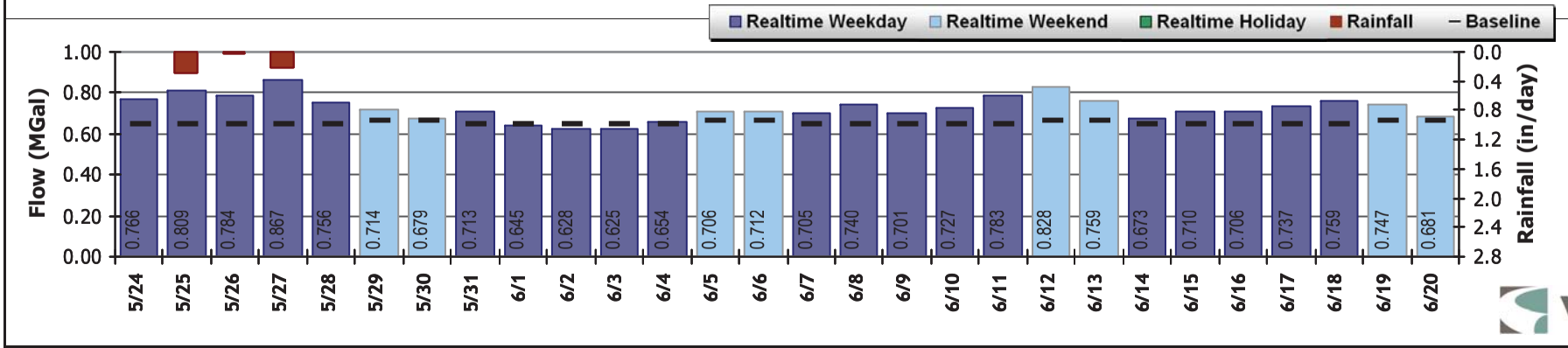
Period Flow Summary
May 24 to June 21, 2010

Monitoring Site:
Site 4A

Total Monthly Rainfall: 0.52 inches Avg Flow: 0.725 mgd Peak Flow: 1.697 mgd Min Flow: 0.255 mgd



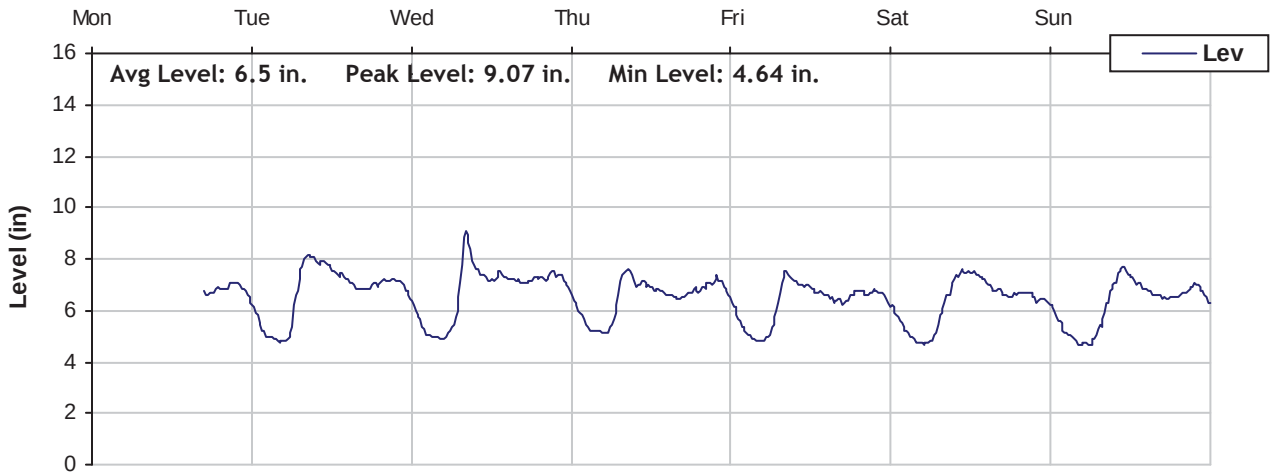


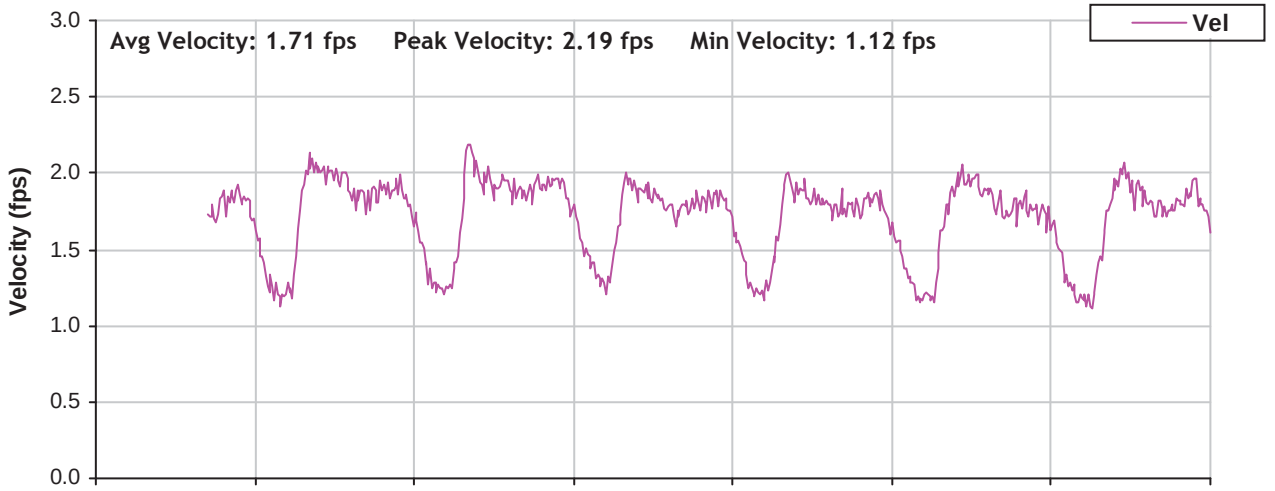


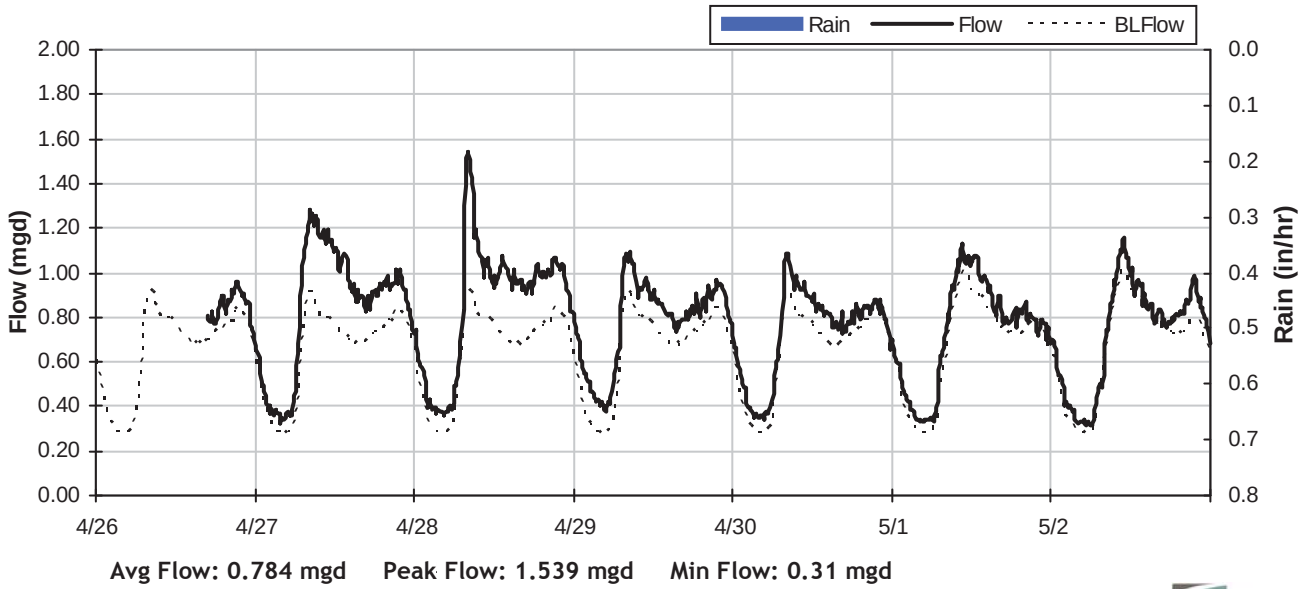
V&A

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 4A



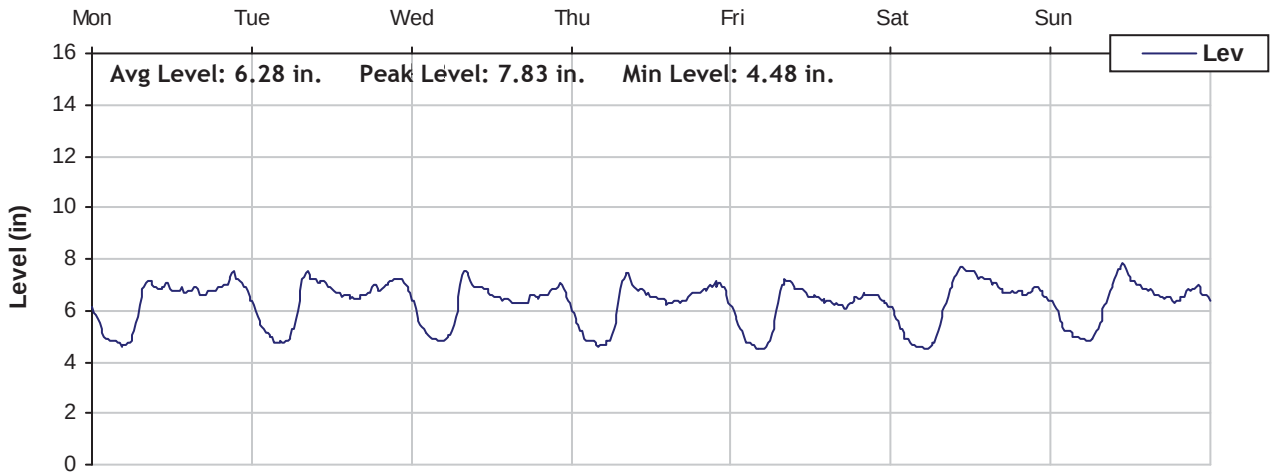


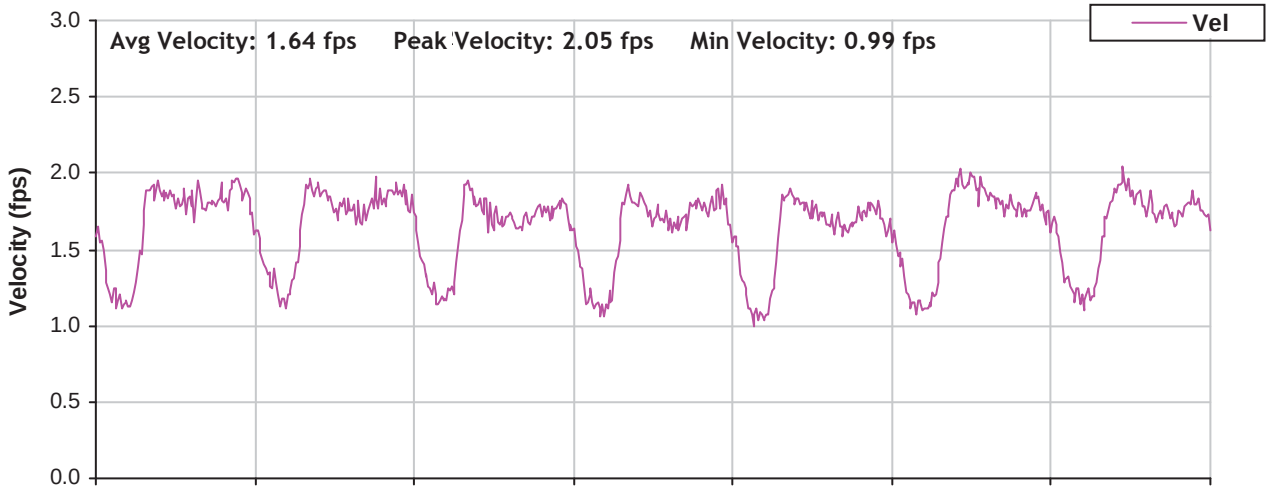


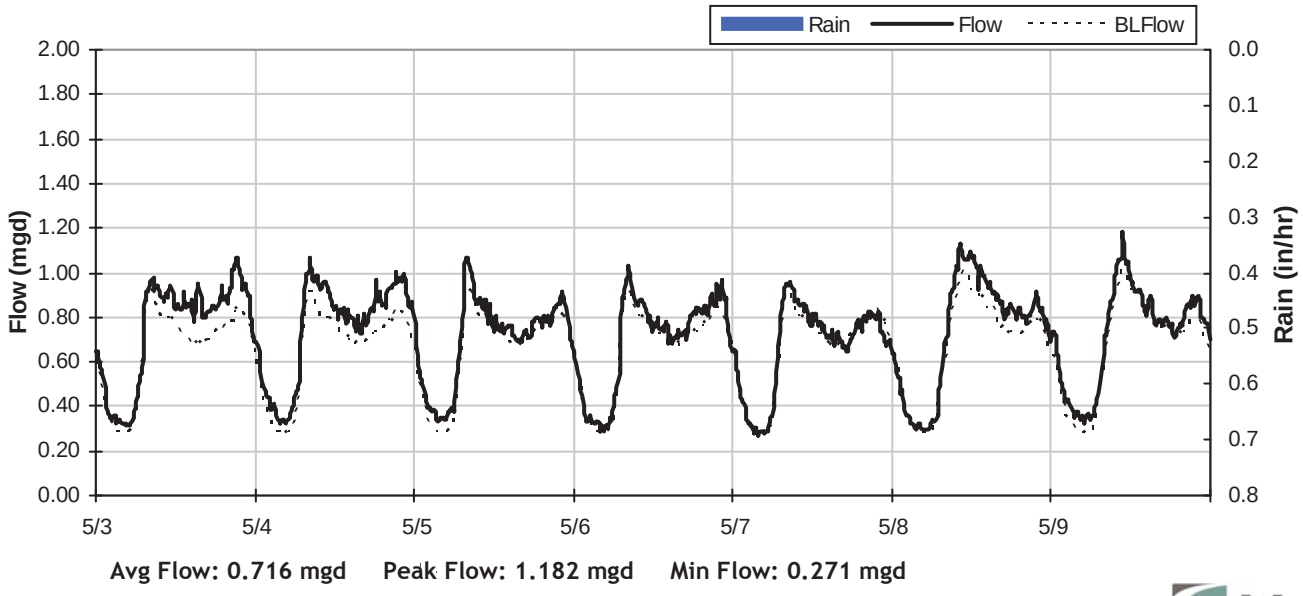
Avg Flow: 0.784 mgd Peak Flow: 1.539 mgd Min Flow: 0.31 mgd

Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 4A

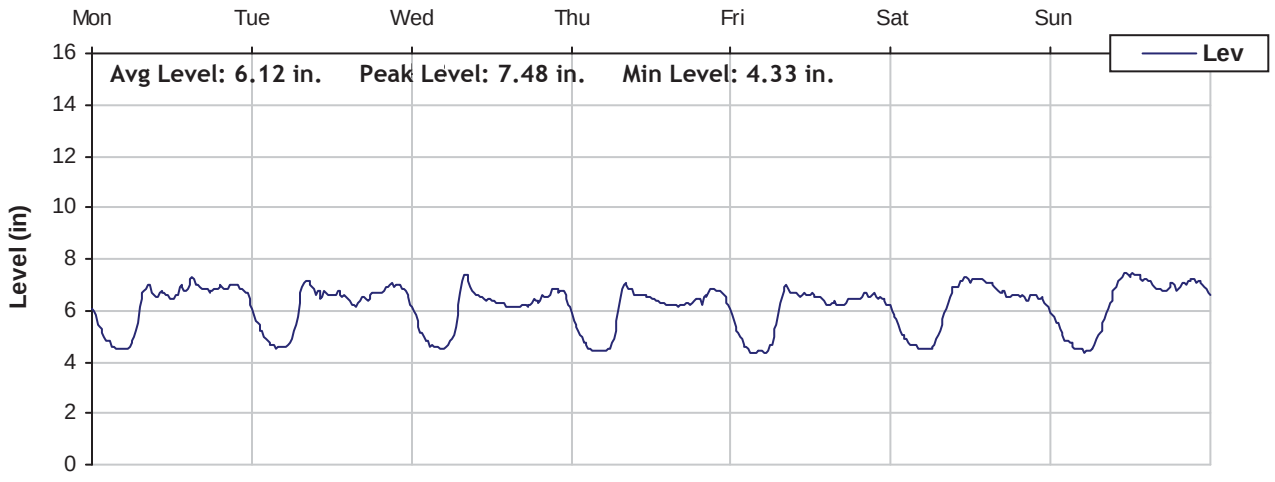


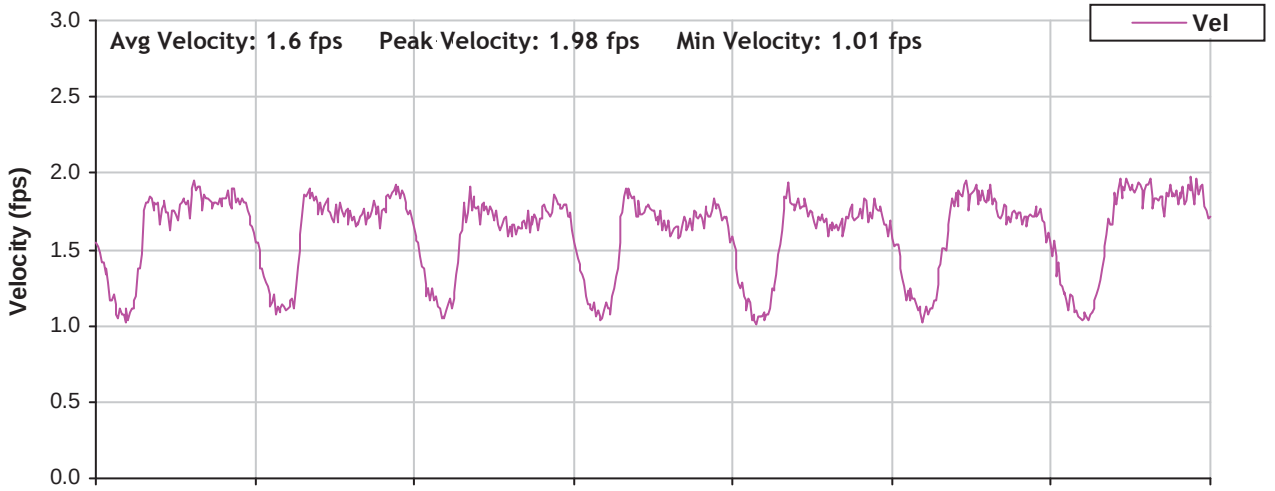


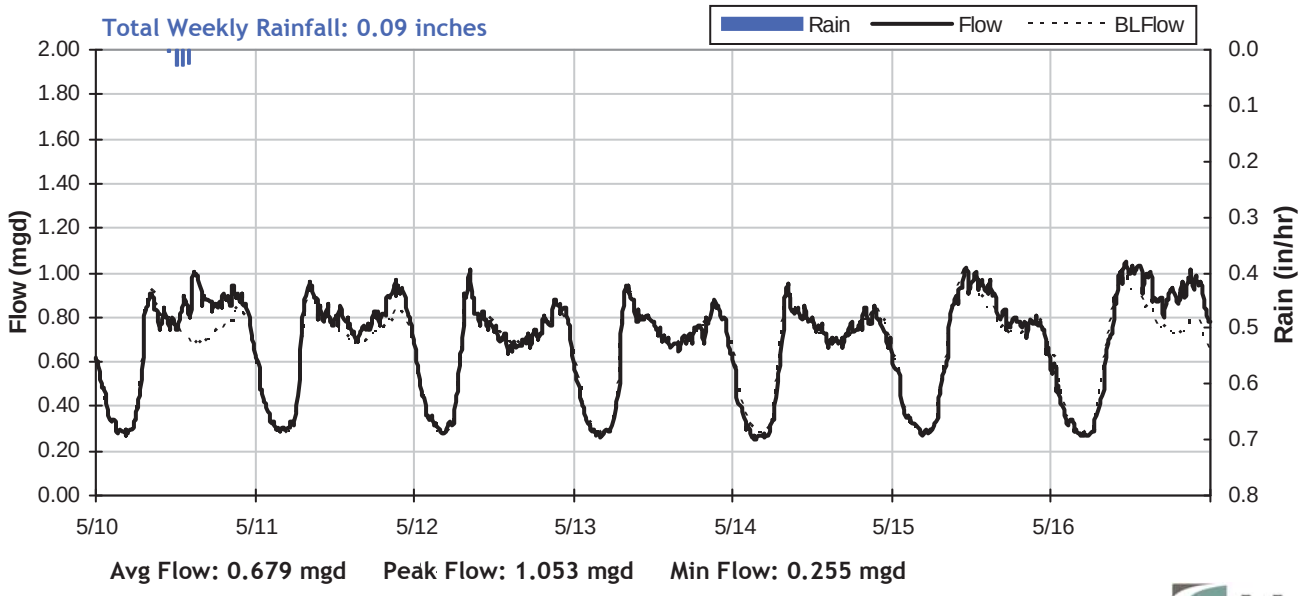


Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 4A



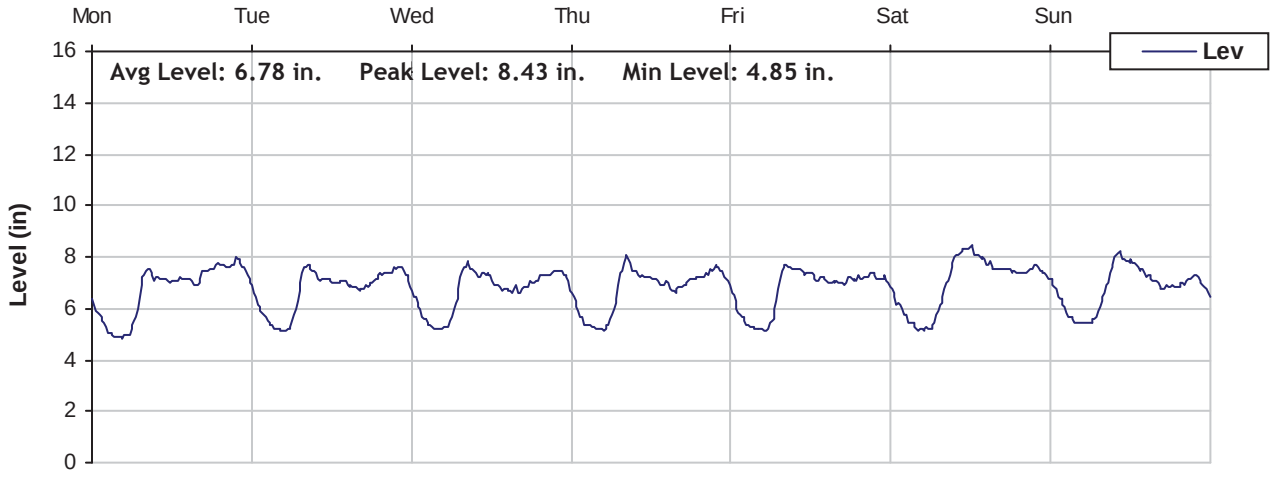


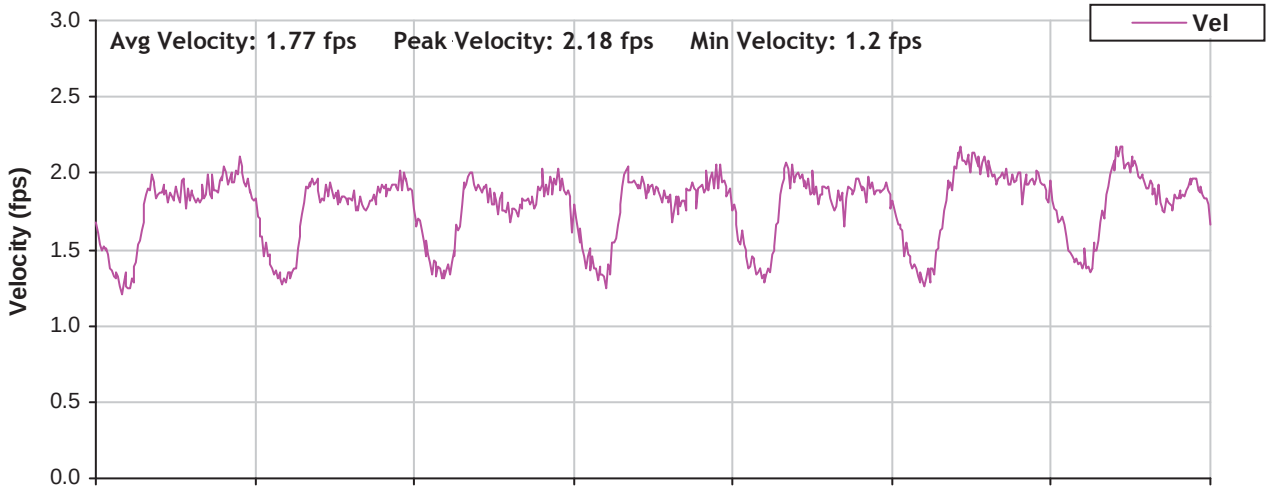


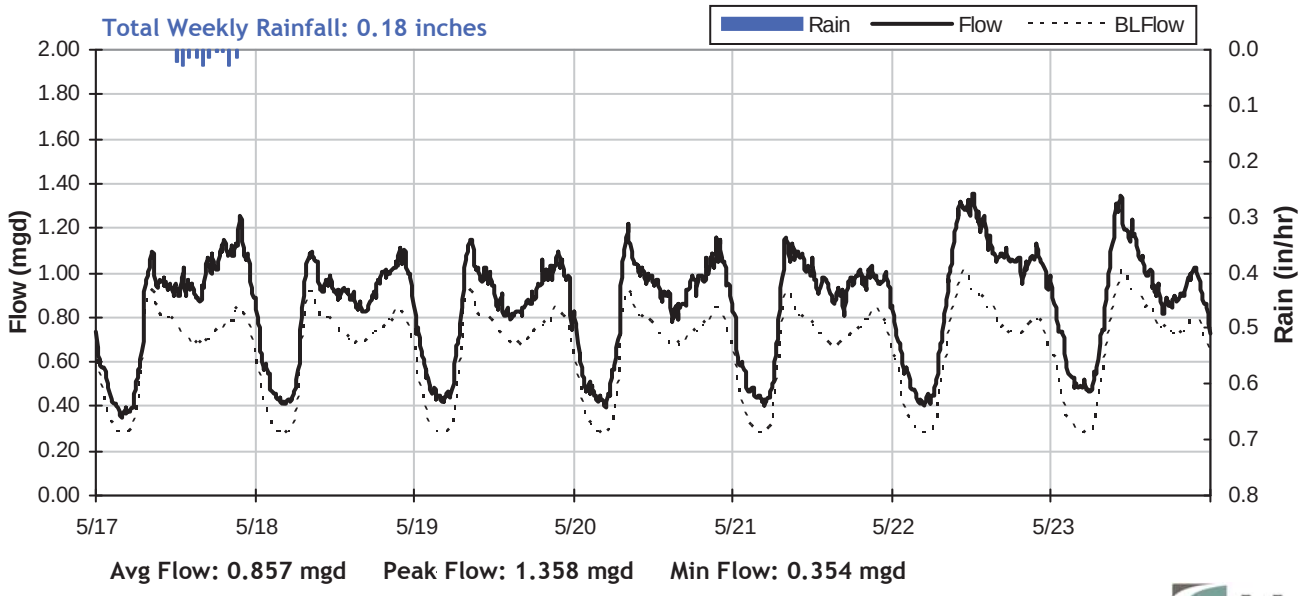
Avg Flow: 0.679 mgd Peak Flow: 1.053 mgd Min Flow: 0.255 mgd

Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 4A



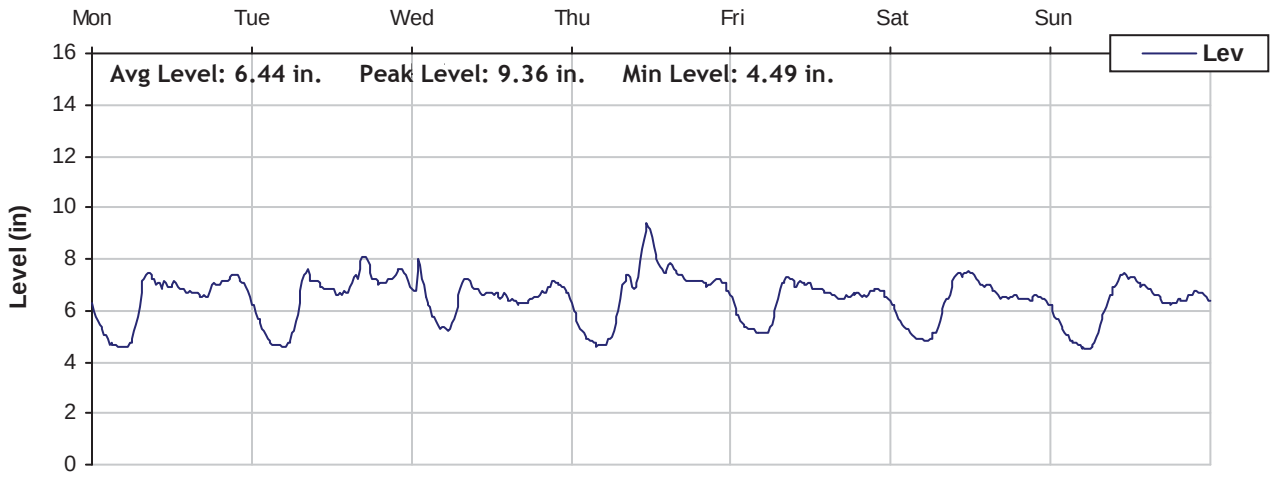


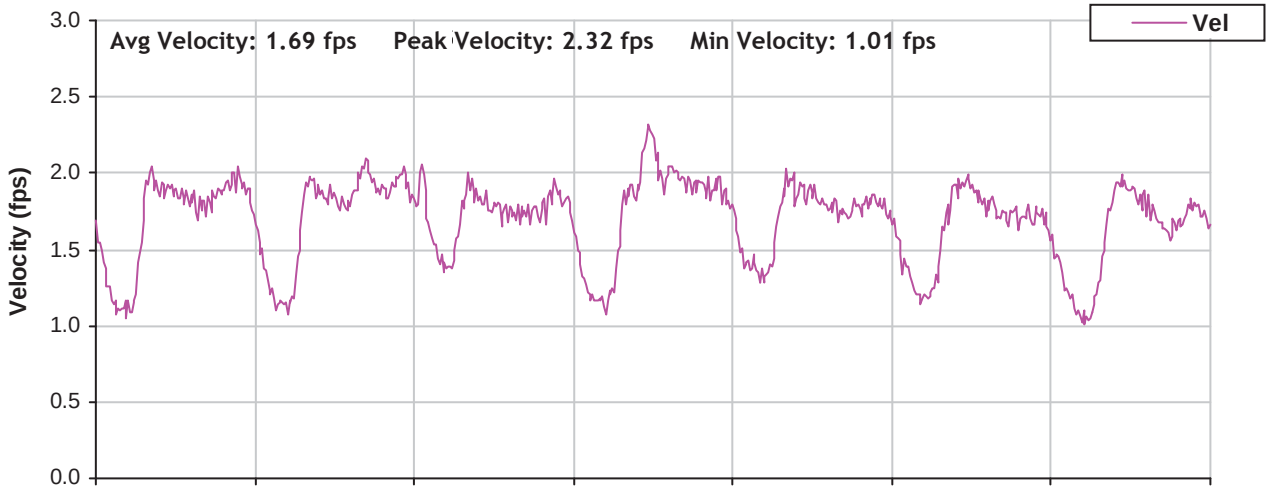


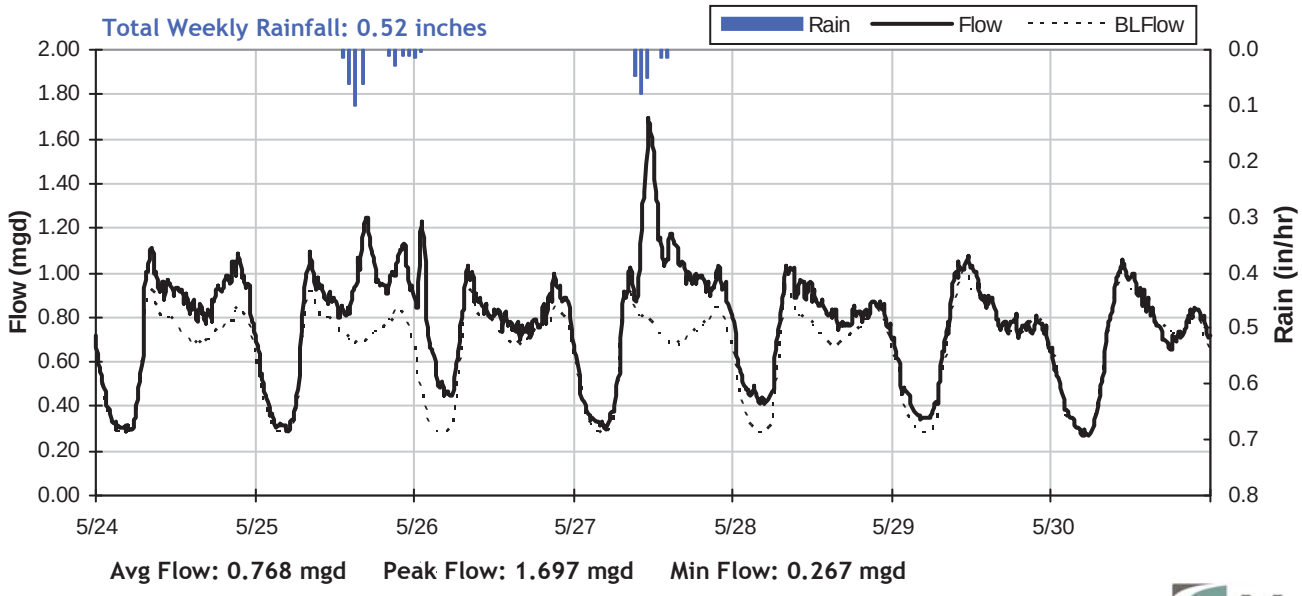
Avg Flow: 0.857 mgd Peak Flow: 1.358 mgd Min Flow: 0.354 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 4A

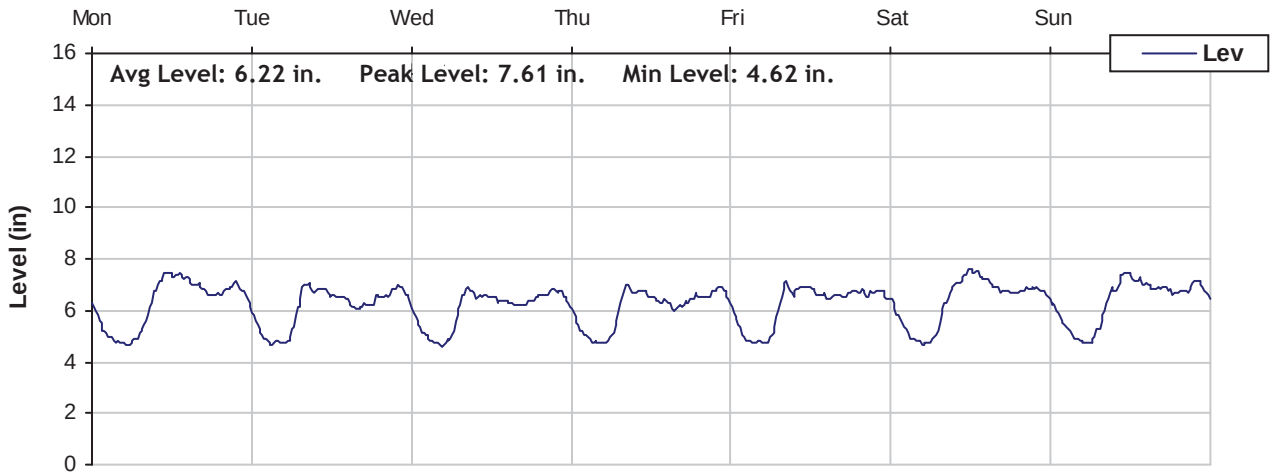


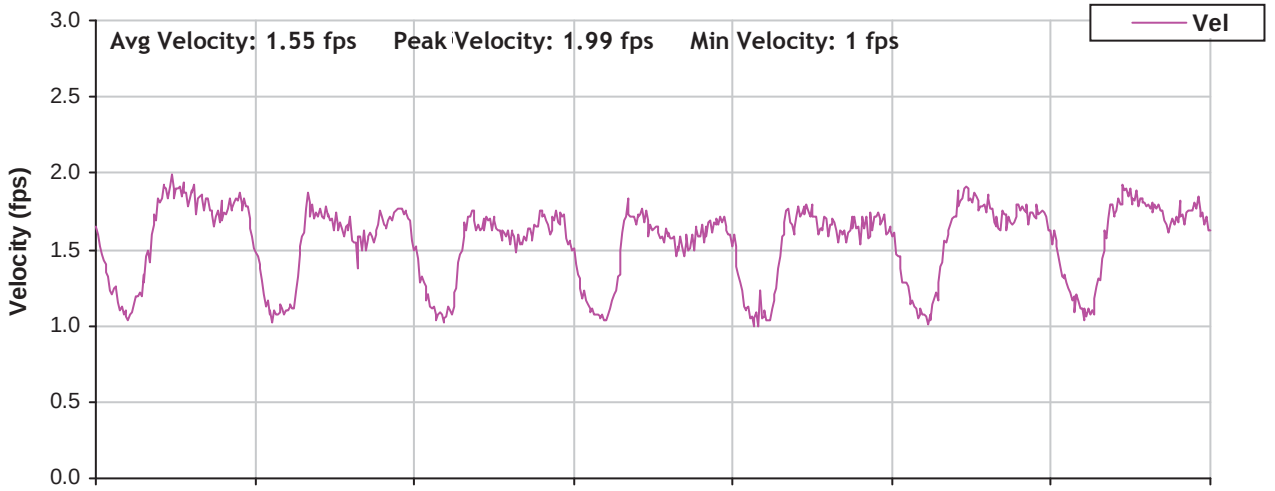


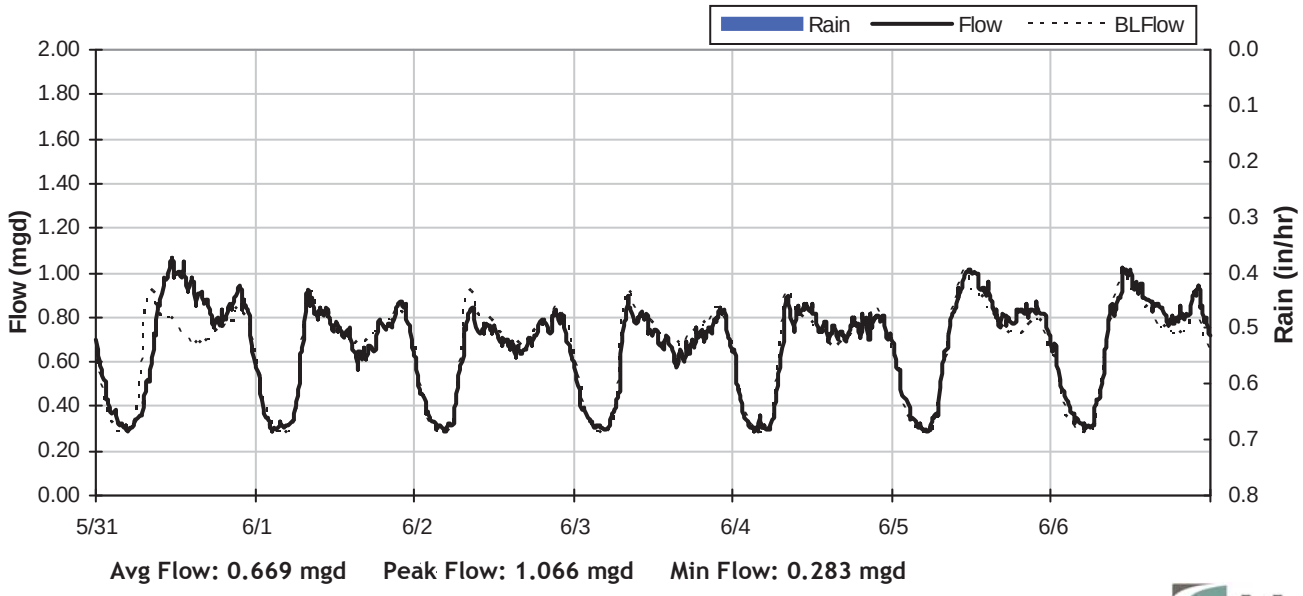


Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 4A



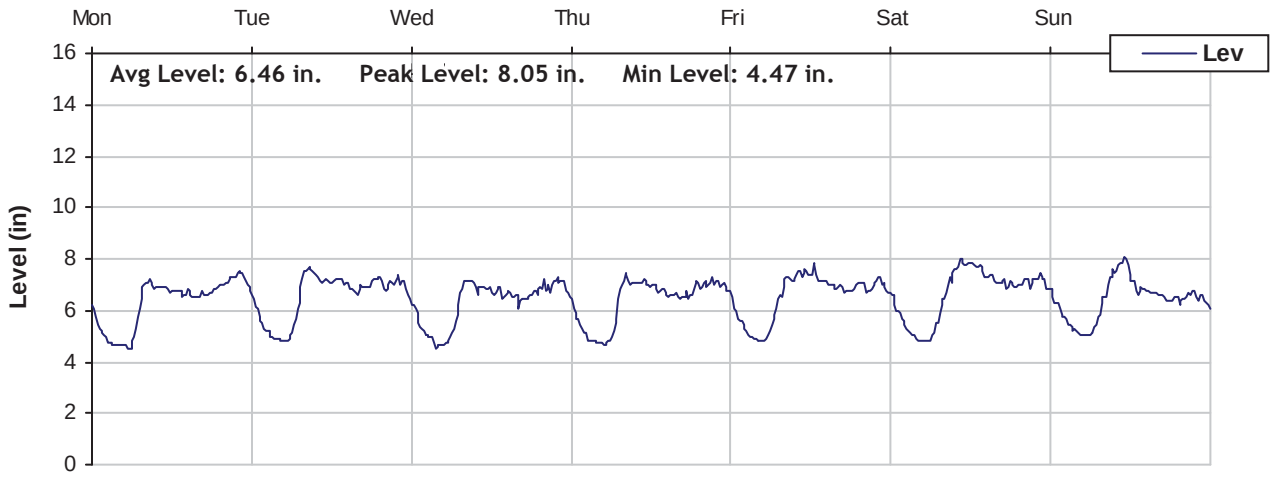


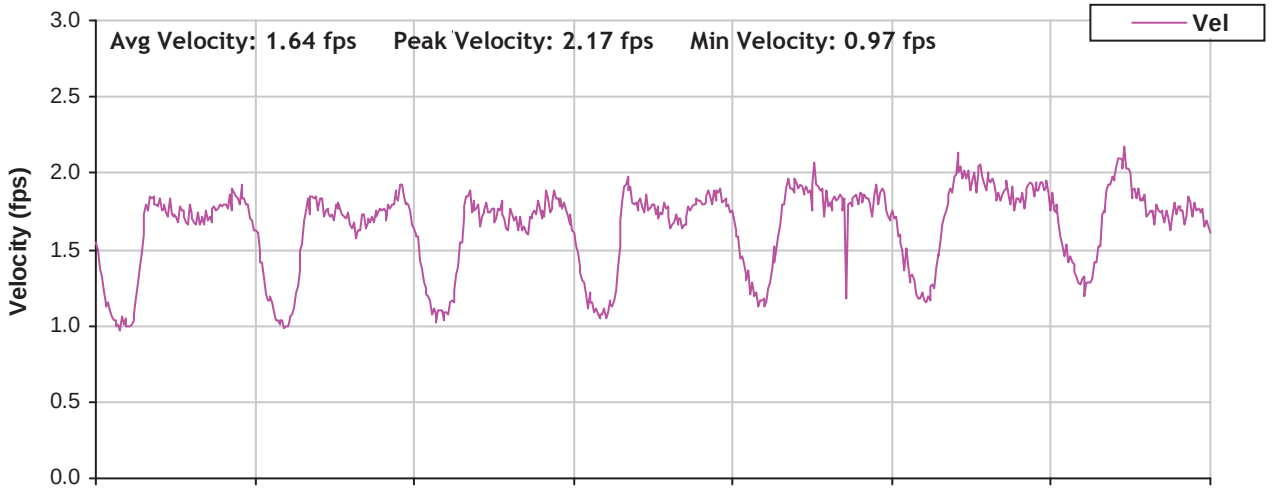


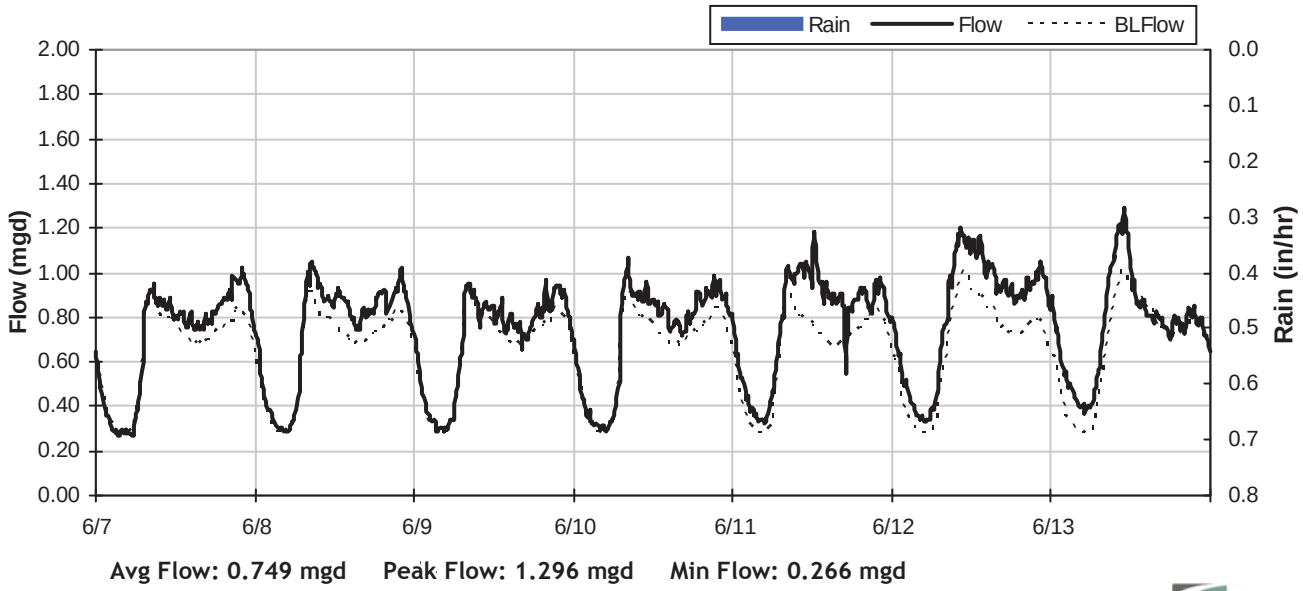
Avg Flow: 0.669 mgd Peak Flow: 1.066 mgd Min Flow: 0.283 mgd

Level, Velocity and Flow
From 6/7/2010 to 6/14/2010

Monitoring Site:
Site 4A

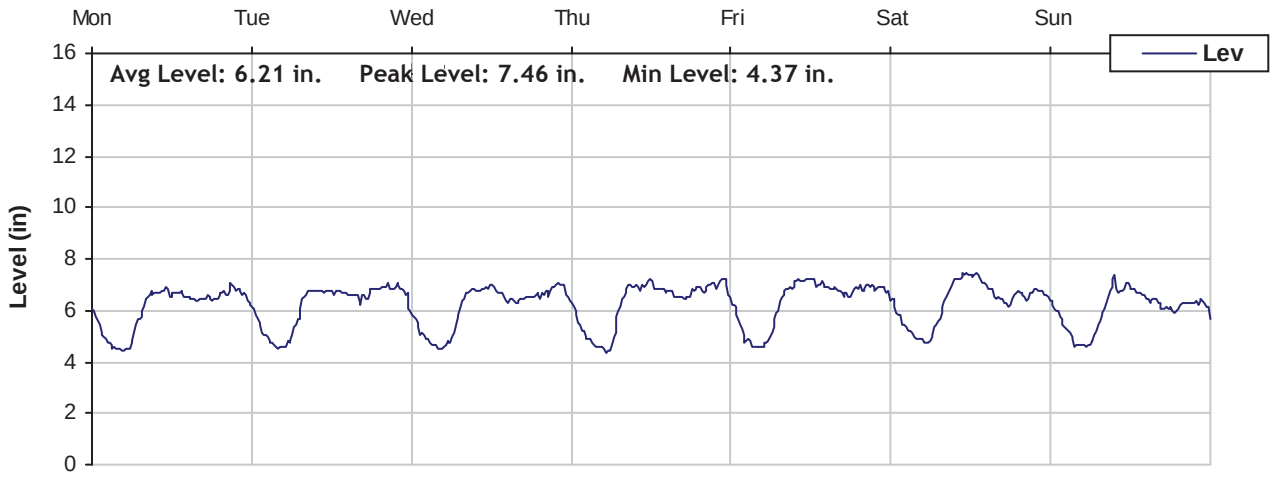


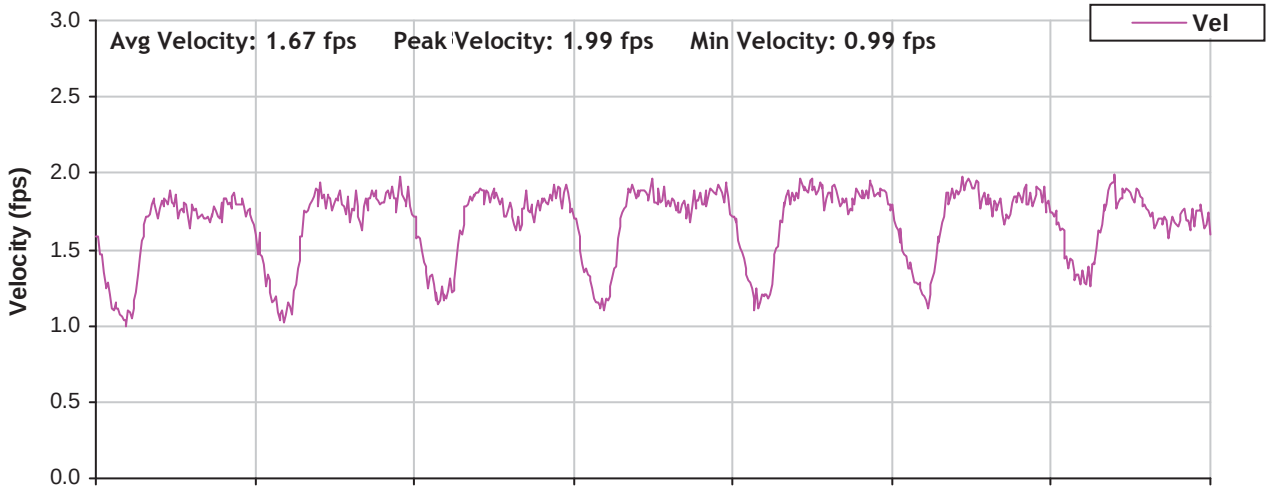


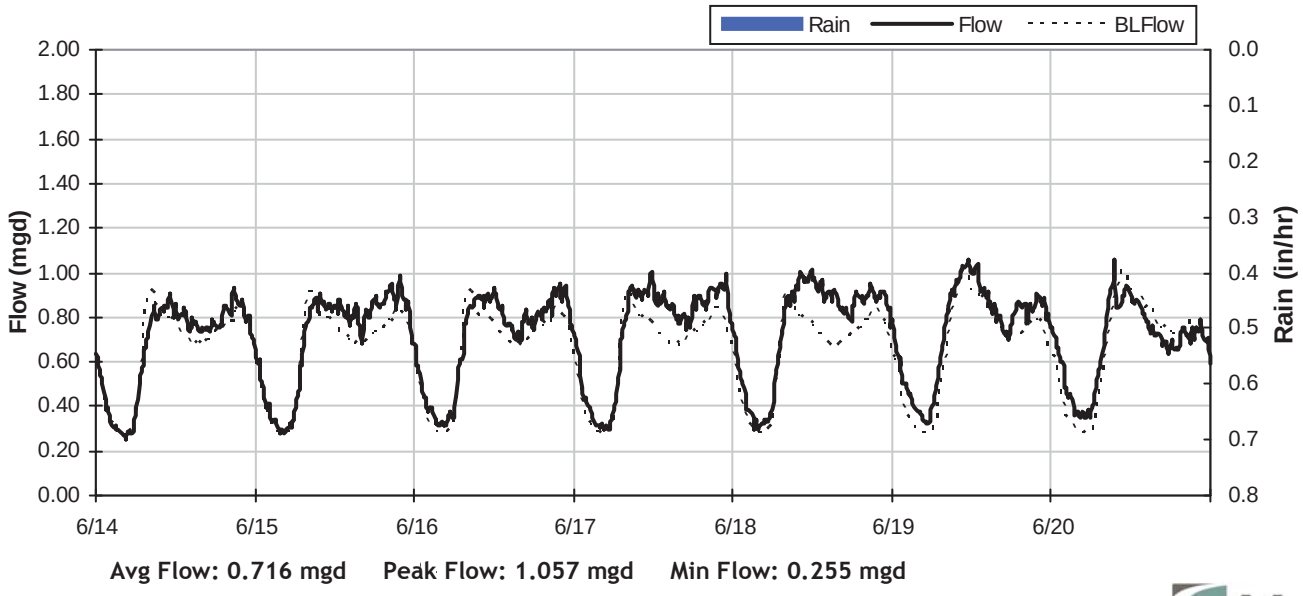


Level, Velocity and Flow
From 6/14/2010 to 6/21/2010

Monitoring Site:
Site 4A







Avg Flow: 0.716 mgd Peak Flow: 1.057 mgd Min Flow: 0.255 mgd

Temporary Flow Monitoring Study

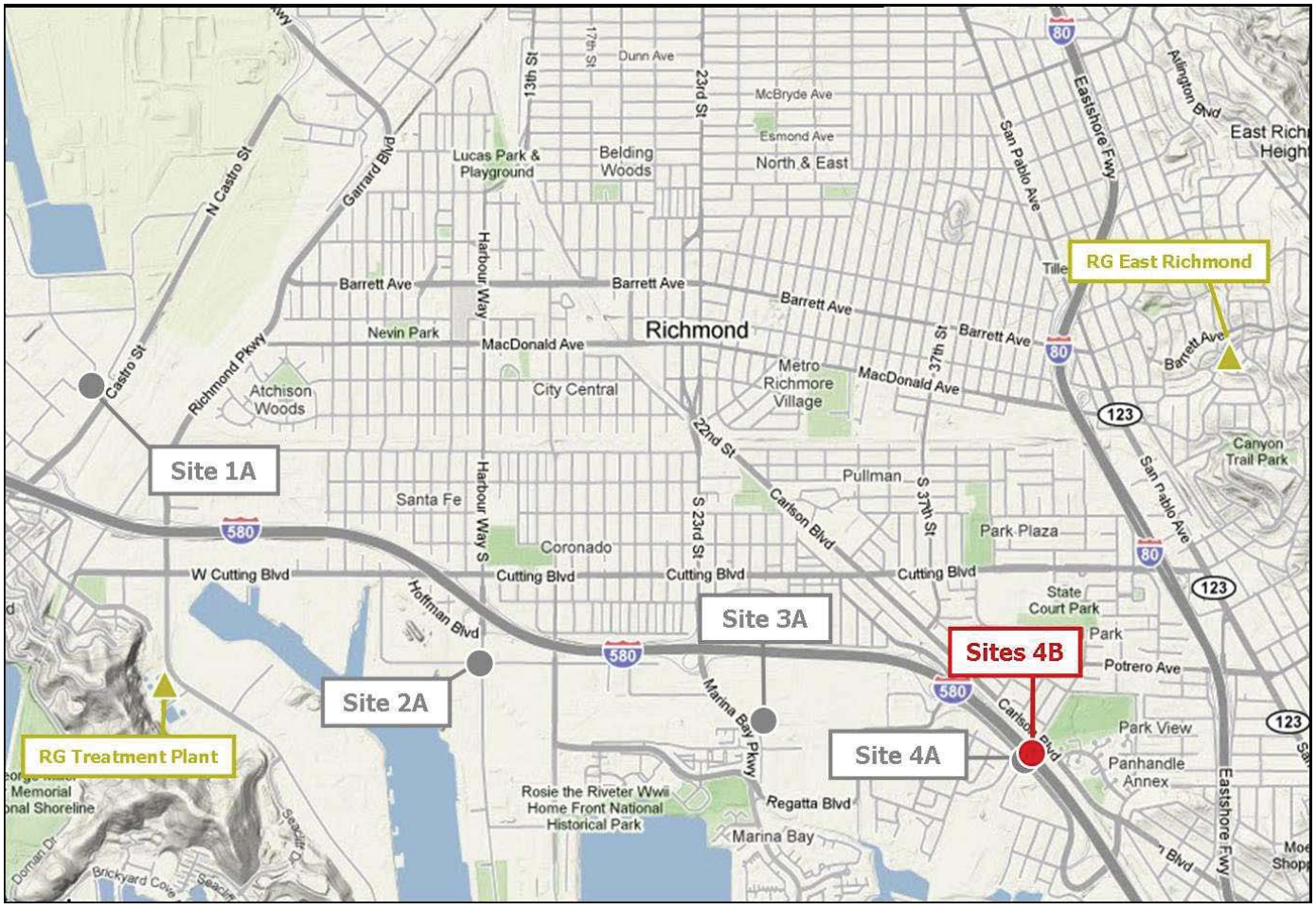
Sanitary Sewer Collection System

Monitoring Site: Site 4B

Location: Meade St., at intersection with Seaver Ave.

Size/Type Line: 24-inch Sanitary Sewer Pipe

Data Summary Report



V&A

Site Information Report

Monitoring Site: Site 4B

Location: Meade St., at intersection with Seaver Ave.

Latitude: 37.9257°

Longitude: -122.3622°

Rim Elevation: 11 *feet*

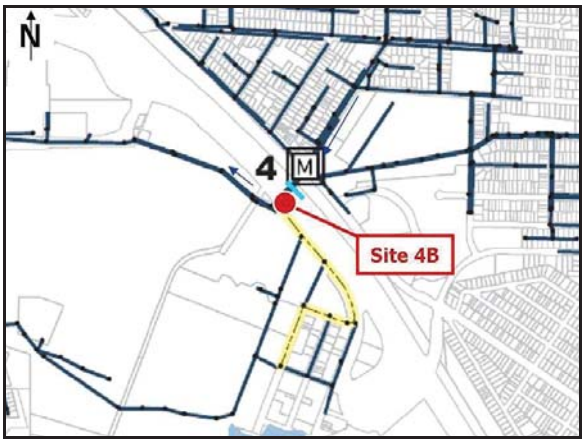
Diameter: 24 *inches*

Average Dry Weather Flow: 0.458 *mgd*

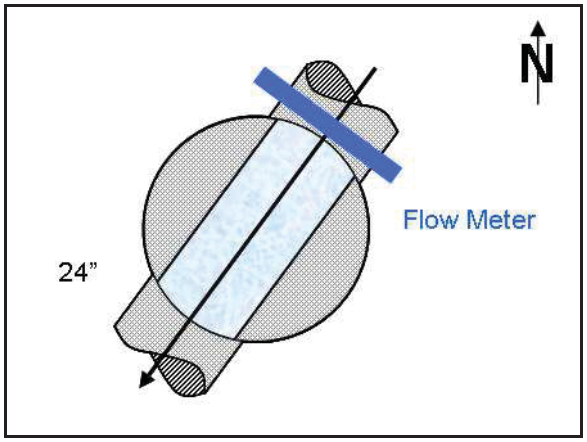
Peak Measured Flow: 1.154 *mgd*

Satellite Photo

Sanitary Map



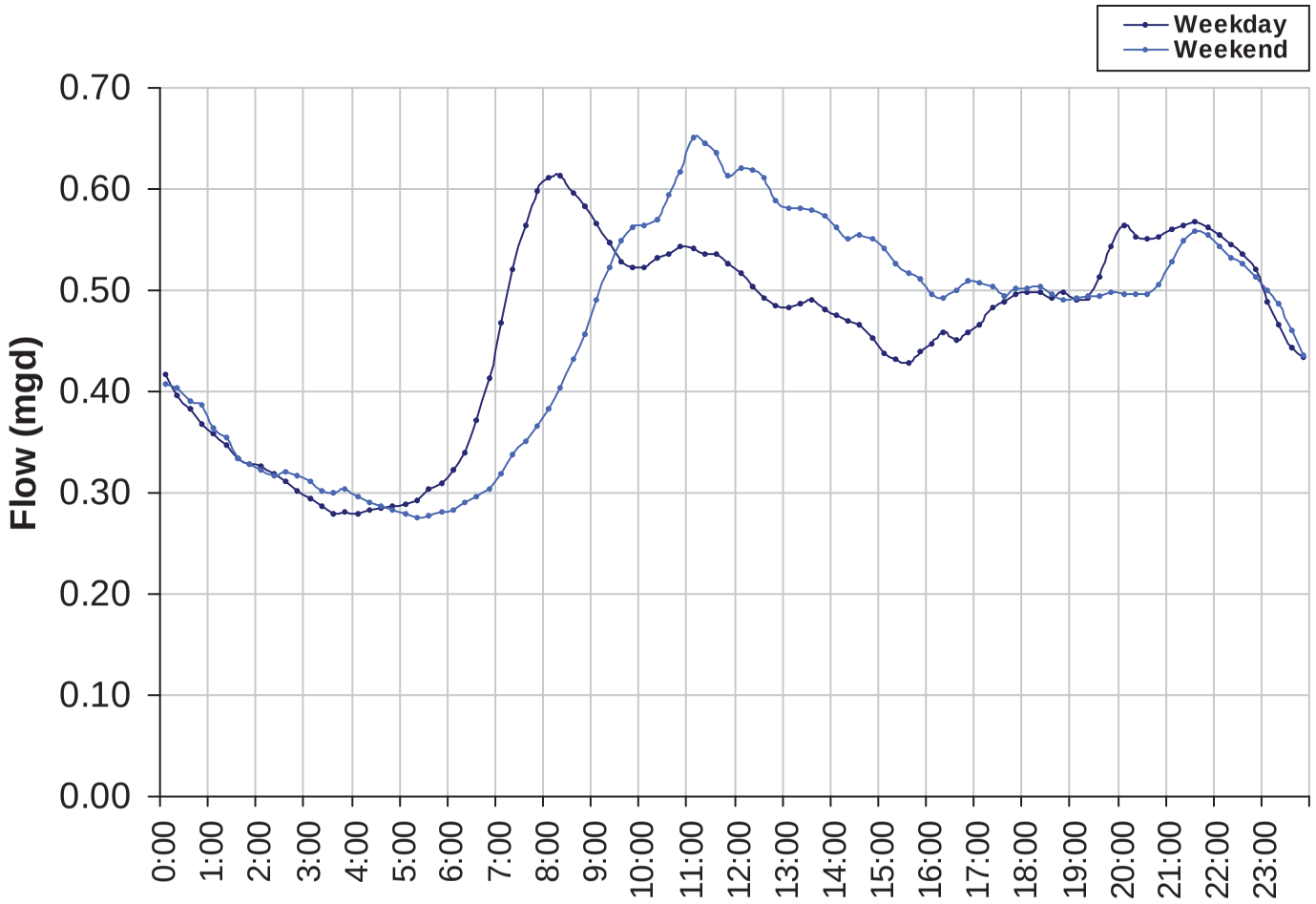
Flow Sketch



Street View Photo

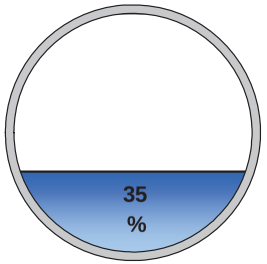
Average Dry Weather Flow

Monitoring Site:
Site 4B



Peak Measured Flow:

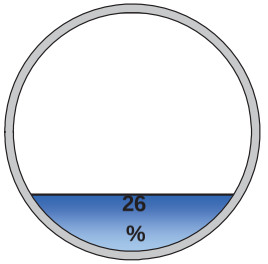
1.15 *mgd*



Peak measured flow shown in weekly graphs on following pages

Average Dry Weather Flow:

0.46 *mgd*

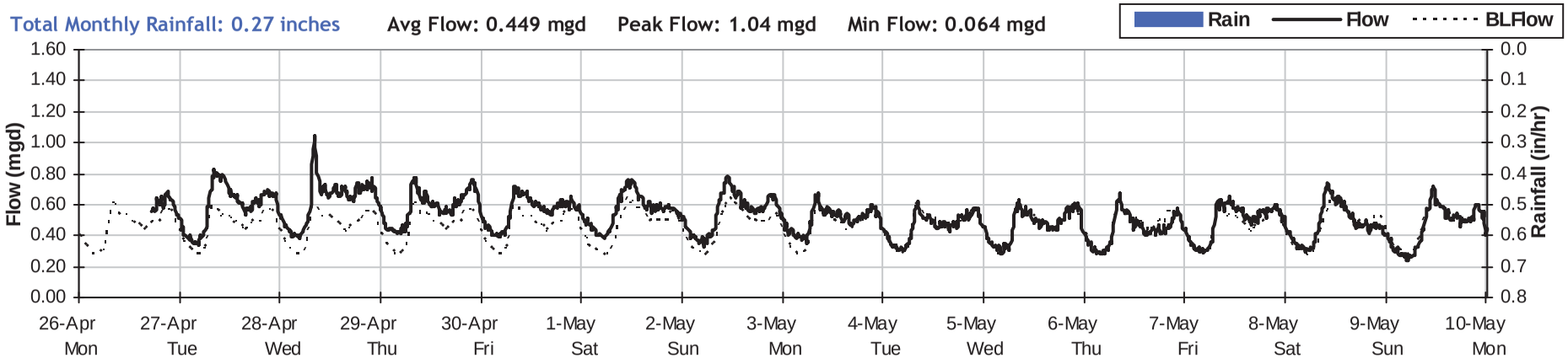


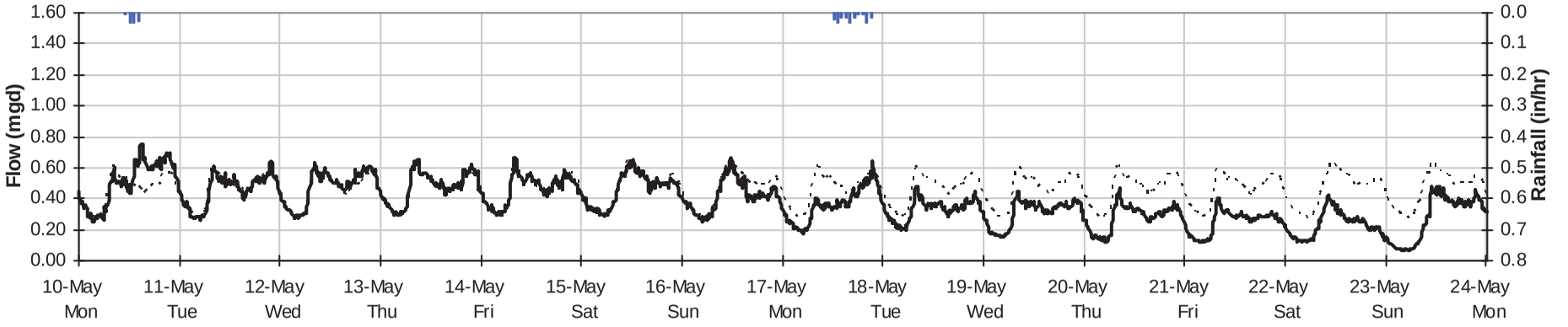
V&A

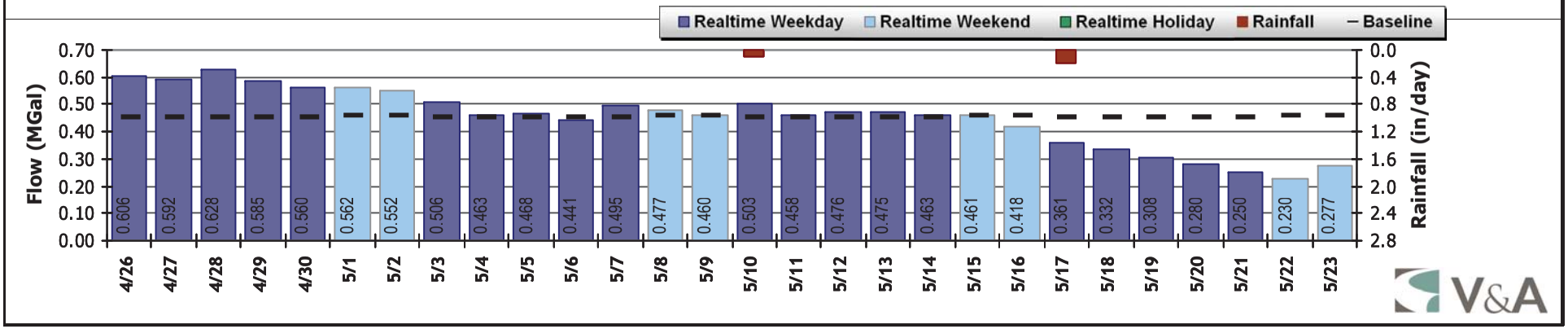
Period Flow Summary
April 26 to May 23, 2010

Monitoring Site:
Site 4B

Total Monthly Rainfall: 0.27 inches Avg Flow: 0.449 mgd Peak Flow: 1.04 mgd Min Flow: 0.064 mgd





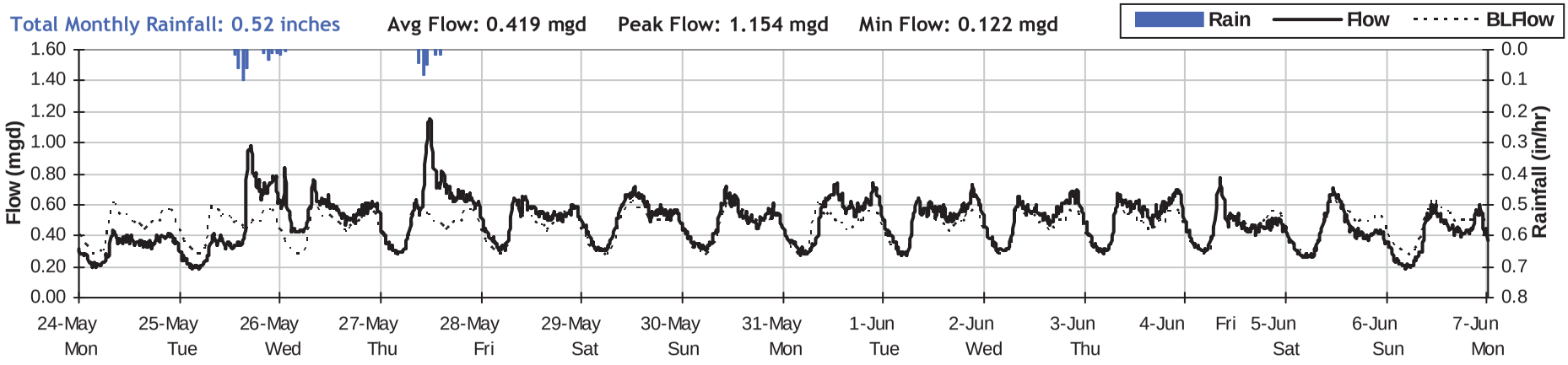


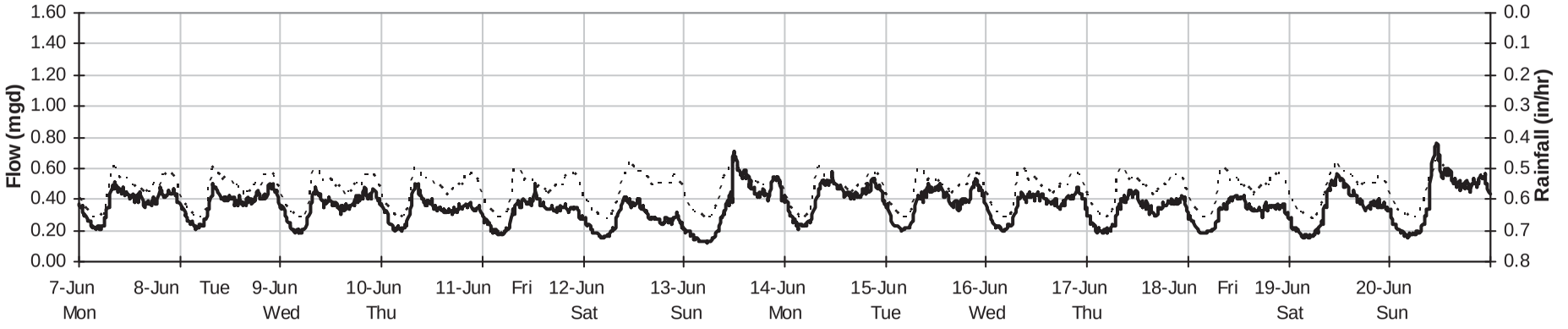
V&A

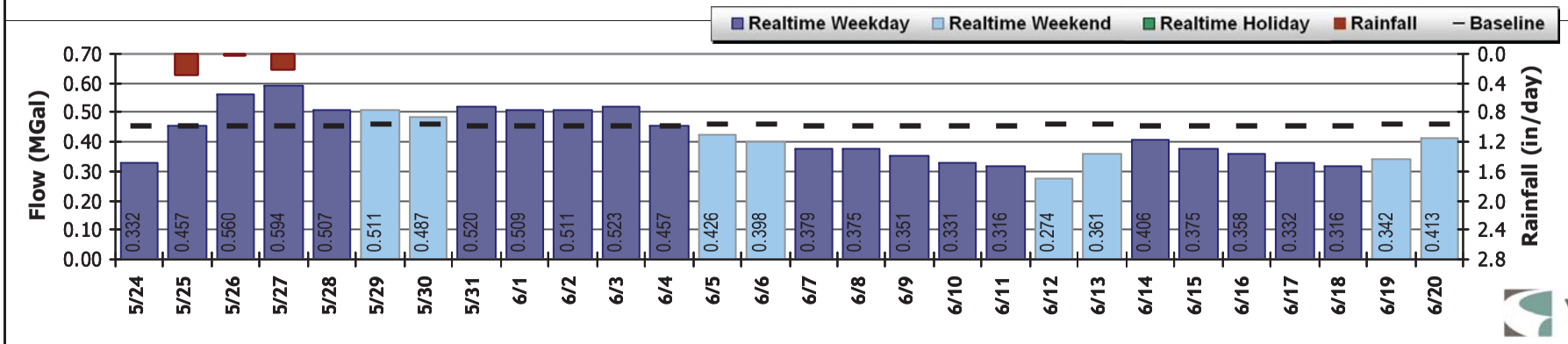
Period Flow Summary
May 24 to June 21, 2010

Monitoring Site:
Site 4B

Total Monthly Rainfall: 0.52 inches Avg Flow: 0.419 mgd Peak Flow: 1.154 mgd Min Flow: 0.122 mgd



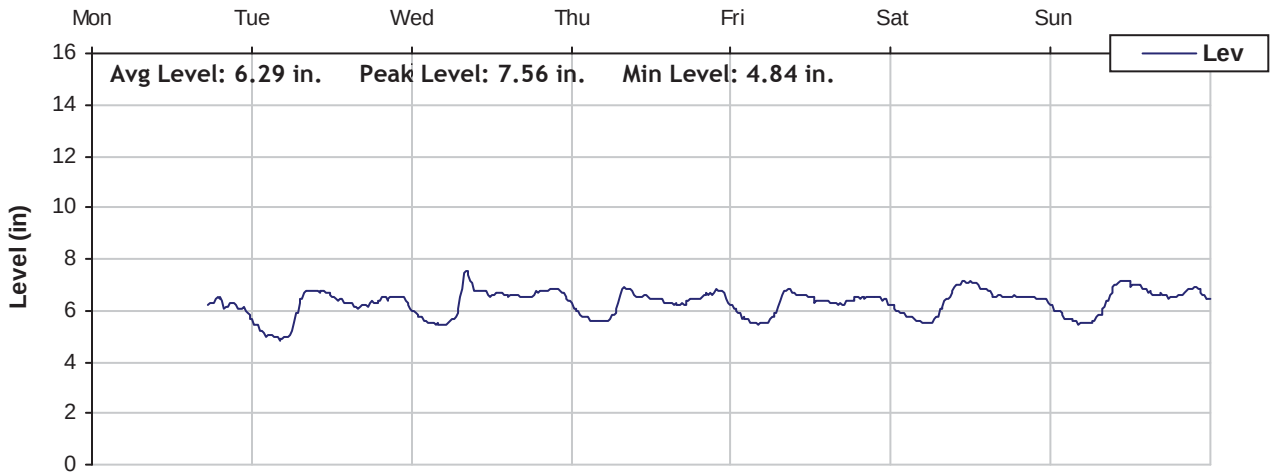


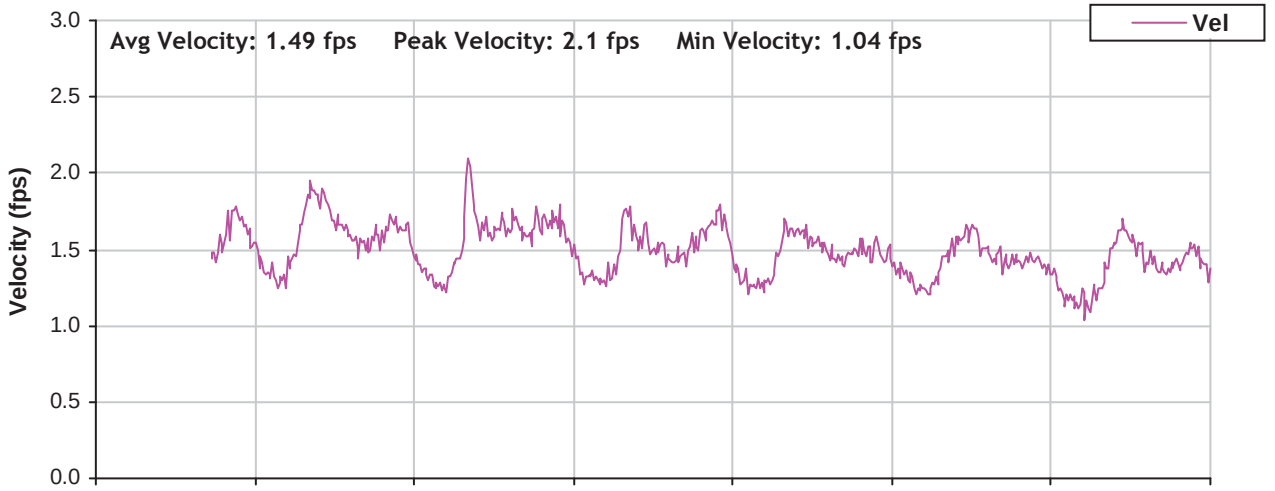


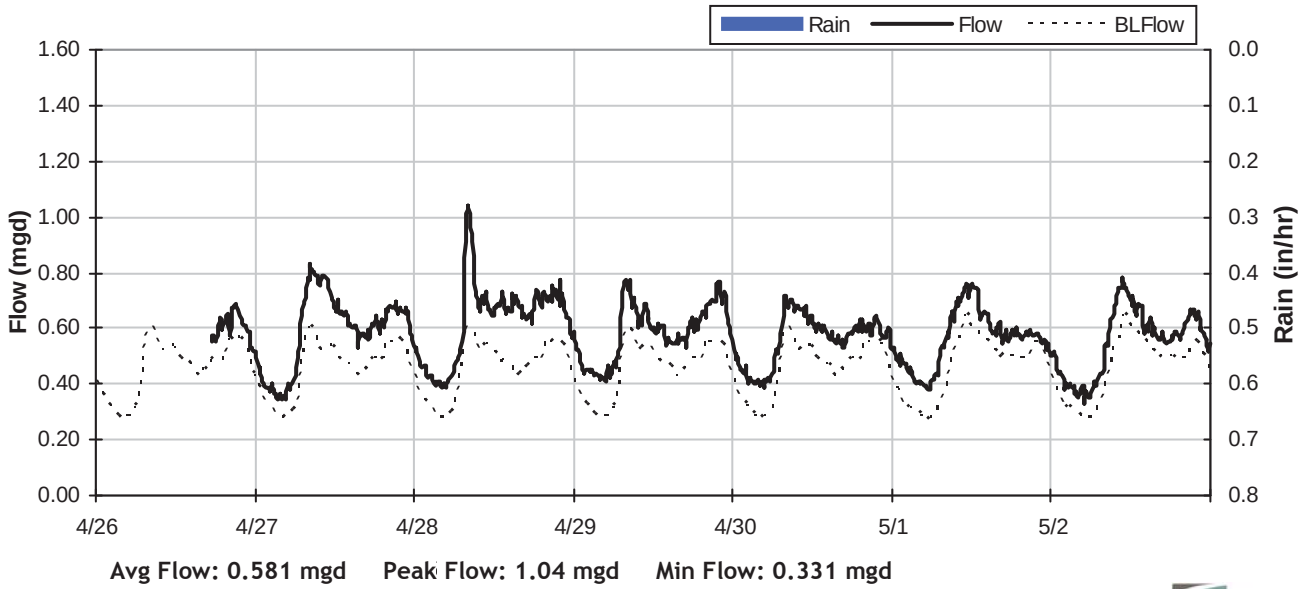
V&A

Level, Velocity and Flow
From 4/26/2010 to 5/3/2010

Monitoring Site:
Site 4B

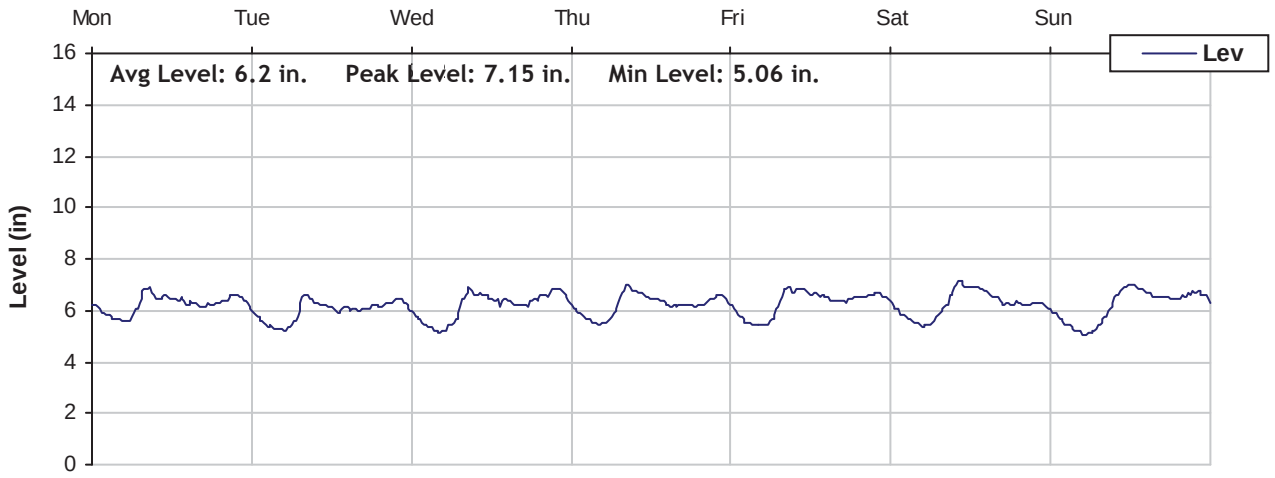


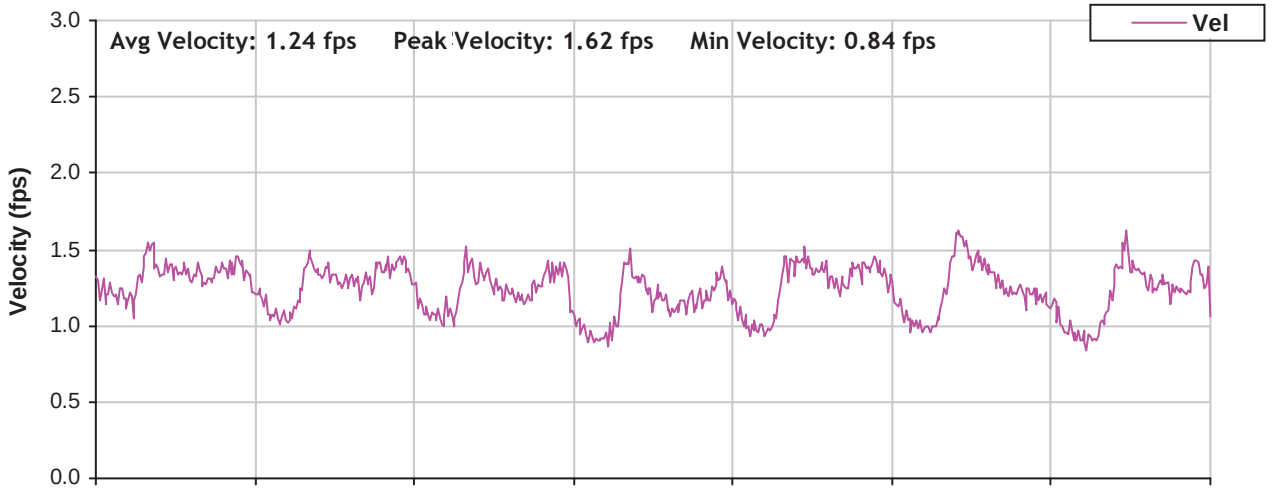


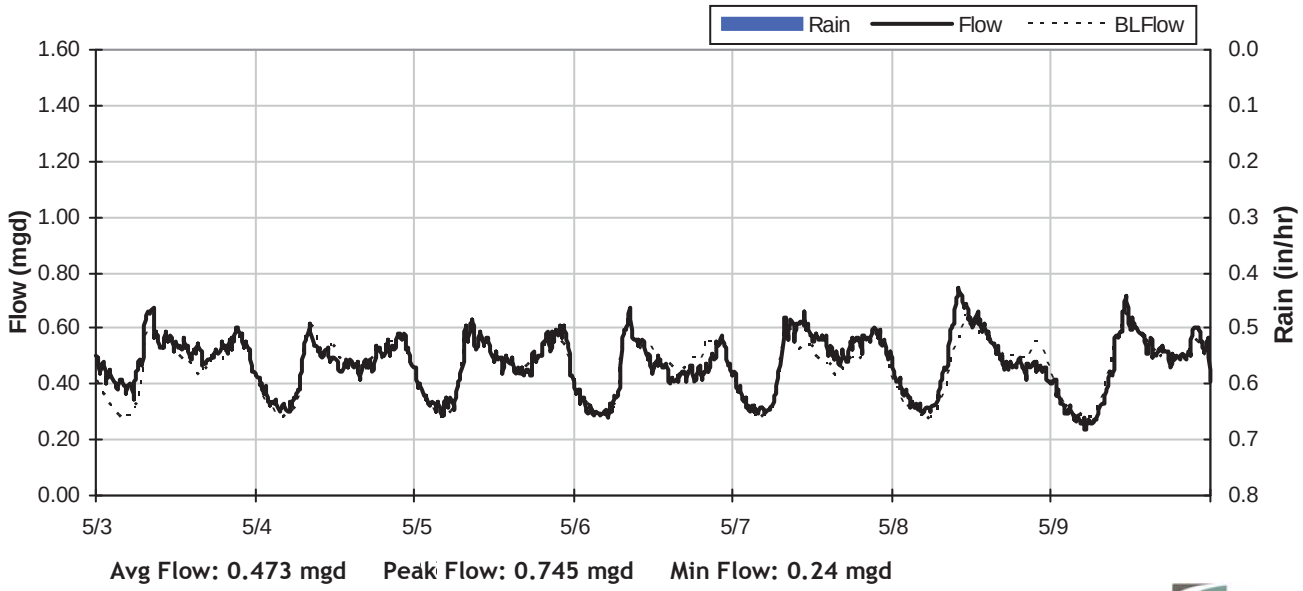


Level, Velocity and Flow
From 5/3/2010 to 5/10/2010

Monitoring Site:
Site 4B



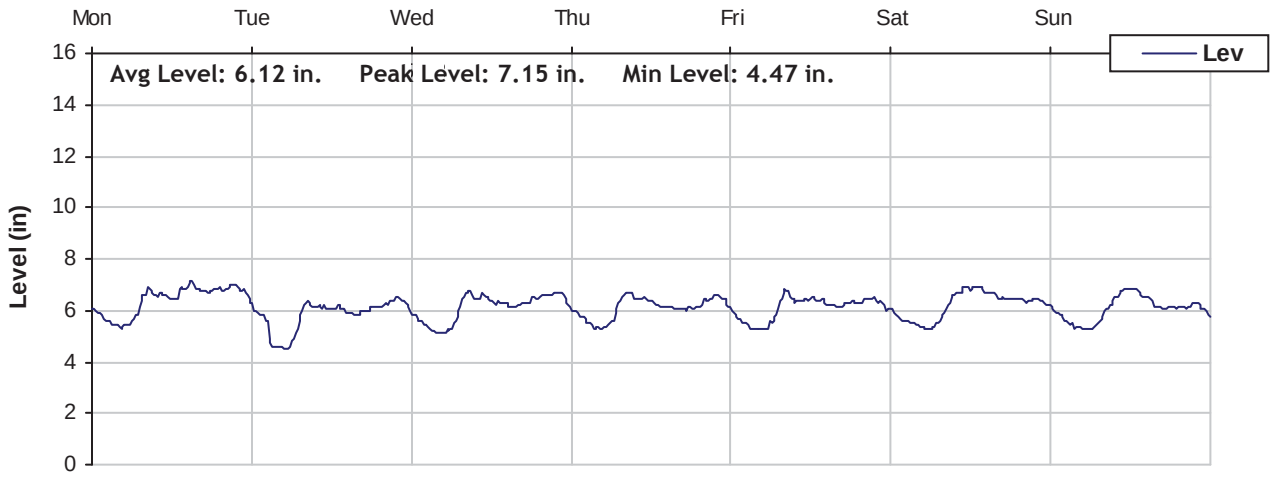


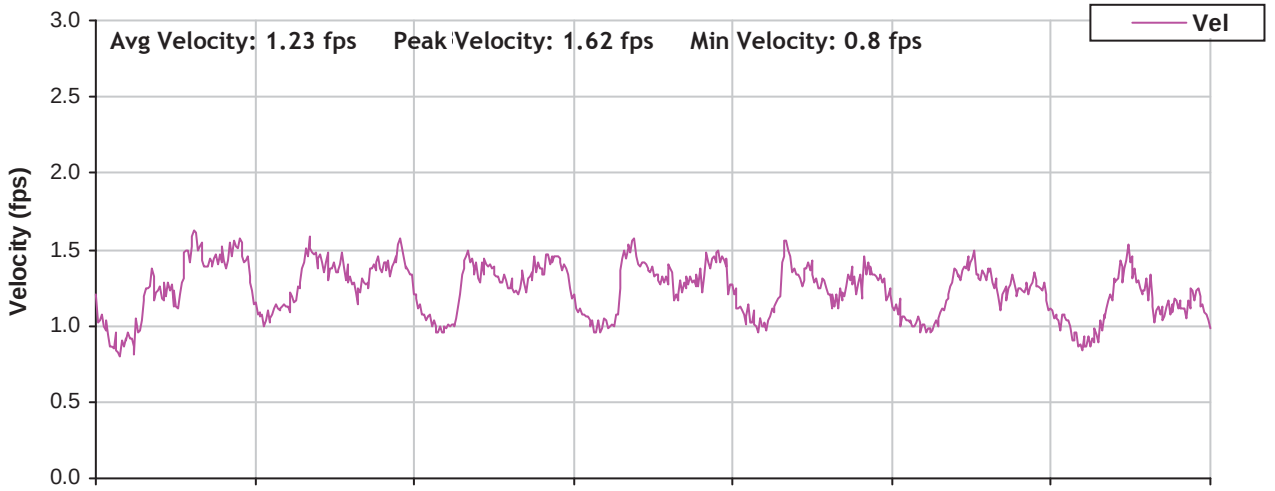


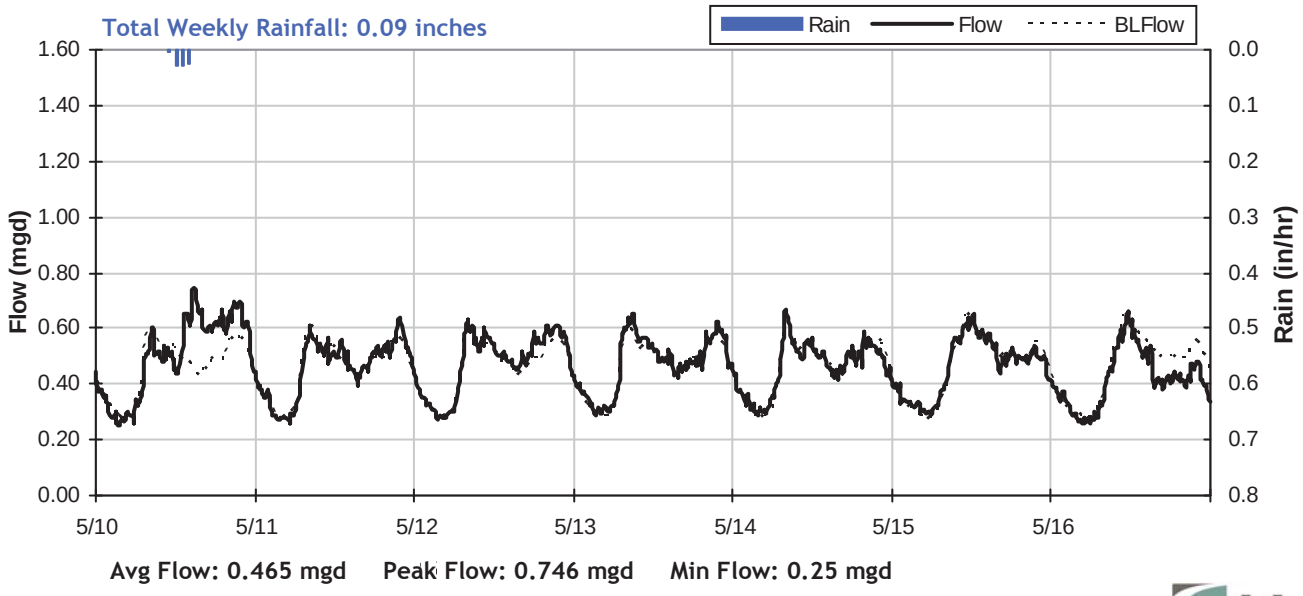
Avg Flow: 0.473 mgd Peak Flow: 0.745 mgd Min Flow: 0.24 mgd

Level, Velocity and Flow
From 5/10/2010 to 5/17/2010

Monitoring Site:
Site 4B

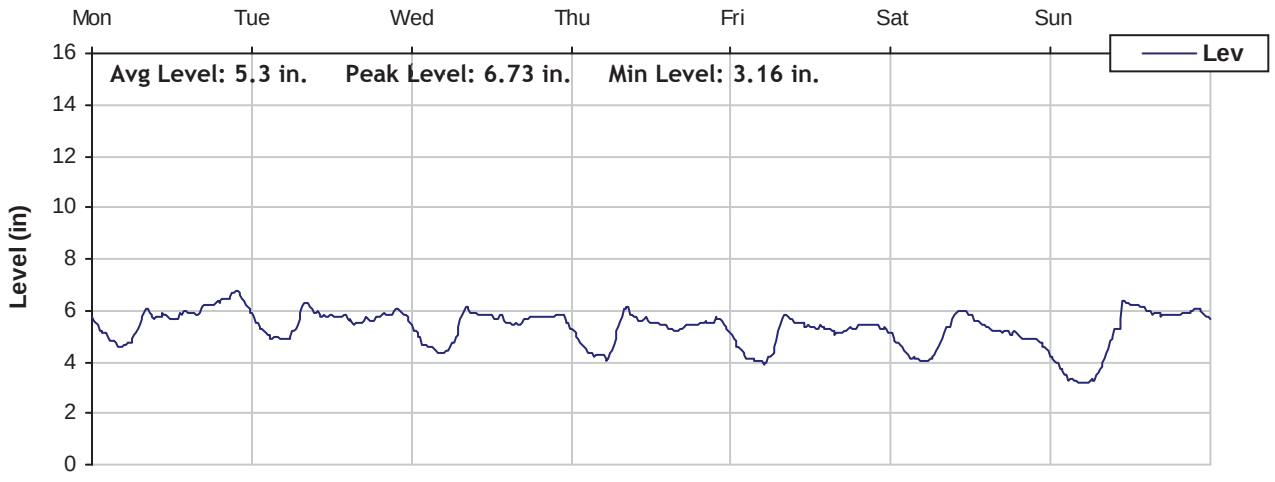


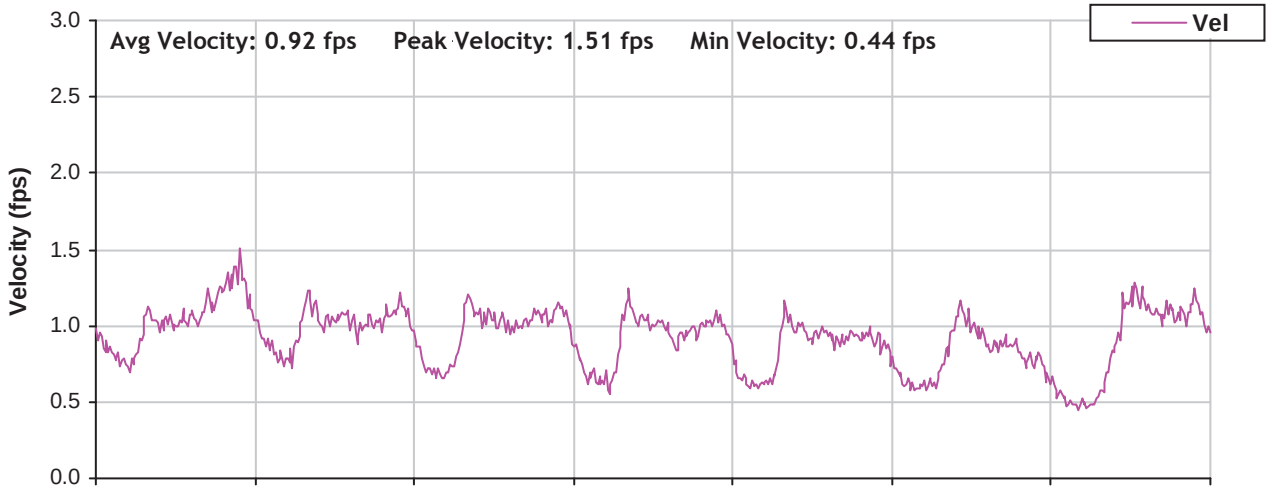


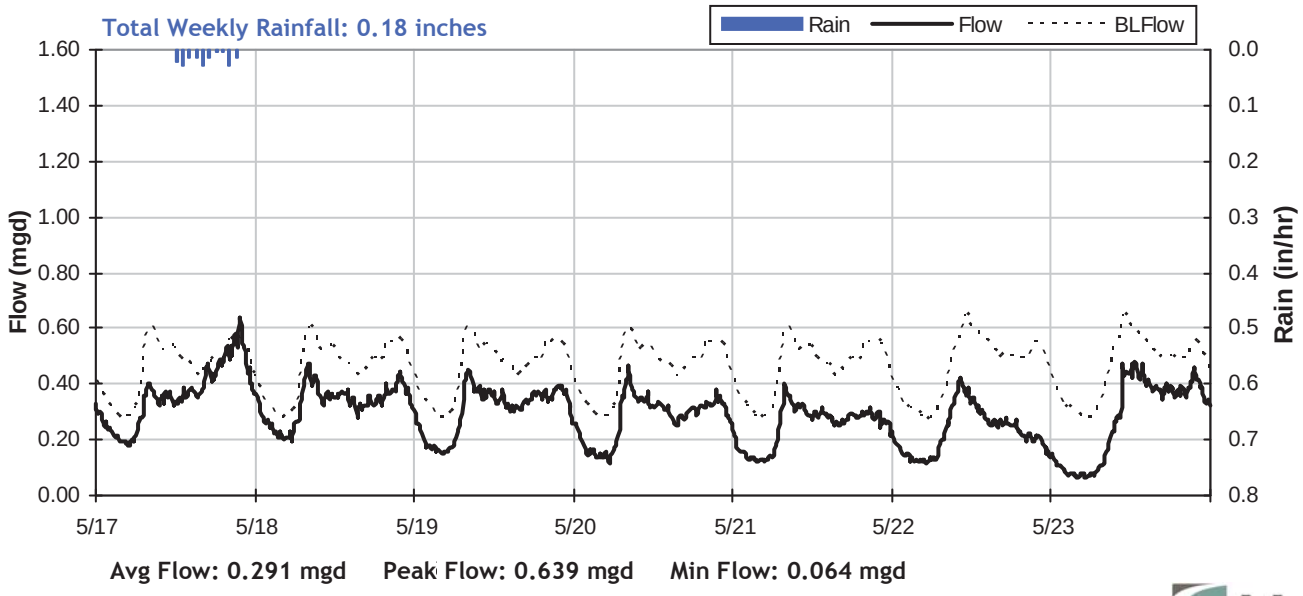


Level, Velocity and Flow
From 5/17/2010 to 5/24/2010

Monitoring Site:
Site 4B



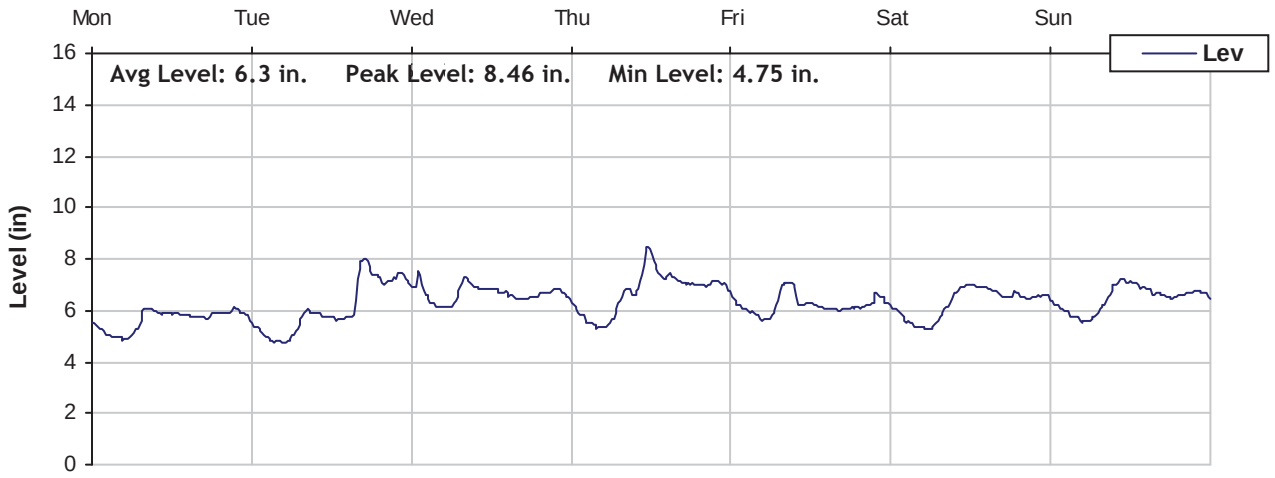


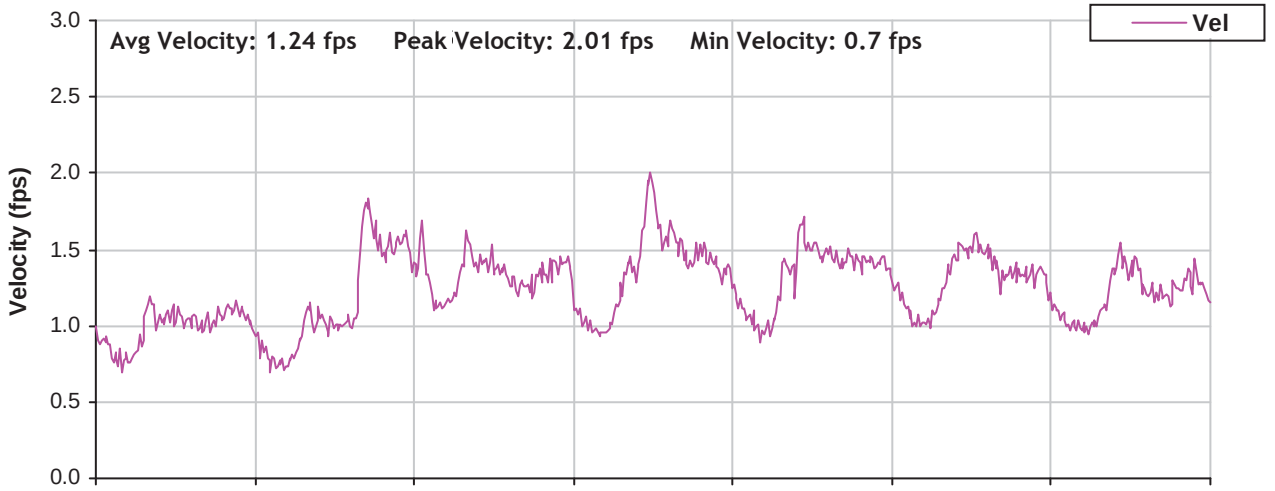


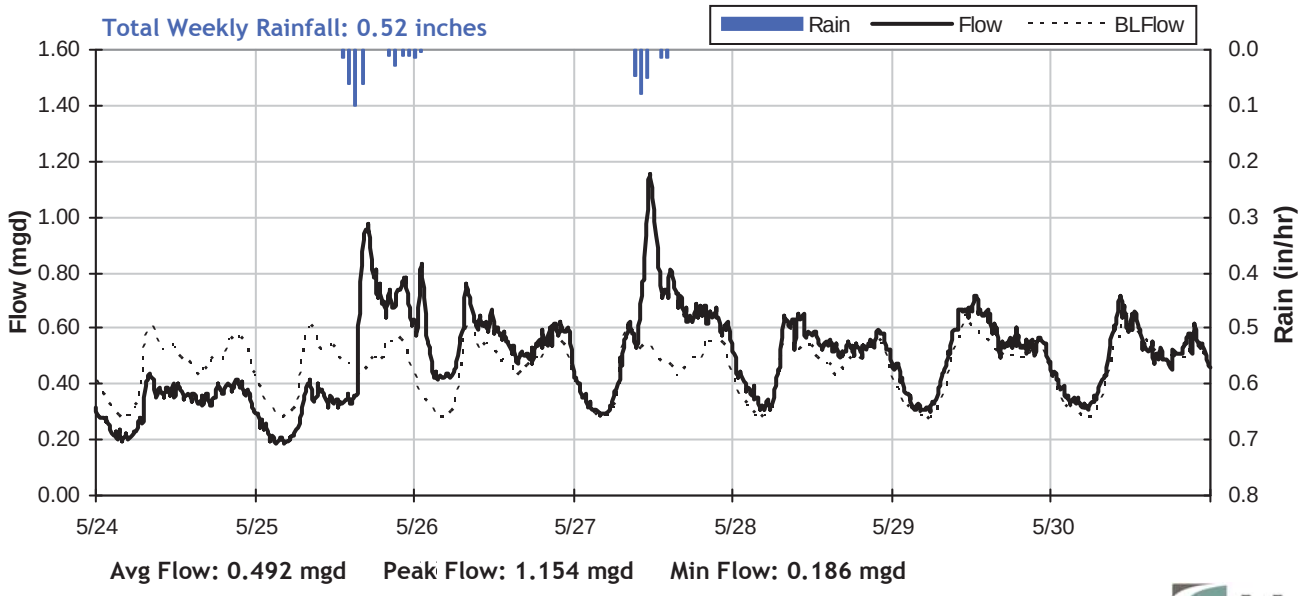
Avg Flow: 0.291 mgd Peak Flow: 0.639 mgd Min Flow: 0.064 mgd

Level, Velocity and Flow
From 5/24/2010 to 5/31/2010

Monitoring Site:
Site 4B

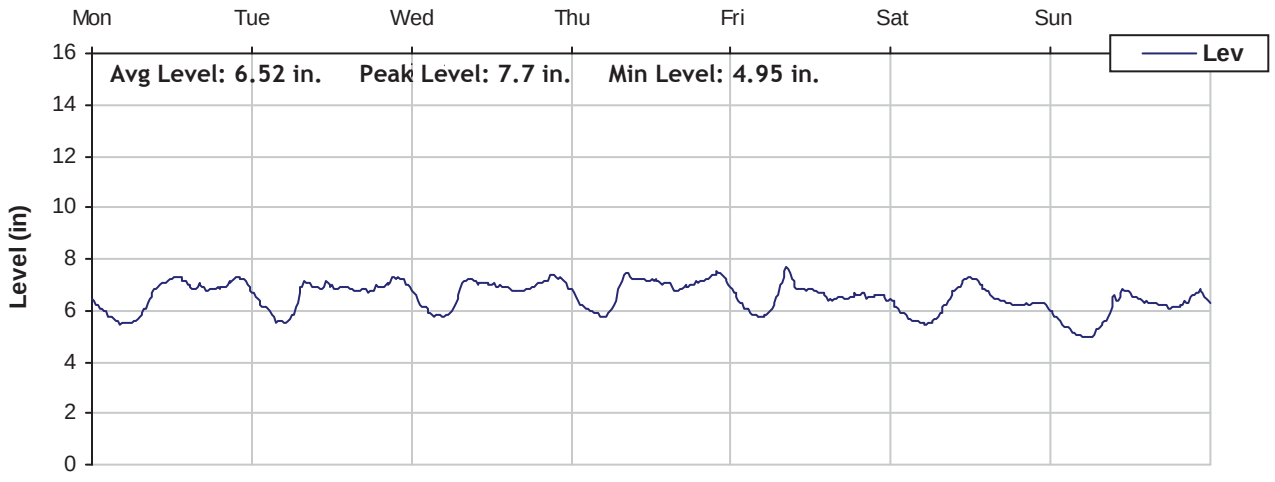


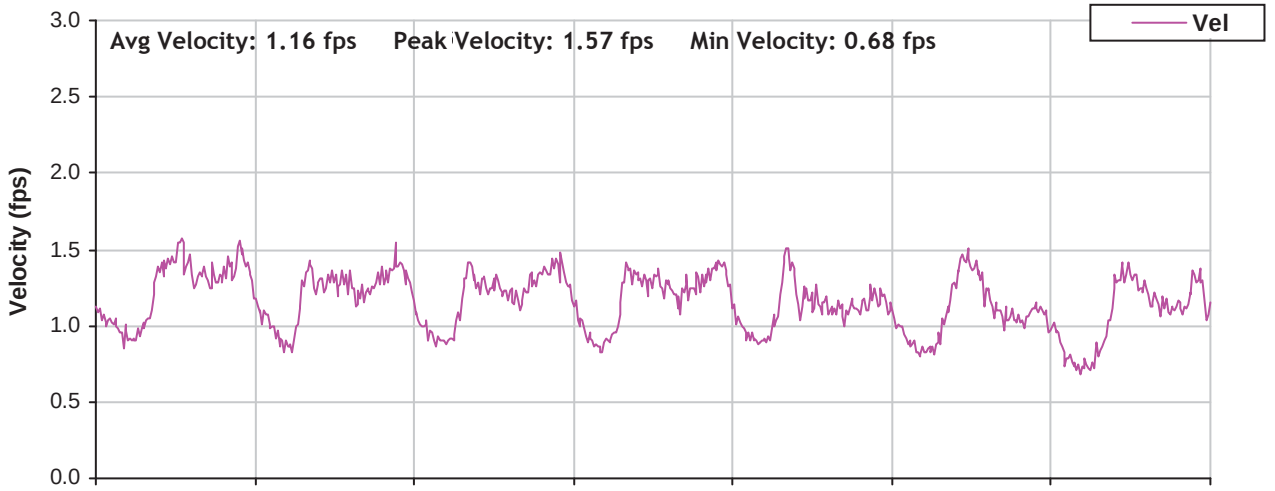


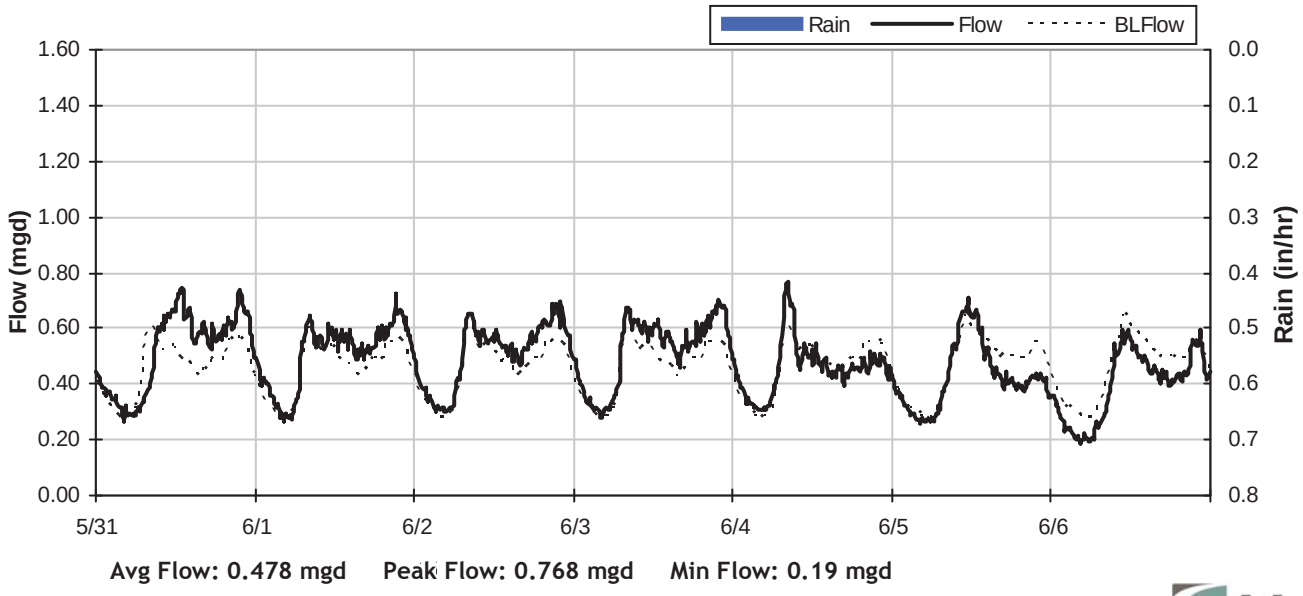


Level, Velocity and Flow
From 5/31/2010 to 6/7/2010

Monitoring Site:
Site 4B

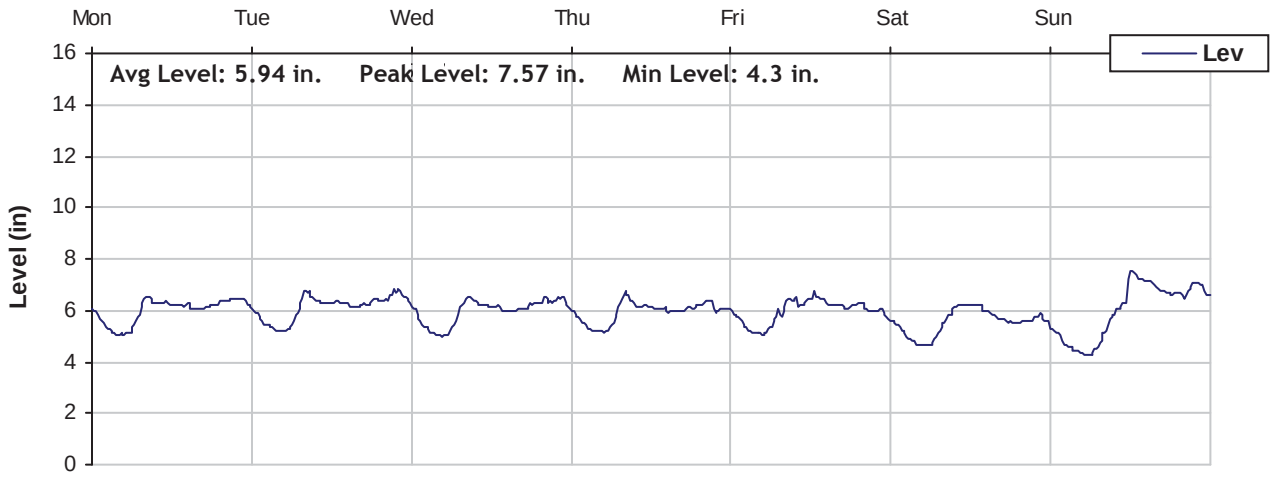


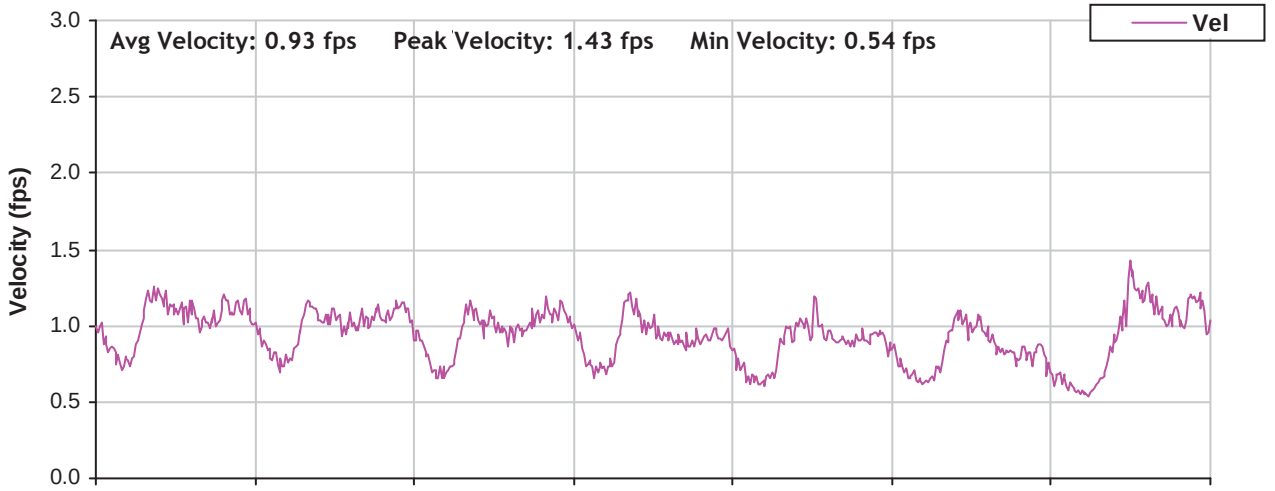


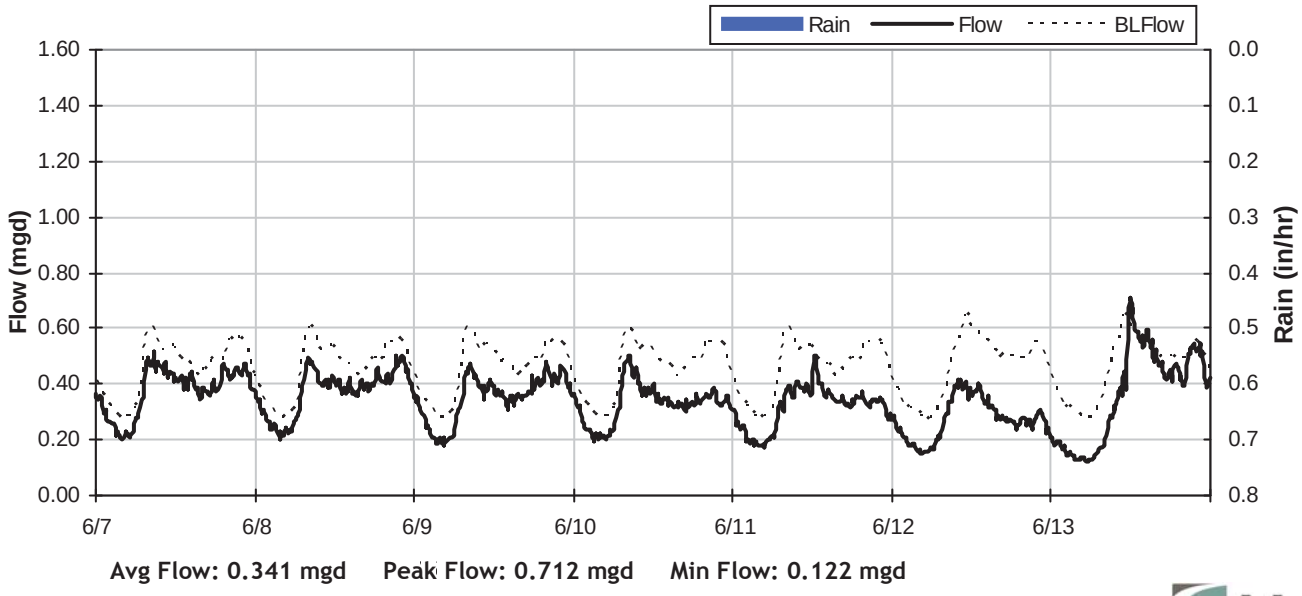


Level, Velocity and Flow
From 6/7/2010 to 6/14/2010

Monitoring Site:
Site 4B



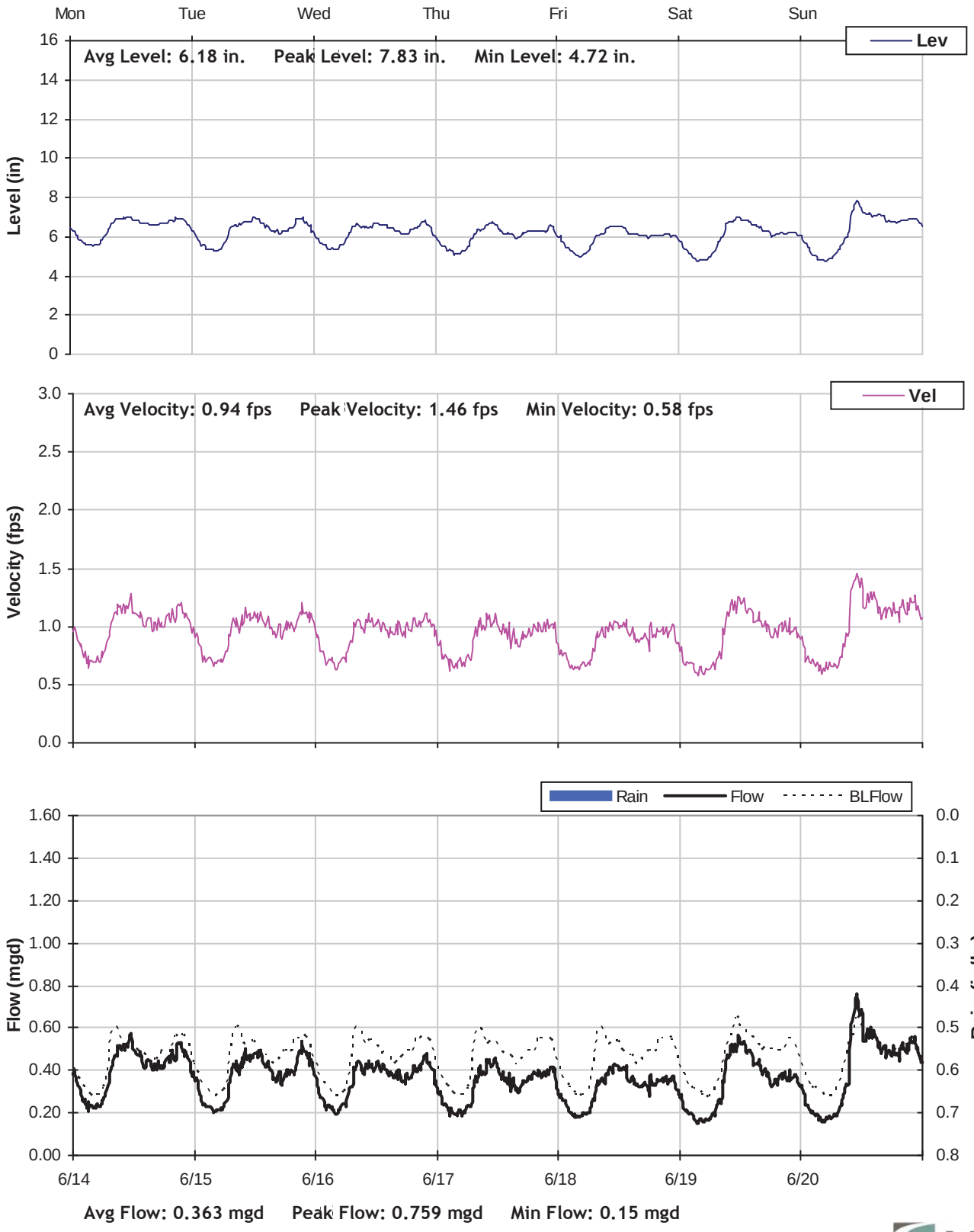




Avg Flow: 0.341 mgd Peak Flow: 0.712 mgd Min Flow: 0.122 mgd

Level, Velocity and Flow
From 6/14/2010 to 6/21/2010

Monitoring Site:
Site 4B



Oakland
155 Grand Avenue, Suite 700
Oakland, CA 94612
510.903.6600 **Tel**
510.903.6601 **Fax**

San Diego
8291 Aero Place, Suite 110
San Diego, CA 92123
858.576.0226 **Tel**
858.576.0004 **Fax**

Seattle
14900 Interurban Avenue, Suite 268
Seattle, WA 96818
206.674.4560 **Tel**
206.674.4561 **Fax**

Houston
8220 Jones Road, Suite 500
Houston, TX 77065
713.840.6490 **Tel**
713.840.6491 **Fax**

vaengineering.com

SANITARY SEWER FLOW MONITORING AND TIDAL INFLOW AND INFILTRATION STUDY

City of Richmond

September 2011

V&A

SANITARY SEWER FLOW MONITORING AND TIDAL INFLOW & INFILTRATION STUDY

Prepared for

WEST YOST ASSOCIATES
Consulting Engineers

Prepared by

V&A

September 2011

TABLE OF CONTENTS

ABBREVIATIONS, TERMS and DEFINITIONS iv

EXECUTIVE SUMMARY 1
Tidal Inflow and Infiltration Analysis Results 4
INTRODUCTION 5
Preface 5
Scope and Purpose 5
Sites and Basins 5
METHODS AND PROCEDURES 7
Confined Space Entry 7
Flow Meter Installation 8
Flow Calculation 8
RESULTS AND ANALYSIS 10
Rainfall 10
Tide 10
Flow Monitoring: Average Dry Weather Flows 10
Flow Monitoring: Peak Measured Flows and Pipeline Capacity Analysis 12
Tidal Inflow and Infiltration 15
Temperature vs. Tide 15
Peak Flows vs. Tide 17
Estimated Tidal Inflow/Infiltration 19

TABLES

Table 1. Peak Flows and Capacity Summary 1
Table 2. Estimated Contribution of Tidal I&I per Basin 4
Table 3. List of Flow Monitoring Sites 6
Table 4. Dry Weather Flow Summary 10
Table 5. Capacity Analysis Summary 12
Table 6. Temperature Summary 16
Table 7. Flow Peak vs. High Tide Summary 18
Table 8. Estimated Contribution of Tidal I&I per Basin 19

FIGURES

Figure 1. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site 2
Figure 2. Peak Measured Flow (Flow Schematic) 3
Figure 3. Flow Monitoring Sites Map 6
Figure 4. Typical Isco 2150 Flow Meter Installation 8
Figure 5. Average Dry Weather Flow (Flow Schematic) 11

Figure 6. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site 13
Figure 7. Peak Measured Flow (Flow Schematic)..... 14
Figure 8. Tide vs. Temperature (°F) for Site 4 (top) and Site 5 (bottom) 15
Figure 9. Tide vs. Flow for Site 4 (top) and Site 5 (bottom) 17

APPENDIX

Appendix A: Flow Monitoring Sites: Data, Graphs, Information

ABBREVIATIONS, TERMS AND DEFINITIONS USED IN THIS REPORT

Table i.
Abbreviations

Abbreviation	Term
ADWF	average dry weather flow
CCTV	closed-circuit television
CIP	capital improvement plan
CO	carbon monoxide
d/*D*	depth/diameter ratio
FM	flow monitor
gpd	gallons per day
gpm	gallons per minute
GWI	groundwater infiltration
H_2S	hydrogen sulfide
I&I	inflow and infiltration
IDM	inch-diameter-mile, miles of pipeline multiplied by the diameter of the pipeline in inches.
IDW	inverse distance weighting
LEL	lower explosive limit
mgd	million gallons per day
NOAA	National Oceanic and Atmospheric Administration
Q	flow rate
SSO	sanitary sewer overflow
WEF	Water Environment Federation
WRCC	Western Regional Climate Center

Table ii.
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 can be expressed as a numeric average or as a curve showing the variation in flow over a day. ADWF includes the influence of normal (non-rain event) groundwater infiltration.
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 the pipelines. A basin may refer to the entire collection system upstream from a flow meter, or if flow meters are aligned in series (flowing into each other), a basin may 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. This term is used as a part of *Capacity Analysis*.
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. This is calculated by subtracting the expected ADWF totalized flow from the measured real-time totalized flow across the limits of the 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 submerged. The variation on groundwater levels and subsequent groundwater infiltration rates are 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.
Infiltration, *Rainfall Responsive*	Rainfall Responsive Infiltration (**RRI**) is storm water which enters the collection system through pipe defects, but normally in sewers constructed close to the ground surface such as private laterals. RRI 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.
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. SSOs are often attributable to high inflow rates.

Term	Definition
Peaking factor	Ratio of peak measured flow to average dry weather flow. This ratio expresses the degree of fluctuation in flow rate over the monitoring period. This is used for *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 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.
Weekend/weekday ratio	The ratio of weekend ADWFs to weekday ADWFs. In residential areas, it is typical that this ratio would be slightly higher than 1.0. In business districts, depending on type of service, this ratio can be significantly less than 1.0.

EXECUTIVE SUMMARY

V&A has completed sanitary sewer flow monitoring and tidal inflow/infiltration (I&I) analysis within the City of Richmond (City). Flow monitoring occurred over a 5-week period from June 28, 2011 to August 2, 2011 at six open channel flow monitoring sites. The purpose of this study was to measure sanitary sewer flows at the flow monitoring sites and conduct analyses pertaining to capacity and tidal infiltration and inflow (I&I) occurring in the basins upstream from the flow monitoring sites.

Site Flow Monitoring and Capacity Results

Table 1 summarizes the peak recorded flows, levels, d/D ratios and peaking factors per site during the flow monitoring period. Note: capacity analysis data is presented on a **site-by-site** basis and represents the hydraulic conditions only at the point site location. Hydraulic conditions in other areas of the collection system will differ.

Table 1.
Peak Flows and Capacity Summary[1]

Site	ADWF (mgd)	Peak Measured Flow (mgd)	Peaking Factor	Diameter (in)	Peak Level (in)	d/D Ratio
Site 1E	3.81	14.01	3.68	54	104.6	1.94
Site 1W	0.97	8.42	8.71	39	94.1	2.41
Site 2	4.86	23.72	4.88	66	118.1	1.79
Site 3	0.11	1.20	10.52	18	54.2	3.01
Site 4**	0.68	4.23	6.26	27	13.1	0.49
Site 5	1.52	5.76	3.80	36	100.1	2.78

**Note: The Site 4 flow meter was not operational at the time of the rainfall event. The peak levels resultant from the plant wet well operations, and the peak flows from the rainfall event, were not recorded for this monitoring site.

The following capacity analysis results are noted:

- **Peaking Factor:** All of the flow monitoring sites had peaking factors that exceeded typical design threshold limits for the peak flow to average dry weather flow ratio.

  d/D Ratio: Five locations had d/D ratios that were above common threshold values for d/D ratio. Site 4 likely surcharged during the wet well operations of June 28, 2011; however, the flow meter was not operational at the time to confirm.

Figure 1 shows bar graphs of the capacity results. Figure 2 shows a schematic diagram of the peak measured flows with peak flow levels.

[1] Notes: (a) ADWF = average dry weather flow. (b) Peak flow as measured during entire flow monitoring period. (c) PF = Peaking Factor = Peak Measured Flow / ADWF. (d) d/D Ratio = peak measured depth / pipe diameter. Values shown are the highest d/D ratios as measured during entire flow monitoring period.

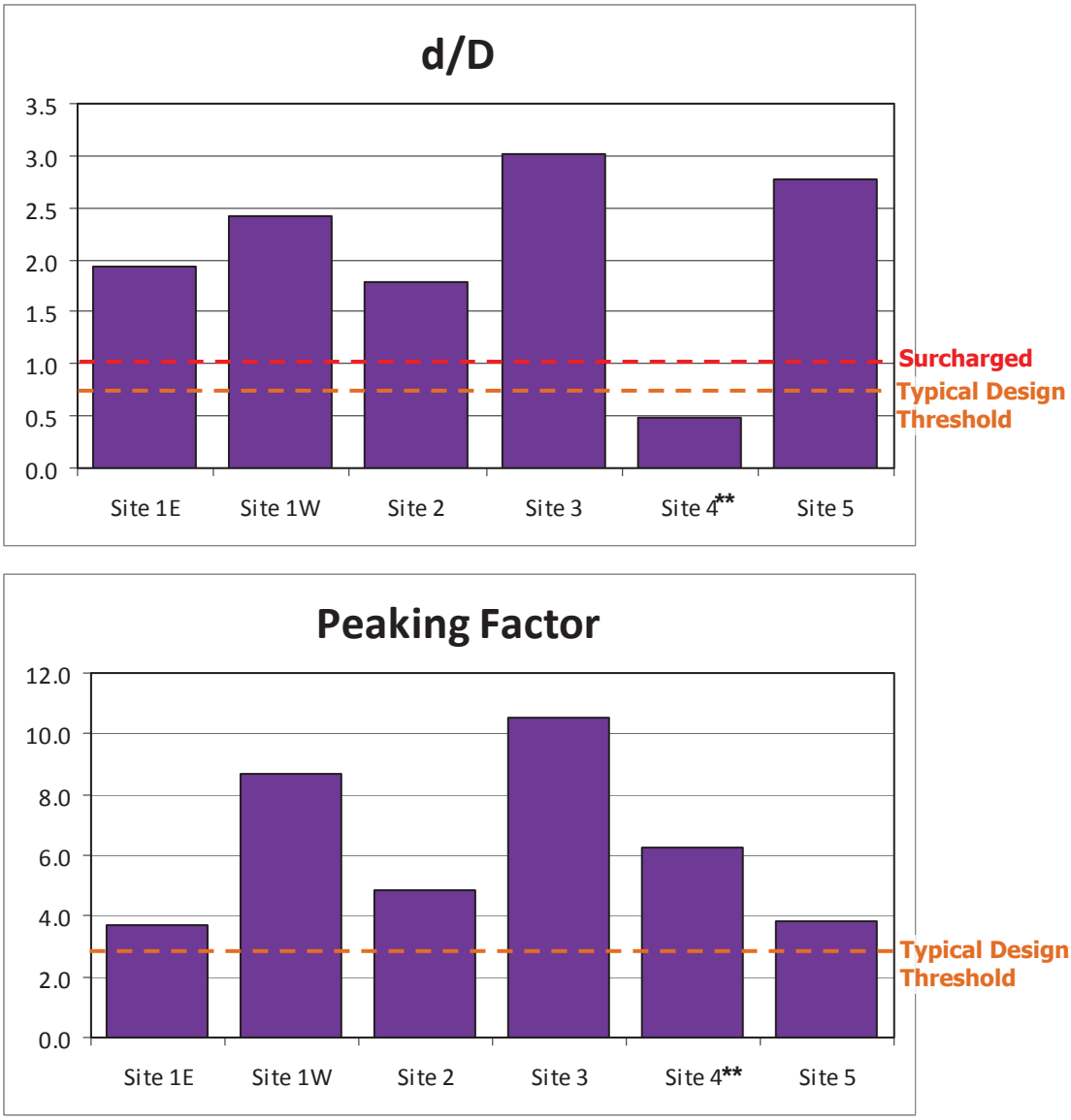


Figure 1. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site

**Note: The Site 4 flow meter was not operational at the time of the rainfall event. The peak levels resultant from the plant wet well operations, and the peak flows from the rainfall event, were not recorded for this monitoring site.

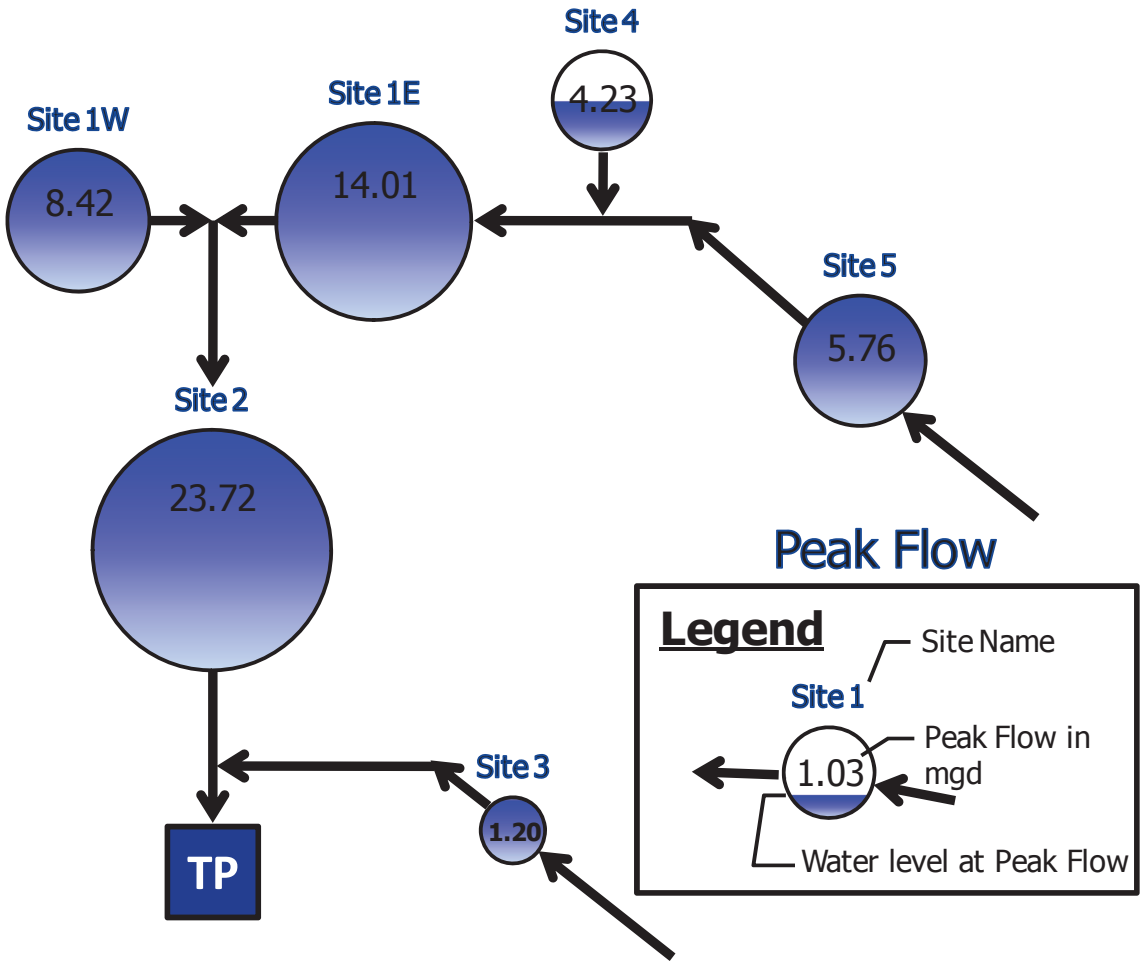


Figure 2. Peak Measured Flow (Flow Schematic)

Tidal Inflow and Infiltration Analysis Results

Table 2 estimates the volume of I&I due to tidal influence for each *basin*. The "Percent I&I to Percent ADWF Ratio" identifies which basins are contributing the most I&I relative to their estimated average dry weather flow; a ratio greater than 1 indicates higher than expected (relative to ADWF) tidal infiltration.

Table 2.
Estimated Contribution of Tidal I&I per Basin

Basin	ADWF (mgd)	% of System Total	Estimated Tidal I&I (mgd)	% of System Total	% I&I to % ADWF Ratio
Basin 1E[2]	1.618	32.5%	0.247	22.4%	0.7
Basin 1W	0.967	19.4%	0.216	19.6%	1.0
Basin 2[3]	0.083	1.7%	0.089	8.0%	4.8
Basin 3	0.114	2.3%	0.009	0.8%	0.4
Basin 4	0.677	13.6%	0.503	45.6%	3.4
Basin 5	1.516	30.5%	0.039	3.5%	0.1
System[4]	**4.974**	**100.0%**	**1.103**	**100.0%**	

The following tidal infiltration and inflow results from this project are noted:

- **Basin 4:** The basin upstream from this Site 4 had the highest percentage of flow that could be attributed to tidal I&I and is responsible for 46% of the tidal I&I in the system. There was a strong correlation between the flow levels, the water temperature and the tide.
- **Basin 1W:** The basin upstream from Site 1W had a moderate tidal response that was observed in the flow response, and less so in the temperature response. On a totalized basis, this site contributed approximately 20% of the tidal I&I to the system. Also, there was a cold-water dumping event on July 16, 2011 that was not related to the tide.
- **Basin 2:** This basin is extremely small, and due to propagation of errors, the values shown in Table 8 are not statistically valid. The 8-inch line that constitutes most of the flow in this basin has been observed to have large volumes of clear water flow entering the system.
- **Basin 1E:** On a totalized basis, Basin 1E contributes approximately 22% of the tidal I&I to the system.
- **Basins 3 and 5:** These basins contribute negligible tidal I&I to the collection system.

[2] Basin 1E = Site 1E less Site 4 less Site 5.

[3] Basin 2 in theory should have very minimal sanitary sewer flow contribution, with one 8-inch inlet line contributing to the basin at Manhole 100039. Given that three very large volumes of flow were subtracted to acquire a small volume of flow, and with propagation of errors, it should be assumed that there may be significant error in the Basin 2 calculation. That stated, the 8-inch inlet line has always been observed by V&A to have large volumes of clear water flow entering the system.

[4] System flows taken as the sum of Site 2 and Site 3.

INTRODUCTION

Preface

The City of Richmond covers 56 square miles along the shores of San Francisco and San Pablo Bays. Approximately 103,468 people call Richmond home. The city has a large industrial section containing such traditional heavy industry companies such as Chevron and Zeneca and newer biotechnology firms. The City retains the services of Veolia Water to run and maintain the wastewater treatment plant and the sanitary sewer collection system.

Scope and Purpose

V&A has completed sanitary sewer flow monitoring and tidal inflow/infiltration (I&I) analysis within the City. Flow monitoring occurred over a 5-week period from June 28, 2011 to August 2, 2011 at six open channel flow monitoring sites. The purpose of this study was to measure sanitary sewer flows at the flow monitoring sites and conduct analyses pertaining to capacity and tidal infiltration and inflow (I&I) occurring in the basins upstream from the flow monitoring sites.

The general geographic area of the study consists of low lying flatlands that may be susceptible to tidal inflow/infiltration. This study was performed during the summer to minimize the possibility and resulting influence of rainfall and the associated infiltration, but was also timed to coincide with the highest tides of the summer. This will help determine which, if any, basins in this area have tidally influenced inflow/infiltration.

Sites and Basins

Flow Monitoring Sites: Flow monitoring sites are the locations where the flow monitors were placed. Flow monitoring site data may include the flows of one or many drainage basins. To isolate a flow monitoring basin, an addition or subtraction of flows may be required. Capacity and flow rate information is presented on a site-by-site basis.

Flow Monitoring 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. A basin may refer to the entire collection system upstream from a flow meter, or if flow meters are aligned in series (flowing into each other), a basin may exclude separately monitored basins upstream. I&I analysis in this report will be conducted on a basin-by-basin basis.

The flow monitoring and rain gauge sites are listed in Table 3 and illustrated in Figure 3. Detailed descriptions of the individual flow monitoring sites, including photographs, are included in *Appendix A*.

Table 3.
List of Flow Monitoring Sites

Monitoring Site	Diameter (in)	Location
Site 1E	54	Intersection of W. Cutting Boulevard and Canal Boulevard
Site 1W	39	Intersection of W. Cutting Boulevard and Canal Boulevard
Site 2	66	In field (approximately 750 feet south of W. Cutting Boulevard), west of Canal Boulevard
Site 3	18	On shoulder of north-bound Canal Boulevard, east of Treatment Plant
Site 4	27	Intersection of W. Cutting Boulevard and S. 3rd Street
Site 5	36	Intersection of Hoffman Boulevard and S. 7th Street

Notes: Site 1W, Site 3, Site 4 and Site 5 are stand-alone basins. Site 1E flows include flows from Site 4 and Site 5. Site 2 flows include flows from Site 1E and Site 1W.

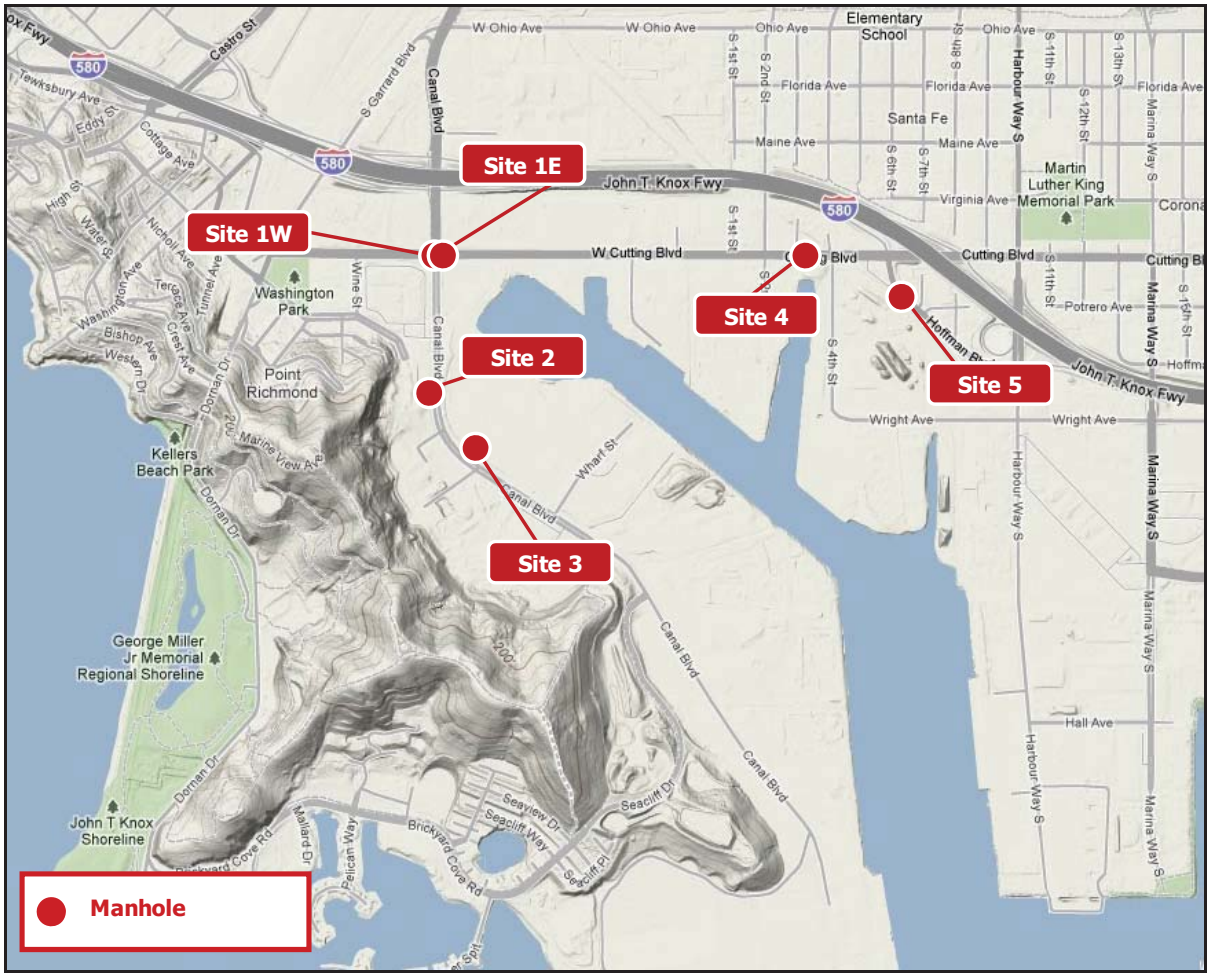


Figure 3. Flow Monitoring Sites Map

METHODS AND PROCEDURES

Confined Space Entry

A confined space (Photo 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 23.0%), and the absence 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). 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 Entrant(s) to monitor the atmosphere on another four-gas monitor and maintaining records of all Entrants, if there are more than one. The Supervisor develops the safe work plan for the job at hand prior to entering.

Photo 1. Confined Space Entry

Photo 2. Typical Personal Four-Gas Monitor

Flow Meter Installation

V&A installed six Isco 2150 area-velocity flow meters in the sewer manholes shown in Figure 3. 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. Figure 4 shows a typical flow meter installation.

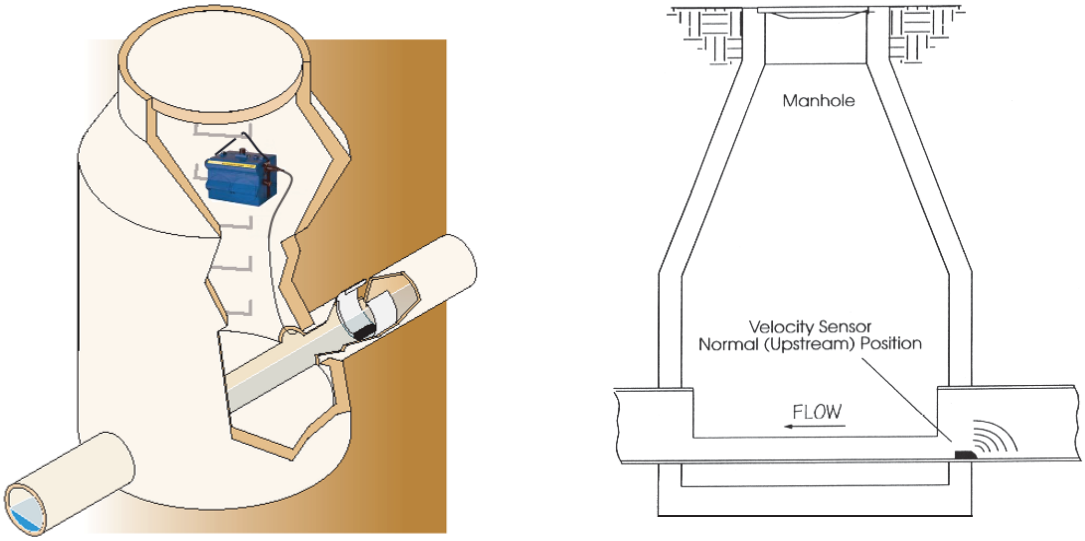


Figure 4. Typical Isco 2150 Flow Meter Installation

Manual level and velocity measurements were taken during installation of the flow meters and again when they were removed. These manual measurements were compared to simultaneous level and velocity readings from the flow meters to ensure proper calibration and accuracy. The pipe diameter was also verified in order to use the correct geometry in calculating flows. The continuous depth and velocity readings were recorded by the flow meters on a 5-minute interval.

Flow Calculation

Data retrieved from the flow meters 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). Based on site hydraulic conditions, data was analyzed for velocity outliers and level drift. In cases of velocity sensor failure due to fouling, gaps were filled using the correlation

between level and velocity in the remaining data. The adjustments made were based on best engineering practices in reducing systematic error in the measurements. Area-velocity flow metering uses the continuity equation,

$$Q = V \cdot A,$$

where Q is the volume flow rate, V is the average velocity as determined by the ultrasonic sensor, and A is the cross-sectional area of flow as determined from the depth of flow.

In a circular pipe, the following formula is used to calculate the cross-sectional area:

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

where D is the pipe diameter and d is the depth of flow.

RESULTS AND ANALYSIS

Rainfall

There was one rainfall event over the flow monitoring period on June 28, 2011. It occurred between 9:45 am and 5:00 pm and resulted in approximately 1 inch of rainfall.

Tide

One purpose of this study was to collect flow monitoring data during a period of minimal rainfall and high tides in an attempt to located areas of possible tidal I&I. The summer tides in late June and early July are the highest tides during which time rain is typically not expected. The highest confirmed tide was 7.2 feet on July 12 at 10:24 pm and the lowest confirmed tide was -0.84 feet on July 14 at 6:24 am. This data was obtained from NOAA Station 9414863 which is located at the Chevron Fuel Pier in Richmond.

Flow Monitoring: Average Dry Weather Flows

Weekday and weekend flow patterns differ and must be separated when determining average dry weather flows. Typically, days least affected by rainfall are used to estimate weekend and weekday average flows. For this project, the influence of the tide was also considered when calculating average dry weather flow (ADWF). To reduce the influence of tide on the ADWF calculations, only days and times where the tide level was lower than 3.5 feet were considered, with the exception of Site 4. Site 4 had tidal I&I that influenced the flows at lower tide levels; to establish ADWF at Site 4, the minimum recorded interval flows were used to estimate the ADWF. Table 4 lists ADWF recorded during this study for the flow monitoring sites. Figure 5 shows a schematic diagram of the average dry weather flows and flow levels. Detailed graphs of the flow monitoring data on a site-by-site basis are included in *Appendix A*.

Table 4.
Dry Weather Flow Summary

Site	Weekday ADWF (mgd)	Weekend ADWF (mgd)	Overall ADWF (mgd)	Weekend/ Weekday Ratio
Site 1E	3.84	3.74	3.81	0.97
Site 1W	0.96	0.98	0.97	1.01
Site 2	4.88	4.82	4.86	0.99
Site 3	0.11	0.12	0.11	1.04
Site 4	0.69	0.65	0.68	0.95
Site 5	1.54	1.46	1.52	0.95

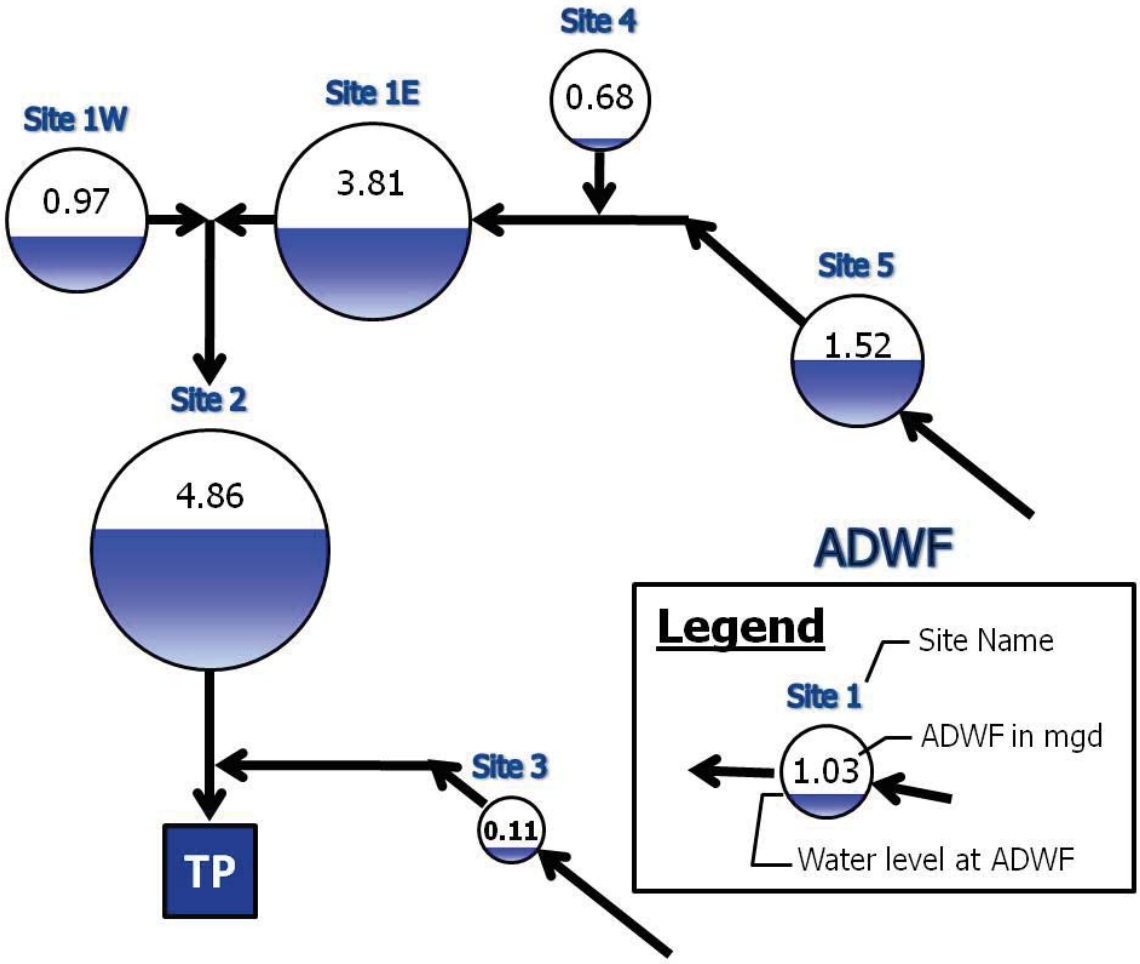


Figure 5. Average Dry Weather Flow (Flow Schematic)

Flow Monitoring: Peak Measured Flows and Pipeline Capacity Analysis

Peak measured flows and the peak measured flow level (elevation) is important to understand the capacity of the flow monitoring system. The peak flows and flow levels reported are from the peak measurements as taken across the entirety of the flow monitoring period. The peaks seen during this monitoring period correspond to the one rain event at the very beginning of the study.

Note: the peak flows and flow levels were influenced by influent wet well operations at the treatment facility, which back flows into the collection system for storage. Also presumably due to wet well operations, five of the six sites experienced a backflow condition on July 15 that was not related to rainfall.

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). A peaking factor threshold value of 3.0 is commonly used for sanitary sewer design.
- **d/D Ratio:** The d/D ratio is the peak measured depth of flow divided by the pipe diameter. A d/D ratio less than 0.75 is a common threshold value used for pipe design. The d/D ratio for each site was computed based on the maximum depth of flow for the flow monitoring study.

Table 5 summarizes the peak recorded flows, levels, d/D ratios and peaking factors per site during the flow monitoring period. Note: capacity analysis data is presented on a **site-by-site** basis and represents the hydraulic conditions only at the point site location. Hydraulic conditions in other areas of the collection system will differ.

Table 5.
Capacity Analysis Summary

Site	ADWF (mgd)	Peak Measured Flow (mgd)	Peaking Factor	Diameter (in)	Peak Level (in)	d/D Ratio
Site 1E	3.81	14.01	3.68	54	104.6	1.94
Site 1W	0.97	8.42	8.71	39	94.1	2.41
Site 2	4.86	23.72	4.88	66	118.1	1.79
Site 3	0.11	1.20	10.52	18	54.2	3.01
Site 4**	0.68	4.23	6.26	27	13.1	0.49
Site 5	1.52	5.76	3.80	36	100.1	2.78

**Note: The Site 4 flow meter was not operational at the time of the rainfall event. The peak levels resultant from the plant wet well operations, and the peak flows from the rainfall event, were not recorded for this monitoring site.

The following capacity analysis results are noted:

- **Peaking Factor:** All of the flow monitoring sites had peaking factors that exceeded typical design threshold limits for peak flow to average dry weather flow ratio.
- **d/D Ratio:** Five locations had d/D ratios that were above common threshold values for d/D ratio. Site 4 likely surcharged during the wet well operations of June 28; however, the flow meter was not operational at the time to confirm.

Figure 6 shows bar graphs of the capacity results. Figure 7 shows a schematic diagram of the peak measured flows with peak flow levels.

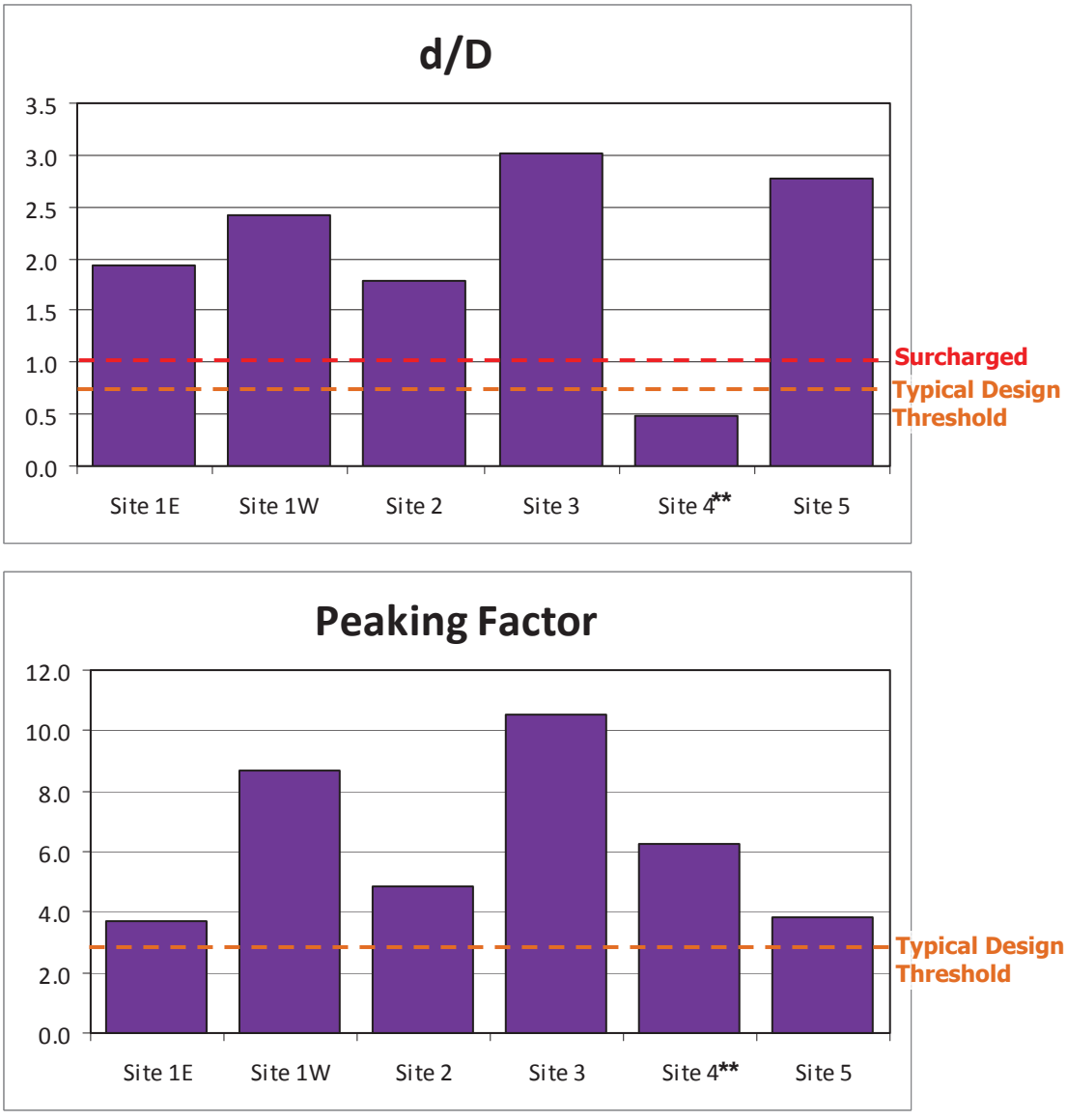


Figure 6. Capacity Bar Graphs: Peaking Factor and d/D Ratio by Site

**Note: The Site 4 flow meter was not operational at the time of the rainfall event. The peak levels resultant from the plant wet well operations, and the peak flows from the rainfall event, were not recorded for this monitoring site.

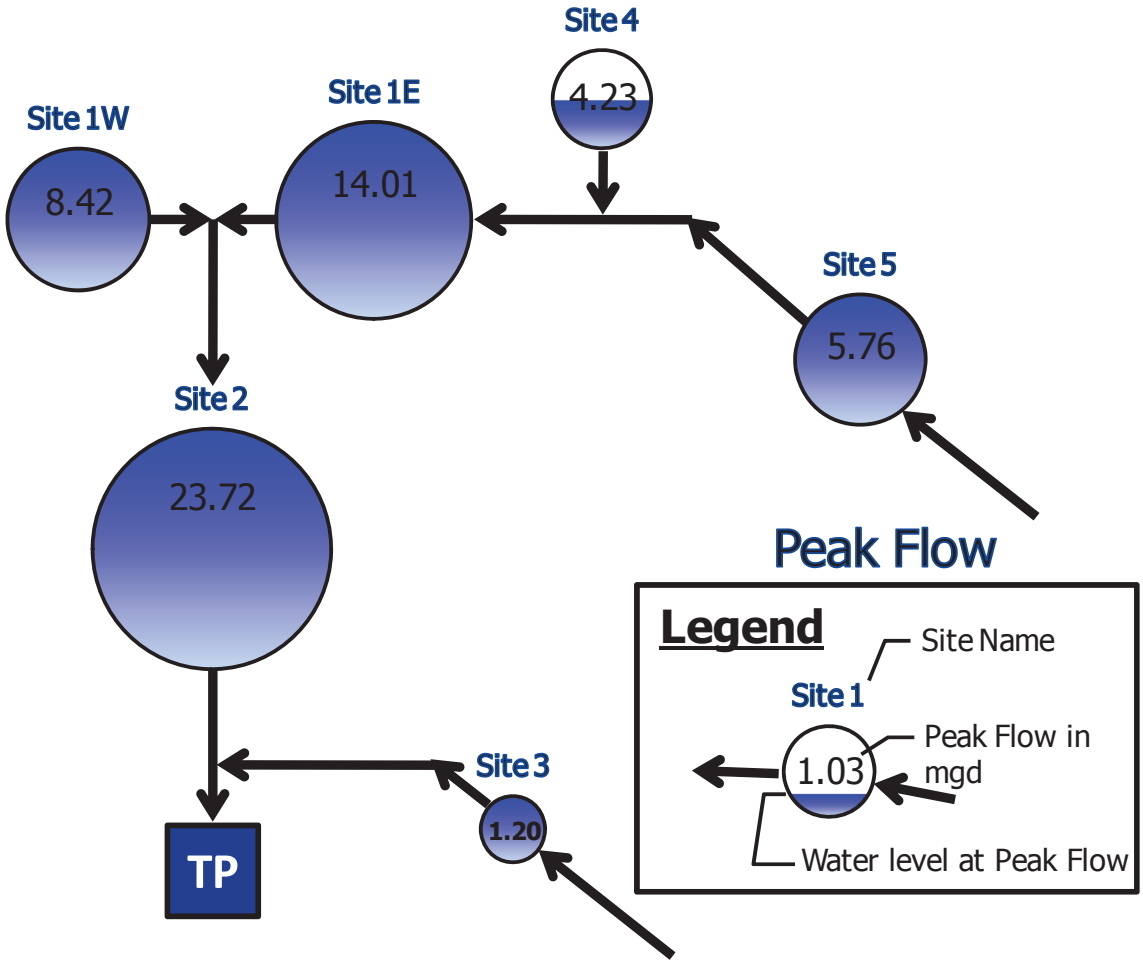


Figure 7. Peak Measured Flow (Flow Schematic)

Tidal Inflow and Infiltration

Temperature vs. Tide

A primary purpose of this study was to conduct analyses pertaining to tidal I&I occurring in the basins upstream from the flow monitoring sites. One parameter that can be an indicator of tidal I&I is the water temperature of the flow. In theory, water from a tidal source would be much colder than typical sanitary flow; thus, I&I from a tidal source should have a corresponding reduction in sanitary sewer flow temperature. The temperature of the waters in the San Francisco Bay typically range from the high 40's to the mid-50's °F, while sanitary flow ranges from the high 60's to the mid 70's °F. It is important to note that sanitary temperature measurements follow a diurnal pattern, with lower temperatures occurring during low-flow hours.

Figure 8 shows graphs of tide and temperature overlaid for Sites 4 and 5 from July 7 to 15, 2011, when there was minimal rain dependent I&I (note: the temperature axis is shown in decreasing order). Trends in decreasing temperature appear to follow peak tides closely in Site 4, while there is no apparent correlation present in Site 5 for the same time period.

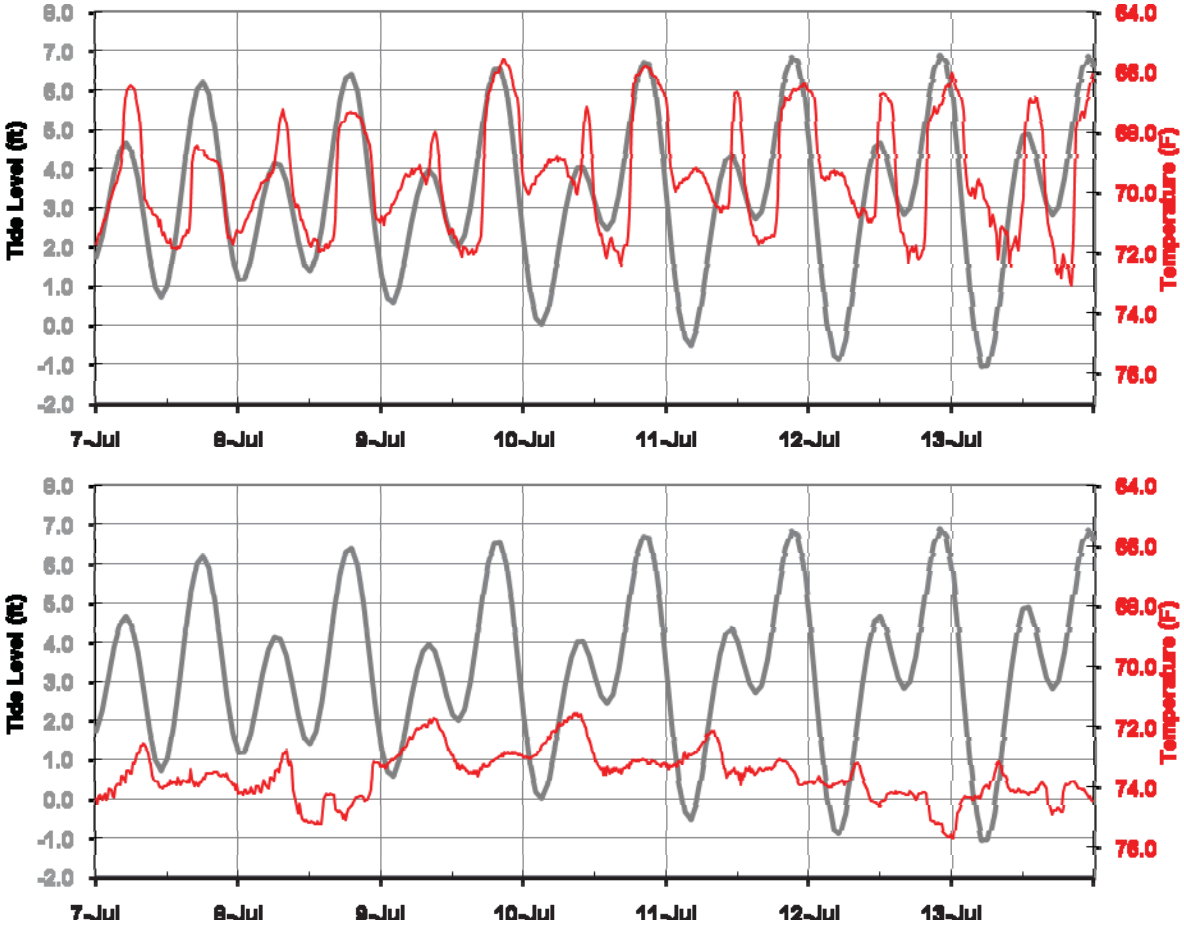


Figure 8. Tide vs. Temperature (°F) for Site 4 (top) and Site 5 (bottom)

While temperature by itself is not conclusive, it provides a metric that can be an indicator of tidal I&I. Table 6 shows the minimum, maximum and average temperatures recorded at each site.

Table 6.
Temperature Summary[5]

Site	Maximum Temperature (°F)	Minimum Temperature (°F)	Average Temperature (°F)	Graphical Correlation
Site 1E	75.2	69.6	72.6	Moderate
Site 1W	73.3	67.8	70.9	Slight
Site 2	75.1	67.8	72.6	Moderate
Site 3	73.2	69.2	71.7	Negligible
Site 4	74.3	65.2	70.3	Strong
Site 5	77.4	71.1	74.1	Negligible

Site 4 has the lowest average temperature, the lowest minimum temperature and the strongest graphical correlation between temperature and tide. Site 1E and Site 2 had moderate correlations; however, it is noted that Site 1E and Site 2 are both downstream from Site 4.

[5] There were low temperatures recorded at Sites 1W and 2 that corresponded to a non-tide related 'dumping' event that occurred upstream of Site 1W on July 16. For the purposes of this table, the temperatures for this period were excluded.

Peak Flows vs. Tide

Another analysis that can provide evidence of tidal I&I is the correlation between the timing of peak flow seen at a site and the peak of either of the daily high tides. If a site experiences substantial tidal I&I, the timing of peak flow would be associated with the high tide at a consistent interval. Figure 9 shows the flow and tide for Sites 4 and 5 for visual reference.

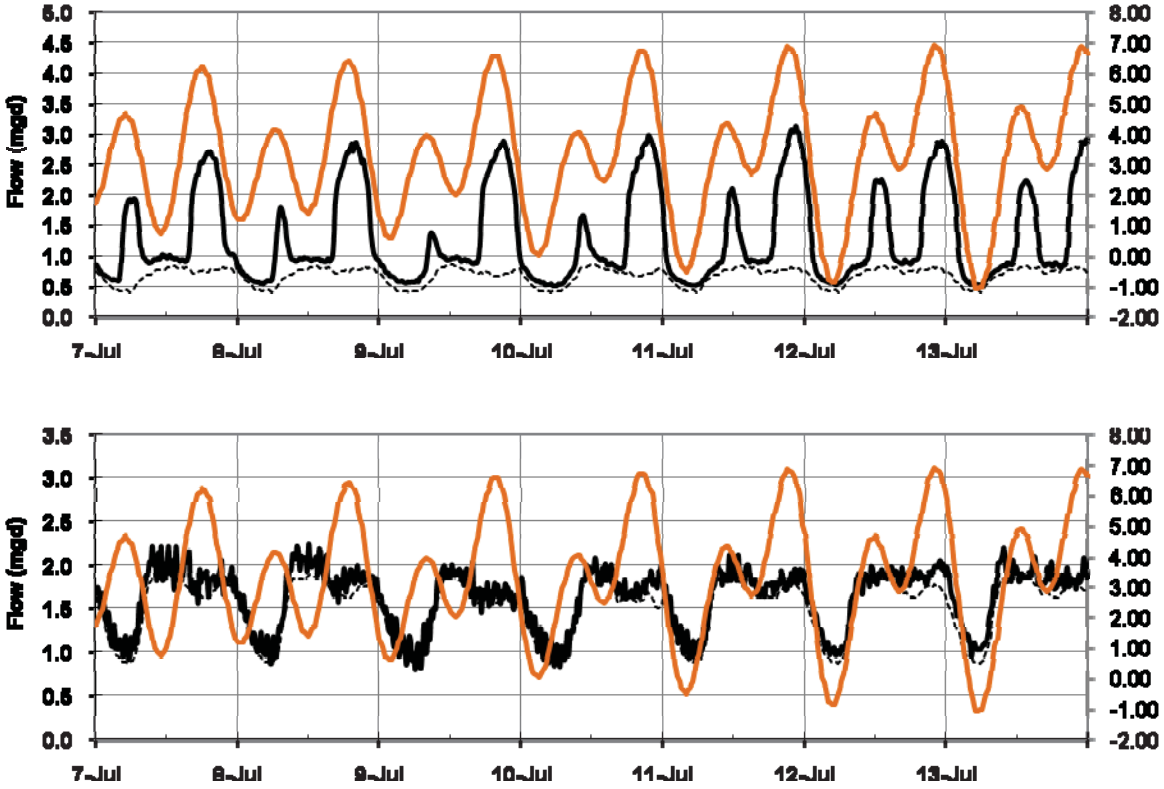


Figure 9. Tide vs. Flow for Site 4 (top) and Site 5 (bottom)

The 3-hour period before and after the peak daily high tides was analyzed for a corresponding peak flow response. Any flow peaks that occurred before the high tide were excluded. The time differences between the remaining flow peaks and corresponding high tides were analyzed and the results are shown in Table 7.

Site 4 was the only location that had a low standard of deviation and had peak flow events that follow all of the corresponding high tides that occurred during the sample period.

Table 7.
Flow Peak vs. High Tide Summary

Site	# of Peaks*	Maximum Time Difference (h:mm)	Minimum Time Difference (h:mm)	Average Time Difference (h:mm)	Standard Deviation
Site 1E	10	3:06	0:15	2:13	0.037
Site 1W	13	3:00	0:21	1:47	0.035
Site 2	12	3:06	0:18	1:51	0.044
Site 3	10	3:06	0:27	2:02	0.038
Site 4	14	1:36	0:45	1:06	0.013
Site 5	10	3:06	0:15	2:06	0.044

* Refers to the number of peak flow events that occur after the corresponding high tide (out of a maximum 14 possible for the sample period).

Estimated Tidal Inflow/Infiltration

A final analysis was performed to quantify the amount of I&I due to tidal influence. The analysis shown in Table 8 is based on the difference between estimated average dry weather flows and actual measured flows. Due to the rain event that occurred on June 28 and the probable sustained infiltration within the Richmond collection system, it was determined that an analysis should be run starting from July 19 to August 2, 2011. The flows during the 15-day analysis period have been averaged to daily quantities. Note: for this analysis, subtraction of flows was utilized to isolate each basin. The "Percent I&I to Percent ADWF Ratio" identifies which basins are contributing the most I&I relative to their estimated average dry weather flow; a ratio greater than 1 indicates higher than expected (relative to ADWF) tidal infiltration.

Table 8.
Estimated Contribution of Tidal I&I per Basin

Basin	ADWF (mgd)	% of System Total	Estimated Tidal I&I (mgd)	% of System Total	% I&I to % ADWF Ratio
Basin 1E[6]	1.618	32.5%	0.247	22.4%	0.7
Basin 1W	0.967	19.4%	0.216	19.6%	1.0
Basin 2[7]	0.083	1.7%	0.089	8.0%	4.8
Basin 3	0.114	2.3%	0.009	0.8%	0.4
Basin 4	0.677	13.6%	0.503	45.6%	3.4
Basin 5	1.516	30.5%	0.039	3.5%	0.1
System[8]	**4.974**	**100.0%**	**1.103**	**100.0%**	

The following tidal infiltration and inflow results from this project are noted:

- **Basin 4:** The basin upstream from Site 4 had the highest percentage of flow that could be attributed to tidal I&I and is responsible for 46% of the tidal I&I in the system. There was a strong correlation between the flow levels, the water temperature and the tide.
- **Basin 1W:** The basin upstream from Site 1W had a moderate tidal response that was observed in the flow response, and less so in the temperature response. On a totalized basis, this site contributed approximately 20% of the tidal I&I to the system. Also, there was a cold-water dumping event on July 16 that was not related to the tide.
- **Basin 2:** This basin is extremely small, and due to propagation of errors, the values shown in Table 8 are not statistically valid. The 8-inch line that constitutes most of the flow in this basin has been observed to have large volumes of clear water flow entering the system.
- **Basin 1E:** On a totalized basis, Basin 1E contributes approximately 22% of the tidal I&I to the system.
- **Basins 3 and 5:** These basins contribute negligible tidal I&I to the collection system.

[6] Basin 1E = Site 1E less Site 4 less Site 5.

[7] Basin 2 in theory should have very minimal sanitary sewer flow contribution, with one 8-inch inlet line contributing to the basin at Manhole 100039. Given that three very large volumes of flow were subtracted to acquire a small volume of flow, and with propagation of errors, it should be assumed that there may be significant error in the Basin 2 calculation. That stated, the 8-inch inlet line has always been observed by V&A to have large volumes of clear water flow entering the system.

[8] System flows taken as the sum of Site 2 and Site 3.

APPENDIX A

FLOW MONITORING SITES: DATA, GRAPHS, INFORMATION

Veolia City of Richmond

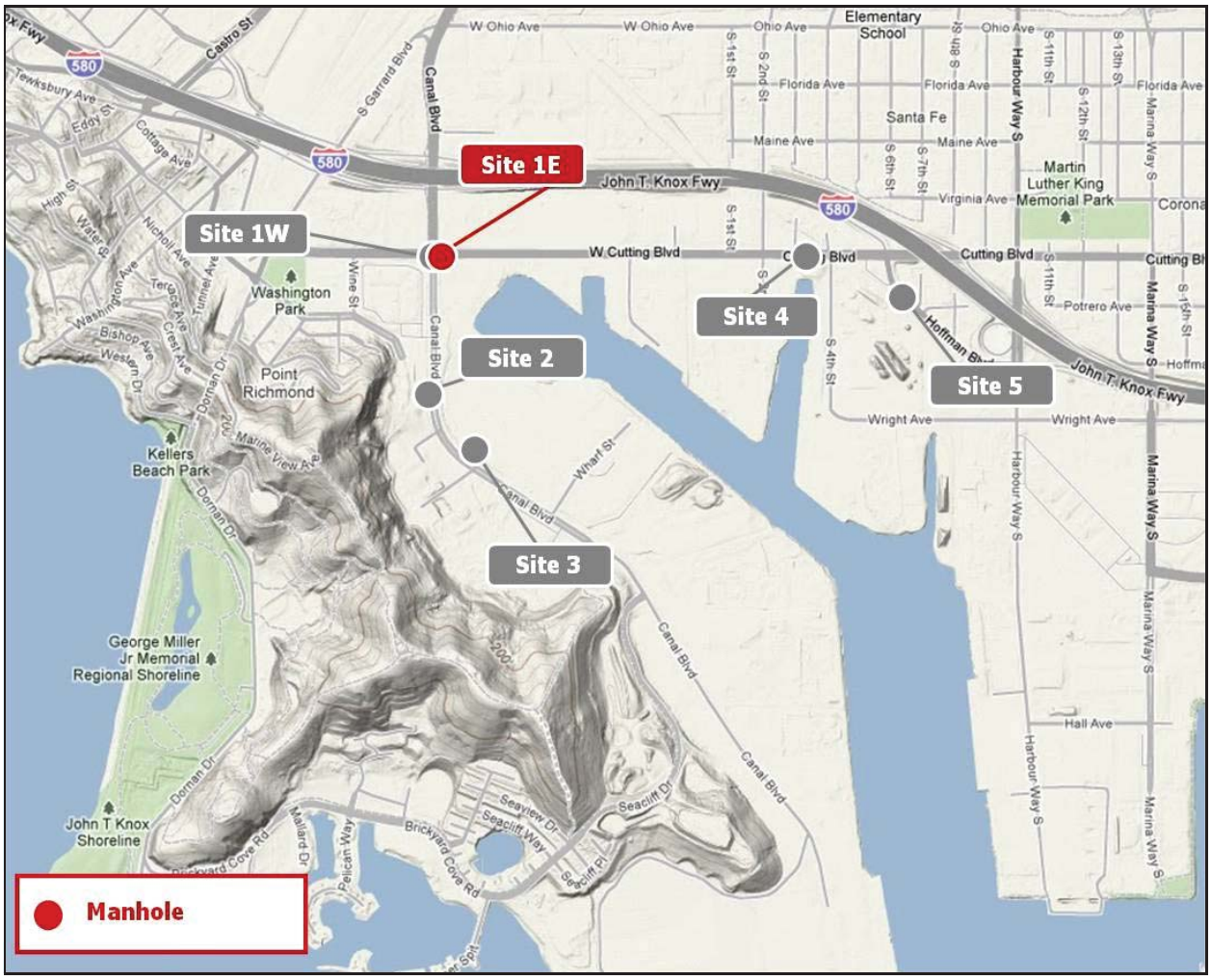
Sanitary Sewer Flow Monitoring

Year 2011

Monitoring Site: 1E

Location: MH ID 100039: Intersection of W. Cutting Boulevard and Canal Boulevard

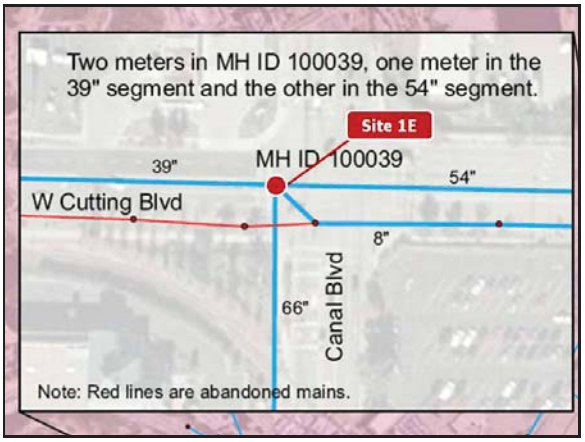
Data Summary Report



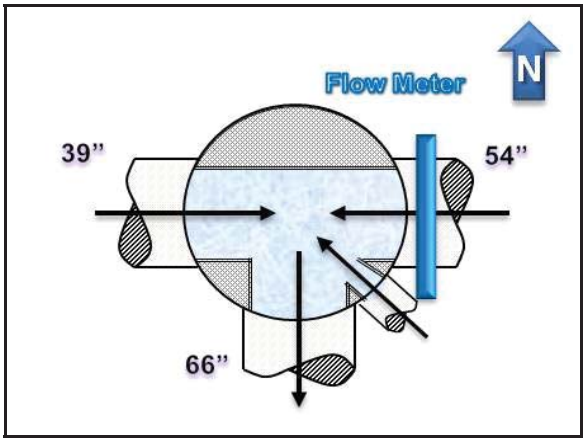
SITE 1E
Site Information Report

Location:	MH ID 100039: Intersection of W. Cutting Boulevard and Canal Boulevard
Coordinates:	122.3784° W, 37.9253° N
Elevation:	9 feet
Diameter:	54 inches
Baseline Flow:	3.81 mgd
Peak Measured Flow:	14.014 mgd

Satellite map



Sewer map



Flow sketch

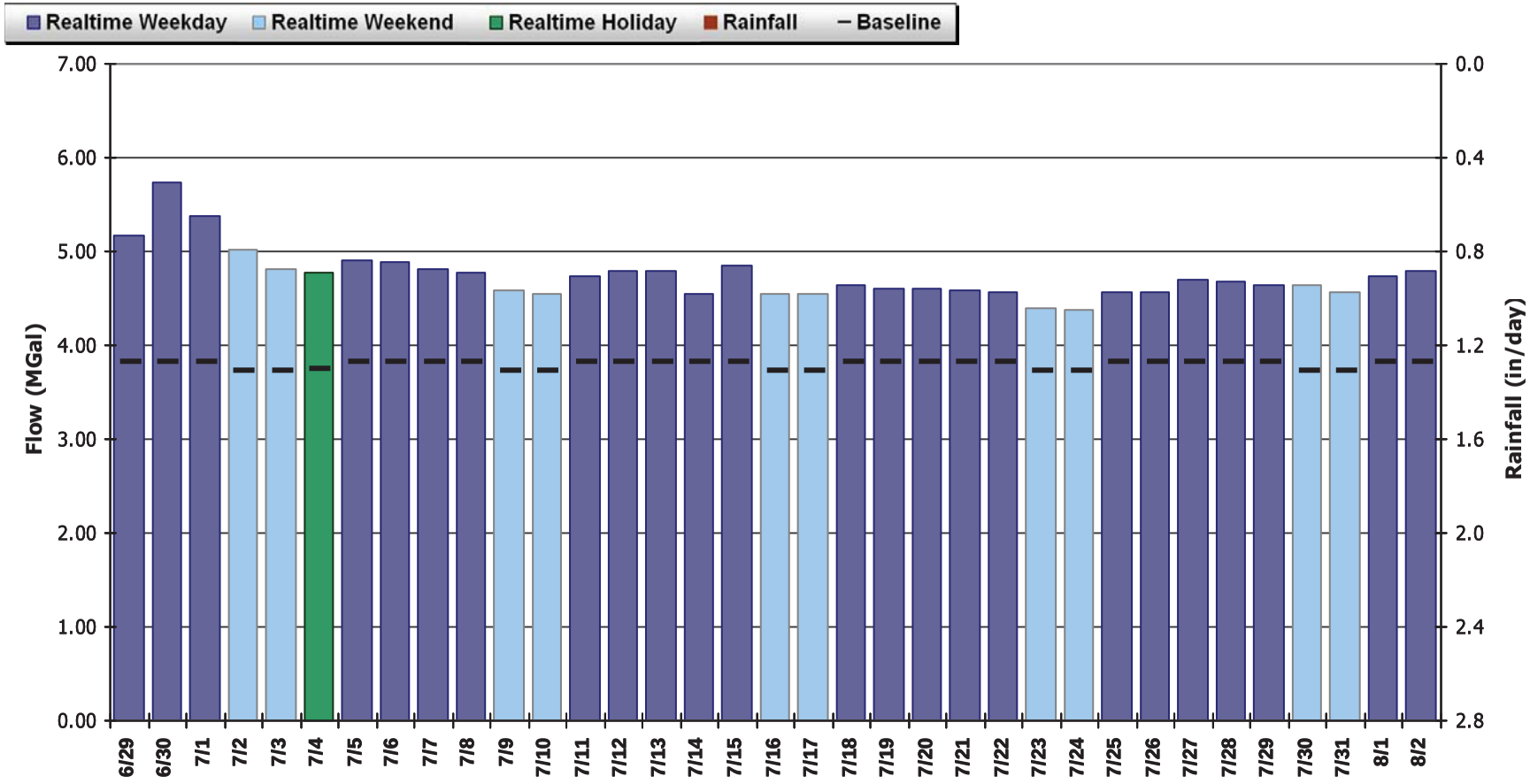
Street view

Plan view

SITE 1E

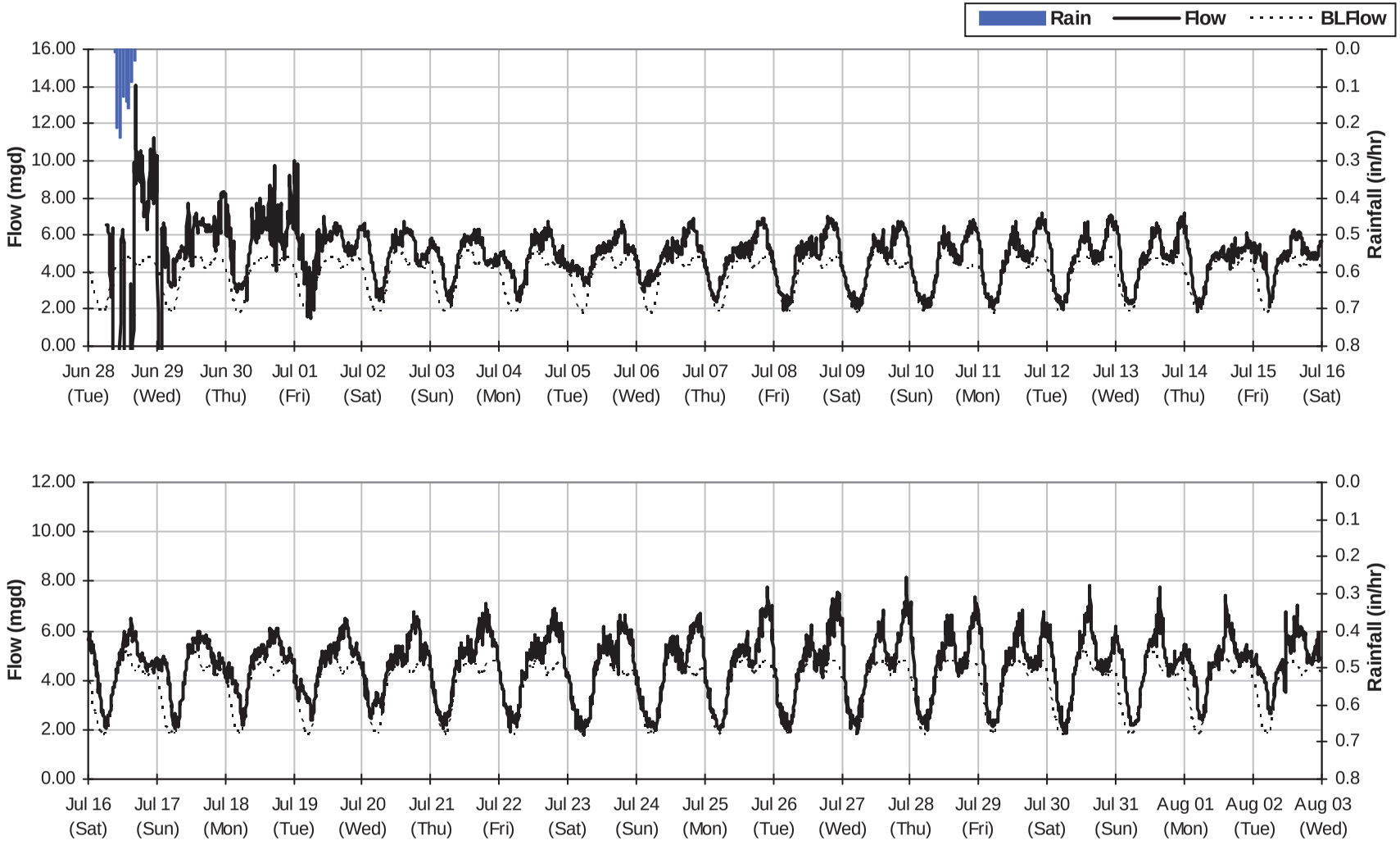
Period Flow Summary: Daily Flow Totals

Avg Daily Flow: 4.739 MGal **Peak Daily Flow: 5.735 MGal** **Min Daily Flow: 4.382 MGal**



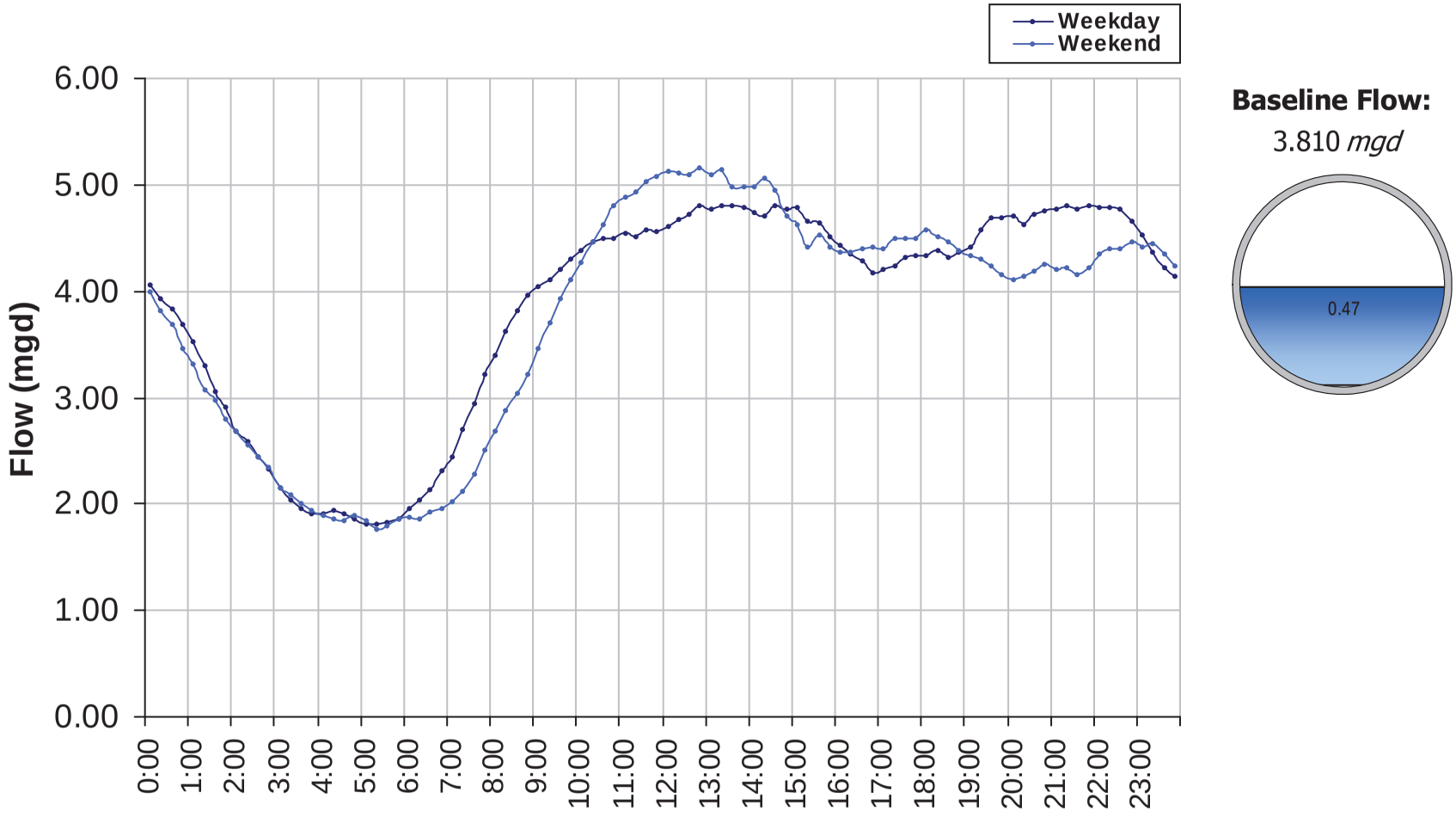
SITE 1E

Period Flow Summary: 15-minute data



SITE 1E

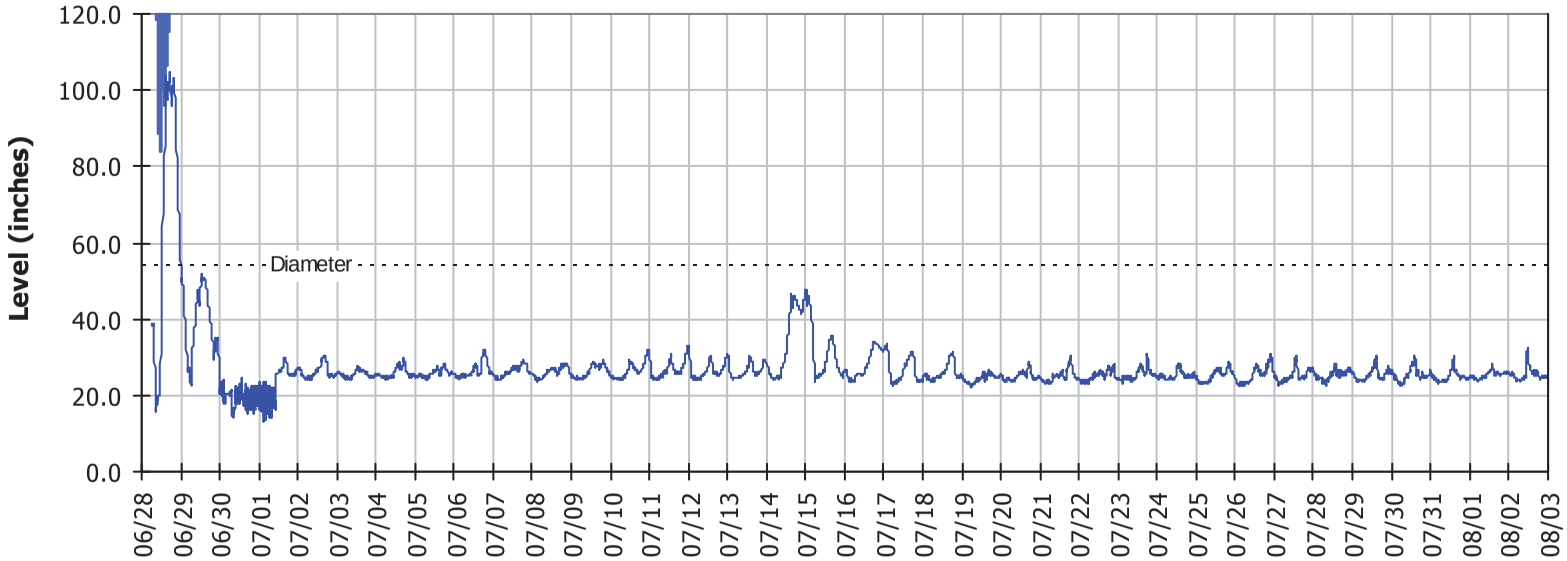
Baseline Flow Hydrographs

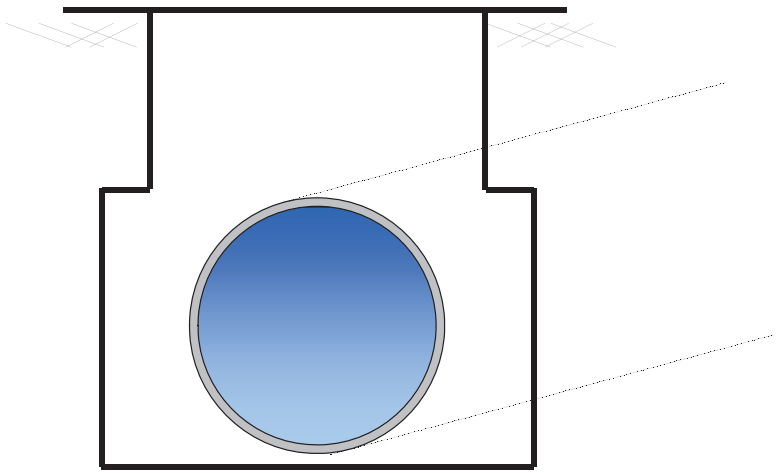


SITE 1E

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period





Pipe Diameter: 54 *inches*

Peak Measured Level: 105 *inches*

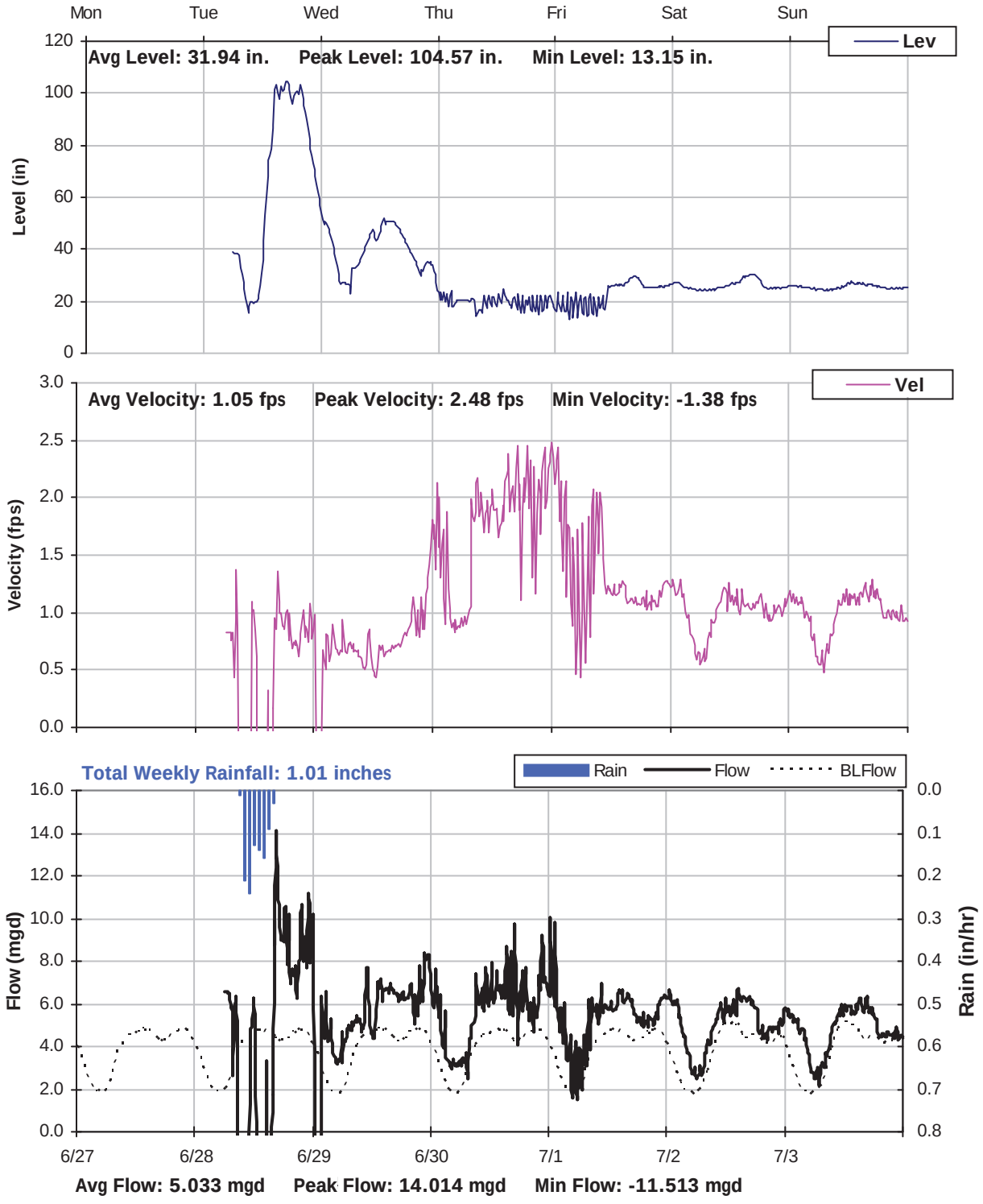
Peak d/D Ratio: 1.94

Surcharged 50.6 inches over crown

SITE 1E

Weekly Level, Velocity and Flow Hydrographs

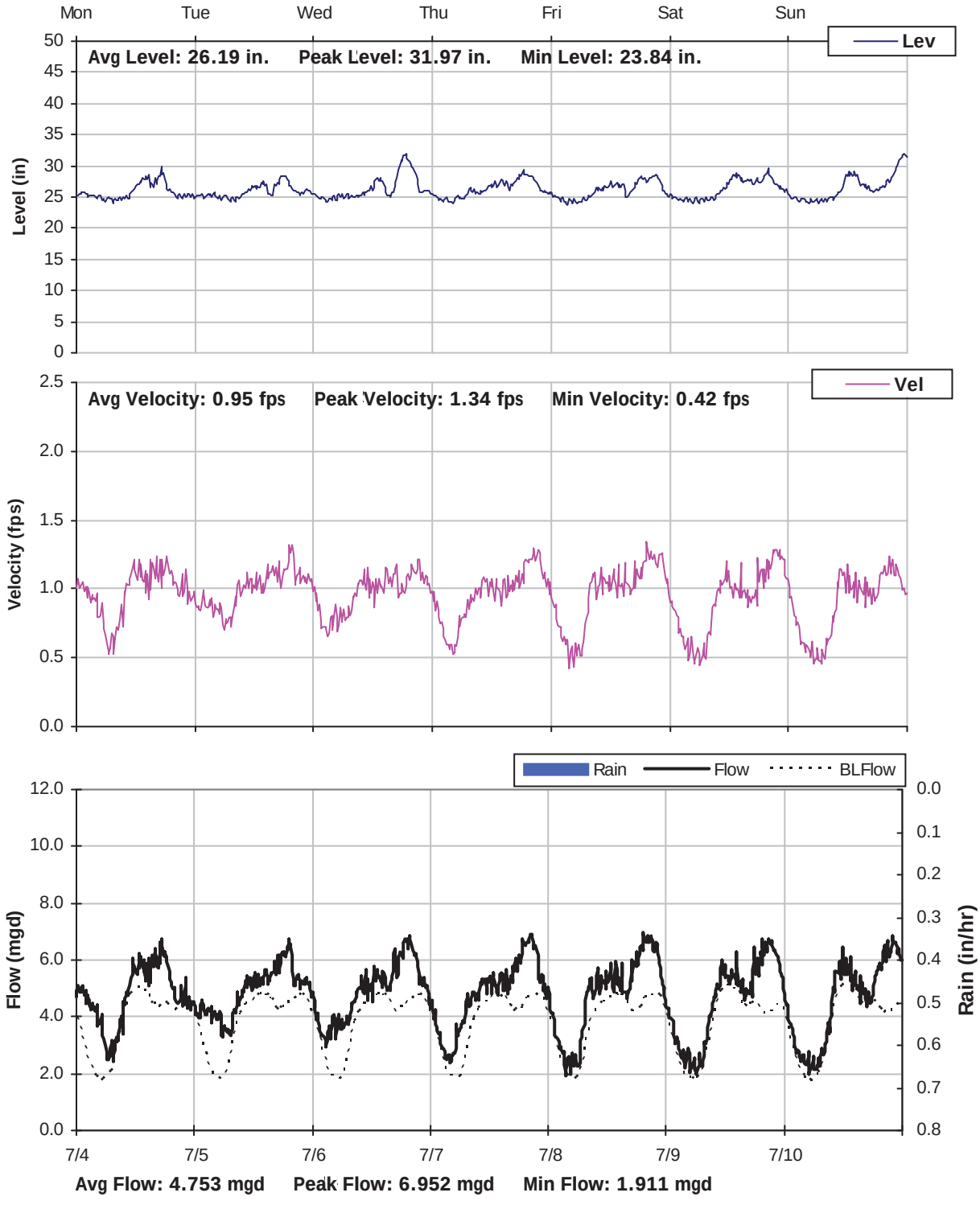
6/27/2011 to 7/4/2011



SITE 1E

Weekly Level, Velocity and Flow Hydrographs

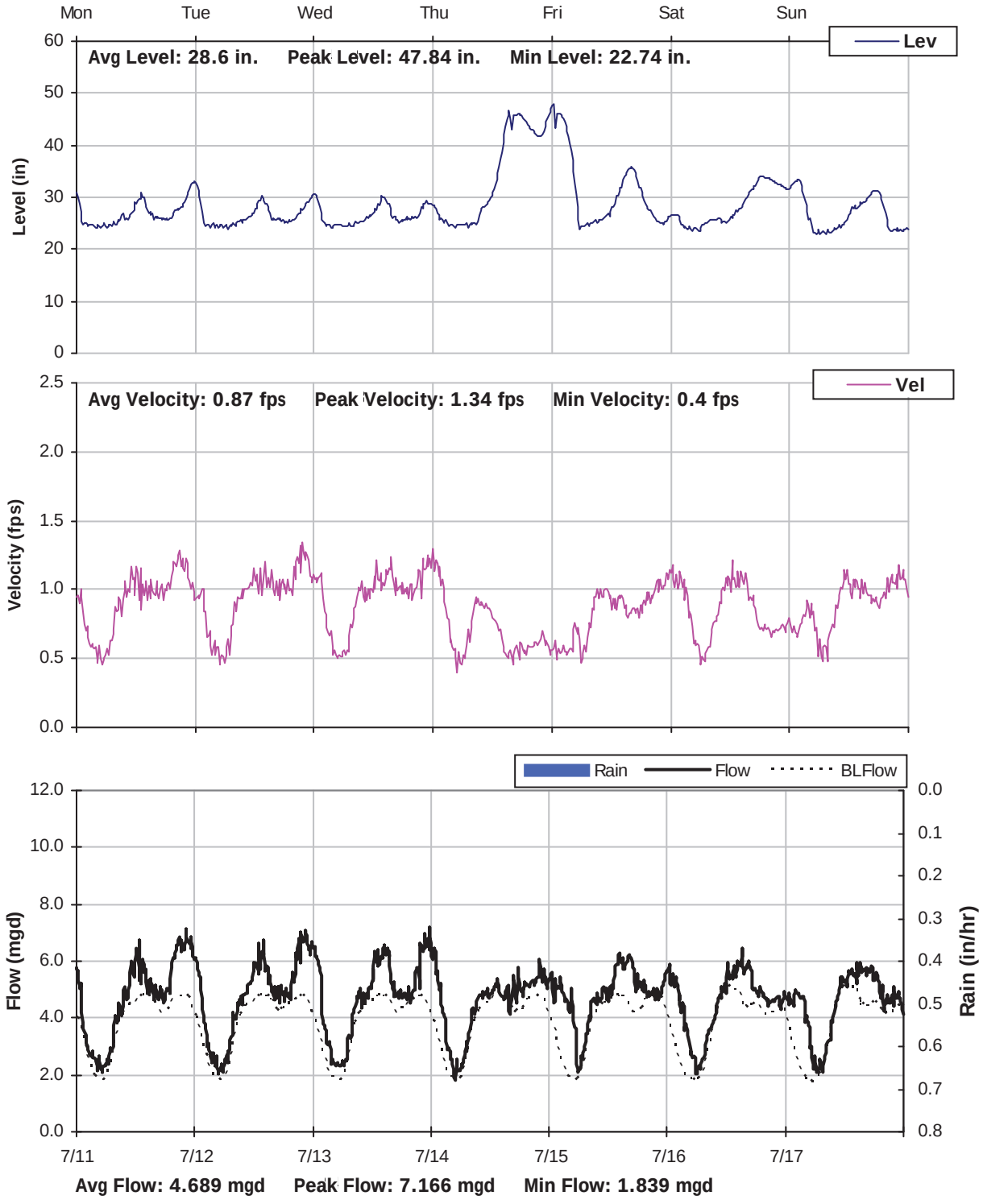
7/4/2011 to 7/11/2011



SITE 1E

Weekly Level, Velocity and Flow Hydrographs

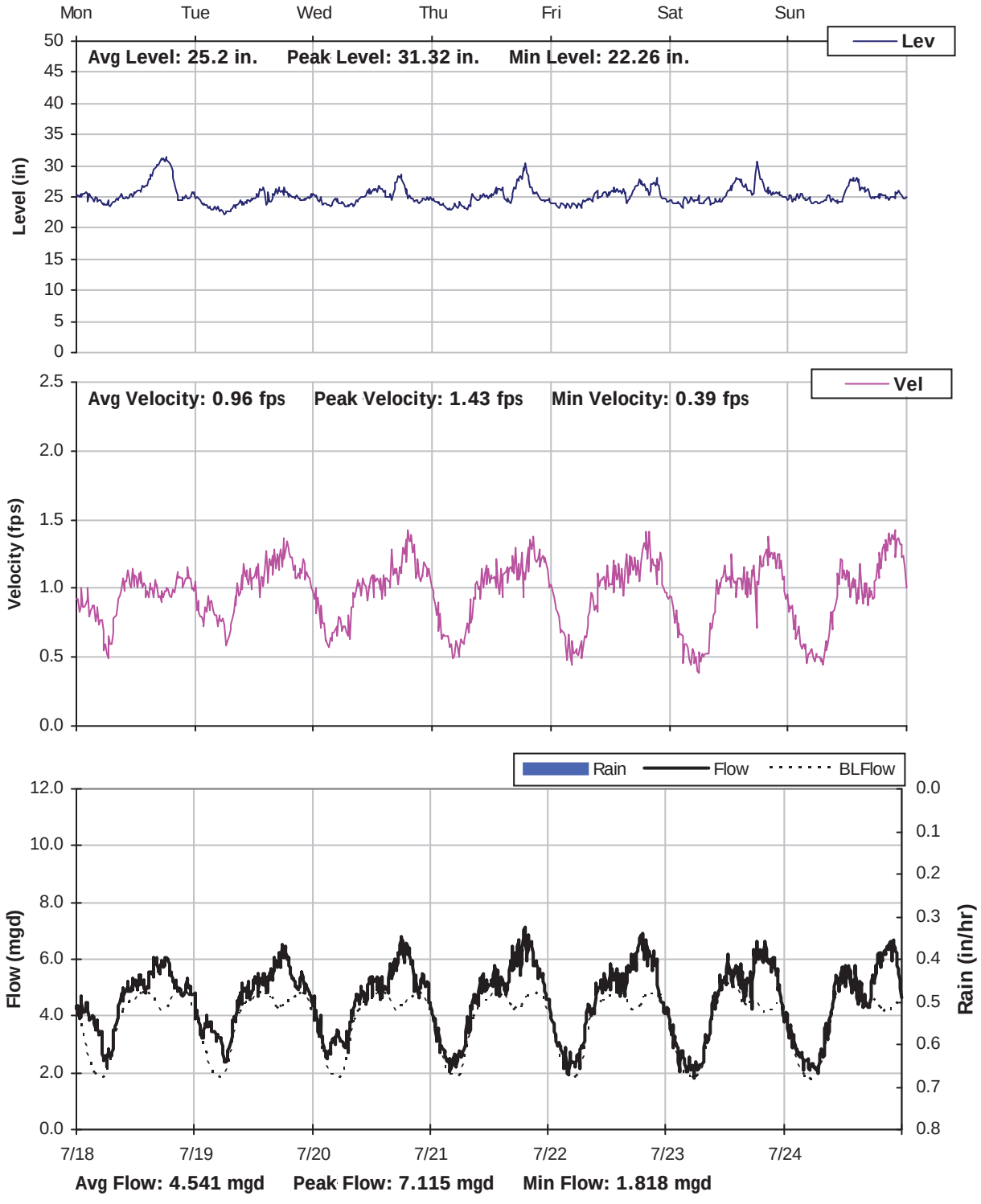
7/11/2011 to 7/18/2011



SITE 1E

Weekly Level, Velocity and Flow Hydrographs

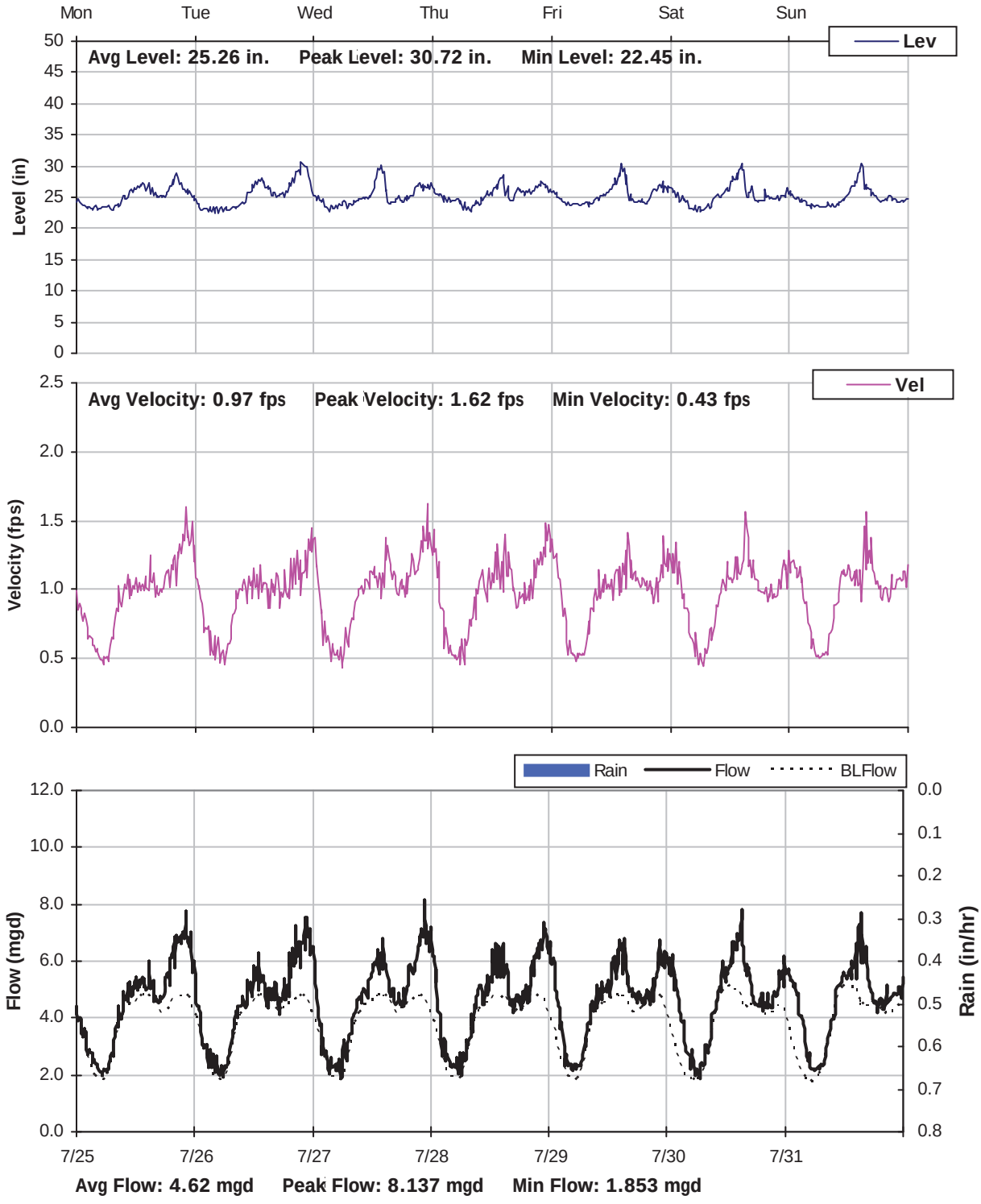
7/18/2011 to 7/25/2011



SITE 1E

Weekly Level, Velocity and Flow Hydrographs

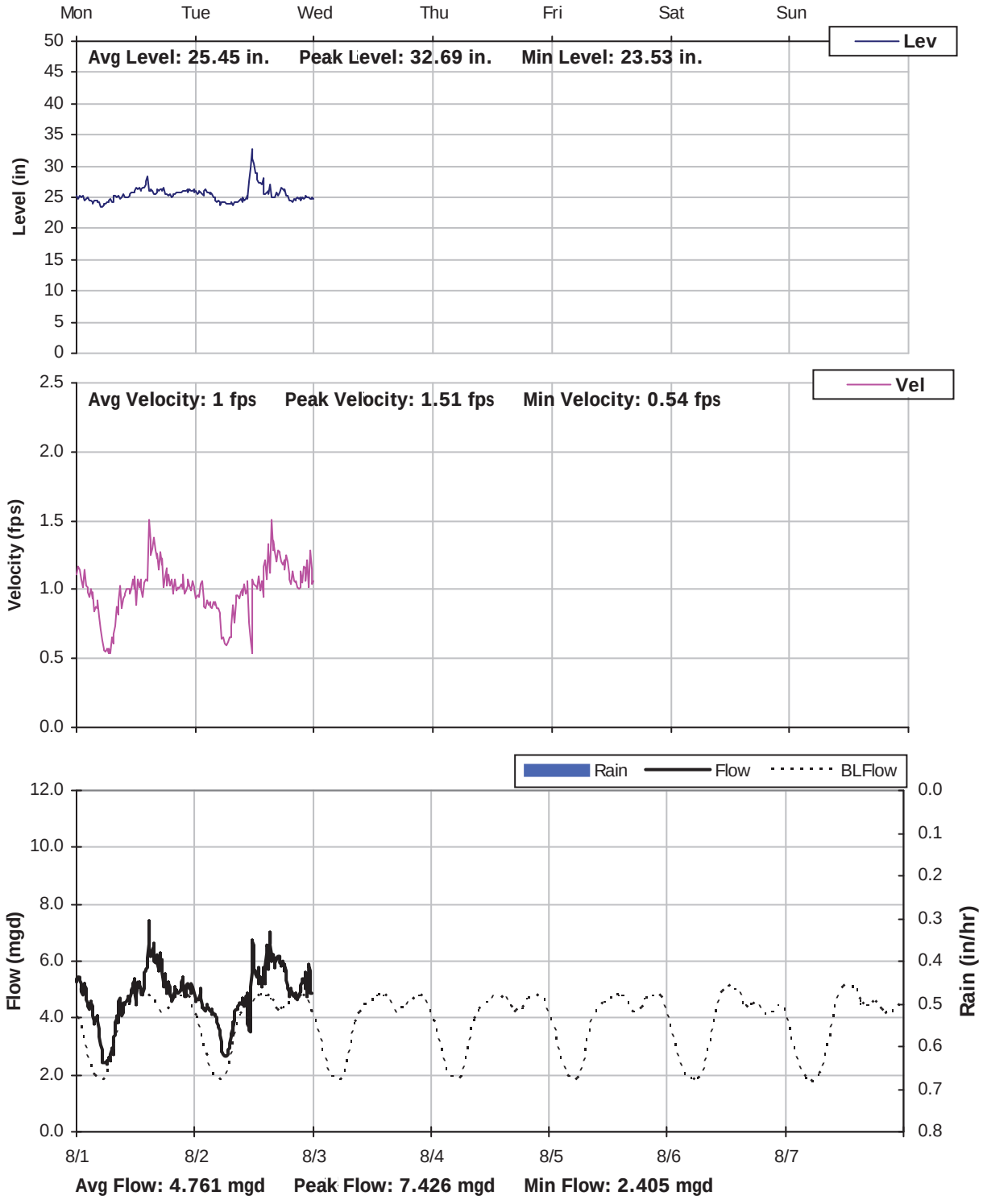
7/25/2011 to 8/1/2011



SITE 1E

Weekly Level, Velocity and Flow Hydrographs

8/1/2011 to 8/8/2011



Veolia City of Richmond

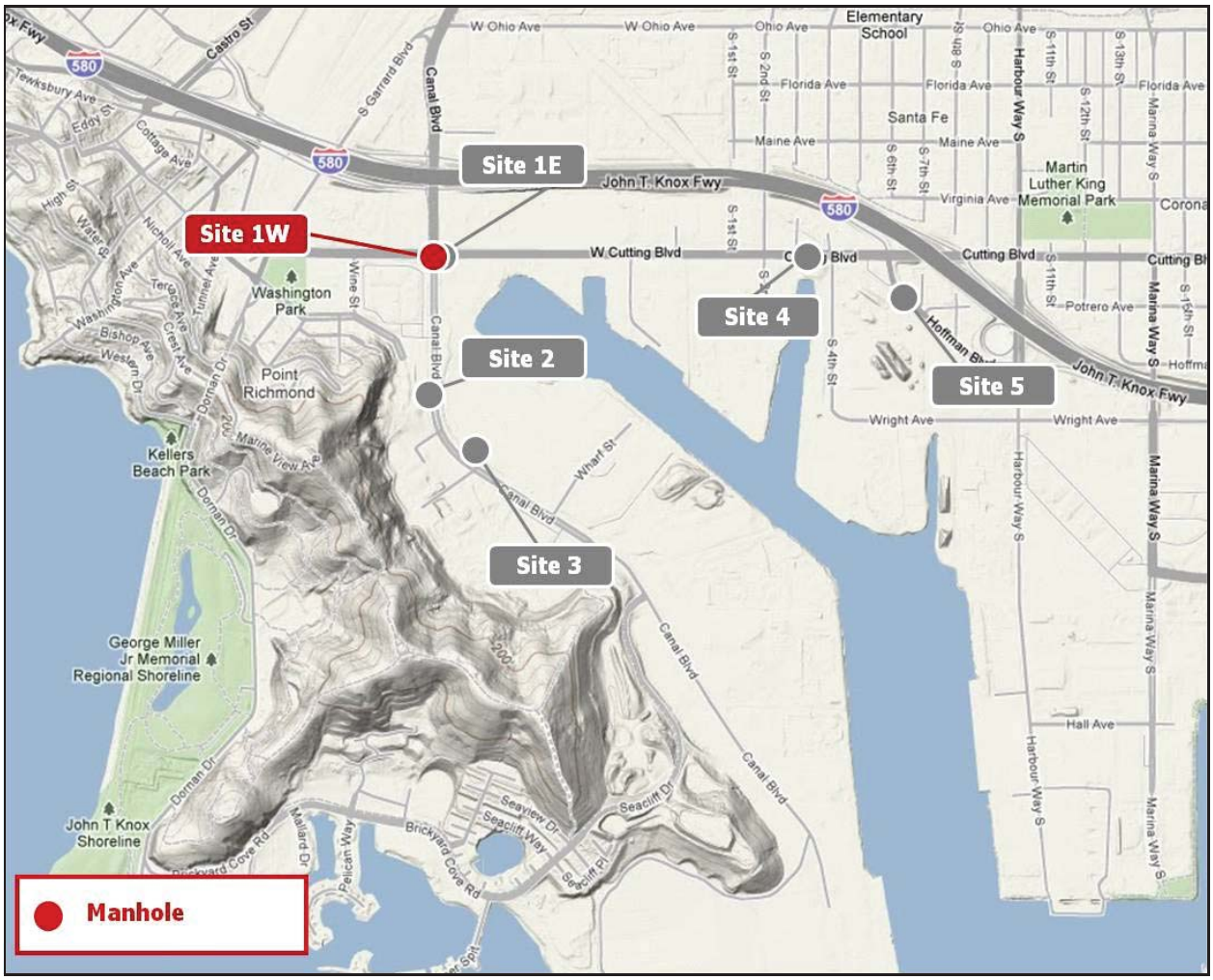
Sanitary Sewer Flow Monitoring

Year 2011

Monitoring Site: 1W

Location: MH ID 100039: Intersection of W. Cutting Boulevard and Canal Boulevard

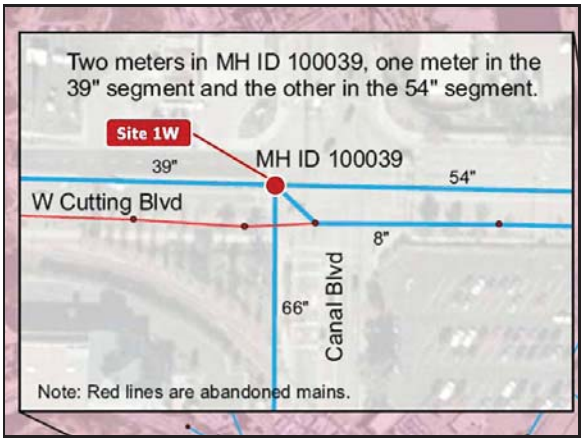
Data Summary Report



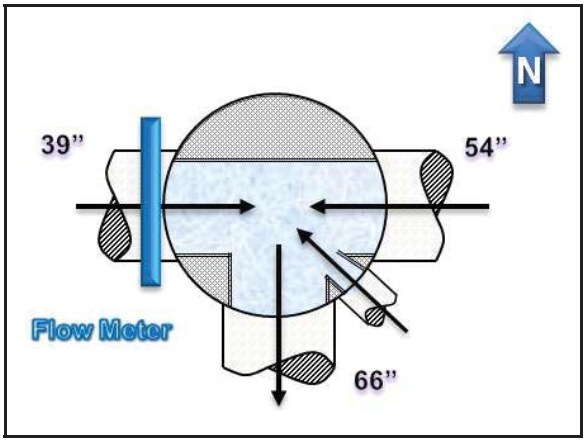
SITE 1W
Site Information Report

Location:	MH ID 100039: Intersection of W. Cutting Boulevard and Canal Boulevard
Coordinates:	122.3784° W, 37.9253° N
Elevation:	9 feet
Diameter:	39 inches
Baseline Flow:	0.967 mgd
Peak Measured Flow:	8.418 mgd

Satellite map



Sewer map



Flow sketch

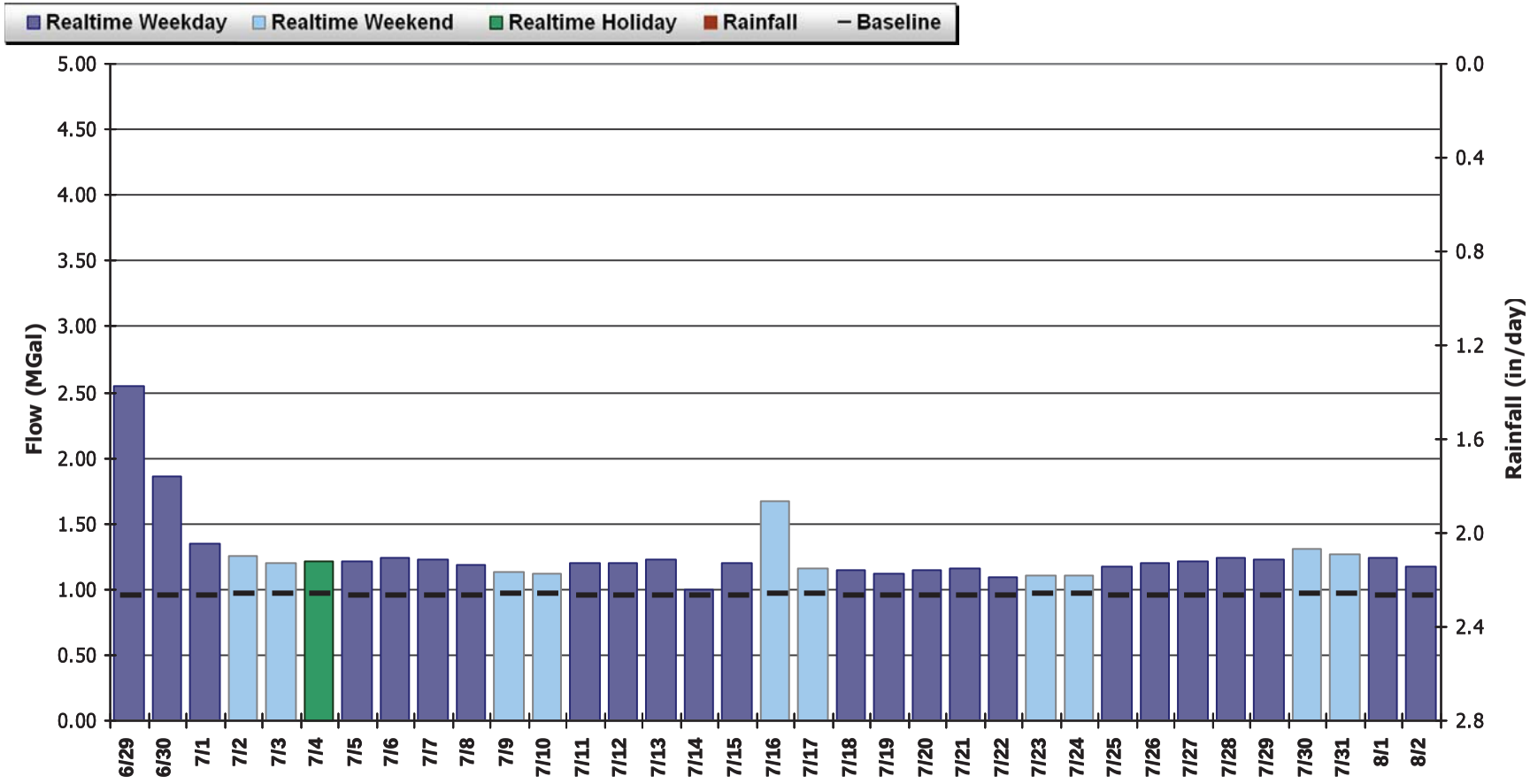
Street view

Plan view

SITE 1W

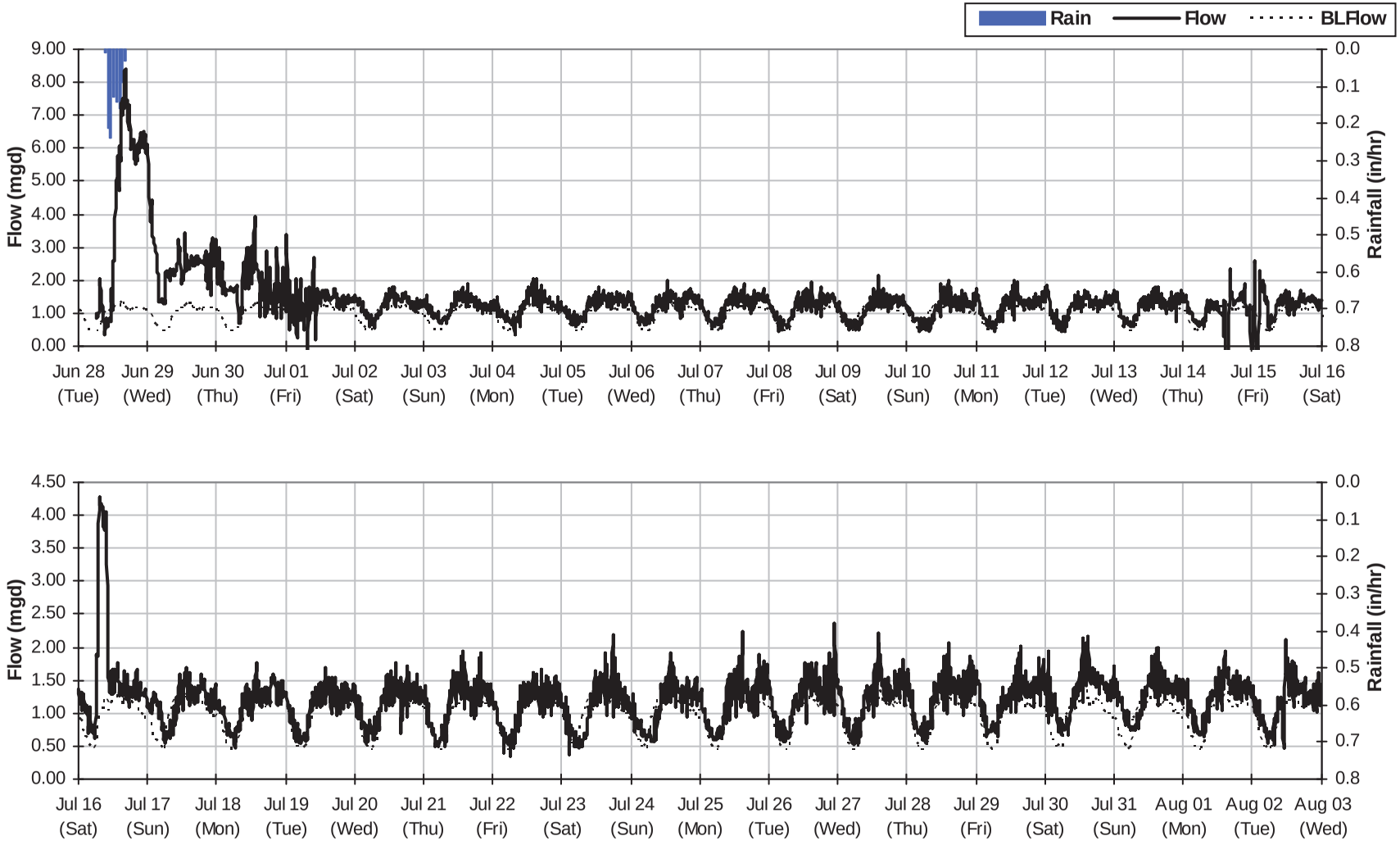
Period Flow Summary: Daily Flow Totals

Avg Daily Flow: 1.259 MGal **Peak Daily Flow: 2.552 MGal** **Min Daily Flow: 1.003 MGal**



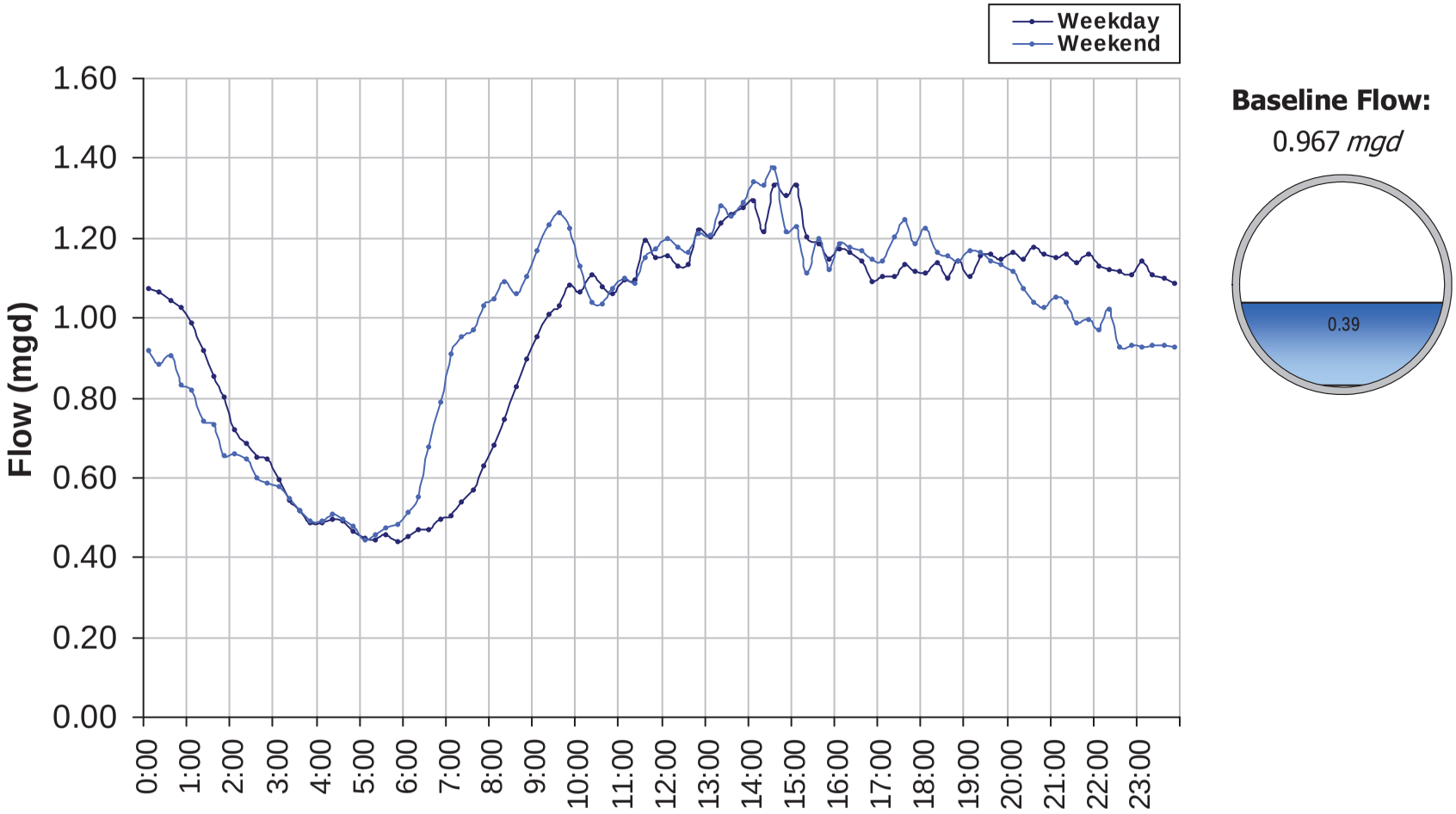
SITE 1W

Period Flow Summary: 15-minute data



SITE 1W

Baseline Flow Hydrographs



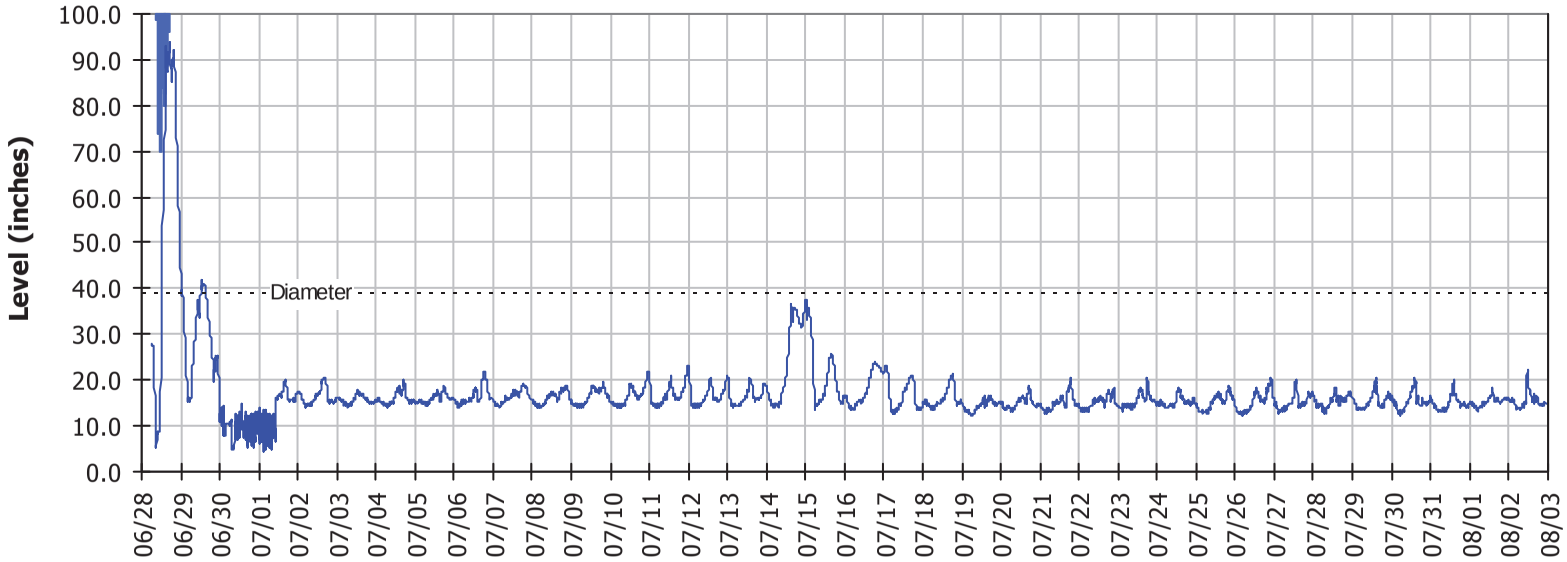
Baseline Flow:

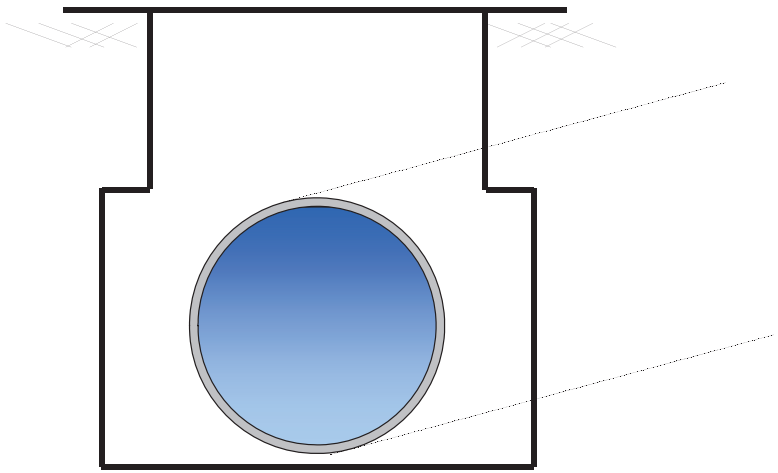
0.967 *mgd*

SITE 1W

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period





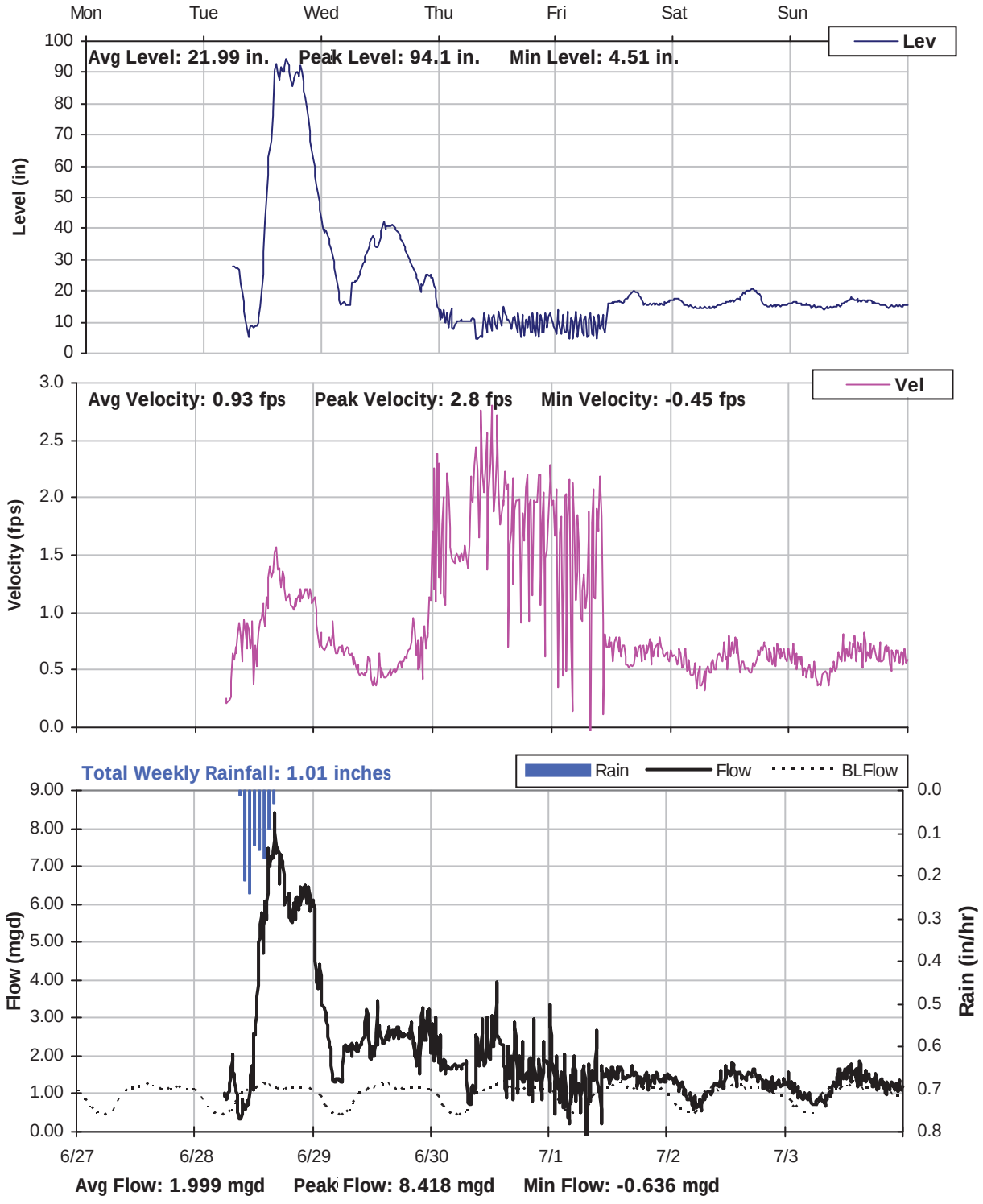
Pipe Diameter: 39 *inches*

Peak Measured Level: 94.1 *inches*

Peak d/D Ratio: 2.41

Surcharged 55.1 inches over crown

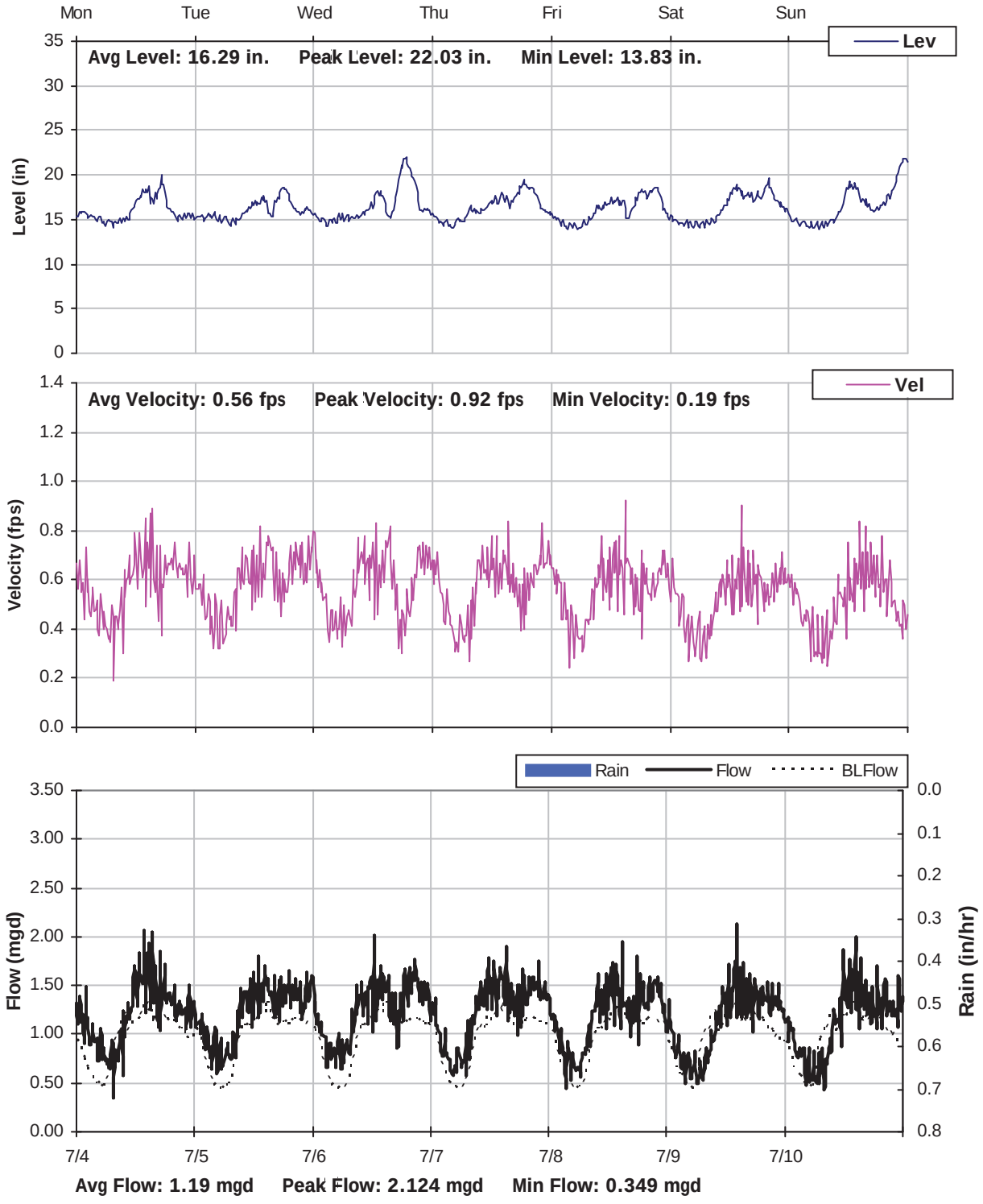
SITE 1W
Weekly Level, Velocity and Flow Hydrographs
6/27/2011 to 7/4/2011



SITE 1W

Weekly Level, Velocity and Flow Hydrographs

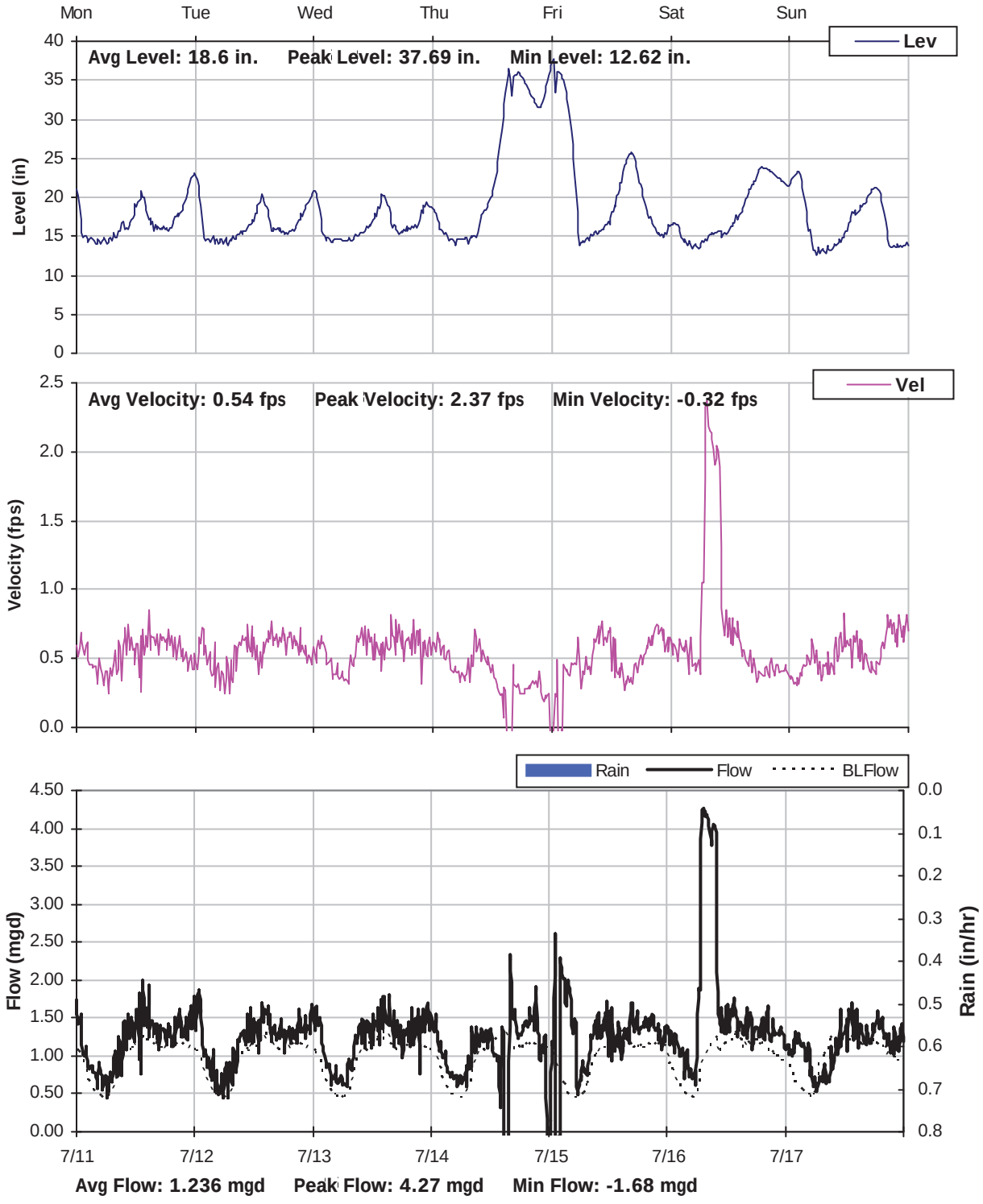
7/4/2011 to 7/11/2011



SITE 1W

Weekly Level, Velocity and Flow Hydrographs

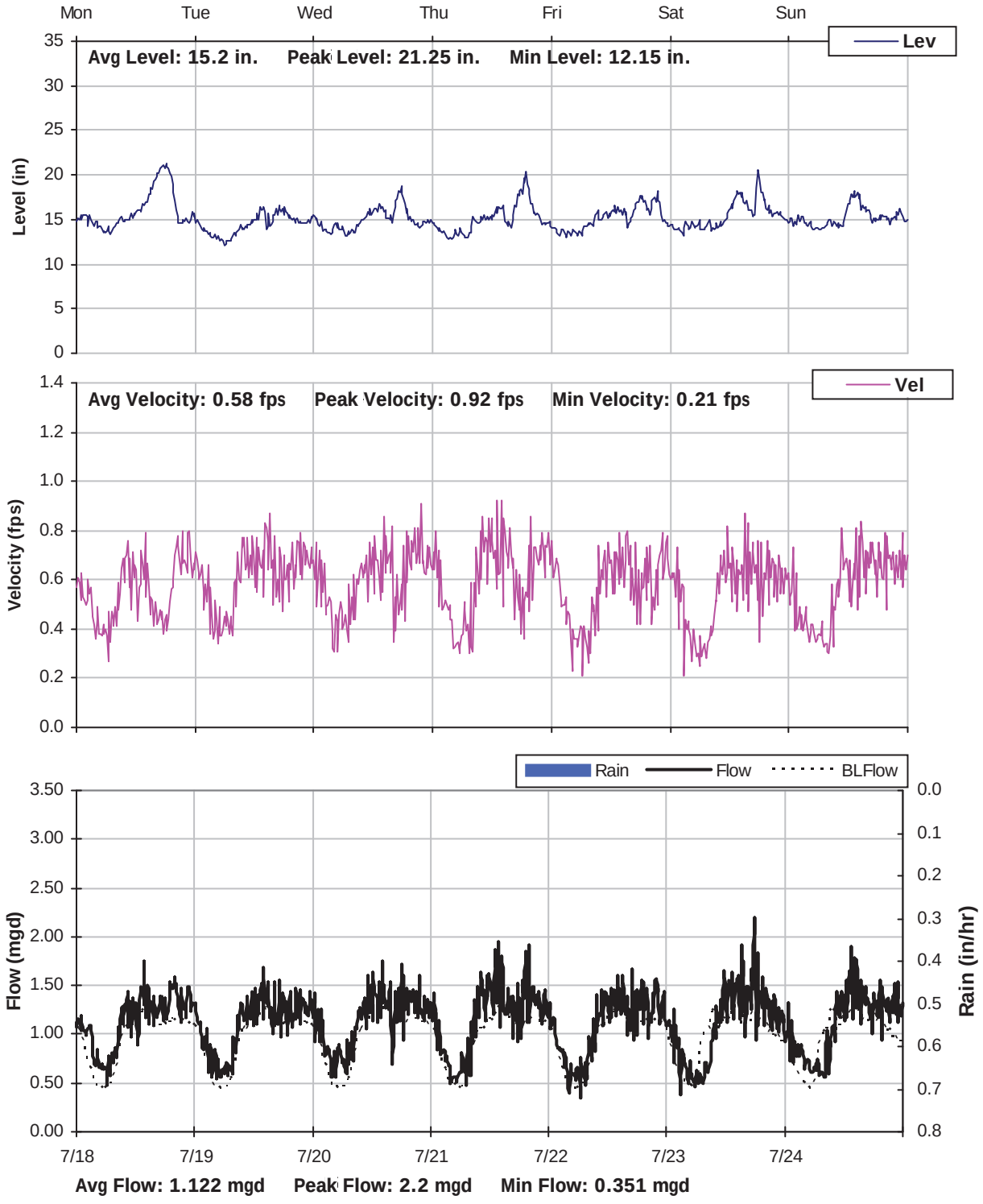
7/11/2011 to 7/18/2011



SITE 1W

Weekly Level, Velocity and Flow Hydrographs

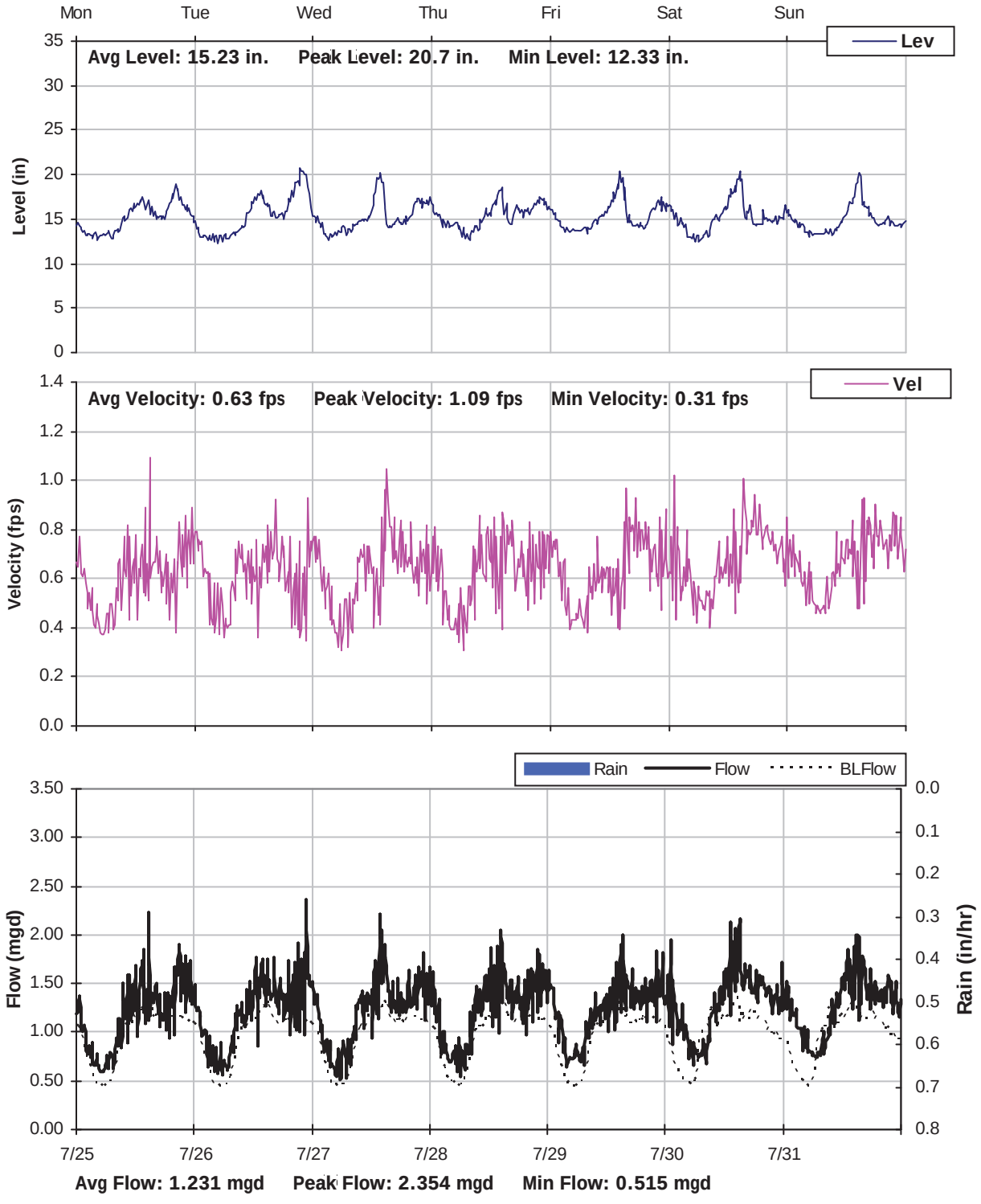
7/18/2011 to 7/25/2011



SITE 1W

Weekly Level, Velocity and Flow Hydrographs

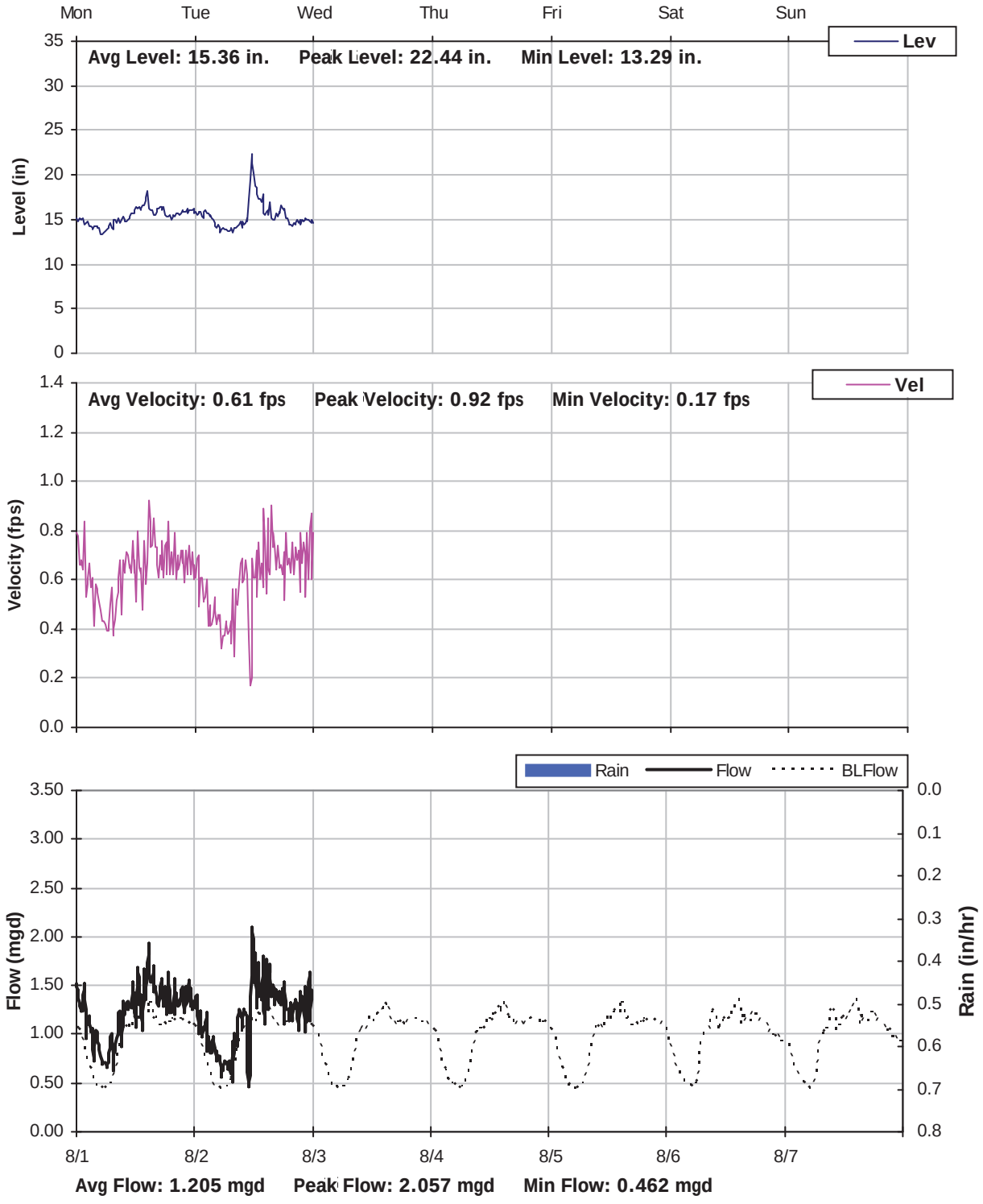
7/25/2011 to 8/1/2011



SITE 1W

Weekly Level, Velocity and Flow Hydrographs

8/1/2011 to 8/8/2011



Veolia City of Richmond

Sanitary Sewer Flow Monitoring

Year 2011

Monitoring Site: 2

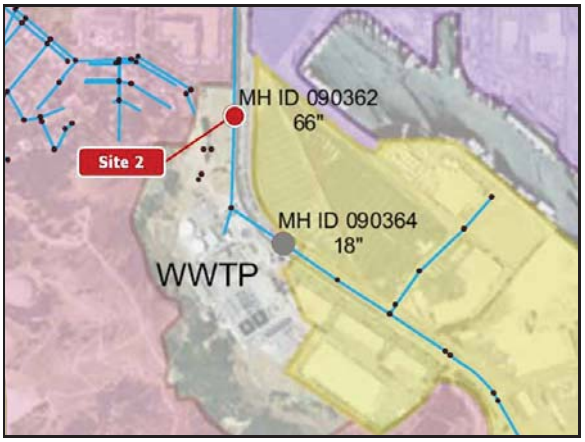
Location: MH ID 090362: In field (approximately 750 feet south of W. Cutting Boulevard), west of Canal Boulevard

Data Summary Report

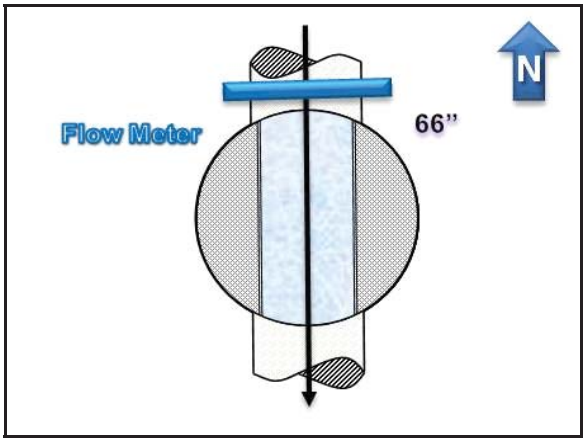
SITE 2
Site Information Report

Location:	MH ID 090362: In field (approximately 750 feet south of W. Cutting Boulevard), west of Canal Boulevard
Coordinates:	122.3783° W, 37.9230° N
Elevation:	14 feet
Diameter:	66 inches
Baseline Flow:	4.86 mgd
Peak Measured Flow:	23.719 mgd

Satellite map



Sewer map



Flow sketch

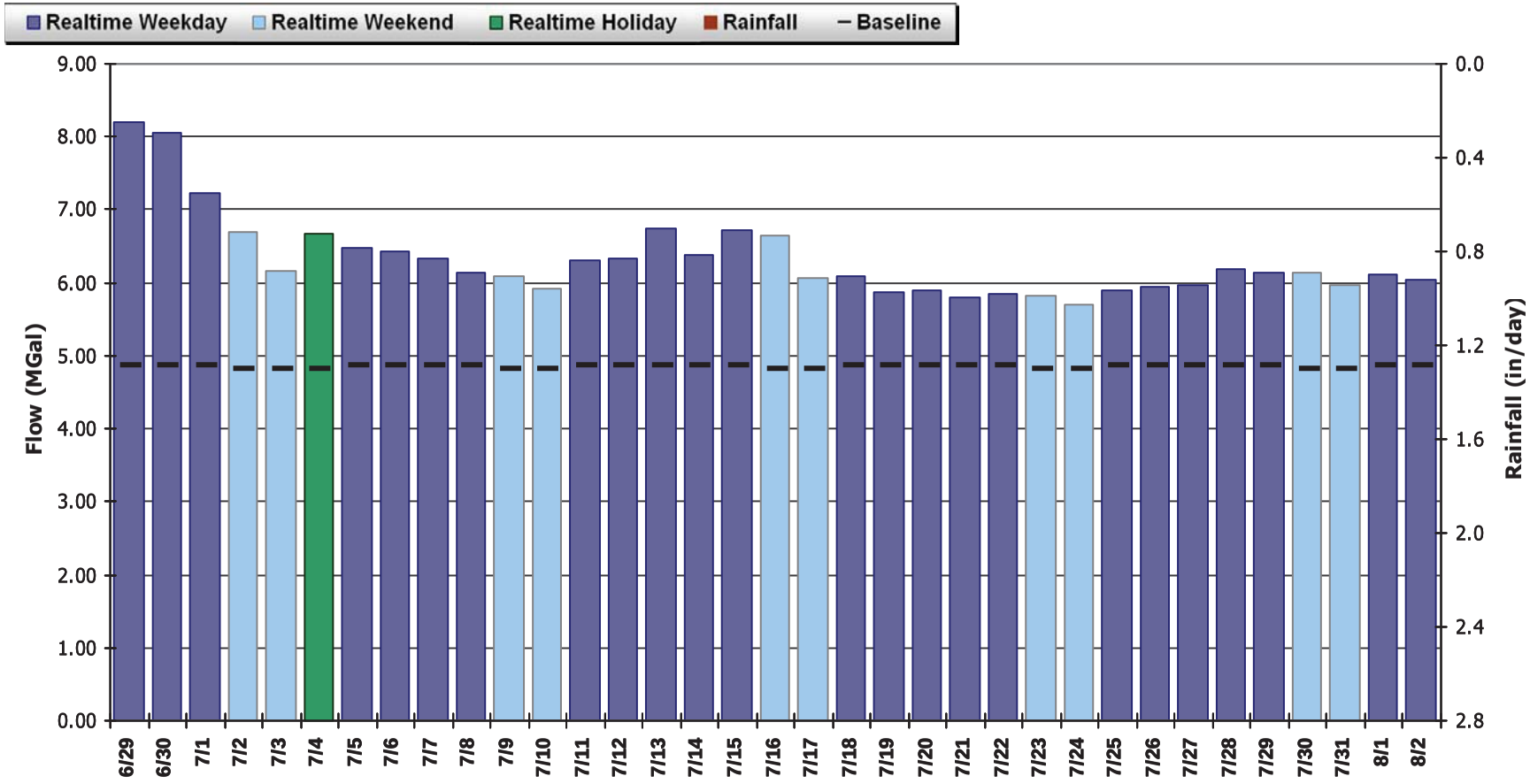
Street view

Plan view

SITE 2

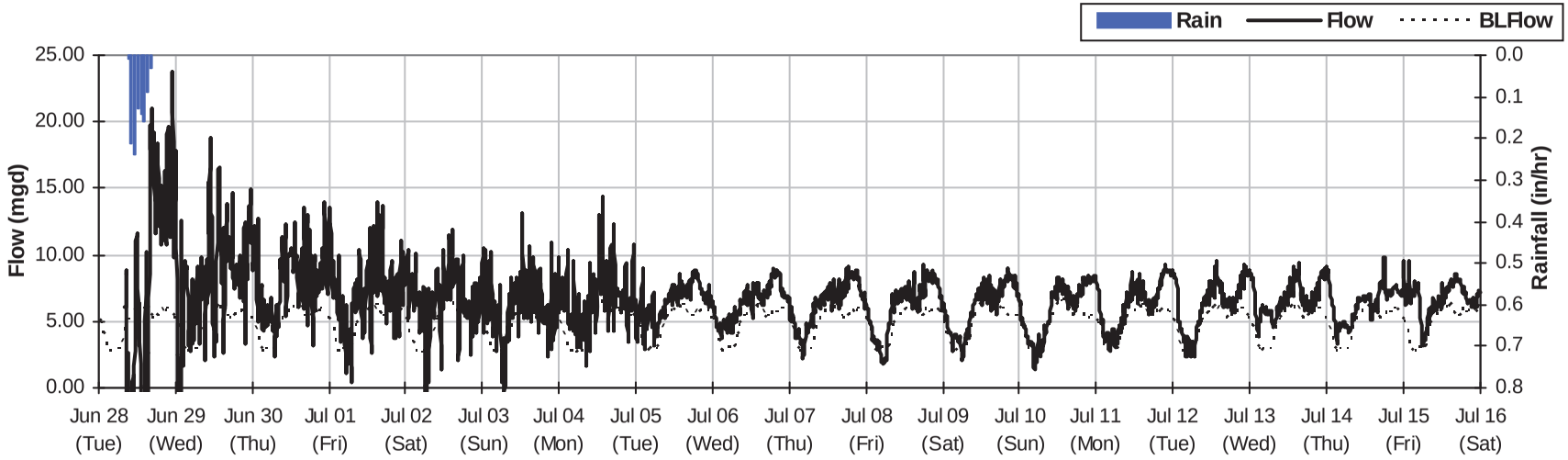
Period Flow Summary: Daily Flow Totals

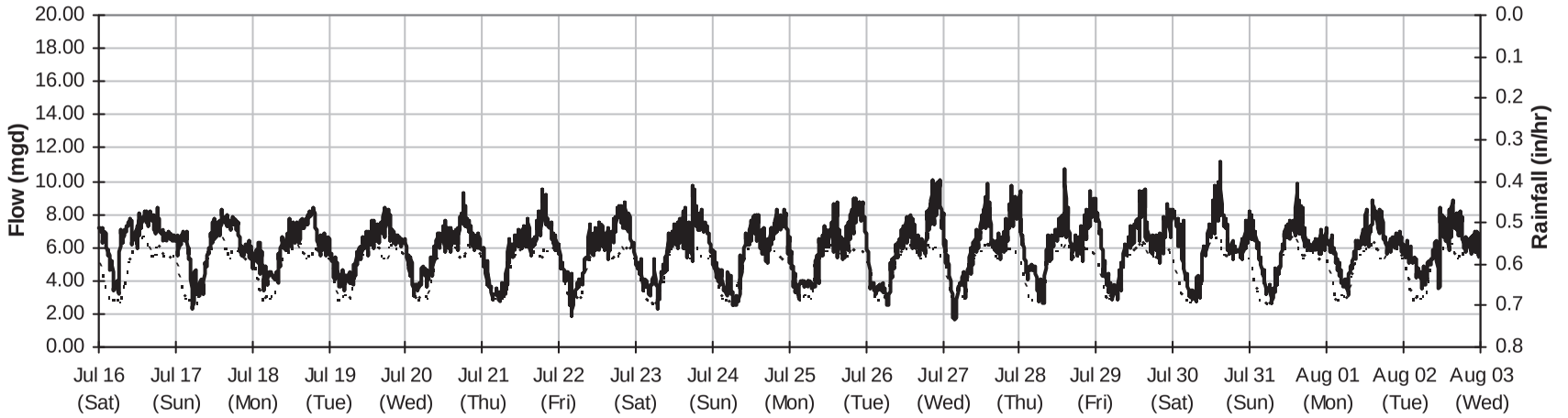
Avg Daily Flow: 6.314 MGal **Peak Daily Flow: 8.201 MGal** **Min Daily Flow: 5.694 MGal**



SITE 2

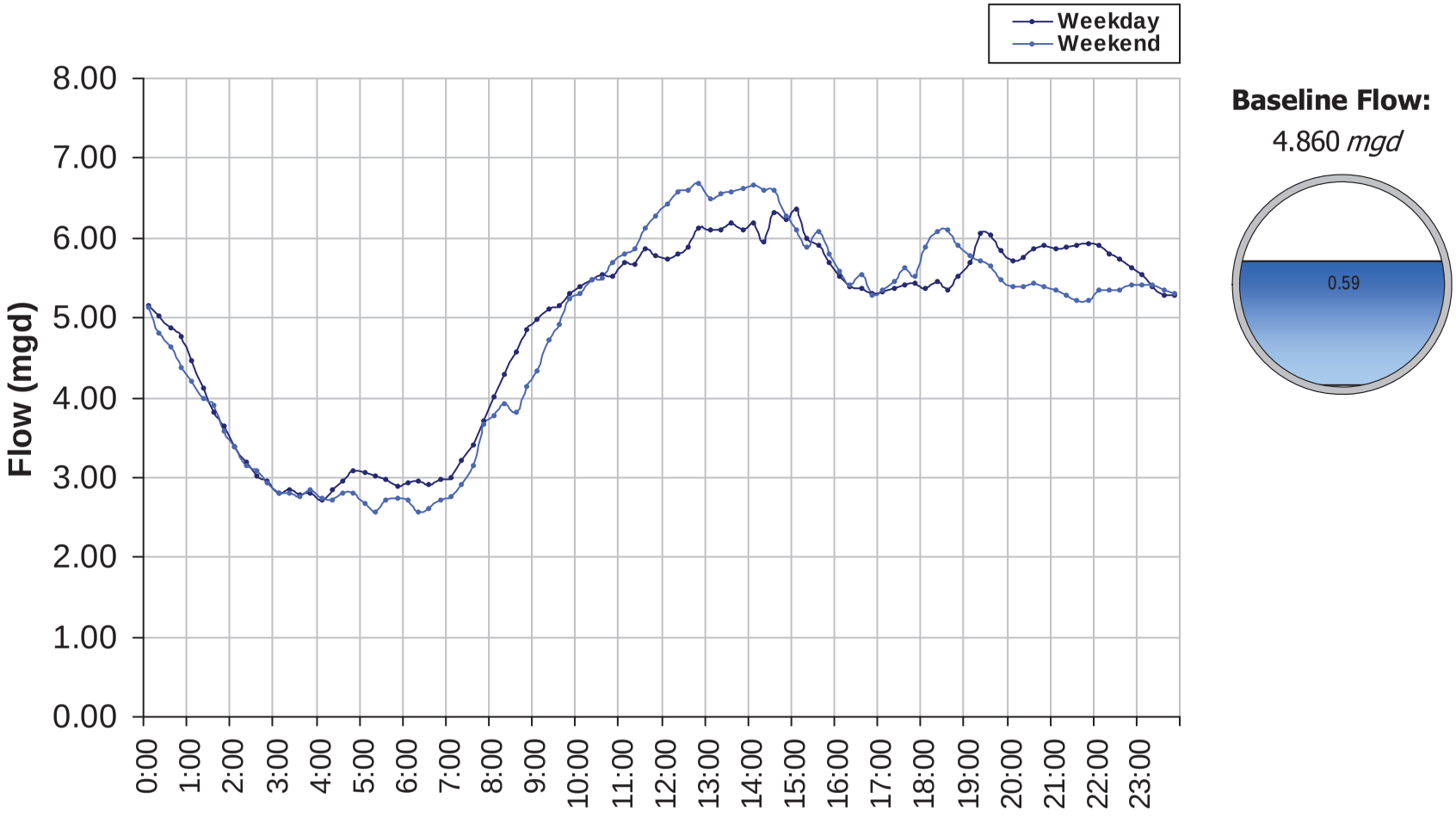
Period Flow Summary: 15-minute data





SITE 2

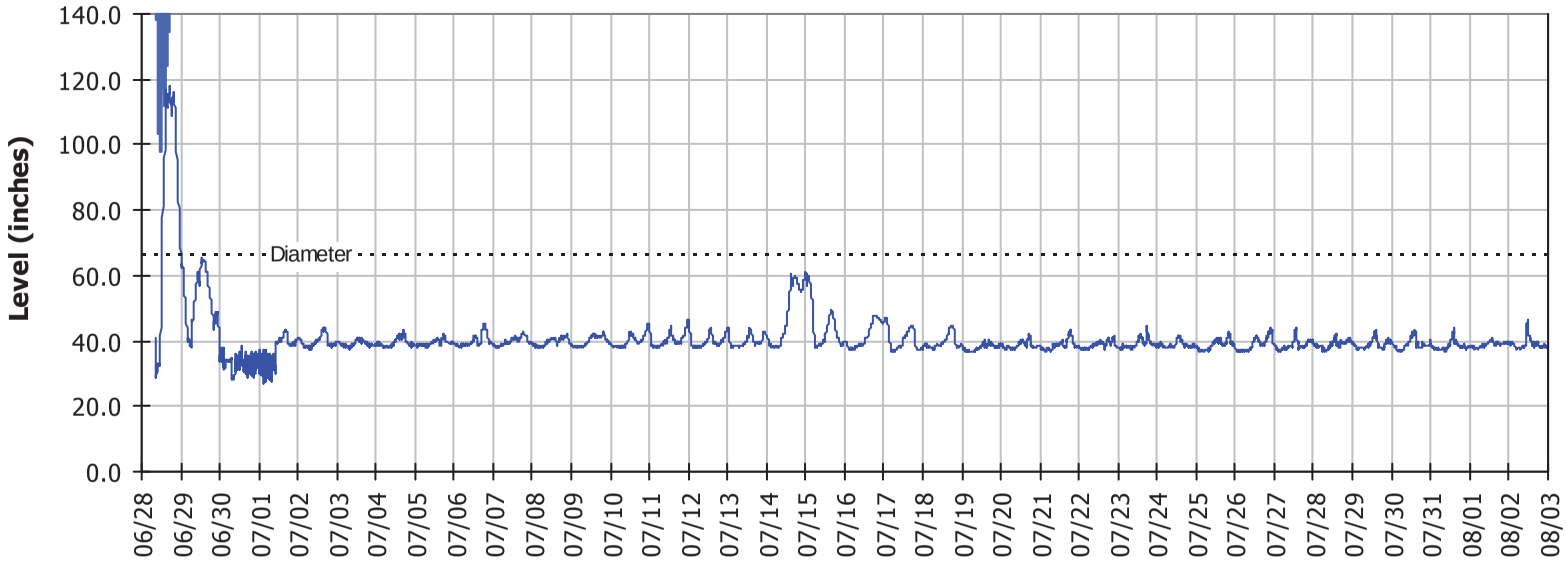
Baseline Flow Hydrographs

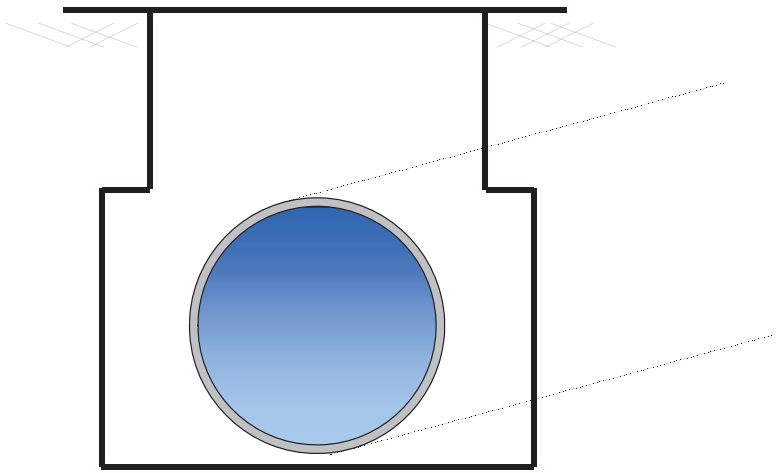


SITE 2

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period





Pipe Diameter: 66 *inches*

Peak Measured Level: 118 *inches*

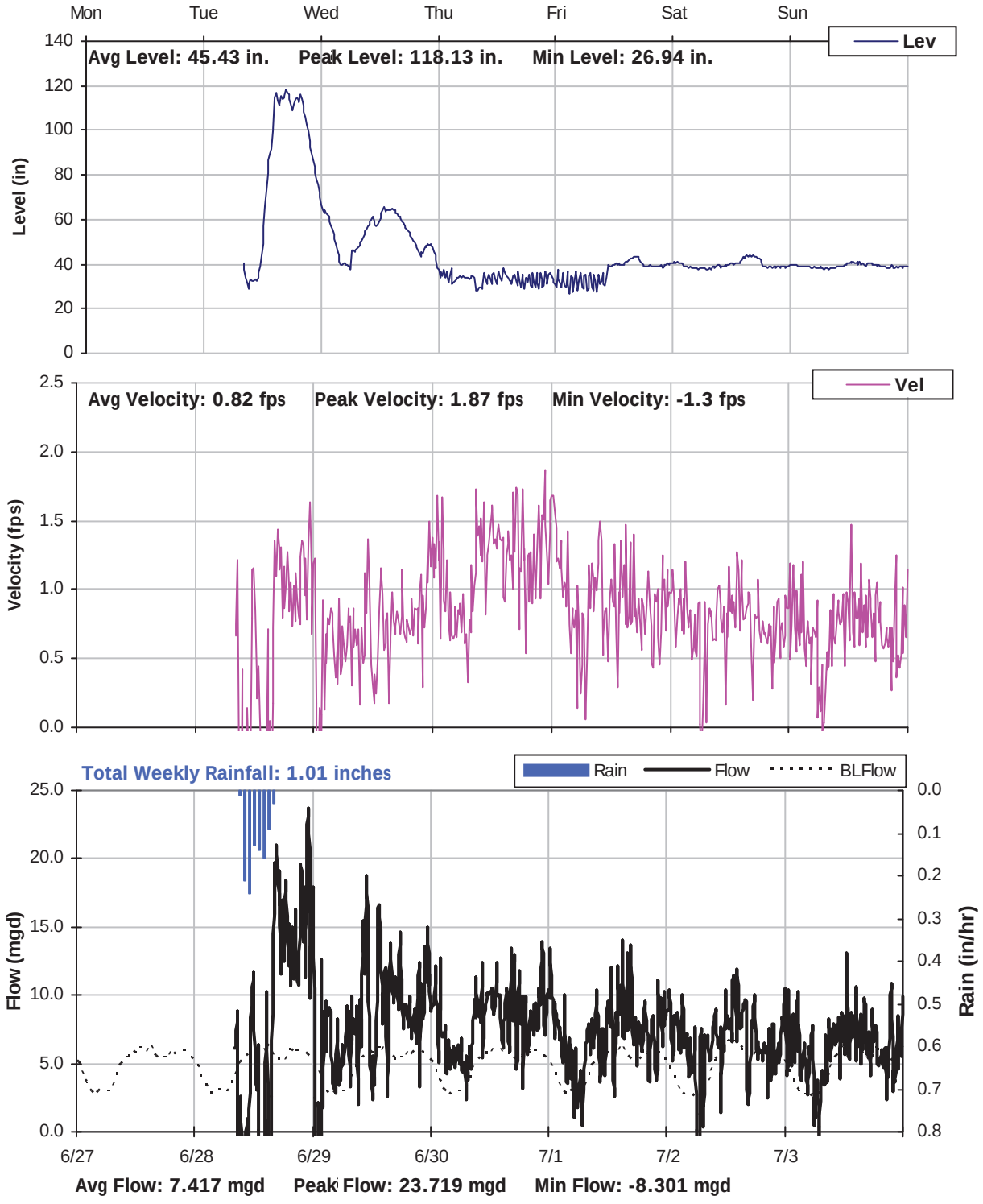
Peak d/D Ratio: 1.79

Surcharged 52.1 inches over crown

SITE 2

Weekly Level, Velocity and Flow Hydrographs

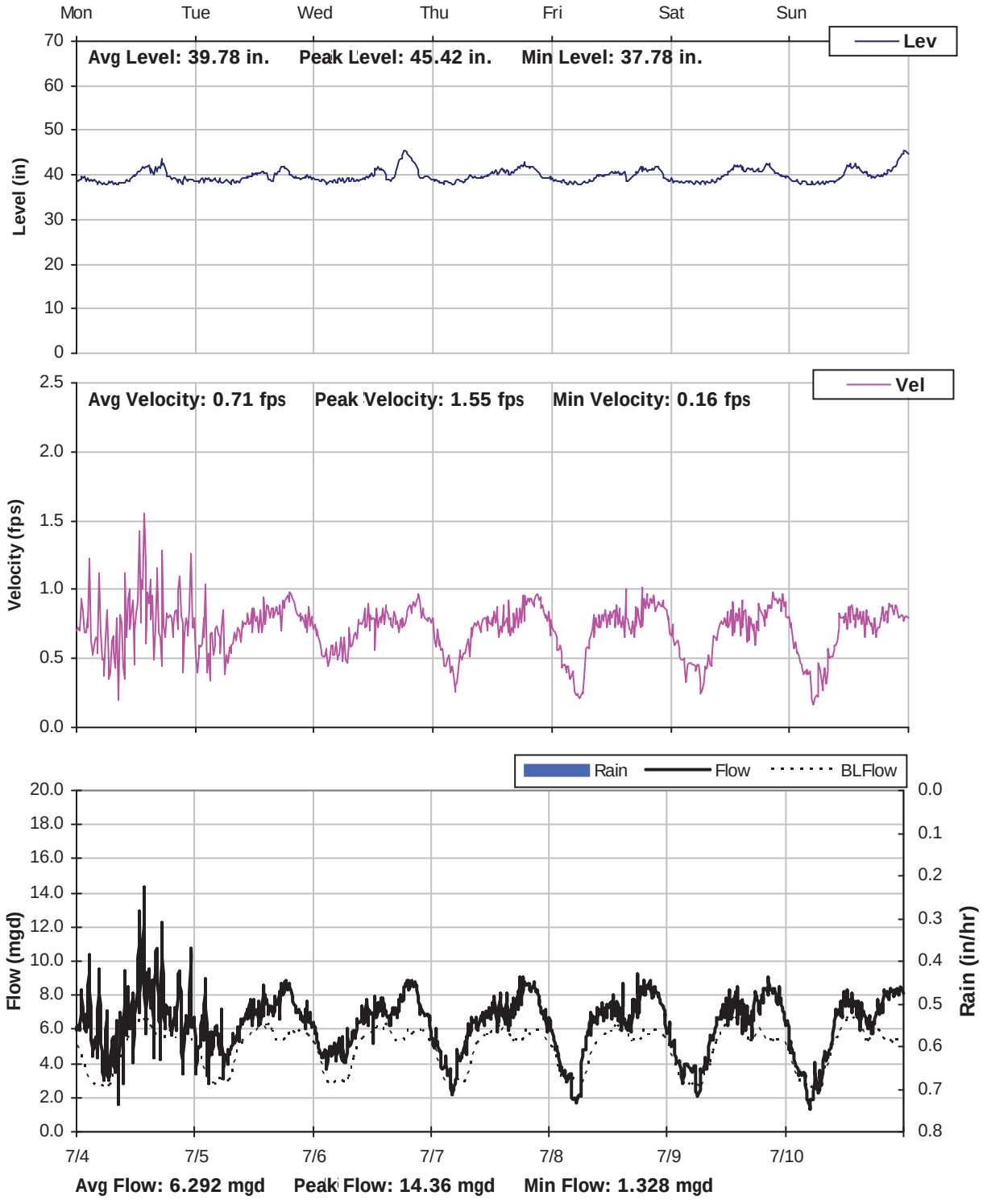
6/27/2011 to 7/4/2011



SITE 2

Weekly Level, Velocity and Flow Hydrographs

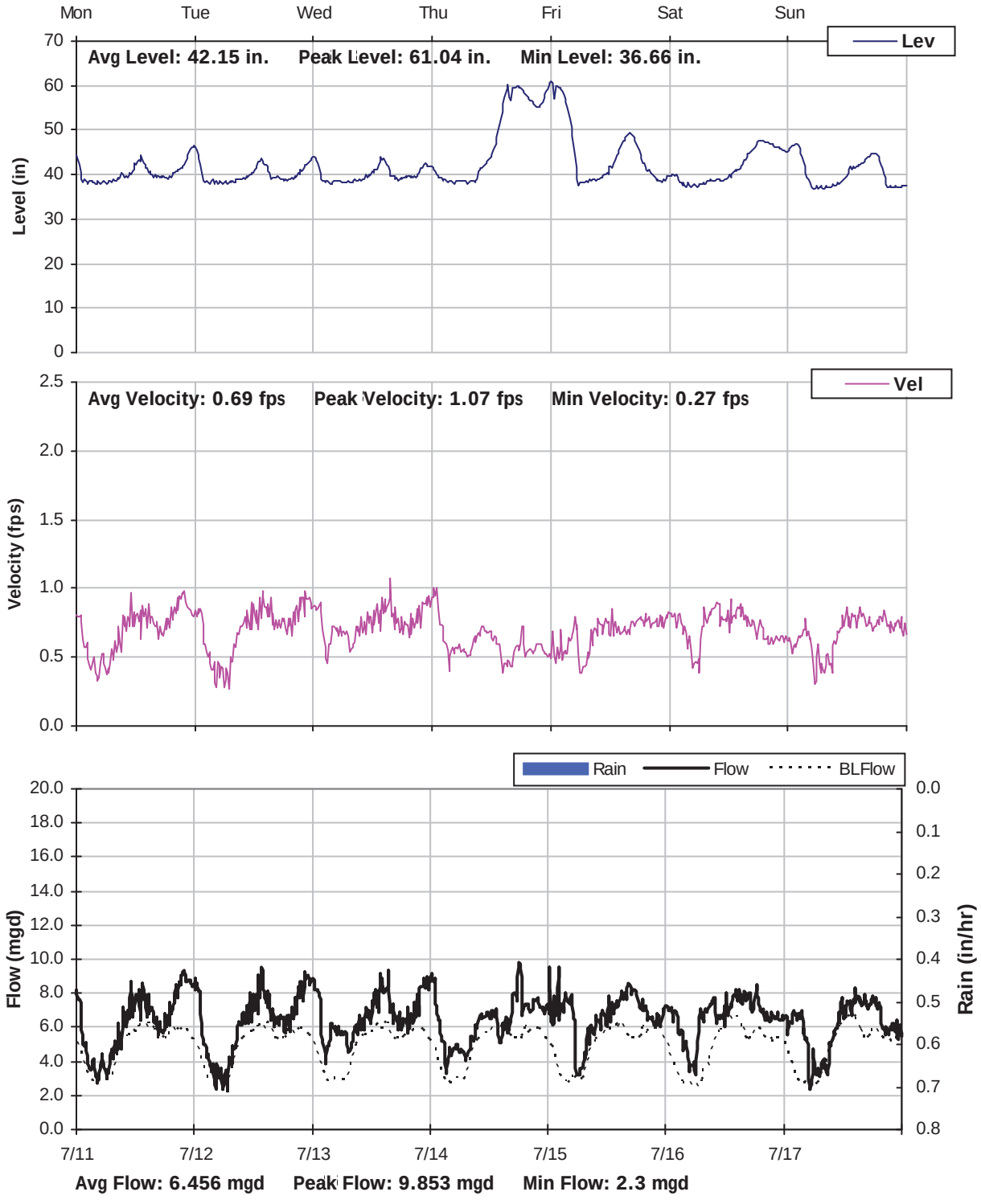
7/4/2011 to 7/11/2011



SITE 2

Weekly Level, Velocity and Flow Hydrographs

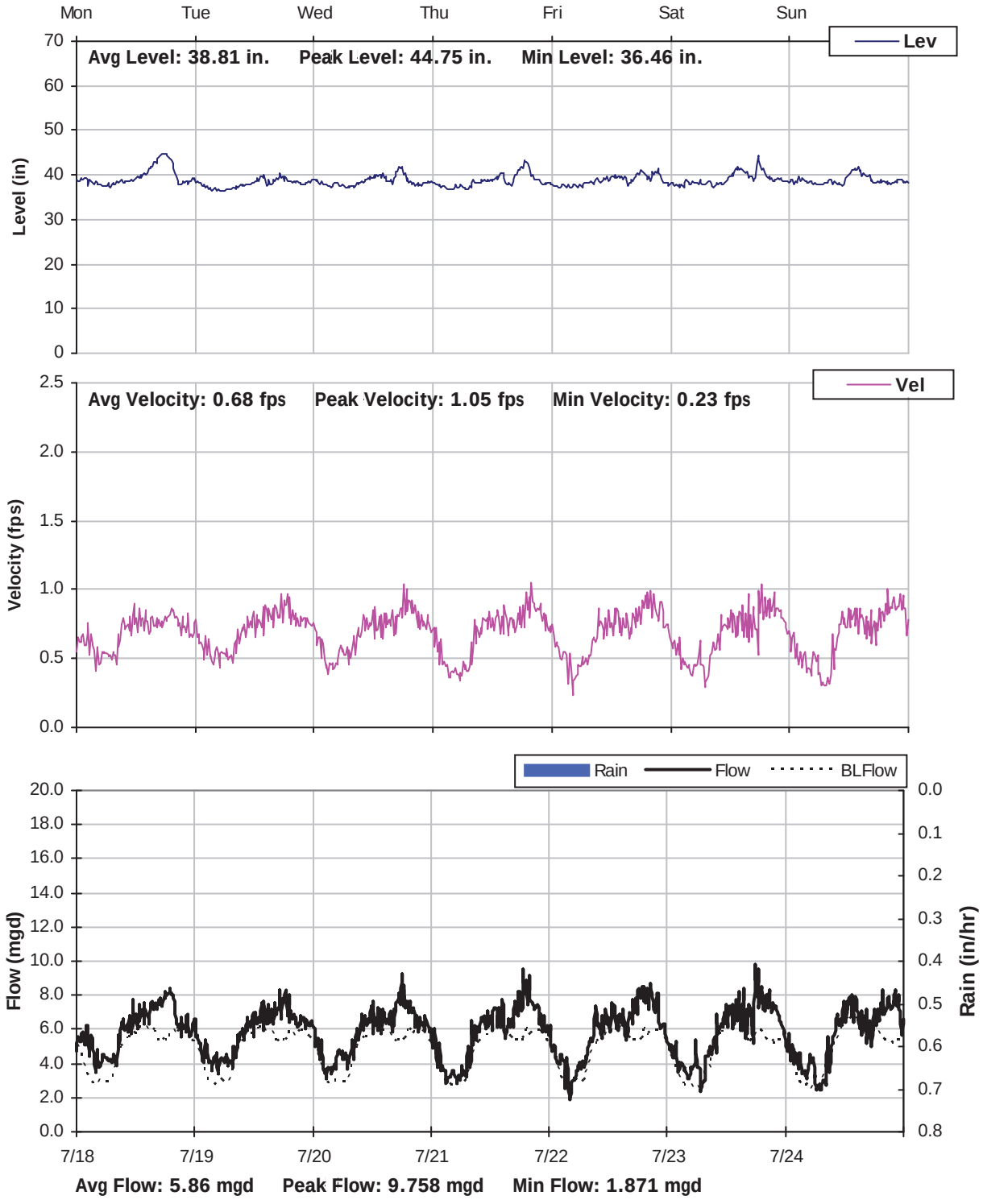
7/11/2011 to 7/18/2011



SITE 2

Weekly Level, Velocity and Flow Hydrographs

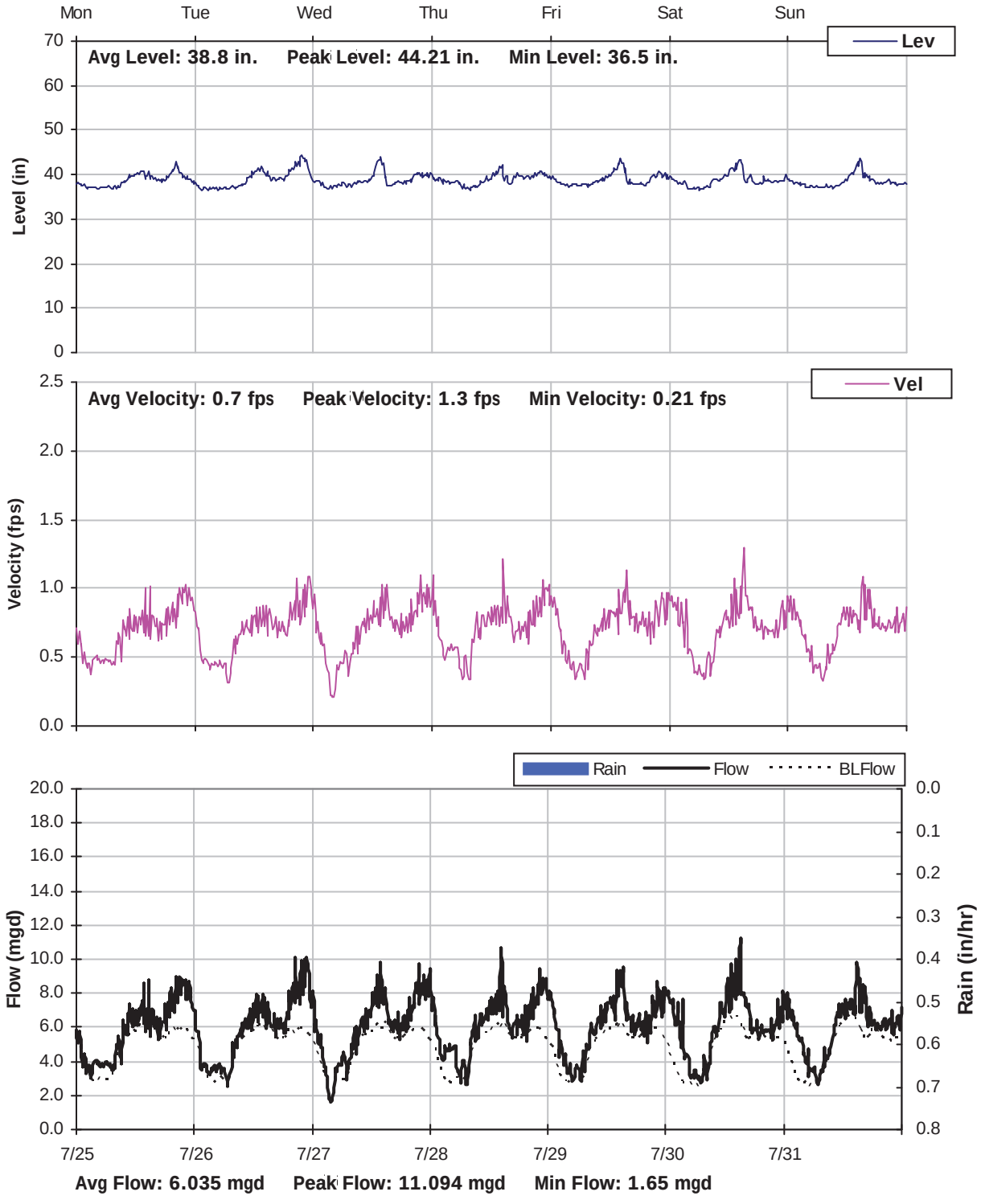
7/18/2011 to 7/25/2011



SITE 2

Weekly Level, Velocity and Flow Hydrographs

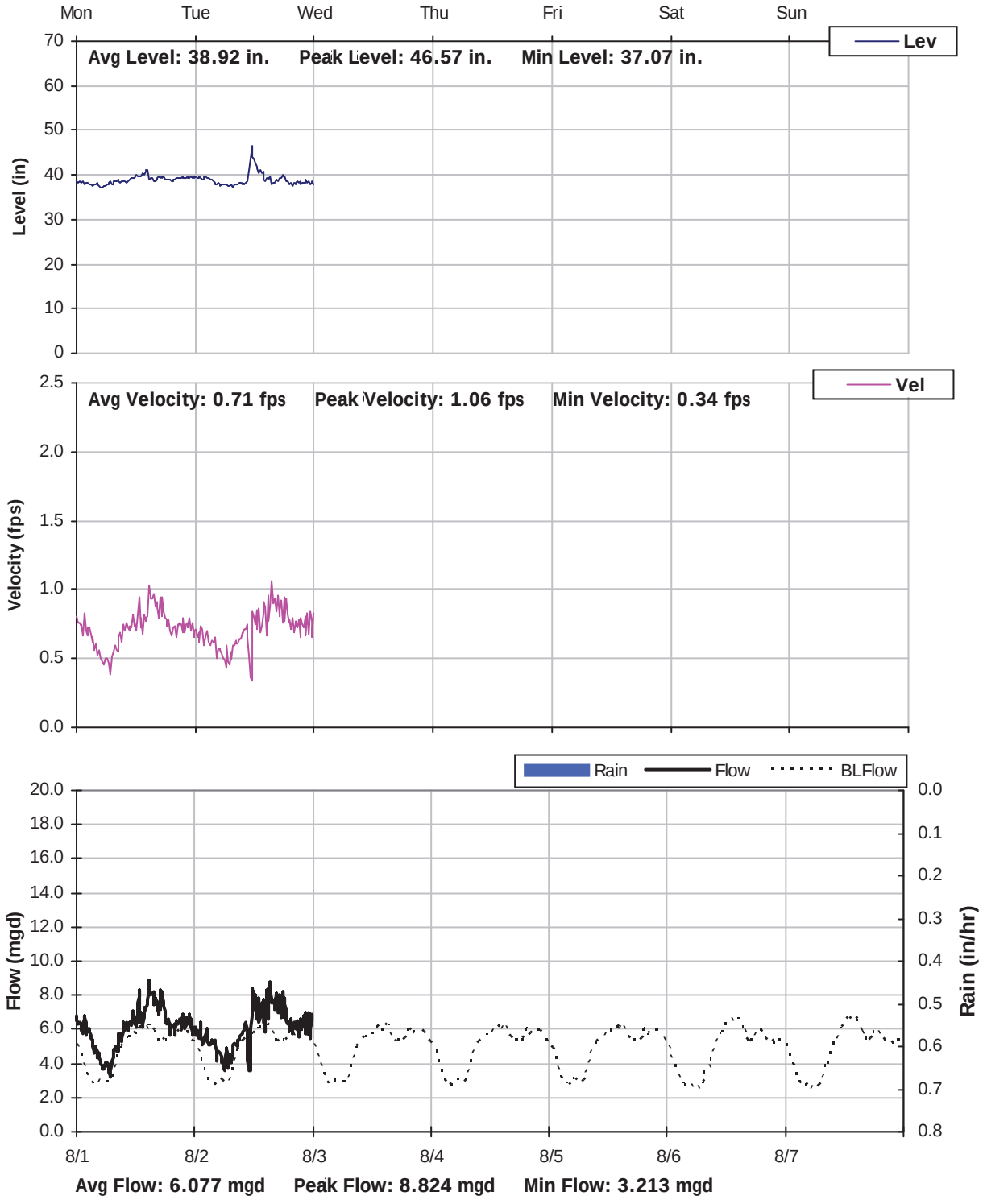
7/25/2011 to 8/1/2011



SITE 2

Weekly Level, Velocity and Flow Hydrographs

8/1/2011 to 8/8/2011



Veolia City of Richmond

Sanitary Sewer Flow Monitoring

Year 2011

Monitoring Site: 3

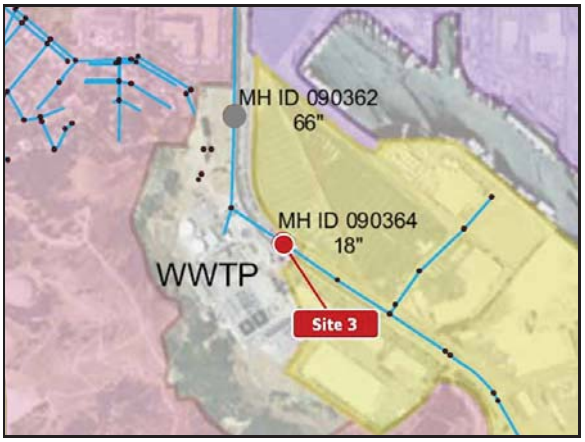
Location: MH ID 090364: On shoulder of north-bound Canal Boulevard, east of Treatment Plant

Data Summary Report

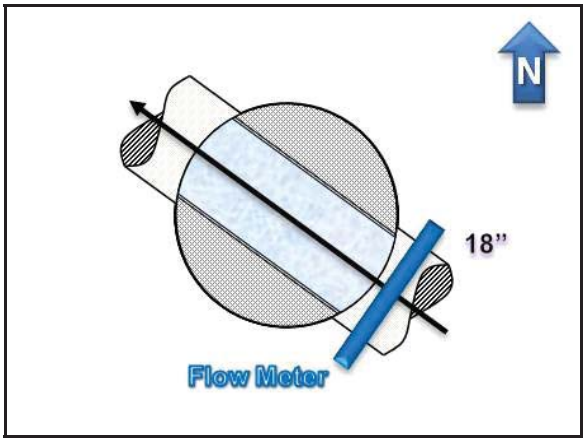
SITE 3
Site Information Report

Location:	MH ID 090364: On shoulder of north-bound Canal Boulevard, east of Treatment Plant
Coordinates:	122.3772° W, 37.9203° N
Elevation:	14 feet
Diameter:	18 inches
Baseline Flow:	0.114 mgd
Peak Measured Flow:	1.2 mgd

Satellite map



Sewer map



Flow sketch

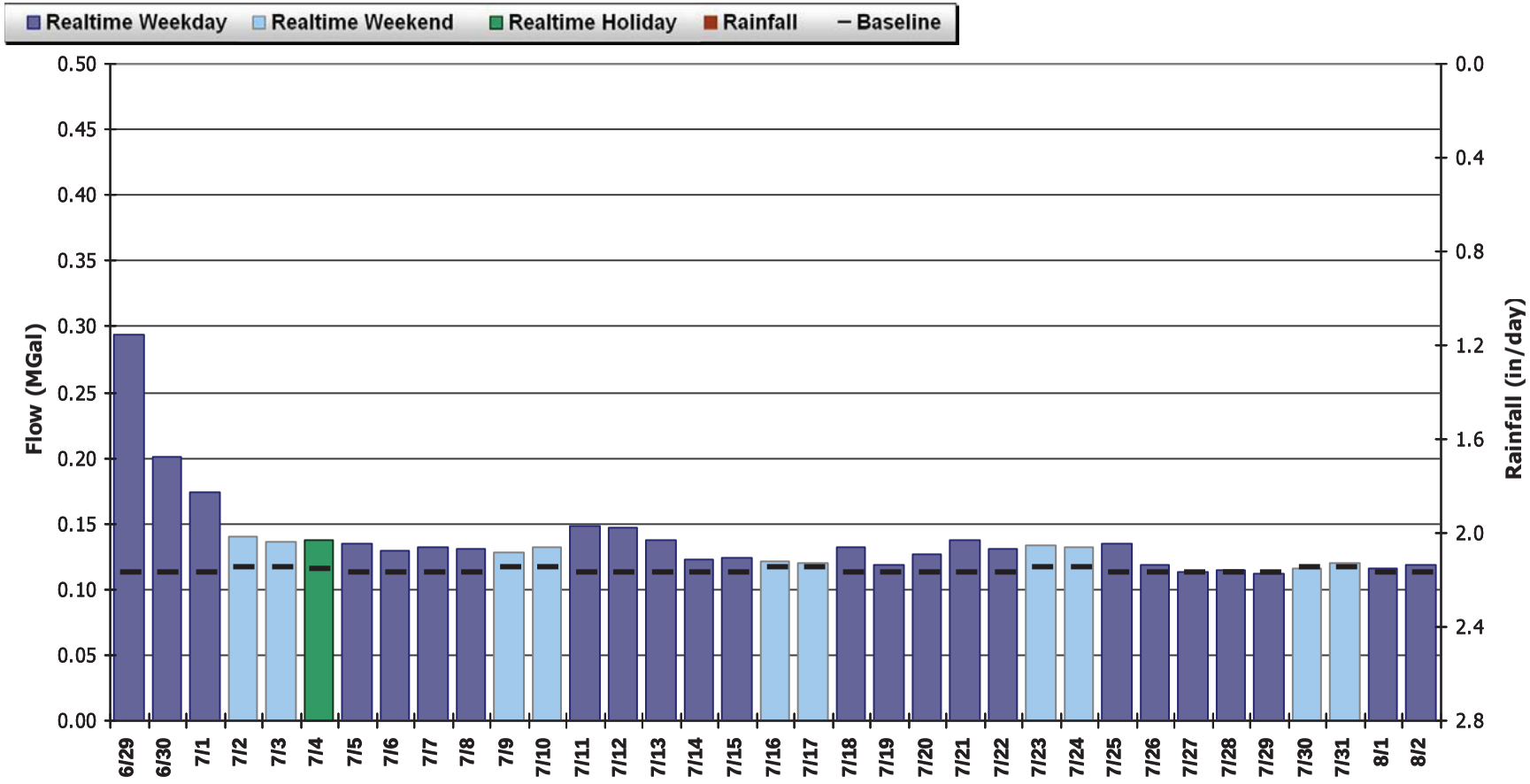
Street view

Plan view

SITE 3

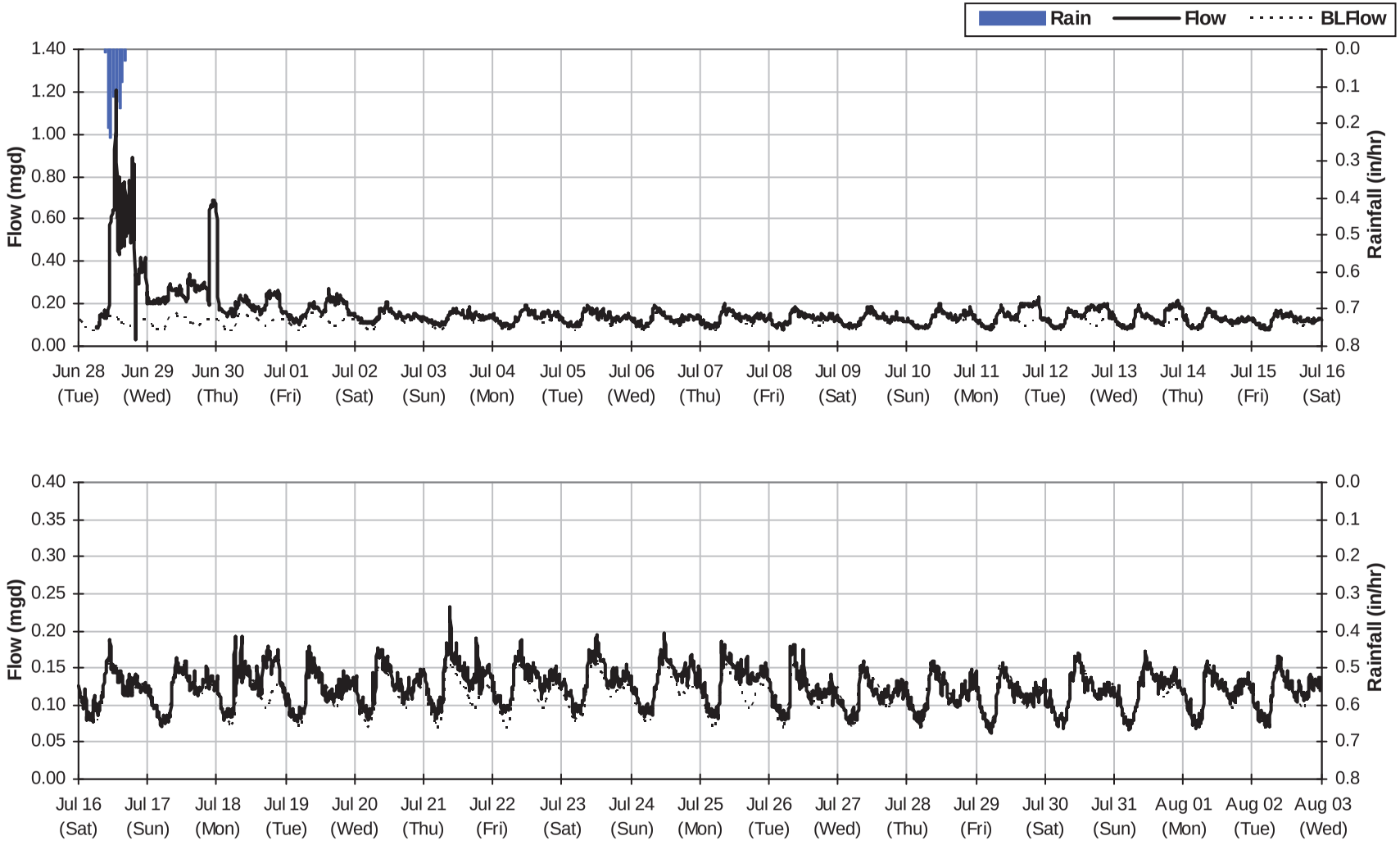
Period Flow Summary: Daily Flow Totals

Avg Daily Flow: 0.136 MGal **Peak Daily Flow: 0.294 MGal** **Min Daily Flow: 0.112 MGal**



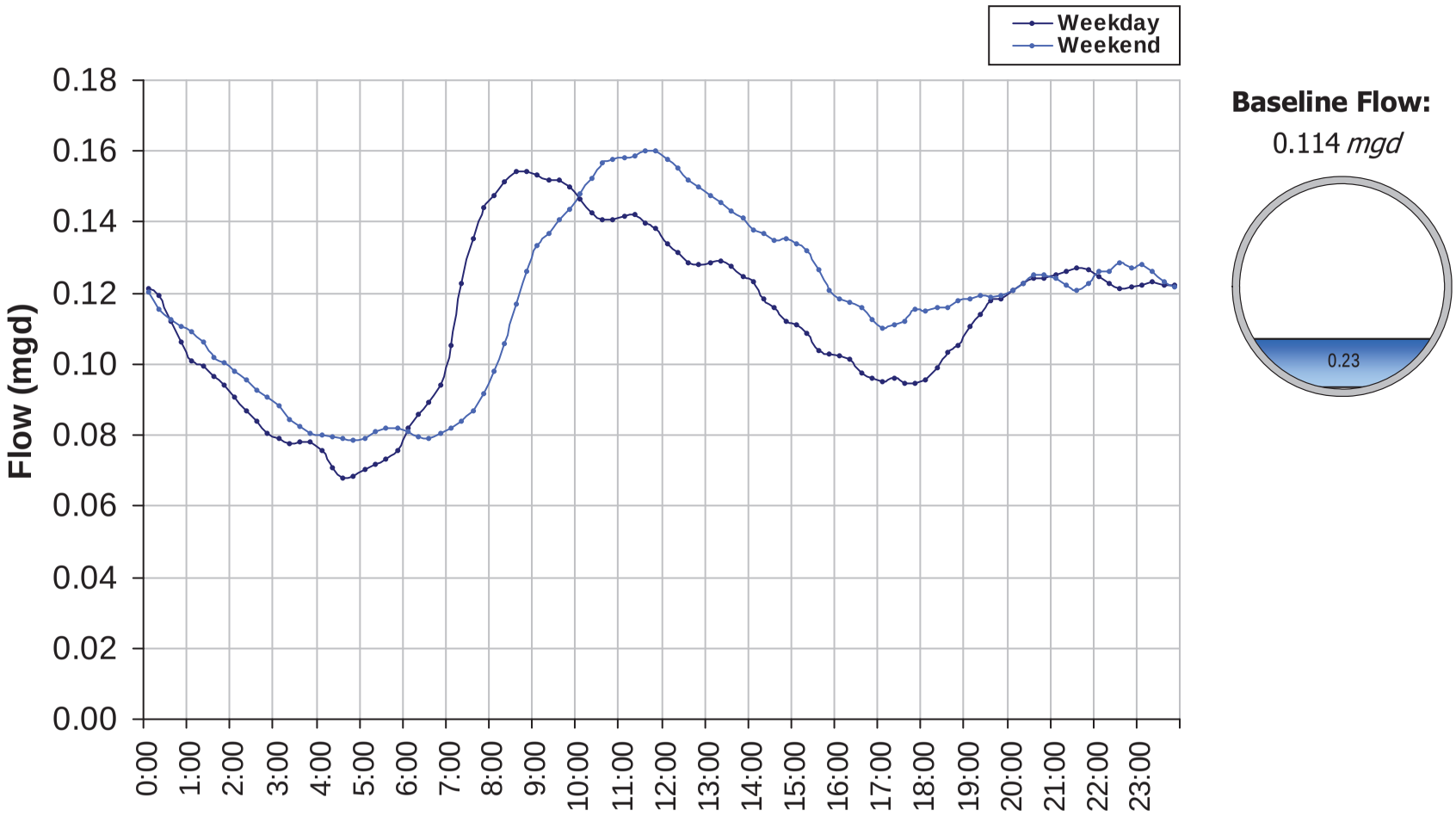
SITE 3

Period Flow Summary: 15-minute data



SITE 3

Baseline Flow Hydrographs



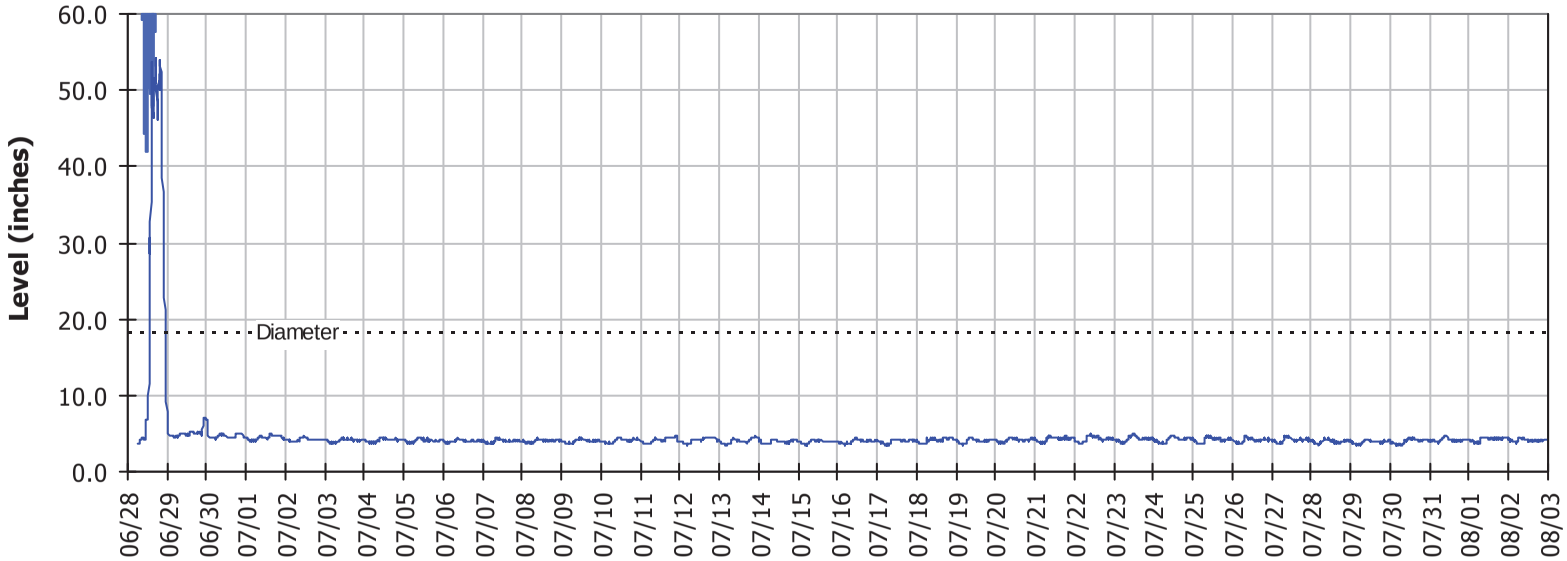
Baseline Flow:

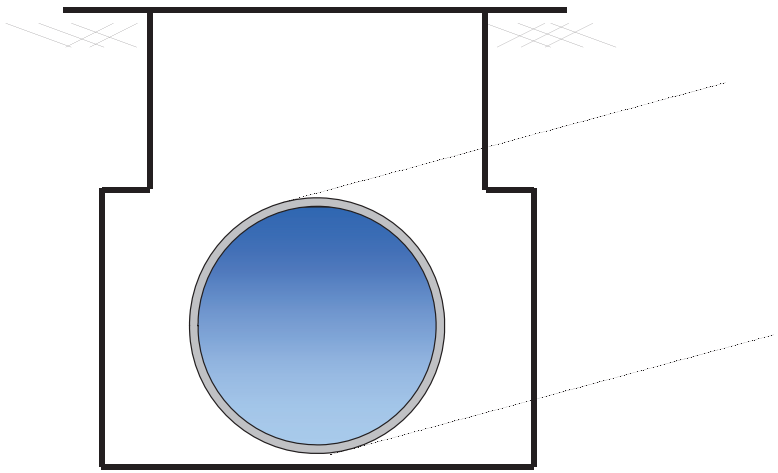
0.114 *mgd*

SITE 3

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period





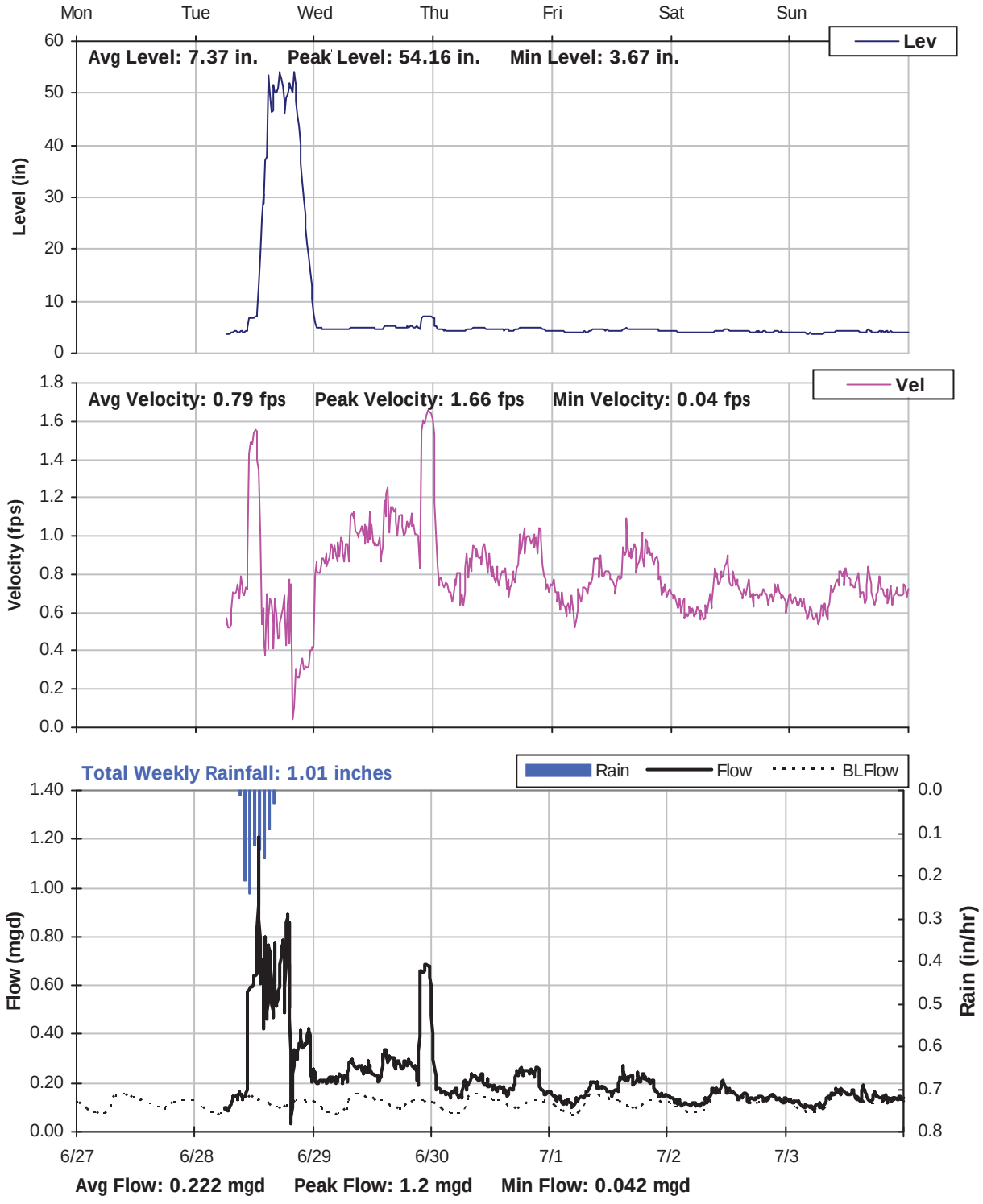
Pipe Diameter: 18 *inches*

Peak Measured Level: 54.2 *inches*

Peak d/D Ratio: 3.01

Surcharged 36.2 inches over crown

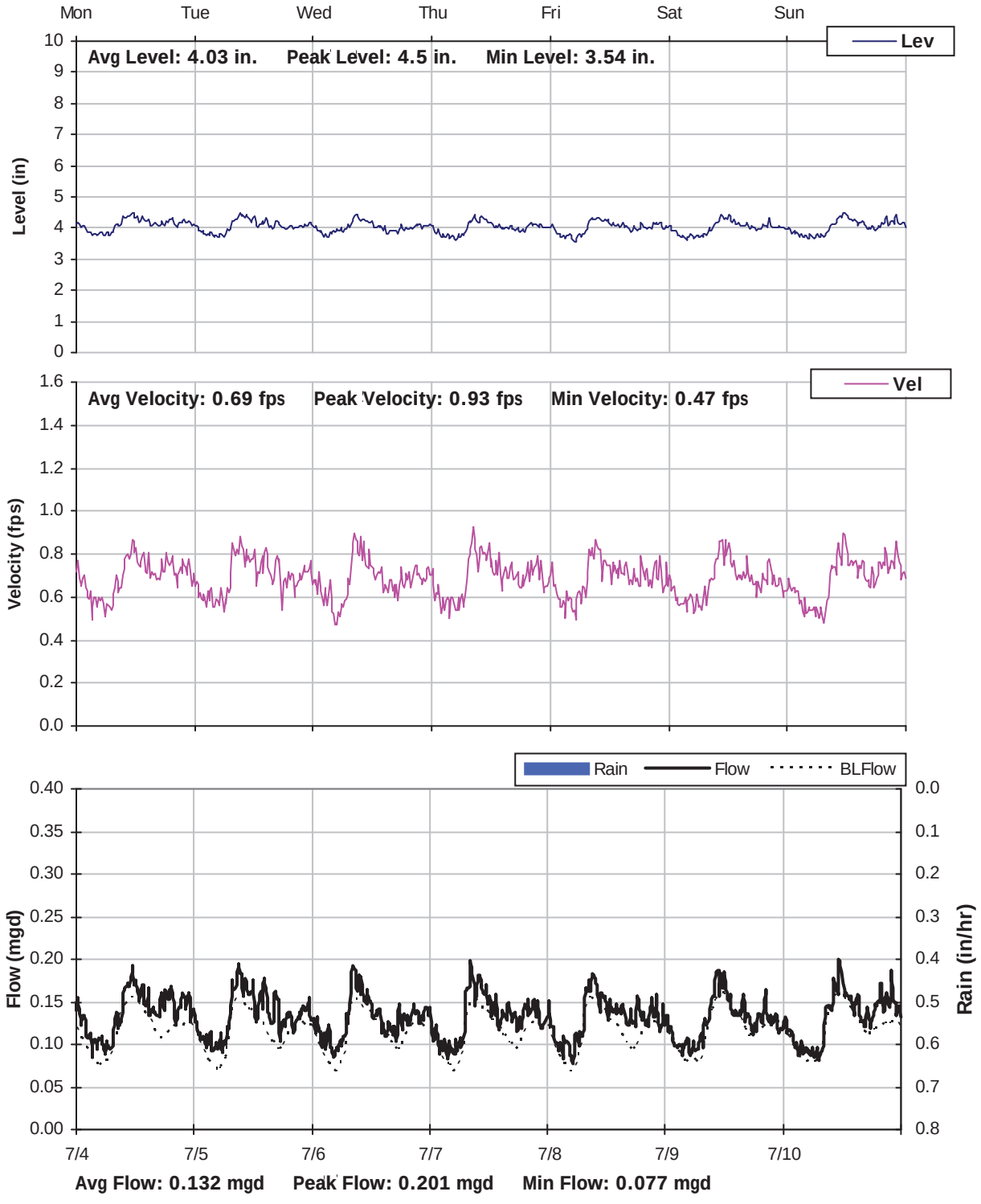
SITE 3
Weekly Level, Velocity and Flow Hydrographs
6/27/2011 to 7/4/2011



SITE 3

Weekly Level, Velocity and Flow Hydrographs

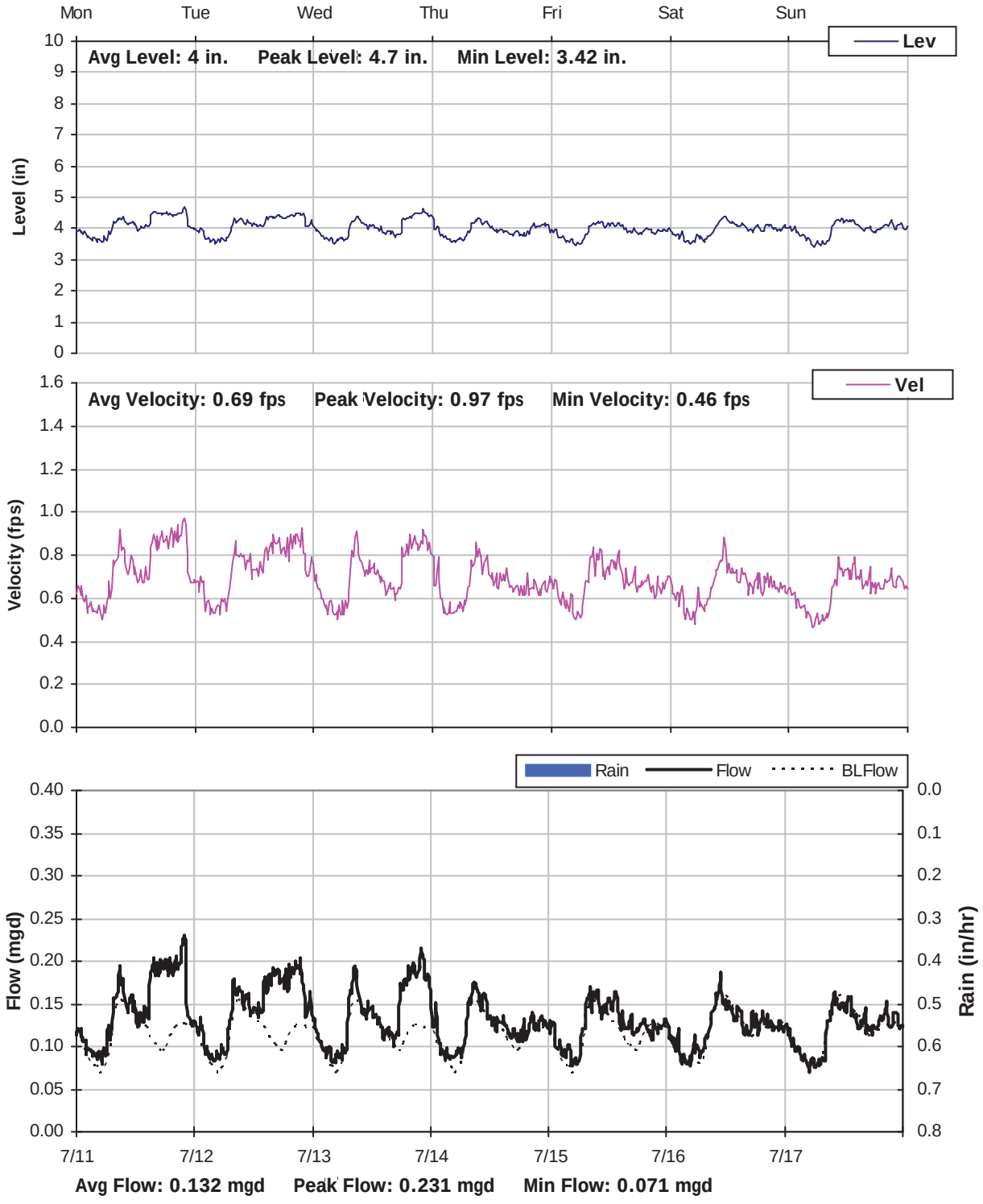
7/4/2011 to 7/11/2011



SITE 3

Weekly Level, Velocity and Flow Hydrographs

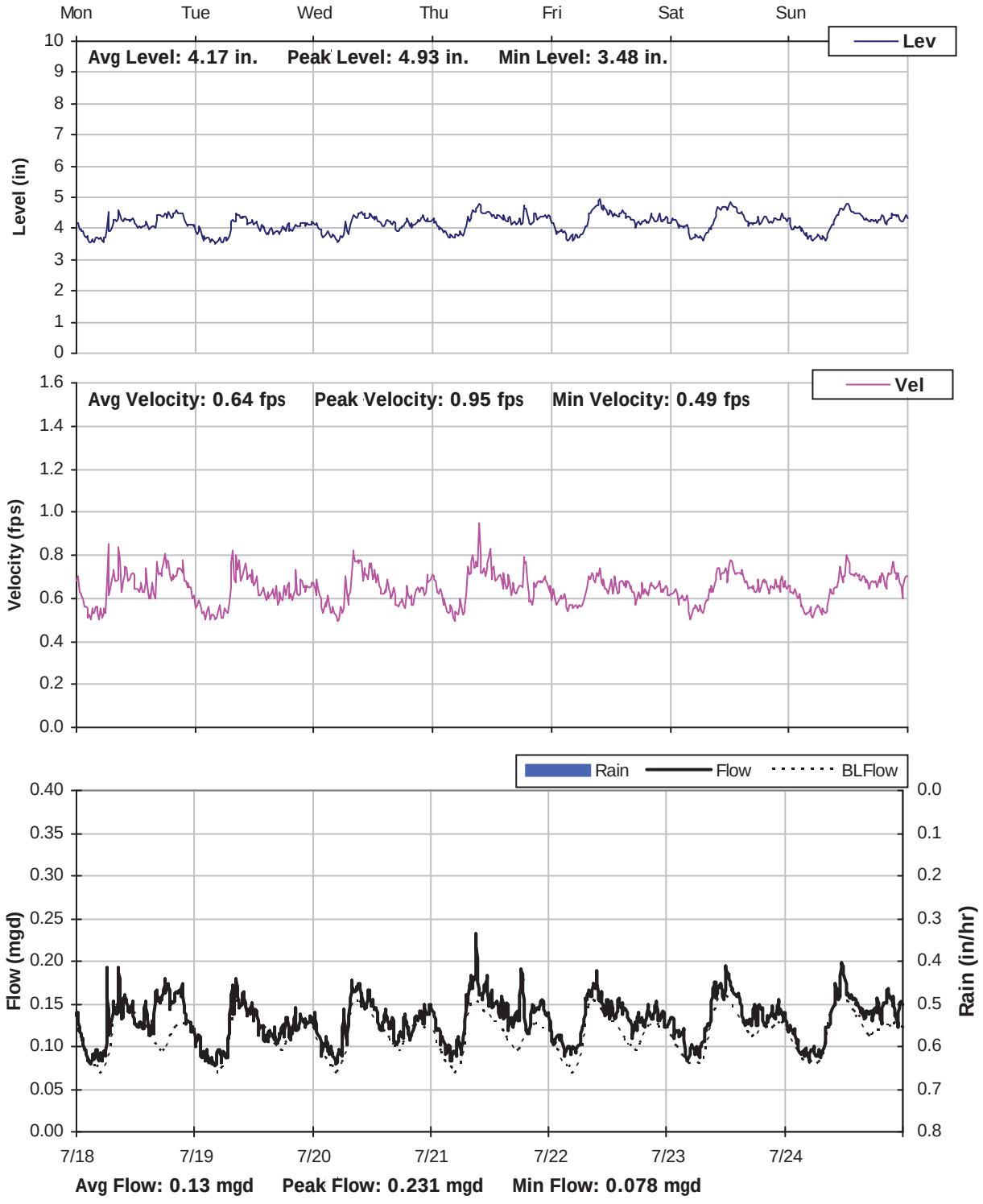
7/11/2011 to 7/18/2011



SITE 3

Weekly Level, Velocity and Flow Hydrographs

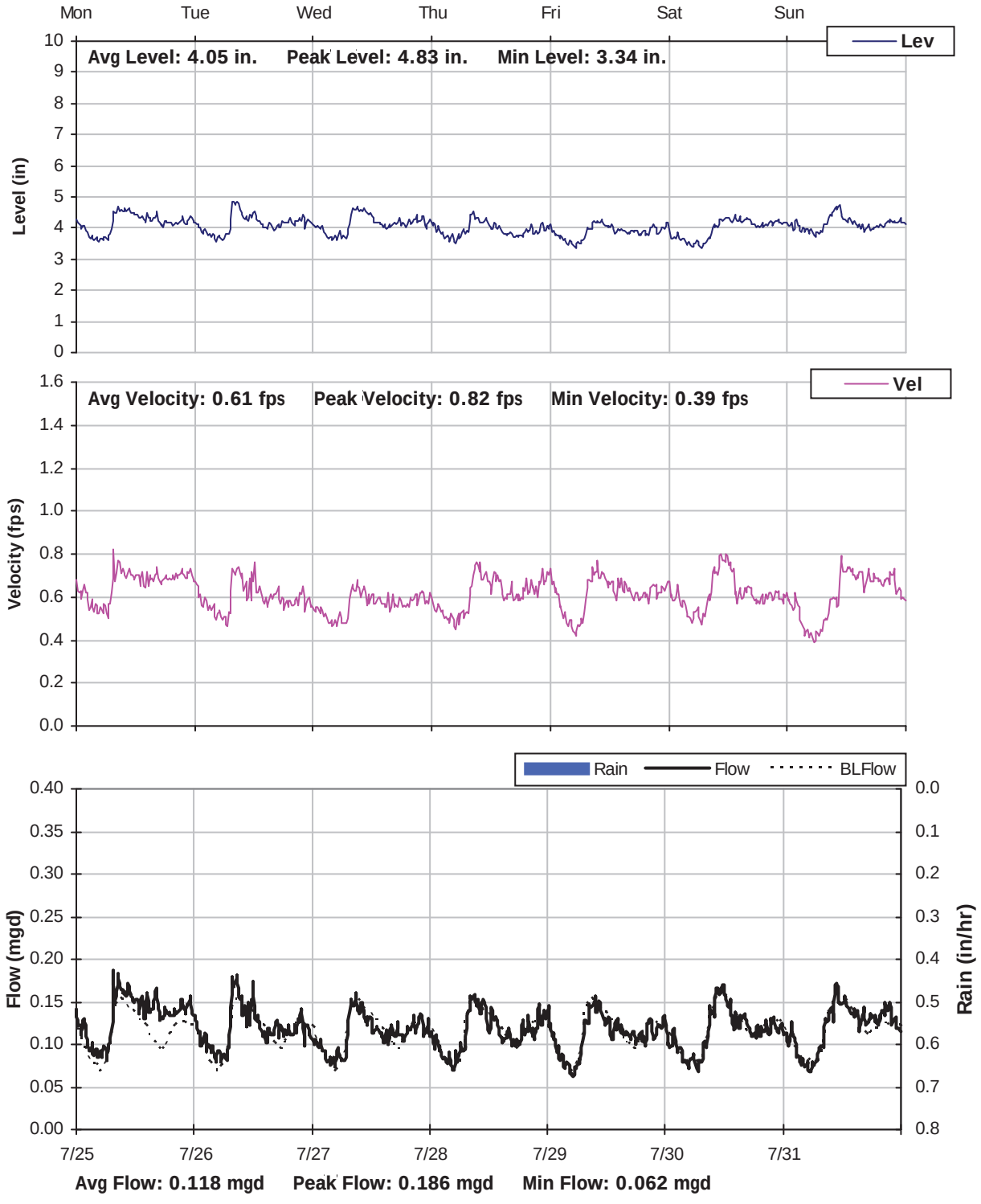
7/18/2011 to 7/25/2011



SITE 3

Weekly Level, Velocity and Flow Hydrographs

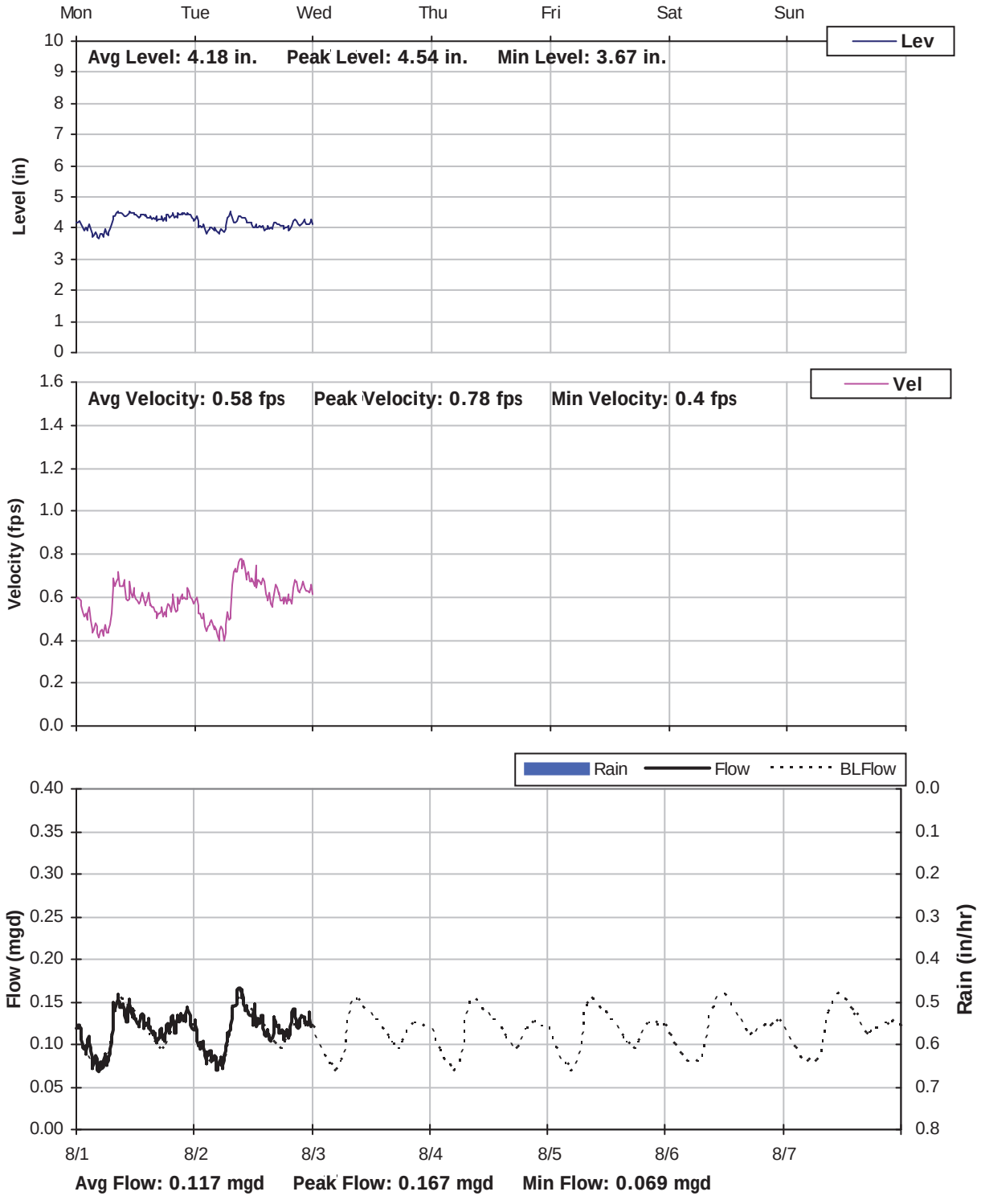
7/25/2011 to 8/1/2011



SITE 3

Weekly Level, Velocity and Flow Hydrographs

8/1/2011 to 8/8/2011



Veolia City of Richmond

Sanitary Sewer Flow Monitoring

Year 2011

Monitoring Site: 4

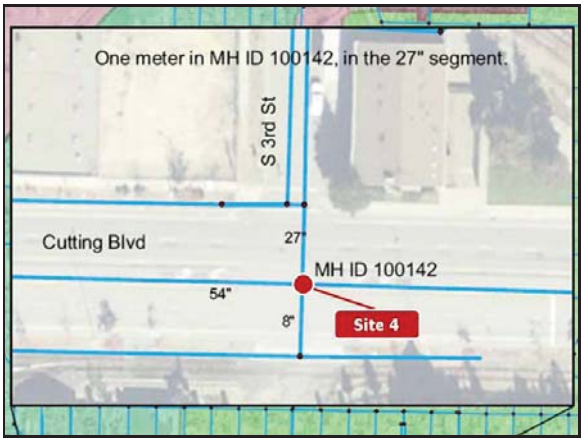
Location: MH ID 100142: Intersection of W. Cutting Boulevard and S. 3rd Street

Data Summary Report

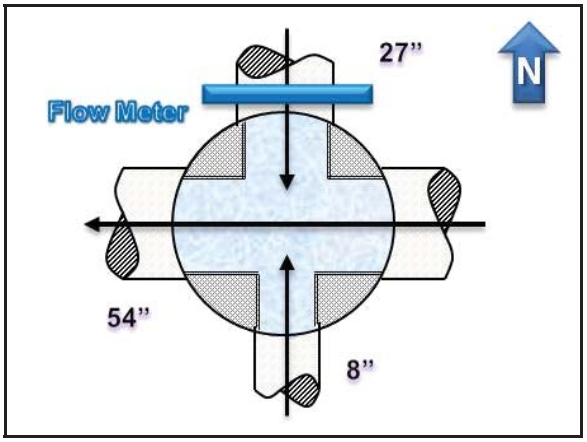
SITE 4
Site Information Report

Location:	MH ID 100142: Intersection of W. Cutting Boulevard and S. 3rd Street
Coordinates:	122.3669° W, 37.9252° N
Elevation:	10 feet
Diameter:	27 inches
Baseline Flow:	0.677 mgd
Peak Measured Flow:	4.235 mgd

Satellite map



Sewer map



Flow sketch

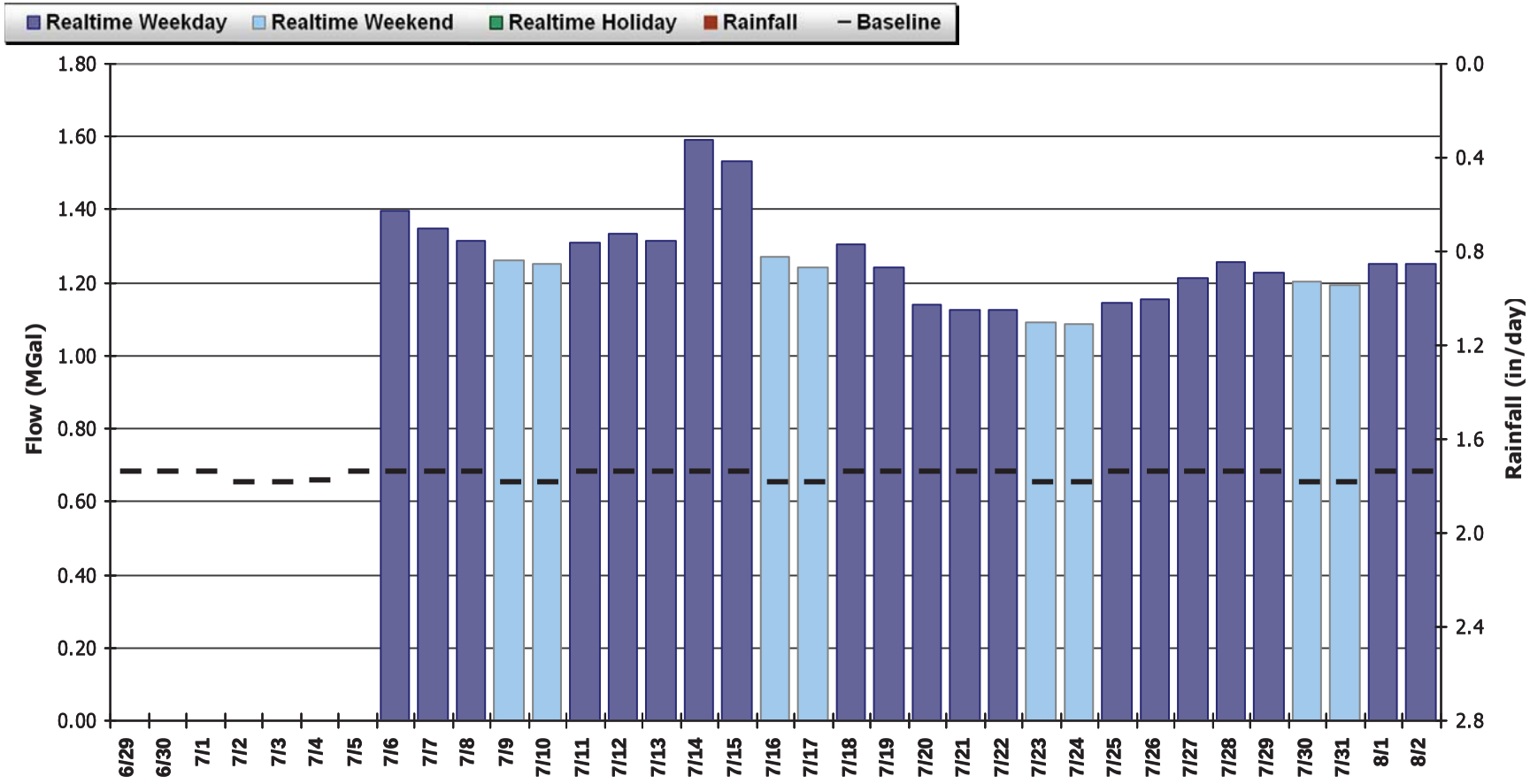
Street view

Plan view

SITE 4

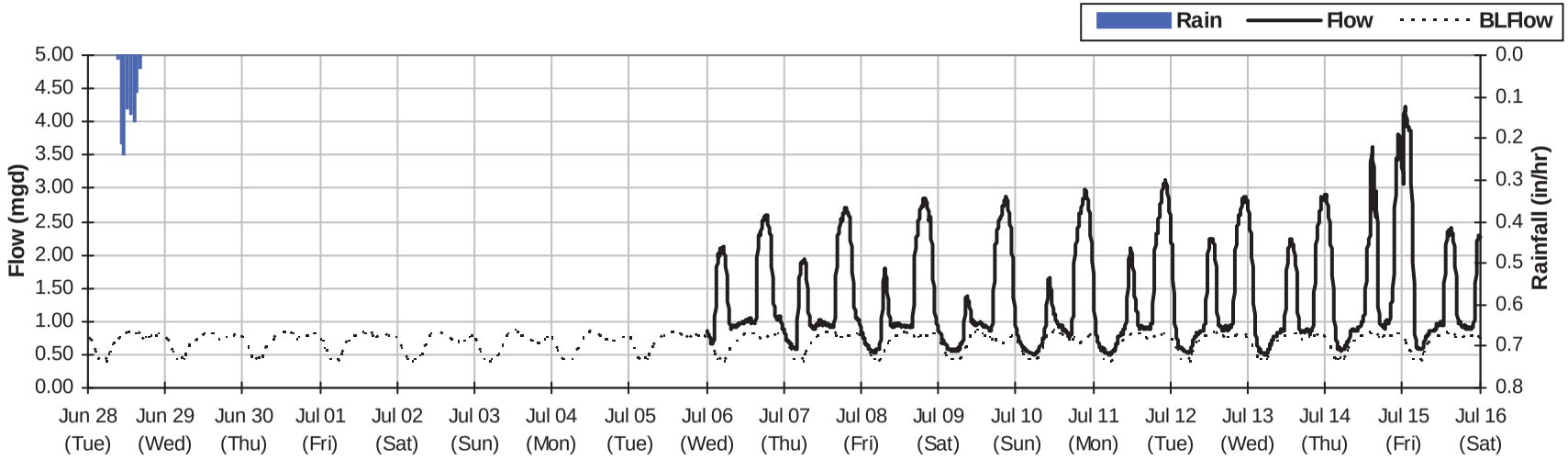
Period Flow Summary: Daily Flow Totals

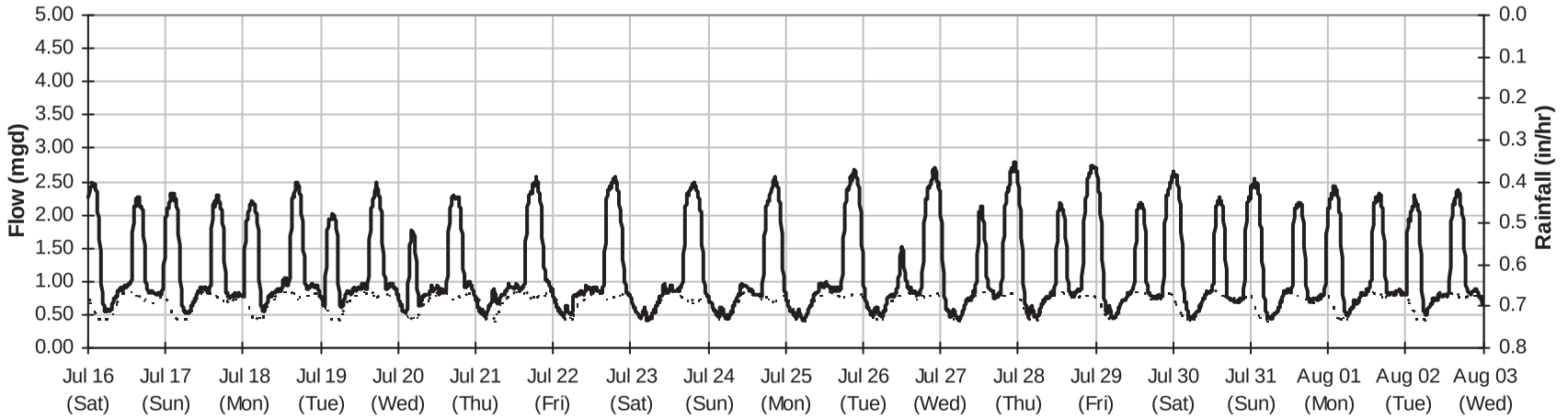
Avg Daily Flow: 1.257 MGal **Peak Daily Flow: 1.593 MGal** **Min Daily Flow: 1.086 MGal**



SITE 4

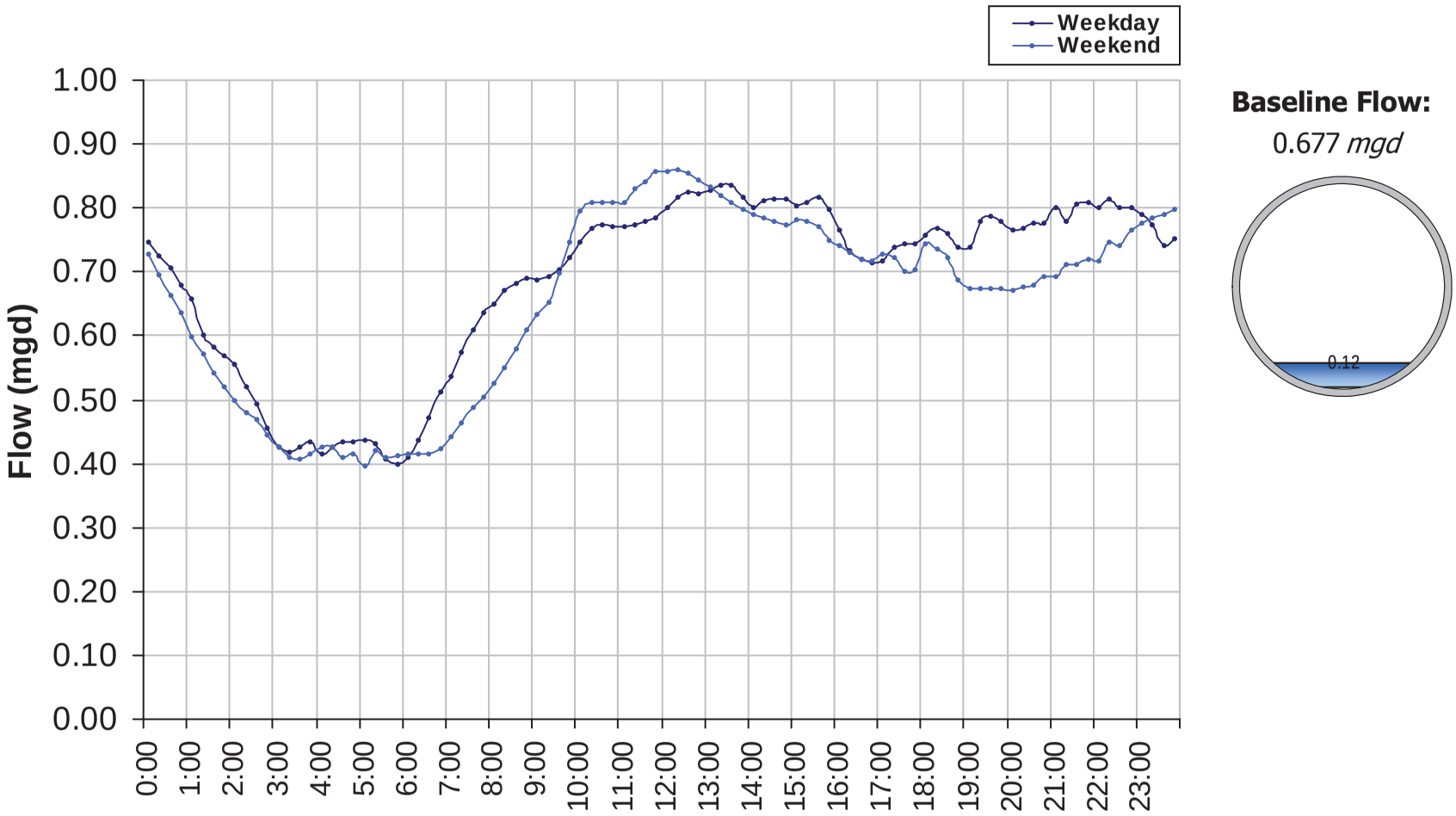
Period Flow Summary: 15-minute data





SITE 4

Baseline Flow Hydrographs



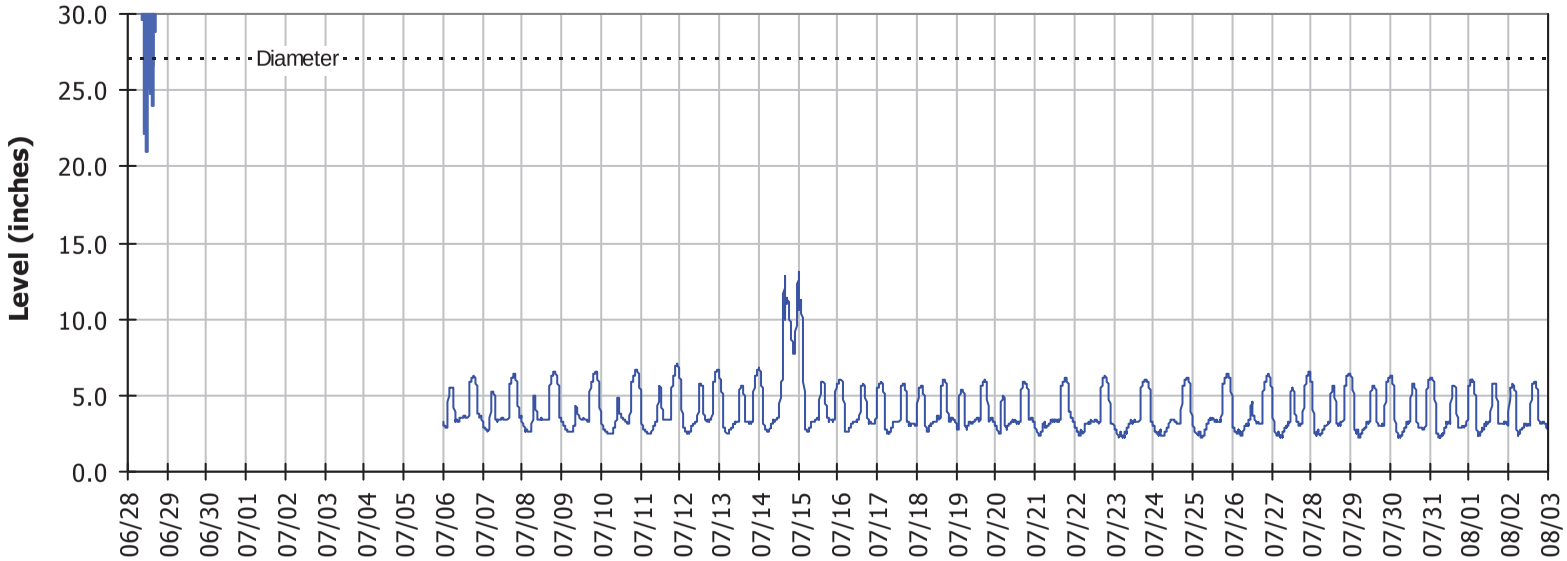
Baseline Flow:

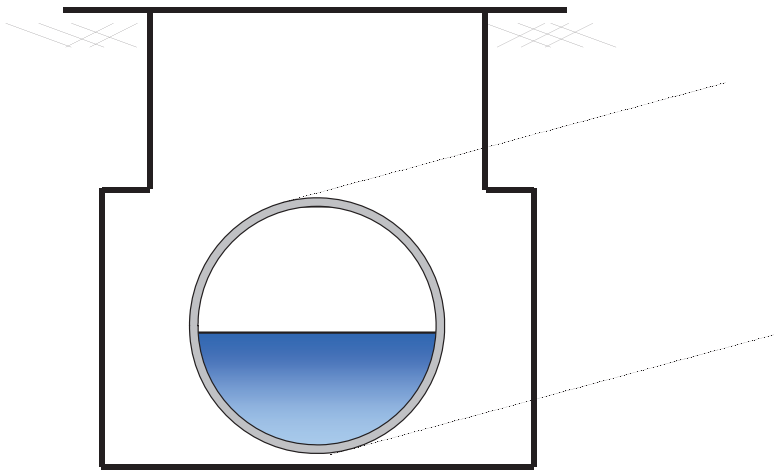
0.677 *mgd*

SITE 4

Site Capacity and Surcharge Summary

Realtime Flow Levels with Rainfall Data over Monitoring Period





Pipe Diameter: 27 *inches*

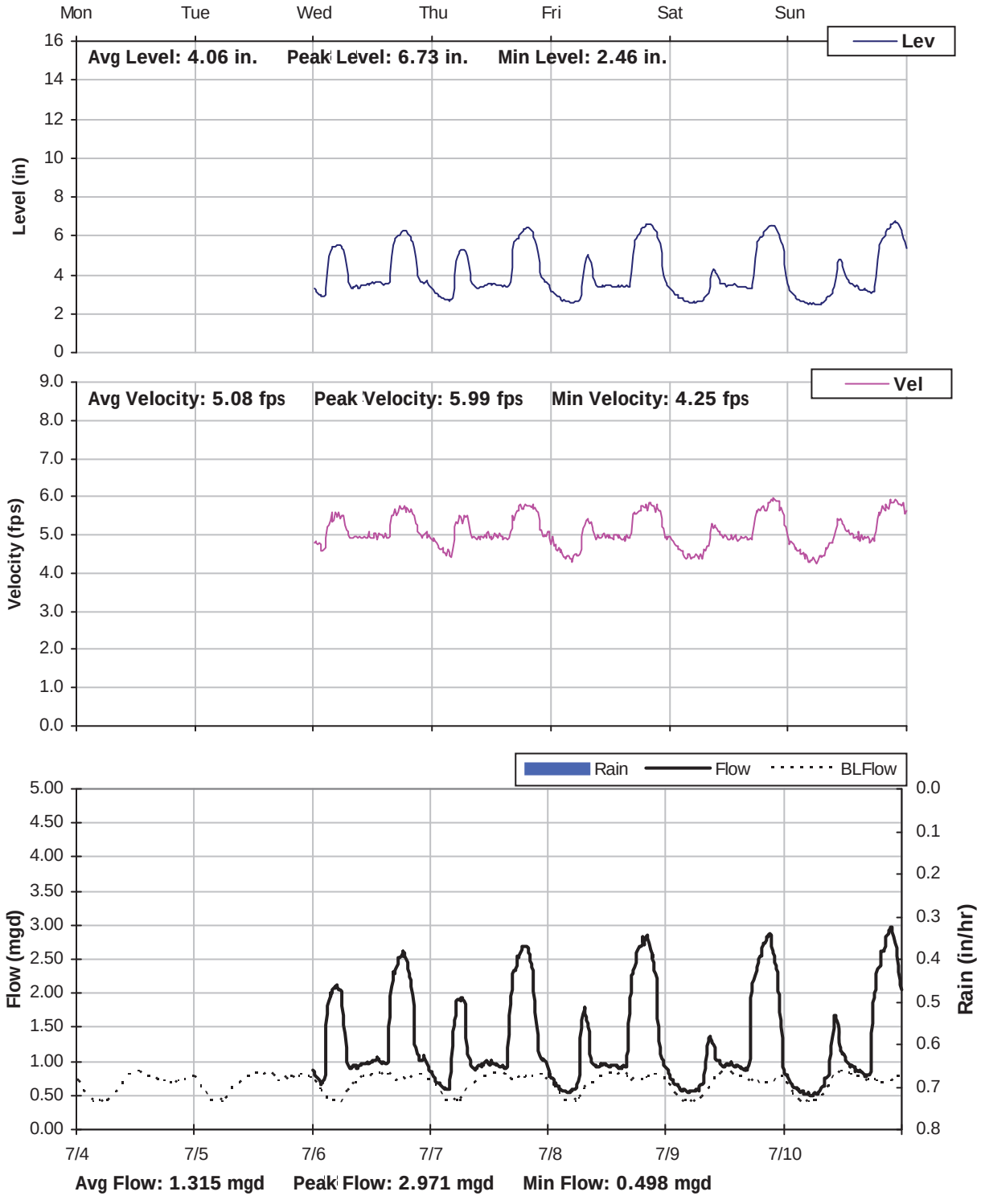
Peak Measured Level: 13.1 *inches*

Peak d/D Ratio: 0.49

SITE 4

Weekly Level, Velocity and Flow Hydrographs

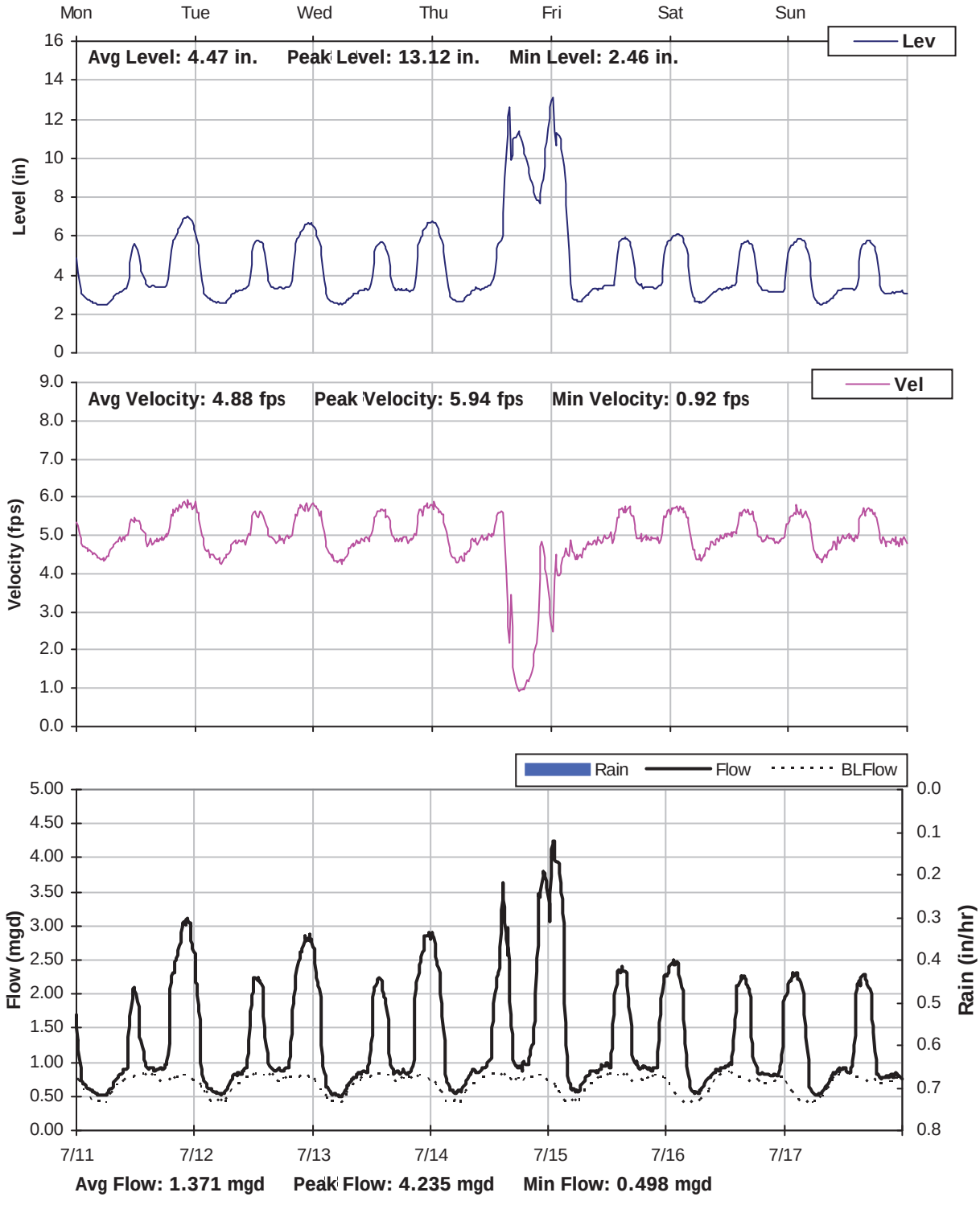
7/4/2011 to 7/11/2011



SITE 4

Weekly Level, Velocity and Flow Hydrographs

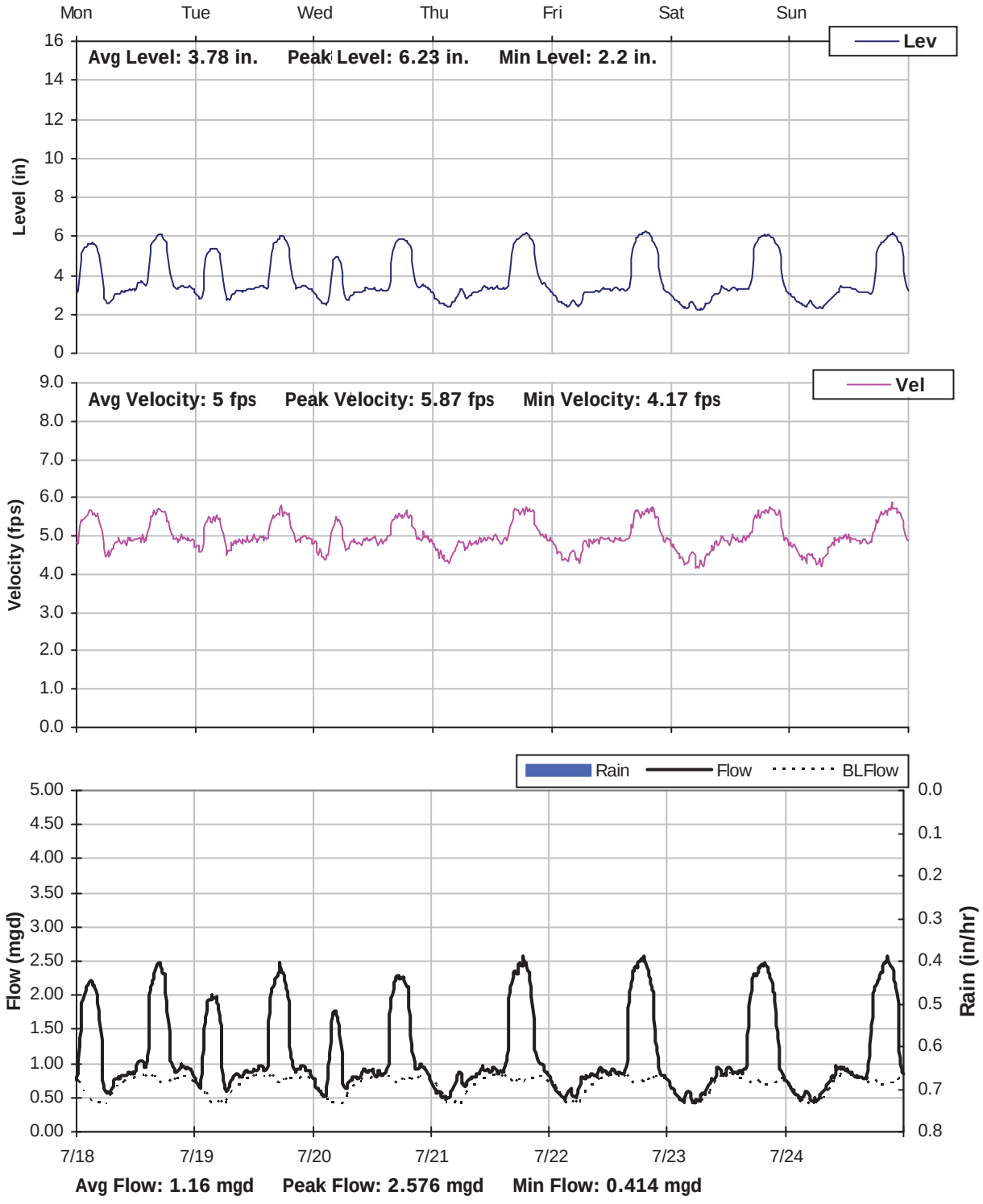
7/11/2011 to 7/18/2011



SITE 4

Weekly Level, Velocity and Flow Hydrographs

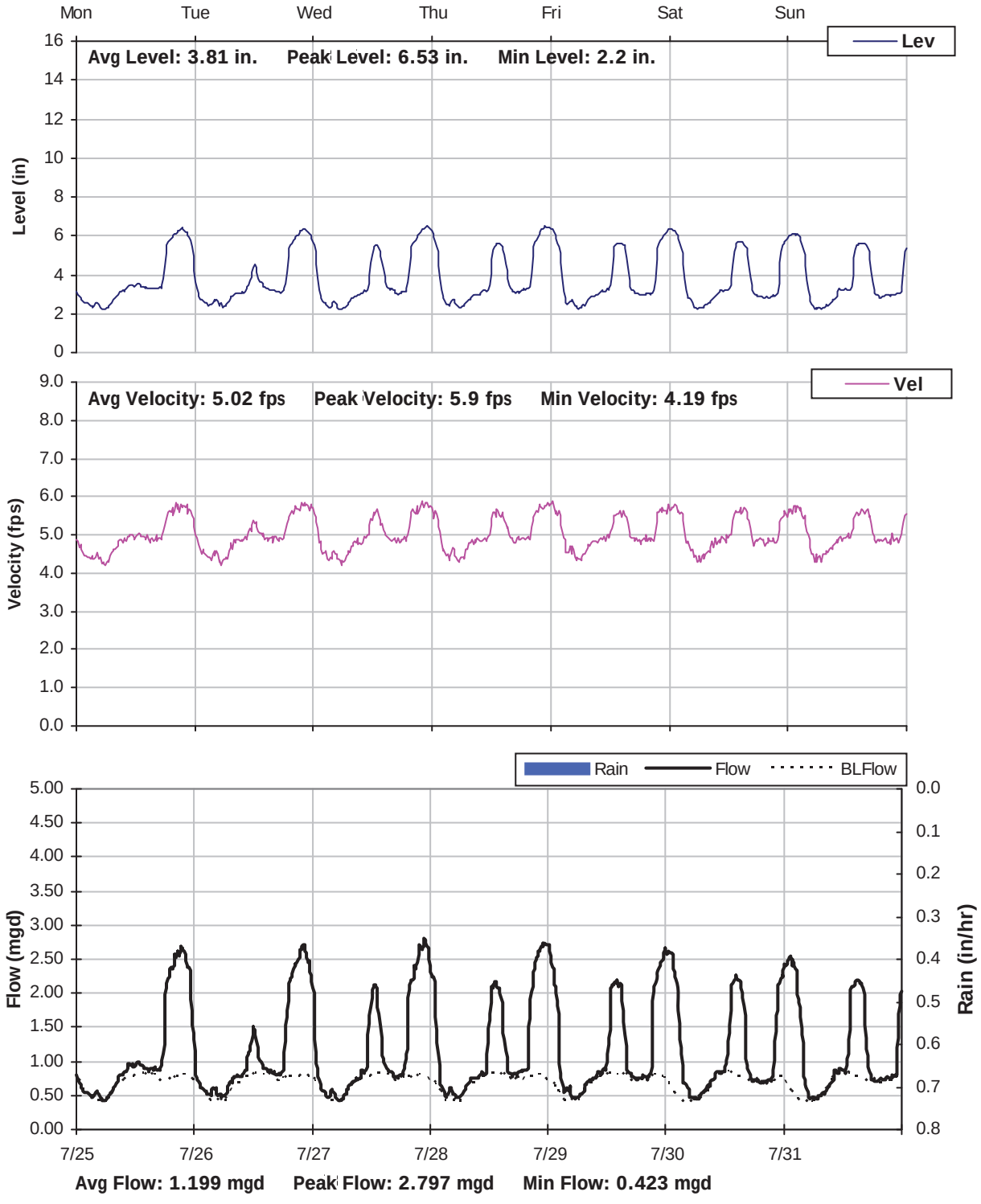
7/18/2011 to 7/25/2011



SITE 4

Weekly Level, Velocity and Flow Hydrographs

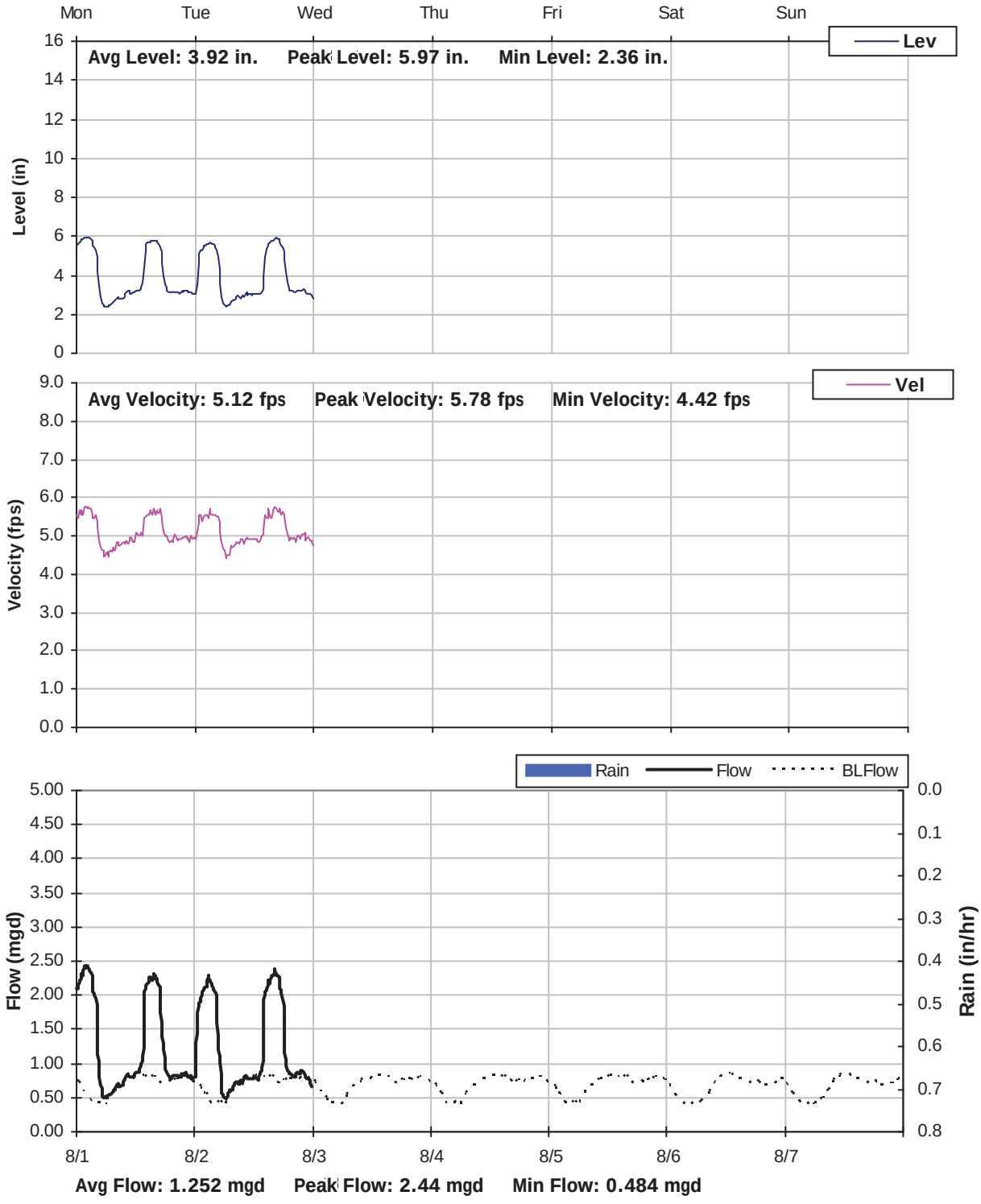
7/25/2011 to 8/1/2011



SITE 4

Weekly Level, Velocity and Flow Hydrographs

8/1/2011 to 8/8/2011



Veolia City of Richmond

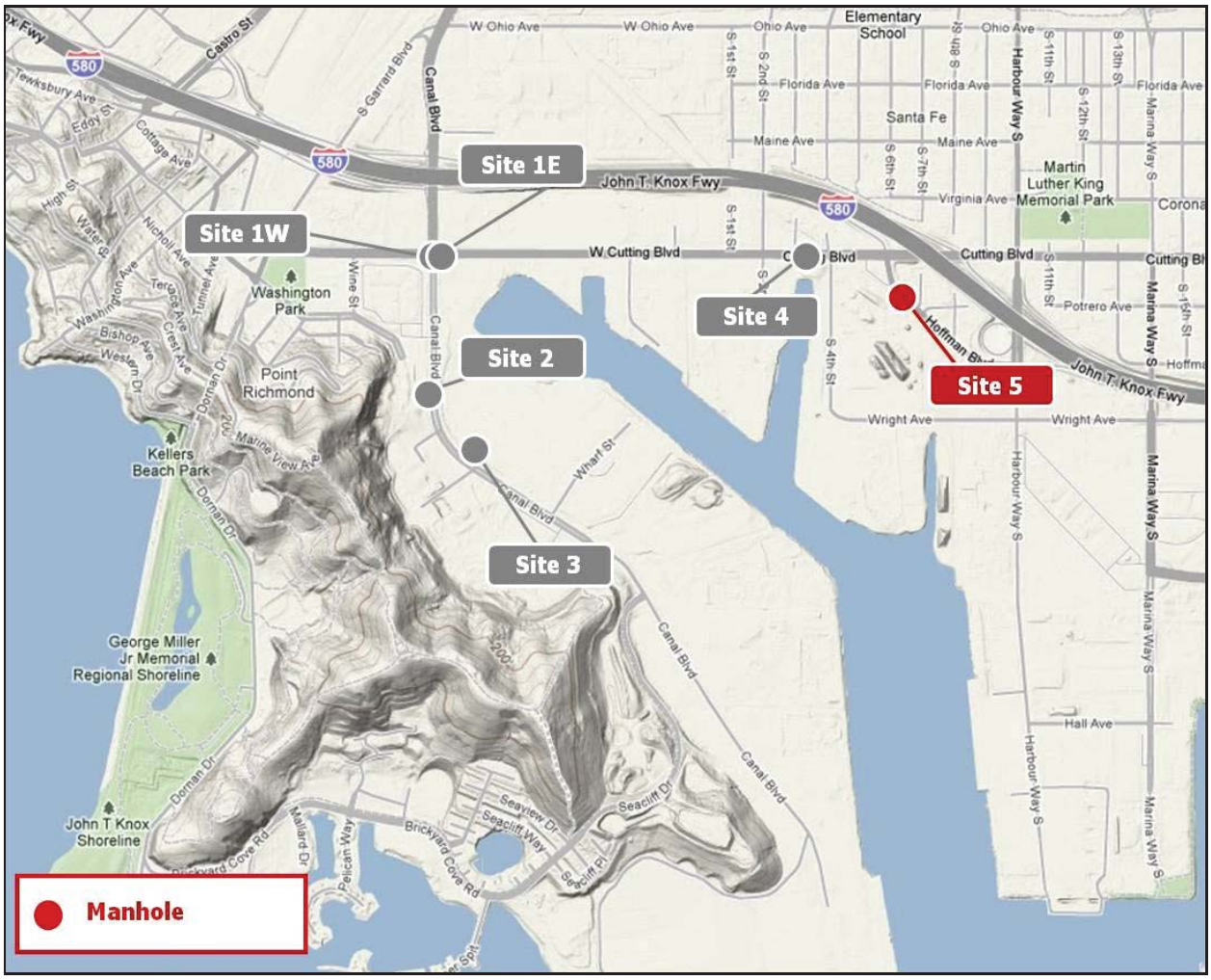
Sanitary Sewer Flow Monitoring

Year 2011

Monitoring Site: 5

Location: MH ID 100167.01: Intersection of Hoffman Boulevard and S. 7th Street

Data Summary Report

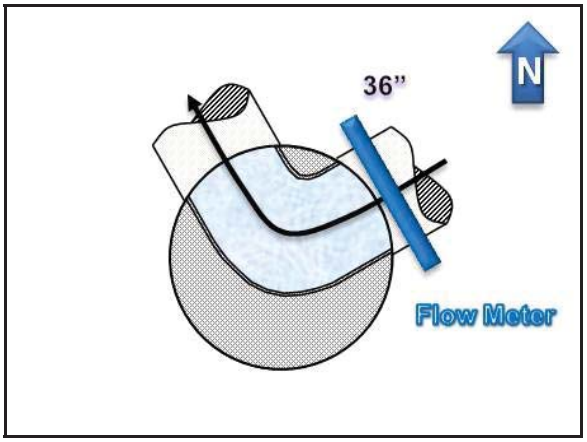


SITE 5
Site Information Report

Location:	MH ID 100167.01: Intersection of Hoffman Boulevard and S. 7th Street
Coordinates:	122.3632° W, 37.9240° N
Elevation:	8 feet
Diameter:	36 inches
Baseline Flow:	1.516 mgd
Peak Measured Flow:	5.757 mgd

Satellite map

Sewer map



Flow sketch

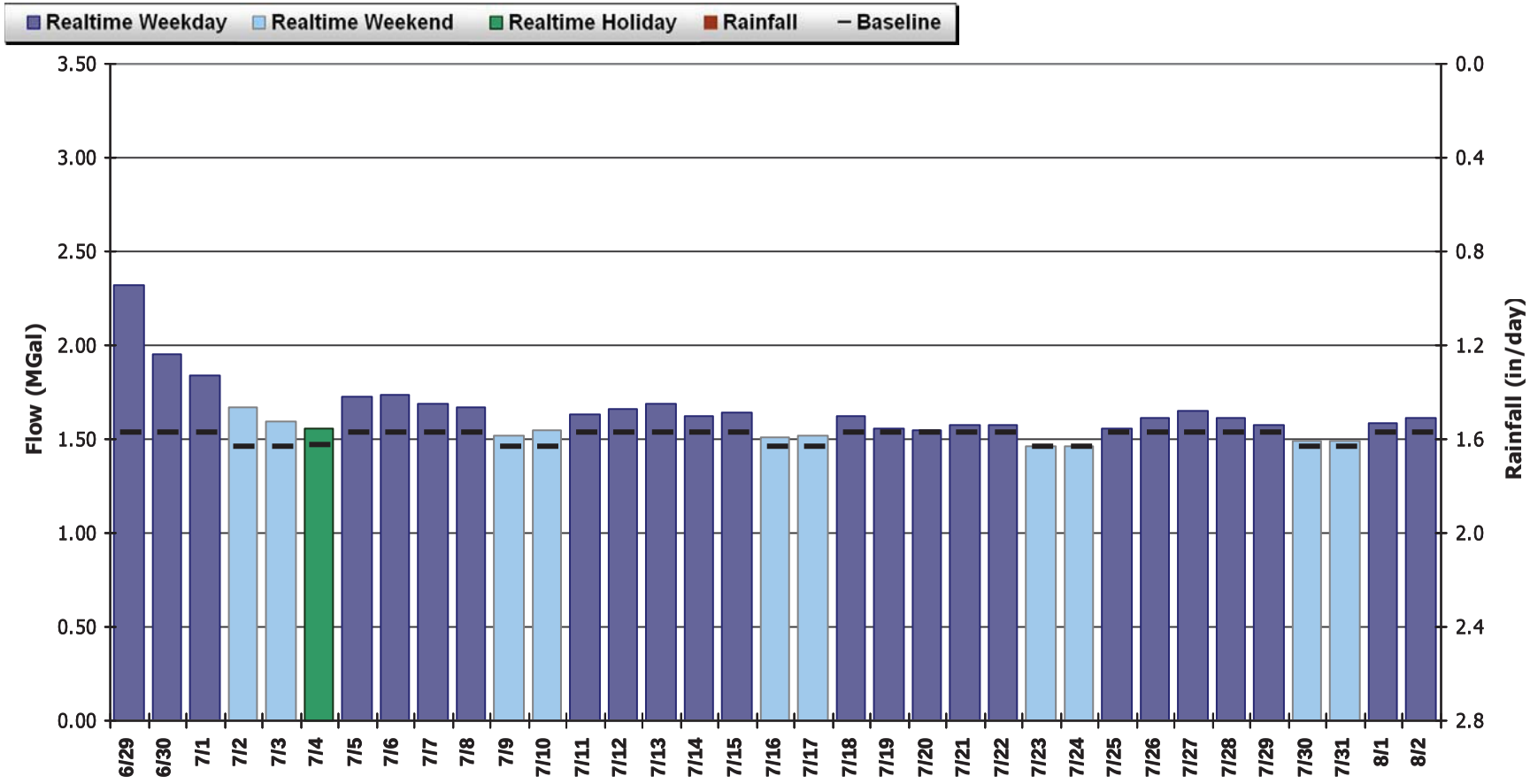
Street view

Plan view

SITE 5

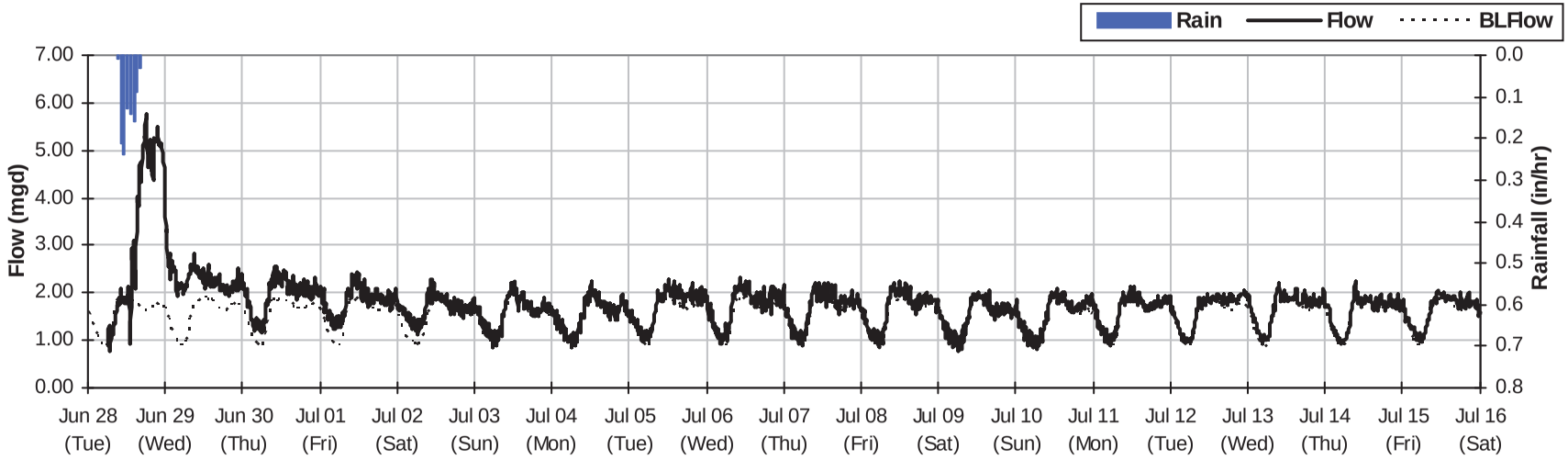
Period Flow Summary: Daily Flow Totals

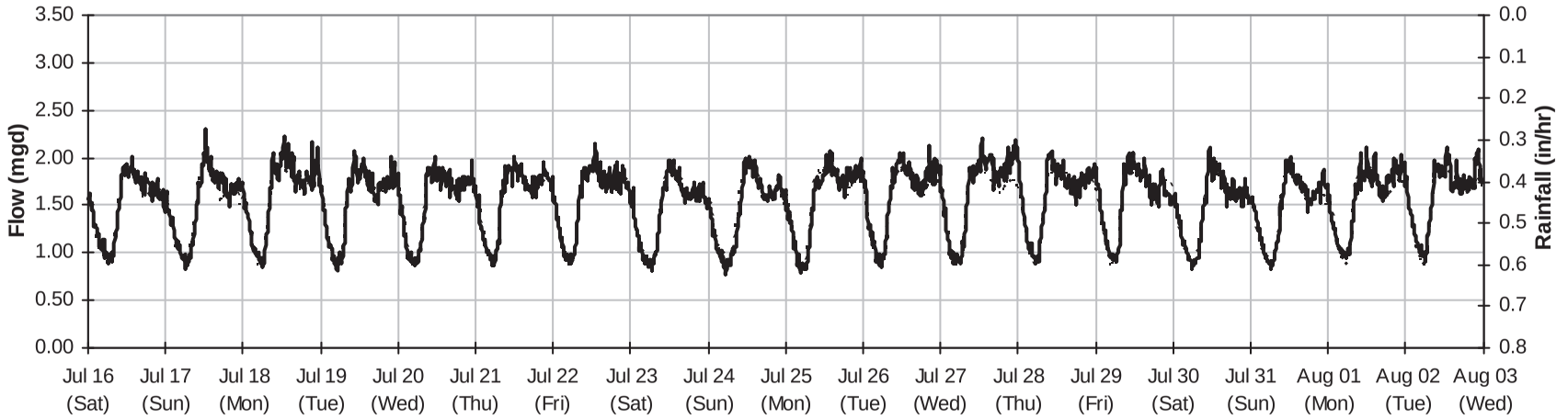
Avg Daily Flow: 1.631 MGal **Peak Daily Flow: 2.316 MGal** **Min Daily Flow: 1.458 MGal**



SITE 5

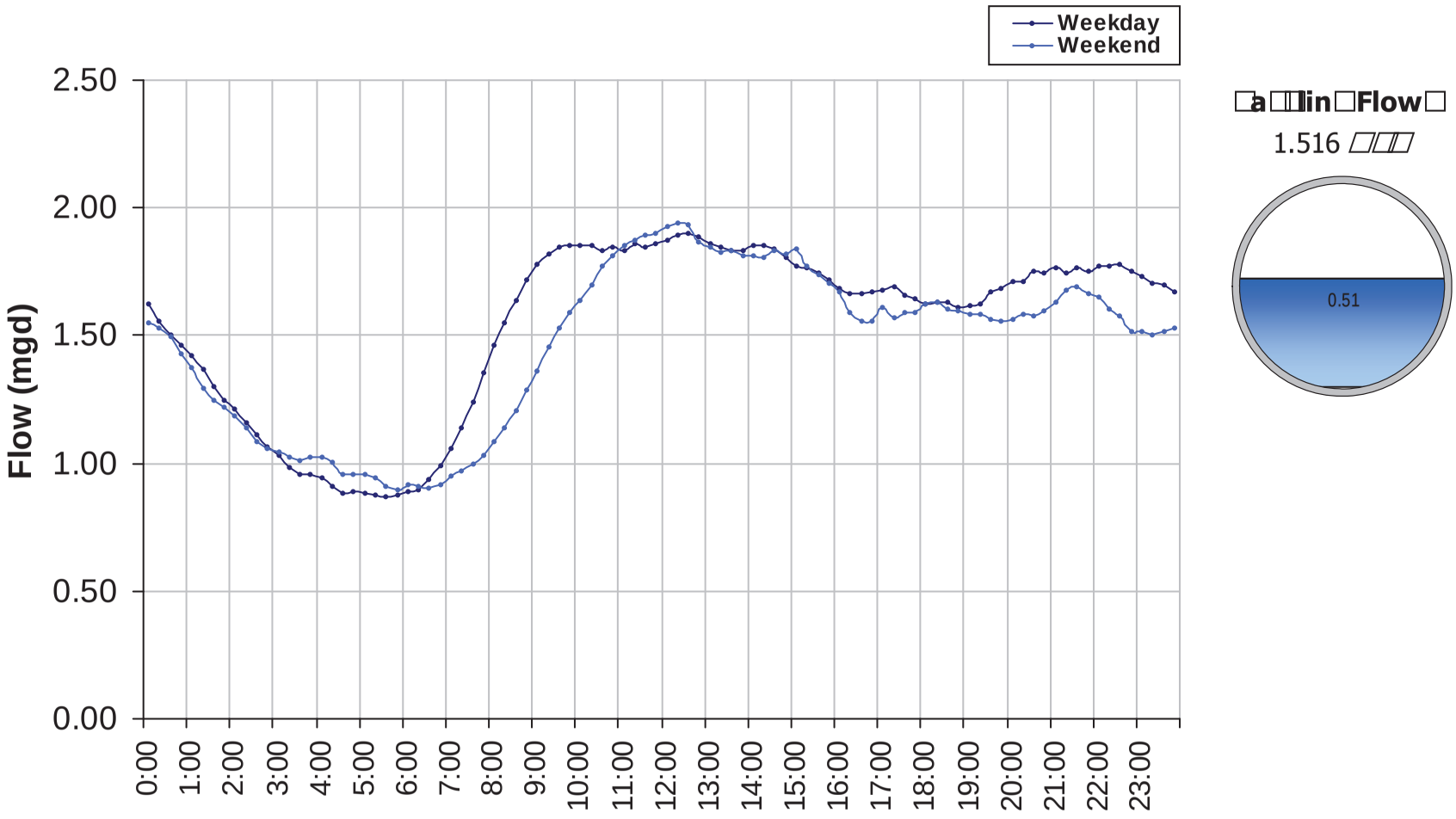
Period Flow Summary: 15-minute data





SITE 5

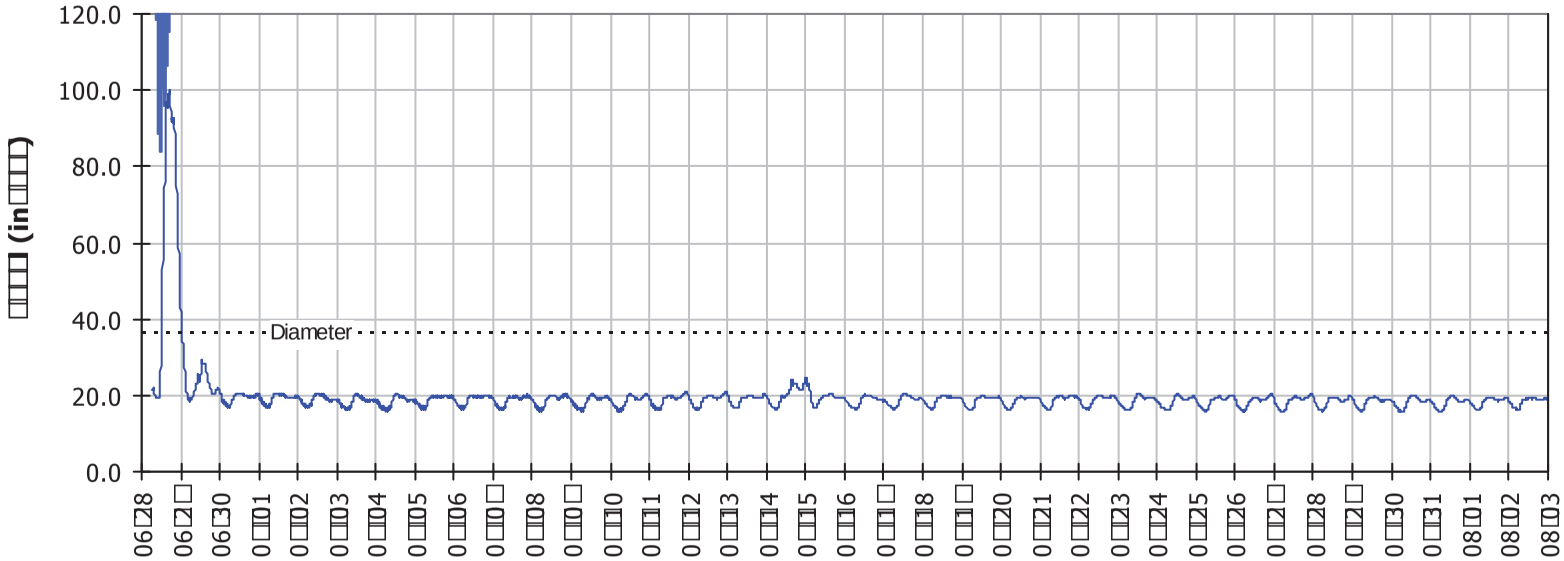
Baseline Flow Hydrographs

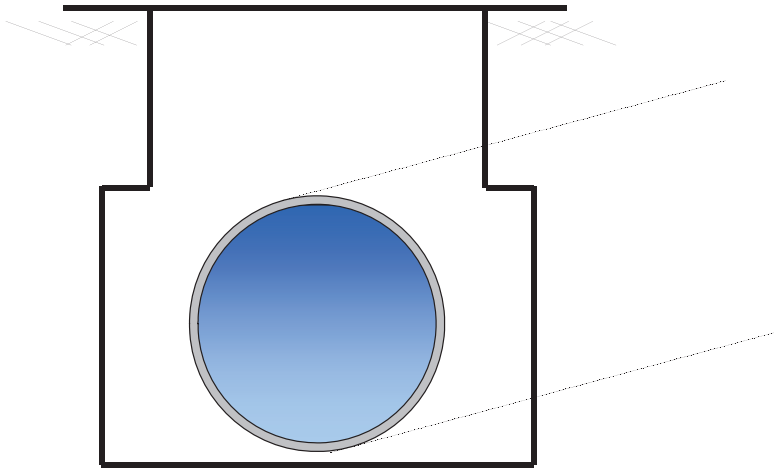


SITE 5

Site Capacity and Surcharge Summary

R□al□i□ □Flow □□□□□l□wi□□Rainfall □a□a o□□□Moni□o□in□ □□□iod





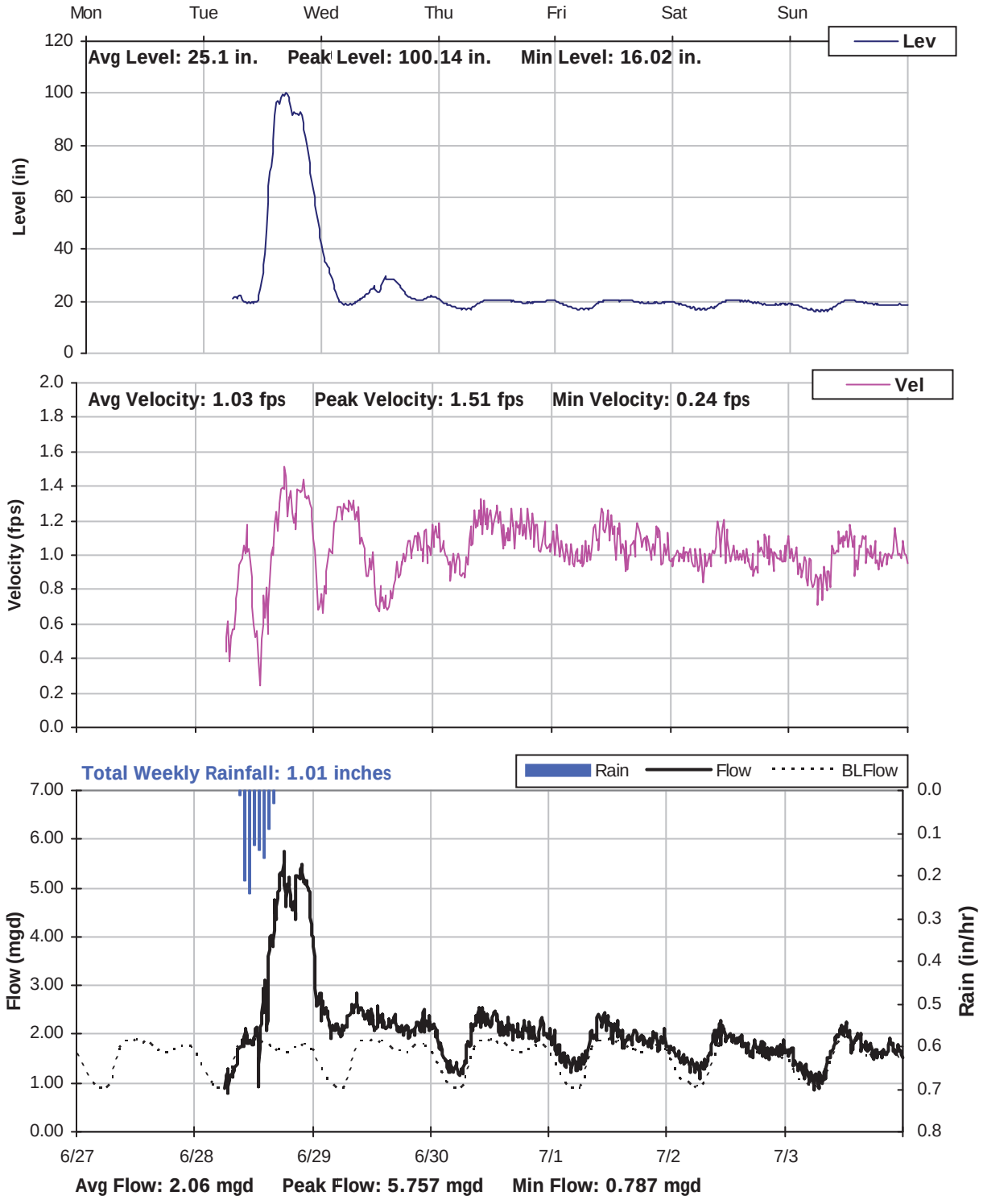
□i□□□ia□ □□□□□ 36

□□a□M□a□□□□d □□□□□l□ 100

□□a□d/□Ra□io□ 2.□8

□□□□a□□□d □□□in□□□□o□□□□down

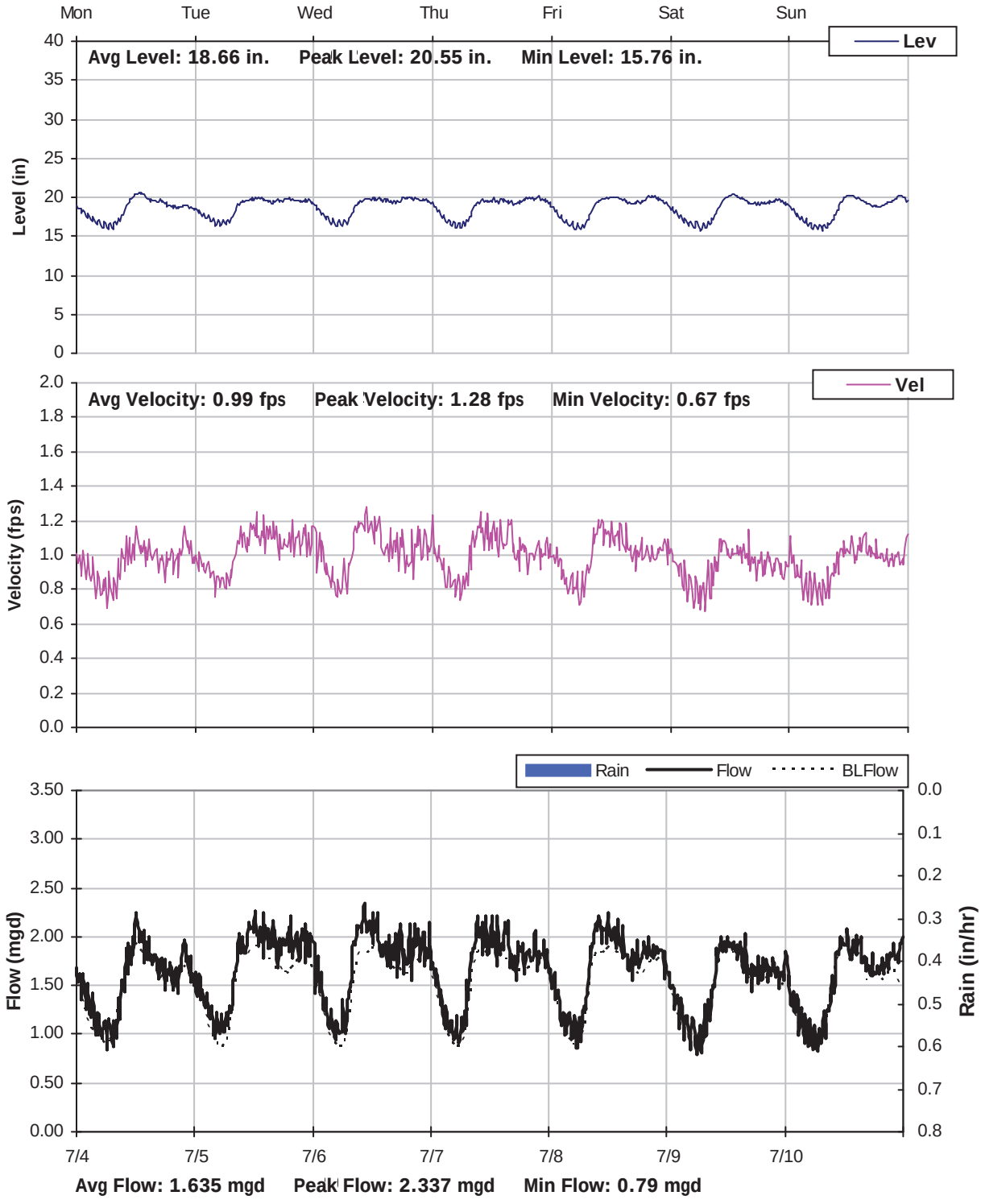
SITE 5
Weekly Level, Velocity and Flow Hydrographs
6/27/2011 to 7/4/2011



SITE 5

Weekly Level, Velocity and Flow Hydrographs

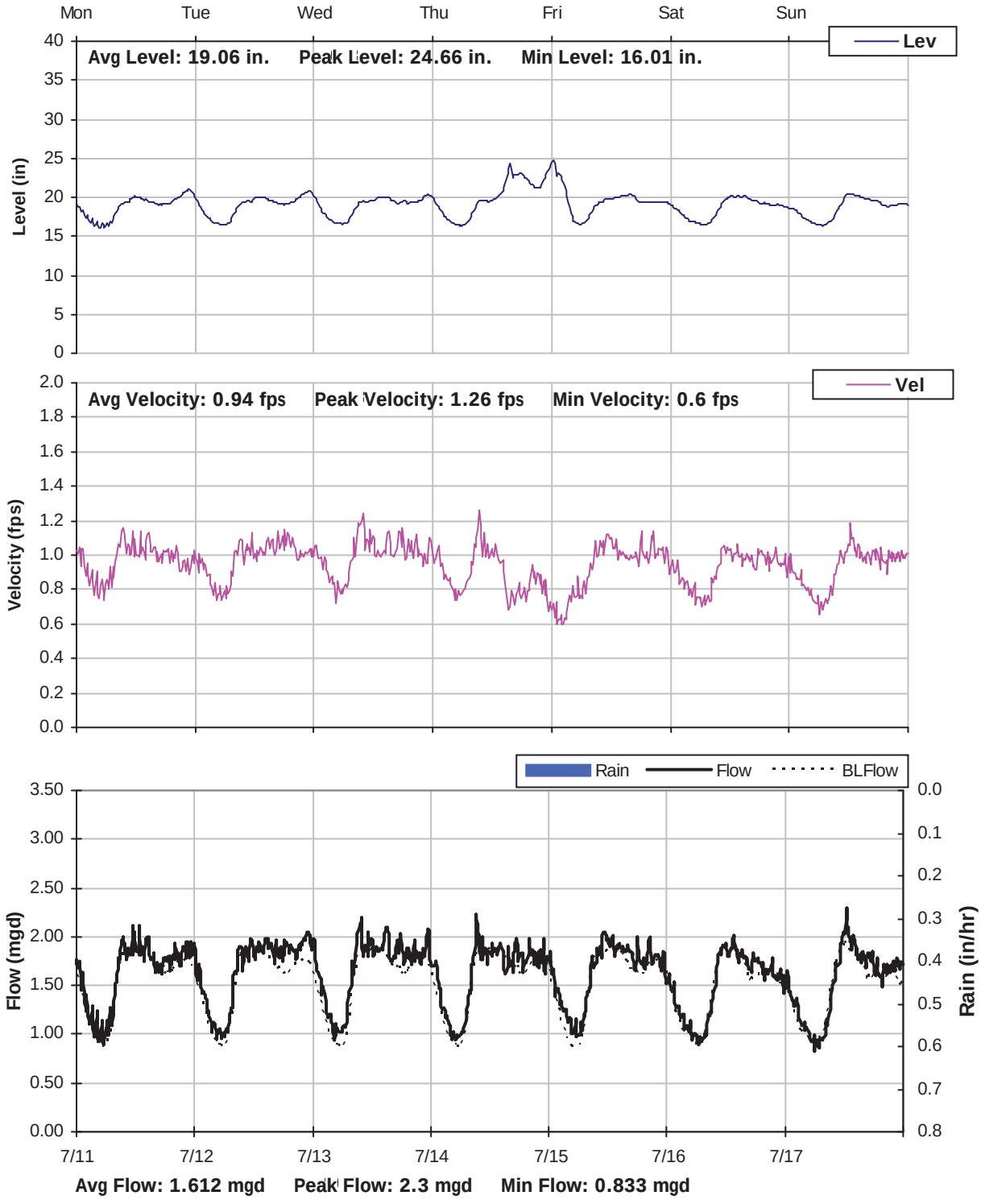
7/4/2011 to 7/11/2011



SITE 5

Weekly Level, Velocity and Flow Hydrographs

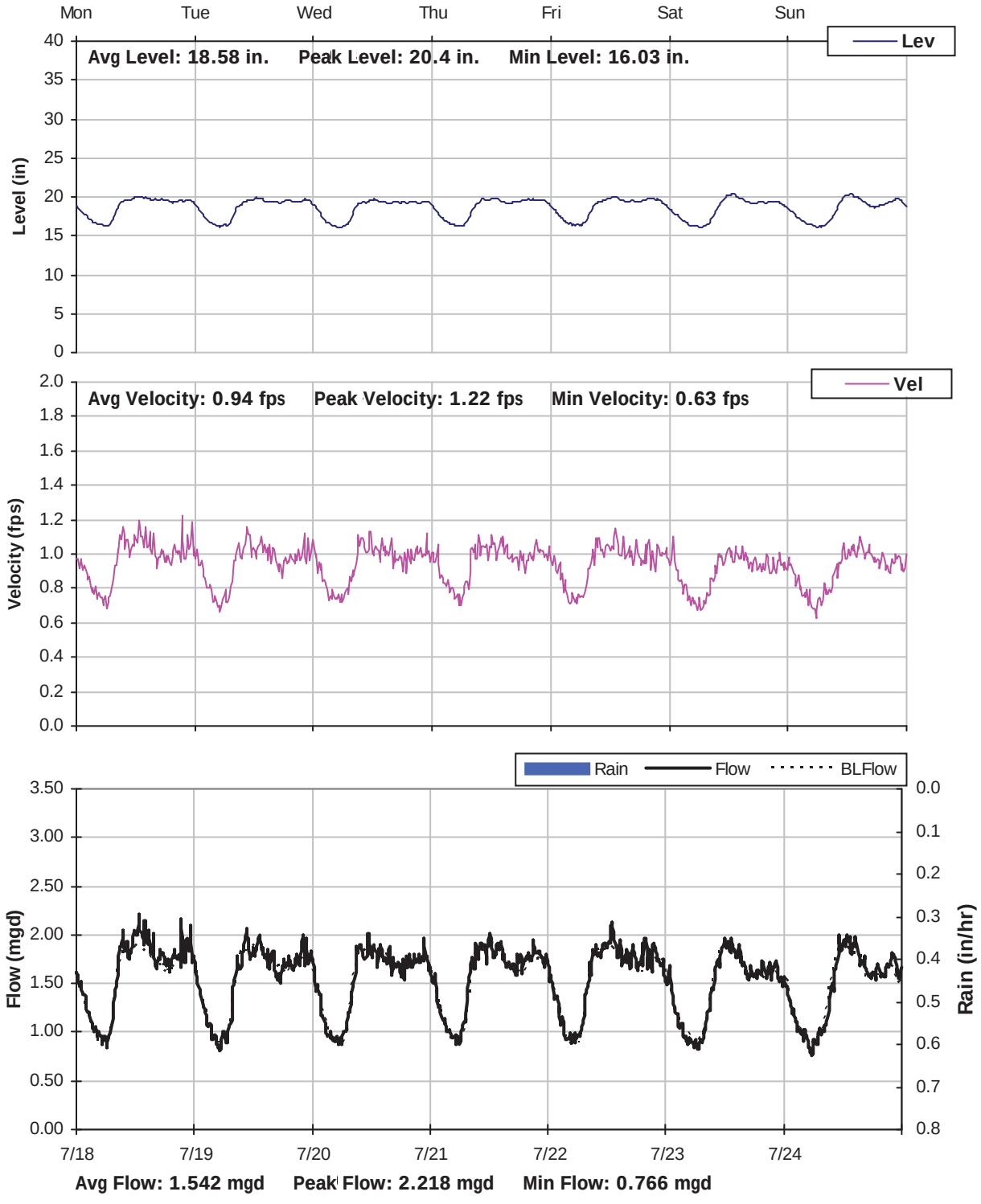
7/11/2011 to 7/18/2011



SITE 5

Weekly Level, Velocity and Flow Hydrographs

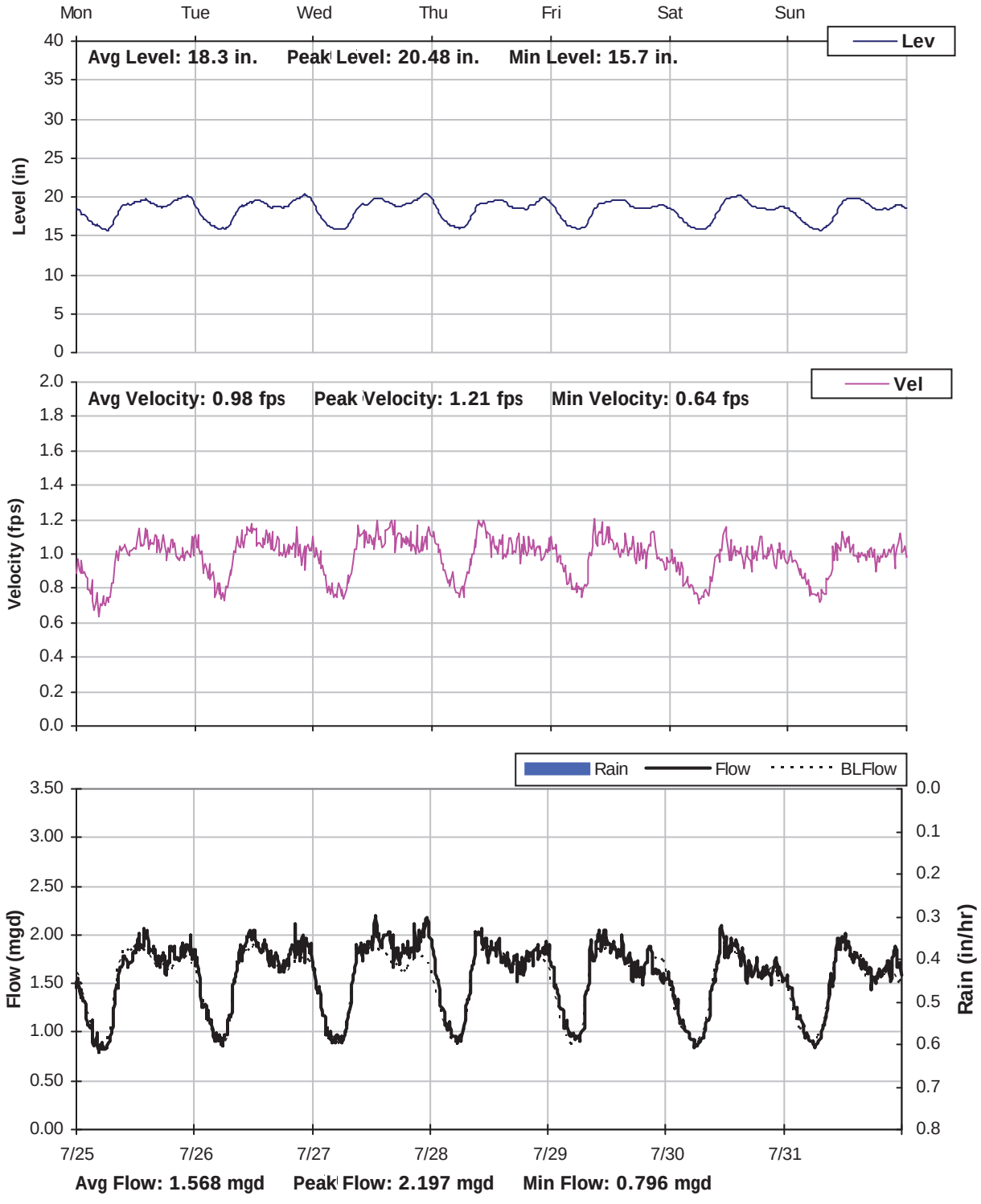
7/18/2011 to 7/25/2011



SITE 5

Weekly Level, Velocity and Flow Hydrographs

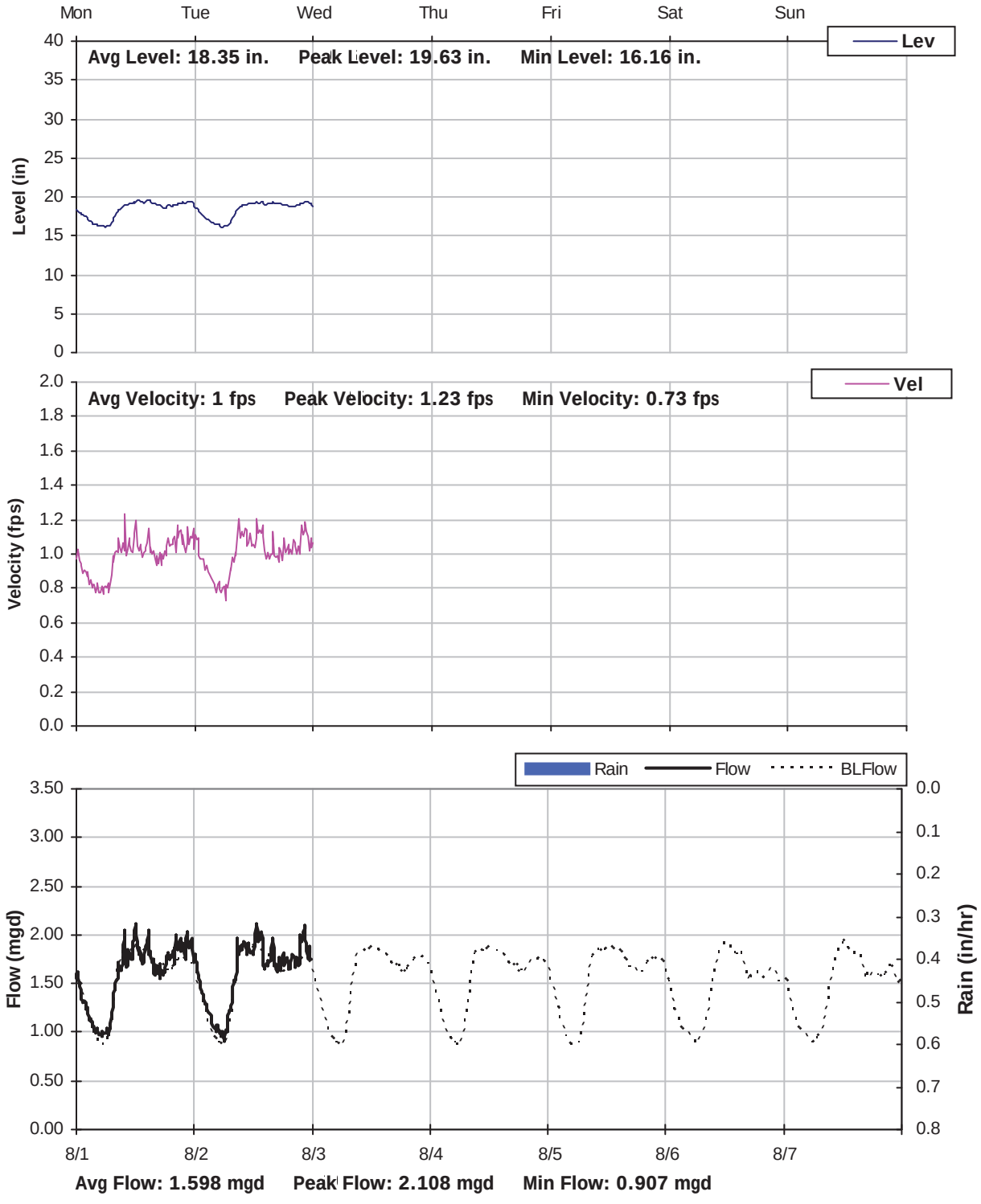
7/25/2011 to 8/1/2011

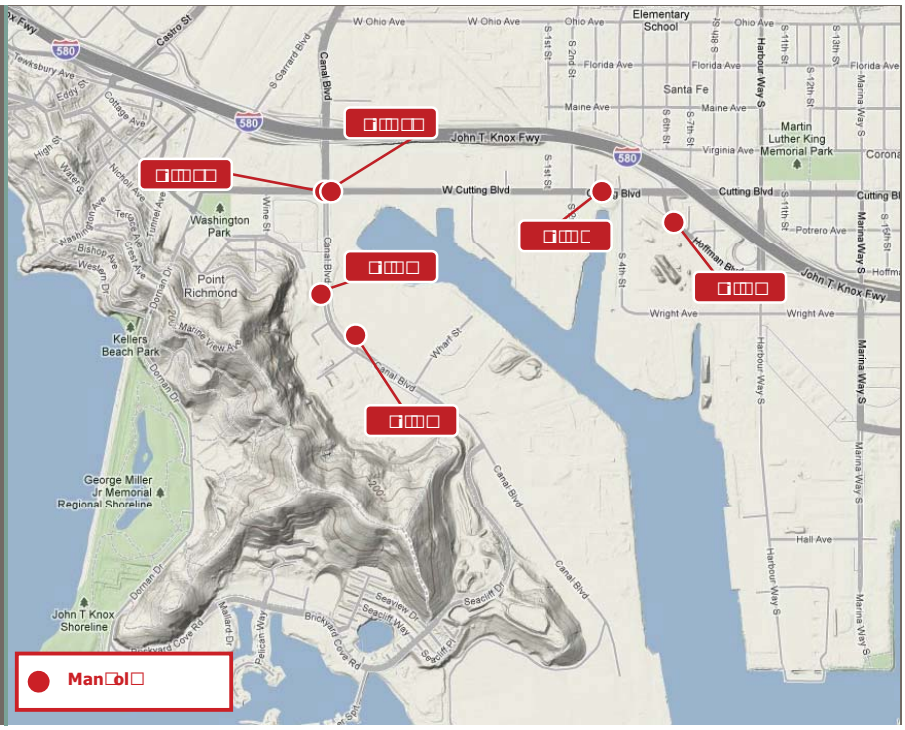


SITE 5

Weekly Level, Velocity and Flow Hydrographs

8/1/2011 to 8/8/2011





V&A

Oakland
155 Grand Avenue, Suite 700
Oakland, CA 94612
510.903.6600 **Tel**
510.903.6601 **Fax**

San Diego
8291 Aero Place, Suite 110
San Diego, CA 92123
858.576.0226 **Tel**
858.576.0004 **Fax**

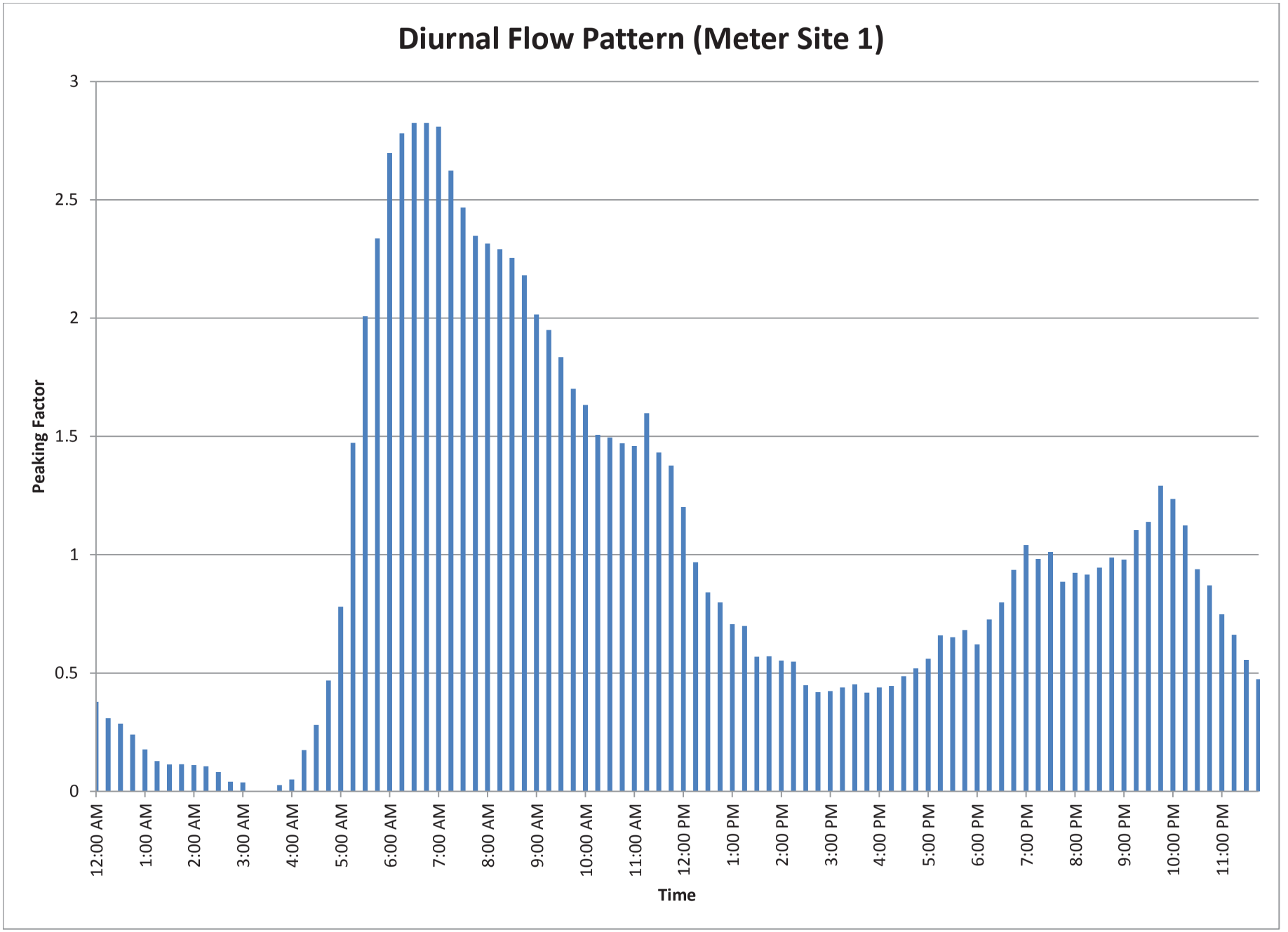
Seattle
14900 Interurban Avenue, Suite 268
Seattle, WA 96818
206.674.4560 **Tel**
206.674.4561 **Fax**

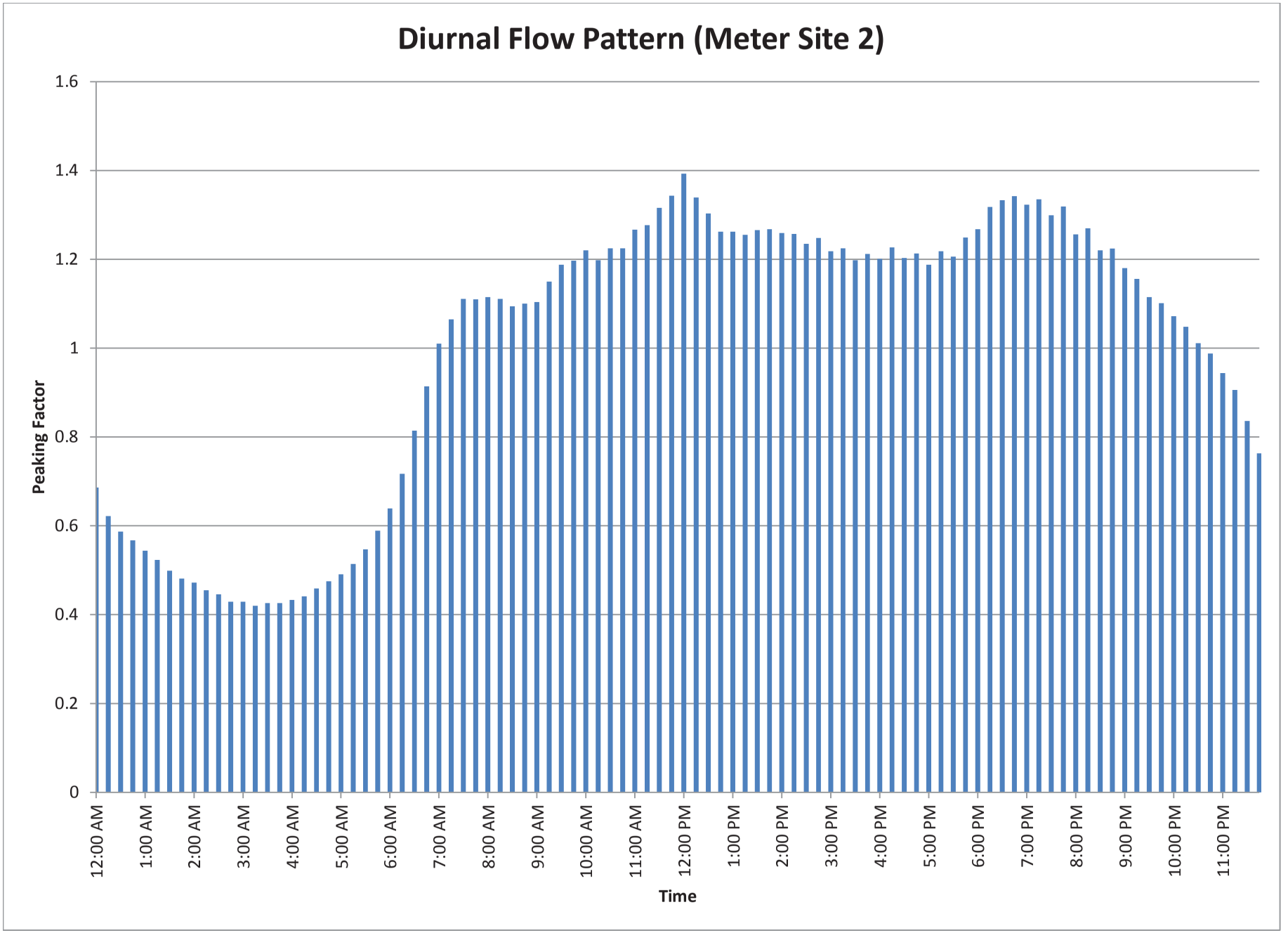
Houston
8220 Jones Road, Suite 500
Houston, TX 77065
713.840.6490 **Tel**
713.840.6491 **Fax**

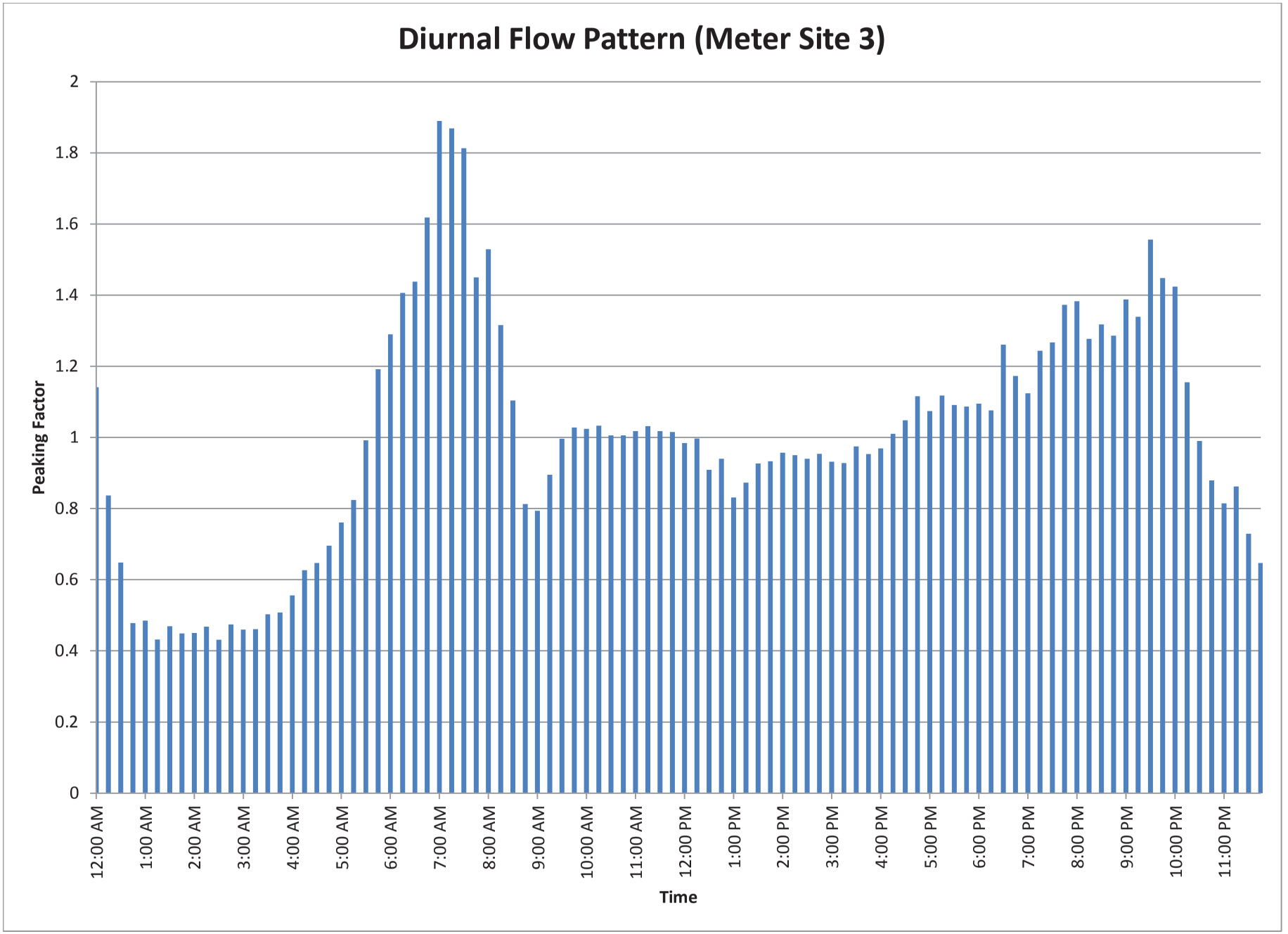
vaengineering.com

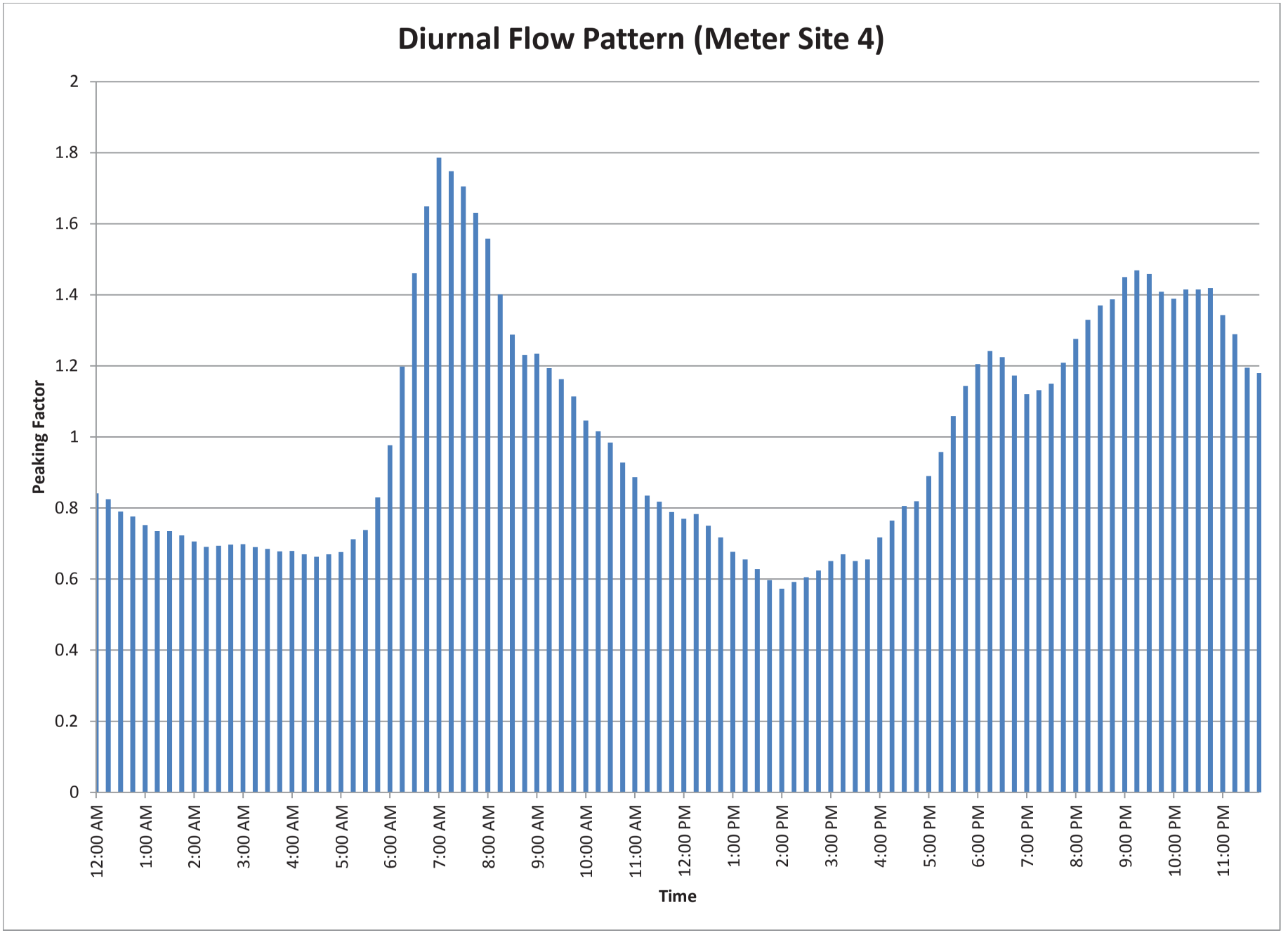
APPENDIX C

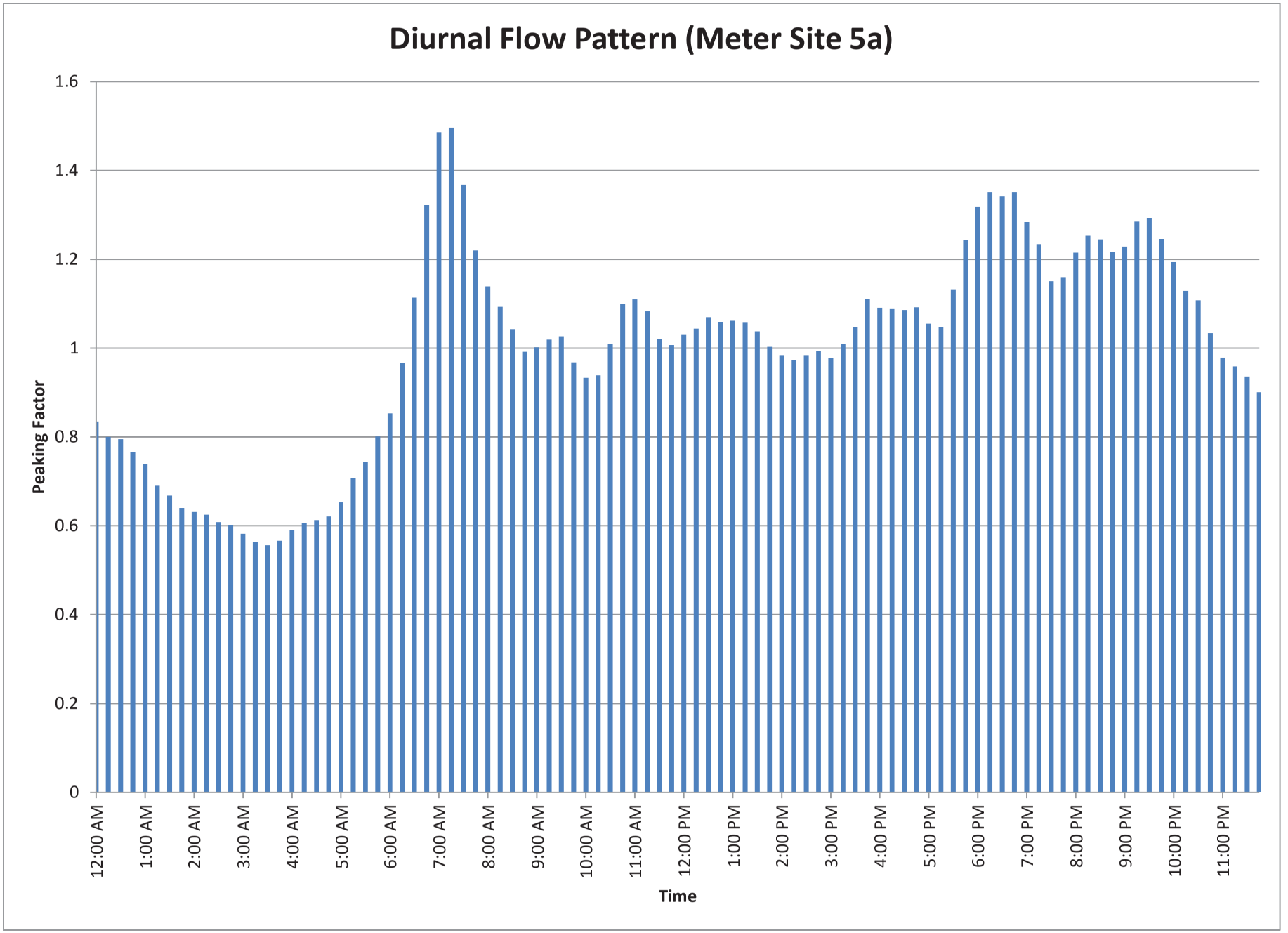
Dry Weather Flow Diurnal Curves

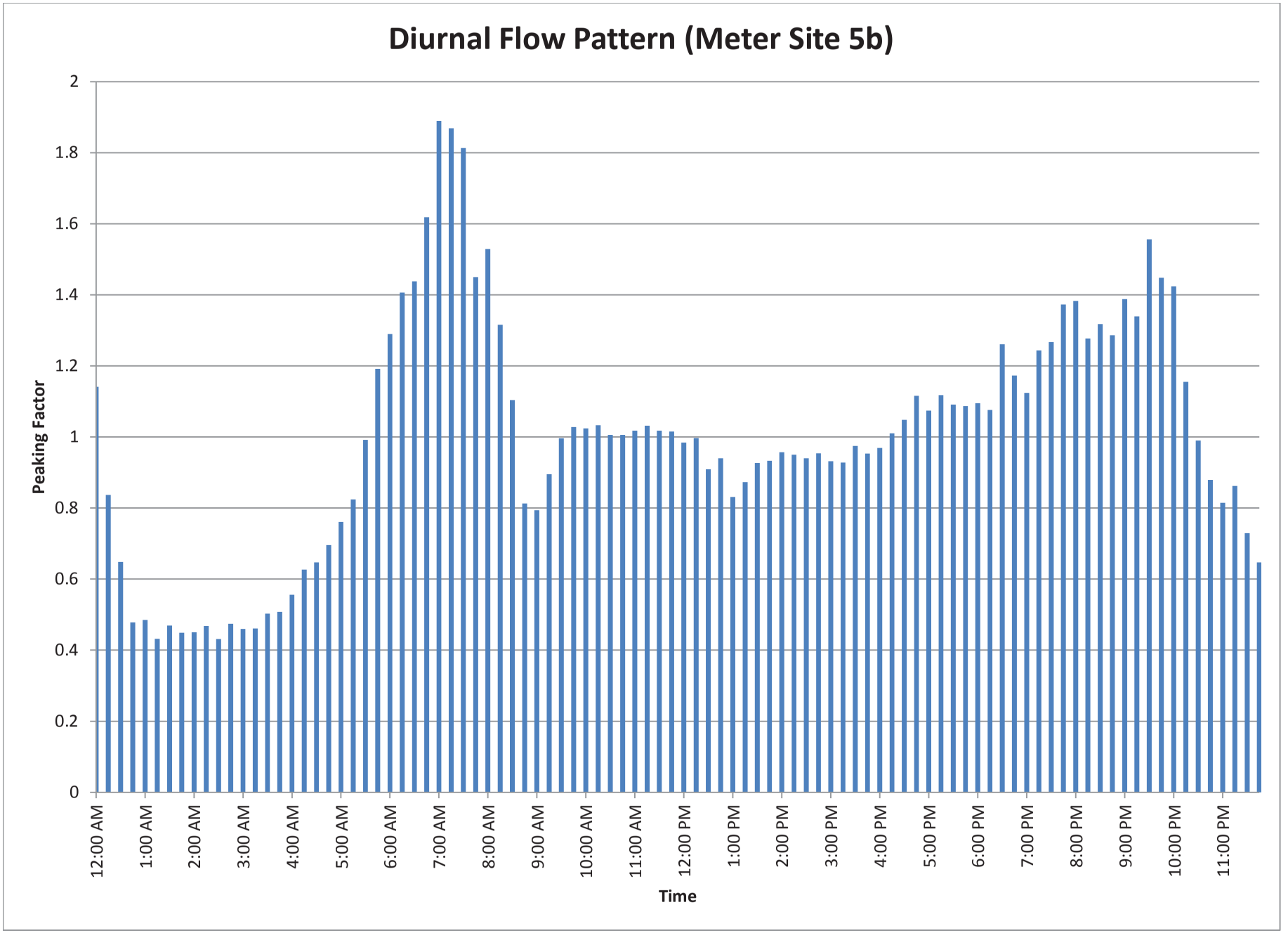

Diurnal Flow Pattern (Meter Site 1)
Peaking Factor
3
2.5
2
1.5
1
0.5
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

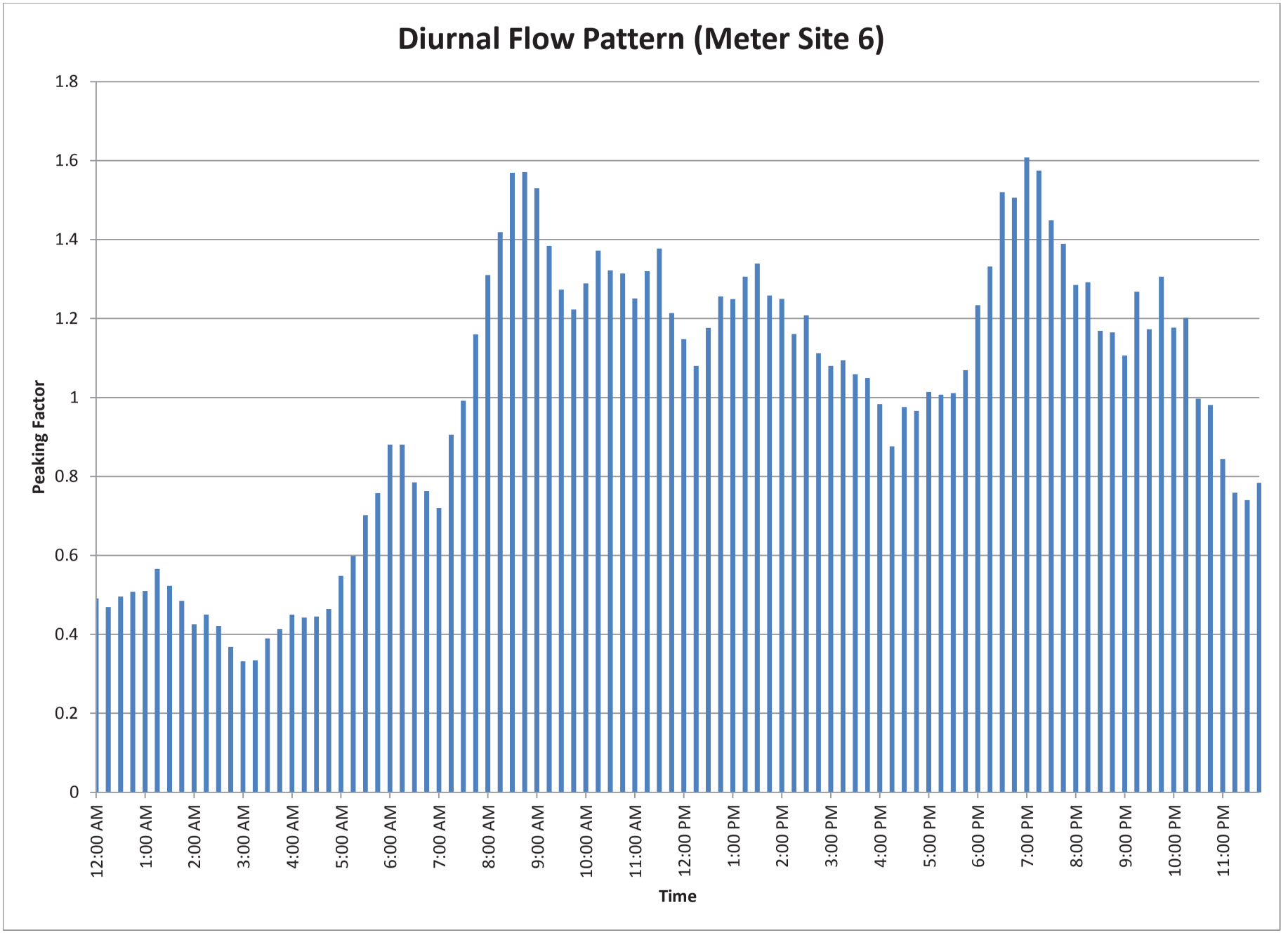

Diurnal Flow Pattern (Meter Site 2)
Peaking Factor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

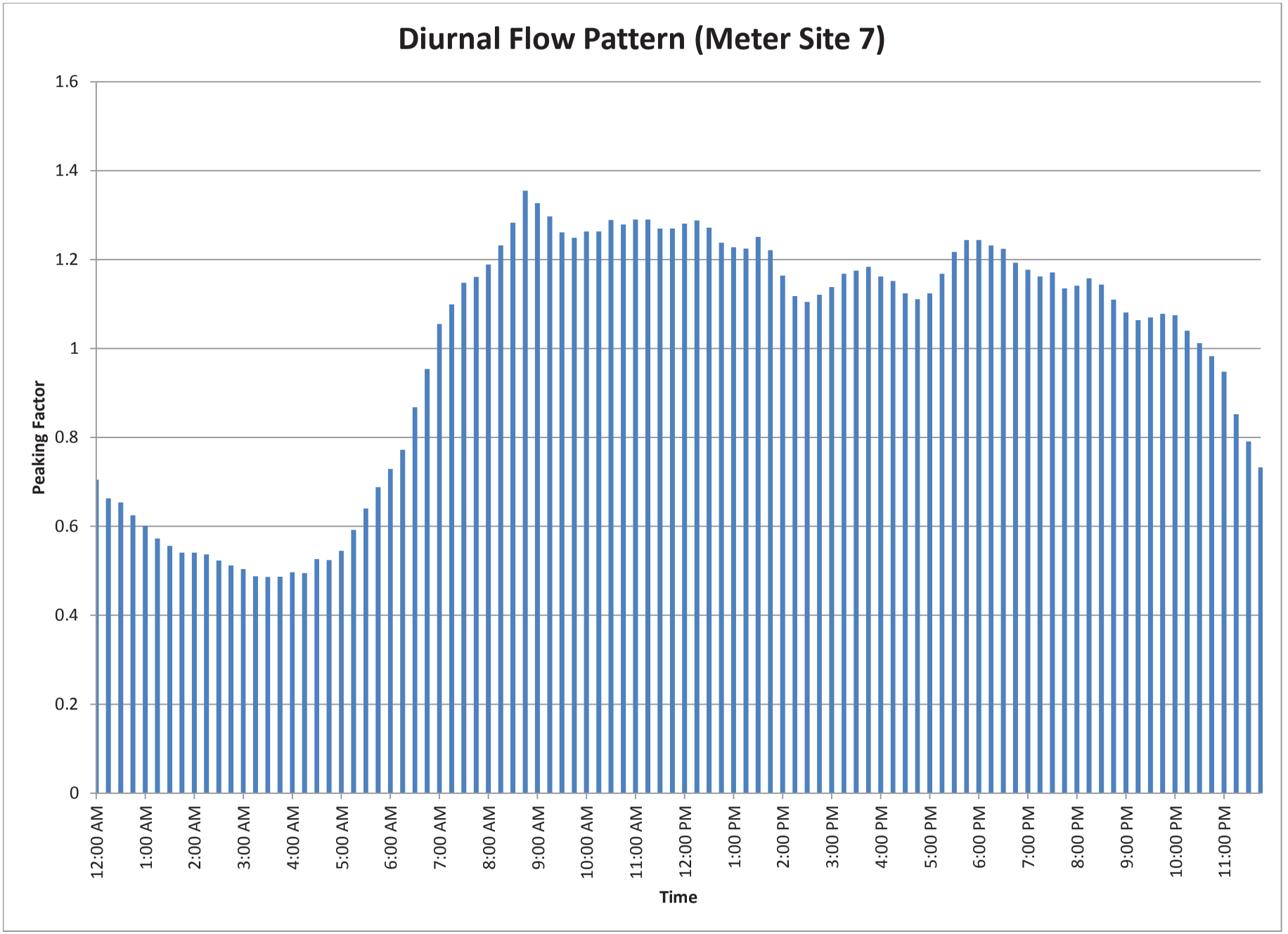

Diurnal Flow Pattern (Meter Site 3)
Peaking Factor
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

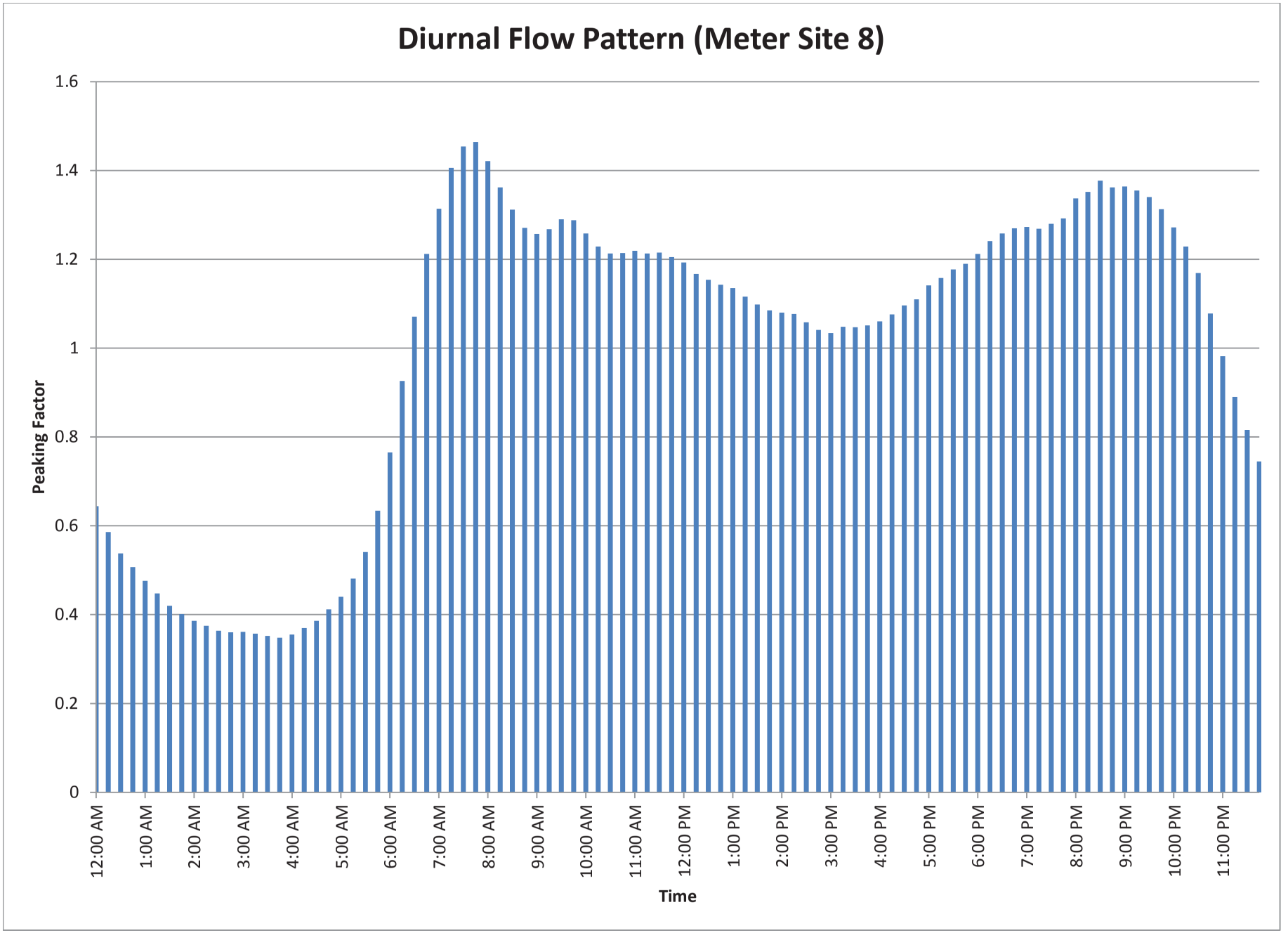

Diurnal Flow Pattern (Meter Site 4)
Peaking Factor
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

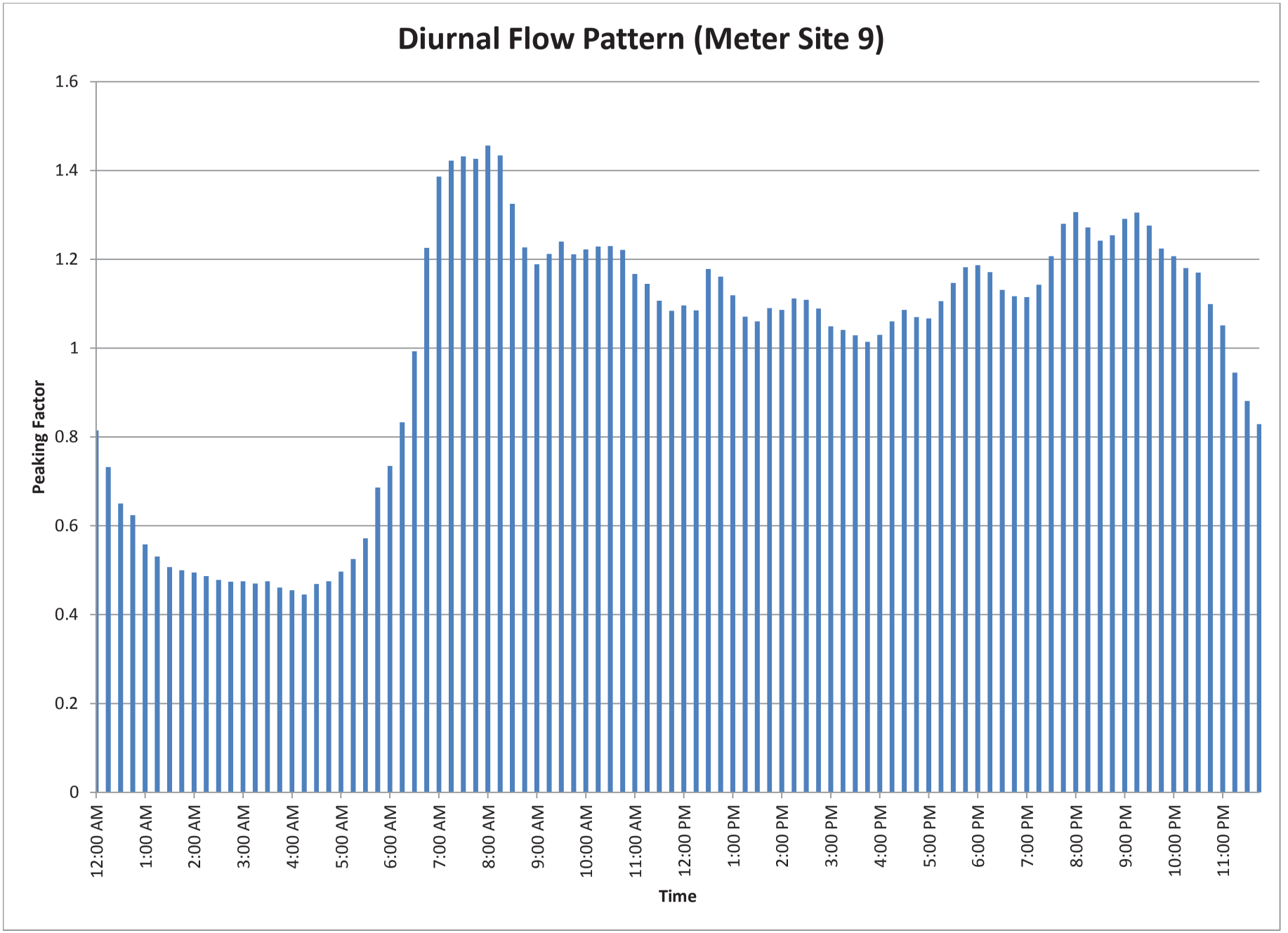

Diurnal Flow Pattern (Meter Site 5a)
Peaking Factor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

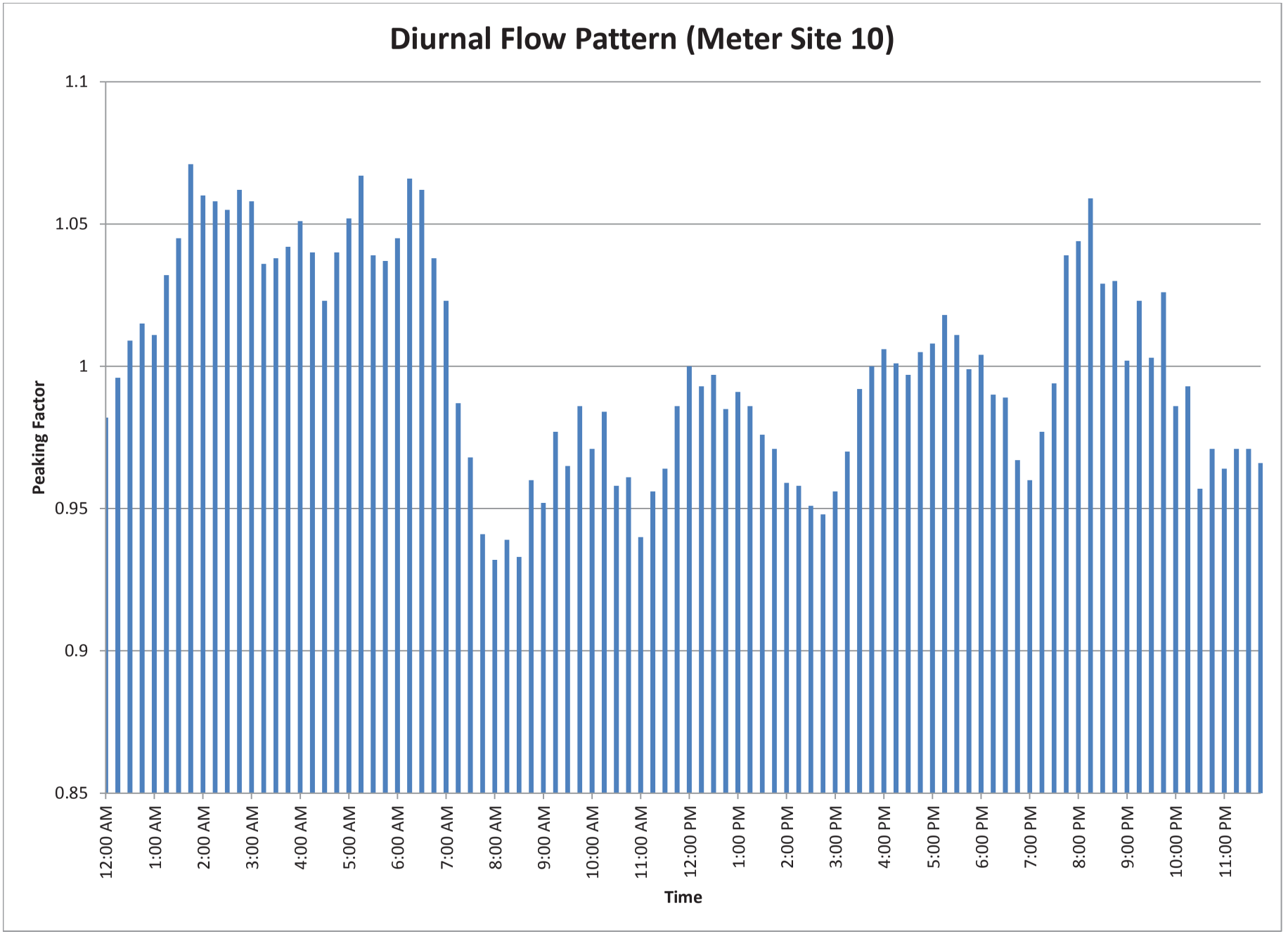

Diurnal Flow Pattern (Meter Site 5b)
Peaking Factor
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

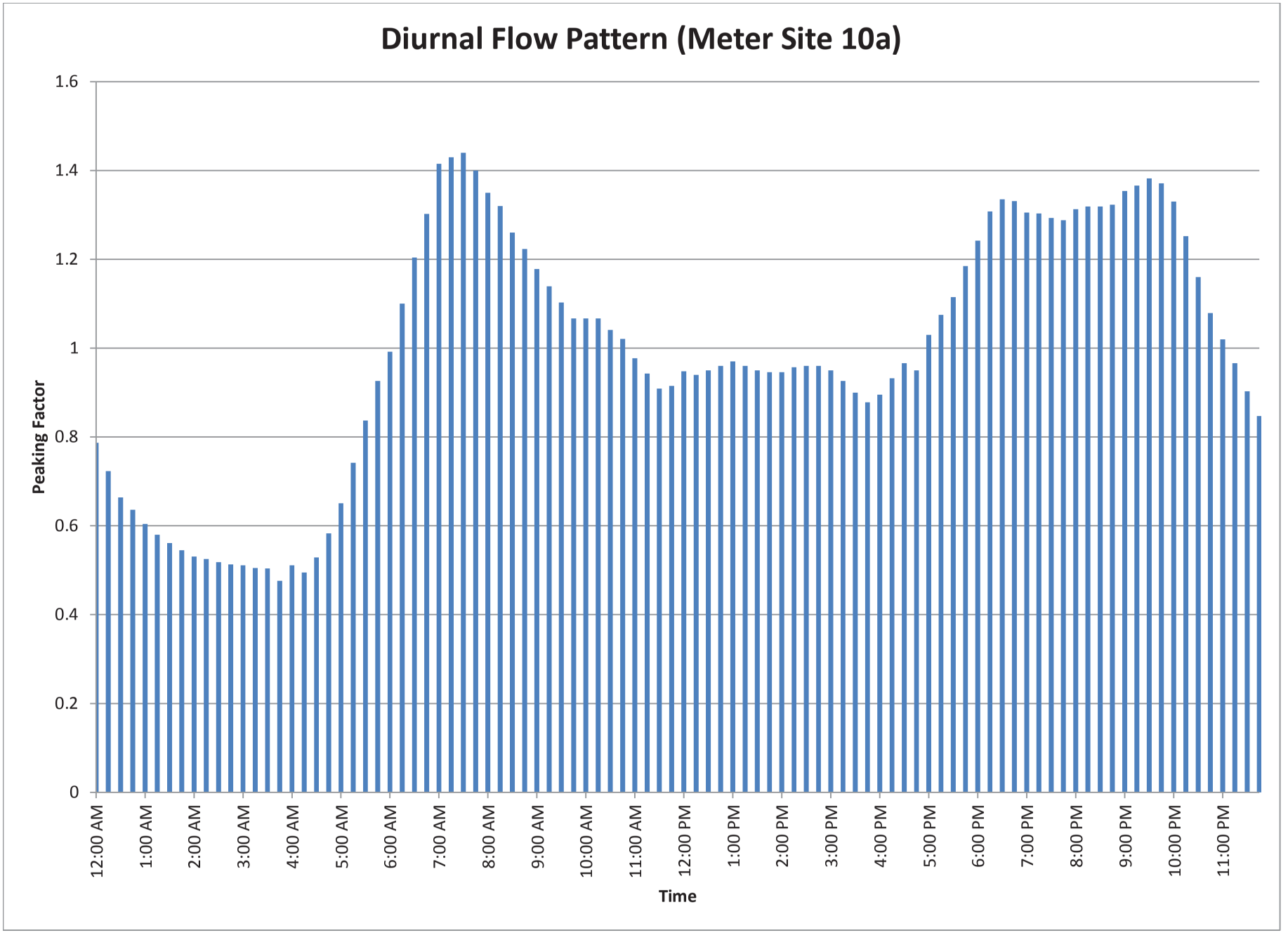

Diurnal Flow Pattern (Meter Site 6)
Peaking Factor
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

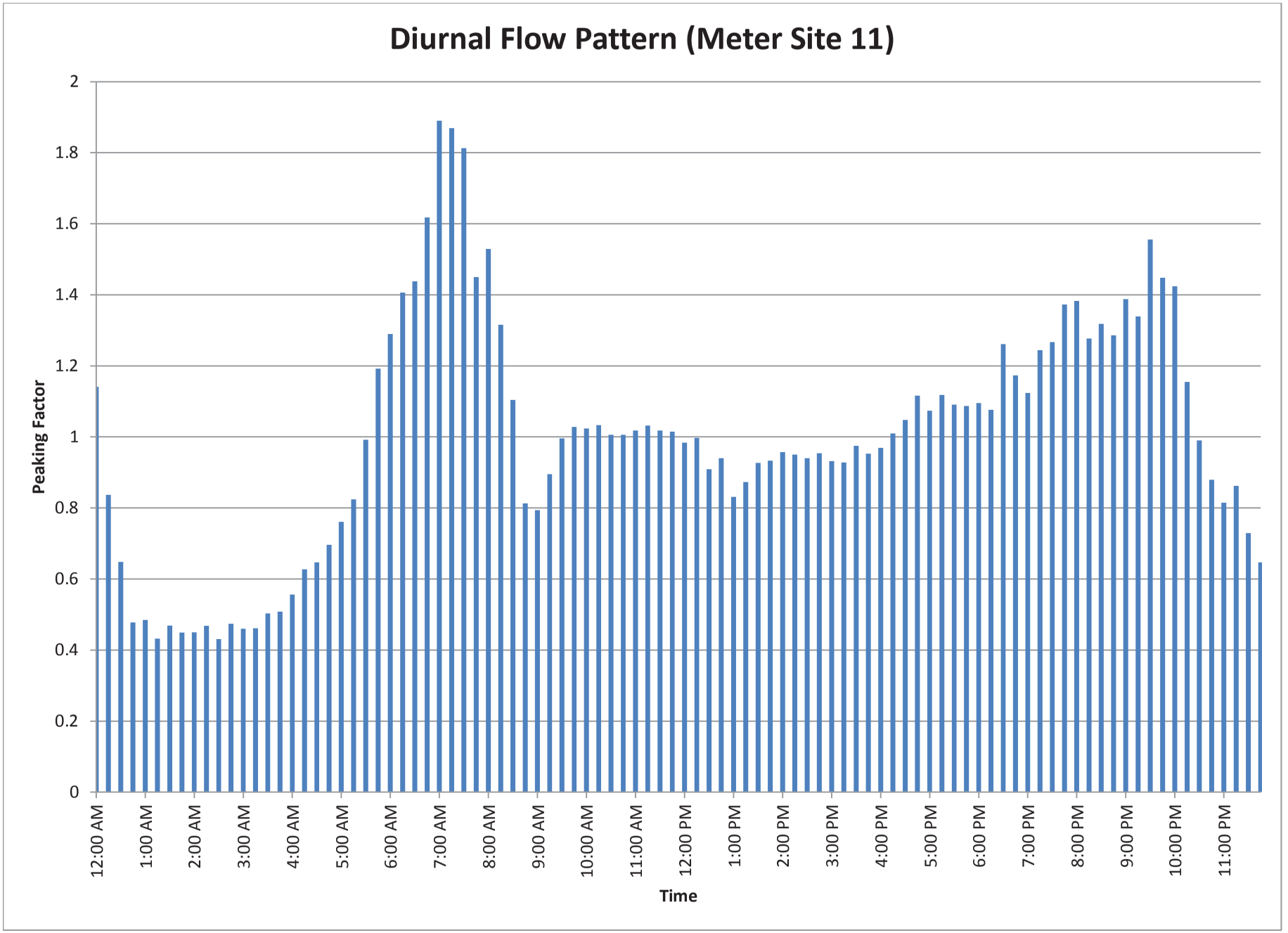

Diurnal Flow Pattern (Meter Site 7)
Peaking Factor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time


Diurnal Flow Pattern (Meter Site 8)
Peaking Factor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time


Diurnal Flow Pattern (Meter Site 9)
Peaking Factor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

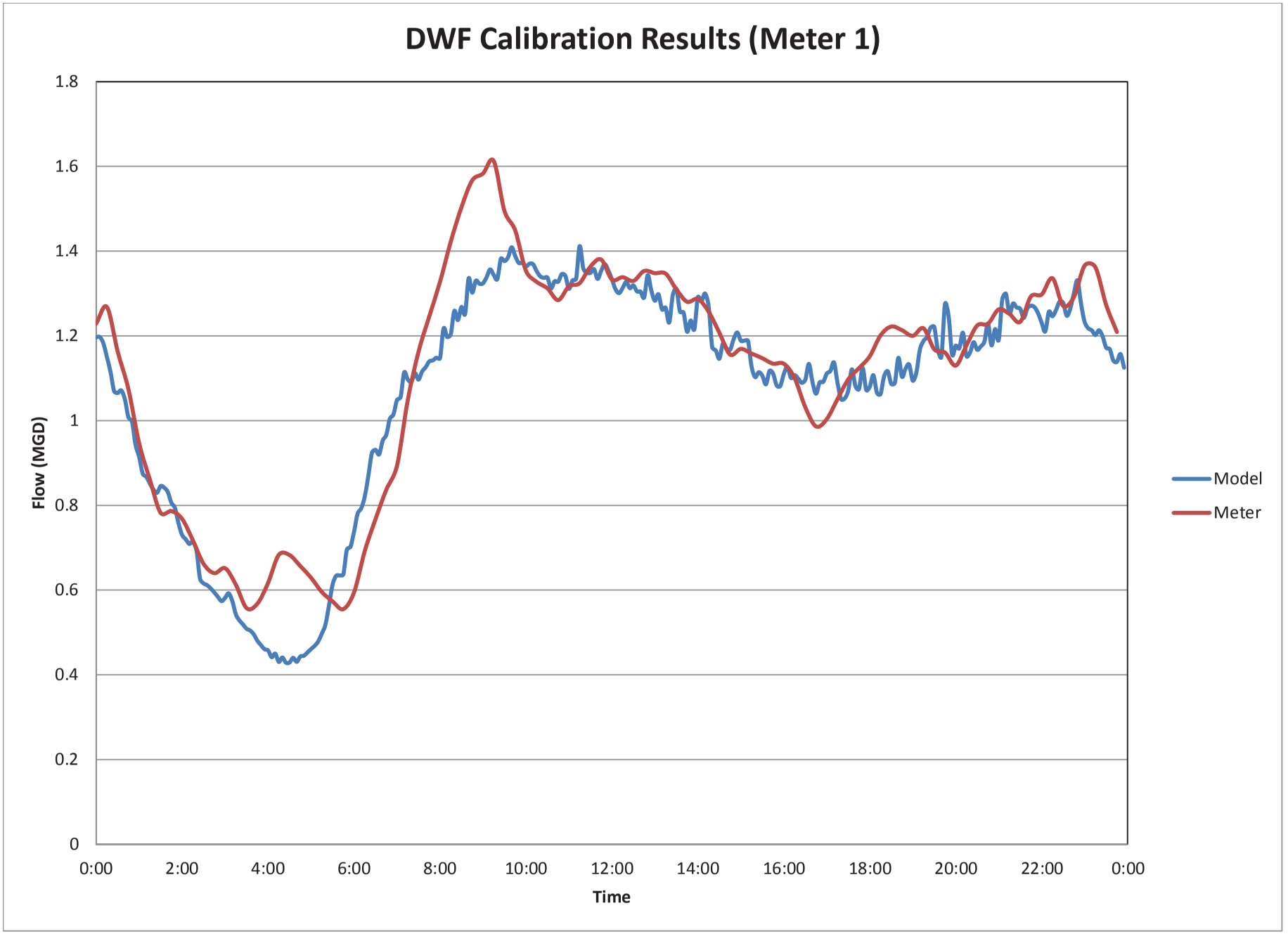

Diurnal Flow Pattern (Meter Site 10)
Peaking Factor
1.1
1.05
1
0.95
0.9
0.85
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

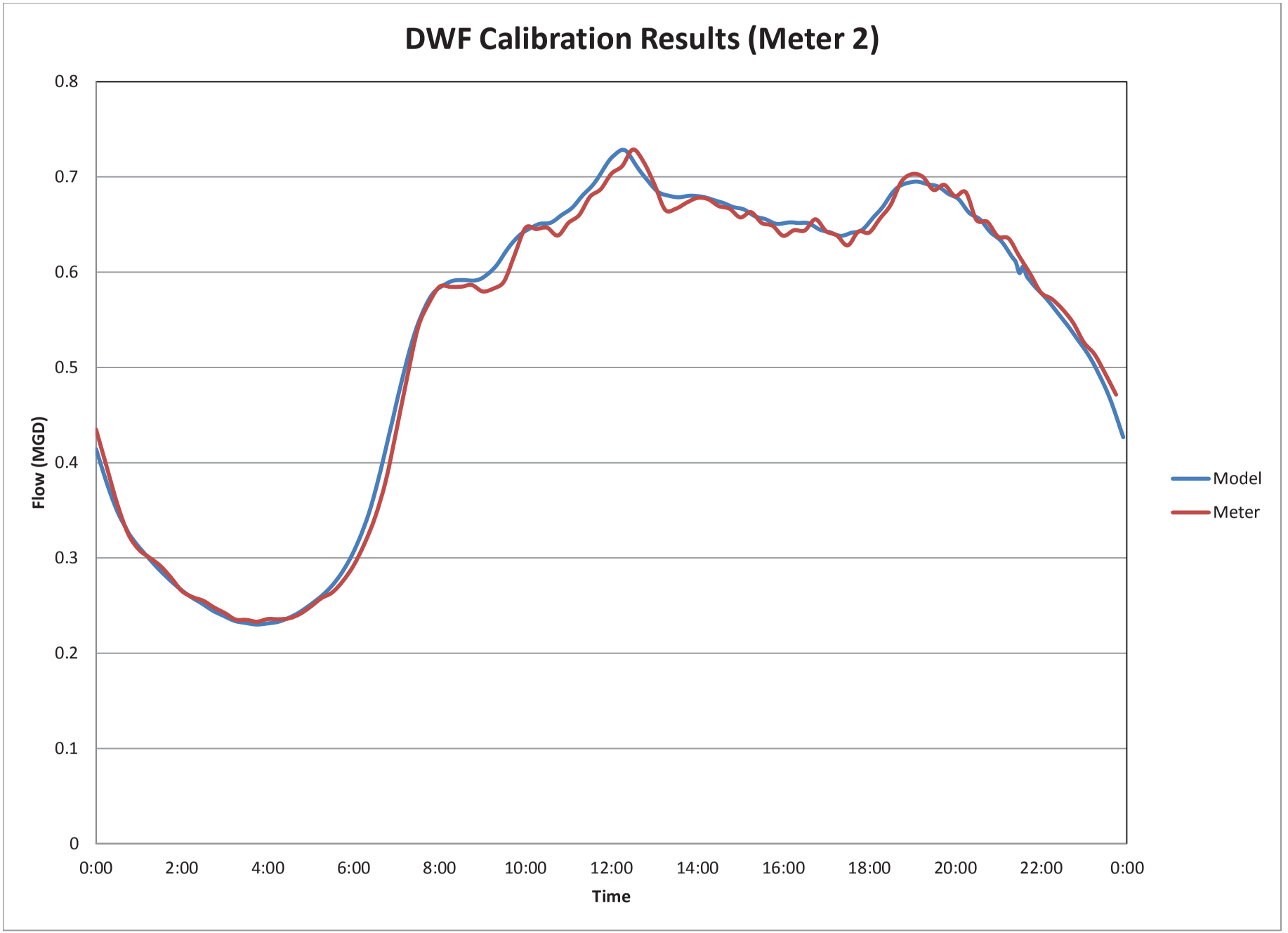

Diurnal Flow Pattern (Meter Site 10a)
Peaking Factor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

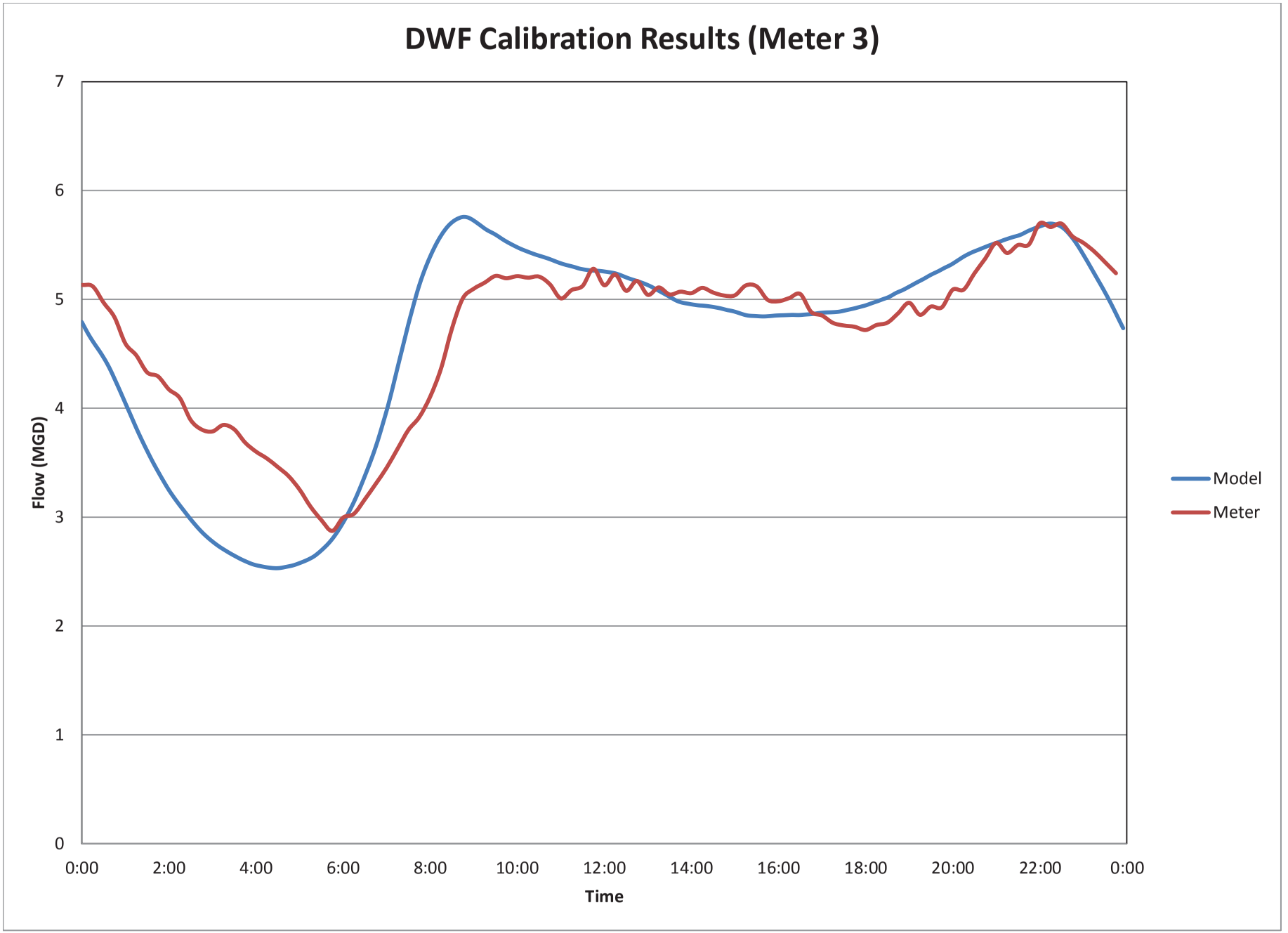

Diurnal Flow Pattern (Meter Site 11)
Peaking Factor
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time

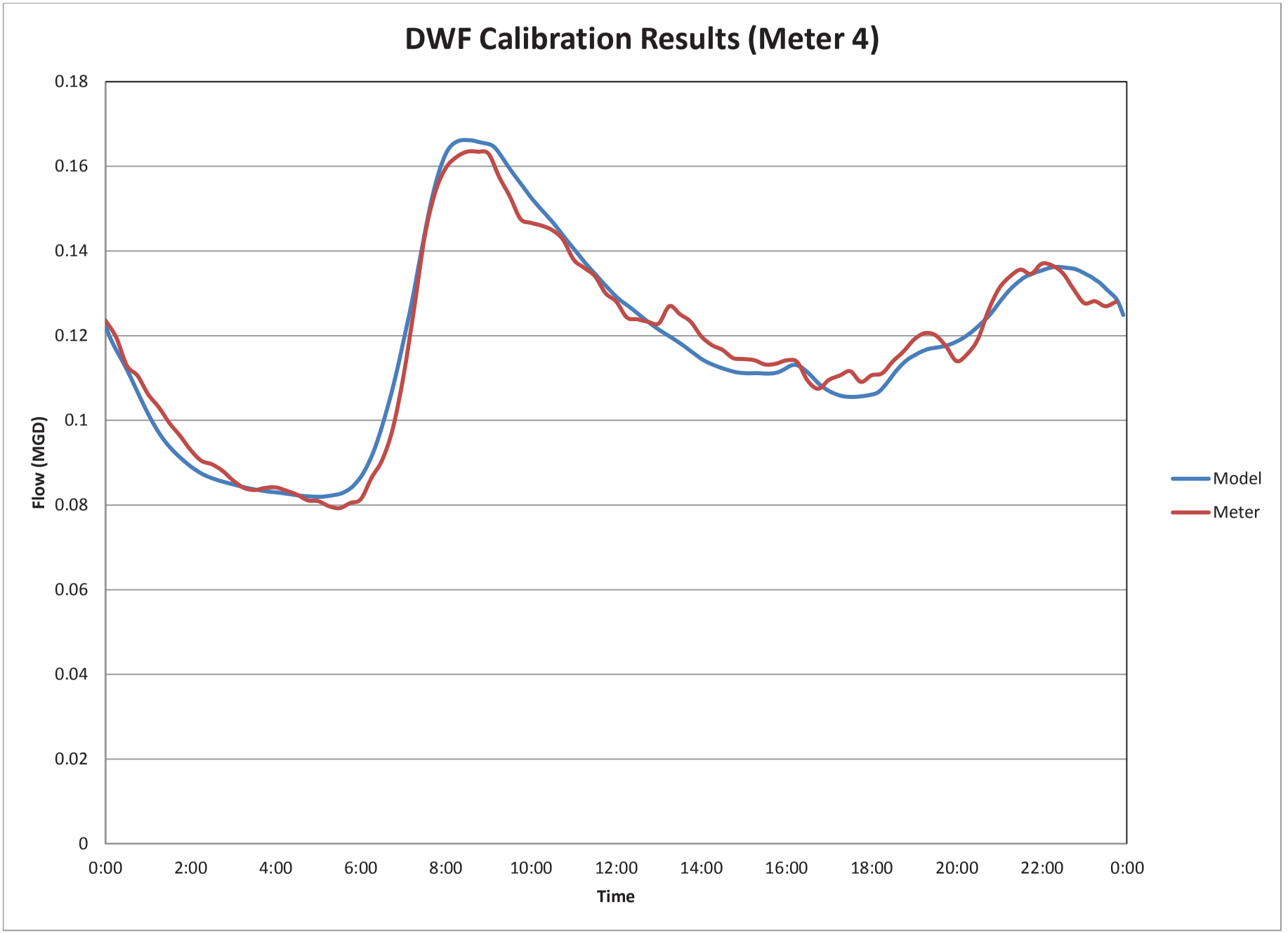
APPENDIX D

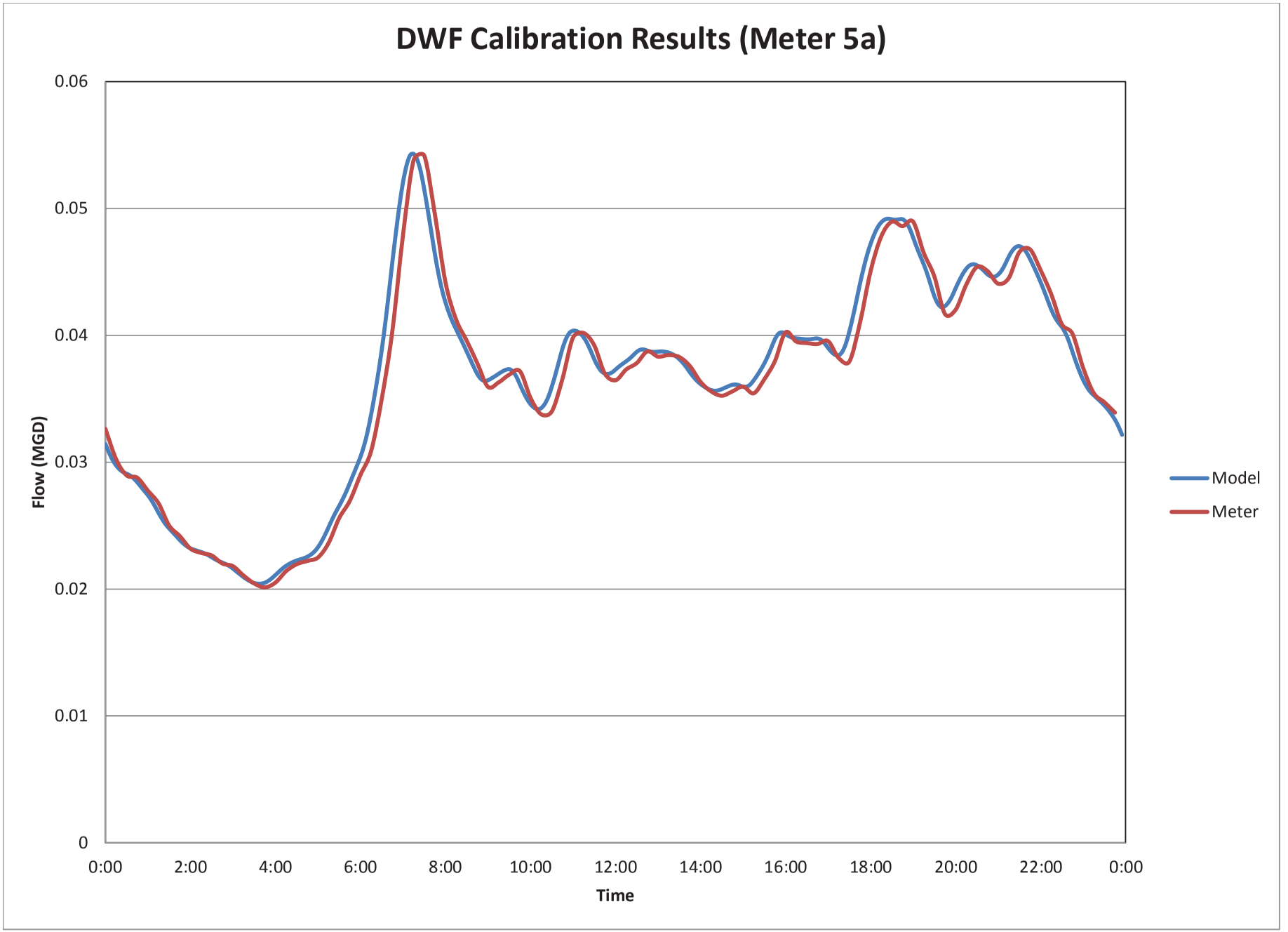
Dry Weather Calibration Hydrographs

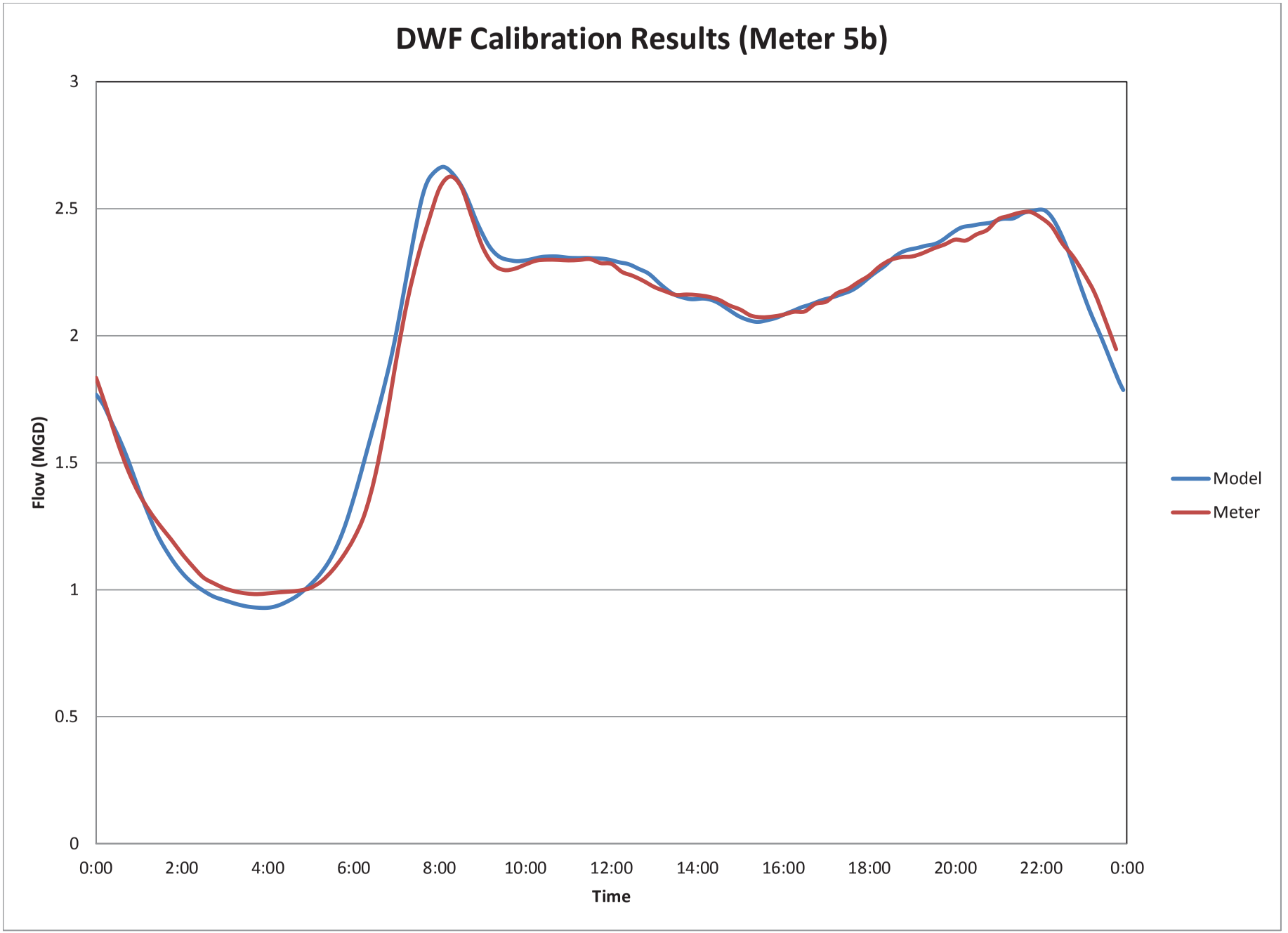

DWF Calibration Results (Meter 1)
Flow (MGD)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

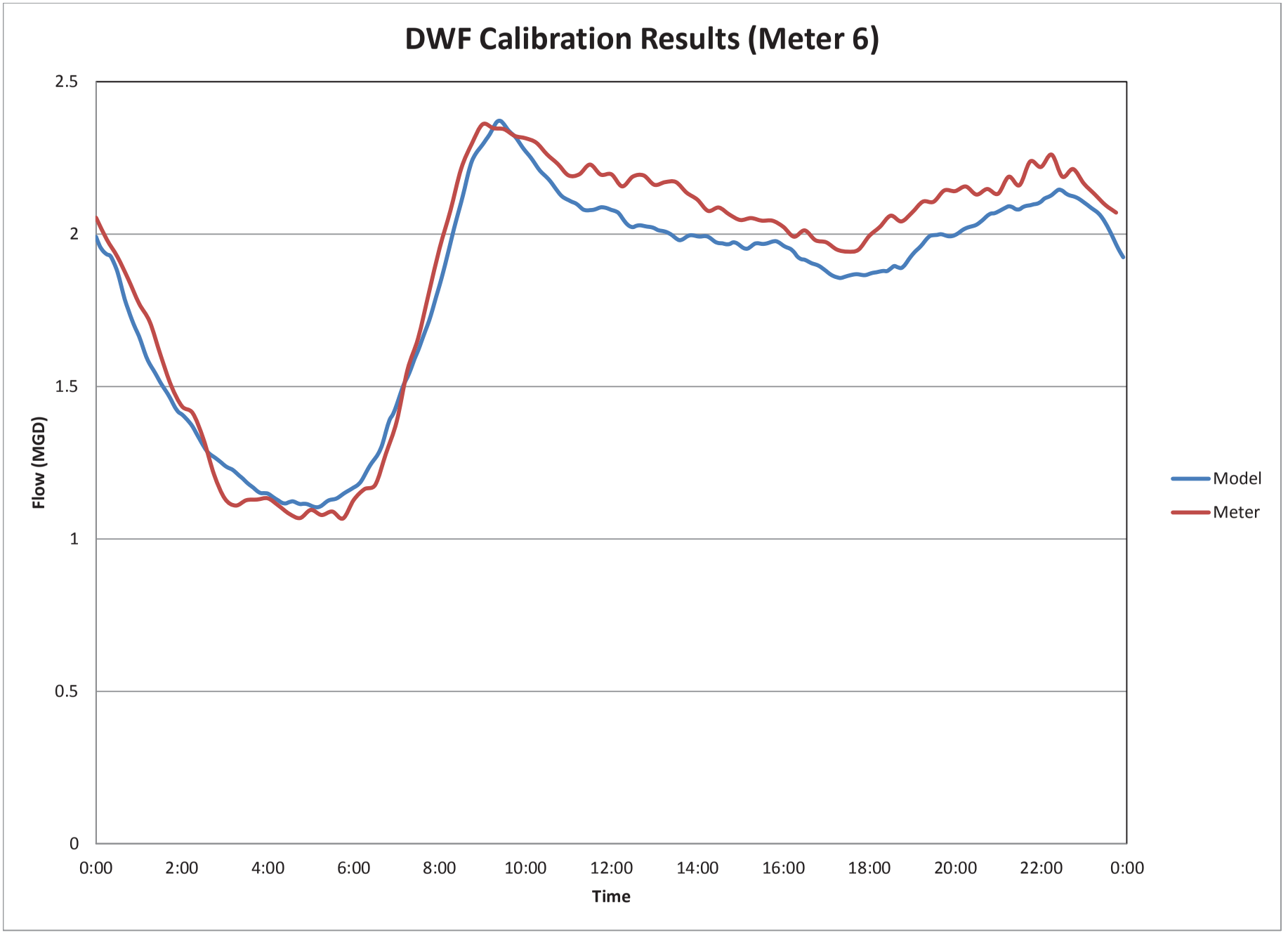

DWF Calibration Results (Meter 2)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Flow (MGD)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

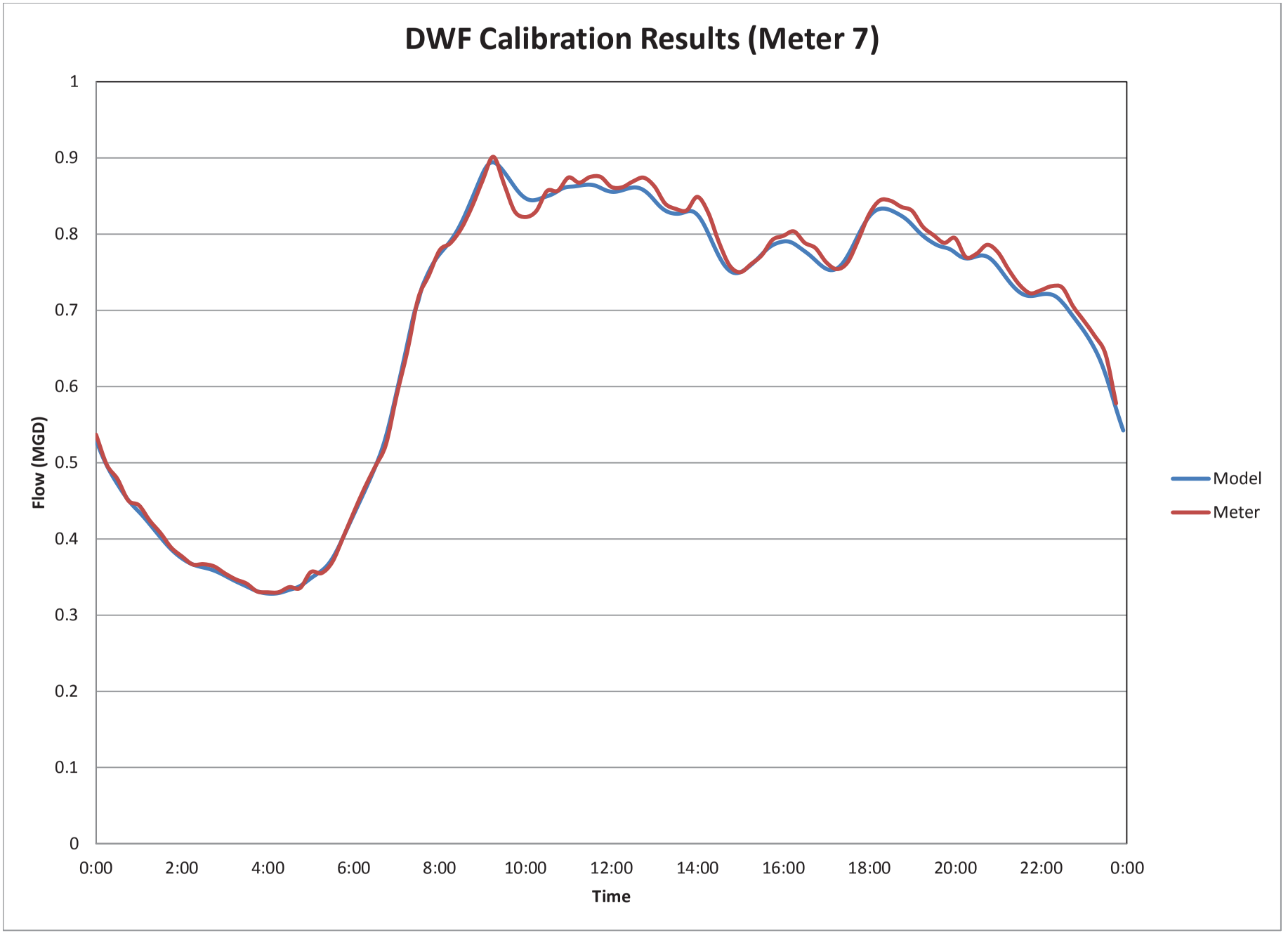

DWF Calibration Results (Meter 3)
Flow (MGD)
7
6
5
4
3
2
1
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

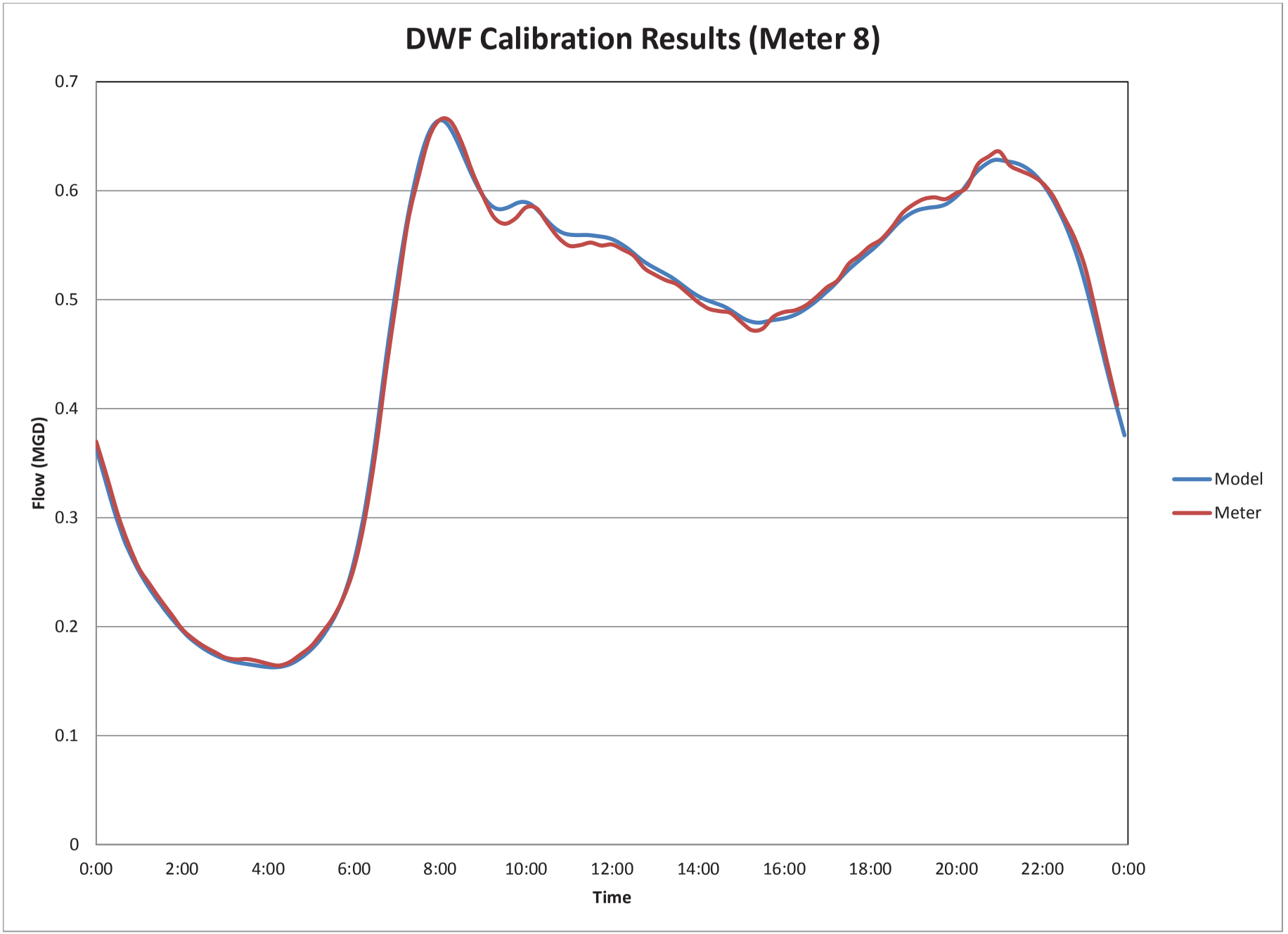

DWF Calibration Results (Meter 4)
Flow (MGD)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

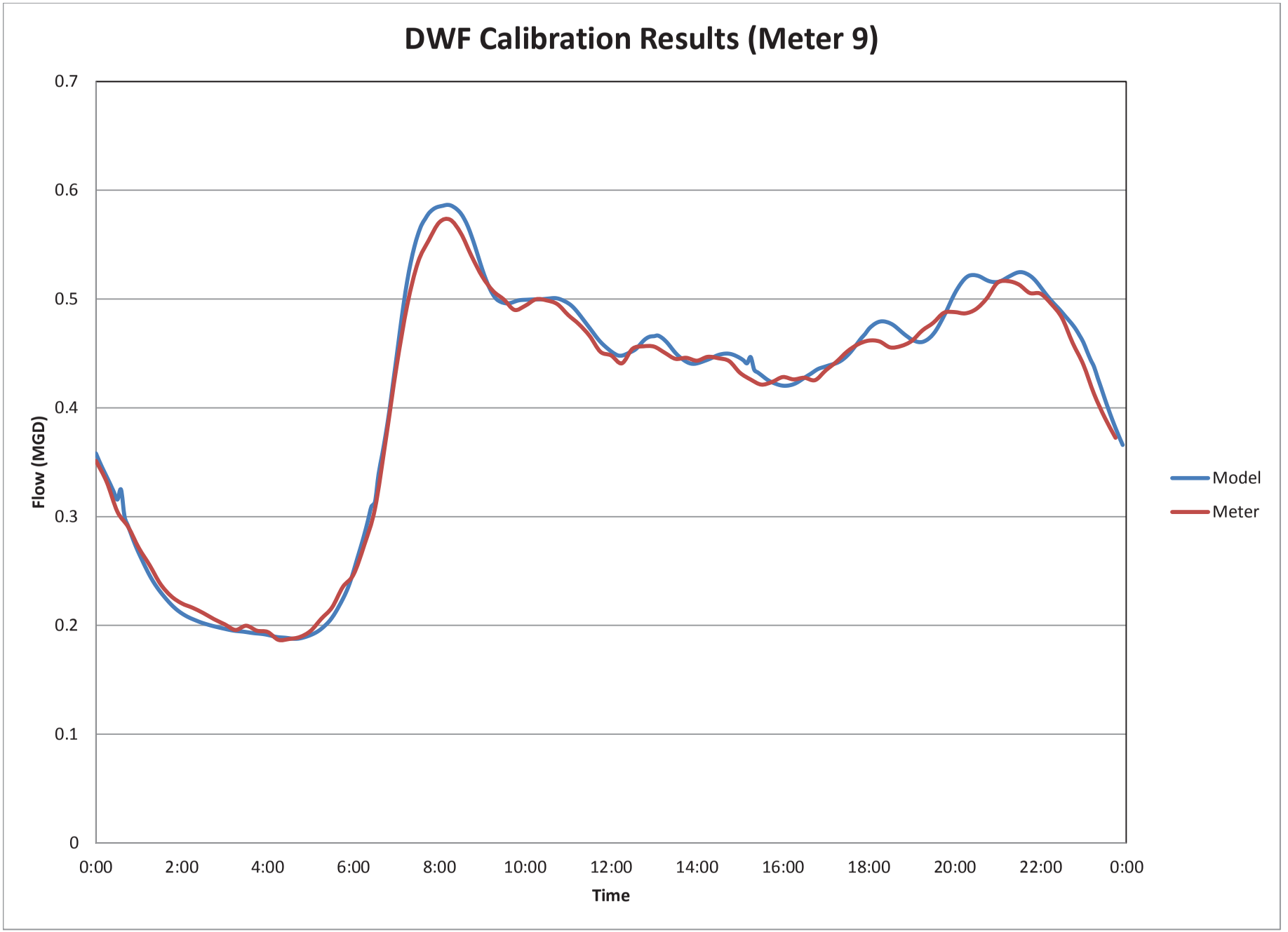

DWF Calibration Results (Meter 5a)
0.06
0.05
0.04
0.03
0.02
0.01
0
Flow (MGD)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

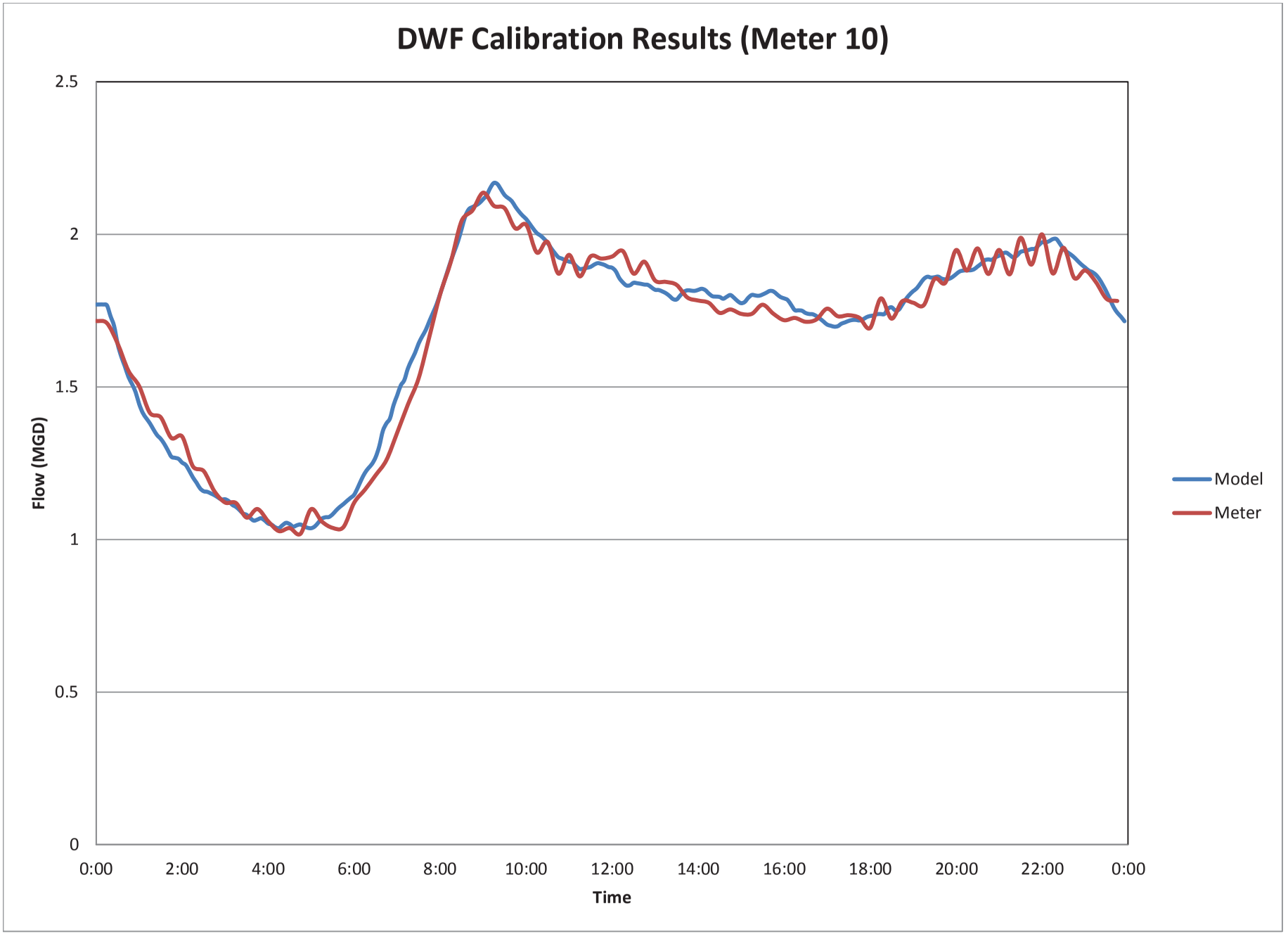

DWF Calibration Results (Meter 5b)
Flow (MGD)
3
2.5
2
1.5
1
0.5
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

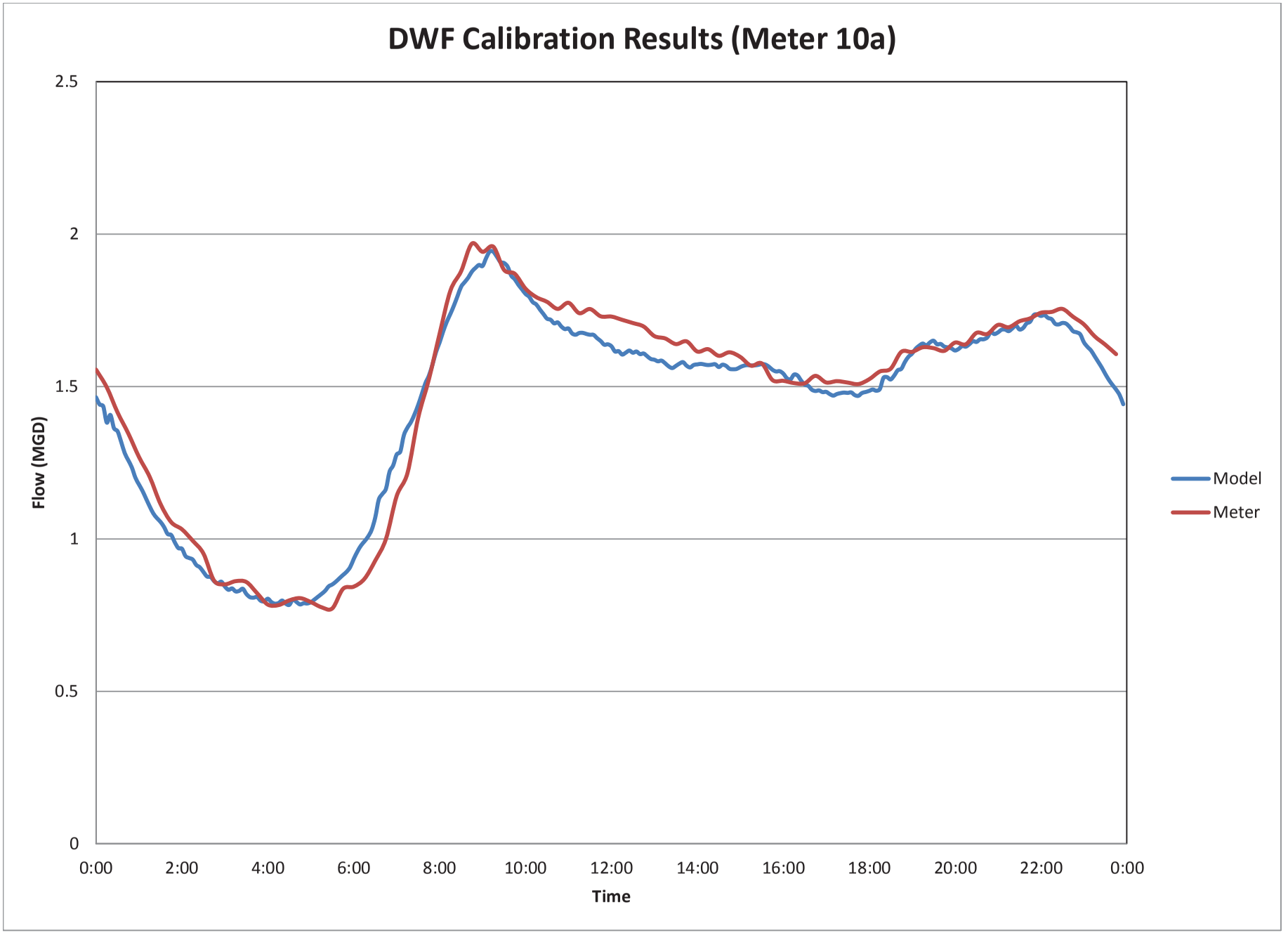

DWF Calibration Results (Meter 6)
2.5
2
1.5
1
0.5
0
Flow (MGD)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

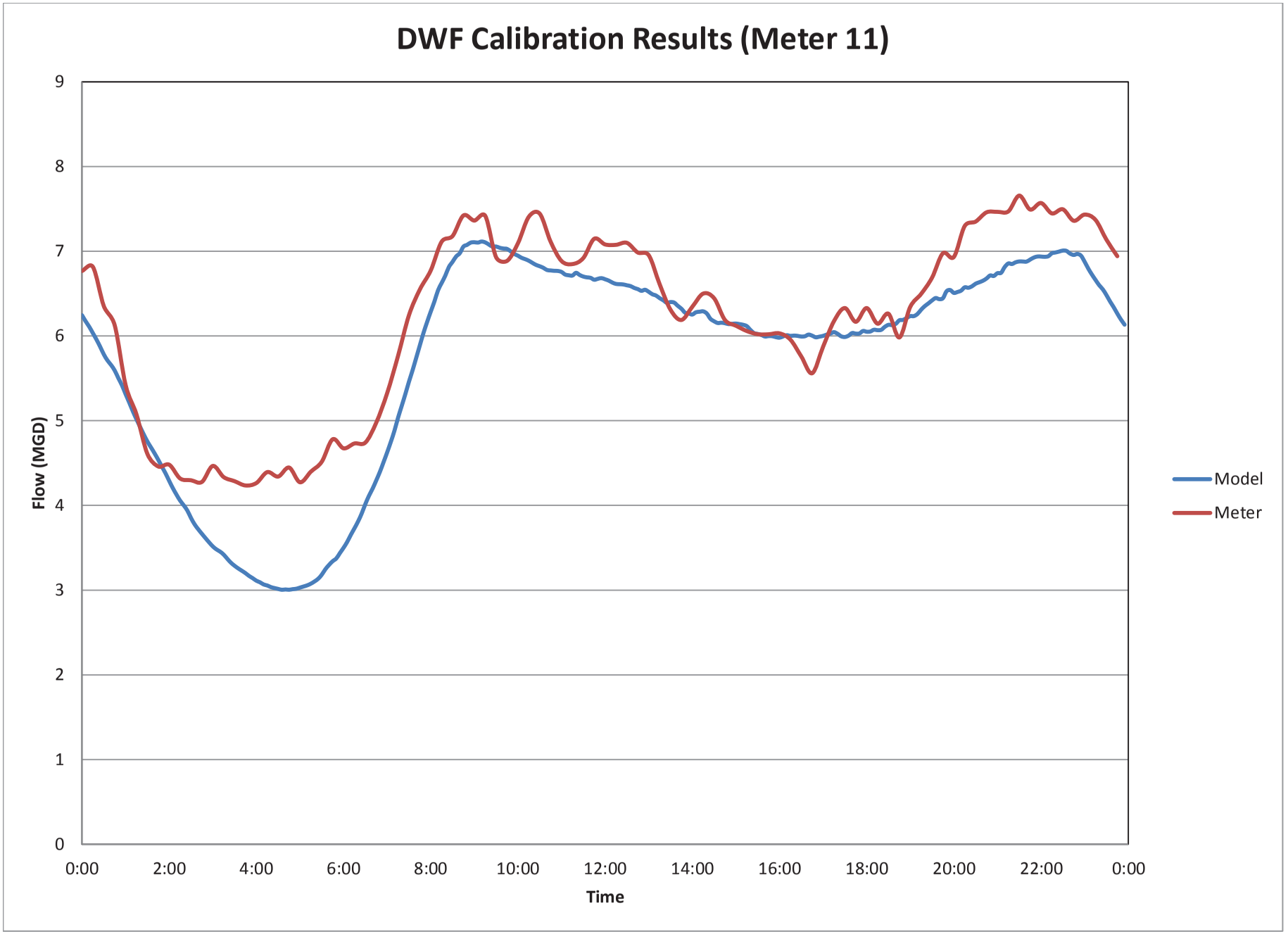

DWF Calibration Results (Meter 7)
Flow (MGD)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter


DWF Calibration Results (Meter 8)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Flow (MGD)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter


DWF Calibration Results (Meter 9)
Flow (MGD)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter


DWF Calibration Results (Meter 10)
Flow (MGD)
2.5
2
1.5
1
0.5
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

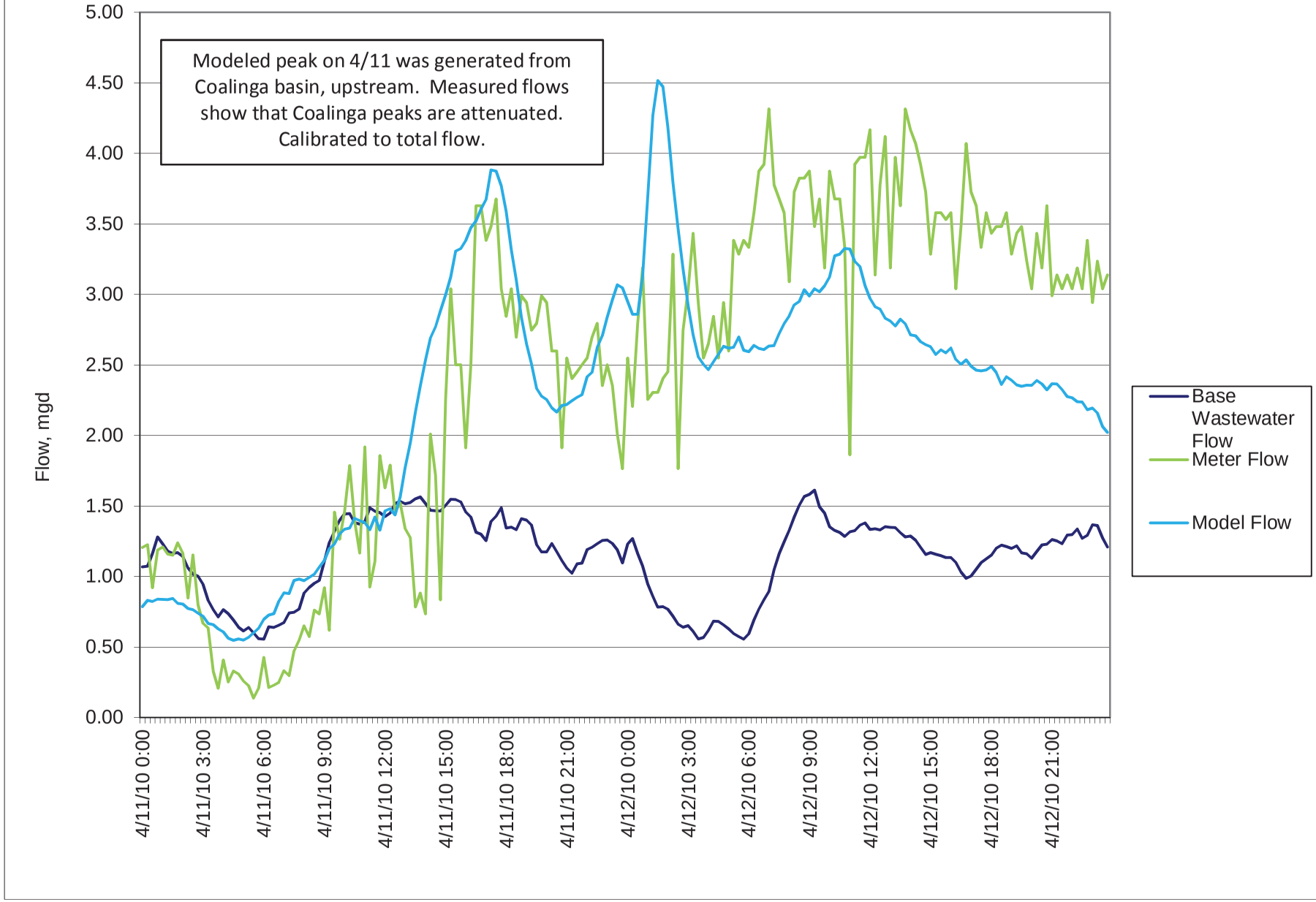

DWF Calibration Results (Meter 10a)
2.5
2
1.5
1
0.5
0
Flow (MGD)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter


DWF Calibration Results (Meter 11)
Flow (MGD)
9
8
7
6
5
4
3
2
1
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Model
Meter

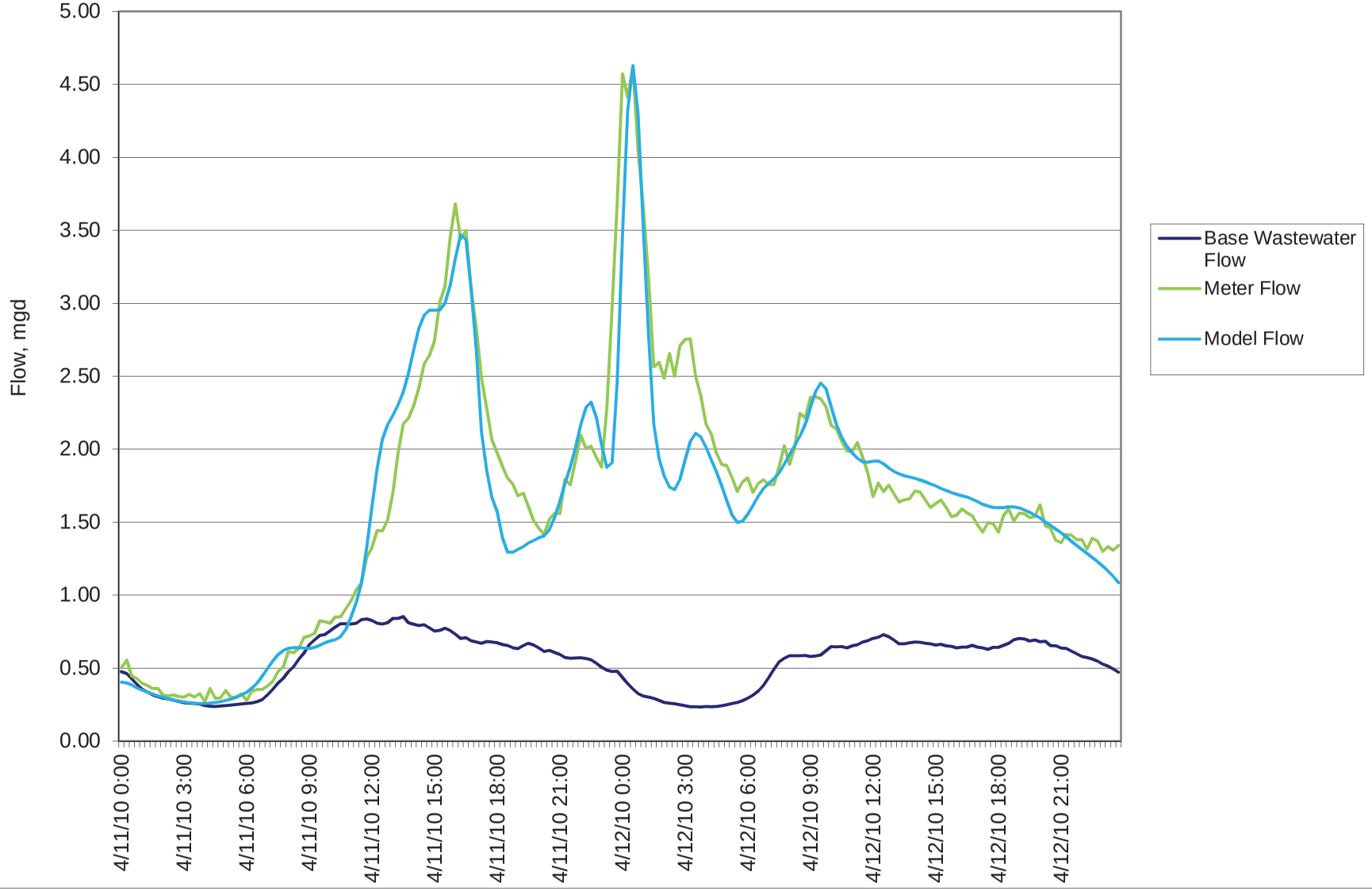
APPENDIX E

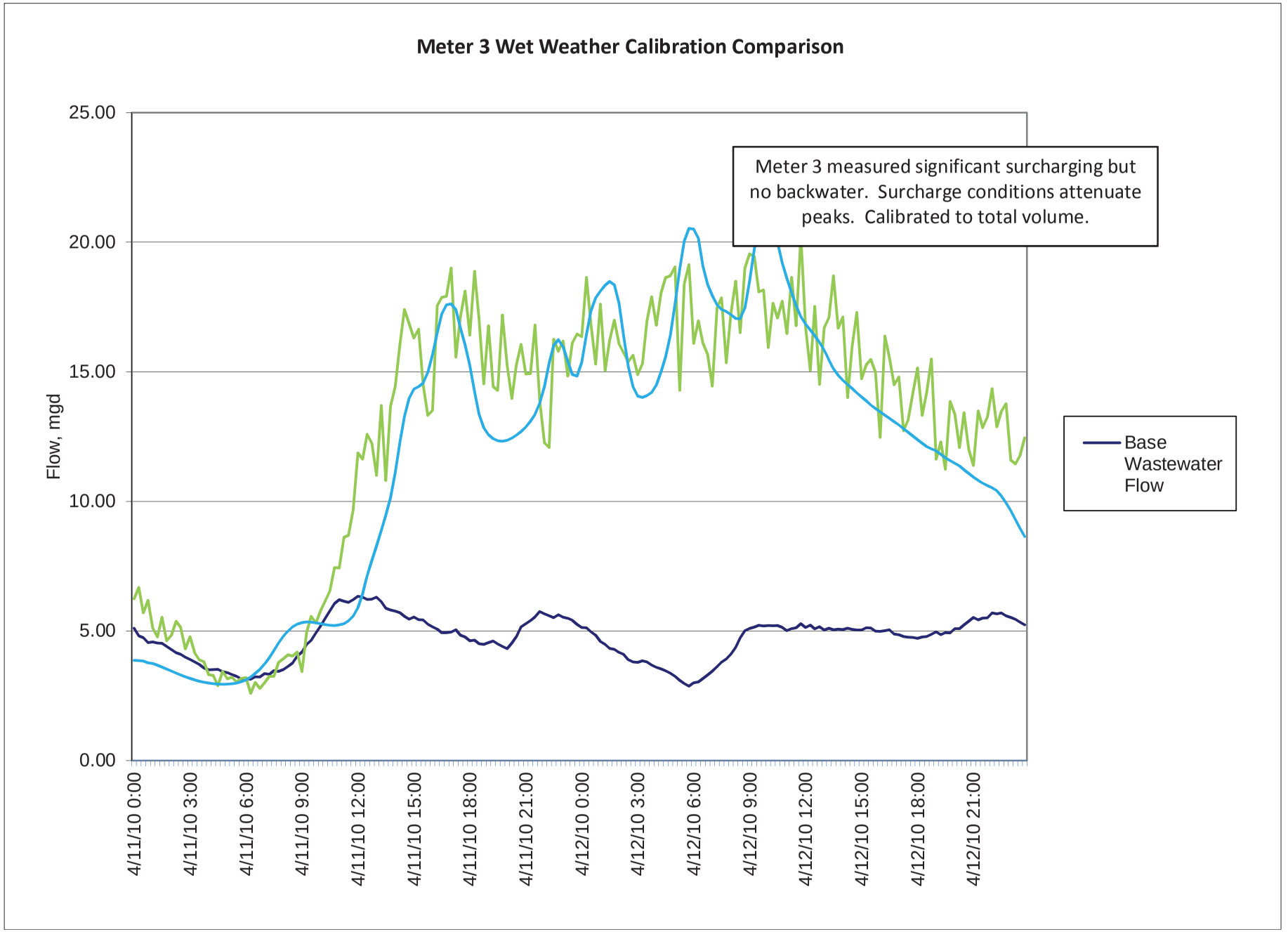
Wet Weather Calibration Hydrographs

Meter 1 Wet Weather Calibration Comparison

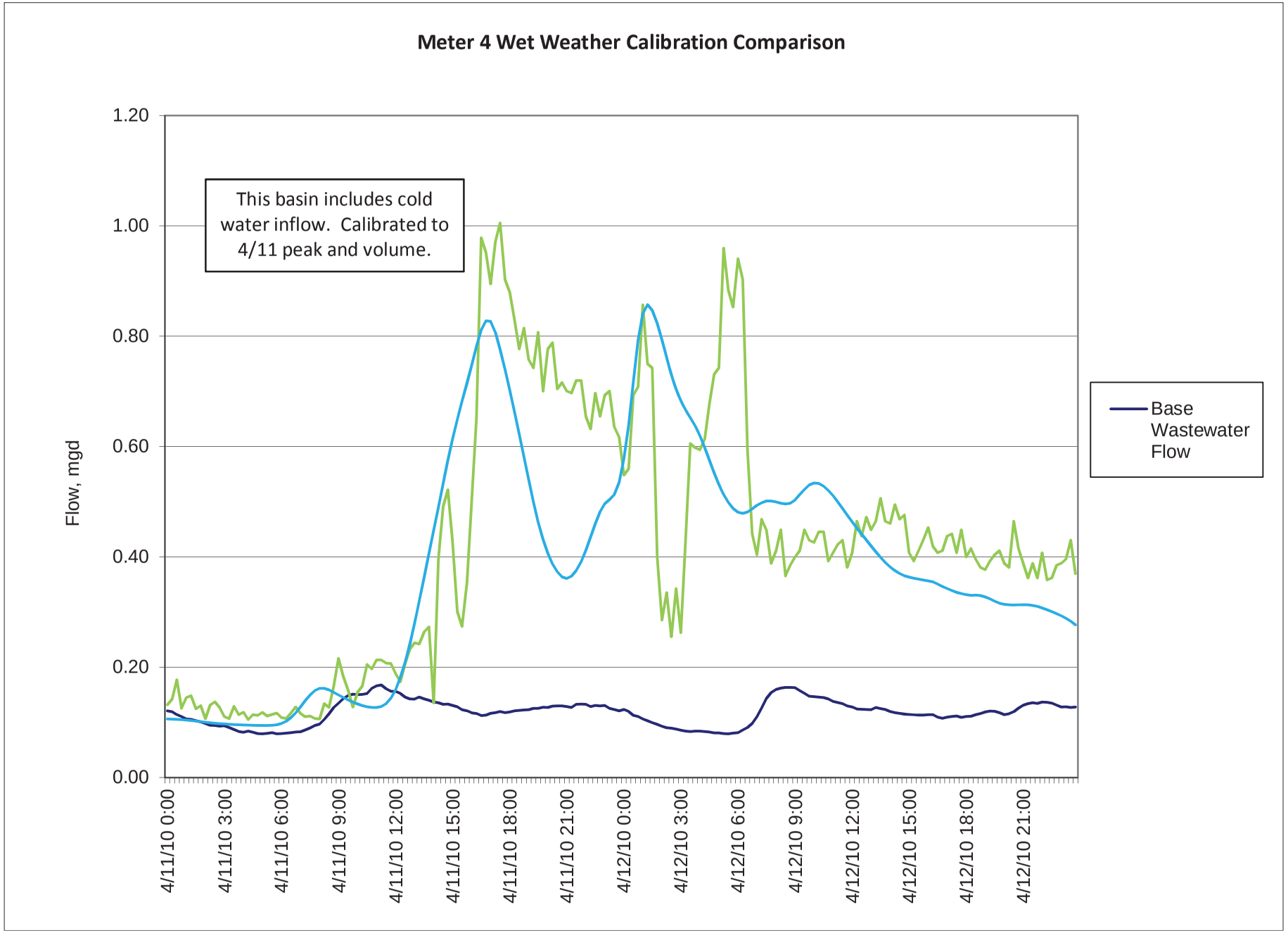


Meter 2 Wet Weather Calibration using M1 Rainfall Data

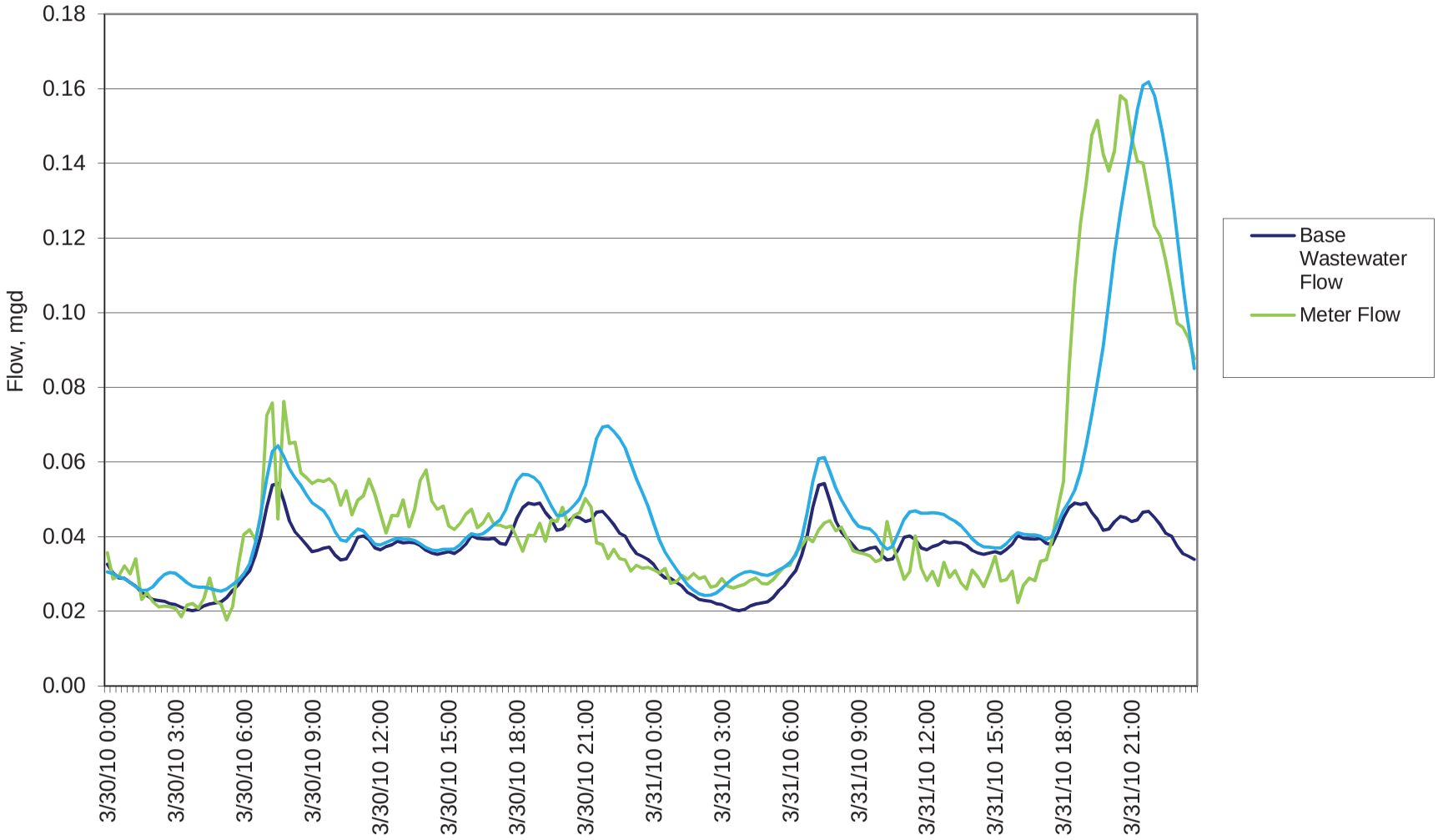



Meter 3 Wet Weather Calibration Comparison
Meter 3 measured significant surcharging but no backwater. Surcharge conditions attenuate peaks. Calibrated to total volume.
Flow, mgd
25.00
20.00
15.00
10.00
5.00
0.00
4/11/10 0:00
4/11/10 3:00
4/11/10 6:00
4/11/10 9:00
4/11/10 12:00
4/11/10 15:00
4/11/10 18:00
4/11/10 21:00
4/12/10 0:00
4/12/10 3:00
4/12/10 6:00
4/12/10 9:00
4/12/10 12:00
4/12/10 15:00
4/12/10 18:00
4/12/10 21:00
Base Wastewater Flow

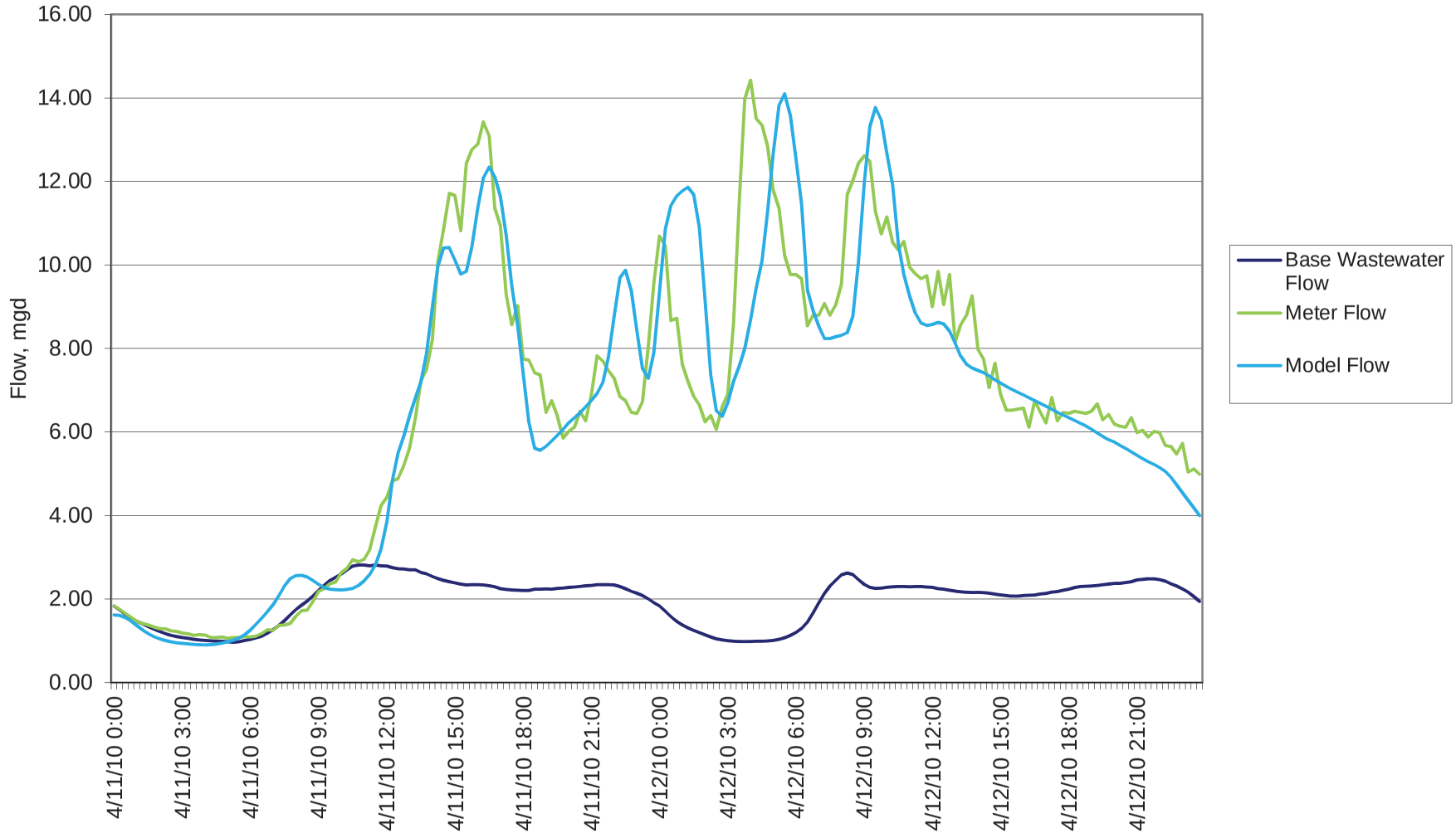
Meter 4 Wet Weather Calibration Comparison

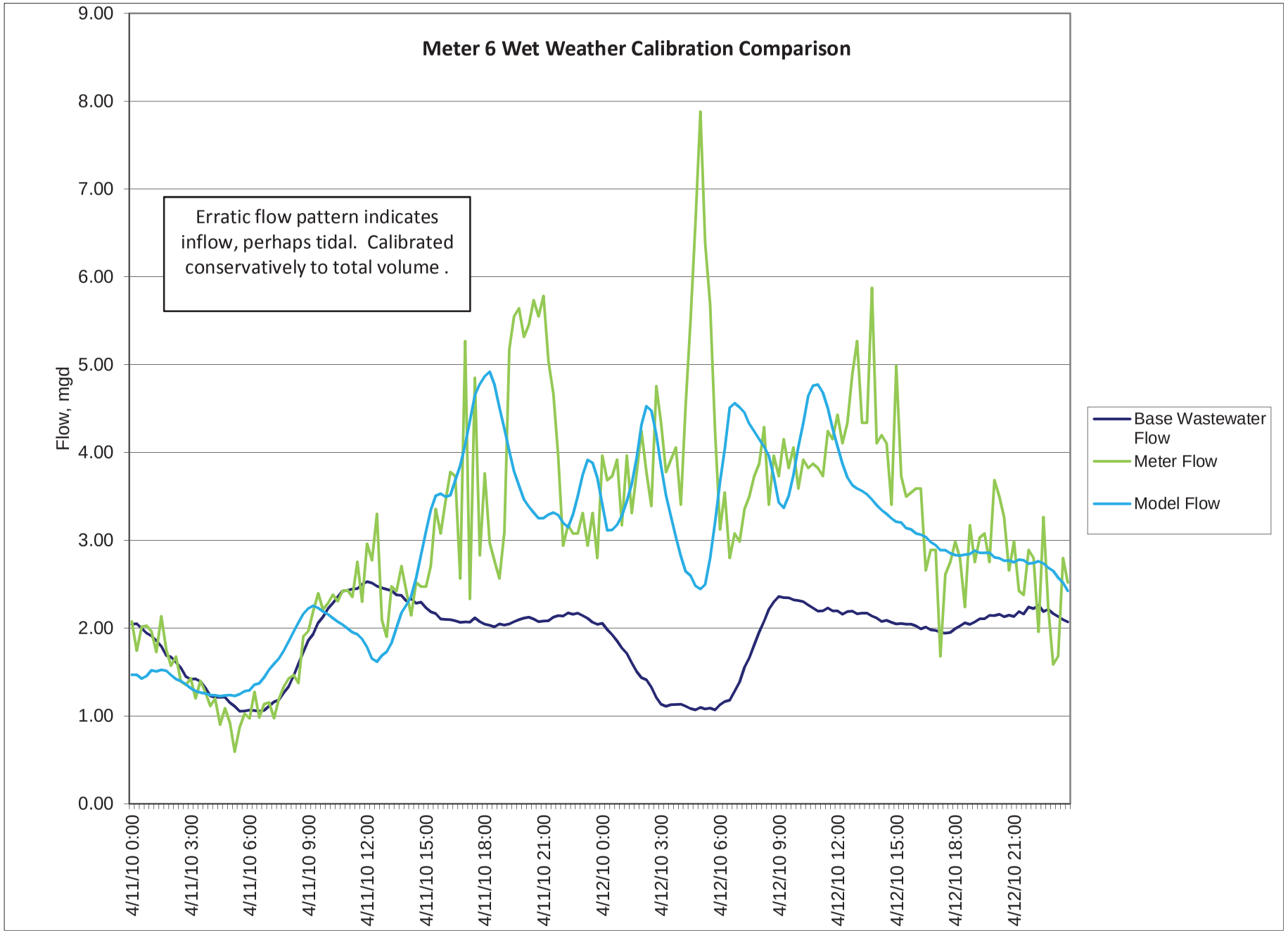


Meter 5a Wet Weather Calibration with March 30-31 Rainfall Event

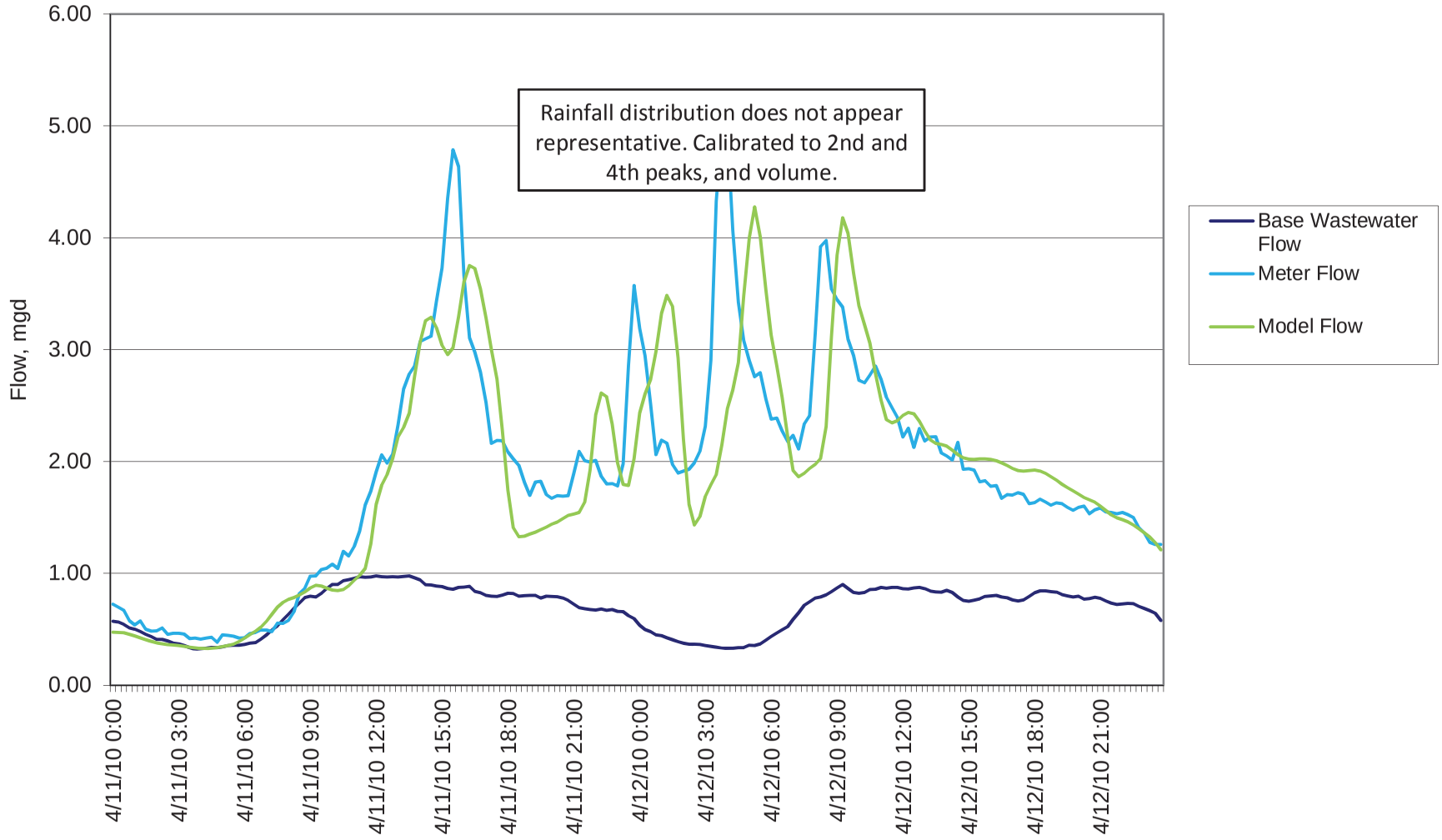


Meter 5b Wet Weather Calibration Comparison

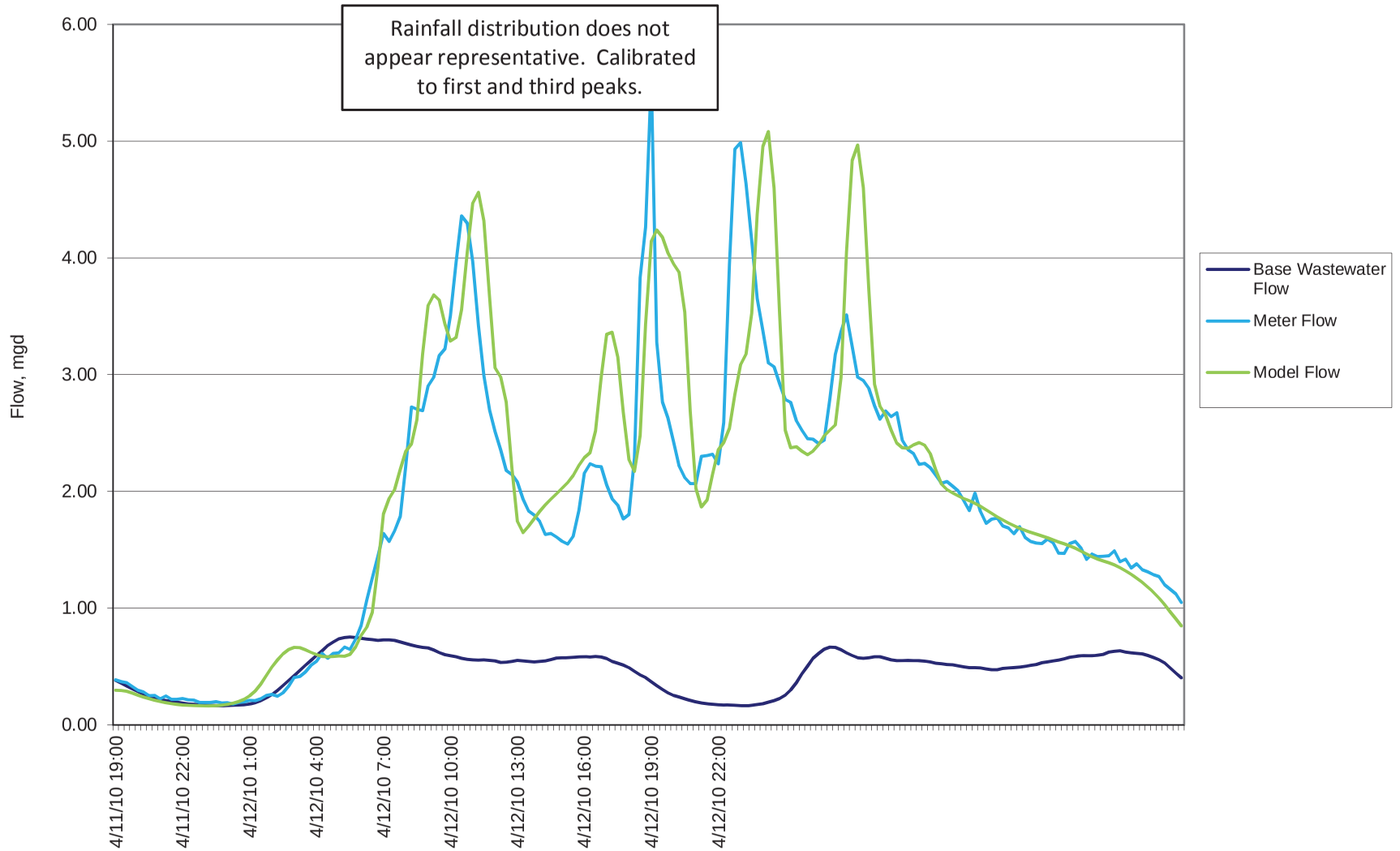



Meter 6 Wet Weather Calibration Comparison
Erratic flow pattern indicates inflow, perhaps tidal. Calibrated conservatively to total volume .
Flow, mgd
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/11/10 0:00
4/11/10 3:00
4/11/10 6:00
4/11/10 9:00
4/11/10 12:00
4/11/10 15:00
4/11/10 18:00
4/11/10 21:00
4/12/10 0:00
4/12/10 3:00
4/12/10 6:00
4/12/10 9:00
4/12/10 12:00
4/12/10 15:00
4/12/10 18:00
4/12/10 21:00
Base Wastewater Flow
Meter Flow
Model Flow

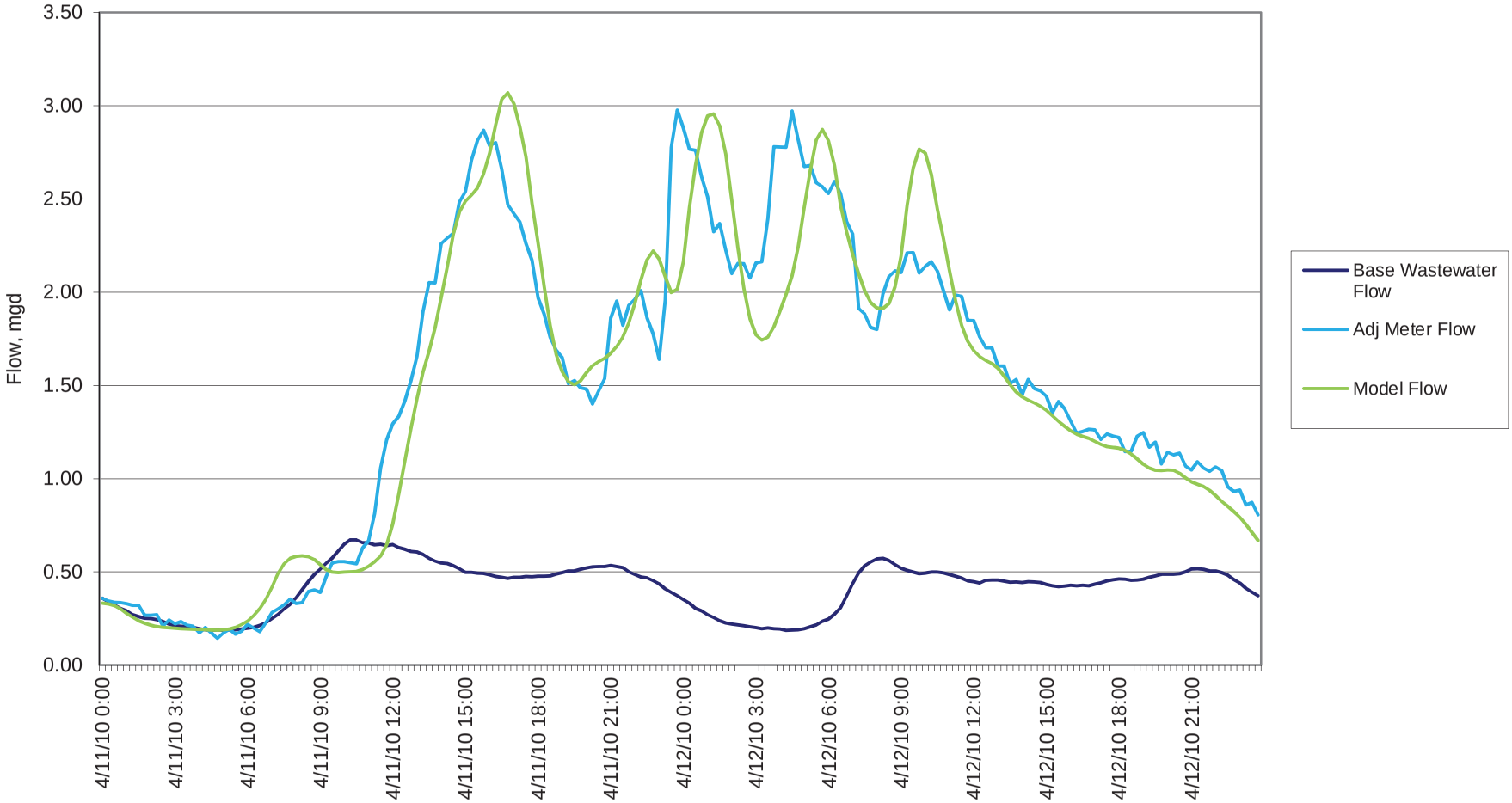
Meter 7 Wet Weather Calibration Comparison

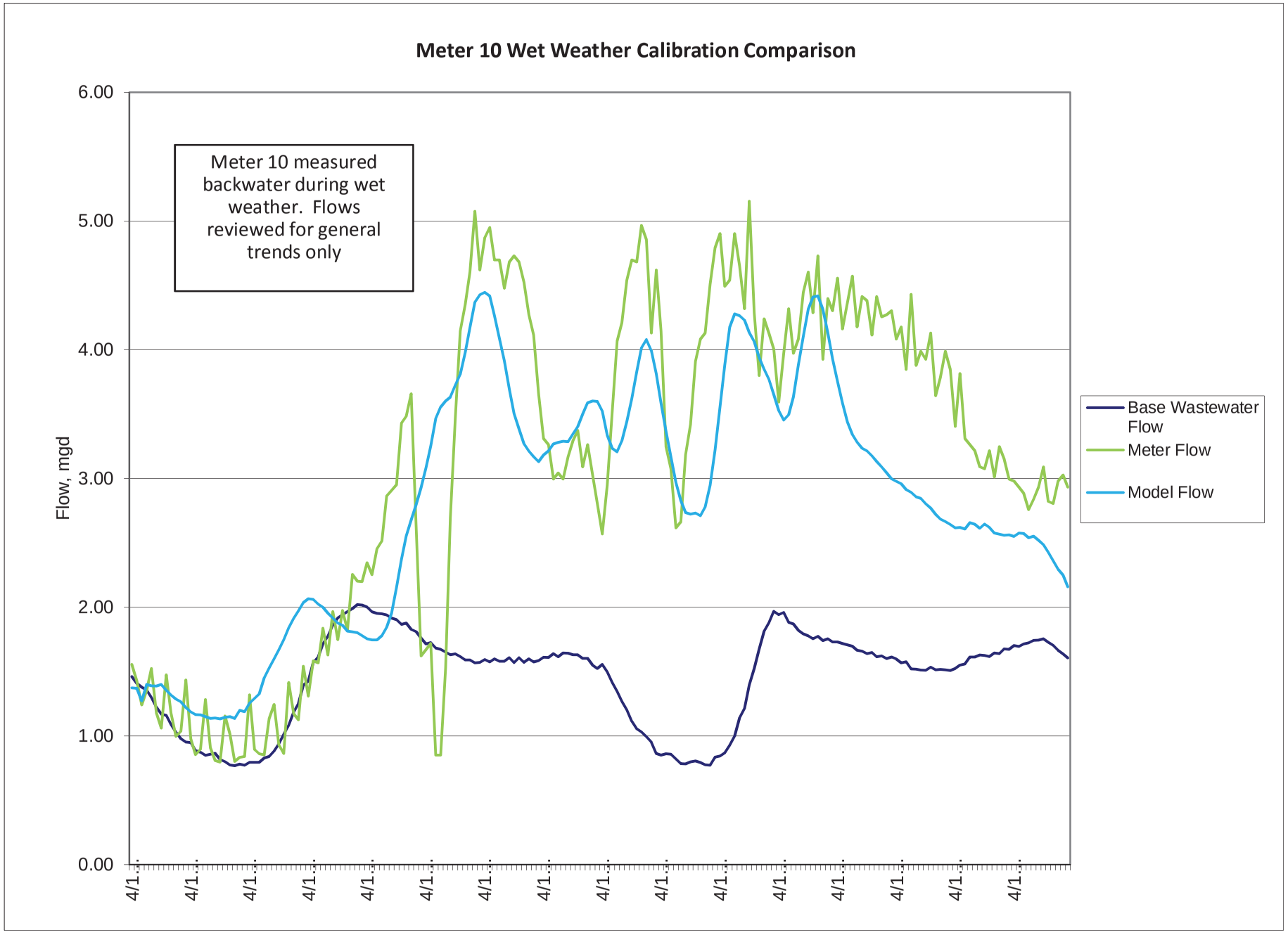


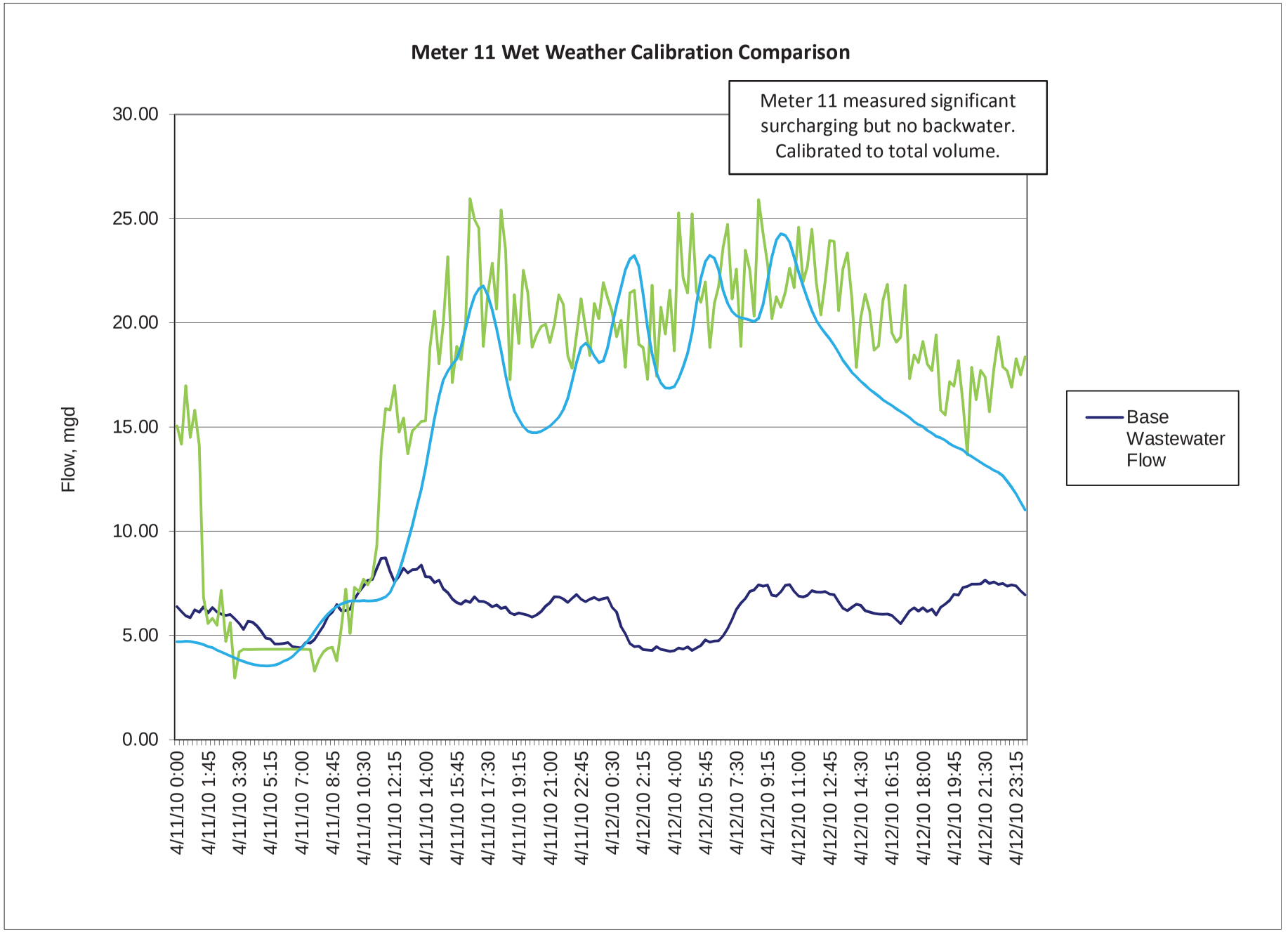
Meter 8 Wet Weather Calibration Comparison



Meter 9 Wet Weather Calibration Comparison (Uses 10a Rainfall Distribution)




Meter 10 Wet Weather Calibration Comparison
Meter 10 measured backwater during wet weather. Flows reviewed for general trends only
Flow, mgd
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1
Base Wastewater Flow
Meter Flow
Model Flow


Meter 11 Wet Weather Calibration Comparison
Meter 11 measured significant surcharging but no backwater. Calibrated to total volume.
Flow, mgd
30.00
25.00
20.00
15.00
10.00
5.00
0.00
4/11/10 0:00
4/11/10 1:45
4/11/10 3:30
4/11/10 5:15
4/11/10 7:00
4/11/10 8:45
4/11/10 10:30
4/11/10 12:15
4/11/10 14:00
4/11/10 15:45
4/11/10 17:30
4/11/10 19:15
4/11/10 21:00
4/11/10 22:45
4/12/10 0:30
4/12/10 2:15
4/12/10 4:00
4/12/10 5:45
4/12/10 7:30
4/12/10 9:15
4/12/10 11:00
4/12/10 12:45
4/12/10 14:30
4/12/10 16:15
4/12/10 18:00
4/12/10 19:45
4/12/10 21:30
4/12/10 23:15
Base Wastewater Flow

APPENDIX F

West Yost TMs Describing Recommended Pipeline Replacement and Repair Projects

TECHNICAL MEMORANDUM

DATE: March 29, 2010 Project No.: 356-02-09-03

TO: Mark Grushayev, Program Manager

CC: John Hart, Senior Project Manager

FROM: Vivian Housen, R.C.E. #C46324

SUBJECT: Veolia Water / City of Richmond
Preliminary Capital Improvement Priorities

DRAFT

This Technical Memorandum (TM) provides a summary of and relative priorities for the City of Richmond (City) capital improvement needs. The projects considered in this TM were identified through various planning studies completed since 2006 by Veolia Water N.A. (Veolia) for the City's wastewater treatment plant, wastewater collection system, and stormwater collection system. Veolia has requested that West Yost Associates (West Yost) consolidate these recommendations and develop relative project priorities and a timeline for completion that enables the City to most effectively meet current legal and regulatory mandates.

This TM is organized as follows:

I. Overview of Legal and Regulatory Mandates
II. Summary of Findings From Existing Planning Documents
III. Capital Improvement Project (CIP) Priorities
IV. CIP Preliminary Costs and Schedule

I. OVERVIEW OF LEGAL AND REGULATORY MANDATES

Veolia and the City operate and maintain the Richmond wastewater collection system and treatment plant in accordance with a number of regulatory documents, including: 1) Regional Water Quality Control Board (RWQCB) National Pollution Discharge Elimination System (NPDES) permit, and 2) Sewer System Management Plan (SSMP), prepared to meet RWQCB guidelines and State Water Resources Control Board (SWRCB) Statewide Collection System Waste Discharge Requirements (Statewide WDR). In addition, the City is required to meet aggressive requirements for the elimination of sewer spills through system-wide infrastructure improvements, as set forth in the 2006 Baykeeper settlement agreement. This section describes these requirements, which drive capital improvement needs for the City of Richmond.

RWQCB NPDES Permit

The City's NPDES permit, most recently adopted by the RWQCB in 2008, is reviewed and requires re-adoption by the RWQCB every five years. The permit establishes numerical limits for discharge of pollutants to the San Francisco Bay pursuant to the federal Clean Water Act and California's Porter-Cologne Water Quality Control Act. The permit also establishes requirements for monitoring wastewater to ensure that the permit holder meets all requirements. In order to meet NPDES permit requirements, the City must continuously maintain its treatment facilities, ensure that these facilities are sufficiently sized to treat wastewater volumes without system upsets, and operate these facilities with certified plant operators. The RWQCB routinely inspects treatment and collection facilities and enforces permit requirements. Violations of permit requirements often lead to significant fines, administrative orders, cease and desist orders, time schedule compliance orders, and/or third party lawsuits that specify capital improvements that are needed to bring the agency back into permit compliance.

RWQCB SSMP and Statewide WDR Requirements

The City's Sewer System Master Plan (SSMP) follows a prescribed outline that describes the City's operating and maintenance practices, including goals and an organizational reporting structure for sewer system overflows; preventive activities and metrics to minimize overflows; control of fats, oils, and grease; predictive system modeling to plan for future increases in sewer flows; sewer design and construction standards; and legal authority to enforce these measures. In conjunction with the SSMP, the City is required to report specific details about every sewer spill through an online reporting system that makes the data available to regulators and the public. At the end of every year, the City must complete an audit of the SSMP and also submit an annual sewer system overflow (SSO) report to the RWQCB. The RWQCB expects to see continuous improvement in maintenance activities, as evidenced by reductions in the number of SSOs. Agencies with high numbers and volumes of SSOs may be subjected to fines, administrative orders, cease and desist orders, time schedule compliance orders, and/or third party lawsuits demanding improvements in the wastewater collection system.

Baykeeper Settlement Agreement

In 2005, after documenting years of large wastewater spills from the City's collection system and violations at the wastewater treatment plant, San Francisco Baykeeper (Baykeeper) filed a lawsuit against the City for violations of the Clean Water Act. In 2006, the City and Baykeeper finalized a settlement agreement that includes specific requirements needed to reduce spills within and from the wastewater collection system. The settlement agreement includes specific objectives that must be achieved within an aggressive schedule. If the City does not achieve these objectives, it becomes vulnerable to further legal actions, fines, and penalties. The Baykeeper settlement requires $4 million per year in collection system improvements through 2011; elimination of overflows from the City's two collection system overflow structures by 2014; 90 percent system-wide spill reduction by 2016; and implementation of a $1 million sewer lateral replacement grant program. In order to achieve these results, the City must complete extensive treatment plant improvements, construct wet weather storage facilities, and complete significant pipeline replacements and stormwater diversions within the collection system.

DRAFT

III. SUMMARY OF FINDINGS FROM EXISTING PLANNING DOCUMENTS

Veolia and the City have completed planning studies that collectively define capital improvement needs for the City's wastewater collection and treatment facilities. These studies include the Sewer System Master Plan (Boyle, 2006), which was replaced by the System Evaluation and Capacity Assurance Plan (Psomas, 2008); and the Wastewater Treatment Master Plan (Carollo, ongoing). To supplement these studies, since 2009, West Yost has reviewed data collected through ongoing operations and maintenance activities, and assessed this data with regard to ongoing capital improvement needs. In addition, Veolia and the City have completed a Storm Drain Master Plan (Boyle, 2006). This section provides a brief overview of each planning study, and a summary of findings as they relate to development of CIP priorities.

Sewer System Master Plan (Boyle, 2006)

The Boyle master plan used a computerized hydraulic model to evaluate the capacity of the system to convey wastewater flows through 2020. The master plan recommends $22.5 million of improvements needed to address capacity needs, and provides individual project costs and a recommended schedule for implementation. The wet weather design storm used for the analysis has a 5-year, 24-hour duration, which is consistent with design criteria that was used in other wastewater planning studies during this time period.

The 2006 Baykeeper settlement agreement included a requirement for evaluation of wet weather system capacity using a 10-year, 24-hour design storm. Therefore, in 2008, in order to comply with the terms of this agreement, Veolia and the City completed a System Evaluation and Capacity Assurance Plan that supersedes the Boyle master plan.

System Evaluation and Capacity Assurance Plan (Psomas, 2008)

The System Evaluation and Capacity Assurance Plan (SECAP) assessed the ability of the City's sewer system to convey anticipated flows from a 10-year, 24-hour design storm. A new hydraulic model was developed to complete this assessment. Although the SECAP report is not clear as to the time period for analysis, it appears that an evaluation was completed for existing and future conditions.

The report provides output data signifying infiltration and flows in excess of design capacity, tables showing existing and recommended pipe sizes, and a graphical representation of six pipeline capital improvement projects that increase pipe diameter to provide needed capacity.

The SECAP study also identified 18 pipe segments requiring replacement based on CCTV inspection data and National Association of Sewer Service Companies (NASSCO) Pipeline Assessment Certification Program (PACP) condition ratings, and recommended installation of flap gates on existing overflow structures to prohibit tidal flows from entering the sewer system during high tides.

DRAFT

Richmond Wastewater Treatment Master Plan (Carollo, Ongoing)

Veolia and the City are completing a long-term master plan for the City's wastewater treatment plant. The wastewater treatment master plan (WWTMP) evaluates existing facilities for the ability to meet current and 2040 discharge requirements, and develops a long-term strategy to meet future discharge requirements. The WWTMP integrates sustainable elements into the proposed projects, including renewable energy and generation of Class A biosolids. The plan establishes dry weather flows based on population projections developed for the 2006 Boyle master plan, and also uses peak hourly wet weather flow estimates from this plan. Wastewater loadings (biological oxygen demand and total suspended solids), which determine treatment process needs, were assumed to remain constant at current concentrations throughout the planning period.

Currently, the City provides secondary (biological) treatment to all dry weather flows. During extreme wet weather events, the City's NPDES permit allows the City to provide secondary treatment to a portion of wet weather flows, and primary treatment only (screening, primary clarification, and disinfection) to the remaining flows. These primary and secondary treated flows are then combined prior to discharge in a process called "blending." Based on recent discharge permits that have been adopted for other Bay Area wastewater dischargers, it is anticipated that in the next permit renewal cycle, the RWQCB may require that the City phase out blending over a predetermined period of time.

The WWTMP recommends three phases of improvements, for a total estimated cost of $130 million (in 2008 dollars). These phases include:

Phase I: Improvements that are required to meet current discharge requirements

Phase II: Improvements that are required to accommodate future growth

Phase III: Improvements that are required to eliminate wet weather blending

In addition, the WWTMP describes but does not provide costs for Phase IV improvements that would be required to remove ammonia from process stream. These projects would address an NPDES permit requirement that is currently applied to surface water (e.g., river) dischargers only, and may be extended to discharges to the San Francisco Bay in the future.

Collection System Master Planning and O&M Support (West Yost, Ongoing)

Since early 2009, West Yost has provided technical support to Veolia on various projects related to the wastewater collection system. In addition to reviewing the formal planning documents discussed above, West Yost has assisted Veolia and the City with review and evaluation of data collected through ongoing system assessments including the following:

1. Smoke testing (SFE, 2006 and 2008)
2. CCTV inspections (Veolia, ongoing)
3. Flow monitoring (V&A, 2010)
4. Sewer system overflows (RWQCB CIWQS database)

DRAFT

5. Keller Beach Interceptor conceptual design studies (K/J, 2000)
6. Discussions with Veolia staff to understand pending emergency replacement needs

The data collected through these efforts provides increasing clarity as to areas of the collection system with the highest need for repair and replacement. Specifically, projects that are required to meet the Baykeeper settlement agreement mandates comprise $58.8 million in improvements. This list includes $9.6 million in wet weather storage projects that are also identified as part of the wastewater treatment master plan. The list of required projects includes the following:

- Pipeline Repairs and Replacements: Point repairs and pipeline replacements are needed to eliminate the City's most significant pipeline structural defects, including pipe failures and significant offsets. These projects include the Sunset Generator and Pennsylvania emergency repair projects, which are needed to address recent system failures.
- San Pablo Avenue project: Pipelines along San Pablo Avenue and in the surrounding neighborhoods have known structural defects and documented SSOs. This project addresses dry weather overflow issues and provided needed capacity to alleviate wet weather overflows. The project was recently publicly advertised, and received competitive bids.
- Keller Beach Interceptor Replacement project: The City operates an existing pipeline that is currently submerged beneath the San Francisco Bay. The condition of the pipeline is unknown, and manhole lids are severely corroded, prohibiting access for inspection. Sewers upstream of the submerged interceptor have known structural defects and have contributed to SSOs. This project replaces the interceptor and tributary pipelines, in order to avoid potential failure and discharge of raw sewage directly into the San Francisco Bay.
- Capacity Improvements: A placeholder is included for near-term capacity improvement projects that are required to eliminate in-system wet weather overflows. This list will be further defined after completion of a collection system master plan update in late 2010.
- Wet Weather Storage: Storage facilities are required to retain diluted wastewater flows during extreme wet weather events. After the storm event subsides, the stored flows are returned to the collection system for treatment at the treatment plant. The cost of storage is expected to be significantly lower than increasing wastewater treatment plant capacity to handle peak wet weather flows, which occur relatively infrequently. The size and location of needed storage will be finalized through the collection system master plan update.
- Elimination of Stormwater Inflow: Tidal inflow through the City's stormwater system appears to add significant flows to the collection system. This project eliminates direct connections between the City's stormwater system and collection system in tidal areas. Reduction of stormwater inflow, and more specifically, tidal inflow, will reduce conveyance and treatment needs and create immediate cost savings in the overall CIP.

DRAFT

IV. CAPITAL IMPROVEMENT PROJECT PRIORITIES

Following discussions with Veolia and the City, relative priorities for collection system and wastewater treatment plant capital projects are listed in ranked order with 1 denoting the highest priority and 5 denoting a high priority, but less critical than those with higher ranking.

Rank 1: Address life safety issues at the wastewater treatment plant

Rank 2: Meet NPDES permit numerical limits for pollutant discharge

Rank 3: Meet Baykeeper settlement agreement mandates

Rank 4: Meet SSMP and Statewide WDR collection system requirements

Rank 5: Prepare the City for potential NPDES permit requirements

Recommended capital improvements outlined in the City's planning studies were compared using this ranking criteria, as shown in Table 1 on the following page. As a result, the relative project priorities are as follows.

- Specific WWTMP Phase I projects are the highest priority. These projects address life safety at the treatment plant, and are needed to meet current NPDES permit requirements. Projects in Phase I that are scheduled for future implementation include the sludge dewatering and thermal drying projects, which, according to an existing agreement between the City and West County Wastewater District, can be delayed until fiscal year 2014-15. In addition, Phase I plant rehabilitation projects that replace aging equipment are considered critical, but not immediate.
- Sunset Generator and Pennsylvania emergency repair, and San Pablo Avenue replacement projects are also the highest priority, as they correct recent system failures.
- Keller Beach Interceptor, Wet Weather Storage, and Stormwater Inflow Elimination projects are next in priority. These projects are the most critical improvements needed to meet current NPDES permit, Baykeeper, and SSMP requirements.
- Projects to increase capacity and repair failing pipelines within the collection system follow in priority. These projects are important components in meeting Baykeeper and SSMP requirements.
- Wastewater treatment master plan Phase II, III, and IV projects are important to meeting future NPDES requirements, and should be scheduled for completion in future years.

V. CIP PRELIMINARY COSTS AND SCHEDULE

Table 2 summarizes project costs and presents a preliminary implementation schedule. For this TM, costs have been adjusted to reflect the current (2010) cost basis. In order to provide consistency between reports, costs from the WWTMP were escalated by three percent per year for the two years between 2008 and 2010.

DRAFT

Costs are distributed over time with the understanding that the City will have approximately $35 million in available funds through FY2012, and must prioritize the projects that will be completed using these funds. FY 2014 marks the year by which the City must eliminate overflows from the two overflow structures in accordance with the Baykeeper settlement agreement. As shown in Table 2, it appears that prior to FY2012, the City requires additional funds beyond the $35 million available, in order to complete the needed projects within the mandated timeframe

Table 1. Relative Ranking of City's Capital Improvement Projects

Planning Study	Project Description	Needed to Meet the Following Requirement				
		Life Safety at Plant	Current NPDES Permit Requirements	Baykeeper Settlement Terms	SSMP Requirements	Anticipated Future NPDES Requirements
SECAP	Six Capacity Expansion Projects			X	X	
SECAP	18 Projects to Correct Known Structural Defects			X	X	
Wastewater Treatment Master Plan	Phase I Projects	X	X			
	Phase II Projects					X
	Phase III Projects					X
	Phase IV Projects					X
Ongoing Collection System Master Planning	Pipe Repairs and Replacements	X (partial)		X	X	
	San Pablo Avenue project			X	X	
	Keller Beach Interceptor Replacement		X	X	X	
	Capacity Improvements			X	X	
	Wet Weather Storage		X	X	X	
	Elimination of Stormwater Inflow		X	X	X	

DRAFT

Table 2. Project Implementation Schedule and Cash Flow

Project	FY2009-10	FY2010-11	FY2011-12	FY2012-13	FY2013-14	Future	Total
WW Treatment Master Plan Phase I (Critical)	$4,290,000	$9,890,000					$14,180,000[a]
WW Treatment Master Plan Phase I (Sludge Dewatering)						$15,590,000	$15,590,000[a]
WW Treatment Master Plan Phase I (Thermal Drying)						$20,000,000	$20,000,000[b]
WW Treatment Master Plan Phase I (Priority)						$40,035,000	$40,035,000[a]
Sunset Generator & Pennsylvania Emergency Repairs	$1,300,000						$1,300,000[c]
San Pablo Avenue Replacement	$1,200,000						$1,200,000[c]
Keller Beach Interceptor Replacement	$120,000	$1,830,000	$2,700,000	$1,350,000			$6,000,000[c]
WW Treatment Master Plan Phase 1 Wet Weather Storage		$960,000	$2,865,000	$2,865,000	$2,860,000		$9,550,000[a]
Stormwater and Tidal Inflow Diversions	$700,000	$1,770,000	$2,500,000	$4,950,000	$680,000		$10,600,000[d]
Capacity Improvements and Replacement of Failed Pipes	$1,200,000	$3,200,000	$4,800,000	$4,800,000	$4,800,000		$18,800,000[d]
WW Treatment Master Plan Phase II						$37,060,000	$37,060,000[a]
WW Treatment Master Plan Phase III						$12,730,000	$12,730,000[a]
Cogeneration Facility (Not in WW Treatment Master Plan)						$5,000,000	$5,000,000[c]
Subtotal	$8,810,000	$17,650,000	$12,865,000	$13,965,000	$8,340,000	130,415,000	$192,045,000
Veolia PM and CM	$2,114,400	$4,236,000	$3,087,600	$3,351,600	$2,001,600	$31,299,600	$46,090,800
Total	$10,924,400	$21,886,000	$15,952,600	$17,316,600	$10,341,600	$161,714,600	$238,135,800

[a] Estimate from Wastewater Treatment Master Plan escalated to 2010 dollars.
[b] Estimate provided by Veolia. Supersedes preliminary wastewater treatment master plan estimates for thermal drying of $7.1M.
[c] Estimates provided by Veolia.
[d] Estimates are placeholders pending completion of flow studies and updated collection system master plan.

WEST YOST ASSOCIATES
Consulting Engineers

TECHNICAL MEMORANDUM

DATE: March 2, 2010 Project No.: 356-02-09-02

TO: Mark Grushayev, Program Manager

CC: John Hart, Senior Project Manager

FROM: Vivian Housen, R.C.E. #C46324

SUBJECT: Veolia Water / City of Richmond
Pipeline Repair Recommendations Based on CCTV Inaccessible Pipe List

DRAFT

This Technical Memorandum (TM) supplements the TM developed by West Yost Associates (West Yost) in July 2009 that presented an approach for addressing the most critical issues that rendered pipes as inaccessible during closed circuit television (CCTV) inspection activities. Since this time, Veolia Water (Veolia) has completed CCTV of the collection system, and has recorded a condition rating for each pipe segment inspected.

In January 2010, Veolia provided two datasets for review: 1) a list of pipelines that are currently designated as inaccessible; 2) system-wide CCTV records with assigned condition ratings. These January datasets were used to develop the recommendations in this TM. Condition ratings included in the Veolia database were assigned using the National Association of Sewer Service Companies (NASSCO) Pipeline Assessment and Certification Program (PACP) protocol. A NASSCO PACP structural defect rating of 5 (PACP 5) designates a defect that requires repair within 0 to 5 years.

In March 2010, Veolia provided an updated Veolia database of inaccessible pipelines, additional pipeline inspection records, and a City of Richmond record of pipeline inspections. These datasets were used only to confirm that the entire system had been inspected. A comparison of the March records to the Veolia GIS database indicates that 84 of the 3,486 pipe segments (2.4%) do not have a matching inspection record. Veolia staff is reviewing this list to identify and correct nomenclature or other issues that may have prevented these 84 records to be retrieved.

This TM presents an approach for correcting the pipe failures that currently render pipelines as inaccessible for CCTV inspection. Failed pipelines that are adjacent to pipes with at least three occurrences of a PACP 5 are grouped into projects and have the highest priority for repair. This TM locates and attempts to prioritize these priority projects, and also provides conceptual project costs. In addition, this TM provides conceptual costs to remedy all other issues that render pipes

2185 North California Boulevard, Suite 315 Walnut Creek, CA 94566 Phone 925 426-2580 Fax 925 426-2585 e-mail: mail@westyost.com

inaccessible for CCTV inspection. Finally, costs are provided for point repairs to repair pipe sections with less than three occurrences of a PACP 5 rating.

This TM is organized as follows:

- Review of July 2009 Findings
- Summary of January 2010 Datasets
- Development of Project List for Improved CCTV Inspection Access
- Recommended Near-Term Projects and Costs
- Future Inaccessible Pipe Repairs and Costs

REVIEW OF JULY 2009 FINDINGS

The July 2009 dataset included 486 pipe segments that were inaccessible during CCTV inspection. The primary reason that the pipelines could not be accessed was due to offset joints (38%). Intruding laterals (22%) and non-standard manhole configurations (22%) accounted for the next impediments to accessibility. Approximately ten percent of the pipelines were inaccessible due to failed pipes.

In July 2009, the inaccessible pipe segments were grouped to create construction efficiencies, and then combined where appropriate with other planned capital improvement projects. Repair projects were then prioritized as follows:

- Priority 1 – Projects to repair failed pipelines
- Priority 2 – Projects to correct offsets, with emphasis on offsets in close proximity to failed pipelines
- Remaining Projects – Other contributors to inaccessible pipelines were noted. The remedies for these issues, which include manhole configurations, angles in pipe, etc., are not likely to have the added benefit of reducing inflow and infiltration (I&I) or sewer system overflows (SSO). Therefore, the projects that are needed to address these issues were considered lower priority and not evaluated further as part of the July 2009 TM.

SUMMARY OF JANUARY 2010 DATASETS

The January 5, 2010 inaccessible dataset is summarized in Table 1.

DRAFT

Table 1. Summary of Inaccessible Pipelines

Cause	Number	Percent
Debris and Grease	98	20%
Manhole channel	94	19%
Offset joint	79	16%
Water level	72	15%
No Access	41	8%
Intruding lateral	31	6%
Pipe defect	29	6%
Keller Beach	22	5%
Other obstruction	12	3%
Angle bend	8	2%
Total	486	100%

Similar to the July 2009 data, the issues hindering CCTV inspection that are also the largest contributors to increased I&I are pipe defects and offset joints, which were found in 22 percent of the inaccessible pipelines.

The January 2010 CCTV and PACP Rating dataset included 236 pipe segments with at least three occurrences of a PACP 5 rating (of this total, 53 segments had at least 6 occurrences of PACP 5). In addition, 191 segments had 2 occurrences of PACP 5 and 619 segments had 1 occurrence of PACP 5.

DEVELOPMENT OF PROJECT LIST FOR IMPROVED CCTV INSPECTION ACCESS

Pipeline segments with point defects that rendered the segment as inaccessible, or with less than three occurrences of PACP 5, were assumed to require point repairs. Pipe segments that were coincident with pipe segments having at least three occurrences of PACP 5 were considered for full replacement. Offset joints that were located adjacent to these pipelines were also reviewed and assigned unit costs for their repair. The repair methods and assumptions used to develop project costs are as follows:

1. Projects to repair failed pipes were considered high priority. It was assumed that these issues, as well as isolated occurrences of PACP 5, can be addressed through point repairs. $5,000 per point repair was applied.
2. Projects to repair pipes with at least three occurrences of PACP 5 were considered high priority. It was assumed that these pipe segments require replacement from manhole to manhole. A unit cost of $175 per lineal foot was applied to these projects.

DRAFT

Table 2. Recommended Projects and Costs

Reference Number	Project Name	Pipe Segment Locations	Approximate Length	Approximate Cost
1	San Pablo Avenue Supplement ★ (Tiller Park)	• Roosevelt Ave., Ventura St., McLaughlin St., Humboldt St., Silva Ave., Key Blvd.	1 point repair 1 offset repair 1,225 lf remove and replace (R/R)	$306,000
2	Bush Avenue ★ (Richmond High)	• Bush Ave., Pine Ave.	3 point repairs 525 lf R/R	$144,000
3	Rheem Avenue	• Rheem Ave.	1 point repair 1,050 lf R/R	$255,000
4	Hellings Avenue	• Hellings Ave.	1 point repair 1,050 lf R/R	$255,000
5	Lowell Avenue	• Lowell Ave., Rheem Ave.	1,050 lf R/R	$248,000
6	McBryde Avenue ★ (Hospital)	• McBryde Ave., Lincoln Ave. (includes trunk sewers)	1 point repair 525 lf R/R	$131,000
7	Esmond Avenue	• Esmond Ave., Gaynor Ave.	1 point repair 1,050 lf R/R	$255,000
8	Garvin Avenue	• Garvin Ave., Humboldt St.	1 point repairs 2 offset repair 875 lf R/R	$234,000
9	16th Street	• 16th St. (12” diameter)	350 lf R/R	$83,000
10	21st Street	• 21st St., 22nd St., Nevin Ave.	1 point repair 1 offset repair 800 lf R/R	$206,000
11	Barrett Avenue	• Barrett Ave.	1 point repair	$7,000
12	43rd Street	• 43rd Street, Wilson Ave., Swans Way	1 point repair 1,050 lf R/R	$255,000
13	Center Avenue	• Center Ave., 29th Street	2 point repairs 1 offset repair 1,050 lf R/R	$272,000
14	35th Street	• 35th St., Ohio Ave., Waller Ave, 38th St.	3 point repairs 1 offset repair 700 lf R/R	$196,000
15	Cutting Blvd.	• Cutting Blvd., 20th St., 22nd St., Potrero Ave. (includes trunk sewer)	1 point repair 1 offset repair 1,225 lf R/R	$227,000
15	Potrero Avenue @ 22nd Street	• Potrero Ave., 22nd to Foothill Ave.	600 lf R/R	$140,000
16	Fall Ave. ★ (Kennedy High)	• Fall Ave., Escuela Ct.	1 point repair 2 offset repairs	$27,000
17	Potrero Ave	• S. 41st St.., Potrero Ave., Rosewood Ave.	1 point repair 1 offset repair 1,050 lf R/R	$265,000
18	Campbell Street	• Campbell St., Fallon Ave.	2 point repairs 1,225 lf R/R	$303,000
			Total	$3,809,000

DRAFT

3. Projects to correct offsets were also reviewed and cost estimates developed, presuming that because the offsets would not allow passage of a CCTV camera, they are severe and require correction. For the purposes of this analysis, only those offsets that are located in close proximity to failed pipes were considered for capital improvement projects. It was assumed that offsets can be addressed through the installation of two new pipe sections. $7,000 per offset correction was applied.
4. Additional mobilization cost of 5 percent and a 30 percent contingency were added to the above cost.

This methodology results in 18 projects to be addressed in the near-term. These projects are shown on the attached map and listed in Table 2. By addressing structural point repairs, joint offsets, and pipeline rehabilitation as part of a comprehensive replacement program, the City will implement a cost effective repair strategy with the multiple benefits of improving maintenance, reducing I&I, and improving long-term reliability.

These projects do not address all of the issues that render pipelines inaccessible for CCTV inspection. The remaining issues are described and assigned conceptual costs later in this TM.

RECOMMENDED NEAR-TERM PROJECTS AND COSTS

Table 2 presents a list of the 18 recommended projects that resulted from this analysis. The total estimated cost for these projects is $3.8 million. The highest priority project listed is the San Pablo Avenue Supplement. This project adds pipes with known structural defects to the San Pablo Avenue Replacement Project, for which bids have been received by the City.

The remaining projects listed in Table 2 are generally equal in priority. However, those projects located close to schools and hospitals are indicated with a "star" and could be raised in importance.

Projects 6 and 15 include trunk sewers (i.e., 10-inch diameter and greater) and are recommended for deferral until the completion of the City's hydraulic model update in late 2010. The hydraulic model update may conclude that these trunk sewers should be upsized in lieu of replacement in kind.

None of the projects appear to coincide with areas of high tidal influence. Tidal influence will be reviewed as part of the City's hydraulic model update. Because tidal influence could be a more significant contributor to I&I than pipe defects, this list should be re-evaluated after completion of the update.

FUTURE INACCESSIBLE PIPE REPAIRS AND COSTS

In addition to the repairs listed in Table 2, the January 2010 dataset included other issues that render pipes inaccessible for CCTV inspection. West Yost recommends that these issues receive continued analysis. Table 3 lists the remaining issues, and conceptual costs required to address these issues. Table 3 also includes 1001 additional point repairs that are needed to eliminate all

DRAFT

occurrences of PACP 5 (191 pipe segments requiring 2 point repairs and 619 pipe segments requiring 1 point repair). The total cost presented in Table 3 is $19.8 million.

Table 3. Additional Issues Rendering Pipes Inaccessible

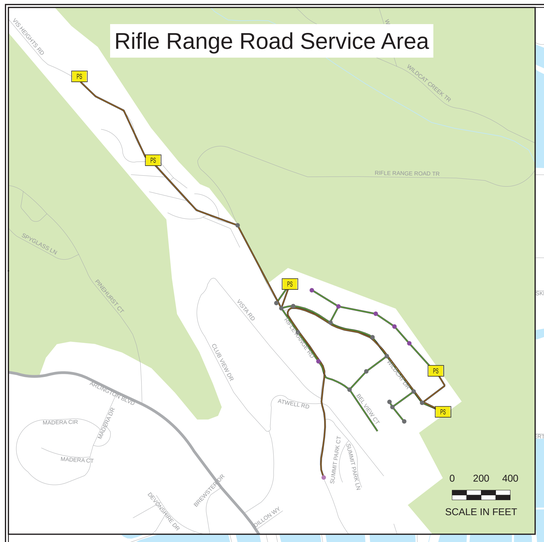
Issue	Number of Pipes	Potential Solution	Unit Repair Cost (incl. mob & contingency)	Total Repair Cost
Debris and Grease	98	Maintenance	n/a	
Manhole channel	94	New or rechanneled manhole	$7,500 ea	$705,000
Offset joint	67	Replace 2 pipe sections	$10,125 ea	$679,000
Water level	72	Replace approx 72 * 300 = 21,600 lf	$236.25/lf	$5,103,000
No Access	41	New manhole	$10,000 ea	$410,000
Intruding lateral	31	Cut lateral	$750 ea	$23,000
Keller Beach	22	CIP	$6,000,000	$6,000,000
Other obstruction	12	Treat as point repair	$6,750 ea	$81,000
Angle bend	8	New manhole	$10,000 ea	$80,000
Isolated PACP 5	1001	Point repair	$6,750 ea	$6,757,000
Total				$19,838,000

In the future, the recommendations provided in this TM should be integrated into a comprehensive, prioritized Capital Improvement Program that also addresses other known structural and capacity issues within the system.

DRAFT

FIGURE 1

City of Richmond
Sewer System Assessment
PIPELINE OBSTRUCTIONS THAT PREVENT COMPLETION OF CCTV INSPECTION



0 375 750
SCALE IN FEET

NOTES:

- Inaccessible pipe obstruction category "Other" includes the following:
  - Diameter
  - Multiple Causes (Intruding Lateral & Offset Joint)
  - Pipe Intrusion
  - Abandoned Pipe
  - Cast Iron Encrustation
  - Defective Lateral
  - Encrustation
  - Intruding Lateral/Not Inaccessible
  - Multiple Causes (Pipe Failure & Offset) Joint
  - Not Inaccessible
- A total of 19 pipes are in the "Other" category.

LEGEND:

Sewer Structure
- PS — Pump Station
- WTP — Treatment Plant

Sewer Manhole
- Split
- Stege
- Active
- Buried
- West County District

Force Main

Gravity Main
- Active
- Relief
- Stege
- West County District

Inaccessible Pipe Obstruction
- Offset Joint
- Manhole Channel
- Intruding Lateral
- Pipe Failure
- Angle Bend
- Other

Street

Park

Water Feature

WEST YOST ASSOCIATES
Consulting Engineers

O:\CW\560\02-09-02\GIS\Fig1_InaccessiblePipes.mxd

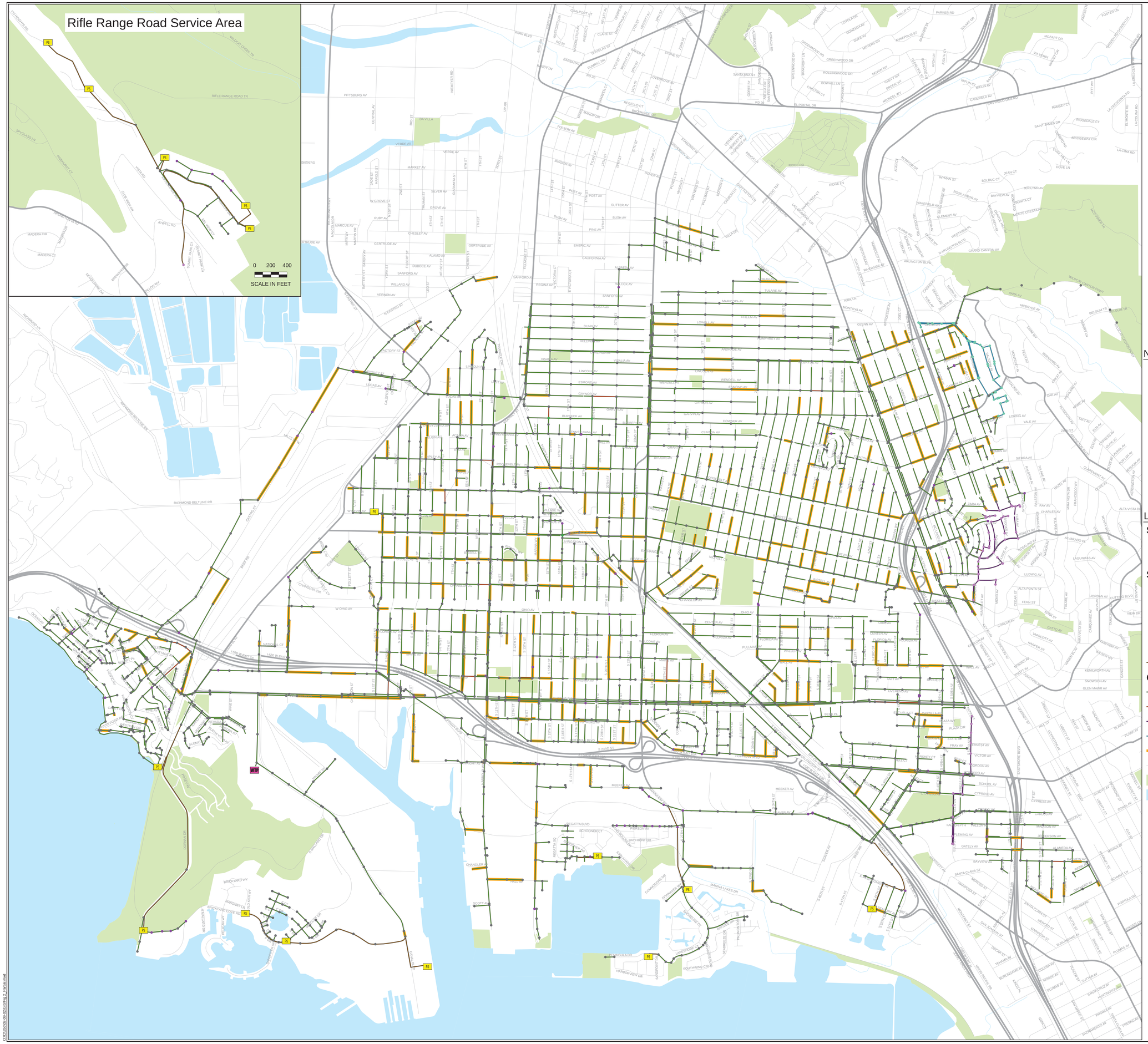


FIGURE 2

City of Richmond
Sewer System Assessment
LOCATIONS OF PARTIAL CCTV INSPECTION

NOTES:

LEGEND:

Sewer Structure
- Pump Station
- Treatment Plant

Sewer Manhole
- Split
- Stege
- Active
- Buried
- West County District

- Force Main

Gravity Main
- Active
- Relief
- Stege
- West County District
- Partial Inspection Location
- Street
- Park
- Water Feature

WEST YOST ASSOCIATES
Consulting Engineers

O:\CM\5602.09-02\GIS\Fig 2_Partial.mxd

APPENDIX G

Capacity Improvement Project Detailed CIP Cost Estimates

Barrett Avenue Relief Sewer

US Manhole	DS Manhole	Original Diam.	Length, ft	New Diam, in	Estimated Cost	Unit Cost, $/ft
I12MH1061	I11MH1464	n/a	2498	24	$ 719,338	288
I11MH1464	I11MH1414	n/a	521	30	$ 187,632	360
I11MH1414	I9MH1093	n/a	3588	30	$ 1,291,536	360
I9MH1093	I9MH1096	n/a	172	36	$ 74,390	432
I9MH1096	I9MH2253	n/a	385	36	$ 166,234	432
I9MH2253	I9MH1656	n/a	154	36	$ 66,658	432
I9MH1656	J9MH1677	n/a	321	36	$ 138,715	432
J9MH1677	J9MH1674	n/a	313	36	$ 135,173	432
J9MH1674	J10MH2266	n/a	856	36	$ 369,792	432
		Subtotal 1	8,808		$ 3,149,467	
				5% of Subtotal 1 or $10,000	$ 157,473	
				Manholes, construction constraints, etc.	$ 2,362,100	
					$ 5,669,041	
				30% of Subtotal 2	$ 1,700,712	
					$ 7,369,753	
				Planning and Design 10% of total construction	$ 736,975	
				Construction Admin and Mgmt 8% of total construction	$ 589,580	
					$ 8,696,000	

13th Street Capacity Improvement Project

US Manhole	DS Manhole	Original Diam.	Length, ft	Relief Diam. in	Estimated Cost	Unit Cost, $/ft
L11MH1628	L11MH1630	10	293	8	$ 28,080	96
L11MH1630	L11MH1634	10	288	8	$ 27,686	96
L11MH1634	L11MH1635	10	289	8	$ 27,706	96
L11MH1635	L11MH1636	10	285	8	$ 27,370	96
L11MH1636	L11MH2091	10	282	8	$ 27,082	96
L11MH2091	L10MH422	10	219	8	$ 21,034	96
L10MH422	K10MH2087	10	415	8	$ 39,792	96
K10MH2087	K10MH2257	10	425	8	$ 40,790	96
K10MH2257	K10MH1744	6	553	12	$ 79,603	144
K10MH1744	K10MH1745	6	500	12	$ 72,029	144
K10MH1745	K10MH1746	6	501	12	$ 72,086	144
K10MH1746	K10MH1747	6	441	12	$ 63,547	144
K10MH1747	K10MH1739	8	269	12	$ 38,794	144
K10MH1739	K10MH2208	8	271	18	$ 58,601	216
K10MH2208	K10MH2205	8	260	18	$ 56,117	216
K10MH2205	K10MH1728	10	260	21	$ 65,621	252
K10MH1728	K10MH2195	10	260	21	$ 65,621	252
K10MH2195	J10MH2194	10	260	21	$ 65,596	252
J10MH2194	J10MH2191	10	261	21	$ 65,646	252
J10MH2191	J10MH1774	10	251	21	$ 63,328	252
J10MH1774	J10MH1776	10	17	21	$ 4,208	252
J10MH1776	J10MH1579	21	109	24	$ 31,363	288
J10MH1579	J10MH1773	21	83	24	$ 23,760	288
J10MH1773	J10MH1772	21	38	24	$ 10,800	288
J10MH1772	J10MH2266	21	587	24	$ 169,085	288
J10MH2266	J9MH1125	21	581	32	$ 223,181	384
J9MH1125	J9MH1127	21	528	32	$ 202,714	384
J9MH1127	J9MH128	21	438	32	$ 168,230	384
J9MH128	J9MH134	24	85	32	$ 32,755	384
J9MH134	J9MH129	24	242	32	$ 92,928	384
J9MH129	J9MH130	24	198	32	$ 76,147	384
J9MH130	J9MH131	24	182	32	$ 69,773	384
J9MH131	J9MH133	24	239	32	$ 91,776	384
J9MH133	J9MH933	24	510	32	$ 195,994	384
J9MH933	J8MH935	24	387	32	$ 148,646	384
J8MH935	J8MH410	33	31	32	$ 11,904	384
J8MH410	J8MH931	33	334	32	$ 128,141	384
		Subtotal 1	11,172		$ 2,687,532	
				5% of Subtotal 1 or $10,000	$ 134,377	
				Manholes, construction constraints, etc.	$ 2,015,649	
					$ 4,837,558	
				30% of Subtotal 2	$ 1,451,267	
					$ 6,288,825	
				Planning and Design 10% of total construction	$ 628,882	
				Construction Admin and Mgmt 8% of total construction	$ 503,106	
					$ 7,421,000	

Cutting Blvd Capacity Improvement Project

Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	Relief Diam in	Estimated Cost	Unit Cost, $/ft
	G11MH877	G11MH881	24	276	21	$ 69,628	252
	G11MH881	G11MH883	24	326	21	$ 82,202	252
	G11MH883	G11MH884	24	431	21	$ 108,511	252
	G11MH884	G11MH1214	24	507	21	$ 127,865	252
	G11MH1214	G11MH1216	24	264	21	$ 66,478	252
	G11MH1216	GHMH1222	24	286	21	$ 72,122	252
	GHMH1222	G11MH2455	24	464	24	$ 133,603	288
	G11MH2455	G11MH1224	24	107	24	$ 30,730	288
	G11MH1224	G11MH1227	24	265	24	$ 76,349	288
	G11MH1227	G10MH1587	24	515	24	$ 148,378	288
	G10MH1587	G10MH1590	24	266	24	$ 76,464	288
	G10MH1590	G10MH1594	24	509	24	$ 146,650	288
	G10MH1594	G10MH1505	24	404	24	$ 116,381	288
	G10MH1505	G10MH1508	24	409	24	$ 117,907	288
	G10MH1508	G10MH1512	24	457	24	$ 131,731	288
	G10MH1512	G10MH1516	24	468	24	$ 134,640	288
	G10MH1516	G9MH1288	24	258	24	$ 74,390	288
			Subtotal 1	6,213		$ 1,714,028	
					5% of Subtotal 1 or $10,000	$ 85,701	
					Manholes, construction constraints, etc.	$ 1,285,521	
						$ 3,085,251	
					30% of Subtotal 2	$ 925,575	
						$ 4,010,826	
					Planning and Design 10% of total construction	$ 401,083	
					Construction Admin and Mgmt 8% of total construction	$ 320,866	
						$ 4,733,000	

Additional Notes:
ENR CCI San Francisco Region (August 2010) = 9909.67

Hoffman Boulevard Capacity Improvement Project

Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	New Diam, in	Estimated Cost	Unit Cost, $/ft
	F11MH1238	F11MH874	10	237	15	$ 42,624	180
	F11MH874	F11MH1236	8	194	15	$ 34,920	180
	F11MH1236	F11MH1240	8	236	15	$ 42,480	180
	F11MH1240	F11MH2594	8	234	15	$ 42,048	180
	F11MH2594	F11MH859	8	209	15	$ 37,656	180
	F11MH859	F11MH2487	8	498	15	$ 89,712	180
	F11MH2487	F11MH860	8	58	15	$ 10,368	180
	F11MH860	F11MH2488	12	120	15	$ 21,618	180
	F11MH2488	F11MH1937	12	512	15	$ 92,232	180
	F11MH1937	F10MH1639	12	289	15	$ 52,020	180
	F10MH1639	F10MH1557	12	290	15	$ 52,236	180
	F10MH1557	F10MH1558	12	294	15	$ 52,884	180
	F10MH1558	F10MH1582	12	302	15	$ 54,288	180
	F10MH1582	F10MH2161	12	149	15	$ 26,748	180
	F10MH2161	F10MH2158	12	154	15	$ 27,648	180
	F10MH2158	F10MH2157	12	305	15	$ 54,954	180
	F10MH2157	F10MH2491	12	105	15	$ 18,846	180
	F10MH2491	F10MH2156	12	202	15	$ 36,324	180
	F10MH2156	F10MH2155	12	321	15	$ 57,834	180
	F10MH2155	F10MH2492	12	78	15	$ 13,986	180
	F10MH2492	F10MH1502	15	284	n/a		
	F10MH1502	F10MH1501	15	308	n/a		
	F10MH1501	F10MH1871	12	21	15		
	F10MH1871	F10MH2489	15	254	n/a		
	F10MH2489	F10MH2490	15	215	18	$ 46,505	216
	F10MH2490	F9MH1330	15	269	18	$ 58,126	216
	F9MH1330	G9MH1289	15	364	18	$ 78,516	216
	G9MH1289	G9MH1290	15	37	18	$ 8,035	216
			Subtotal 1	5,692		$ 1,052,608	
					5% of Subtotal 1 or $10,000	$ 52,630	
					Manholes, construction constraints, etc.	$ 789,456	
						$ 1,894,694	
					30% of Subtotal 2	$ 568,408	
						$ 2,463,102	
					Planning and Design 10% of total construction	$ 246,310	
					Construction Admin and Mgmt 8% of total construction	$ 197,048	
						$ 2,906,000	

Additional Notes:

ENR CCI San Francisco Region (August 2010) = 9909.67

1st Street Capacity Improvement Project							
Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	Relief Diam., in	Estimated Cost	Unit Cost, $/ft
	J9MH1685	J9MH1684	12	160	18	$ 34,452	216
	J9MH1684	J9MH1683	12	84	18	$ 18,187	216
	J9MH1683	J9MH1682	12	331	18	$ 71,496	216
	J9MH1682	I9MH1664	12	400	18	$ 86,443	216
	I9MH1664	I9MH1111	16	349	24	$ 100,368	288
	I9MH1111	I9MH1108	16	359	24	$ 103,421	288
	I9MH1108	I9MH1107	18	256	24	$ 73,843	288
	I9MH1107	I9MH1106	18	568	24	$ 163,526	288
	I9MH1106	I9MH1100	18	290	24	$ 83,578	288
	I9MH1100	I9MH1099	18	289	24	$ 83,318	288
	I9MH1099	I9MH1101	18	431	24	$ 124,013	288
	I9MH1101	H9MH1718	18	479	27	$ 155,293	324
	H9MH1718	H9MH1748	20	586	27	$ 189,767	324
	H9MH1748	H9MH143	20	347	27	$ 112,396	324
	H9MH143	H9MH145	20	32	27	$ 10,368	324
	H9MH145	H9MH1130	20	138	27	$ 44,582	324
	H9MH1130	H9MH1259	18	98	27	$ 31,817	324
	H9MH1259	H9MH1258	20	12	27	$ 3,856	324
	H9MH1258	H9MH1261	20	42	27	$ 13,511	324
	H9MH1261	H9MH2398	20	309	27	$ 100,213	324
	H9MH2398	G9MH2397	20	139	27	$ 44,874	324
	G9MH2397	G9MH1143	18	184	27	$ 59,519	324
	G9MH1143	G9MH1145	18	391	27	$ 126,781	324
	G9MH1145	G9SF728	18	134	27	$ 43,481	324
	G9SF728	G9MH418	21	256	27	$ 82,976	324
	G9MH418	G9MH1319	21	103	27	$ 33,404	324
	G9MH1319	G9MH1323	24	232	27	$ 75,038	324
	G9MH1323	G9MH1324	24	19	27	$ 6,253	324
	G9MH1324	G9MH2251	24	324	27	$ 104,879	324
	G9MH2251	G9MH2250	24	10	27	$ 3,337	324
	G9MH2250	G9MH1314	27	44	27	$ 14,191	324
	G9MH1314	G9MH1312	27	98	27	$ 31,687	324
	G9MH1312	G9MH1311	27	43	27	$ 13,770	324
			Subtotal 1	7,535		$ 2,244,640	
					5% of Subtotal 1 or $10,000	$ 112,232	
					Manholes, construction constraints, etc.	$ 1,683,480	
						$ 4,040,351	
					30% of Subtotal 2	$ 1,212,105	
						$ 5,252,457	
					Planning and Design 10% of total construction	$ 525,246	
					Construction Admin and Mgmt 8% of total construction	$ 420,197	
						$ 6,198,000	

Additional Notes:
ENR CCI San Francisco Region (August 2010) = 9909.67

MacDonald Ave at 23rd Street Capacity Improvement Project

Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	New Diam, in	Estimated Cost	Unit Cost, $/ft
	H11MH1486	H11MH1175	10	240	12	$ 34,517	144
	H11MH1175	H11MH1174	10	251	12	$ 36,086	144
	H11MH1174	H11MH1173	10	250	12	$ 35,957	144
	H11MH1173	H11MH1172	10	247	12	$ 35,539	144
	H11MH1172	H11MH1171	10	253	12	$ 36,389	144
	H11MH1171	H11MH1158	10	251	12	$ 36,072	144
	H11MH1158	H11MH1157	10	264	12	$ 38,059	144
	H11MH1157	I11MH1470	12	347	15	$ 62,442	180
			Subtotal 1	2,101		$ 315,061	
					5% of Subtotal 1 or $10,000	$ 15,753	
					Manhole repairs, lateral connections, cleanouts, construction constraints, etc.	$ 315,061	
						$ 645,875	
					30% of Subtotal 2	$ 193,763	
						$ 839,638	
					Planning and Design 10% of total construction	$ 83,964	
					Construction Admin and Mgmt 8% of total construction	$ 67,171	
						$ 991,000	

Additional Notes:
ENR CCI San Francisco Region (August 2010) = 9909.67

Virginia Way at S. Harbour Way Capacity Improvement Project

Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	New Diam, in	Estimated Cost	Unit Cost, $/ft
	G10MH1523	G10MH1521	10	276	12	$ 39,773	144
	G10MH1521	G10MH1520	10	241	12	$ 34,704	144
	G10MH1520	G10MH1517	10	249	12	$ 35,856	144
	G10MH1517	G9MH1284	10	256	12	$ 36,893	144
			Subtotal 1	1,022		$ 147,226	
					5% of Subtotal 1 or $10,000	$ 10,000	
					Manhole repairs, lateral connections, cleanouts, construction constraints, etc.	$ 147,226	
						$ 304,451	
					30% of Subtotal 2	$ 91,335	
						$ 395,787	
					Planning and Design 10% of total construction	$ 75,000	
					Construction Admin and Mgmt 8% of total construction	$ 31,663	
						$ 502,000	

Additional Notes:

ENR CCI San Francisco Region (August 2010) = 9909.67

San Pablo Avenue Capacity Improvement Project

Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	Relief Diam in	Estimated Cost	Unit Cost, $/ft
	J13MH175	J13MH728	10	367	12	$ 52,790	144
	J13MH728	J13MH727	10	305	12	$ 43,906	144
	J13MH727	J13MH720	10	381	12	$ 54,821	144
	J13MH720	J13MH722	10	279	12	$ 40,147	144
	J13MH722	J13MH292	10	319	12	$ 45,965	144
	J13MH292	I13MH291	10	229	12	$ 32,904	144
	I13MH291	I13MH73	10	224	12	$ 32,227	144
	I13MH73	IK13MH68	12	213	12	$ 30,701	144
	IK13MH68	I13MH40	10	206	12	$ 29,592	144
	I13MH40	I13MH38	10	61	12	$ 8,712	144
	I13MH38	I13MH41	10	187	12	$ 26,870	144
	I13MH41	I13MH2093	16	327	n/a		
	I13MH2093	I13MH47	16	200	n/a		
	I13MH47	I13MH46	16	125	n/a		
	I13MH46	I13MH45	16	153	n/a		
	I13MH45	I13MH44	16	135	21	$ 34,020	252
	I13MH44	H13MH619	16	502	21	$ 126,454	252
	H13MH619	H13MH249	16	651	21	$ 164,153	252
	H13MH249	H13MH1563	18	141	21	$ 35,633	252
	H13MH1563	H13MH240	18	403	21	$ 101,455	252
	H13MH240	H13MH236	20	100	21	$ 25,200	252
	H13MH226	H13MH229	8	275	10	$ 32,964	120
	H13MH229	H13MH244	8	204	10	$ 24,444	120
	H13MH244	H13MH248	8	78	10	$ 9,348	120
	H13MH248	H13MH249	8	46	10	$ 5,472	120
	I13MH2095	I13MH37	12	448	15	$ 80,604	180
			Subtotal 1	5,750		$ 1,038,382	
					5% of Subtotal 1 or $10,000	$ 51,919	
					Manholes, construction constraints, etc.	$ 778,786	
						$ 1,869,087	
					30% of Subtotal 2	$ 560,726	
						$ 2,429,813	
					Planning and Design 10% of total construction	$ 242,981	
					Construction Admin and Mgmt 8% of total construction	$ 194,385	
						$ 2,867,000	

Additional Notes:

ENR CCI San Francisco Region (August 2010) = 9909.67

Carlson Avenue Capacity Improvement Project

Priority	US Manhole	DS Manhole	Original Diam.	Length, ft	New Diam, in	Estimated Cost	Unit Cost, $/ft
	G11MH838	G11MH841	12	470	15	$ 84,618	180
	G11MH841	G11MH842	12	39	15	$ 6,948	180
	G11MH842	G11MH2416	12	210	15	$ 37,782	180
	G11MH2416	G11MH843	12	496	15	$ 89,190	180
	G11MH843	G11MH844	12	511	15	$ 92,016	180
	G11MH844	G11MH880	12	635	15	$ 114,318	180
	G11MH880	F11MH860	12	58	15	$ 10,368	180
			Subtotal 1	2,418		$ 435,240	
					5% of Subtotal 1 or $10,000	$ 21,762	
					Manhole repairs, lateral connections, cleanouts, construction constraints, etc.	$ 435,240	
						$ 892,242	
					30% of Subtotal 2	$ 267,673	
						$ 1,159,915	
					Planning and Design 10% of total construction	$ 115,991	
					Construction Admin and Mgmt 8% of total construction	$ 92,793	
						$ 1,369,000	

Additional Notes:

ENR CCI San Francisco Region (August 2010) = 9909.67