Delaware County Regional Water Quality Control Authority (DELCORA)
CSO Long Term Control Plan Update

Existing Service Area Characterization Report (Final)

August 2017

GREELEY AND HANSEN

REPORT SIGNATURE COVER SHEET

Signature of this cover signifies agreement with the content of the DELCORA Existing Service Area Characterization Report.

I certify under penalty of law that the document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

DELCORA MANAGEMENT		
Executive Director	*Signature*	8/8/17 *Date*
DELCORA ENGINEERING		
Director of Engineering	*Signature*	8/8/17 *Date*
DELCORA OPERATIONS AND MAINTENANCE		
Director of Operation and Maintenance	*Signature*	8/8/2017 *Date*

REVISION CONTROL

REV. NO.	DATE ISSUED	PREPARED BY	DESCRIPTION OF CHANGES

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Section 1 Introduction

1.1 Introduction

The Delaware County Regional Water Quality Control Authority (DELCORA) is a municipal wastewater authority that owns, operates and maintains collection systems that serve approximately a half-million people in southeastern Pennsylvania, including 45 municipalities in Delaware and Chester Counties, and is responsible for the collection, transmission, treatment and disposal of approximately 65 million gallons per day (MGD) of wastewater generated in southeastern Pennsylvania. DELCORA operates a Combined Sewer System (CSS) that is comprised of sewer sections that accept both stormwater and sanitary wastewater, which is treated at DELCORA's Western Regional Treatment Plant (WRTP).

Under National Pollutant Discharge Elimination System (NPDES) Permit No. PA0027103, DELCORA is authorized to discharge from the Western Regional Treatment Plant (Outfall 001), four stormwater outfalls at the WRTP (028-031) and from twenty-six (26) combined sewer overflow (CSO) regulators that discharge to twenty-five (25) CSO outfalls (002-027, 032, 033), and then discharge to the Delaware River, Chester Creek and/or Ridley Creek. CSOs are point source discharges that must be provided control measures in accordance with the Federal Clean Water Act and the 1994 National CSO Policy. CSO are allowed to discharge only when flows in the CSS exceed the conveyance or treatment capacities of the system during wet weather periods, and dry weather overflows are prohibited.

DELCORA is in the process of developing a Long Term Control Plan (LTCP) Update for the Combined Sewer System as part of a Consent Decree entered with the United States Environmental Protection Agency (USEPA or EPA) and the Pennsylvania Department of Environmental Protection (PADEP or DEP). Paragraph V.A.16 of the Consent Decree requires DELCORA to submit an Existing Service Area Characterization Report to the USEPA and PADEP for review and approval.

This Existing Service Area Characterization Report has been prepared to fulfill the requirements of Paragraph V.A.16 of the Consent Decree, and of the federal CSO Control Policy Section II.C.1 – Characterization, Monitoring and Modeling of the Combined Sewer System. This Service Area Characterization Report presents the results to characterize, monitor and model DELCORA's combined sewer system, and incorporates the conclusions about Sensitive Areas that were previously determined in DELCORA's report *Identification of Sensitive Areas and Pollutants of Concerns* (Greeley and Hansen, 2016c).

1.2 Regulatory Requirements

On August 17, 2015, a Consent Decree was lodged in the United States District Court for the Eastern District of Pennsylvania that requires DELCORA to complete and submit a revised and updated Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) to the United States Environmental Protection Agency (USEPA or EPA) and the Pennsylvania Department of Environmental Protection (PADEP or DEP) for review and approval. Consent Decree Paragraph V.A.16 (Existing Service Area Characterization) requires that within two years after the Date of Lodging of the Consent Decree, DELCORA shall submit to the USEPA and PADEP a System Characterization Report for review and

approval. Details of the Consent Decree requirements and the associated regulatory requirements for the Existing Service Area Characterization are respectively found below in Sections 1.2.1.
Requirements from the Consent Decree

The primary requirements for the Existing Service Area Characterization Report are established in the Consent Decree. Paragraph V.A.16 of the Consent Decree, Existing Service Area Characterization, states that:

> *"Not later than two years (24) months after the Date of Lodging of the Consent Decree, DELCORA shall submit a characterization of the Model Area that includes all of the information required by CSO Control Policy Section II.C.1 and associated guidance to Plaintiffs for review and approval in accordance with the requirements of Section VI (Review and Approval of Submittals). The characterization shall include, but not be limited to, the following:*
>
> *DELCORA shall use the updated, calibrated, and validated H&H Model to characterize the expected volume, frequency, and duration of CSO discharge events from each CSO during the Typical Year, based on an inter-event period of twelve (12) hours;*
>
> *DELCORA shall incorporate the results of its investigation of Sensitive Areas;*
>
> *DELCORA shall provide a characterization of current water quality in its Receiving waters, based upon all available sampling data, and its efforts to identify POCs.*
>
> *The characterization submitted pursuant to this paragraph shall include the entire model Area, including the hydrology (i.e., runoff) from and within the entire Model Area."*

Additionally, the Consent Decree requires Rainfall and Flow Monitoring in Paragraph V.A.14.d. that:

> *"Rainfall and flow monitoring that shall be carried out in accordance with current good industry practice for a period of at least twelve (12) months, in accordance with the schedule included in the approved plan. Rainfall data shall be obtained at a minimum effective density of 1 gauge/virtual radar-based gauge per square kilometer, for the entire Model Area. Flow monitoring shall be carried out using sufficient monitors to allow the accurate characterization of dry and wet weather flows for the entire Model Area, and the response of each CSO to wet weather flows."*

1.2.1 Requirements from the USEPA's CSO Control Policy

Additional requirements for the Existing Service Area Characterization Report are established in the USEPA's CSO Control Policy (USEPA, 1994). Section II.C.1 of the CSO Control Policy "Characterization, Monitoring and Modeling of the Combined Sewer System" states:

> *"In order to design a CSO control plan to adequately meet the requirements of the CWA, a permittee should have a thorough understanding of its sewer system, the response of the system to various precipitation events, the characteristics of the overflows, and the water quality impacts that result from CSOs. The permittee should adequately characterize through monitoring,*

modelling, and other means as appropriate, for a range of storm events, the response of its sewer system to wet weather events including the number, location and frequency of CSOs volume, concentration and mass of pollutants discharged and the impacts of the CSOs on the receiving waters and their designated uses."

The CSO Control Policy states that the major elements of a sewer system characterization include:
Rainfall Records

"The permittee should examine the complete rainfall record for the geographic area of its existing CSS using sound statistical procedures and best available data. The permittee should evaluate flow variations in the receiving water body to correlate between CSOs and receiving water conditions."

Combined Sewer System Characterization

"The permittee should evaluate the nature and extent of its sewer system through evaluation of available sewer system records, field inspections and other activities necessary to understand the number, location and frequency of overflows and their location relative to sensitive areas and to pollution sources in the collection system, such as indirect significant industrial users."

CSO Monitoring

"The permittee should develop a comprehensive, representative monitoring program that measures the frequency, duration, flow rate, volume and pollutant concentration of CSO discharges and assesses the impact of the CSOs on the receiving waters."

Modeling

"Modeling of a sewer system is recognized as a valuable tool for predicting sewer system response to various wet weather events and assessing water quality impacts when evaluating different control strategies and alternatives. EPA supports the proper and effective use of models, where appropriate, in the evaluation of the nine minimum controls and the development of the long-term CSO control plan."

1.3 Contents of this Report

To satisfy the requirements of DELCORA's Consent Decree and of the CSO Control Policy, this Existing Service Area Characterization Report provides a comprehensive characterization of DELCORA's combined sewer system and of the CSS monitoring and modeling that DELCORA has completed. In addition to describing the characteristics of the wastewater collection system, this report presents the results of DELCORA's rainfall and flow monitoring programs, its receiving water monitoring program, and the results from the H&H model from the typical year for the Combined Sewer System.

Table 1-1 lists the individual sections of the Report and contents.

Table 1-1 DELCORA Existing Service Area Characterization Report

Section	Description
Section 1 Introduction	This section introduces DELCORA's system, the Consent Decree requirements, requirements from the USEPA's CSO Control Policy, as well as individual sections of the Plan.
Section 2 Overview of DELCORA's Facilities and Service Areas	This section provides an overview of DELCORA's facilities, a description of DELCORA's Service Areas, an overview of DELCORA's treatment facilities, and an overview of DELCORA's combined sewer system within the City of Chester.
Section 3 Characteristics of the Model Area Sewer System	This section describes the details of the combined sewer system and includes the physical characteristics and attributes of DELCORA's Sewer System. These include system configuration, regulator, manhole; pump stations and force main characteristics.
Section 4 Collection of Precipitation and Sewer Flow Data	This section presents the results of DELCORA's efforts to collect precipitation monitoring data for locations throughout the areas served by DELCORA's Sewer System. It also presents the results of DELCORA's efforts to collect flow monitoring data in the combined sewer system and in the receiving waters. It presents the dry weather and wet weather flow data for DELCORA's Sewer System.
Section 5 Characteristics of the Receiving Waters and Watersheds	This section provides an overview of the location, physical characteristics, waterbody classifications and analysis of the current water quality of DELCORA's receiving waters. This section also incorporates the results of DELCORA's investigation of Sensitive Areas, and their relative location to the CSOs.
Section 6 Collection of Water Quality Data	This section presents the results of DELCORA's investigation into the current water quality in the receiving waters. This section also presents the CSO water quality data resulting from DELCORA's CSO Monitoring Program.
Section 7 Typical Hydrologic Period	This section summarizes the typical hydrologic period to be used for modeling based on previously submitted *Typical Hydrologic Period Report.*
Section 8 Hydrologic and Hydraulic Modeling	This section provides an overview of the Hydrologic and Hydraulic Model of the combined sewer system that DELCORA has developed. It also presents the results from the modeling of DELCORA's sewer system and the expected volume, frequency, and duration of CSO discharge events from each CSO during the Typical Hydrologic Period.

Section 2 Overview of DELCORA's Facilities and Service Areas

2.1 Overview of DELCORA's Facilities

DELCORA owns and operates an extensive conveyance system of pump stations, force mains, and sewers that provide the core infrastructure for the transmission of wastewater to treatment facilities in Delaware County and the City of Philadelphia as shown diagrammatically in Figure 2-1. The total service area served by DELCORA, as shown on Figure 2-2, is approximately 82,977 acres and illustrates that DELCORA serves a significant and widespread portion of Delaware County. To support the service area, DELCORA owns and operates over 129 miles of separate and combined sewers and over 14 miles of large-diameter (>24-inch) force mains. Included in the 129 miles of sewers are: 11.7 miles of an interceptor system; 3,209 manholes; and twenty-six (26) combined sewer regulators that discharge to twenty-five (25) combined sewer outfalls, as CSO Regulators #009 and #010 both discharge to CSO Outfall #009. The combined sewer area simulated in DELCORA's Hydrologic and Hydraulic (H&H) model is located within the City of Chester and consists of a drainage area of approximately 1,506 acres. It comprises approximately half of Chester City's serviced area. The location of Chester City's service area is illustrated on Figure 2-2.

DELCORA has characterized its service areas as "Eastern" and "Western." Historically, the Eastern service area discharged to the Philadelphia Water Department's Southwest Water Pollution Control Plant (PSWPCP) while the Western Service Area discharged to DELCORA's Western Regional Treatment Plant (WRTP). In 2002, DELCORA completed the installation of a force main that connects the Eastern Service Area's Central Delaware Pump Station (CDPS) to the Chester Force Main. This connection allows DELCORA to send flow from the CDPS to the WRTP. Dry weather flow and a portion of the wet weather flow from the Central Delaware County Authority in the Eastern Service Area now discharges to the WRTP while only those CDPS flows above 20 MGD are to be directed to the PWD-SWPCP. Figure 2-1 shows the interconnections in DELCORA's system. The left side of the figure indicates the Western Service Area and the right side indicates the Eastern Service Area. This interconnectivity coupled with the legal agreements DELCORA maintains with the municipalities and conveyance authorities in Delaware County creates the complicated legal/financial framework under which DELCORA operates.

Under its National Pollutant Discharge Elimination System (NPDES) Permit No. PA0027103, issued and administered by the PADEP, DELCORA is authorized to discharge from the Western Regional Treatment Plant (Outfall #001), four storm water outfalls at the WRTP (028-031) and from the 26 CSO regulators (#002-#005, #007-#026, #032 and #033) that ultimately discharge to the Delaware River, Chester Creek and/or Ridley Creek. There are a total of 26 combined sewer overflow (CSO) regulators listed with 25 discharge points (Regulators 009 and 010 both discharge at Outfall 009) in DELCORA's existing NPDES Permit.

Figure 2-1: DELCORA Conveyance System

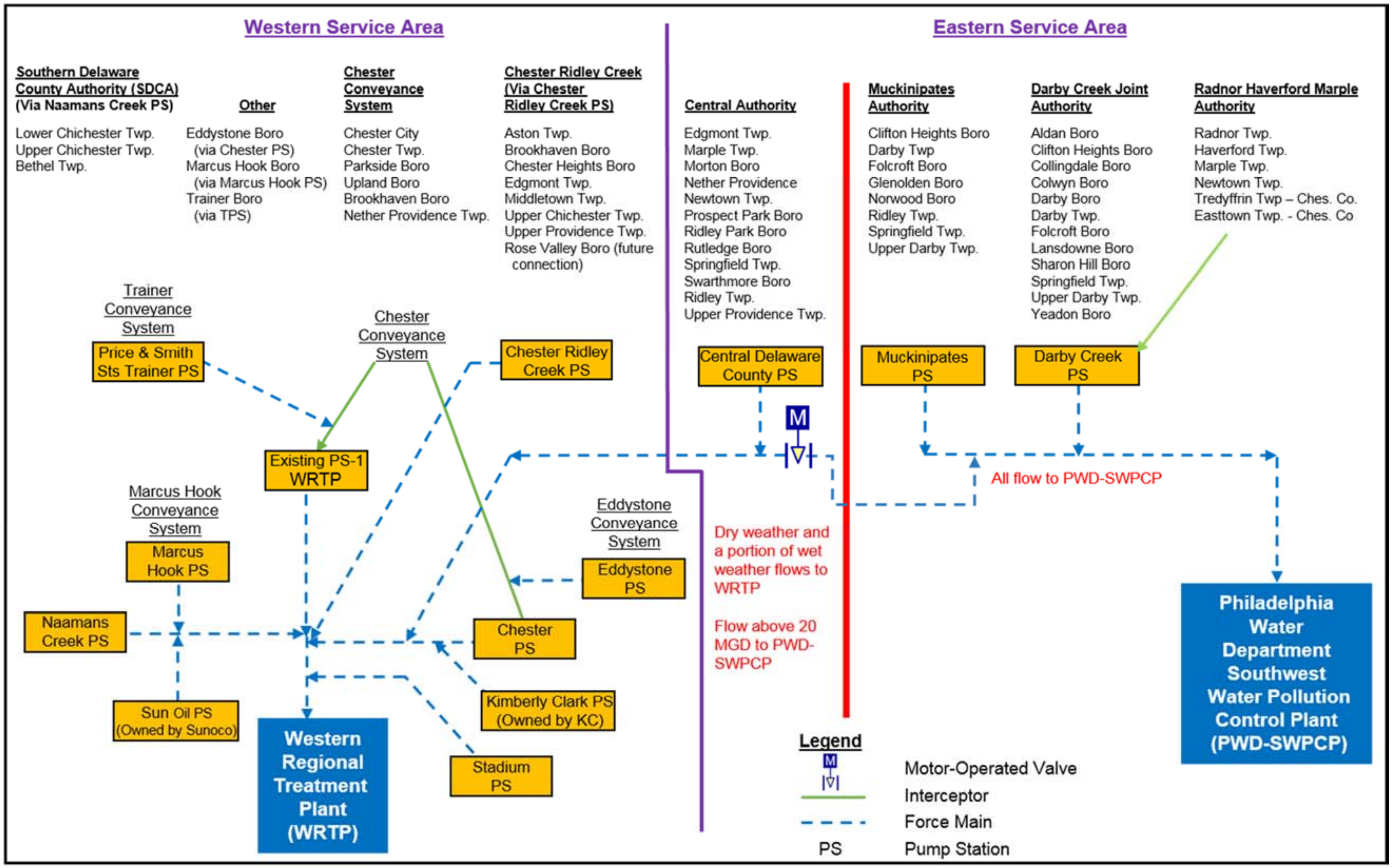
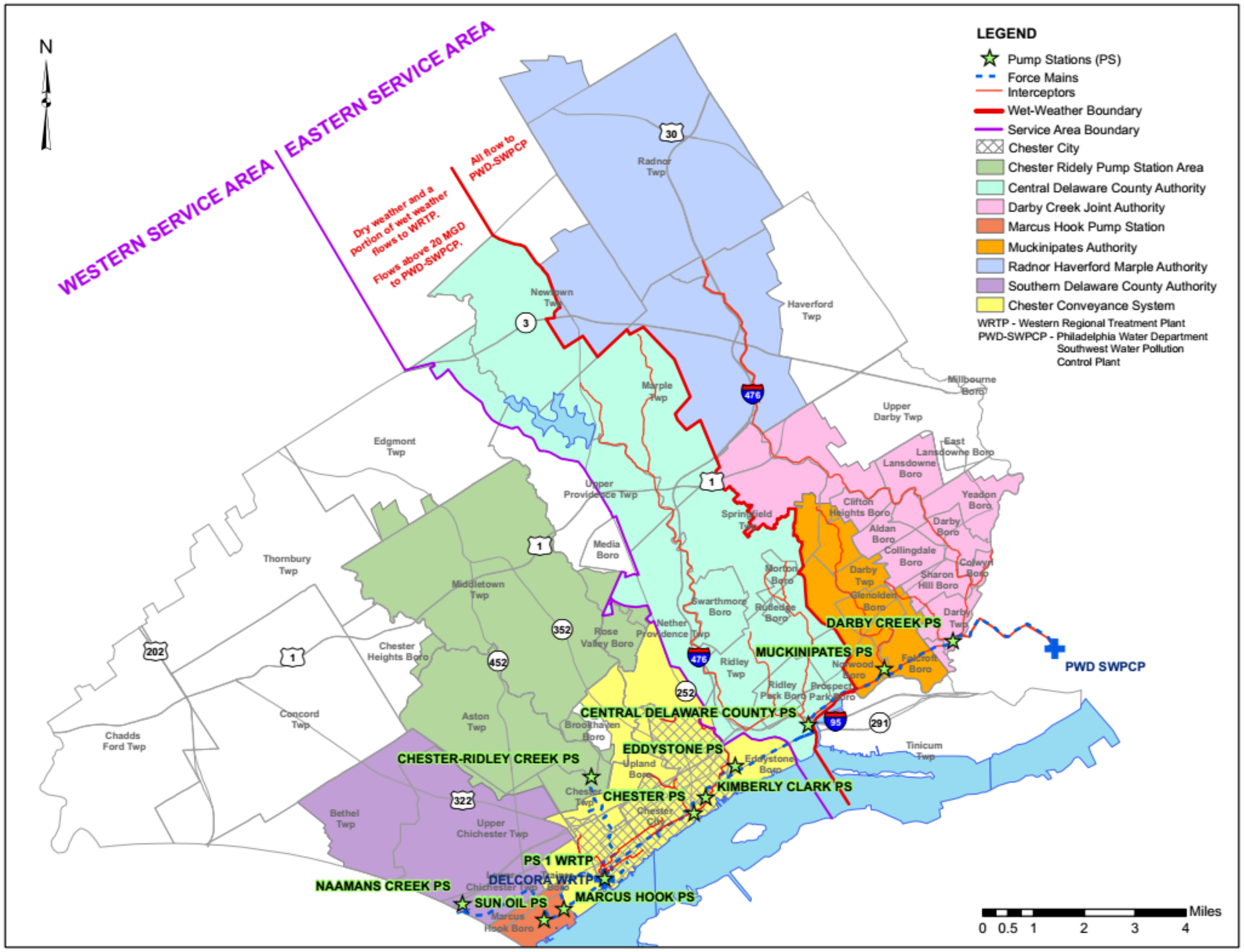


Figure 2-2: DELCORA Service Area



2.2 DELCORA's Service Areas

As mentioned previously and depicted in Figure 2-2, DELCORA serves a significant and widespread portion of Delaware County. To support this service area, DELCORA owns and operates over 137 miles of gravity sewers and over 14 miles of large-diameter (>24-inch) force mains. Historically, DELCORA has characterized its service areas as "Eastern" and "Western." The Western Service Area discharges to the Western Regional Treatment Plant. The Eastern Service Area discharges to the Philadelphia Southwest Water Pollution Control Plant (PSWPCP). In 2002, DELCORA completed the installation of a force main that connects the Eastern Service Area's Central Delaware Pump Station (CDPS) to the Chester Force Main. This connection allows DELCORA to send flow from the CDPS to the WRTP. Flows above 20 MGD are to be directed to the PWD-SWPCP. As such, dry weather flow and a portion of the wet weather flow from the Central Delaware County Authority in the Eastern Service Area are discharged to the WRTP.

2.2.1 Eastern Service Area

The Eastern Service Area is composed of four subareas that are served by conveyance authorities. These areas are the Radnor Haverford Marple (RHM) Authority, Darby Creek Joint Authority (DCJA), Muckinipates Authority (MA), and Central Delaware County Authority (CDCA) and are delineated in Figure 2-2. Each of these authorities has a legal agreement with their member municipalities to dispose of their wastewater. In turn, DELCORA has legal agreements with each of the authorities, except RHM, to receive and dispose of the collected wastewater. RHM discharges to the DCJA.

DELCORA owns and operates three large pump stations that serve DELCORA's Eastern Service Area; they are the Central Delaware County Pump Station, the Muckinipates Pump Station, and the Darby Creek Pump Station. These pump stations are designed to pump the wastewater from DELCORA's Eastern Service Area to the Philadelphia Southwest Water Pollution Control Plant for treatment. Originally constructed in the 1970s, the Central Delaware Pump Station (serving CDCA) is rated for 40 MGD. As originally designed, the Central Delaware pump station discharges though a 1.9-mile, 36-inch-diameter prestressed concrete cylinder pipe (PCCP) force main that runs northeast toward the Muckinipates Pump Station. The next pump station is the 24-MGD Muckinipates Pump Station (serving MA). Here the force main increases to 48 inches in diameter and continues approximately 1.65 miles northeast to the Darby Creek Pump Station. Upon reaching the 60-MGD Darby Creek Pump Station (serving DCJA and RHM), the force main increases in diameter to 66 inches and continues approximately 2.5 miles on to PSWPCP.

The operation of the Central Delaware Pump Station (CDPS) had been modified in 2002 to allow for flow from the CDPS to be discharged to the WRTP. Currently, wastewater flows up to 20 MGD are discharged to WRTP and the wastewater flows in excess of 20 MGD are conveyed to PWD-SWPCP.

2.2.2 Western Service Area

DELCORA's Western Service Area is also shown in Figure 2-2. DELCORA owns and operates the collection system in the following communities in the Western service area:

Chester City
Chester Township[1]
Marcus Hook Borough
Parkside Borough
Rose Valley Borough[2]
Upland Borough
Trainer Borough

DELCORA does not own or operate the collection system in the following communities in the Western Service Area:

Brookhaven Borough
Lower Chichester Township
Nether Providence Township
Eddystone Borough

2.3 Model Area

As described in the Consent Decree, the characterization report will evaluate the Model Area comprising those areas hydraulically connected to the WRTP. Section V.A.14.b of the Consent Decree describes the Model Area as follows:

> *"… all areas tributary to the entire Collection System, as well as all areas tributary to all municipal wastewater collection and transmission systems that are, as of the date the LTCP is submitted, hydraulically connected to, or that directly or indirectly influence flow to, the CSOs and/or the WRTP, regardless of who owns or operates the system(s), including but not limited to the entire "Western Service Area" and "Eastern Service Area" depicted on Figure 1-2 of the Long-Term Control Plan submitted by DELCORA in April 2012, and attached as Appendix A hereto (collectively, the "Model Area")."*

As shown in the schematic of DELCORA's conveyance system (see Figure 2-1), the conveyance system is divided into the Western Service Area and the Eastern Service Area. The Western Service Area discharges to DELCORA's WRTP and is therefore included in the Model Area. The Eastern Service Area is served by three pumps stations: the Central Delaware Pump Station, the Muckinipates Pump Station and the Darby Creek Pump Station. Up to 20 MGD (which includes both dry and wet weather flows) from the Central Delaware Pump Station can be pumped to, and thus is hydraulically connected to, DELCORA's WRTP. Therefore, municipalities connected to the Central Delaware Pump Station are

[1] DELCORA owns only a portion of the collection system in Chester Township.
[2] Rose Valley Borough collection system discharges to its own treatment plant and a portion is discharged to the WRTP via Nether Providence's collection system.

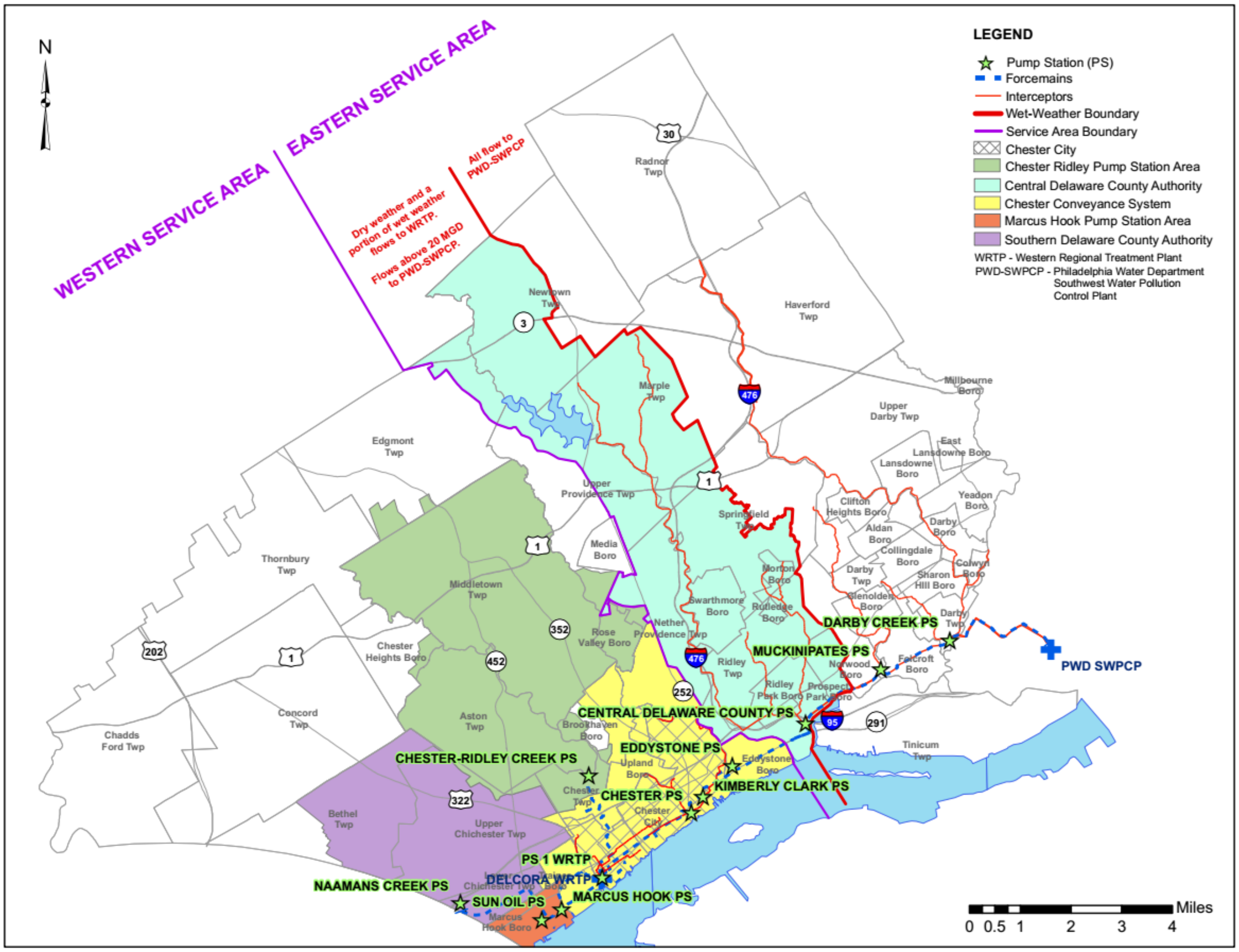
considered part of the Model Area. Sewage from the Muckinipates Pump Station and the Darby Creek Pump Station flows to the PWD-SWPCP rather than to the WRTP. Therefore, municipalities connected to these pump stations are not hydraulically connected to the WRTP and do not directly or indirectly influence CSOs or flow to the WRTP, and, therefore, are not considered part of the Model Area. In summary, the Model Area includes the municipalities in the Western Service Area plus those municipalities in the Eastern Service Area that are connected to the Central Delaware Pump Station, as described in Table 2-1. The Model Area is illustrated in Figure 2-3.

Table 2-1: Model Area

Municipality	Service Area
Aston Township	Western
Bethel Township*	Western (SDCA)
Brookhaven Borough*	Western
Chester City	Western
Chester Township	Western
Eddystone Borough	Western
Edgmont Township*	Eastern (CDCA)
Lower Chichester Township	Western
Marcus Hook Borough	Western
Marple Township*	Eastern (CDCA)
Middletown Township	Western
Morton Borough	Eastern (CDCA)
Nether Providence Township	Eastern (CDCA) and Western
Newtown Township*	Eastern (CDCA)
Parkside Borough	Western
Prospect Park Borough	Eastern (CDCA)
Ridley Park Borough	Eastern (CDCA)
Ridley Township*	Eastern (CDCA)
Rose Valley Borough	Western
Rutledge Borough	Eastern
Springfield Township*	Eastern (CDCA)
Swarthmore Borough	Eastern (CDCA)
Trainer Borough	Western
Upland Borough	Western
Upper Chichester Township	Western (SDCA)
Upper Providence Township*	Eastern (CDCA) and Western

*Indicates that only a portion of the municipality contributes flow to WRTP
CDCA: Central Delaware County Authority
SDCA: Southern Delaware County Authority

Figure 2-3: DELCORA LTCP Model Area



2.4 Watersheds

The watersheds of concern for the Model Area include portions of the Delaware River, Chester Creek and Ridley Creek watersheds. Figure 2-4 illustrates the watershed boundaries along with the boundaries of the Model Area.

2.5 DELCORA's Treatment Facilities

DELCORA's primary treatment facility is the WRTP located at 3201 W. front Street in Chester, PA. The WRTP is a permitted 44 MGD activated sludge treatment plant, shown schematically in Figure 2-5. The PADEP and the Delaware River Basin Commission (DRBC) have approved the re-rate of the WRTP to 50 MGD. DELCORA will need to extend the WRTP discharge outfall approximately 455 feet into the Delaware River to meet DRBC regulatory requirements for a re-rate to 50 MGD. Peak capacity at the WRTP is approximately 110 MGD. Based on data obtained for the period 18 March 2016 to 1 May 2017, the annual average dry weather flow to the WRTP is approximately 28 MGD. This facility treats all wastewater from the Model Area, including all flows from the Western Service Area as well as up to 20 MGD from the Central Delaware County Authority.

All wastewater from the Muckinipates Authority, Darby Creek Joint Authority, and the Radnor Haverford Marple Authority are transported to the PSWPCP for treatment and disposal. The Central Delaware Pump Station can direct flow to the WRTP via the Central Diversion Force Main or to the PSWPCP. DELCORA has an agreement with the City of Philadelphia for the disposal of wastewater. This agreement specifies DELCORA's flow thresholds to the PSWPCP to be an annual average of 50 MGD, a daily maximum of 75 MGD, and an instantaneous peak flow of 100 MGD. Flows above these thresholds are subject to exceedance charges.

DELCORA also purchased the Rose Valley Treatment Plant in 2009. The Rose Valley Treatment Plant is permitted at 0.13 MGD and is located in Delaware County. On March 1, 2010, DELCORA purchased the Riverside Treatment Plant in Pocopson Township, Chester County. It is permitted at 0.045 MGD.

Figure 2-4: Watershed Boundaries

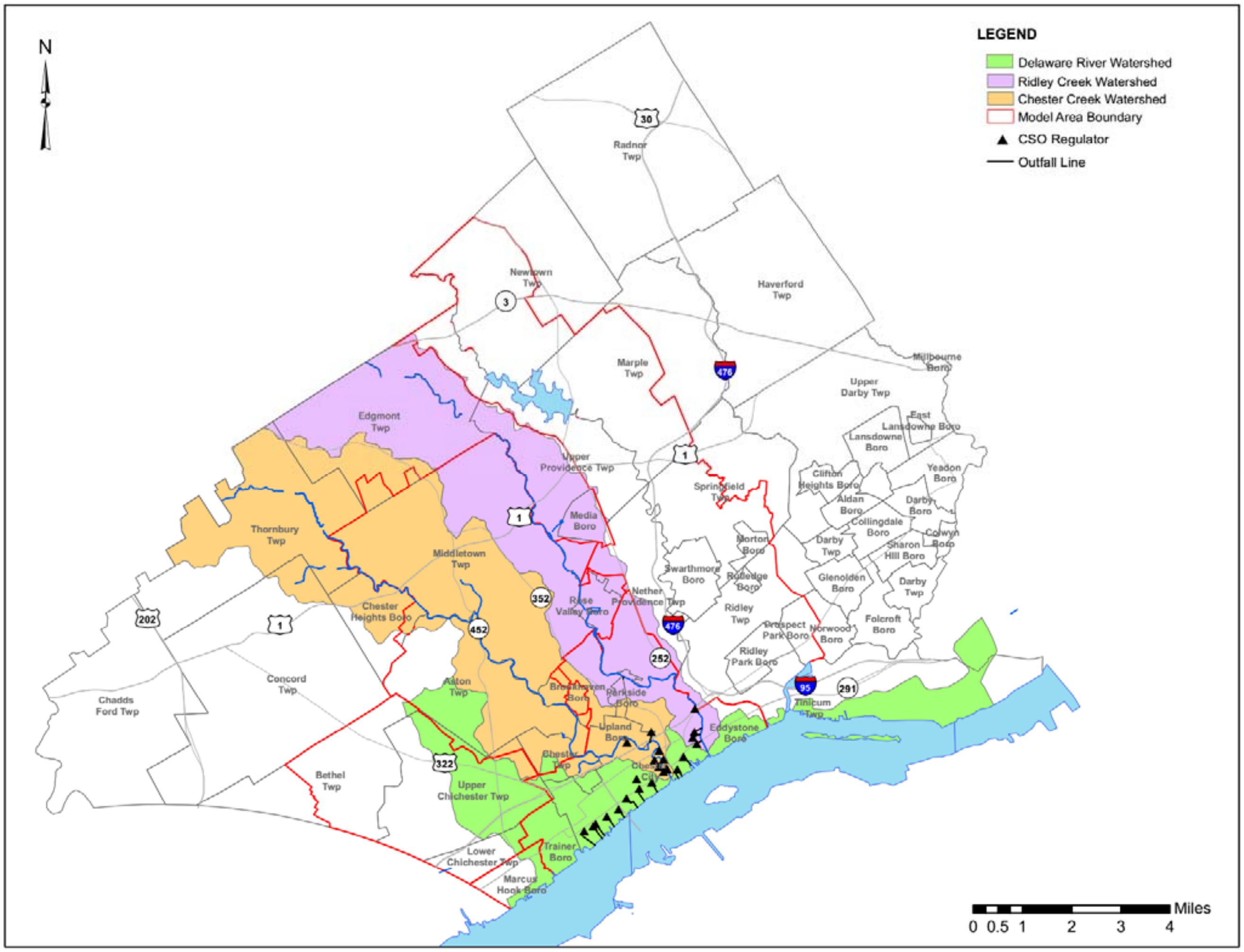
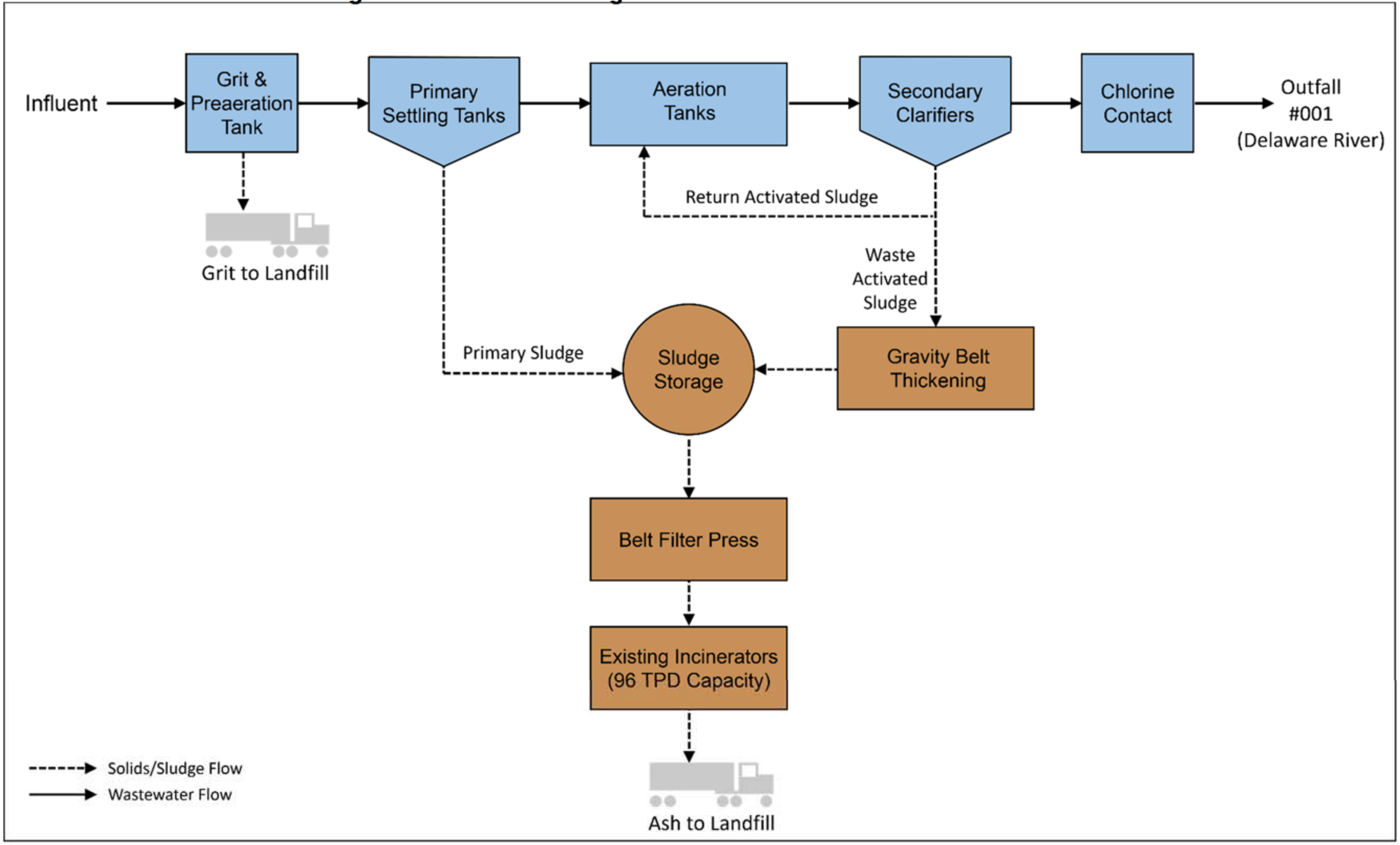


Figure 2-5: Western Regional Treatment Plant CSO Schematic



Section 3 Characteristics of the Model Area Sewer System

3.1 Introduction

This section presents an investigation of the collection system to meet the requirements of Section II.C.1.b, Combined Sewer System Characterization, of the USEPA's CSO Control Policy. Section II.C.1.b requires DELCORA to evaluate the nature and extent of the sewer system through evaluation of available sewer records and inspections necessary to understand the number, location and frequency of overflows, and their locations relative to Sensitive Areas and to pollution sources in the collection system.

3.2 Sources of Collection System Data

The characteristics and attributes of DELCORA's collection system were determined through the collection, assessment, and evaluation of existing data and information, as part of the implementation of the *Hydrologic and Hydraulic Model Update and Calibration Plan* (Greeley and Hansen, 2015).

Data and information on the collection system were obtained from several sources including DELCORA's input, DELCORA's Geographic Information System (GIS), as-built record drawings, design drawings and field surveys.

3.3 Overview of Sewer System Characteristics

The wastewater collection system within the Model Area consists of separated storm and sanitary sewer piping in some areas and combined sewer system piping in other areas. The Model Area covers approximately 50,000 acres, with approximately 48,540 acres served by separated storm and sanitary systems while only 1,463 acres are served by a combined sewer system. The combined sewer system is located entirely within the City of Chester. However, the City of Chester also has areas that are served by separated storm and sanitary piping or are direct drainage. The remaining areas of the Model Area outside of the City of Chester are all served by separated storm and sanitary sewer piping.

In separated areas, the sanitary sewers convey wastewater to the WRTP for treatment and stormwater runoff is collected through storm sewers and discharged directly to the receiving waters.

Within the City of Chester's combined sewer areas, however, sanitary and storm sewers are combined into the same pipe. During dry weather, the sanitary wastewater is conveyed to the WRTP. During large storms, the stormwater runoff causes the carrying capacity of these combined sewers to be exceeded, and part of this combined flow may discharge directly to the receiving waters without undergoing any treatment.

Sewersheds (subcatchments) are delineated based on the drainage network and area characteristics. Each sewershed has a dry weather and a wet weather flow input to the model network. The model network comprises 114 sewersheds (subcatchments), including 53 combined and 61 separated subcatchments.

3.4 Characteristics of Separated Sewer Areas

Sanitary sewers within the separated areas deliver flow to the WRTP through connections to DELCORA's sewers and through connections to DELCORA's pump station. In many cases, DELCORA does not own or operate the sanitary sewers in separated areas. Consequently, detailed information regarding the characteristics of sanitary sewers from the separated areas is not included in this Report. For modeling purposes, the separated areas will be treated as node inputs to the H&H Model. Flow inputs at the nodes will be derived as described in Sections 4 and 8. Key characteristics necessary for developing flow inputs include delineation of subcatchment boundaries (see Figures 3-1 and 3-2) and areas (see Table 3-1).

3.5 Characteristics of Combined Sewer System

As noted in Section 2.1, the combined portion of DELCORA's sewer system is located within the City of Chester (City), and it comprises approximately half of the City's serviced area. The combined wastewater/stormwater system in the City is complicated by the fact that parts of the system are owned, operated and maintained by two governmental entities, the City and DELCORA. DELCORA owns, operates and maintains the parts of the system that convey wastewater, such as the street sewers, collectors, interceptors, and CSO regulators and CSO outfalls. The City owns, operates and maintains the inlets, stormwater-only sewers that connect to the combined sewer system and any stormwater-only outfalls. The City is also responsible for the maintenance and cleaning of the streets, planning, zoning, and development controls.

The CSS system in the City of Chester has several key components that all impact how the system operates. These key components are the local street sewers, combined collector sewers, CSO regulators, interceptors, and outfalls. The system starts with local street sewers that take flow from houses and businesses as well as the stormwater inlets that drain the streets. These local street sewers typically range in size from 12" to 24" in diameter. The local street sewers discharge to combined collector sewers (shown in Figure 2-1) which flow to the CSO regulators. The combined collector sewers are larger pipes typically range in size from 18" to 72" in diameter and connect directly to the CSO regulator.

Generally, in the CSO drainage areas, flows from the separate sanitary sewers flow into the combined sewers. Flows from the combined sewers in the collection system flow to the regulator structures where dry weather flow and a portion of wet weather flow are diverted into the interceptors. The remainder of the wet weather flow that exceeds the capacity of the interceptors is discharged directly to the closest receiving water (Delaware River, Chester Creek or Ridley Creek) through the CSO outfalls.

3.5.1 Overall Configuration

A schematic of the CSS was developed to facilitate the development, calibration, and validation of the H&H Model. The schematic illustrates the relationship between all major regulators, interceptors, outfalls, pump stations, force mains and other major appurtenances. The schematic also includes the location of the flow meters, and provides and good understanding of the relationship between the flow meters. The schematic of the collection system components is shown on Figure 3-3.

Figure 3-1: DELCORA Model Area Subcatchments

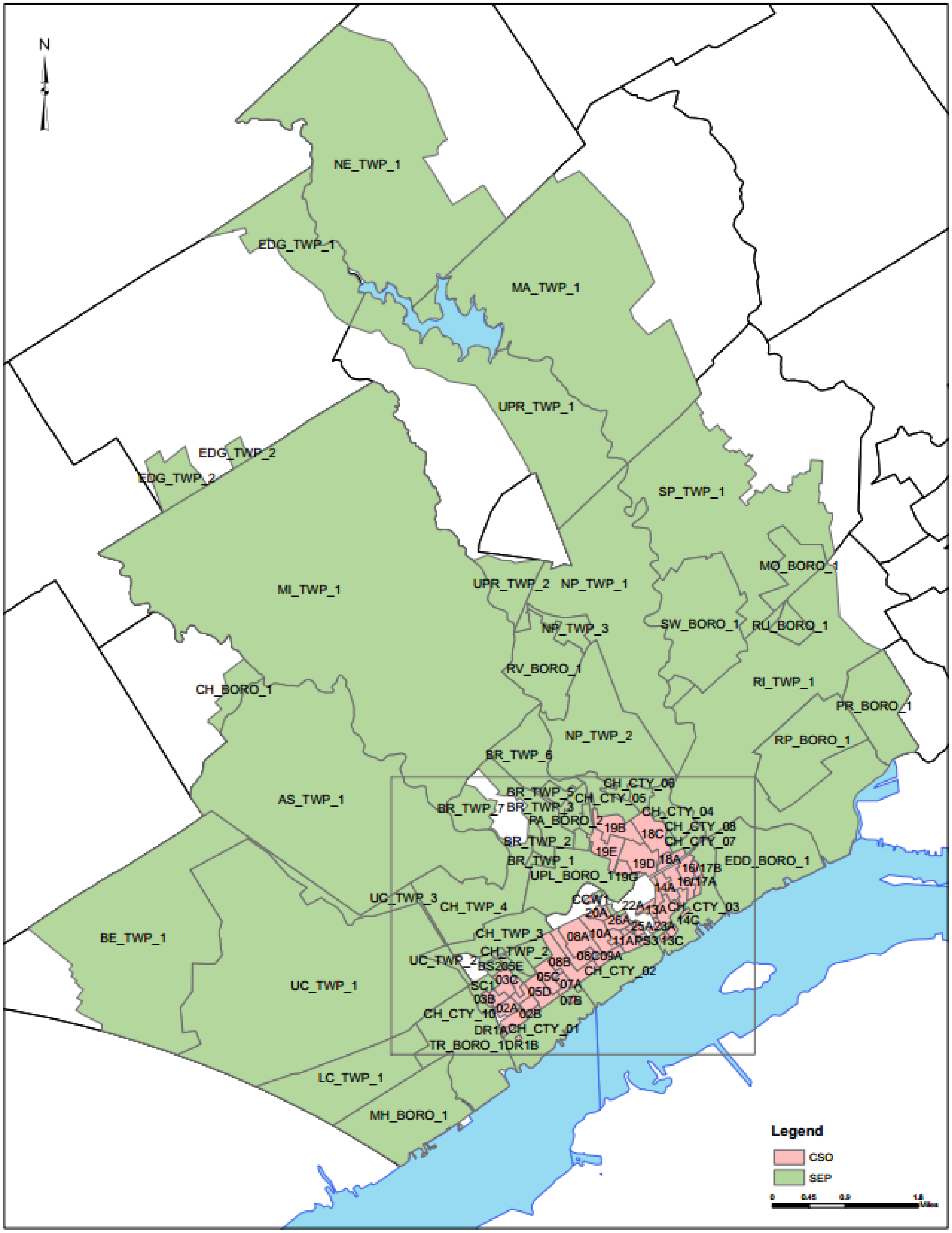


Figure 3-2: DELCORA CSS Area Subcatchments (Enlarged)

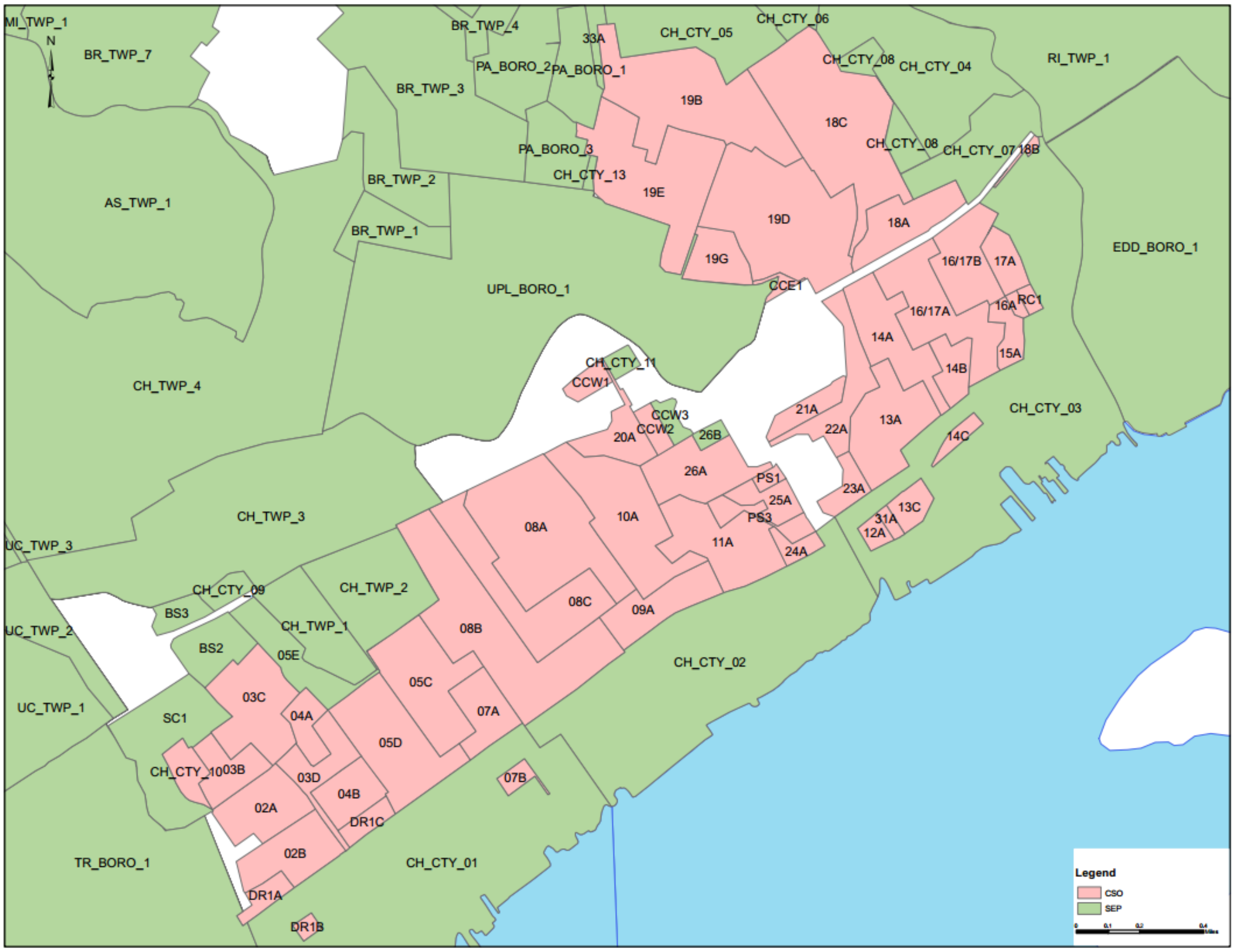


Figure 3-3: Schematic of Chester CSO System

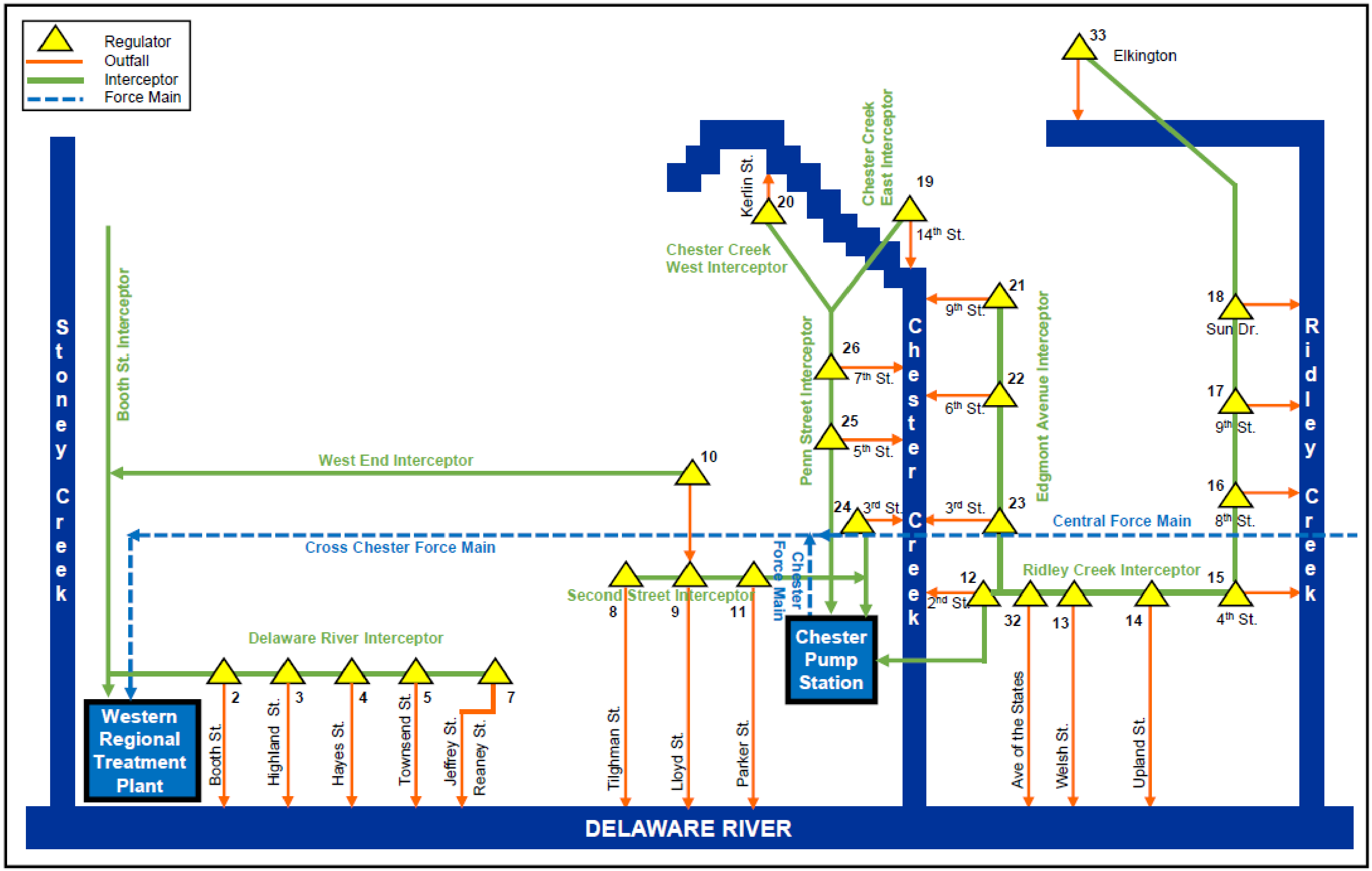


Figure 3-4 depicts the locations of DELCORA's CSO regulators and outfalls. Figure 3-4 also depicts the various drainage subcatchments that flow to each of the CSO regulators. Information about the 26 CSO drainage areas including their subcatchments, total acreage and combined sewer acreage are shown depicted in Table 3-1. Together Figure 3-4 and Table 3-1 also provide a sewer system characterization and illustrate the breakdown of each outfall and how each drainage area has combined sewers and separate sewers.

3.5.2 Sewer Mains

Sewer data was collected from DELCORA's GIS in support of the work to develop and update and calibrate the H&H model. Most of the pipe input characteristics, including upstream and downstream nodes, dimension, shape, number of barrels, and flap gate information, were found or estimated from record drawings, design drawings and sewer gravity main GIS shapefiles. If sewer main information was not available, sewer length was estimated in GIS geometry measurement; sewer size were assumed based on upstream and downstream sewers; sewer upstream and downstream offsets were estimated based on sewer connectivity assuming constant slope. Conduit ID was inherited from the 2012 H&H Model and new IDs were provided for the pipes not in the 2012 H&H Model.

Manhole information, including invert and rim elevations, were found or estimated from record drawings, design drawings, and the sewer manhole shape file. For water tight manholes or manholes with bolted down covers, a surcharge depth of 50-ft will be applied. Manhole ID was inherited from the name of the manhole in the sewer GIS. The naming convention is "MH_XXXX". Manhole input information was updated based on the latest available GIS information.

3.5.3 Flow Diversion Structures and CSO Regulators

The Chester CSO system contains 26 permitted CSO regulators as listed in Table 3-2. The CSO regulators and outfalls serve as combined sewer reliefs necessitated by stormwater entering the sewer system and exceeding the hydraulic capacity of the sewers and/or treatment plant. Wet weather flows in excess of the collection system's capacity are discharged to the Delaware River, Chester Creek or Ridley Creek. Although there are 26 regulators, there are only 25 CSO discharge locations, as CSO #010 discharges to the Delaware River through CSO #009. Table 3-2 shows that eleven of the outfalls, CSO Outfalls #002, 003, 004, 005, 007, 008, 009, 011, 013, 014, and 032, discharge excess wet weather flows into the Delaware River. Nine of the outfalls, CSO Outfalls #012, 019, 020, 021, 022, 023, 024, 025 and 026, discharge excess wet weather flows into the Chester Creek. The remaining five designated outfalls, Outfall #015, 016, 017, 018 and 033[3] , discharge excess wet weather flows into the Ridley Creek.

Since the approval of the first LTCP in 1999, DELCORA has under-taken a program to replace and/or rehabilitate CSO regulators and tide gates in the City of Chester CSO system. In some cases, regulators have been eliminated. The modifications DELCORA committed to in the 1999 LTCP include a complete

[3] DELCORA's NPDES permit includes 26 regulators. After the NPDES permit was issued, CSO regulator 033 was disconnected from the CSS.

Figure 3-4: CSS Area Delineation

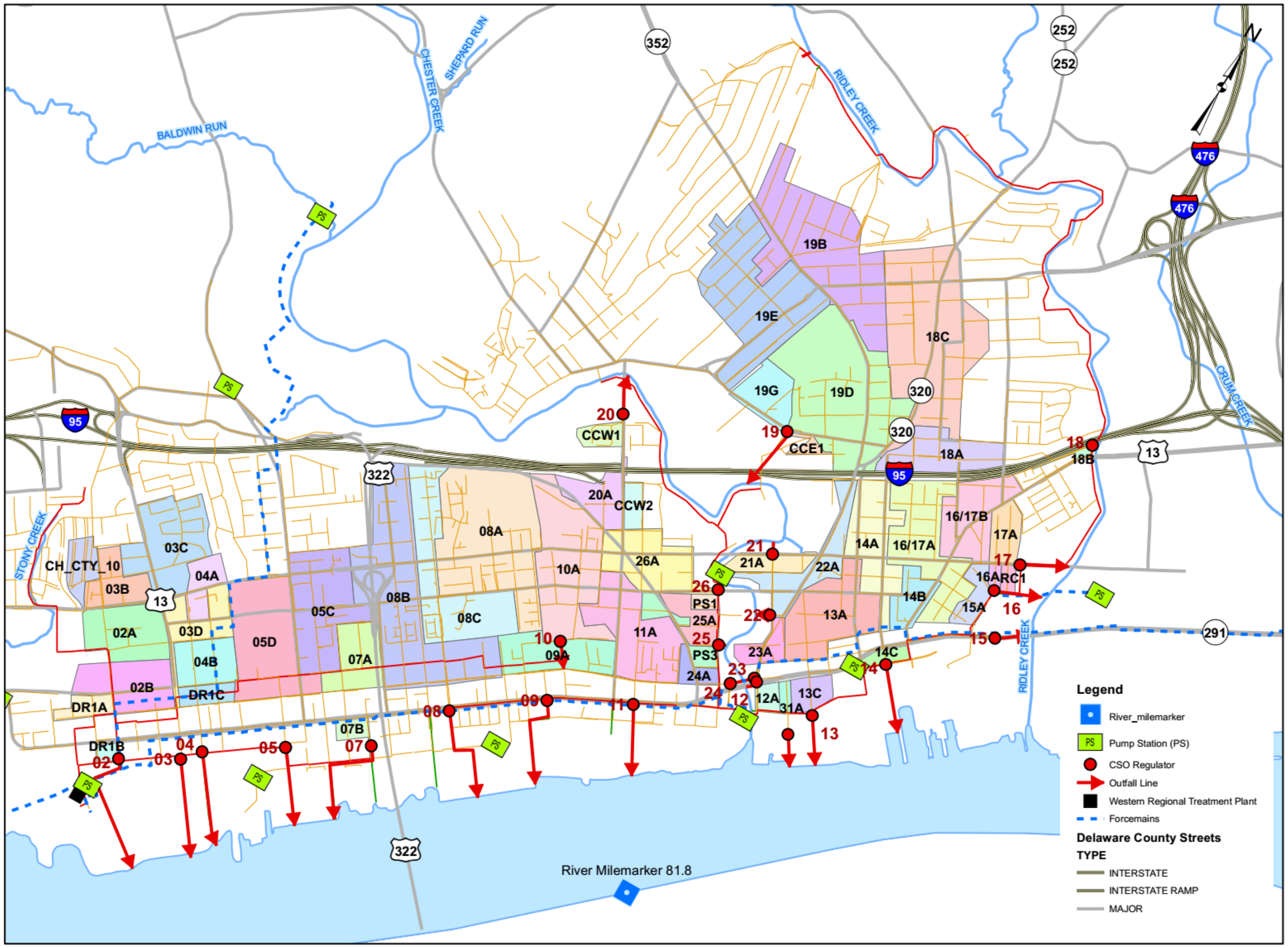


Table 3-1: Subcatchments in the Model Area Sewer System

CSO Regulator/Interceptor/ Pump Station	Subarea	Collection System Type	Area/Subarea (ac)	Total Area (ac)	Municipality
Regulator 2	02A	CSS	29	58	Chester City
	02B	CSS	29		Chester City
Regulator 3	03B	CSS	19	87	Chester City
	03C	CSS	43		Chester City
	03D	CSS	20		Chester City
Regulator 4	04A	CSS	12	31	Chester City
	04B	CSS	19		Chester City
Regulator 5	05C	CSS	49	233	Chester City
	05D	CSS	53		Chester City
	05E	Separate	27		Chester City
	CH_TWP_2	Separate	59		Chester Twp
	CH_CTY_9	Separate	7		Chester City
	CH_TWP_1	Separate	38		Chester Twp
Regulator 7	07A	CSS	21	26	Chester City
	07B	CSS	5		Chester City
Regulator 8	08A	CSS	89	237	Chester City
	08B	CSS	96		Chester City
	08C	CSS	52		Chester City
Regulator 9	09A	CSS	27	27	Chester City
Regulator 10	10A	CSS	60	60	Chester City
Regulator 11	11A	CSS	44	44	Chester City
Regulator 12	12A	CSS	5	5	Chester City
Regulator 13	13A	CSS	41	50	Chester City
	13C	CSS	9		Chester City
Regulator 14	14A	CSS	35	53	Chester City
	14B	CSS	13		Chester City
	14C	CSS	5		Chester City
Regulator 15	15A	CSS	10	10	Chester City
Regulator 16/17	16/17A	CSS	46	77	Chester City
	16/17B	CSS	31		Chester City
Regulator 16	16A	CSS	2	2	Chester City
Regulator 17	17A	CSS	12	12	Chester City
Regulator 18	18A	CSS	28	130	Chester City
	18B	CSS	2		Chester City
	18C	CSS	100		Chester City
Regulator 19	18C	Separate	100	421	Chester City
	19B	CSS	88		Chester City
	19D	CSS	94		Chester City
	19E	CSS	76		Chester City
	19G	CSS	18		Chester City
	PA_BORO_1	Separate	28		Parkside Boro
	CH_CTY_08	Separate	17		Chester City
Regulator 20	20A	CSS	18	18	Chester City
Regulator 21	21A	CSS	11	11	Chester City
Regulator 22	22A	CSS	27	27	Chester City
Regulator 23	23A	CSS	10	10	Chester City
Regulator 24	24A	CSS	6	6	Chester City
Regulator 25	25A	CSS	12	12	Chester City

CSO Regulator/Interceptor/ Pump Station	Subarea	Collection System Type	Area/Subarea (ac)	Total Area (ac)	Municipality
Regulator 26	26A	CSS	33	37	Chester City
	26B	Separate	4		Chester City
Regulator 32	31A	CSS	3	3	Chester City
Chester Creek Interceptor East	CCE1	CSS	3	3	Chester City
Chester Creek Interceptor West	CCW1	CSS	7	552	Chester City
	CCW2	CSS	6		Chester City
	CCW3	Separate	5		
	CH_CTY_11	Separate	5		Chester City
	PA_BORO_3	Separate	27		Parkside Boro
	BR_TWP_1	Separate	27		Brookhaven Boro
	BR_TWP_2	Separate	49		Brookhaven Boro
	CH_CTY_13	Separate	2		Parkside Boro
	UPL_BORO_1	Separate	424		Upland Boro
2nd Street Interceptor	CH_CTY_02	Separate	238	238	Chester City
Penn Street Interceptor	PS1	CSS	3	13	Chester City
	PS3	CSS	10		Chester City
Ridley Creek Interceptor	RC1	CSS	3	2,327	Chester City
	CH_CTY_03	Separate	276		Chester City
	33A	Separate	9		Chester City
	CH_CTY_04	Separate	137		Chester City
	CH_CTY_05	Separate	124		Chester City
	CH_CTY_06	Separate	44		Chester City
	CH_CTY_07	Separate	44		Chester City
	BR_TWP_6	Separate	327		Brookhaven Boro
	NP_TWP_2	Separate	991		Nether Providence Twp
	PA_BORO_2	Separate	71		Parkside Boro
	BR_TWP_3	Separate	236		Brookhaven Boro
	BR_TWP_4	Separate	21		Brookhaven Boro
	BR_TWP_5	Separate	44		Brookhaven Boro
Stony Creek Interceptor	SC1	CSS	54	54	Chester City
West End Interceptor	DR1A	CSS	8	1,023	Chester City
	DR1C	CSS	7		Chester City
	CH_CTY_10	CSS	11		Chester City
	TR_BORO_1	Separate	669		Trainer Boro
	CH_TWP_3	Separate	245		Chester Twp
	UC_TWP_2	Separate	51		Upper Chichester Twp
	BS2	CSS	22		Chester City
	BS3	CSS	10		Chester City
Delaware River Interceptor	DR1B	CSS	3	332	Chester City
	CH_CTY_01	Separate	329		Chester City
Eddystone Pump Station	EDD_BORO_1	Separate	664	664	Eddystone Boro
Central Delaware Pump Station	RI_TWP_1	Separate	2,806	18,806	Ridley Twp
	RP_BORO_1	Separate	679		Ridley Park Boro
	RU_BORO_1	Separate	90		Rutledge Boro
	SP_TWP_1	Separate	2,208		Springfield Twp
	SW_BORO_1	Separate	898		Swarthmore Boro
	UPR_TWP_1	Separate	1,722		Upper Providence Twp
	PR_BORO_1	Separate	477		Prospect Park Boro
	MO_BORO_1	Separate	238		Morton Boro

CSO Regulator/Interceptor/ Pump Station	Subarea	Collection System Type	Area/Subarea (ac)	Total Area (ac)	Municipality
	NE_TWP_1	Separate	3,422		Newtown Twp
	NP_TWP_1	Separate	1,927		Nether Providence Twp
	EDG_TWP_1	Separate	735		Edgmont Twp
	MA_TWP_1	Separate	3,604		Marple Twp
Chester Ridley Creek Pump Station	UC_TWP_3	Separate	192	14,513	Upper Chichester Twp
	UPR_TWP_2	Separate	248		Upper Providence Twp
	RV_BORO_1	Separate	471		Rose Valley Boro
	NP_TWP_3	Separate	110		Nether Providence Twp
	AS_TWP_1	Separate	3,732		Aston Twp
	CH_TWP_4	Separate	593		Chester Twp
	EDG_TWP_2	Separate	258		Edgmont Twp
	MI_TWP_1	Separate	8,612		Middletown Twp
	BR_TWP_7	Separate	156		Brookhaven Boro
	CH_BORO_1	Separate	141		Chester Heights Boro
Marcus Hook Pump Station	LC_TWP_1	Separate	700	1,401	Lower Chichester Twp
	MH_BORO_1	Separate	701		Marcus Hook Boro
Naamans Creek Pump Station	BE_TWP_1	Separate	2,500	6,528	Bethel Twp
	UC_TWP_1	Separate	4,028		Upper Chichester Twp

Table 3-2: CSO Regulator Information

CSO Regulator No.	CSO Regulator Location	CSO Receiving Water	Latitude	Longitude	CSO Regulator Type	Regulator Replacement Status
002	Front & Booth	Delaware River	39°49'30"N	75°23'31"W	Brown & Brown	Replaced 2010
003	Front & Highland	Delaware River	39°49'34"N	75°23'11"W	Brown & Brown	Replaced 2010
004	Front & Hayes	Delaware River	39°50'36"N	75°23'07"W	McNulty	In Progress; Anticipated Completion Fall 2017
005	Front & Townsend	Delaware River	39°49'46"N	75°22'53"W	Brown & Brown	Replaced
007	Delaware & Reaney	Delaware River	39°49'51"N	75°22'45"W	Brown & Brown	Replaced
008	2nd & Tilghman	Delaware River	39°50'05"N	75°22'22"W	Brown & Brown	Replaced
009	2nd & Lloyd	Delaware River	39°50'14"N	75°22'10"W	Brown & Brown	Replaced
010*	5th & Pusey	Delaware River	39°50'26"N	75°22'19"W	Brown & Brown	Replaced
011	2nd & Parker	Delaware River	39°50'26"N	75°21'54"W	Brown & Brown	Replaced
012	2nd & Edgmont	Chester Creek	39°50'42"N	75°21'38"W	Brown & Brown	Replaced
013	2nd & Welsh	Delaware River	39°50'37"N	75°21'17"W	Brown & Brown	Replaced
014	3rd & Upland	Delaware River	39°50'50"N	75°21'05"W	Brown & Brown	Replaced
015	4th & Melrose	Ridley Creek	39°51'03"N	75°20'48"W	Brown & Brown	2022
016	8th & McDowell	Ridley Creek	39°51'15"N	75°20'53"W	Brown & Brown	Replaced
017	9th & Campbell	Ridley Creek	39°51'16"N	75°20'51"W	Brown & Brown	2021
018	Sun Dr. & Hancock	Ridley Creek	39°51'47"N	75°20'57"W	Brown & Brown	Scheduled for 2017
019	14th & Crozer Hospital	Chester Creek	39°51'24"N	75°21'54"W	Brown & Brown	2024
020	Kerlin & Finland	Chester Creek	39°51'24"N	75°22'27"W	Brown & Brown	Replaced
021	9th & Sproul	Chester Creek	39°51'08"N	75°21'49"W	Brown & Brown	Replaced
022	6th & Sproul	Chester Creek	39°50'56"N	75°21'47"W	Brown & Brown	Replaced
023	3rd & Edgmont	Chester Creek	39°50'45"N	75°21'42"W	Brown & Brown	Replaced
024	3rd & Dock	Chester Creek	39°50'44"N	75°21'43"W	Brown & Brown	Replaced
025	5th & Penn	Chester Creek	39°50'49"N	75°21'50"W	Brown & Brown	Replaced

CSO Regulator No.	CSO Regulator Location	CSO Receiving Water	Latitude	Longitude	CSO Regulator Type	Regulator Replacement Status
026	7th & Penn	Chester Creek	39°50'58"N	75°21'55"W	Brown & Brown	Replaced
032	2nd & Avenue of the States	Delaware River	39°50'34"N	75°21'25"W	No CSO Regulator	Removed Mechanisms
033	Elkington Blvd. and Ridley Creek	Ridley Creek	39°52'22"N	75°22'29"W	No CSO Regulator	See Notes
Notes: - CSO Regulator 010 discharges at Outfall 009. - CSO Regulators 006 ad 007 have been disconnected from CSS and removed from NPDES permit - CSO Regulator 033 has been disconnected from the CSS but had not been removed from NPDES permit at the date of this Report						

replacement of the mechanism, installation of a monitoring system to determine if flow is passing over the CSO regulator diversion weir to the outfall, and conversion of the CSO regulators to Type A. After installation of the first CSO regulator monitoring systems, DELCORA determined that the monitoring system improves system operation and significantly reduces dry-weather overflows by notifying operators at the WRTP that flow is passing over the diversion weir. (If it is not raining, this notification is indication of a dry-weather overflow and DELCORA dispatches a maintenance crew to correct the situation.) After this determination, DELCORA installed the monitoring system on all CSO regulators even though it was not required until the CSO regulator was replaced. DELCORA continues to use this system and it provides critical information to maintain proper operation of the CSO regulators.

As indicated in Table 3-2, the majority of the City's CSO regulators are Brown & Brown type regulators. The original CSO regulators were Type B regulators in which the regulator gate position is controlled by the level in the trunk sewer entering the CSO regulator chamber. As part of its regulator replacement program DELCORA is replacing the regulators with Type A regulators in which the gate position is controlled by the level in the interceptor. This allows for the interceptor to operate at full capacity thus maximizing amount of flow being sent to the WRTP for treatment. Flow that cannot enter the interceptor because it is at capacity, passes over the CSO regulator diversion weir and into the outfall for release to the receiving water.

The updated model includes twenty-five[1] (25) CSO regulators, which were modeled as weirs and orifices. The configuration of CSO regulators was obtained from both record drawings and field surveys.

3.5.3.1 Flow Diversion Structure Components

The key components required for modeling these structures include float-operated gates, orifice plates and diversion weirs. Schematic representations of the flow diversion structures are shown in Figure 3-5. Table 3-2 lists basic information for each of DELCORA's 26 CSO regulators. Appendix A contains the data collected for each CSO regulator structure in the collection system that was utilized in the updated H&H Model. Appendix A, Table A-1, shows the invert elevation of the outfall pipe at the regulator and the invert elevation of the outfall pipe at the receiving stream.

Regulator Gates

Characteristics of the regulator gates were obtained from as-built drawings and field surveys. The gates are rectangular, covering rectangular openings except at Regulator #004, which is circular. The gates open and close based on their associated floats. Settings for opening and closing of the gates based on levels in the float chamber and regulator limit settings were obtained as part of the characterization survey. All regulator gates are modeled as side-type orifices and have been assigned a discharge coefficient of 0.65. For cases where the regulator float and gate have been removed, dry weather flow and some portion of the wet weather flow will pass through the opening previously covered by the now removed gate. Flow through this opening will be modeled as an orifice. When weather flow exceeds the capacity of the orifice, the level in the sewer will continue to rise until it is high enough for a portion of the flow to pass over the weir and discharge through the associated outfall. Regulator gate ID is named according to the CSO regulator points. For example, the regulator gate for CSO regulator 003 is named "REG_003_Gate." A summary of regulator gate characteristics is shown in Appendix A, Table A-2.

Orifices

Most of the regulators include an orifice between the regulator gate and the downstream interceptor. All orifices in the collection system are side orifice type, rectangular in shape and were assigned a discharge coefficient of 0.65. The dimensions are based on record drawings.

A summary of the orifice data used in the model is contained in Appendix A, Table A-3. The updated H&H model has 20 orifices. All orifices are side type and are rectangular in shape. Regulators 004, 015, 017 018 and 032 do not have an orifice plate. Regulators 006, 027 and 033 are no longer connected to the CSS and therefore do not have any orifices, weirs or outfalls included in the H&H model. The orifice ID used in the H&H model is named according to the CSO overflow points. For example, the orifice for CSO 03 is named “REG_03_Orifplate”.

Weirs

Characteristics for the diversion weirs were obtained from record drawings and were field verified as necessary. All weirs were found to be of the transverse type with no end contractions. All weirs are assigned a discharge coefficient of 3.33. Weir ID will be named according to the CSO overflow points. For example, the weir for CSO 03 will be named “Weir_03”. A summary of the weir data used in the model is contained in Appendix A, Table A-4.

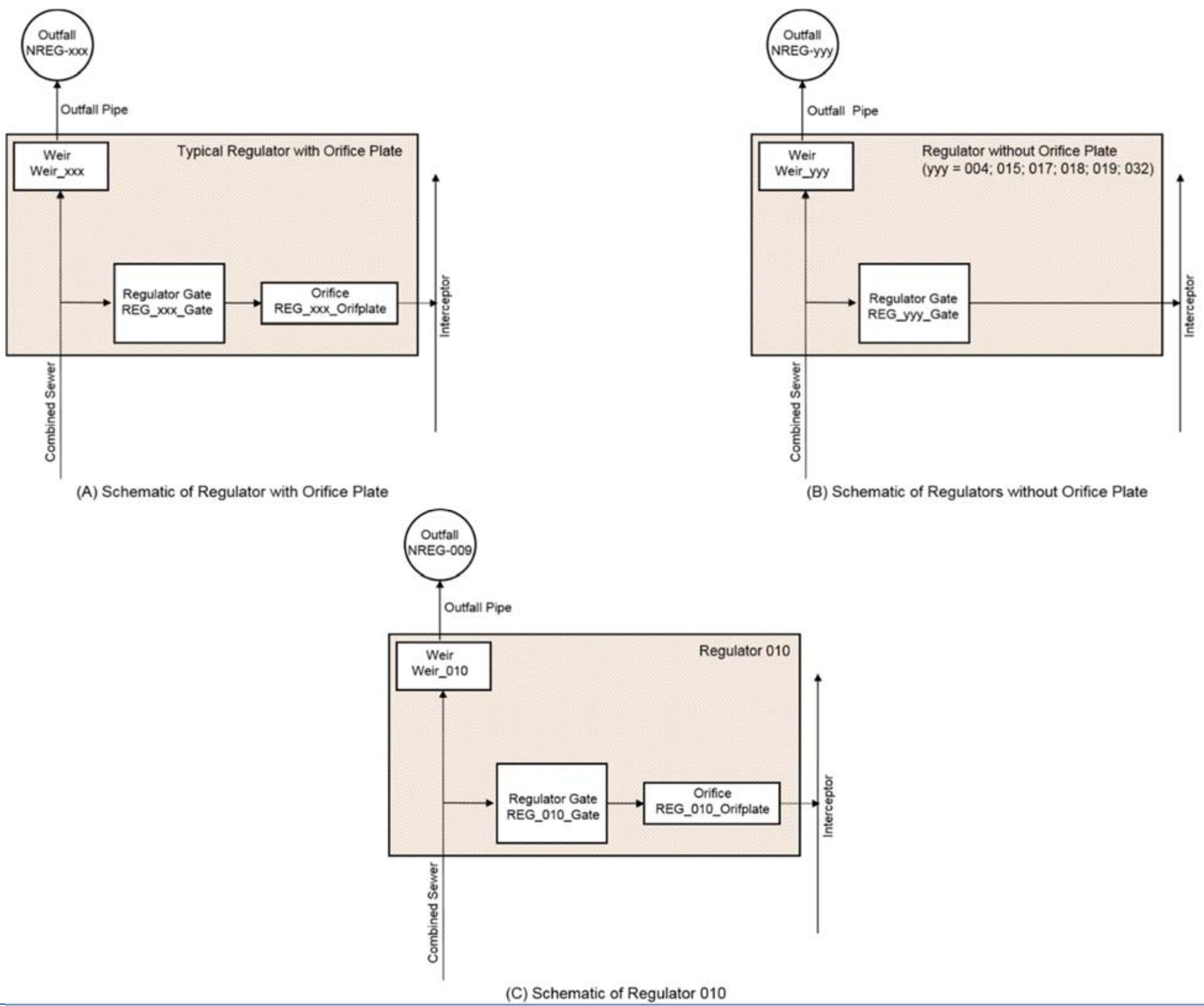
3.5.4 Interceptors

The interceptors convey flow from the CSO regulators to the WRTP or to the Chester Pump Station, which discharges directly to the WRTP. The interceptors shown on Figure 2-3 vary in size from 24” to 72” in diameter. Any flow entering the interceptor system will eventually reach the WRTP for treatment.

Figure 3-3 is a schematic of the Chester CSO system and shows the outfalls and the interceptors that are connected to each CSO. Specifically as diagrammed in Figure 3-3, the relationship between DELCORA’s interceptors and outfalls are as follows:

- The Delaware River Interceptor conveys dry weather flow and a portion of wet weather flow from CSO Service Areas 002, 003, 004, 005 and 007 into the Booth Street Interceptor that then leads to the WRTP.
- The Second Street Interceptor conveys dry weather flow and a portion of wet weather flow from CSO Service Areas 008, 009, 011 and 024 to the Chester Pump Station, which is then pumped to the WRTP.
- The West End Interceptor conveys dry weather flow and a portion of wet weather flow from CSO Service Area 010 into the Booth Street Interceptor and then to the WRTP.
- The Ridley Creek Interceptor conveys dry weather flow and a portion of wet weather flow from CSO Service Areas 012, 013, 014, 015, 016, 017, 018 and 032 to the Chester Pump Station, which pumps the flow to the WRTP.

Figure 3-5: Flow Diversion Structure Schematic



- The Edgmont Avenue Interceptor conveys dry weather flow and a portion of wet weather flow from CSO Service Areas 021, 022 and 023 into the Ridley Creek Interceptor and from there to the Chester Pump Station and then to the WRTP.
- The Chester Creek East Interceptor and the Chester Creek West Interceptor respectively convey the dry weather flow and a portion of the wet weather flow from CSO Service Areas 019 and 020. These two interceptors then both flow into the Penn Street Interceptor that also conveys the dry weather flow and a portion of wet weather flow from CSO Service Areas 025 and 026 to the Chester Pump Station, which pumps the flow to the WRTP.

3.5.5 CSO Outfalls

Outfalls are the discharge points at the receiving streams. The outfalls can either be free outfalls without any boundary conditions or the outfalls can have a boundary condition that the head needs to overcome for outflow to occur. The outfalls in the DELCORA's collection system are mostly in the tidal river reach. Therefore, appropriate tidal stages from NOAA data were used to set boundary conditions. Outfalls can have a flap gate or other backflow device at the end to prevent backflow.

CSO outfalls will be simulated as outfall nodes in the model. Outfall ID will be named according to the CSO regulator overflow points. For example, the outfall for CSO regulator 002 will be named "NREG-002". The inverts of outfalls were estimated based on record drawings and design drawings.

A summary of the outfall data used in the model is contained in Appendix A, Table A-5. One regulator (Regulator 010) does not have its own outfall, but rather discharges through the same outfall (Outfall 009) as Regulator 009. Also, Regulator 033 has been disconnected from the CSS and, therefore, its outfall is not included in the updated H&H model. As a result, there are a total of 25 CSO outfalls in the updated H&H model.

3.5.6 Drainage Areas and Subcatchments

Each of the 25 CSO regulators has a unique drainage area associated with it. A CSO drainage area is defined as the entire surface area contributing overland wet weather flow to a specific CSO. Subcatchments are smaller drainage basins located within the overall CSO drainage area. Subcatchments are more useful when developing a model, because the area is smaller and it becomes more site-specific. Subcatchment boundaries were determined from sewer system maps and local topography. GIS software was then used to estimate the acreage within a subcatchment boundary. There are a total of 53 subcatchments within DELCORA's 25 drainage areas of the CSS. An overall configuration of the CSS drainage areas is presented in Figure 3-4. This figure shows the boundaries of each of the 25 CSO regulator drainage areas (subcatchments), as well the combined and separated portions of these service areas. Table 3-1 presented a listing of the subcatchment areas associated with each CSO regulator, and the type of collection system (CSS or separated) within the subcatchment.

3.5.7 Percent Imperviousness

Areas that are impervious to rainfall infiltration, like pavement and rooftops, generate the most runoff in urban settings. Percent imperviousness is the fraction or percentage of a particular subcatchment that is covered by impervious materials like parking lots, streets, and rooftops. The percent of directly connected impervious area is the ratio of hydraulically connected impervious areas (parking lots, streets, etc.) to the total subcatchment area. Directly connected impervious areas are effectively connected to the sewer collection system. As a result, runoff from these areas is completely captured by the collection system. Runoff from the rest of the impervious area is deemed not to be captured by the system due to various potential reasons including, but not limited to, drains to pervious areas/creeks/streams, limited number and capacity of stormwater inlets, and bypassing. For model construction, the percent imperviousness was calculated using the high resolution land cover raster published by the Chesapeake Conservancy (Chesapeake Conservancy, 2017) as well as the land use shapefile published in 2015 by the Delaware Valley Regional Planning Commission as the initial inputs. Then, the impervious percentage values were adjusted during the model calibration process (see Section 7) to best simulate the observed hydrologic response over the selection of precipitation events.

For the separated areas within the City of Chester, the initial percent imperviousness was set at 0% because the impervious area in the separated area is not contributing runoff to the CSS, therefore it is not effectively connected. Subcatchment parameters mentioned hereafter were set at default values for the separated subcatchments.

3.5.8 Depression Storage

Depression storage is the rainfall abstraction volume that must be filled prior to the occurrence of runoff. It represents the loss (initial abstraction) caused by surface ponding, surface wetting, etc. The initial values of depression storage were set to 0.05 for impervious surfaces and 0.15 for pervious surfaces. Typical depression storage values are 0.05-0.10 for impervious surfaces and 0.10-0.30 for pervious surfaces. Depression storage is an empirical value and may be treated as a calibration parameter, especially to adjust runoff volumes.

In the model, the subcatchment was divided into three subareas: pervious area with depression storage, impervious area with depression storage, and impervious area without depression storage. The initial percent of the impervious area without depression storage was set to 0.10.

3.5.9 Soil Infiltration Parameters

Soil information is needed to estimate infiltration in the pervious areas of the CSS. The rate of infiltration is a function of soil properties and antecedent soil conditions. Infiltration parameters influence the runoff hydrograph from the combined sewer system subcatchments by absorbing rainfall into the soil. The infiltration capacity of the soil is exceeded when the soil becomes saturated during continuous simulation and heavy precipitation. When soil saturation is reached, most of the subsequent rainfall becomes runoff making the pervious areas behave as impervious areas.

Three infiltration methods are available in the software: the Horton method, Green-Ampt method, or Natural Resources Conservation Service (NRCS) Curve Number method. The Horton method has been extensively used for similar type of modeling work and it was used in this modeling effort to estimate infiltration. The required soil parameters for Horton method include:

- Maximum Infiltration rate (in/hr)
- Minimum Infiltration Rate (in/hr)

- Decay Constant (/hr)
- Drying time (d)
- Maximum Infiltration Volume Possible (inch)

To determine the Horton infiltration parameters, a soil map was first obtained from the NRCS (USDA, 2017). The soil types were then correlated to standard hydrologic soil groups.[4] A map of the hydrologic soil groups found in the CSS is presented in Figure 3-6. Hydrologic soil groups found in DELCORA's CSS are groups A, B, C, B/D and C/D. Horton's infiltration parameters for these soil groups were estimated based on typical values from literature and are shown in Table 3-3.

Table 3-3: Horton Infiltration Parameters

Horton Infiltration Parameter	Soil A	Soil B	Soil C	Soil B/D	Soil C/D
Max Infiltration Rate (in/hr)	5	3	2	2	1.5
Min Infiltration Rate (in/hr)	1.18	0.43	0.2	0.22	0.06
Decay Constant (1/hr)	4	4	4	4	4
Drying Time (d)	2	3	8	8	10.5
Max Volume (in)	14	13.2	12.5	9.8	7.0

3.6 Collection System Pump Stations and Force Mains

Major pump stations in the Western Service Area and the Central Delaware Pump Station in the Eastern Service Area were added to the updated model, as well as force mains connecting the pump stations to the WRTP. The list of the pump stations included in the H&H Model is as follows:

- Chester PS (CPS)
- Existing PS-1 (EPS-1)
- Marcus Hook PS (MHPS)
- Naamans Creek PS (NCPS)
- Eddystone PS (EDPS)
- Central Delaware PS (CDPS)
- Chester Ridley Creek PS (CRPS)
- Sun Oil PS (Owned by Sunoco) (SPS)
- Kimberly Clark PS (Owned by KC) (KCPS)

[4] Soil types can be categorized into standard hydrologic soil groups A, B, C and D, with group A having the lowest runoff potential and group D having the highest runoff potential. Dual rated groups are group D in their natural state, but can behave according to the first letter if the area is drained. Additional information regarding hydrologic soil group descriptions can be found in the Appendix.

The following pump stations were excluded from the H&H Model:

- Price & Smith Street Trainer PS
- Stadium PS

Flow from the Price & Smith Street Trainer PS discharges to the downstream existing PS-1 Pump Station (EPS-1) where it is re-pumped. The updated H&H model assumes that all flow from subcatchments associated with the Price and Smith Street Trainer PS can be treated as an input to EPS-1.
Flow from the Stadium PS is sanitary sewage with no wet weather flow. The Stadium PS discharges flow only during events held at the stadium. Due to the limited flow, its sporadic nature and the lack of wet weather flow, the Stadium PS is expected to have negligible effect on the wet weather capacity of the CSS. Therefore, the Stadium PS was not included in the H&H Model.

DELCORA owns or operates a number of lift stations that contribute to the Western Service Area and whose flows are handled by the above list of pumps stations. It was determined that the behavior of these lift stations would not require modeling and that inflow can be assumed to equal outflow to the downstream conduit.

Figure 3-7 presents a map of the pump stations that are included within the updated H&H model.

3.6.1 Force Mains

DELCORA's Model Area include several force mains to convey flow from various pump stations to the WRTP.

- Chester Force Main
- Central Force Main
- Chester-Ridley Creek Force Main
- Naaman's Creek Force Main
- Marcus Hook/Sun Oil Force Main
- Eddystone Force Main
- Kimberly Clark Force Main.
- Existing Pump Station Force Main

The 40-MGD Chester Pump Station discharges to the Chester Force Main which then runs to the WRTP as a 54-inch diameter ductile iron force main.

The Central Delaware Pump Station (CDPS) discharges through two force mains, one of which connects to the Model Area and the WRTP while the other delivers flow to PSWPCP. The force main to the Model Area is referred to as the Central Force Main and is a 3.4-mile, 24-inch ductile iron force main which subsequently connects to the Chester Force Main. This connection allows DELCORA to send up to 27 MGD of flow from the CDPS to the WRTP, however, DELCORA's operating policy limits this flow to 20 MGD, with flows above this point to be directed to PSWPCP. Only the force main connecting to the Model Area is included in the updated H&H model.

A schematic representation showing the force mains can be found in Figure 3-3. A map showing the location of the force mains is depicted in Figure 3-8.

Figure 3-6: Hydrologic Soil Groups for CSS Area

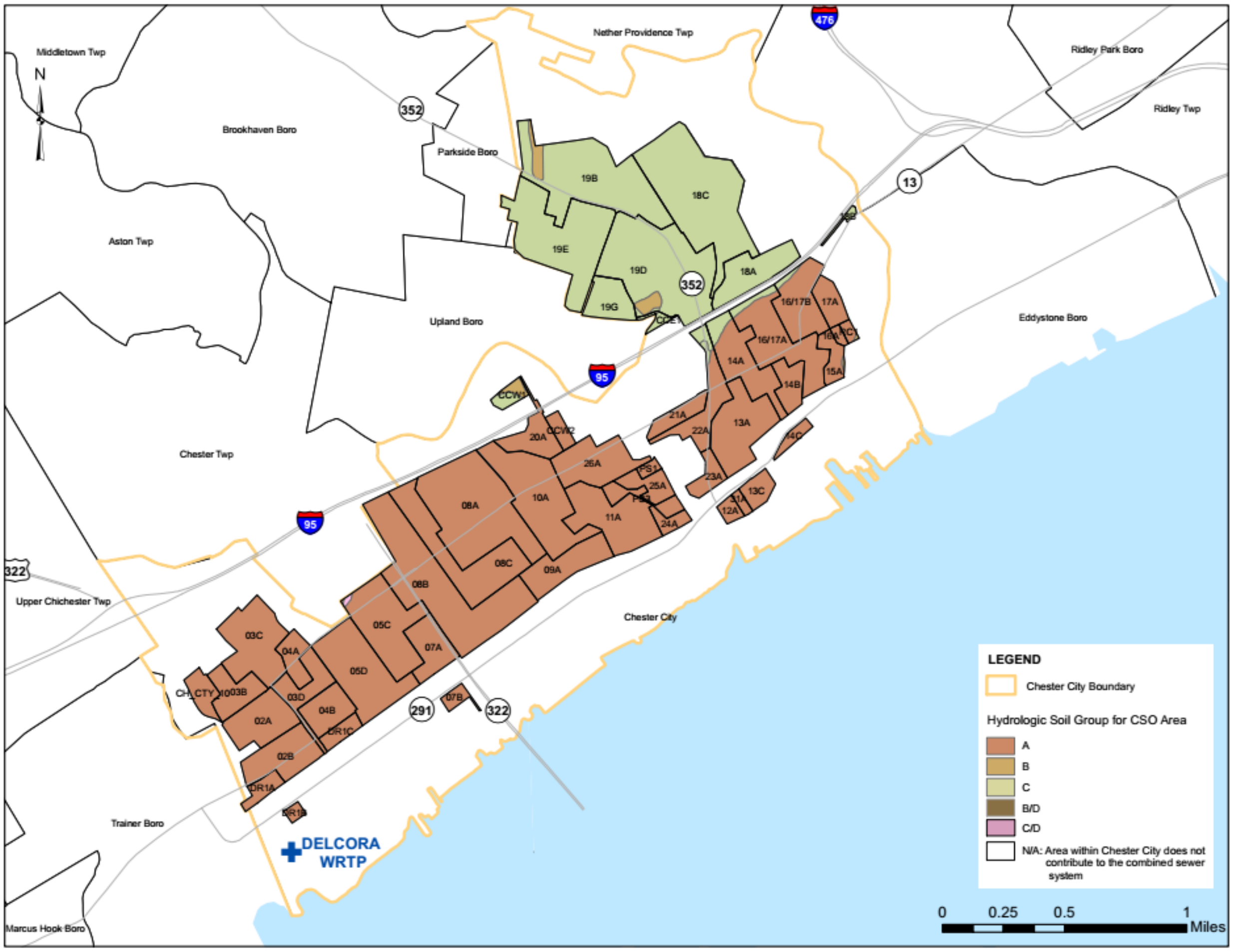


Figure 3-7: Pump Stations Included in the H&H Model

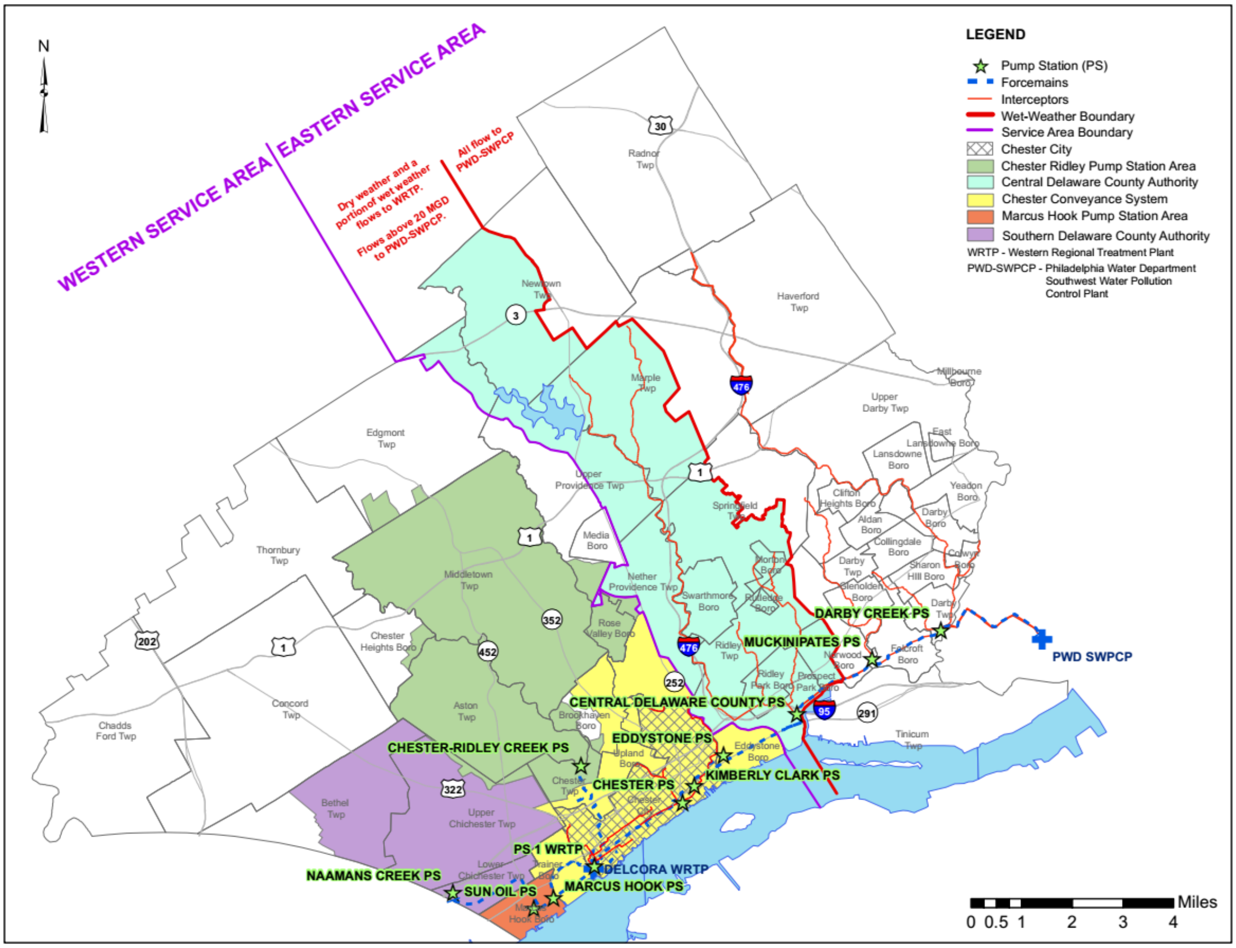
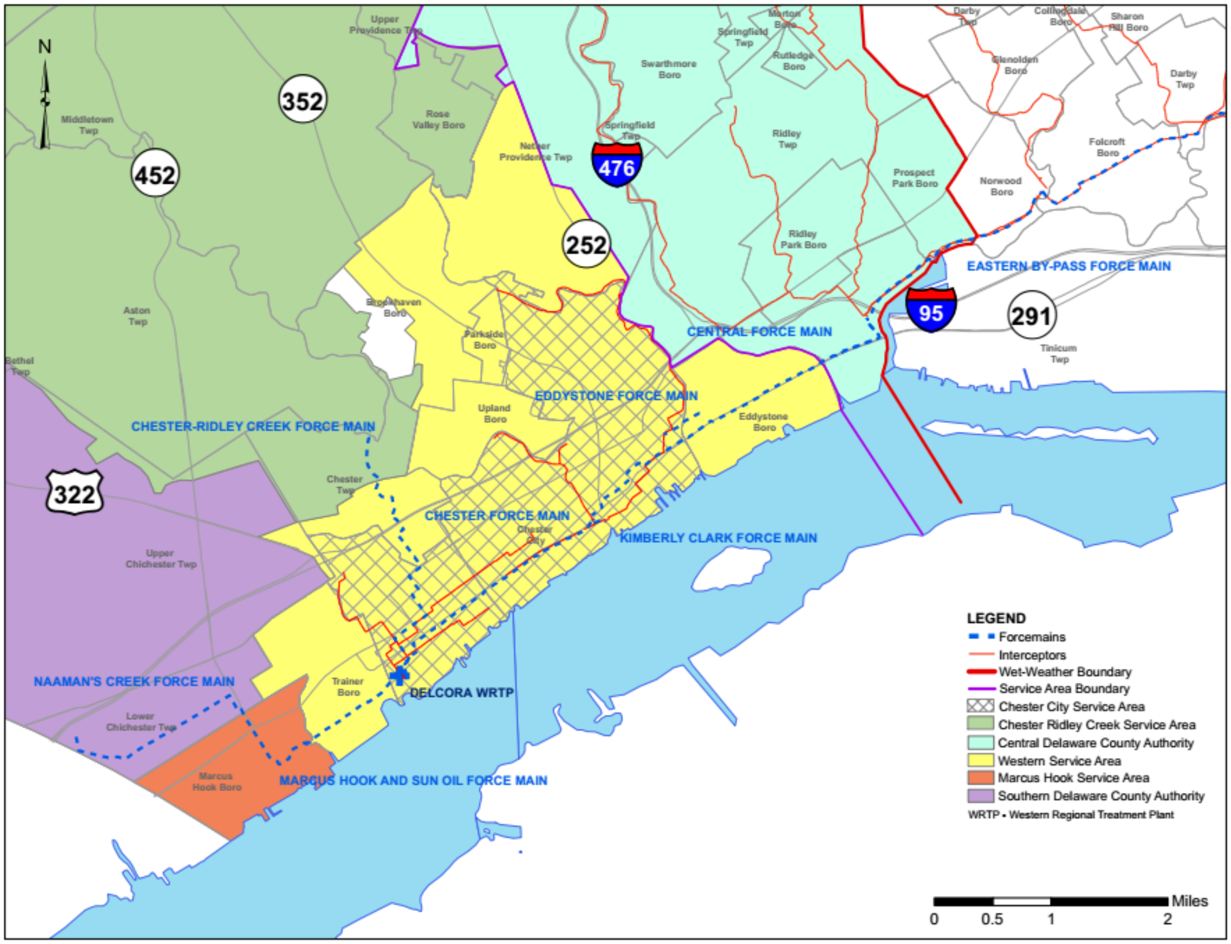


Figure 3-8: Force Mains



Section 4 Collection of Precipitation and Sewer Flow Data

4.1 Introduction

This section presents information on the collection of precipitation and sewer flow data to meet the requirements of Section V.A.14.d of the Consent Decree, and Paragraphs II.A.C.1.a and b of the USEPA's CSO Control Policy. Section V.A.14.d of the Consent Decree requires DELCORA to conduct rainfall monitoring in accordance with current good industry practice for a period of at least (12) months.

The rainfall and flow monitoring program was developed to provide adequate data for the development, calibration and validation of the H&H Model. The goals of this program were met by collecting rainfall and flow monitoring data for just over 12 months, from March 18, 2016 to April 4, 2017. Rainfall and flow monitoring data were collected on a monthly basis with quarterly reports were submitted to US EPA on August 28, 2016; November 1, 2016; February 1, 2017; and May 1, 2017. DELCORA considers Consent Decree requirements to be met due to no comments from US EPA and PA DEP.

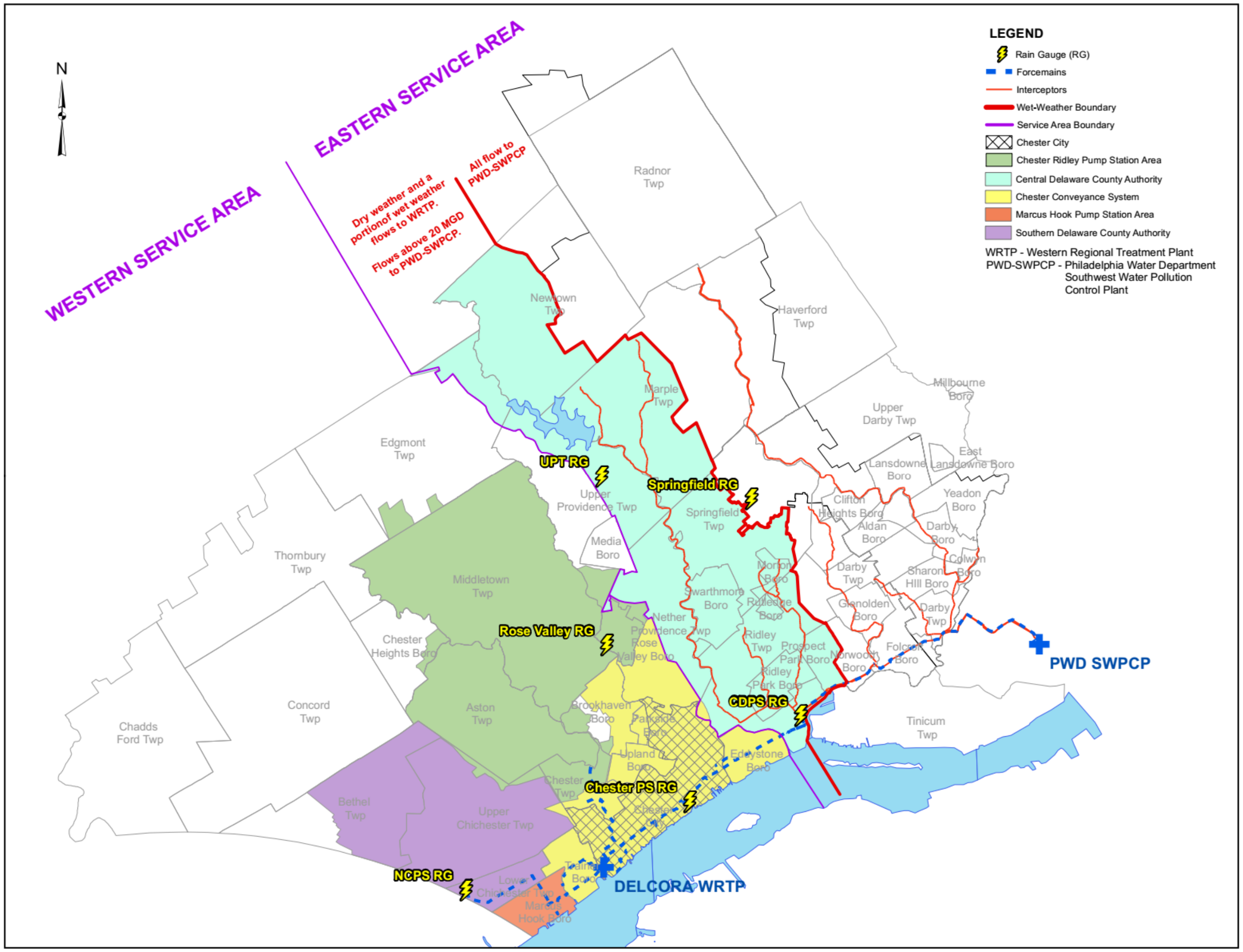
After it was carefully reviewed and analyzed, the data was deemed adequate to facilitate the development, calibration and validation of the H&H Model. This section contains a summary of the rainfall and flow monitoring program and discusses the network of rainfall and flow monitoring instrumentation, outlines the monitoring program, and describes how the data collected for the rainfall and flow monitoring program was analyzed for use in the H&H Model calibration and validation. Additional details can be found in the rainfall and flow monitoring quarterly reports, in the *Hydrologic and Hydraulic Model Update and Calibration Plan* (Greeley and Hansen, 2015), and in the *Sewer System Hydrologic and Hydraulic Model Report* (Greeley and Hansen, 2017c).

4.2 Rainfall Monitoring and Analysis

A total of six (6) rain gauges were used for the monitoring program. As depicted in Figure 4-1, the gauges are stationed at the following locations:

- Rose Valley
- Chester Pump Station (CPS)
- Naaman's Creek Pump Station (NCPS)
- Springfield
- Upper Providence Township (UPT)
- Central Delaware County Pump Station (CDPS)

Figure 4-1: Rain Gauge Locations



Five out of six of the gauges provided data at 5 minute intervals. One rain gauge provided data on 15-minute intervals. The gauge rainfall data from the six rain gauges installed throughout the DELCORA service area was analyzed and used to:

- Document rainfall and flow monitoring locations,
- Overview flow monitoring data quality,
- Analyze rainfall data to identify dry weather and wet weather conditions and to characterize individual rainfall event for precipitation depth, duration, maximum intensity, and return frequency,
- Analyze flow data to determine dry weather flow and diurnal pattern, wet weather flow and peak factor, and system response to wet weather events, and
- Determine the wet weather events for H&H Model calibration and validation.

An inter-event time of 48 hours was used to identify individual rainfall events. The inter-event time specifies the minimum duration in which precipitation does not occur. Based on this criterion, a dry weather time period and the number of total rainfall events were identified. The rainfall events during the flow monitoring periods had a wide variation in terms of total depth, intensity, duration, and antecedent conditions to provide a large dataset for balanced model calibration and validation.

4.3 Rain Event Summary

The rainfall events were characterized by event start time, event end time, rainfall depth, duration, maximum intensity, and return frequency. As an initial screening criterion, rainfall events with a minimum of 0.9 inches of rainfall were identified. Further screening based on requiring at least two dry days prior to the event resulted in an initial list of ten (10) candidate events for calibration and validation as listed in Table 4-1 below.

Table 4-1: Top 10 Rainfall Events

Event	Event Start	Event End	Chester-PS Rainfall (in)	Duration (hr)	Max Intensity (in/hr)
E1	5/29/16 19:00	5/30/16 5:00	1.82	11.00	0.78
E2	9/28/16 12:00	9/30/16 10:00	2.36	47.00	0.37
E3	11/29/16 7:00	11/29/16 20:00	1.08	14.00	0.21
E4	3/30/17 21:00	4/1/17 3:00	1.83	31.00	0.25
E5	5/21/16 11:00	5/22/16 21:00	1.71	35.00	0.33
E6	7/28/16 15:00	7/29/16 9:00	1.26	19.00	0.74
E7	9/19/16 8:00	9/19/16 16:00	0.96	9.00	0.42
E8	3/13/16 18:00	3/14/16 14:00	1.08	21.00	0.25
E9	5/6/16 4:00	5/7/16 11:00	1.18	32.00	0.24
E10	10/8/16 14:00	10/9/16 11:00	1.00	22.00	0.15

4.4 Gauge-Adjusted, Radar Estimated Precipitation

According to the Consent Decree, rainfall data to be used for calibration and validation of the model *"…shall be obtained at a minimum effective density of 1 gauge/virtual radar-based gauge per kilometer"*. In order to achieve this density, Gauge-Adjusted Radar Rainfall (GARR) was employed. The rain gauges used to complete the flow monitoring program and choose the wet weather events used in calibration and validation were also used in the GARR analysis which provided effective spatial coverage of the entire Model Area. GARR data was provided for each of the subbasins in the Model Area. This rainfall data was input as a time series into the H&H Model for calibration and validation. An in-depth explanation of the use of GARR data in both the H&H Model and the Water Quality Model can be found in the *Sewer System Hydraulic and Hydrologic Report* and the *Water Quality Monitoring and Modeling Quality Assurance Project Plan*, respectively (Greeley and Hansen, 2017c), (Greeley and Hansen, 2017b).

4.5 Flow Monitoring

DELCORA owns and operates a flow monitoring network across the DELCORA Service Area. The monitoring network includes various types of flow meters located throughout DELCORA's Eastern Service Area and Western Service Area, at the WRTP, in each of the Pump Stations, and at the tie-in points where other municipal collection systems tie-into the collection system. Seven existing flow meters in the separated area (outside the CSO area), eight existing flow meters at pump stations and one existing flow meter at WRTP were used for the calibration and validation of the H&H Model. In addition, temporary flow meters were installed at 38 new locations to characterize surface runoff from the combined area and CSO discharges. The locations of flow meters installed specifically for the flow monitoring program and the H&H Model calibration and validation can be categorized into the following five categories:

1. Located on the influent pipe to CSO regulators, this is to measure the influent flow to CSO regulators and for combined area runoff calibration. Sixteen (16) meters were installed for this category.
2. Located on the effluent pipe and overflow pipe of CSO regulators, this is to measure the CSO overflows and calibrate CSO regulator parameters. Twelve (12) meters were installed for this category. They are on the effluent and overflow pipe of CSOs 02, 03, 05, 08, 14, & 19.
3. Located on the side-line from the combined areas (flows from the combined area tie into interceptor instead of CSO regulator). This is to measure flows from the combined area and to calibrate combined area runoff parameters. Two (2) meters were installed for this category.
4. Located upstream of the combined area, this is to measure flows from the upstream separated area for RDII characterization. Three (3) meters were installed for this category.
5. Located in the main interceptors to measure level and flows in the major interceptors. Five (5) meters were installed for this category.

Table 4-2 lists the flow meter locations and location categories of the meters. Figures 4-2 and 4-3 show the locations of the flow meters that were used for H&H Model calibration and validation. After initial installation of the new temporary flow meters, difficulties were encountered at Manhole MH3029. The site was severely surcharged during field investigation. Meanwhile it was found that at Manhole MH3002 (four manholes upstream of MH3029, approximately 800 feet upstream) another existing flow meter (Ridley Creek MH-28) was already installed for DELCORA. Instead of installing a new temporary flow meter around the site, the existing meter Ridley Creek MH-28 was used for the flow monitoring program.

Data was gathered from a total of 55 flow meters, 38 of which were newly installed as part of the flow monitoring program.

Table 4-2: Flow Monitoring Locations

Flow Meter	Approximate Location	Category
In-02	Influent pipe to CSO 02 Regulator	On the influent pipe to regulator
In-03	Influent pipe to CSO 03 Regulator	On the influent pipe to regulator
In-05	Influent pipe to CSO 05 Regulator	On the influent pipe to regulator
In-08	Influent pipe to CSO 08 Regulator	On the influent pipe to regulator
In-09	Influent pipe to CSO 09 Regulator	On the influent pipe to regulator
In-10	Influent pipe to CSO 10 Regulator	On the influent pipe to regulator
In-11	Influent pipe to CSO 11 Regulator	On the influent pipe to regulator
In-13	Influent pipe to CSO 13 Regulator	On the influent pipe to regulator
In-14	Influent pipe to CSO 14 Regulator	On the influent pipe to regulator
In-16	Influent pipe to CSO 16 Regulator	On the influent pipe to regulator
In-17	Influent pipe to CSO 17 Regulator	On the influent pipe to regulator
In-18	Influent pipe to CSO 18 Regulator	On the influent pipe to regulator
In-19-1	Influent pipe to CSO 19 Regulator (from East)	On the influent pipe to regulator
In-19-2	Influent pipe to CSO 19 Regulator (from West)	On the influent pipe to regulator
In-25	Influent pipe to CSO 25 Regulator	On the influent pipe to regulator
In-26	Influent pipe to CSO 26 Regulator	On the influent pipe to regulator
INT- 2nd St	2nd Street Interceptor	On the interceptor pipe
INT-DRI	Delaware River Interceptor	On the interceptor pipe
INT-Ridley 2	Ridley Creek Interceptor	On the interceptor pipe
INT-Ridley 3	Ridley Creek Interceptor	On the interceptor pipe
INT-West End	West End Interceptor	On the interceptor pipe
Side-1	Side line on Penn St. to 2nd St. Interceptor	On the side-line from the combined area
Side-2	Side line on Highland Ave. to West End Interceptor	On the side-line from the combined area
Sep-1	Upstream of the CSO 02 Drainage	On the separated area
Sep-2	Upstream of the CSO 05 Drainage	On the separated area
Sep-3	Upstream from Upland Borough	On the separated area
Sep-4 (Existing MH-28 after first quarterly report)	Upstream from Eastern Chester	On the separated area
CSO-02	Outfall pipe from CSO 02 Regulator	On the outfall pipe

Flow Meter	Approximate Location	Category
CSO-03	Outfall pipe from CSO 03 Regulator	On the outfall pipe
CSO-05	Outfall pipe from CSO 05 Regulator	On the outfall pipe
CSO-08	Outfall pipe from CSO 08 Regulator	On the outfall pipe
CSO-14	Outfall pipe from CSO 14 Regulator	On the outfall pipe
CSO-19	Outfall pipe from CSO 19 Regulator	On the outfall pipe
Eff-02	Effluent pipe for CSO-02 Regulator	On the effluent pipe
Eff-03	Effluent pipe for CSO-03 Regulator	On the effluent pipe
Eff-05	Effluent pipe for CSO-05 Regulator	On the effluent pipe
Eff-08	Effluent pipe for CSO-08 Regulator	On the effluent pipe
Eff-14	Effluent pipe for CSO-14 Regulator	On the effluent pipe
Eff-19	Effluent pipe for CSO-19 Regulator	On the effluent pipe
BR MH-1 (Existing)	Upstream from Brookhaven MH-1	On the separated area
BR MH-3 (Existing)	Downstream from Brookhaven MH-3	On the separated area
BR MH-5 (Existing)	Downstream from Brookhaven MH-5	On the separated area
BR MH-6 (Existing)	Downstream from Brookhaven MH-6	On the separated area
RC MH-26 (Existing)	Ridley Creek Interceptor	On the interceptor pipe
RC MH-30 (Existing)	Ridley Creek Interceptor	On the interceptor pipe
RC MH-32 (Existing)	Ridley Creek Interceptor	On the interceptor pipe
WRTP (Existing)	At WRTP	At WRTP

Figure 4-2: DELCORA Flow Meters

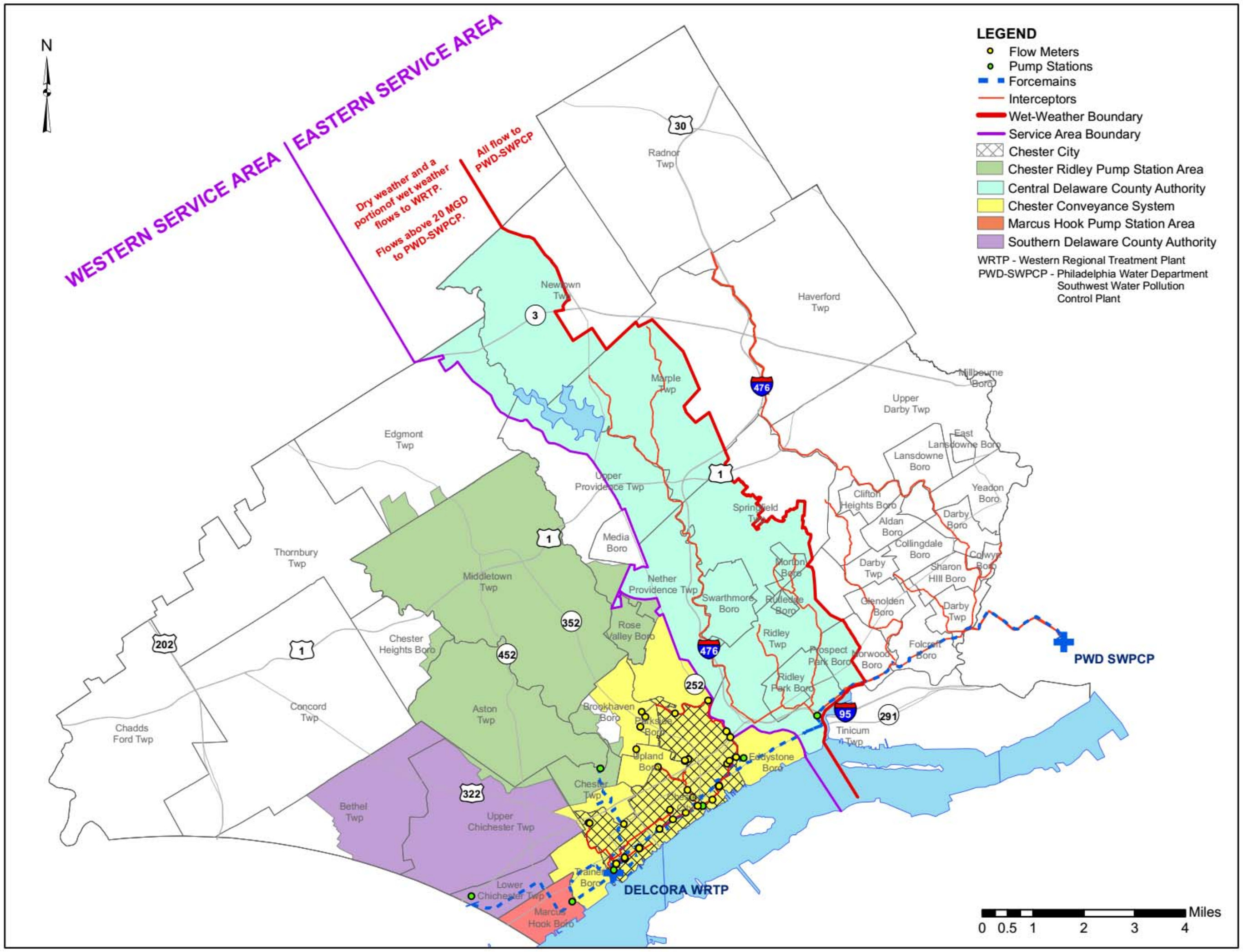
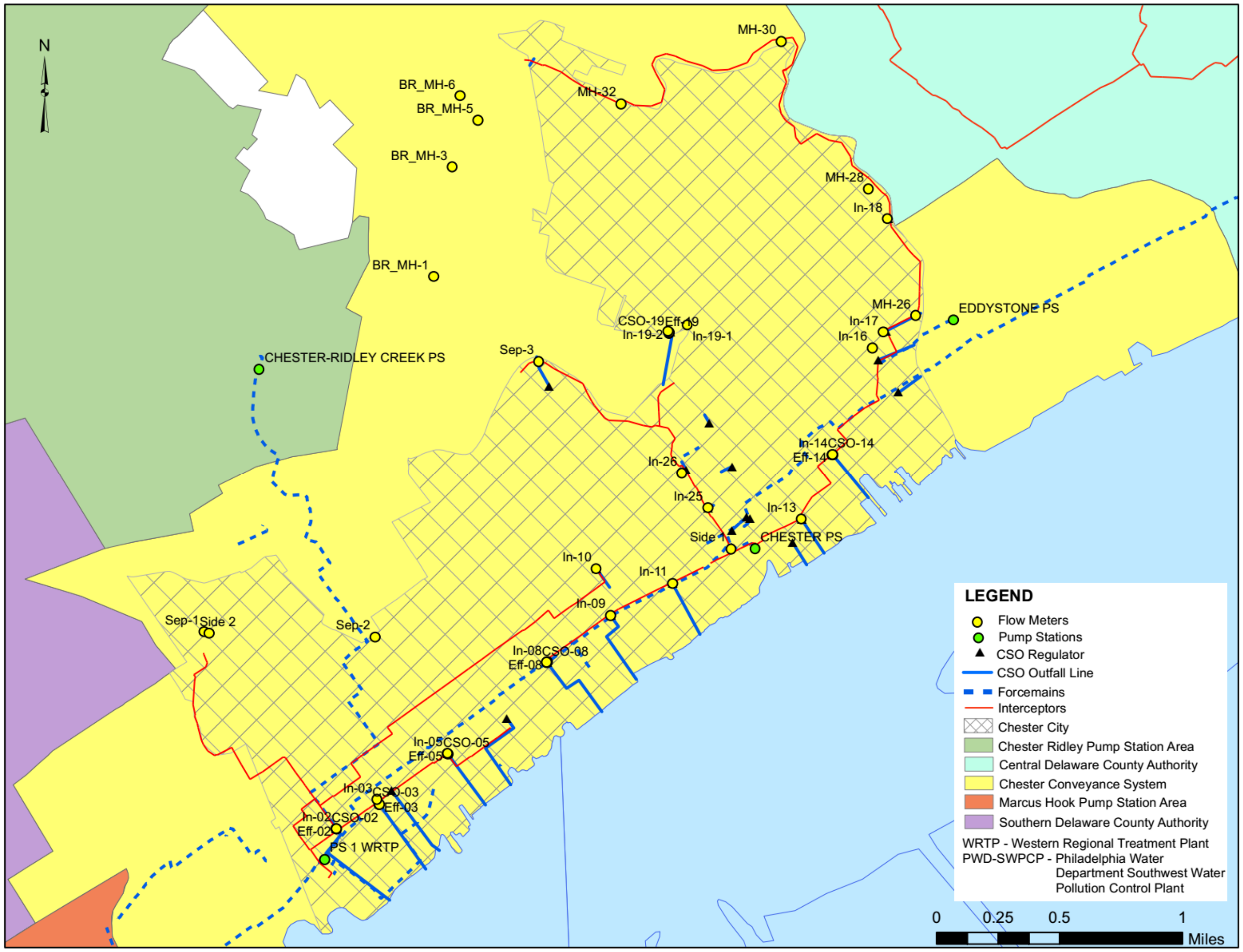


Figure 4-3: Enlarged Map of Flow Meters



The network of flow meters can be grouped to define metersheds where flow from a given area discharges through a common flowmeter. Subcatchments associated with each metershed are shown in Table 4-3 along with the associated metershed acreage. Rainfall and flow data gathered for each metershed will be used to calibrate the associated subcatchments in the H&H Model.

Table 4-3: Metersheds in the H&H Model

Metershed ID	Subcatchment ID	Metershed Area (ac)
BR_MH-1	BR_TWP_2	49
BR_MH-3	BR_TWP_3	236
BR_MH-5	BR_TWP_4	21
BR_MH-6	BR_TWP_5	44
In-02	02A	112
	02B	
	SC1	
In-03	03B	82
	03C	
	03D	
In-05	05C	161
	05D	
	CH_TWP_2	
In-08	08A	237
	08B	
	CH_CTY_12	
In-09	09A	27
In-10	10A	60
In-11	11A	44
In-13	13A	50
	13C	
In-14	14A	53
	14B	
	14C	
In-16	16A	2
In-16,In-17	16/17A	77
	16/17B	
In-17	17A	12
In-18	18A	130
	18B	

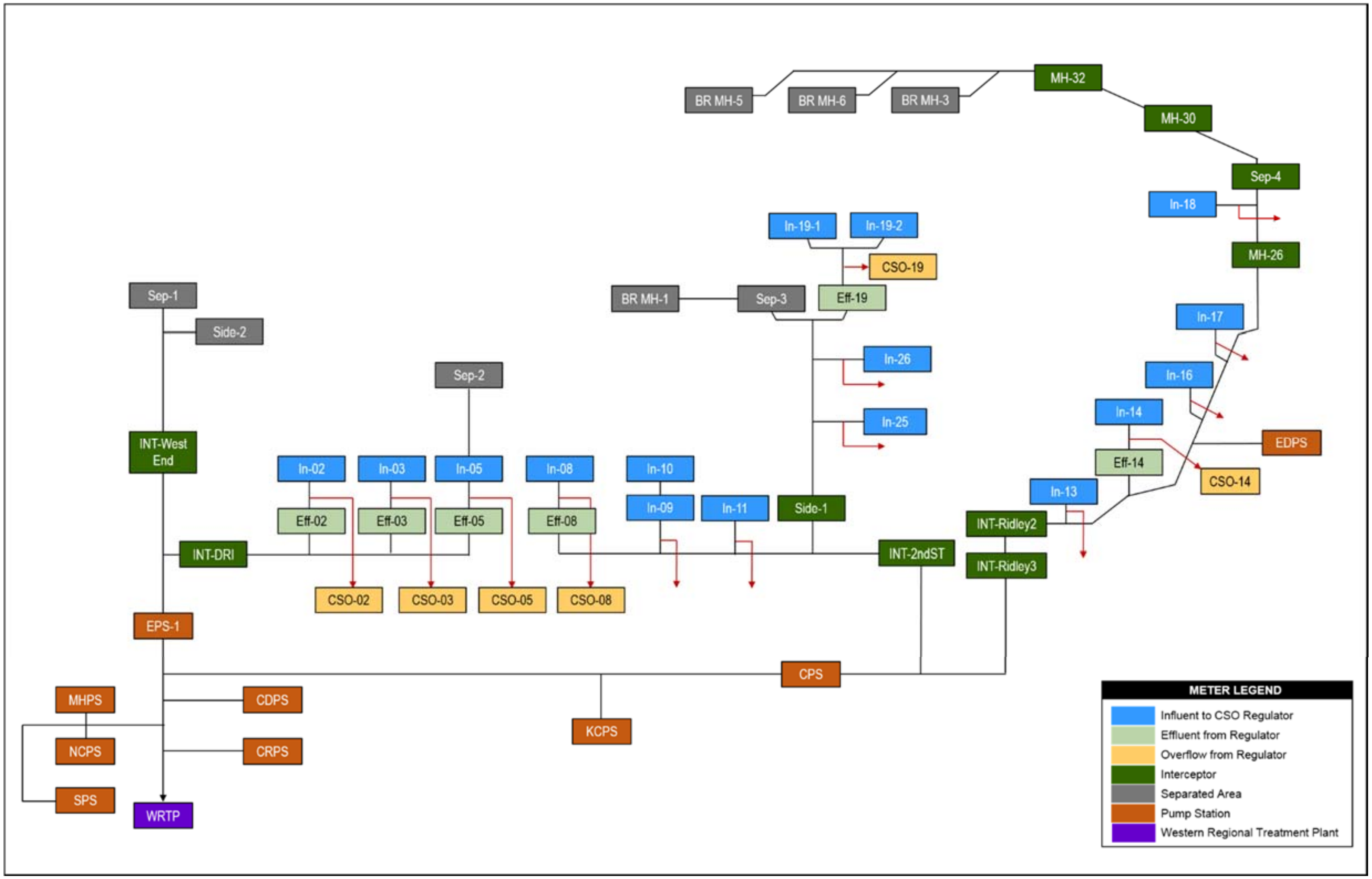
Metershed ID	Subcatchment ID	Metershed Area (ac)
	18C	
In-19-1	18C	327
	CH_CTY_08	
	19B	
	19D	
	PA_BORO_1	
In-19-2	19E	94
	19G	
In-25	25A	12
In-26	26A	37
	26B	
INT-2nd St	24A	6
INT-DRI	04A	57
	04B	
	07A	
	07B	
INT-Ridley 2	15A	16
	31A	
	RC1	
INT-Ridley 3	21A	53
	22A	
	23A	
	12A	
INT-West End	DR1A	26
	DR1C	
	CH_CTY_10	
MH-26	CH_CTY_07	44
MH-28 (Sep-4)	CH_CTY_04	137
MH-30	CH_CTY_06	1,035
	NP_TWP_2	
MH-32	PA_BORO_2	531
	33A	
	BR_TWP_6	
	CH_CTY_05	
Central PS (PS-1)	CH_CTY_02	514

Metershed ID	Subcatchment ID	Metershed Area (ac)
	CH_CTY_03	
Eddystone PS (PS-10)	EDD_BORO_1	664
Marcus Hook PS (PS-11)	LC_TWP_1	1,401
	MH_BORO_1	
Naamans Creek PS (PS-15)	BE_TWP_1	6,528
	UC_TWP_1	
Chester Ridley Creek PS (PS-24*)	EDG_TWP_2	14,513
	MI_TWP_1	
	NP_TWP_3	
	RV_BORO_1	
	UPR_TWP_2	
	AS_TWP_1	
	BR_TWP_7	
	CH_BORO_1	
	CH_TWP_4	
	UC_TWP_3	
Existing PS-1 (PS-3)	TR_BORO_1	1,001
	DR1B	
	CH_CTY_01	
Central Delaware PS Total and Central Delaware PS to WRTP (PS-7)	EDG_TWP_1	18,806
	MA_TWP_1	
	MO_BORO_1	
	NE_TWP_1	
	NP_TWP_1	
	PR_BORO_1	
	RI_TWP_1	
	RP_BORO_1	
	RU_BORO_1	
	SP_TWP_1	
	SW_BORO_1	
	UPR_TWP_1	
Sep-1	CH_TWP_3	296
	UC_TWP_2	
Sep-2	CH_CTY_09	45
	CH_TWP_1	

Metershed ID	Subcatchment ID	Metershed Area (ac)
Sep-3	BR_TWP_1	480
	CH_CTY_13	
	PA_BORO_3	
	UPL_BORO_1	
Side-1	20A	52
	CCE1	
	CCW1	
	CCW2	
	PS1	
	PS3	
	CH_CTY_11	
Side-2	BS3	32
	BS2	

A schematic of the collection system was created to facilitate the development, calibration and validation of the H&H Model and is shown below as Figure 4-4. The schematic illustrates the relationship between all major trunk sewers, force mains, interceptors, pump stations, and other major appurtenances. The schematic also includes the location of the flow meters, and provides and good understanding of the relationship between them. Figures of the diversion structure configurations were also developed to help give a better understanding of the collection system.

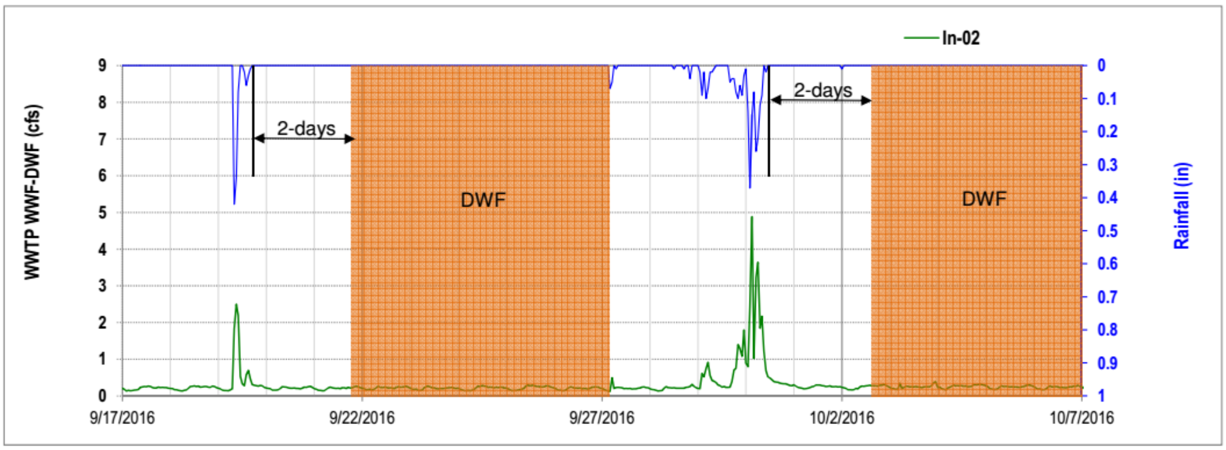
Figure 4-4: Flow Monitoring Schematic



4.6 Dry Weather Flow (DWF) Analysis

A "dry weather" condition was defined as a period with no precipitation that begins 48 hours after the last wet weather event ends and lasts until the beginning of the next precipitation event (i.e. the rain gauge read a 0.01 inch value). Dry weather flow (DWF) periods based on this definition are illustrated in the hydrograph shown in Figure 5-4**.**

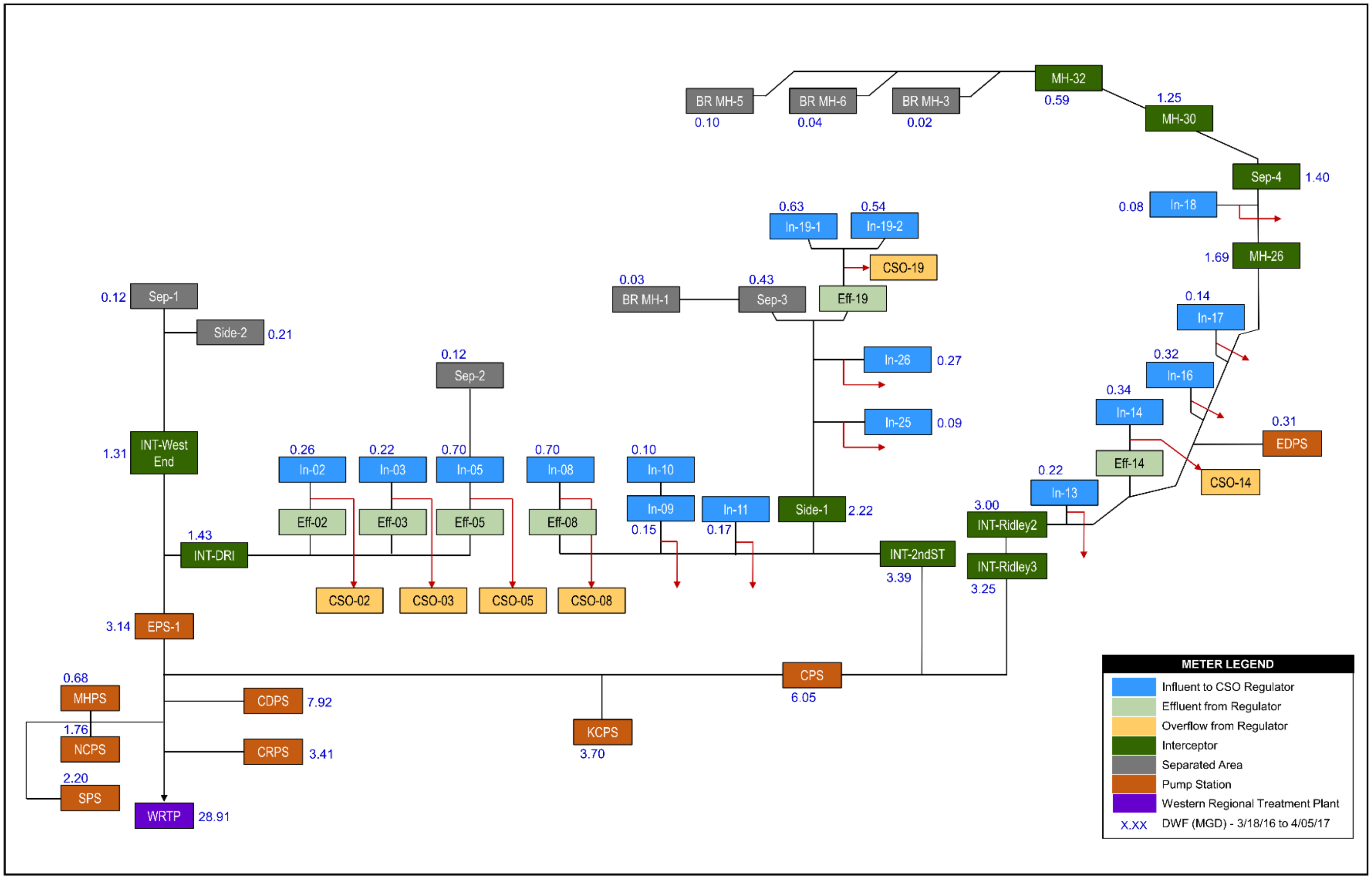
Figure 4-5: Hydrograph to Show Dry Weather Flow



Overall hourly average DWF was calculated by taking the average of the monitored DWF for each hour during the flow monitoring period. Monthly DWF was calculated by averaging the DWF for each month during the flow monitoring period. The overall hourly and monthly DWFs for all monitoring sites were analyzed and used as inputs in the H&H Model.

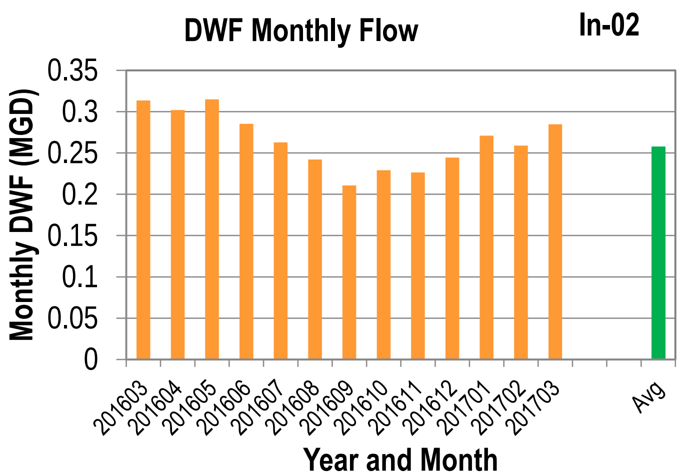
The DWFs for the one year monitoring period are also shown in the schematic in Figure 4-6. Each value displayed next to each flow meter represents the DWF overall average (in MGD) for one quarter. These values were ultimately averaged and input into the model as the overall annual average DWF. Generally the downstream dry weather flow is greater than the upstream locations for all of the meters. For meters immediately upstream and downstream of CSO regulators, the upstream and downstream dry weather flows should be similar.

Figure 4-6: Dry Weather Flow Balance Schematic



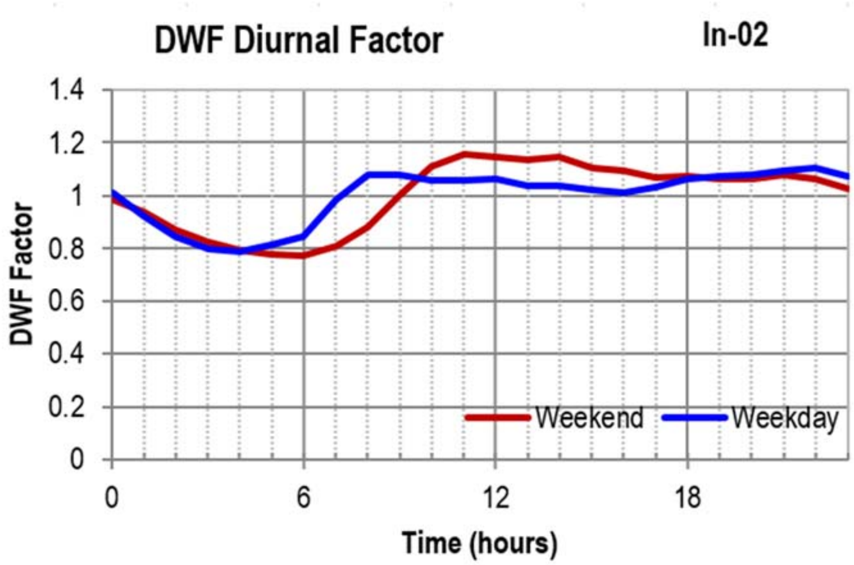
Monthly DWFs were calculated during the DWF analysis by averaging the overall DWF during each month. Average monthly DWFs were input into the model along with the overall annual averages for each flow meter. Figure 4-7 below shows the monthly DWFs input into the model for meter In-02.

Figure 4-7: Average Monthly DWF



The DWFs vary throughout the day, with the highest flows normally occurring around noon and the lowest rates between midnight and early morning. Flow data from the dry weather periods were used to develop a diurnal pattern for each flow meter. Diurnal patterns were analyzed for both weekdays and weekends. In the plot shown on Figure 4-8, the weekend DWF peak and valley have a 3-hour lag compared to the weekday pattern. The weekday and weekend diurnal patterns were input into the model along with the overall annual average values discussed above.

Figure 4-8: Weekday and Weekend Dry Weather Flow Diurnal Pattern

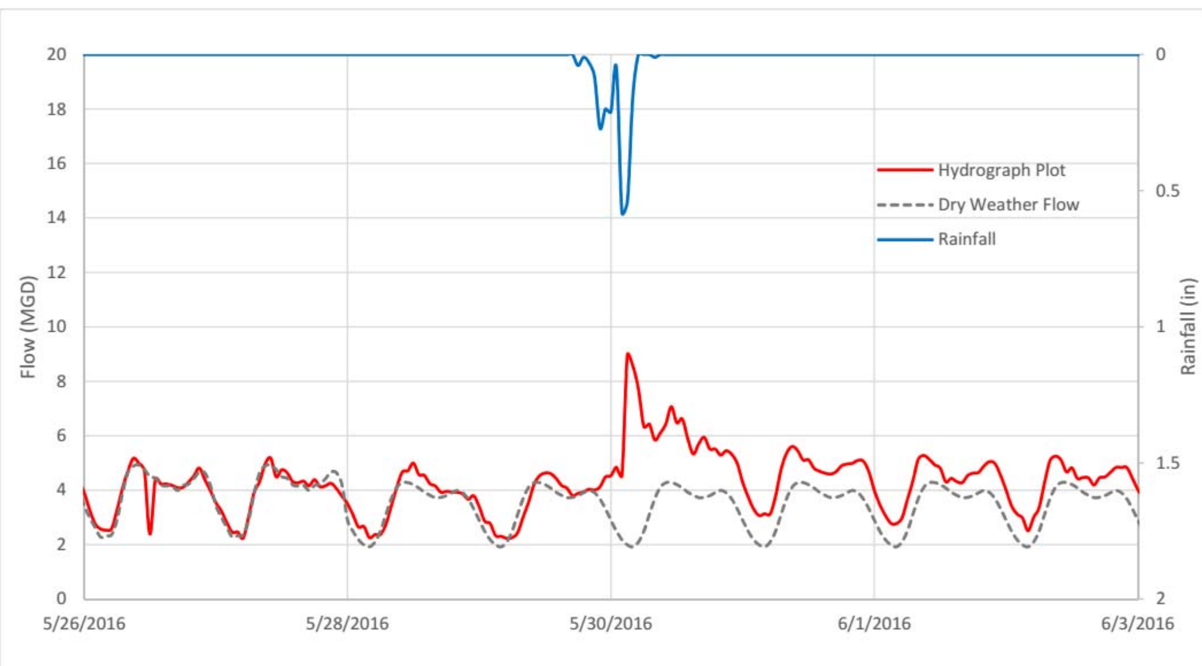


4.7 Wet Weather Flow Analysis

Wet weather flows are the combination of dry weather flows and additional flows that enter the system during wet weather conditions. The additional flows are from combined area surface runoff and RDII. Inflow normally occurs when rainfall enters the system through direct connections such as roof leaders, yard drains, catch basins, sump pumps, manhole covers and frame seals or indirect connections with storm sewers. Inflow is usually recognized graphically by large magnitude, short duration spikes immediately following a rain event. Infiltration occurs during wet weather conditions when water enters a sewer system from the ground through means which include, but not limited to, deteriorated pipes, pipe joints, connections, or manholes. It is significantly influenced by the size and duration of the rainfall event. Infiltration is often recognized graphically by a gradual increase in flow after a wet weather event. The increased flow typically sustains for a short period after rainfall has stopped and then gradually drops off.

The peaking factor represents the ratio of the peak wet weather flow to the average dry weather flow. Usually, an hourly peaking factor is used to represent the wet weather peaking factor. Peaking factors were analyzed for each flow monitoring site. The peaking factors in the separated area can be used to determine the extent of the RDII within a particular basin. Figure 4-9 is a flow hydrograph plot showing an hourly peaking factor of approximately 4.5 for the monitoring site. This high peaking factor indicates that a significant amount of RDII enters the collection system. The immediate flow increase shortly after the rainfall indicates significant inflow into the collection pipes, and the long tail back to the base flow indicates infiltration occurrence at the site as well.

Figure 4-9: Hydrographs of Flow Meters in Separated Area (Example Plot)



4.8 Wet Weather Event Selection for Model Calibration and Validation Flow Analysis

Based on the rainfall and flow monitoring data analysis, the rainfall events shown in Table 4-4 were selected for model calibration and validation. The events were selected from the top ten rain events that are shown in Table 4-1. The calibration and validation events cover variations in terms of rainfall depth, intensity, duration and antecedent conditions.

Table 4-4: Calibration and Validation Rainfall Events

Event	Start	End	Chester-PS Rainfall (in)	Duration (hr)	Max Intensity (in/hr)
E1	5/29/16 19:00	5/30/16 5:00	1.82	11.00	0.78
E2	9/28/16 12:00	9/30/16 10:00	2.36	47.00	0.37
E3	11/29/16 7:00	11/29/16 20:00	1.08	14.00	0.21
E4	3/30/2017 21:00	4/1/20170 3:00	1.83	31.00	0.25
E5	5/21/16 11:00	5/22/16 21:00	1.71	35.00	0.33
E6	7/28/16 15:00	7/29/16 9:00	1.26	19.00	0.74

Storms were chosen from the top ten rain events based first on their accumulation, with larger depths being preferred. But, if a rain event had a preceding storm, it was lowered in rank. Events with varying durations were chosen so that variations in length of time of a storm could be calibrated in the model. Higher intensity storms were chosen over lower intensity storms. But, again, if an event had a preceding storm, it was lowered in rank.

The amount of rainfall that accumulated at the Chester Pump Station rain gauge during event 2 was the largest at 2.36 inches. Event 2 also had the longest duration at 47 hours. However, event 1 had the highest intensity at 0.78 inches per hour.

4.9 Flow Monitoring Data Summary

The majority of the flow meters measured flow, level and velocity data for each flow monitoring site at 5-minute intervals, other flow meters measured the same parameters in 15 minute intervals. Metering data was analyzed for dry weather flows (DWF) and wet weather flows (WWF) for each monitoring site.

The DWF was ultimately used as inputs into the model. Overall annual average DWFs, average monthly DWFs, and weekday and weekend diurnal patterns were input into the model for each flow meter in the combined area. The WWF were used to calibrate the model output. Model data was compared side by side with metered data for each wet weather event for each flow meter.

4.10 Collection of WRTP Operational Data

In addition to flow data collected from the flow meters located in the collection system, flow data from DELCORA's WRTP influent flow meter was obtained for the same time period. A summary of the plant flow data is shown in Figures 4-10-through 4-13.

Figure 4-10: DELCORA WRTP Influent Flow

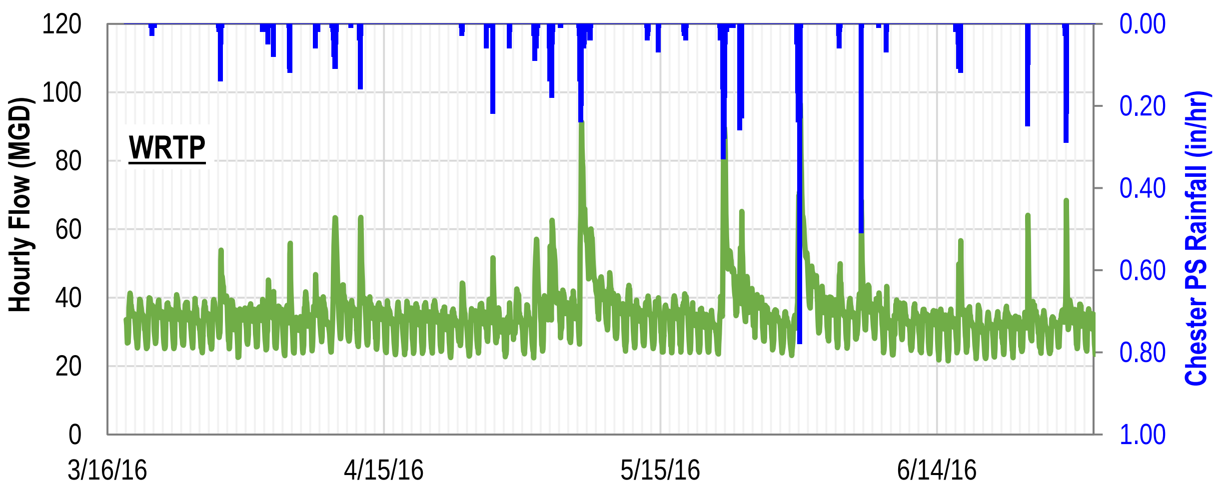


Figure 4-11: DELCORA WRTP Influent Flow

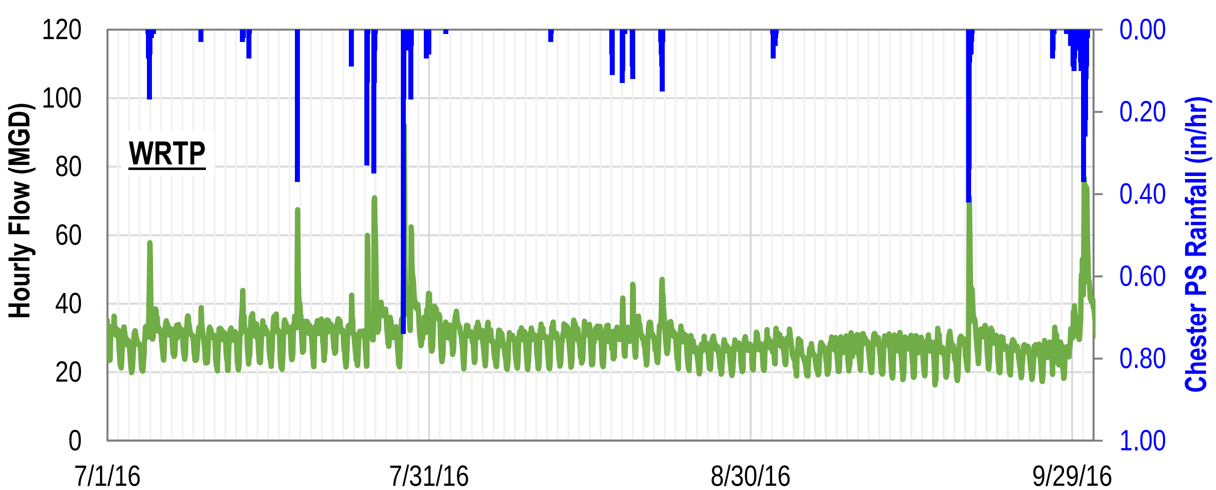


Figure 4-12: DELCORA WRTP Influent Flow

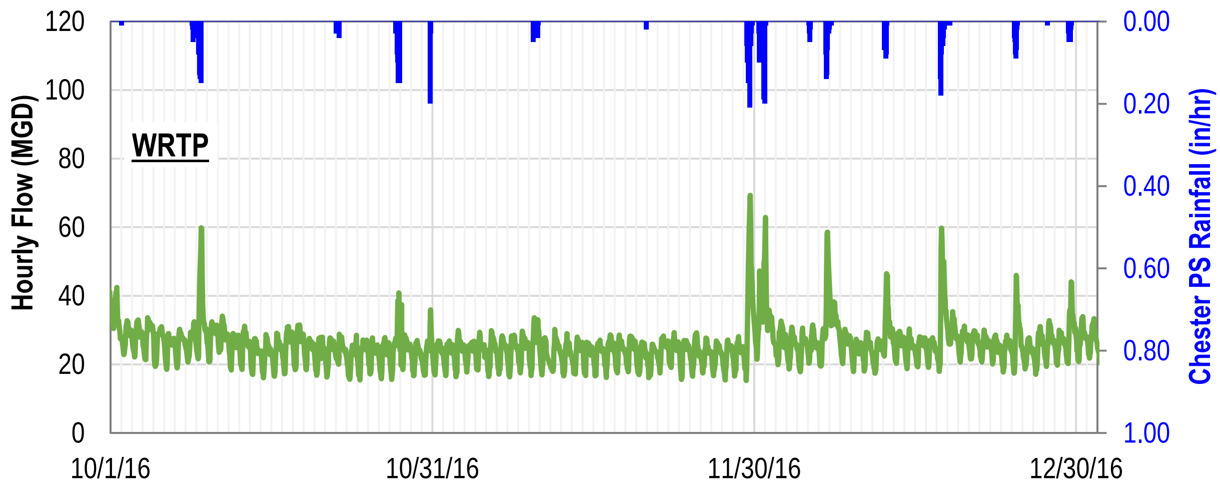
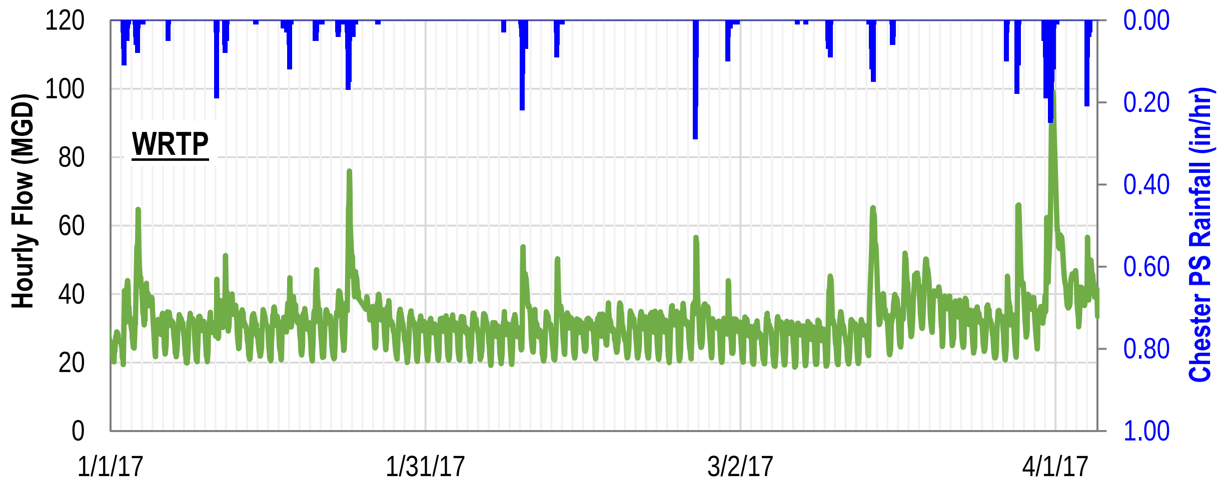


Figure 4-13: DELCORA WRTP Influent Flow



4.11 Summary

The rainfall and flow monitoring program was developed to provide adequate data for the development, calibration and validation of the H&H and Water Quality Models. The goals of this program were met with the collection of the flow monitoring and rainfall data for more than 12 months.

Rainfall data was collected for five rain gauges throughout the Model Area. The Chester rain gauge was analyzed to determine which wet weather events would be used for model calibration. All rain gauge data was ultimately compared with GARR data as a quality check. The GARR data was input into the model as rainfall data.

The flow meter data was analyzed based on the rainfall patterns and then input into the model as overall annual average DWF, average monthly DWFs, and weekday and weekend diurnal curves for each meter in the combined area. To calibrate the model, model-generated data was compared to the metered-data hydrographs for each wet weather event for each flow meter.

Section 5 Characteristics of the Receiving Waters

5.1 Physical Characteristics

The CSS discharges to portions of the Delaware River and two of its tributaries, Chester Creek and Ridley Creek. These receiving waters are located in the tidal portion of the Delaware River Basin, which stretches from the mouth of the Delaware Bay (River Mile 0) to Trenton (River Mile 133.4). The segment of the Delaware River directly impacted by DELCORA's CSO discharges is Zone 4, which extends from River Mile 78.8 to River Mile 95.0 (see Figure 5-1). Chester Creek is located at River Mile 82.93 and Ridley Creek at River Mile 83.8. These creeks are tidally influenced tributaries to the Delaware River. For Chester Creek, the tidal portion extends from the mouth of the tributary at Delaware River upstream to Kerlin Street in Chester City while for Ridley Creek, the tidal portion extends from the mouth of the tributary at the Delaware River upstream to MacDade Boulevard in Chester City (PAFBC, 2017).

In March 2017, an elevation (bathymetric) survey was conducted by LimnoTech for the lower portions of Chester and Ridley Creeks. Figure 5-2 shows the transect locations where elevation measurements were collected. Reaches surveyed included the lower 2.75 miles of Chester Creek and 3.25 miles of Ridley Creek to their discharge into the Delaware River. Transects were collected on ¼-mile interval spacing. Access to the creeks on the upper portions, generally greater than 1 mile upstream, was by wading where the bottom was shallow and firm. The portions below 1 mile were too deep and soft to be accessed on foot and a john boat with tagline was utilized.

Each creek cross section was surveyed at approximately five locations across the bed, water surface, bank toe, and bank top. Access to the entire upland bank at transect locations was not always possible; so the closest points safely accessed to the bank toe were surveyed.

Elevation measurements from this survey were compared with similar elevation data from a 1977 Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) of the creeks (FEMA, 2015). Though the FEMA study was completed several decades ago, it serves as a useful check on the accuracy and sufficiency of the bathymetric survey data. Figures 5-3 and 5-4 compare the LimnoTech survey data with the FEMA data.

In Chester Creek, the LimnoTech bed elevations are substantially higher (about five to ten feet) than FEMA elevations. Higher contemporary creek elevations influence both the degree of tidal exchange in the lower reaches of the creeks, and travel times of upland runoff and base flow to the Delaware River. To check for potential bias in the LimnoTech measurements, the LimnoTech measurements of water surface elevation were compared to similar data maintained by NOAA at a nearby tide gage (Philadelphia gage, #8545240). These measurements of water surface elevation agreed well (within two inches) which is a strong indication that the LimnoTech creek bed elevations are not biased high.

Figure 5-1: Zones of the Delaware River and Bay

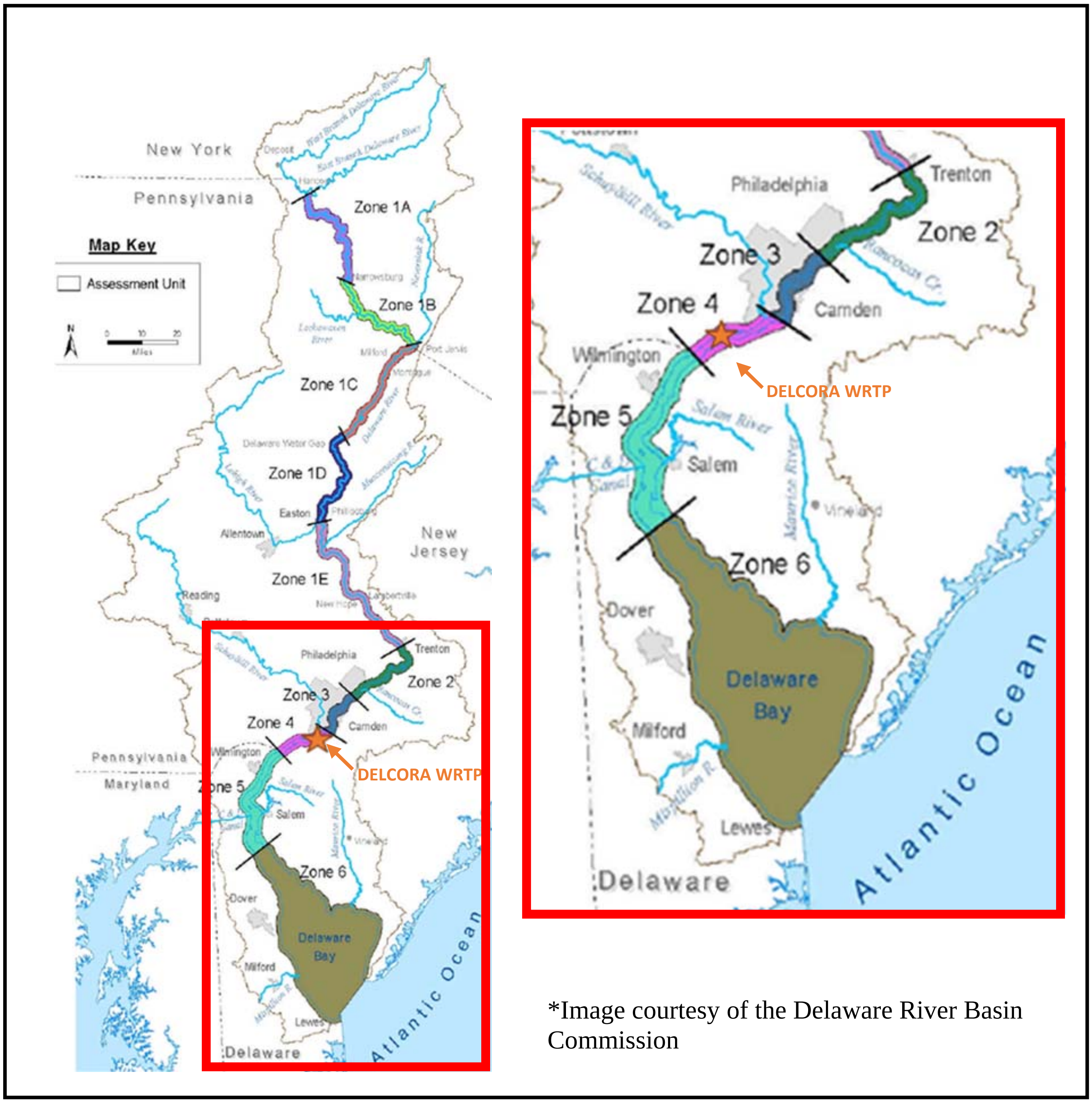


*Image courtesy of the Delaware River Basin Commission

Figure 5-2: Locations of Creek Elevation Measurements in Chester and Ridley Creeks

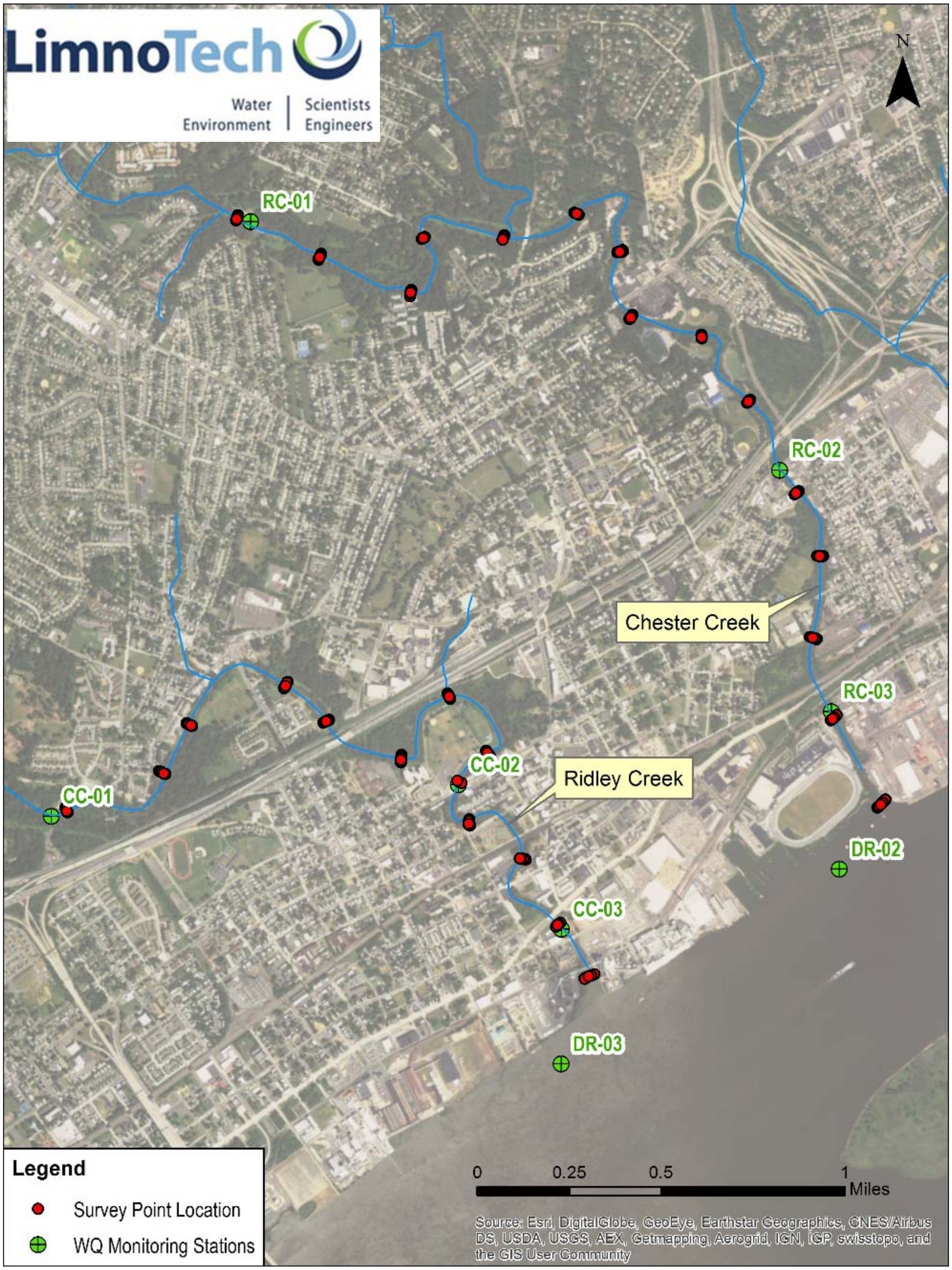


Figure 5-3: Comparison of Chester Creek bed elevation measurements

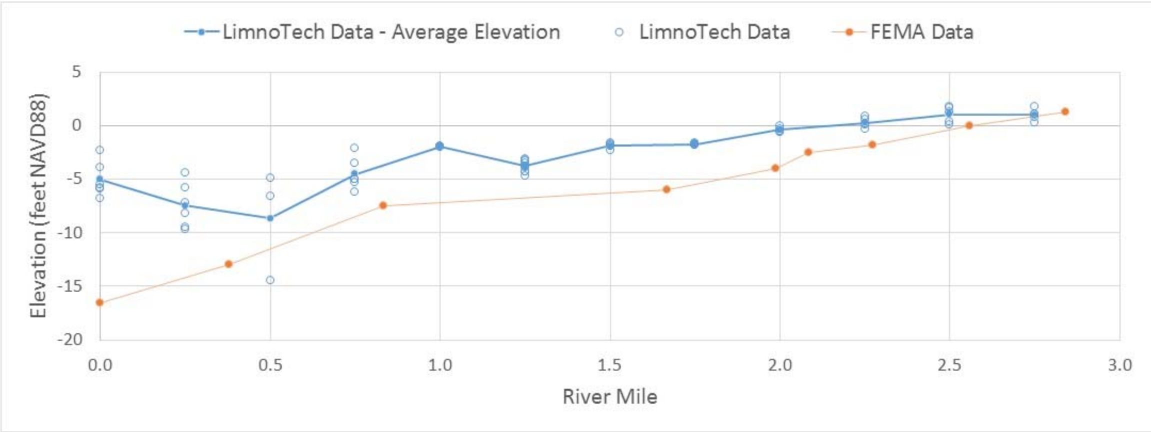
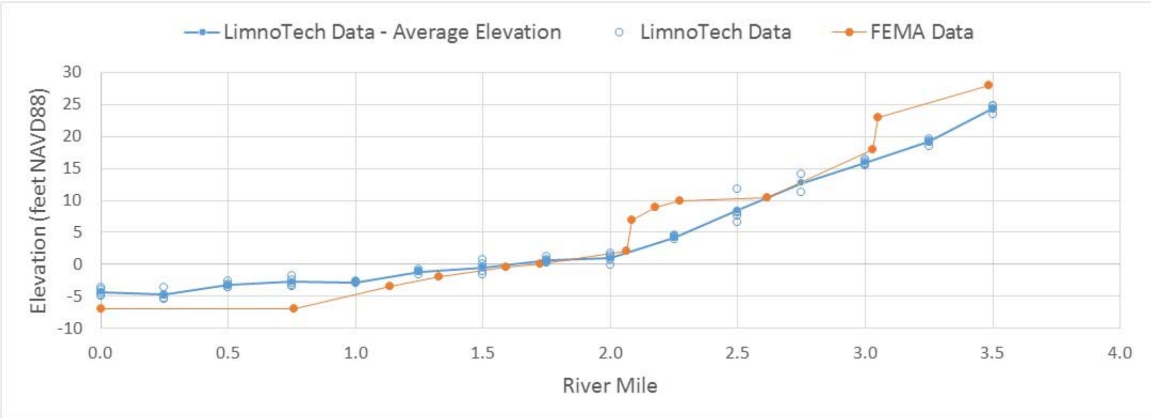


Figure 5-4: Comparison of Ridley Creek Bed Elevation Measurements



Higher creek bed elevations near the Chester Creek mouth are an indication that soft sediments have accumulated there since the 1970s. The highest observed peak flow in Chester Creek occurred a few years before the FEMA survey (in 1971, peak flow of 21,000 cfs) while recent peak flows have been significantly lower (average peak flow of 4,000 cfs in the last ten years) (USGS, 2017). Lower contemporary peak flows may have allowed for the accumulation of soft sediments in the lower reaches of Chester Creek.

Another significant observation from the LimnoTech data is that a pipe crossing near river mile 1.0 in Chester Creek created a high point in the creek bed profile. This high point acts to slightly reduce upstream water currents during lower flow conditions. This would tend to lengthen travel times of bacteria.

In Ridley Creek the LimnoTech data show a more constant bed slope between river miles 2.0 and 3.5 than the FEMA data. This is because low head dams existed in the 1970s near river miles 2.0 and 3.0, but are no longer in place. These dams previously acted to accumulate sediments in their shallow upstream pools, but when the dams were no longer present these accumulated sediments were likely washed away downstream.

These comparisons between the LimnoTech survey data, the historical FEMA data, and the NOAA tide gage, show consistency and provide confidence in the data collected. These comparison also help to identify locations where the creek bed has changed in the last several decades in ways that would influence creek hydraulics and pollutant transport.

The Delaware River bathymetric survey information was obtained online from National Oceanic and Atmospheric Administration (NOAA) website.

- NOAA, 2009. Hydrographic Survey H12149. Pennsylvania and New Jersey. Delaware River. Data obtained online at: https://www.ngdc.noaa.gov/nos/H12001-H14000/H12149.html
- NOAA, 2009. Hydrographic Survey H12150. Pennsylvania and New Jersey. Delaware River. Data obtained online at: https://www.ngdc.noaa.gov/nos/H12001-H14000/H12150.html

The survey was conducted in 2009, although other surveys conducted by NOAA over time (going back several decades) will also be used to construct the bathymetry datasets for the Water Quality Model. This information will serve to assist in determining tidal currents and mixing within the Delaware River Estuary as part of the Water Quality Modeling.

5.2 Watershed Drainage Basins

The Chester Creek and Ridley Creek watersheds extend from the mouth of the tributaries upstream through Delaware County and into Chester County, well beyond the boundaries of DELCORA’s Model Area. The extent of the watersheds within Delaware County is illustrated in Figure 2-4, along with the boundaries of DELCORA’s Model Area.

5.3 Pollutants of Concern

This section provides a summary of the current water quality in DELCORA's receiving waters based on DELCORA's efforts to identify Pollutants of Concerns, in order to meet the requirements of Section V.A.16.c of the Consent Decree. To satisfy this Consent Decree requirement, DELCORA submitted the *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c), which was approved by PA DEP and US EPA on October 13, 2016. The remainder of Section 5 is based on this approved report.

DELCORA's CSOs discharge to three receiving waters - the Delaware River, the Chester Creek and the Ridley Creek – all of which are within the Delaware Estuary portion of the Delaware River Basin. As part of the *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c), DELCORA conducted a literature review to determine the applicable water quality standards (WQS) for each of the three receiving water bodies, the designated uses for the water bodies, the primary causes of impairment, and the Total Maximum Daily Load (TMDL) status of the water bodies (if any).

Requirements of the USEPA's CSO Guidance Document

Section 2.5.3.3 of the USEPA's CSO Guidance document states that to assess the impacts of wet weather runoff, the water quality of the receiving waters should be understood for normal dry weather periods. The water quality data that is collected during dry weather conditions provides a basis for comparing the data collected during wet weather conditions. The CSO Guidance Document says:

> *"Receiving water monitoring should include identified parameters of concern. These parameters typically include those previously identified for combined sewage and CSO monitoring.*
>
> - *pH*
> - *BOD*
> - *TDS*
> - *TSS*
> - *Nutrients*
> - *Metals*
> - *Indicator bacteria*
>
> *Knowledge of the site-specific water quality concerns could expand the list to include dissolved oxygen, toxics, biological assessment, and sediment."*

5.4 Receiving Water Use Designations and Applicable Water Quality Standards

Information about the applicable water quality standards (WQS), the designated uses and the impairment status for the three receiving water bodies impacted by DELCORA's CSOs were obtained from the PADEP's 2014 Integrated Water Quality Monitoring and Assessment Report (or "303(d) list"), the Pennsylvania Code, the Delaware River Basin Commission's (DRBC's) Water Quality Regulations (WQRs) and from the DRBC's 2014 Delaware River and Bay Water Quality Assessment (DRBC, 2014).

5.4.1 2014 PA Integrated Water Quality Monitoring and Assessment Report (303(d) list)

The primary source of information about the causes of impairment, and the Total Maximum Daily Load (TMDL) status of the water bodies (if any) is the 2014 PA Integrated Water Quality Monitoring and Assessment Report (PA Integrated Report), which satisfies Pennsylvania's requirement of both Section 303(d) and 305(b) of the Clean Water Act (CWA). The PA Integrated Report lists all impaired surface waters within Pennsylvania that are not attaining designated and existing uses, even after appropriate and required pollution control technologies have been applied. A TMDL is designed to reduce pollutant loads to impaired waters and enable these waters to meet water quality standards.

The Integrated Report uses a five-part categorization (lists) of water according to their use attainment status. The categories represent varying levels of use attainment, ranging from Category 1, where all designated water uses are met to Category 5, where impairment by pollutants required the development of a TMDL to correct. Each segment of the waterbody is placed into one of these five categories. "Impairment" of a receiving water body is indicated to exist for a particular parameter if the parameter appears in Categories 4A and 5, as they indicate the need for a TMDL in the receiving water body and the limiting of additional loadings for those parameters.

The PADEP's website explains the categories as follows:

- *Category 1:* *Waters attaining all designated uses.*
- *Category 2:* *Waters where some, but not all, designated uses are met. Attainment status of the remaining designated uses maybe unknown because data are insufficient to categorize a water body consistent with the states' listing methodology or may be impaired.*
- *Category 3:* *Waters for which there are insufficient or no data and information to determine, consistent with the state's listing methodology, if designated uses are met.*
- *Category 4:* *Waters impaired for one or more designated use but not needing a TMDL. States may place these waters in one of the following three subcategories:*
  - *Category 4A:* *TMDL is approved.*
  - *Category 4B:* *Expected to meet all designated uses within a reasonable timeframe (three years).*
  - *Category 4C:* *Not impaired by a pollutant.*
- *Category 5:* *Waters impaired for one or more designated uses by any pollutant and requiring the development of a TMDL. Category five includes waters shown to be impaired as the result of biological assessment used to evaluate aquatic life even if the specific pollutant is not known unless the state can demonstrate that non-pollutant stressors cause impairment or that no pollutant(s) causes or contribute to the impairment*."

The Category 5 list constitutes the Section 303(d) list that the USEPA will approve or disapprove under the CWA. For the purposes of the determination of Pollutants of Concern, Categories 4A and 5 are the relevant categories as they indicate the need for a TMDL in the receiving water body and the limiting of additional loadings for those parameters. All of the lists are sorted by an 8-digit Hydrologic Unit Code (HUC) that is particular for the water body of interest. For DELCORA's drainage area, the HUC for the

Lower Delaware River (02040202) was used for searching the data in the PA Integrated Report for all three of DELCORA's receiving water bodies.

5.4.2 PA Code Title 25 §93.9g

The primary source of information for the Critical Use Designation for each section of the three receiving water bodies is 25 Pa. Code §93.9g – Drainage List. The relevant Critical Use Designations for DELCORA's receiving water bodies include Warm Water Fishes (WWF), Migratory Fishes (MF), Trout Stocking (TSF), and Water Contact Sports/Recreation (WC).

- The "WWF" designation indicates the maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm water habitat.
- The "MF" designation indicates the passage, maintenance and propagation of anadromous and catadromous fishes and other fishes which move to or from flowing waters to complete their life cycle in other waters.
- The "TSF" designation indicates maintenance of stocked trout from February 15 to July 31 and maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm water habitat.
- The "WC" designation indicates the use of the water for swimming and related activities.

5.4.3 DRBC's Water Quality Regulations and PA Code Title 25 §93.7

The applicable water quality standards for the three receiving water bodies are found in the Delaware River Basin Commission's Water Quality Regulations, and in Water Quality Criteria lists found in 25 Pa. Code §93.7 and §93.8c. For the Delaware River, the water quality standards are dictated by the DRBC's WQRs that have primacy over the standards in the PA Code. The water quality standards in the PA Code apply to the non-tidal portions of the Chester Creek and Ridley Creek, and to the Delaware River if there is no standard listed for a particular parameter in the DRBC's WQRs.

5.4.4 DRBC's 2014 Delaware River and Bay Water Quality Assessment

The DRBC's 2014 Delaware River and Bay Water Quality Assessment (DRBC, 2014) reports the extent to which waters of the Delaware River and Bay are attaining designated uses in accordance with Delaware River Basin Commissions' Water Quality Regulations for the period October 1, 2008 through September 30, 2013. The 2014 Assessment involves the comparison of key water quality parameters with the applicable DRBC water quality regulations. The states of Pennsylvania, New Jersey, Delaware and New York consider the DRBC's Assessment report as part of their determinations as to whether sections of the Delaware River should be listed on the state 303(d) list for a certain pollutant.

5.5 Delaware River

5.5.1 2014 PA Integrated Water Quality Monitoring and Assessment Report (303(d) list)

The 2014 PA Integrated Water Quality and Assessment Report ("the 303(d) List") lists a 61.02 mile segment of the Lower Delaware River in Category 4A as having an approved TMDL for polychlorinated biphenyls (PCBs) from an unknown source related to its fish consumption use. The USEPA approved a

TMDL for PCBs for Zone 2 through Zones 5 in 2003, and a second PCB TMDL was approved for Zone 6 in 2006. The TMDLs for PCBs encompass the Delaware River Estuary and stretch from the mouth of the Delaware River upstream to the Trenton, NJ /Morrisville, PA Bridge. The segment of the Delaware River having an approved TMDL for PCBs is shown in yellow in the map in Figure 5-5, which was derived from the PADEP's eMapPA website.

While the Delaware River is impaired from PCBs, the PCBs are not normally associated with CSOs. Given this reason, and the fact that the PCB impairment begins well upstream of DELCORA's service area – PCBs were screened as not being a Pollutant of Concern (POC). Furthermore, the additional CSO sampling results from November/December 2015 showed that PCBs were found to be at a lower concentration than the Reporting Detection Limit (RDL). For this additional reason it was determined that PCBs are not associated with DELCORA's CSO discharges.

5.5.2 Designated Critical Uses and Specific Water Quality Criteria from PA Code

The Critical Uses for the Delaware River in the area of DELCORA's CSO discharges are designated in Pa. Code §93.9. All stretches of the Delaware River in this area are designated as Warm Water Fishes (WWF) (maintenance only) and Migratory Fishes (MF) (passage only). Additionally the Delaware River has a Water Contact (WC) designation downstream of River Mile 81.8, which is located directly adjacent to the City of Chester between CSO #009 and #011.

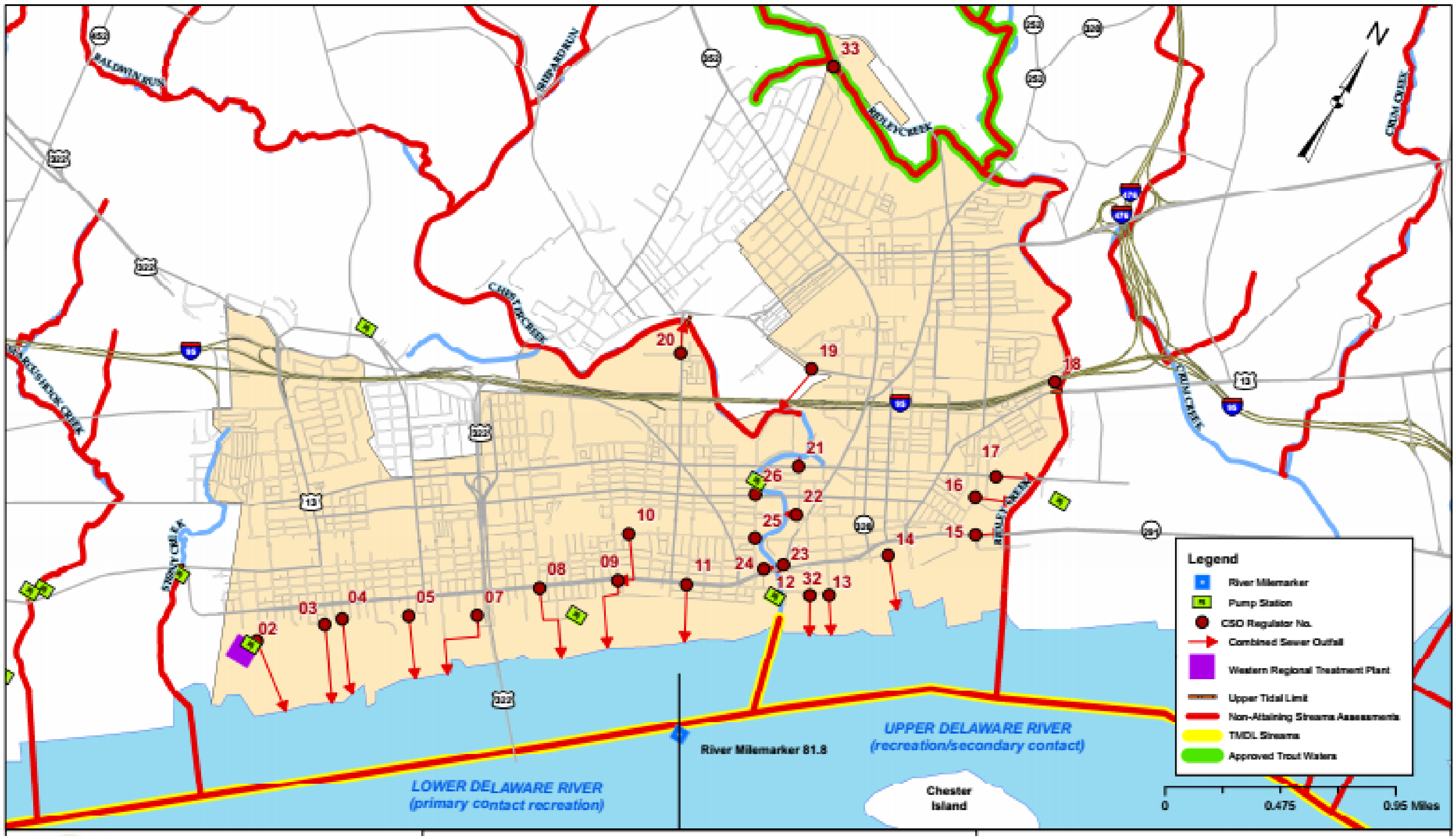
For WC-designated waters, 25 Pa. Code §93.7 establishes the following as the water quality criterion for fecal coliform bacteria:

- Fecal Coliform – A geometric mean of 200 colonies per 100 mL during the swimming season (May 1 through September 30) based on a minimum of five samples collected during a 30-day period. For the remainder of the year, the maximum fecal coliform level shall be a geometric mean of 2,000 colonies/100 mL based on a minimum of five samples collected during a 30-day period. There are no fecal coliform bacteria criteria for the Delaware River or tributaries that are not designated as WC waters or for Potable Water Supply (PWS).

For WWF and MF waters the WWF designation is the more restrictive of the two, and 25 Pa. Code §93.7 establishes the following additional standards for WWF waters:

- Dissolved Oxygen – The minimum value for dissolved oxygen must be above 5.0 mg/L, with the 7-day average value above 5.5 mg/L
- Alkalinity – A minimum of 20 mg/L as CaCO3, except where naturally occurring conditions are less
- Ammonia Nitrogen – the maximum total ammonia nitrogen concentration (in mg/L) at all times shall be the numerical value given by un-ionized ammonia nitrogen (NH3-N) x (log-1[pKT-pH] + 1)
- Iron – 30-day average 1.5 mg/L as total recoverable
- pH – From 6.0 to 9.0 inclusive

Figure 5-5: Non-Attaining Streams and TMDL Streams within DELCORA's Service Area



- Temperature – A table is included within 25 Pa. Code §93.7 for maximum water temperatures in the receiving water body at various times of the year
- Total Residual Chlorine – Four-day average 0.011 mg/L; 1-hour average 0.019 mg/L

5.5.3 Designated Zone and Water Quality Regulations from the DRBC

25 Pa. Code §93.9 lists the DRBC regulations for Water Quality Zone 4 as exceptions to PA Code's specific water quality criteria. The DRBC's water quality regulations have primacy over the standards in the PA Code for the Delaware River.

The DRBC defines Zone 4 as that part of the Delaware River extending from R.M. 78.8 to R.M. 95.0, the Pennsylvania-Delaware state boundary line to the upstream side of the Philadelphia Navy Yard, including the tidal portions of the tributaries thereof. The DRBC states that the quality of Zone 4 waters shall be maintained in a safe and satisfactory condition for the following uses:

- Industrial water supplies after reasonable treatment
- Maintenance of resident fish and other aquatic life
- Passage of anadromous fish
- Wildlife
- Recreation - secondary contact above R.M. 81.8
- Recreation (all water-contact sports) below R.M. 81.8
- Navigation

The DRBC's Stream Quality Objectives for Zone 4 are as follows:

1. Dissolved Oxygen
   - 24-hour average concentration shall not be less than 3.5 mg/L.
   - During the periods from April 1 to June 15, and September 16 to December 31, the DO shall not have a seasonal average less than 6.5 mg/L.

2. Temperature shall not exceed:
   - 5°F (2.8°C) above the average 24-hour temperature gradient displayed during the 1961-66 period, or
   - A maximum of 86°F (30.0°C), whichever is less.

   (NOTE: The DRBC's 2014 Delaware River and Bay Water Quality Assessment states that *"atmospheric temperatures and meteorological conditions are strong drivers of water temperature. DRBC previously demonstrated that water temperatures are strongly liked to air temperatures, and that a notable increase in air temperatures is observable between the temperature gradient period (1961-1966) and the current period. At present, we [i.e., DRBC] lack the tools to determine which portion of the exceedance is attributable to potentially controllable anthropogenic thermal inputs, and which portion is due to metrological drivers beyond our control"*.

3. pH between 6.5 and 8.5 inclusive, unless outside this range due to natural conditions.

4. Phenols maximum 0.02 mg/l, unless exceeded due to natural conditions.

5. Threshold Odor Number not to exceed 24 at 60°C.

6. Synthetic Detergents. (M.B.A.S.). Maximum 30- day average 1.0 mg/L.

7. Radioactivity
   - Alpha emitters - maximum 3 pc/L (picocuries per liter);
   - Beta emitters - maximum 1,000 pc/L.

8. Bacteria
   - Fecal Coliform
     - Above R.M. 81.8: maximum geometric average 770 per 100 milliliters
     - Below R.M. 81.8: maximum geometric average 200 per 100 milliliters
   - Enterococcus
     - Above R.M. 81.8: maximum geometric average 88 per 100 milliliters
     - Below R.M. 81.8: maximum geometric average 33 per 100 milliliters

9. Total Dissolved Solids not to exceed 133% of background.
   (NOTE: The background TDS concentration is at present undefined, according to the DRBC's 2014 Delaware River and Bay Water Quality Assessment.)

10. Turbidity unless exceeded due to natural conditions.
    - Maximum 30-day average 40 units (NTU)
    - Maximum 150 NTU

11. Alkalinity between 20 and 120 mg/L.

12. Toxic Pollutants
    - Applicable criteria to protect the taste and odor of ingested water and fish are presented in the DRBC's WQRs Table 4.
    - Applicable freshwater stream quality objectives for the protection of aquatic life are presented in the DRBC's WQRs Table 5.
    - Applicable freshwater stream quality objectives for the protection of human health are presented in the DRBC's WQRs Tables 6 and 7.

5.5.4 DRBC Evaluation of Use Attainment Status

Table 5-1 presents a summary of Table 23 from the DRBC's 2014 Delaware River and Bay Water Quality Assessment for Zone 4 of the Delaware River. Zone 4 is the portion of the Delaware River directly impacted by DELCORA's CSO discharges and it extends from R.M. 95.0 to R.M. 78.8, the

Pennsylvania-Delaware state line including the tidal portions of the tributaries thereof. The extent of Zone 4 can be seen in Figure 5-1.

Table 5-1: Summary of the 2014 DRBC Integrated Assessment for Zone 4 of the Delaware River

Zone	Designated Use			
	Aquatic Life	Drinking Water	Recreation	Fish Consumption
4	NS	N/A	S	NS

Notes:

N/A - Not applicable
NS - The Designated Use is not supported
S - The Designated Use is supported

5.5.4.1 Water Contact Recreation

Table 5-1 shows that the designated use for Water Contact Recreation is being attained for the Delaware River below R.M. 81.8.

5.5.4.2 Aquatic Life

Table 5-1 shows that the designated use for Aquatic Life is not being attained. According to the DRBC's Assessment report (DRBC, 2014), "*the composite aquatic life assessment for 2014 yields a result of "Not Supporting" for all assessment units* (or zones). *It is important to note, however, that this result is largely driven by the requirement to categorize as not meeting criteria any assessment unit* (or zone) *with 1 exceedance plus 1 confirmatory exceedance."*

The DRBC's Assessment Report also states: *"Data showed multiple exceedances of aluminum acute and chronic freshwater objectives for the support of aquatic life in Zone 4. Of 35 surface water samples tested for aluminum in Zone 4 during the assessment period, 34 exceeded the chronic criterion and 8 exceeded the acute criterion at 21PA_WQX-WQN0182 near Marcus Hook, PA. No exceedances of aluminum were reported in Zones 2, 3, 5 and 6."* As part of the Recommendations for Future Action at the end of the report, the DRBC states that the *"exceedances of aluminum criteria in Zone 4 warrant further attention"*.

5.5.4.3 Fish Consumption

Table 5-2 shows that the designated use for Fish Consumption is not being attained. The DRBC's 2014 Delaware River and Bay Water Quality Assessment report states that their assessment criterion for fish consumption is based on the presence of fish consumption advisories from the four Basin states for the mainstem of the Delaware River. If a fish consumption advisory is present, this resulted in the DRBC making an assessment of "not supporting the designated use".

The Assessment report states that the violation criteria for PCBs is also supported by the presence of measureable concentrations of PCBs in the river that exceeded the surface water quality standard.

Twenty-two mainstem channel sites were sampled for PCBs in 2012, from Biles Channel near Trenton, NJ to the ocean boundary between Cape May and Lewis. It was found that all of the samples exceeded the current PCB water quality criteria of 16 µg/L for the protection of human health from carcinogenic effects.

The 2016 Commonwealth of Pennsylvania Fish Consumption Advisories for Zones 2, 3, and 4 of the Delaware River (Trenton, NJ/Morrisville, PA Bridge to PA/DE border) are as shown below in Table 5-2. These advisories identify PCBs as a pollutant of concern in fish tissue.

Table 5-2: PA Fish Consumption Advisory Summary for PCBs in the Delaware River

Fish Species	Meal Frequency	Contaminant
White Perch	1 meal/month	PCB
Flathead Catfish	1 meal/month	PCB
Channel Catfish	1 meal/month	PCB
Striped Bass: over 28 inches in length	1 meal/month	PCB
Carp	6 meals/year	PCB
American Eel	Do Not Eat	PCB

5.6 Chester Creek

5.6.1 2014 PA Integrated Water Quality Monitoring and Assessment Report (303(d) list)

Chester Creek is listed in Category 5 of the 2014 Pennsylvania Integrated Water Quality Monitoring and Assessment Report as not meeting its recreational use due to pathogens, and for not meeting its aquatic life use due to siltation. “Pathogens” were listed in 2006 for three segments totaling 0.94 miles, and a TMDL is anticipated in 2019. The source for the pathogens is listed as “unknown”, and these three stream segments are all well upstream of DELCORA’s service area. Therefore it appears that the noted impairment of the Chester Creek due to pathogens is not related to DELCORA’s CSO discharges.

“Siltation” was listed in 2014 for four segments of the creek totaling 18.41 miles, and a TMDL is anticipated in 2027. The source for the siltation was identified as “urban runoff/storm sewers”. The majority of Chester Creek is not attaining its designated use for aquatic life due to siltation, and the vast majority of these impaired segments are located upstream of DELCORA’s service area and are shown in red in the map in Figure 5-5. However, one of DELCORA’s CSO outfalls does discharge to the furthest downstream segment of the Chester Creek that is impaired by siltation, which is Outfall #020 near Kerlin Street and Finland Drive. Siltation is measured by the water quality parameter Turbidity with units of Nephelometric Turbidity Units (NTU). The impacts of DELCORA’s CSO discharges on the levels of Turbidity within the impaired sections of the Chester Creek have been evaluated further and are discussed herein.

For the Chester Creek, the 2014 PA Integrated Water Quality & Assessment Report shows the creek to be impaired for Aquatic Life from siltation, with Urban Runoff/Storm Sewers identified as the source. The impairment of the Chester Creek by siltation primarily occurs upstream of DELCORA's service area as shown in Figure 5-5. The term "Siltation" is not defined in the 2014 PA Integrated Water Quality & Assessment Report, but through various sources could be defined as:

> *"the pollution of water by fine particulate terrestrial clastic material, with a particle size dominated by silt or clay. It refers both to the increased concentration of suspended sediments, and to the increased accumulation (temporary or permanent) of fine sediments on bottoms where they are undesirable. Siltation is most often caused by soil erosion or sediment spill."*

There is not a water quality standard for "siltation", however, siltation can be considered as closely related to the widely used water quality parameter of "Turbidity", which is associated with CSO discharges. For this reason "Turbidity" was reviewed further as a surrogate for siltation to determine if it might be considered as a POC. Per available USEPA STORET data, the Turbidity concentrations on the Chester Creek was found to be below the WQS and therefore siltation was screened-out as not being a POC.

Category 4A lists a 0.81-mile segment of Chester Creek at its mouth that does not meet its designated use for fish consumption due to PCBs from an unknown source, and for which a TMDL for PCBs was issued in 2006. This is shown in yellow in the map in Figure 5-5 and is related to the TMDL for PCBs in the Delaware River Estuary.

5.6.2 Designated Critical Uses and Specific Water Quality Criteria from PA Code

The Critical Uses for the Chester Creek in the area of DELCORA's CSO discharges are designated in 25 Pa. Code §93.9. All stretches of the Chester Creek in this area are designated as Warm Water Fishes (WWF) (maintenance only) and Migratory Fishes (MF) (passage only). The same specific water quality criteria apply to the WWF and MF Critical Use designations for Chester Creek as apply for the Delaware River.

5.7 Ridley Creek

5.7.1 2014 PA Integrated Water Quality Monitoring and Assessment Report (303(d) list)

Ridley Creek is listed in Category 5 of the 2014 Pennsylvania Integrated Water Quality Monitoring and Assessment Report as not meeting its aquatic life use due to siltation. The "Siltation" was listed in 2012 for five segments totaling 26.76 miles, and a TMDL is anticipated in 2025. The source for the siltation was identified as "unknown" or from "urban runoff/storm sewers".

In actuality, it appears that the majority of Ridley Creek is not attaining its designated use for aquatic life due to siltation, and the vast majority of these impaired segments are located well upstream of DELCORA's service area and are shown in red in the map in Figure 5-5. However, all of Ridley Creek within DELCORA's service area is shown as impaired for aquatic life due to siltation. As with the

Chester Creek, the Ridley Creek is listed in the 2014 PA Integrated Water Quality & Assessment Report as impaired for Aquatic Life from siltation, with Urban Runoff/Storm Sewers identified as the source.

However as noted for the Chester Creek, there is not a water quality standard for "siltation" but it can be considered as closely related to the widely used water quality parameter of "Turbidity", which is associated with CSO discharges. Per available USEPA STORET data, the Turbidity concentration for the Ridley Creek was found to be below the WQS and therefore siltation was screened-out as not being a POC.

5.7.2 Designated Critical Uses and Specific Water Quality Criteria from PA Code:

The Critical Uses for the Ridley Creek in the area of DELCORA's CSO discharges are designated in 25 Pa. Code §93.9. All stretches of the Ridley Creek in this area are designated as Warm Water Fishes (WWF) (maintenance only), Migratory Fishes (MF) (passage only), or Trout Stocking (TSF). The TSF stretch only applies in the sections of the Ridley Creek upstream of the Chestnut Street bridge crossing.

The same specific water quality criteria apply to the WWF and MF Critical Use designations for Ridley Creek as apply to the Chester Creek and Delaware River, except for the parameters of Dissolved Oxygen and Temperature – which are more stringent in the TSF stretch because of the high oxygen needs of trout.

Specifically, for TSF waters 25 Pa. Code §93.7 establishes the following additional standards:

- Dissolved Oxygen – For the period February 15 to July 31 of any year, the minimum value for dissolved oxygen must be above 5.0 mg/L, with the 7-day average value above 6.0 mg/L. For the remainder of the year, the minimum value for dissolved oxygen must be above 5.0 mg/L, with the 7-day average value above 5.5 mg/L.
- Temperature – A separate table is included within 25 Pa. Code §93.7 for maximum water temperatures in the receiving water body at various times of the year for TSF waters.

5.8 Pollutants of Concern in the Receiving Waters

As part of the requirements of the Consent Decree, DELCORA was tasked to identify the Pollutants of Concern associated with it CSOs into the Delaware River, Chester Creek and Ridley Creek. The result of these investigations were documented in DELCORA's *Identification of Sensitive Areas and Pollutants of Concern* Report. This section summarizes the Pollutant of Concerns that were determined for each of DELCORA's receiving waters.

5.8.1 Consent Decree Requirements for the Determination of POCs

For the Identification of Pollutants of Concern, Section V.A.11 of the Consent Decree specifically states:

> *"For each of its Receiving Waters, DELCORA shall review existing water quality data and recent PADEP CWA § 303(d) listings to identify POCs. Even if a water body has not been formally listed as out of compliance with its water quality standards and designated uses, if available data indicate such impairment exists and such impairment involves pollutants associated with CSOs, DELCORA shall consider the related pollutants to be POCs."*

5.8.2 Methodology for Determination of the POCs

In the effort to identify the Pollutants of Concerns related to its CSO discharges, DELCORA reviewed the 2014 PA Integrated Water Quality Monitoring and Assessment Report (303(d) List), the historic sampling data for the influent to the Western Regional Treatment Plant, the USEPA's Storage and Retrieval (STORET) Data repository, historic water quality sampling data from the Chester and Ridley Creeks, and additional sampling results from the CSOs that were taken in November and December of 2015.

For the identification of the POCs, DELCORA took an inclusive approach to determine that all relevant water quality parameters were appropriately considered and evaluated. The first step was to develop a comprehensive list of the overall "Parameters Considered", which was then further evaluated and refined to determine the list of the applicable POCs. Development of the list of Parameters Considered was meant to cast a wide net as the first step towards identifying any parameters that might possibly be of concern.

The initial list of the Parameters Considered was compiled from six (6) primary reference sources from the USEPA, PADEP and the DRBC. The Parameters Considered list initially consisted of those specific parameters listed in the USEPA's CSO Guidance Document. Additional parameters were added from the parameters requiring sampling per DELCORA's NPDES permit, from the PA Code's specific water quality criteria for DELCORA's three receiving water bodies, from the DRBC's Water Quality Regulations for Zone 4 of the Delaware River, from the 2014 PA Integrated Water Quality Monitoring and Assessment Report (a.k.a. "303(d) List"), and from the DRBC's 2014 Delaware River and Bay Water Quality Assessment report (DRBC, 2014). Once the initial list of Parameters Considered was developed, additional parameters were added onto the list if they had been detected during the historical sampling data of the influent to the WRTP, and in the existing CSO monitoring data (as required by the NPDES permit). One year's worth of DELCORA's plant influent historical sampling data from September 1, 2014 through September 1, 2015 was collected and analyzed to identify additional Parameters Considered.

To help narrow the list of the Parameters Considered additional wet weather sampling at the CSOs was required. The additional sampling occurred on November 19th and December 1st, 2015 at the three CSO locations DELCORA is required to regularly monitor; the Chester Pump Station wet well, CSO #018 at Sun Drive and Hancock Street, and at CSO #019 at 14th Street and Crozer Hospital. The CSO sampling results were used to confirm if the Parameters Considered were actually prevalent in DELCORA's CSO discharges. If a parameter on the Parameters Considered list was not detected in the November and December 2015 wet weather sampling of the CSOs, those parameters were not considered further as POCs.

For each of the remaining Parameters Considered, the receiving stream water quality data from the USEPA STORET data warehouse for the years 2010 through 2015 was compared to the applicable WQS to check for exceedances. Both the acute and chronic conditions for the Parameters Considered were reviewed, where applicable, to determine if there had been exceedances of the applicable water quality standards. The segments of the Delaware River, Chester Creek and Ridley Creek have unique water quality standards that apply to them depending on the regulating authority, their designated uses, and the specific location within the waterbody. The Delaware River was broken down into two sections for the evaluation; one for the Delaware River upstream of R.M 81.8 ("upper Delaware") and the second for the Delaware River downstream of R.M 81.8 ("lower Delaware") based on the Water Contact Recreation designated use for the Delaware River below R.M. 81.8 and the more stringent requirements associated with primary contact.

Once the Parameters Considered list was narrowed using the November/December 2015 additional sampling results at the CSOs, the parameters remaining on the narrowed list of Parameters Considered were further evaluated to determine if they are Pollutants of Concern. A parameter was considered to be a "Pollutant of Concern" for a water body if more than 10% of the samples taken exceeded the applicable water quality standard. This criteria was based on guidance provided by the USEPA, which recommends a "greater than 10% exceedance percentage" for determining that waters only partially meet their designated use for aquatic life support. If a parameter was determined to be a POC, it is to be further investigated through additional receiving water quality monitoring and modeling. A parameter was considered to be only a "Parameter of Potential Concern" (POPC) if 2 – 10% of the samples taken exceeded the applicable water quality standard, and any identified POPCs are to continue to be monitored and re-evaluated should the monitoring show their concentrations to increase over time.

5.8.3 Summary of the Identified POCs for each Receiving Water

Three (3) POCs were determined and these include Fecal Coliform bacteria, Enterococcus bacteria and E. coli bacteria. These three POCs apply to each of DELCORA's three receiving waters; the Delaware River, Chester Creek and Ridley Creek. These three POCs are parameters typically associated with CSO discharges, and the list of the POCs is summarized below. The concentrations of these identified POCs in the Delaware River, Chester Creek and Ridley Creek have been further investigated through the receiving water quality monitoring and modeling, subsequently described in Section 6 of this report.

The identified POCs for each of the receiving water bodies are listed below.

- For the lower Delaware River (Downstream of R.M. 81.8)
  - Fecal Coliform Bacteria
  - Enterococcus Bacteria
  - E. coli Bacteria
- For the upper Delaware River (Upstream of R.M. 81.8)
  - Fecal Coliform Bacteria
  - Enterococcus Bacteria
  - E. coli Bacteria
- For the Chester Creek
  - Fecal Coliform Bacteria
  - Enterococcus Bacteria
  - E. coli Bacteria
- For the Ridley Creek
  - Fecal Coliform Bacteria
  - Enterococcus Bacteria
  - E. coli Bacteria

No Parameters of Potential Concern were identified.

5.9 Identification of Sensitive Areas

This section presents information on the identification of Sensitive Areas to meet the requirements of Section V.A.16.b of the Consent Decree, and Paragraph II.A.C.1.b of the USEPA's CSO Control Policy. The information in this section is summarized from the Sensitive Areas investigation originally presented in DELCORA's report *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c).

5.9.1 Regulatory Requirements

5.9.1.1 Consent Decree Requirements

For the Identification of Sensitive Areas, Section V.A.11 of the Consent Decree states:

> *"For each of its Receiving Waters, DELCORA shall contact appropriate agencies, access available data sources, and collect additional data as necessary to identify Sensitive Areas. DELCORA shall fully document all such contacts and the associated responses, and all additional investigations carried out to identify Sensitive Areas. DELCORA shall also identify any additional areas that, while not Sensitive Areas, have been identified by DELCORA as being appropriate for prioritization ("Priority Areas")."*
>
> *Additionally, "For each of its Receiving Waters, DELCORA shall conduct community outreach and appropriate studies to determine whether and to what extent primary contact recreation is occurring in each Receiving Water, and shall fully document its outreach and study methods, and its findings."*

5.9.1.2 Requirements of the USEPA's CSO Control Policy and Sensitive Areas Definition

The USEPA's CSO Control Policy (59 Fed Reg 75 [April 19, 1994]: 18688-18698) "expects a permittee's long-term CSO control plan to give the highest priority to controlling overflows to sensitive areas" (Section II.C.3). The CSO Control Policy states the six (6) criteria for defining an area as a "Sensitive Area" include:

1. Designated Outstanding National Resource Waters
2. National Marine Sanctuaries
3. Waters with threatened or endangered species and their habitat
4. Waters with primary contact recreation
5. Public drinking water intakes or their designated protected areas
6. Shellfish beds

The CSO Control Policy states that if Sensitive Areas are present and impacted, the LTCP should include provisions to:

- Prohibit new or significantly increased overflows
- Eliminate or relocate overflows wherever physically possible and economically achievable
- Treat overflows where necessary
- Where elimination or treatment is not achievable, reassess impacts each permit cycle

Sensitive Areas should be considered prior to the evaluation of CSO control alternatives. This allows a CSO community to identify and estimate costs for controls that could eliminate or relocate CSOs from Sensitive Areas where pollutant loadings pose a high environmental or public health risk and where control efforts should be focused.

5.9.1.3 Priority Areas Definition

The term "Priority Areas" is not specifically defined by the USEPA in the Consent Decree nor in the CSO Control Policy or Guidance Document. For the purposes of this report, the term "Priority Areas" is defined as follows:

> *"Areas having some environmental significance but not to the level of "sensitive areas" as defined in the federal CSO Control Policy. These priority areas may include: public access areas (i.e., near marinas, schools, playgrounds, parks, or athletic fields); or use of shallow streams for recreational activity, with something less than full contact (i.e., wading)".*

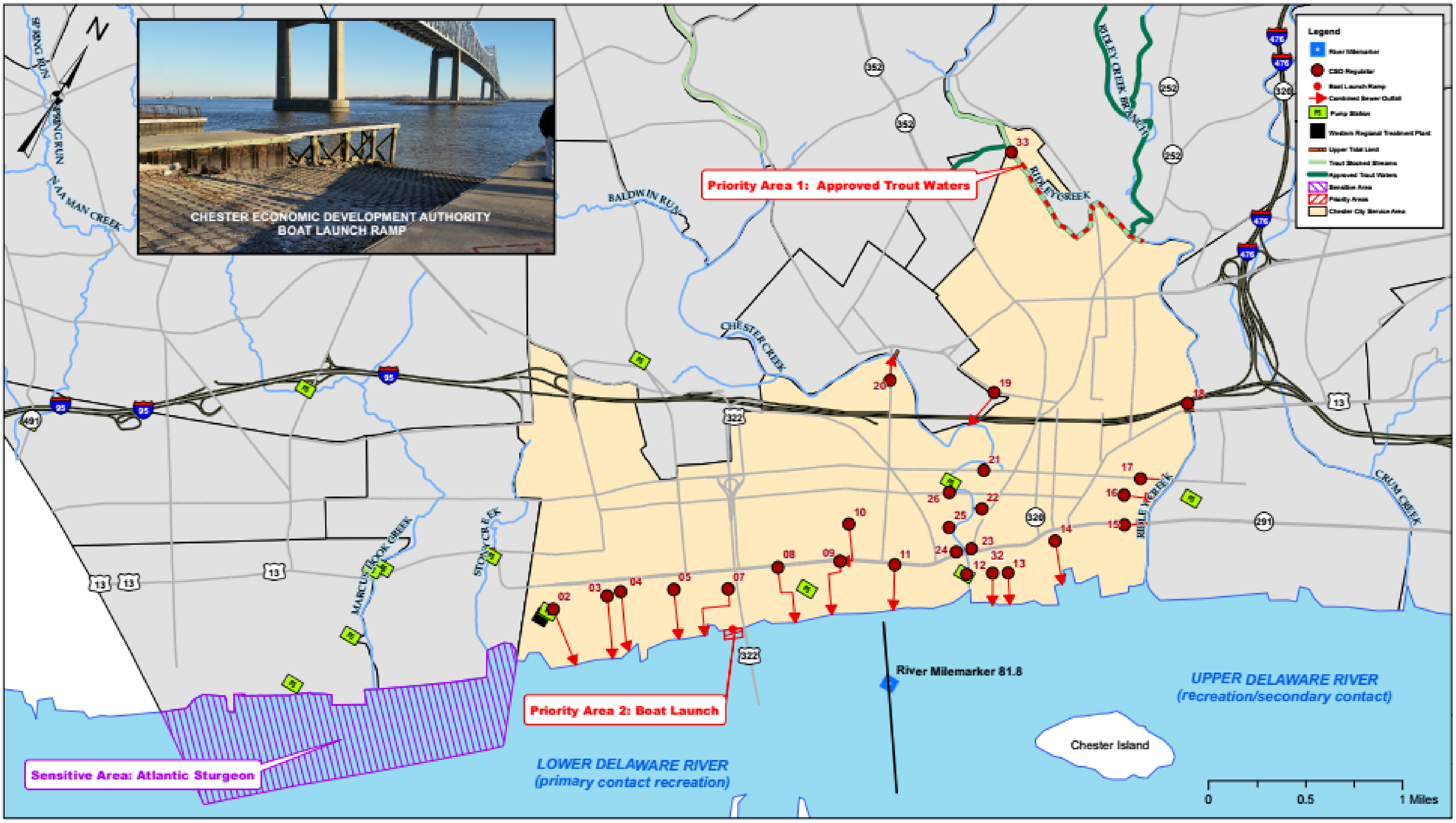
5.9.2 Summary of Sensitive and Priority Areas

The six criteria for Sensitive Areas identified in the CSO policy were evaluated for the Delaware River, Chester Creek and Ridley Creek within DELCORA's service area including reaches upstream of the CSOs. Special consideration was given to areas downstream and within the tidal influence of DELCORA's CSOs as any potential Sensitive Areas within hydraulic proximity to outfalls that may be impacted by their discharge. A comprehensive review of online databases, correspondence with regulatory agencies and local environmental organizations, and responses to the public survey was conducted to identify potential Sensitive Areas and Priority Areas within the CSS portion of the collection system. A summary of the findings for areas within the project boundary is presented below. A map of the sensitive and priority areas is shown in Figure 5-6. Additional details can be found in the report *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c).

5.9.2.1 Summary of Sensitive Areas

The habitat for year-of-young Atlantic Sturgeon downstream of CSO #002 in the Delaware River meets the Sensitive Area criteria for Endangered or Threatened species. The Atlantic Sturgeon is listed as a threatened species by the US Fish and Wildlife Service with documented habitat in the Delaware River downstream approximately one-half mile downstream of DELCORA's most southern outfall.

Figure 5-6: Sensitive and Priority Areas



There are no Outstanding National Resource Waters nor National Marine Sanctuaries within the project area. Shellfish beds are located well downstream of the CSO locations and are outside the project boundaries. There are numerous drinking water intakes in the geographical area but none are located in close proximity downstream of DELCORA's CSOs on the Delaware River. No drinking water intake locations were found that meet the criteria of a Sensitive Area.

5.9.2.2 Summary of Priority Areas

Priority Areas include areas having some environmental significance but not to the level of "Sensitive Areas" as defined in the federal CSO Control Policy. Two Priority Areas were identified:

- Approved trout waters in Ridley Creek
- Chester Economic Development Authority's boat launch in Chester City

The northern reaches of Ridley Creek within DELCORA's service area are designated as Approved Trout Waters and Trout Stocked Streams. The portion of the approved trout waters from CSO #033 downstream to Chestnut Street (see Figure 5-6) is considered a Priority Area because of this special environmental use.

The boat launch located between CSO #007 and #008 along the Delaware River is located within the portion of the waterbody rated for primary contact. The boat launch is considered a Priority Area due to its location to CSO #007 and #008.

5.9.2.3 Other Considerations

Bald eagles are known to nest in the vicinity of the project area. While the Bald Eagle has been removed from the Federal list of threatened and endangered species, the Bald Eagle along with the Golden Eagle continues to be protected under the Bald and Golden Eagle Protection Act (BGEPA) and the Migratory Bird Treaty Act (MBTA). These Acts prohibit anyone to "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, destroy, molest, disturb, or otherwise harm eagles, their nests, or their eggs". Under the BGEPA, "disturb" means to agitate or bother a Bald or Golden Eagle to a degree that causes, or is likely to cause, based on the best scientific information available: (1) injury to an eagle; (2) decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior; or (3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior. Since the Bald Eagle has been removed from the Federal list of threatened and endangered species, the Sensitive Area criteria for Threatened or Endangered Species does not apply to the project study area. However, it is acknowledged that these species require special consideration. During the development of CSO abatement alternatives, the project will be evaluated for project size, location and layout in order to comply with the BGEPA and MBTA.

Section 6 Collection of Water Quality Data

6.1 Background

The USEPA CSO Control Policy Section II.C.4 states that the long term CSO control plan should adopt one of the two approaches, Presumptive or Demonstration Approach, for CSO controls sufficient to meet CWA requirements. The DELCORA *Alternatives Evaluation Approach Report* (Greeley and Hansen, 2016b) was submitted to the USEPA and the PADEP in April 2016 proposing to utilize the Demonstration Approach for the DELCORA receiving streams. The USEPA approved this report thereby approving the demonstration approach for each receiving stream in October 2016.

Consent Decree requires that if DELCORA utilizes the Demonstration Approach in one or more of its Receiving Waters, then it is to establish a Monitoring Program to collect any additional data needed to facilitate the development, calibration, and validation of the Receiving Stream Water Quality Modeling Program, once the existing data have been assessed. The calibrated and validated Water Quality Model will be used to evaluate Typical Hydrologic Period in-stream conditions for each identified Pollutant of Concern, previously identified in DELCORA's *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c).

This section presents the results of the Water Quality Monitoring Program and includes water quality data collected from CSO discharges, storm water discharges, and from the three receiving waters. The Water Quality Monitoring Program was run concurrently with the Rain fall and Flow Monitoring Program in the spring of 2017. The goal of this program was to collect water quality data for the calibration and validation of the Water Quality receiving stream model. The final sampling results analysis is being conducted at this time and will be included in the final Water Quality Sampling Report and the final Water Quality Modeling Report to be issued August 2017 and February 2018 respectively. This Section also includes summary information previously presented in DELCORA's *Water Quality Monitoring and Modeling Work Plan* (Greeley and Hansen, 2017a) and *Water Quality Monitoring and Modeling Quality Assurance Project Plan* (Greeley and Hansen, 2017).

6.2 Regulatory Requirements

6.2.1 Consent Decree Requirements

Paragraphs V.A.10.e and V.A.10.f of the Consent Decree require that the development of the LTCP include:

V.A.10.e. *Develop and implementation of a Water Quality Model*

V.A.10.f *Characterization of the service area and the Receiving Waters as required by CSO Control Policy Paragraph II.C.1 and associated guidance.*

Consent Decree Paragraph V.A.15.a.(iv) specifically requires that:

> *"For each water body in which the Demonstration Approach is to be used, the Water Quality Model Plan shall address:*
> *i. Background, Scope and Purpose, Description of System;*
> *ii. Water quality modeling software to be employed;*
> *iii. Model configuration and development, including reaches to be modeled, and segmentation and boundary conditions;*
> *iv. Calibration and validation (dry weather and wet weather, including events and data to be employed, detailed information regarding all additional data collection activities (if needed), quantitative and qualitative calibration criteria, and utilization of H&H Model outputs;*
> *v. Use of the Water Quality Model to evaluate Typical Year instream conditions for each identified pollutant of concern;*
> *vi. Schedule for model development and implementation, including integration into LTCP development consistent with other dates required pursuant to the Consent Decree."*

The Consent Decree further specifies that within sixty (60) days after the approved Water Quality Model Plan is fully implemented according to the schedule included therein, DELCORA shall submit to EPA and PADEP a Water Quality Model Report for review and approval which shall specifically address each item set forth in Paragraph 15(a)(i)-(vi). Per the Water Quality Model Work Plan schedule, the Water Quality Model Report will be submitted February 2018 and will address the items mentioned above including Water Quality Modeling sampling results and assessment.

6.3 Overview of Historical Water Quality Monitoring

The Water Quality Monitoring Program (WQMP) was designed to collect data that will be used to assess water quality concerns identified in the Delaware River watershed and its tributaries, Chester Creek and Ridley Creek, in the vicinity of Chester, PA. Pollutants of concern (POCs) are identified in the *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c) which was approved by US EPA on October 13, 2016. Table 6-1 below lists the POCs that were identified for the receiving streams and were approved for further investigation through water quality monitoring and modeling. The POCs are *Fecal coliform, Escherichia coli (E. coli)*, and *Enterococcus* and are the primary focus of the WQMP.

Table 6-1: List of Pollutants of Concern (POC)

No.	Upper Delaware River		Lower Delaware River		Chester Creek		Ridley Creek	
Pollutants of Concern (>10% of observed samples exceed WQS)								
1	Fecal Coliform[b]	100%	Fecal Coliform[b]	100%	Fecal Coliform[a],[b]	100%	Fecal Coliform[a],[b]	100%
2	Enterococcus [b],[c]	100%	Enterococcus [b],[c]	100%	Enterococcus [b],[c]	100%	Enterococcus [b],[c]	100%
3	E. coli[c]	100%	E. coli[c]	100%	E. coli[c]	100%	E. coli[c]	100%

[a] Based on historical sampling conducted in 2010 upstream and downstream of CSO outfalls only on Chester and Ridley Creeks.

[b] Fecal Coliform and Enterococcus are listed as POCs due to both being parameters typically associated with CSOs.

[c] DRBC regulations are available for Enterococcus and it is typically associated with CSOs and therefore it is included as a POC. However, in consultation with PADEP Enterococcus could be replaced with E. coli bacteria in the future (based on the anticipation that national standards on E. coli will be adopted in Pennsylvania) and therefore E.coli is also included as a POC.

In completing the initial step of characterizing the watershed, historical data was compiled, reviewed and assessed to determine the need to augment existing data to address the watershed issues identified. This review indicated that one of the POCs, *E. coli*, has not been sampled in all the receiving waters and the data that have been collected for the remaining POCs were of insufficient frequency and spatial density to be useful in the modeling process.

6.3.1 Historic Water Quality Sampling

The Water Quality Model requires robust flow and water quality datasets to build confidence in its use as a tool for CSO planning. Data are needed in the modeled receiving waters for use in model calibration and validation as well as for the predominant wet weather sources, such as DELCORA's CSOs and the City of Chester's MS4 runoff to estimate pollutant loadings to the model. The existing water quality data were reviewed for their adequacy in meeting the data needs of the water quality model for the POCs (fecal coliform, *E. coli*, and *Enterococcus*). The review indicated that Chester Creek and Ridley Creek have limited POC data. Although the Delaware River has more extensive POC data, it lacks the temporal frequency needed to characterize wet weather impacts from DELCORA's CSOs.

It would have been difficult to constrain the Water Quality Model's representation of DELCORA's sources on the receiving waters without additional monitoring data designed specifically for calibrating and validating a robust water quality model. Existing flow data were also reviewed for adequacy; reports of mean daily stream discharge are available from several stream gages along the Delaware River and in tributaries near the DELCORA service area, ranging from as early as 1912 to the present. The existing flow and water quality data are described in this section.

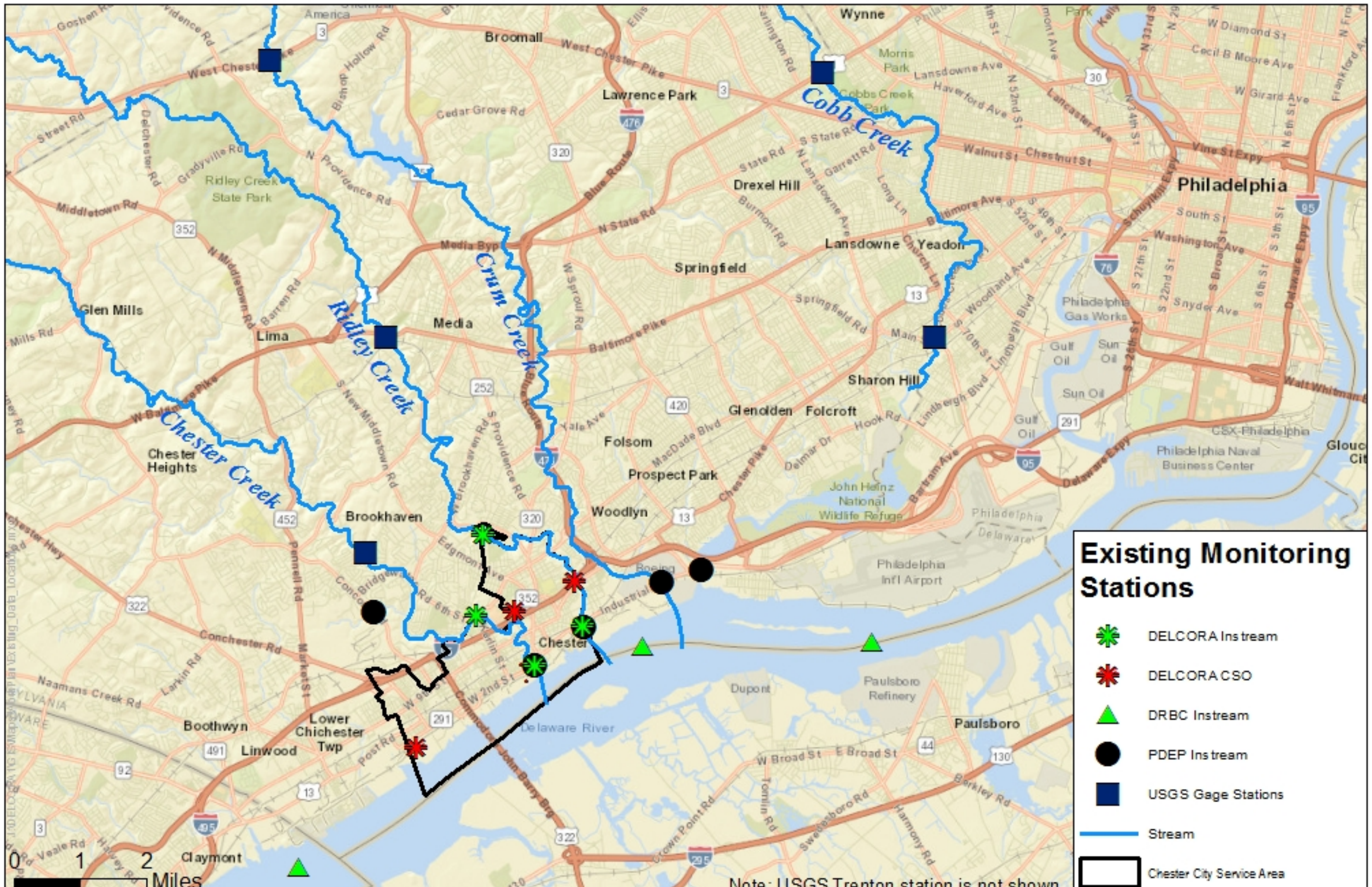
Flow data for the Delaware River and tributaries in the DELCORA service area were obtained from the USGS National Water Information System. Reports of mean daily stream discharge were available from five stream gages in DELCORA service area measuring daily mean discharge: Crum Creek near Newtown Square, PA (1980-2016); Chester Creek near Chester, PA (1931-2016); Ridley Creek near Media, PA (1986-2016); Cobbs Creek at U.S. Highway No. 1 at Philadelphia, PA (1964-2016); and Cobbs Creek at Mt. Moriah Cemetery, Philadelphia, PA (2005-2016). Though not in service area, mean daily discharge data were also obtained from the gage at the Delaware River at Trenton, NJ (1912-2016) because it is expected that these data will be used to inform the upstream boundary for the hydraulic portion of the water quality model. The USGS Pennsylvania Water Science Center has conducted water quality sampling at various points in the state. However, none of their sampling locations are near to the DELCORA service area or local waterways.

Monthly effluent data from DELCORA's WWTP are available from the Pennsylvania Department of Environmental Protection's (PADEP) eDMR website (*www.dep.pa.gov/edmr*). Reported data include monthly geometric mean and instantaneous maximum values for fecal coliform from 2009 through 2016. PADEP also monitors water quality of tidal streams that empty into the Delaware River, through the Pennsylvania Water Quality Tributary Project funded by the Delaware River Basin Commission (DRBC). This program monitored for fecal coliform levels in Chester Creek, Ridley Creek, Darby Creek, Crum Creek, and others twice annually from 2007-2010. PADEP also operates the PA Surface Water Quality Monitoring Network, through which Baldwin Run (a tributary to Chester Creek) was sampled monthly for fecal coliform from 1998-1999.

The Delaware River Basin Commission operates its Boat Run program to monitor ambient, sampling for *E. coli*, *Enterococcus*, and fecal coliform at various sites along the Delaware River (Figure 6-1). Samples were collected from each station between one and three times each month from March through November every year since 1999. Through this program, data are available at three sites near DELCORA: Eddystone (2005-2016), Paulsboro (1999-2016), and Marcus Hook (1999-2016).

Since 2009, DELCORA has also done their own sampling at CSO outfall sites and in receiving waters. In 2010, a survey was conducted to measure fecal coliform levels in Ridley and Chester Creeks during wet and dry weather. There were two sample sites in each creek, and over the course of the study, six surveys were conducted. Four surveys occurred during dry weather, one during a wet event, and one during a wet event after a storm. During each survey, one sample was collected at each site. In 2009, DELCORA began sampling in the CSO system as required by their NPDES permit. Four outfalls and pump stations were sampled once annually for fecal coliform from 2009-2011, and three outfalls were sampled once annually for fecal coliform from 2012-2014. In 2015, four outfalls and pump stations were sampled for fecal coliform and *Enterococcus*, on three separate occasions. *E. coli* was not measured in any of these surveys.

Figure 6-1: Historical Flow and Water Quality Sampling Locations Near DELCORA Service Area



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The extent of the historical water quality data and its adequacy to support the Water Quality Model development and calibration can be summarized as follows:

- Some CSO water quality data had been collected but mostly for fecal coliform. There were no CSO data for *E. coli*. Another limitation in the CSO data is that the CSO samples did not coincide with in-stream sampling, making it difficult to directly link CSO loads to in-stream impacts.
- No water quality sampling for the POCs had been done of the stormwater runoff in the separated areas of the DELCORA service area.
- The Delaware River had the most data of the receiving waters and it had data for all three POCs. However, the data were collected at regular intervals, independent of weather condition, and typically only one sample per location per survey was collected. These periodic sampling events do not provide enough data to characterize DELCORA loads on the river.
- The tributaries (Chester Creek and Ridley Creek) have been sampled sporadically and rarely within the tidal zone adjacent to DELCORA's service area. Wet weather data collected by DELCORA, consisting of only one sample per event, were not sufficient to characterize the magnitude and duration of the POCs' pollutographs over a storm event. Data are most robust for fecal coliform. There was less data for *Enterococcus* and none for *E. coli*. In addition, no sampling had been conducted in these tributaries since 2010.

DELCORA's Water Quality Monitoring Program conducted during Spring 2017 builds on the water quality sampling that had already been done while addressing the limitations identified in the historical data. The WQMP included a comprehensive monitoring assessment of all of the POCs to characterize loads and in-stream conditions, and these data were used to inform the Water Quality Model development, calibration and validation.

There has not been routine, on-going monitoring for the pollutants of concern in the tributary waterways adjacent to the DELCORA service area. The Delaware River Basin Commission samples the Delaware River near Chester approximately once a month between April and October. The analysis of these samples includes fecal coliform, *E. coli*, and *Enterococcus*, which are the pollutants of concern (POCs).

6.4 Overview of the Water Quality Monitoring Program

6.4.1 Water Quality Monitoring Objectives

The Water Quality Monitoring Program (WQMP) is designed to collect data that will be used to develop and calibrate watershed and receiving water quality models that will be used to assess water quality concerns for the POCs identified in the *Identification of Sensitive Areas and Pollutants of Concern Report* (Greeley and Hansen, 2016c). The report identified three indicator bacteria (fecal coliform, *Escherichia coliform* (*E. coli*), and enterococcus) as pollutants of concern (POC) that are potentially impacting receiving water quality during CSO discharges in all three of the receiving waters (Delaware River, Chester Creek and Ridley Creek).

Existing water quality data provides insight into the conditions in the river and streams in the project area but are of insufficient frequency and spatial density to fully support the modeling process. In addition, *E. coli*, one of the identified POCs, was not monitored in the available data. The water quality monitoring objectives are to collect water quality data for the POCs during dry and wet weather event periods that can be used to characterize the bacteria sources in the Delaware River watershed in the vicinity of the City of Chester, PA, and to calibrate and validate the Water Quality Model, consistent with the Consent Decree requirements in Paragraph V.A.15.a. Additional in situ parameters that included salinity, temperature and conductivity were collected to inform the development of the Water Quality Model.

The collection of new water quality data was required to address the shortcomings of the historical water quality data by:

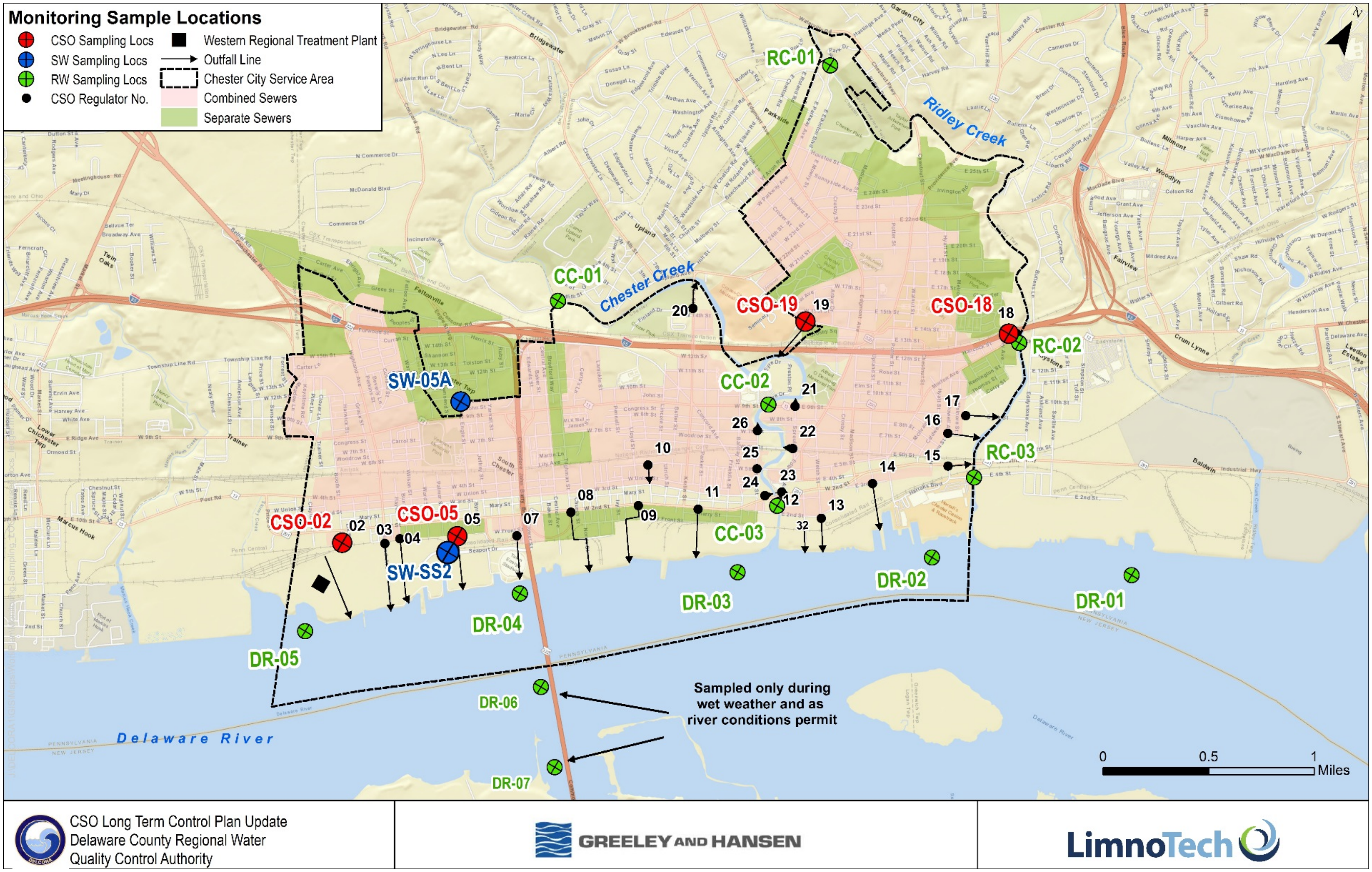
- Providing the frequency needed for in-stream concentrations (multiple samples spaced over several days) during wet weather to calibrate fecal coliform, *E. coli* and *Enterococcus* concentrations in the Receiving Water Quality Model;
- Providing wet weather event data for a range of storm conditions to calibrate and validate the Receiving Water Quality Model;
- Capturing the effects of the wet weather event throughout the CSO model area;
- Providing better constraints on calculated loads from storm water, tributary, and CSO sources than when using historical data

6.4.2 Water Quality Sampling Locations

Water quality monitoring was undertaken at thirteen (13) in-stream locations (seven of which are Delaware River sampling locations), four (4) CSO locations in the DELCORA combined sewer system area, and two (2) stormwater locations in the City of Chester municipal separate storm sewer system, as shown in Figure 6-2. Water quality monitoring and sampling was conducted as follows:

- Eleven (11) in-stream locations in the vicinity of the DELCORA CSO area were sampled for water quality for (3) dry weather events; one of which was targeted for collection during a tributary low-flow period (less than 25th percentile flow). The mid-stream and far-shore Delaware River locations were not sampled during the dry weather surveys because it was expected that water quality in the river is relatively uniform laterally due to

Figure 6-2: Receiving Water (RW), Combined Sewer (CSO) and Stormwater (SW) Monitoring Locations



the lack of active sources during dry weather. Grab samples and *in situ* measurements were collected at each location during each event.

- All thirteen (13) in-stream locations were sampled for water quality using grab samples and in situ monitoring for three (3) discrete wet weather events, according to the surface water quality monitoring program protocols described in the Monitoring Work Plan;
- Up to four (4) CSO and two (2) stormwater outfall locations were sampled for water quality for the same three (3) discrete wet weather events according to the outfall monitoring program protocols described in the Monitoring Work Plan. Samples for all outfalls were collected as grab samples.

The sampling events were planned to be distributed across the sampling season, which is assumed to be March through June 2017. Additionally, bathymetry surveys in the lower portion of the Chester and Ridley Creek were conducted to inform the development of the Water Quality Model.

Monitoring locations were selected to characterize the watershed at a sub-watershed level, recognizing various political and hydrologic features, land uses and potential pollutant sources. Site selection and analytical parameters were designed to characterize stormwater outfalls, CSOs, tributaries upstream and within the Chester CSO discharge area, and the main stem of the Delaware River in the project area. The sampling locations are shown in Figure 6-2 and listed in Tables 6-2, 6-3 and 6-4.

Tables 2-1, 2-2 and 2-3 include summaries of the rationales for each sampling location selected. The Chester Creek and Ridley Creek locations were selected to distinguish, to the extent possible, between upstream, stormwater and Chester CSO pollutant loads. The Delaware River sampling locations provided a characterization of water quality entering the Chester CSO area from either tidal direction as well as water quality within the CSO discharge area. During wet weather, three samples were collected across the transect corresponding to the DR-03 sampling location during each sampling round, when sampling across the river was feasible, to characterize lateral variability in the Delaware River during storm events.

The CSO sampling locations were selected based on their outfall discharge location, relatively high frequency of overflow, their overflow volume, and their accessibility. The stormwater sampling locations were selected to characterize the water quality associated with the predominant land uses (residential and commercial/industrial) in the study area. Each stormwater sampling location is in an area that is representative of the land use elsewhere in the City’s stormwater area.

Table 6-2: Tributary Receiving Water Sampling Locations

Station ID	Easting[1]	Northing[1]	Receiving Water	Type	Description	Rationale
CC-01	243291.419	371541.259	Chester Creek	Tributary	Chester Creek at Upland-Incinerator Rd.	Upstream of all City sources and upstream of tidal influence
CC-02	248598.992	372750.444	Chester Creek	Tributary	Chester Creek at North Eyre Rd[2]	Characterize impacts from non-CSO urban runoff sources
CC-03	250712.383	369489.807	Chester Creek	Tributary	Chester Creek at E 2nd St.	Characterize impacts from all CSOs discharging to Chester Creek
RC-01	243755.086	380967.554	Ridley Creek	Tributary	Ridley Creek at East Brookhaven Road	Upstream of all City sources and upstream of tidal influence
RC-02	253932.835	376122.878	Ridley Creek	Tributary	Ridley Creek at Chester Pike	Characterize impacts from non-CSO urban runoff sources
RC-03	254545.954	372628.232	Ridley Creek	Tributary	Ridley Creek at East 4th St.	Characterize impacts from all CSOs discharging to Ridley Creek

Notes:

[1] Northing/Easting are referenced to NAD 1983 State Plane New Jersey FIPS 2900 Feet

[2] 9th Street may be used as sampling location if conditions for sampling from the bank at North Eyre St. are deemed unsafe.

Table 6-3: Main Stem Receiving Water Sampling Locations

Station ID	Easting[1]	Northing[1]	Receiving Water	Type	Description	Rationale
DR-01	259153.030	372425.510	Delaware River	Main stem	Delaware River between Ridley Creek and Crum Creek	"Upstream" of DELCORA's CSO discharges[2]
DR-02	250456.388	367784.535	Delaware River	Main stem	Delaware River between CSO-14 and Ridley Creek	Characterize Ridley Creek impacts on Delaware River, in the upper Delaware River (Secondary contact area)
DR-03	245922.404	364715.470	Delaware River	Main stem	Delaware River between CSO-11 and Chester Creek	Characterize Chester Creek impacts on Delaware River, in the upper Delaware River (Secondary contact area)
DR-03-MID[3]	252036.389	365265.510	Delaware River	Main stem	Delaware River mid-stream along the transect of DR-03	Characterize lateral variability in the Delaware River during storm events
DR-03-LDB[3]	253703.965	362951.038	Delaware River	Main stem	Delaware River far shore (left descending bank) along the transect of DR-03	Characterize lateral variability in the Delaware River during storm events
DR-04	241663.723	361297.935	Delaware River	Main stem	Delaware River at the boat launch off Highway 322	Priority area, in the lower Delaware River (Primary contact area)
DR-05	254551.896	370426.118	Delaware River	Main stem	Delaware River between CSO-002 and Stony Creek	"Downstream" of DELCORA's CSO discharges[2], in the Atlantic sturgeon sensitive area

Notes:
[1] Northing/Easting are referenced to NAD 1983 State Plane New Jersey FIPS 2900 Feet
[2] "Upstream" and "downstream" subject to tidal conditions at time of sampling
[3] These locations will be sampled during the wet weather events only, when river conditions permit. POC concentrations are assumed to be laterally well-mixed during dry weather due to the absence of significant pollutant sources.

Table 6-4: CSO and Stormwater Sampling Locations

Station ID	Easting	Northing	Receiving Water	Type	Description	Rationale
CSO-19	248984.7240	374039.747	Chester Creek	CSO	14th and Crozer Hospital	Discharges to Chester Creek, one of the largest volume CSOs in DELCORA system
CSO-05	243892.0527	365166.574	Delaware River	CSO	Front and Townsend	Discharges to Delaware River, one of the largest volume CSOs in DELCORA system
CSO-02	241439.9527	363646.588	Delaware River	CSO	Front and Booth	Aggregates cumulative effect of CS conditions, one of the volume CSOs in DELCORA system
CSO-18	253767.9703	376303.599	Ridley Creek	CSO	Sun Drive and Hancock St.	Discharges to Ridley Creek
SW-05A	242360.2937	368165.917	Chester Creek	SW		Characterize runoff quality from predominantly residential area representative of the residential portion of the study area
SW-SS2	248649.2079	368230.704	Delaware River	SW		Characterize runoff quality from predominantly commercial/industrial area representative of the commercial/industrial portion of the study area

Note: The sampling locations will be finalized once a sampling contractor has been selected and potential sampling locations are assessed with respect to accessibility, feasibility, safety, and representativeness. The northing/eastings information will likely be updated prior to the initiation of the Sampling Program. Northing/Easting are referenced to NAD 1983 State Plane New Jersey FIPS 2900 Feet

6.4.3 Analytical Parameters

All of the in-stream dry and wet weather samples were analyzed for the parameters shown in Table 6-5: Analytical and Field Parameters. The outfall samples were analyzed for only *E. coli*, *Enterococcus* and fecal coliform.

Table 6-5: Analytical and Field Parameters

Parameter	Description	Sampling Program	Type of Measurement
E. coli	Escherichia coli	Dry, Wet	Grab
Enterococcus	Enterococcus sp.	Dry, Wet	Grab
Fecal Coliform	Fecal coliform	Dry, Wet	Grab
wTemp	Water temperature	Dry, Wet, Receiving Water Only	In-situ
Cond	Conductivity	Dry, Wet, Receiving Water Only	In-situ
Salinity	Salinity	Dry, Wet, Receiving Water Only	In-situ

6.4.4 Sampling Schedule and Dates

6.4.4.1 Dry Weather Sampling

The collection of water quality samples was performed for three (3) dry weather (DW) events; with one dry weather sampling event occurring during a low-flow period (less than 25th percentile flow) in Chester Creek and Ridley Creek. Below are the River and Creeks flows for during each of the dry weather sampling events. Table 6-6 below presents the Delaware River, Chester Creek and Ridley Creek flow during each dry weather sampling event. Dry Weather Sampling Event 3 is closest to the 25th percentile river flow.

Table 6-6: Observed River and Creek Flow Statistics

Water Body	Gage Identification	Gage Description	25th Percentile Flow	Dry Weather Event 1		Dry Weather Event 2		Dry Weather Event 3	
			(cfs)	(cfs)	Percentile	(cfs)	Percentile	(cfs)	Percentile
Delaware River	USGS 01463500	Delaware River at Trenton, NJ	4,600	13,323	70.1	16,306	78.1	10,862	62.1
Chester Creek	USGS 01477000	Chester Creek near Chester, PA	41	75.7	60.5	63.9	50.7	46.8	32.2
Ridley Creek	USGS 01476480	Ridley Creek at Media, PA	18	29.4	49	25.0	41.7	19.0	27.5

Source:
- 25th percentile flow (cfs) and percentile for each water body is courtesy of the U.S. Geological Survey (USGS) StreamStats (https://streamstats.usgs.gov/ss/)
- Observed flow data (cfs) for each Dry Weather Event is courtesy of the following current/historical observations link on the National Water Information System (NWIS) webpage:
  Delaware River: https://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=01463500
  Chester Creek: https://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=01477000
  Ridley Creek: https://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=01476480

Two rounds of sampling were conducted for each dry weather survey: one round was completed during ebb (outgoing) tide and the second round was completed during flood (incoming) tide. The following table summarizes the dates of the DW events.

DW Sampling Event	Event Date
DW-1	3/23/2017
DW-2	5/10/2017
DW-3	6/13/2017

These events were distributed across the sampling season, of March through June 2017. The criteria used to define a dry weather event are as follows:

- No precipitation within the upstream watershed at least 48 hours before the event
- No precipitation forecasted for a minimum of three days; and

Dry weather event samples were taken at eleven (11) locations:

- **Three (3) locations on Chester Creek** intended to characterize water quality upstream of DELCORA's service area as well as in the portion of the creek adjacent to DELCORA's CSO discharges and the area adjacent to the City of Chester outside the combined sewer service area. Additionally, because DELCORA's CSO discharges are within the tidal extent of the Delaware Bay River, the downstream sampling locations were intended to also reflect these tidal influences on water quality.

- **Three (3) locations on Ridley Creek** intended to characterize water quality upstream of DELCORA's service area as well as in the portion of the creek adjacent to DELCORA's CSO discharges and the area adjacent to the City of Chester outside the combined sewer service area. Additionally, because DELCORA's CSO discharges are within the tidal extent of the Delaware Bay, the downstream sampling locations were intended to also reflect these tidal influences on water quality
- **Five (5) locations on the Delaware River** intended to characterize water quality in the vicinity of DELCORA's CSO discharges. Sampling locations were selected to separate to the extent possible the effect of DELCORA's CSOs on water quality from other sources contributing pollutants to the waterways. Sampling was conducted near the shoreline adjacent to the City of Chester.

The locations of these sample stations are shown in Figure 6-2, and details for these stations are provided in Tables 6-2, 6-3 and 6-4. The set of parameters for which the samples were analyzed is provided in Table 6-5. In-situ measurements of physical parameters, such as salinity, temperature, and conductivity were collected at each sampling location with a YSI sonde. .In the Delaware River, *in situ* measurements were made at three depths at each sampling location during each round of sampling.

6.4.4.2 Wet Weather Sampling

The collection of water quality samples was performed for three (3) wet weather events. The purpose of the wet weather sampling was to characterize the impact of CSO discharges and non-CSO source runoff on in-stream water quality. The wet weather events spanned a range of precipitation, flow and seasonal conditions. One of the wet weather sampling events was also chosen as a calibration event for the H&H Model and the Water Quality Model.

The goal was to sample storms of at least 0.5 inches of precipitation. The criteria used to define a wet weather event included:

- No precipitation within the upstream watershed 48 hours before the event;
- Forecasts for a 60% (or greater) chance of rain over the entire DELCORA project area; and,
- Approximately 0.50 inches of rainfall forecasted over a six-hour period.

The following table lists the dates that each wet weather sampling event occurred:

WW Sampling Event	Event Date
WW-1	3/31/2017
WW-2	5/5/2017
WW-3	5/22/2017

Wet weather event samples were taken at all 13 in-stream locations as well as at six source locations in the intervals described below:

- **Six (6) In-Stream Tributary Sampling Locations:** Three (3) locations were on the Chester Creek and three (3) locations were on the Ridley Creek. The locations were the same locations used for the dry weather surveys. Tributary locations were sampled up to five times per event at the following approximate intervals: Hour 0.5-2.5, Hour 4.5-6.5, Hour 8.5-10.5, Hour 14.5-16.5, and Hour 22-24. Sampling intervals were defined by the start of rainfall rather than CSO or SSO activation. A total of 30 samples was collected during each wet weather sampling event from in-stream locations. One field blank and one field duplicate was collected during each event to be used as field quality control (QC).

- **Seven (7) In-Stream Delaware River Locations:** Seven locations were on the Delaware River and were sampled up to ten times per event at the following approximate intervals: Hour 0, Hour 2, Hour 4, Hour 6, Hour 9, Hour 12, Hour 15, Hour 18, Hour 21, and Hour 24 intervals were defined by the start of rainfall rather than CSO or SSO activation. The frequency of sampling was intended to capture in-stream impacts in the vicinity of DELCORA's service area from both DELCORA's CSOs as well as upstream sources. Two additional locations on the Delaware River, one at mid-stream and one near the far shore, were added to characterize lateral variability in water quality during storm event conditions, when sampling across the river was feasible. The sampling regimen was also designed to allow a semi-quantitative mass balance to be computed over a complete tidal cycle. A total of 70 samples were collected during each wet weather sampling event. If river conditions were unsafe for sampling (e.g. small craft advisories, heavy barge traffic, etc.), sampling was suspended for one or more locations and/or sampling rounds. One field blank and one field duplicate was collected during each event to be used for field QC. Final selection of sampling locations and sampling intervals was determined prior to the start of the sampling program and based on logistic considerations (e.g. can seven locations be sampled and dropped off to a courier within the 3 hour sampling window), safety and accessibility to the Delaware River, and available resources. For some of the sampling events some of the planned intervals samples were not obtained if the storm event stopped before the designated sample time or if the boat could not reach the location due to restrictions on the Delaware River.
- **Six (6) Outfall Locations:** Sampling was conducted at two (2) stormwater outfalls and four (4) combined sewer overflow outfalls. The CSO and stormwater sampling locations were finalized prior to the initiation of the sampling program based on accessibility of sampling, safety of sampling personnel, equipment risk, and available resources. Each of the outfall locations had eight sets of samples collected for each event at the following intervals: 1st flush, 30 minutes, and 60 minutes, 2 hours, 4 hours, 8 hours, 12 hours, 24 hours. Samples were collected from CSO-05, CSO -02 and CSO-18 and during each wet weather sampling event, and if all monitored outfalls discharge for 24 hours. If a location was not flowing, no sample was collected. However, the actual number of samples was less than the amount indicated since not all the monitored outfalls discharged for the full 24 hour monitoring period. One field blank and one field duplicate were collected during each event to be used as field QC.

The locations of these stations are shown in Figure 6-2. Details for these stations are provided in Tables 6-2, 6-3 and 6-4. The set of parameters for which the samples were analyzed are summarized in Table 6-5. *In-situ* measurements were not collected at the outfall locations.

Sampling crews conducted all wet weather event sampling using the protocols described in the DELCORA's *Water Quality Monitoring and Modeling Quality Assurance Project Plan* (Greeley and Hansen, 2017b). Samples were delivered to the laboratory and analyzed for the parameters shown in Table 6-5: Analytical and Field Parameters.

Determination to mobilize for a Wet Weather Event was a collaborative effort between Greeley and Hansen, LimnoTech, Eurofin (Lab) and DELCORA field sampling team. The intent was to identify a storm that was at least ½ inch rainfall and a 4 to 6 hour window in which a wet weather event may commence 24 hours in advance to assist in mobilization of the sampling crews meeting the requirements stated above for a WW event.

6.4.4.3 In situ Measurements (Receiving Water Only)

Instantaneous water quality measurements (such as salinity, temperature, and conductivity) using field instruments was also collected at the receiving water locations as specified in the *Water Quality Monitoring and Modeling Work Plan* (Greeley and Hansen, 2017a). These measurements, along with calibration and maintenance, were conducted following the SOPs for Water Quality Field Measurements in the Work Plan. Field instruments were calibrated before initiating monitoring activities for each event and a post-monitoring calibration check was conducted at the end of the event.

Salinity, temperature, and conductivity were measured at all in-stream sampling locations using a YSI 6920 sonde during both wet and dry sampling events, prior to sample collection. Whenever possible in the Chester Creek and Ridley Creek, measurements were made mid-channel at mid-depth. Whenever possible in the Delaware River, measurements were made at the surface, mid-depth and near the bottom.

6.4.5 QAPP Overview

Prior to the start of the spring 2017 water quality sampling activities, DELCORA submitted to the EPA and PADEP its *Water Quality Monitoring and Modeling Quality Assurance Project Plan* (Greeley and Hansen, 2017b). This Quality Assurance Project Plan (QAPP) was developed to meet the requirements of the DELCORA Consent Decree Paragraph Section V.A.15.a.(iv) requiring detailed information regarding all additional data collection and water quality modeling activities. The purpose of the QAPP was to document the necessary procedures required to assure that the project is executed in a manner consistent with applicable USEPA guidance documents and with generally accepted and approved quality assurance objectives. The QAPP was organized in accordance with the basic groups and subgroup elements discussed in the USEPA guidance for QAPPs. The four basic groups include project management (Group A); data generation and acquisition (Group B); assessment and oversight (Group C); and data validation and usability activities (Group D). The groups are subdivided into elements covering specific topics related to each group. The Section and Subsection headings of this QAPP include references to the USEPA QAPP Guidance group letters and element numbers to facilitate cross-reference with the Guidance.

The QAPP integrates quality control policies and project-specific work tasks to successfully conduct water quality monitoring and modeling to support the CSO Long Term Control Plan update. Greeley & Hansen served as the contracting authority for the project and provided overall project management. LimnoTech served as the technical advisor for the sampling program and provided the data integration and interaction role. The field contractor, Weston conducted the actual sampling program, and the laboratory contractor, Eurofins, performed laboratory analysis for the project.

The QAPP was designed and organized in terms of compliance with USEPA requirements. It was the overall intent of the QAPP to provide professional guidelines for activities by all personnel on the project and to ensure that quality assurance/quality control QA/QC procedures are followed.

6.5 Receiving Water Quality Results

The identified pollutant of concerns for the Delaware River, Chester Creek and Ridley Creek are the same three indicator bacteria; fecal coliform, *Escherichia coliform* (*E. coli*), and enterococcus. Consequently, the Water Quality Monitoring Program primarily focused on the concentrations of these three parameters.

Water Quality Sampling has been completed; however, the results are currently being reviewed for quality assurance and analyzed. A summary of the sampling results are presented in Appendix D of this report; however, the analysis and conclusions are currently being conducted and will be presented in the final Water Quality Sampling Report and the final Water Quality Modeling Report.

Section 7 Typical Hydrologic Period

7.1 Introduction

7.1.1 DELCORA's Consent Decree

According to the Consent Decree between the USEPA, PADEP, and DELCORA, DELCORA shall submit to Plaintiffs a report or technical memorandum describing DELCORA's statistical evaluation of long-term local rainfall patterns and the identification of an appropriate typical period for LTCP development purposes. To satisfy this Consent Decree requirement, DELCORA submitted the *Typical Hydrologic Period Report* (Greeley and Hansen, 2016a), which was approved by PADEP and USEPA on May 23, 2016. The remainder of Section 7 is based on this approved report.

The statistical evaluation in the *Typical Hydrologic Period Report* (Greeley and Hansen, 2016a) utilizes local long-term rainfall record from the Philadelphia International Airport. It considers various appropriate rain year characteristics, including distributions of event rainfall totals, event durations, and peak and average rainfall intensities.

7.1.2 Typical Year for CSO LTCP Development

Precipitation generates urban storm water, combined sewer overflows (CSOs), and increased wet weather flows to the wastewater treatment plant. These will contribute bacteria and pollutants to the Delaware River and its tributaries. The effect of these contributors on the Delaware River mainly depends on the magnitude and duration of rainfall events and on the prevailing ambient river conditions controlling dilution and transport of the pollutants. This variability and complexity poses a significant challenge for assessing the performance of wet weather and CSO control alternatives.

In accordance with the USEPA CSO Control Policy (CSO Policy), dated April 19, 1994, the CSO control alternatives should be assessed on a "system-wide, annual average basis". This is accomplished by continuous simulation using a typical hydrologic period for the combined sewer system (CSS) and receiving water quality modeling applications. The CSO Policy supports continuous simulation modeling, i.e., using long-term rainfall records rather than records for individual storms. Long-term continuous rainfall records enable simulations to be based on a sequence of storms so that the additive effect of storms occurring close together can be examined. They also enable storms with a range of characteristics to be included.

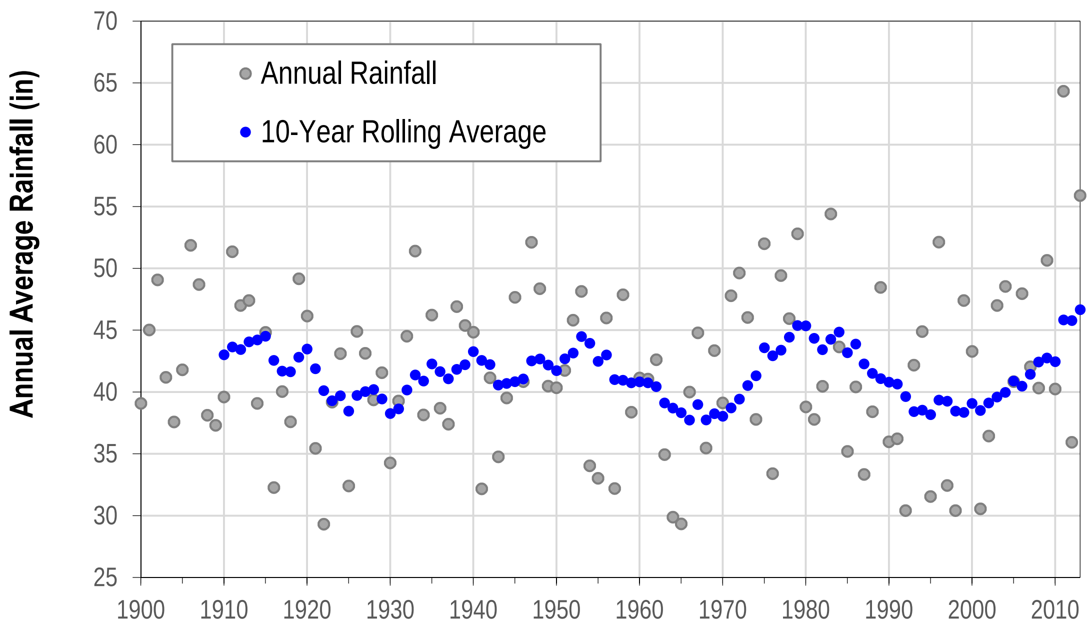
Typically, a 3- to 5-year period is evaluated to balance between manageable model simulation time and representation of various rainfall/river conditions. In this study, a 3-year period is deemed most appropriate considering the modeling complexity. The representative three-year period is intended to contain a relatively wet year, a dry year and an average year. Average year conditions are defined as the arithmetic average of the predictions for the selected period.

7.1.3 Climate Change Considerations

Average U.S. precipitation has increased since 1900, but there are regional differences, with some areas having larger increases, and others, decreases. Local climate change should be considered when selecting appropriate data records for the typical period analysis.
Rainfall data from the Philadelphia International Airport were obtained from the National Oceanic and Atmospheric Administration (NOAA). Hourly rainfall data is available from 1900 through 2013. This provides sufficient data to evaluate climate change in the area. Figure 7-1 shows annual rainfall from 1900 to 2013. A 10-year rolling average trend line is also shown in the figure for characterizing long-term precipitation pattern. In the past 114 years, annual rainfall ranges from 29.3 to 64.33 inches, with the wettest year in 2011. The 10-year rolling average rainfall indicates that precipitation in the area runs through various dry and wet cycles, however with more extreme conditions (dry and wet) in recent years.

Considering the climate change, it is determined that the typical period for the LTCPU be selected based on statistical analysis of rainfall records in recent 30 years (i.e., 1984-2013).

Figure 7-1: Historical Annual Rainfall at Philadelphia International Airport



7.1.4 Methodology of Typical Year Selection

The typical hydrologic period is selected to provide representative and unbiased approximations of expected future conditions in terms of both averages and historical variability. Representativeness is assessed using objective criteria for each of the ambient factors (i.e., river flow and rainfall). As indicated in the previous section, the selection of the typical hydrologic period is based on the historical records in the past 30 years from 1984 through 2013.

The following datasets are used for the analysis of the typical hydrologic period:

- Hourly precipitation data for the National Climate Data Center gauge at Philadelphia International Airport for 1984 - 2013.
- Daily Delaware River stream flow data from the U.S. Geological Survey gauge at Trenton, NJ (USGS 01463500) for 1984 - 2013. This is the closest USGS gauge that with daily river flow available.

Key criteria parameters used in the evaluation are listed in Table 7-1. Each parameter is given a weighting factor to describe the individual importance on the averageness of the analyzed time period. The parameters that are given the highest impact weighting include the following:

- The total annual rainfall depth, which drives the total runoff volume.
- The maximum peak intensity, which usually defines the biggest overflow event.
- The median Delaware River flow; the impact of sewer overflows on the water quality of the receiving water is dependent on the magnitude of the flows in river, and in the project area, intense local rainfall events are typically independent from watershed wide high flow events.

Table 7-1: Hydrologic Period Ranking Parameters

Key Parameter	Weighting Factor	Comments
Annual rainfall depth	25.0%	Important for evaluating annual overflow volume
Number of events > 0.1” rainfall depth	2.5%	Typically storms over 0.1” would start to cause surface runoff
Number of events > 0.25” rainfall depth	2.5%	Previous model indicates system overflows at storms over 0.25”
Number of events > 1.5” rainfall depth	7.5%	Storms to be controlled to meet potential presumption approach
Number of back-to-back events	5.0%	Important for evaluating the antecedent conditions
Maximum peak intensity	20.0%	Storms with high intensity causes overflows
Average rainfall duration	2.5%	Important for evaluating wet weather durations
Average rainfall intensity	5.0%	Important for evaluating overall rainfall intensity
Delaware River flow - 25th percentile	2.5%	Important for evaluating dilution power of the Delaware River flow for water quality
Delaware River flow - 50th percentile	25.0%	
Delaware River flow - 75th percentile	2.5%	

7.2 Typical Year Selection for DELCORA

7.2.1 Annual Rainfall and River Flow Statistics

30-year hourly precipitation data (1984 - 2013) from the Philadelphia International Airport was analyzed to evaluate all individual rainfall events in the period. An inter-event time (IET) of 6 hours (i.e. minimum dry time of 6 hours between rainfall events was used to differentiate between individual events. Precipitation periods with a total rainfall volume of greater than 0.1 inch were counted as rainfall events. If the next rainfall event's starting time is within one day of the previous rainfall event's ending time, these two rainfall events are considered as back-to-back rainfall events. All rainfall events for the data period were analyzed for duration, inter-event duration, total rainfall amount, as well as maximum and average rainfall intensities. A total of 1,934 rainfall events were counted for the period of 1984 - 2013.

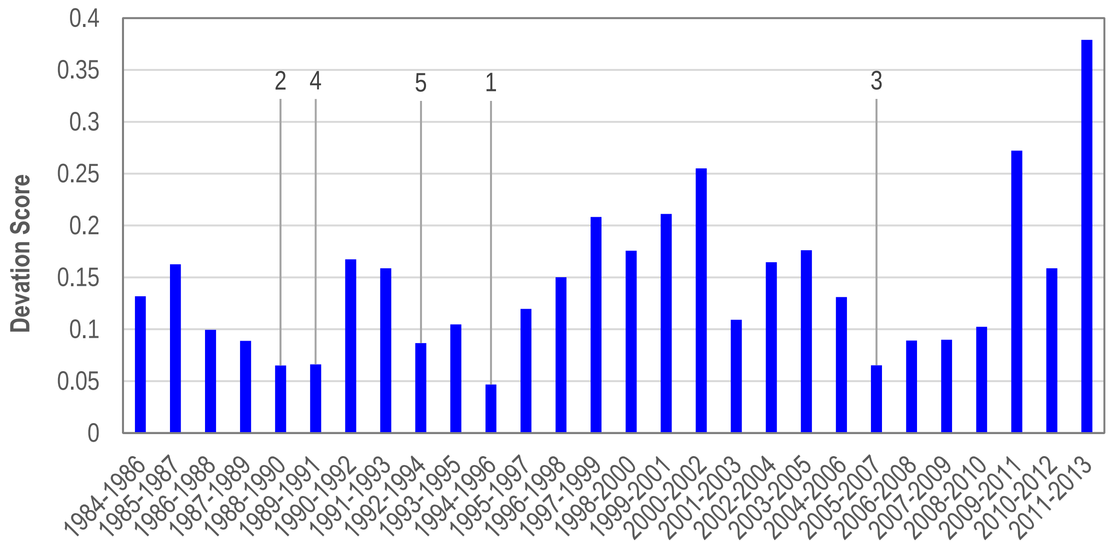
7.2.2 Three-year Rainfall and River Flow Analysis

Once annual rainfall and river flow statistic were determined for the 30 year period, three-year rainfall and river flow characteristics were developed based on an annual average of the three consecutive years. The goal of using a three-year analysis period was to find a period that had a relatively dry year, a relatively wet year, and a relatively average year. That way, any evaluations done using the typical hydrologic period have a more diverse spectrum of wet weather events and dry weather periods.

7.2.3 Ranking Analysis

With the weighting factors listed in Table 7-1, a deviation score was developed for each individual period. The 3-year periods were then ranked based on the deviation score. The lower the deviation score (Figure 7-2 Y-axis), the higher the rank for the hydrologic period (i.e., the closer it is to the average condition). Figure 7-2 shows the ranking results of the 28 hydrologic periods, with a ranking of 1 being the highest and a ranking of 28 being the lowest ranked hydrologic period. Hydrologic period 1994-1996 is ranked No.1 because it has the lowest deviation score of 0.047.

Figure 7-2: Ranking Score of 3-year Period, 1984-2013



7.2.4 Top 5 Ranked 3-year Hydrologic Periods

Based on the ranking analysis, the top 5 ranked hydrologic periods are:

- Rank 1: 1994-1996
- Rank 2: 1988-1990
- Rank 3: 2005-2007
- Rank 4: 1989-1991
- Rank 5: 1992-1994

Table 7-2 shows rainfall and river flow statistics for these top ranked hydrologic periods.

Table 7-2: Top 5 Ranked Hydrologic Periods

Rank	Year	Rainfall								Delaware River Flow (cfs)		
		Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
1	1994-1996	42.9	1.50	0.08	10.1	65	47	5	7	5,611	9,710	16,775
2	1988-1990	41.0	1.69	0.08	10.5	63	44	5	10	5,598	8,338	13,925
3	2005-2007	43.6	1.55	0.09	10.6	61	45	6	10	6,030	10,450	17,533
4	1989-1991	40.2	1.50	0.08	10.8	63	45	5	10	5,187	8,043	14,467
5	1992-1994	39.2	1.50	0.08	10.6	64	41	5	8	5,070	7,760	13,167
Average 1984-2013		**41.3**	**1.53**	**0.08**	**10.7**	**62**	**44**	**5**	**9**	**5,540**	**9,325**	**15,770**

Rainfall return frequency during 1988 through 2013 was analyzed to understand the distribution of the large rainfall events with return frequencies above 1-year. Table 7-3 summarizes quantity of large rainfall events with return frequencies for the top 5 ranked hydrologic periods.

- All of the top 5 hydrologic periods have a 25-yr storm.
- Hydrologic period 1994-1996 (Rank 1) contains one 25-yr storm, one 10-yr storm and three 1-year storm. Hydrologic period 1988-1990 (Rank 2) contains one 25-yr storm, one 10-yr storm, three 2-year storm and one 1-year storm.
- Hydrologic period 1994-1996 (Rank 1) is more conservative because its annual average rainfall amount of 42.9” is slightly greater than the 30-yr average. It is considered a better option than hydrologic period 1988-1990 (Rank 2), which has a slightly less annual rainfall than the average.

Table 7-3: Rainfall Return Frequency Summary for the Top 5 Ranked Hydrologic Periods

Rank	Year	Quantity of Rainfall Events with Return Frequency above				
		25-yr	10-yr	5-yr	2-yr	1-yr
1	1994-1996	1	1			3
2	1988-1990	1	1		3	1
3	2005-2007	1	1		2	4
4	1989-1991	1			2	3
5	1992-1994	1	1			3

The analysis was also conducted with an IET of 12 hours, and the top five ranked hydrologic periods. The top four hydrologic periods based on the IET of 12 hours are the same as the analysis based on the IET of 6 hours, which include the 3-year period 1994 - 1996 remaining as Rank 1.

7.2.5 Selected Hydrologic Period

The 3-year period 1994-1996 (Rank 1) will be used as the typical hydrologic period for the CSO LTCPU. This period contains a wide range of storms and antecedent conditions. The hydrologic period of 1994-1996 is also evaluated for longer historical rainfall records up to 100 years. It is ranked No. 1 for the 50-years record and No. 2 for the 100-year records (Table 7-4).

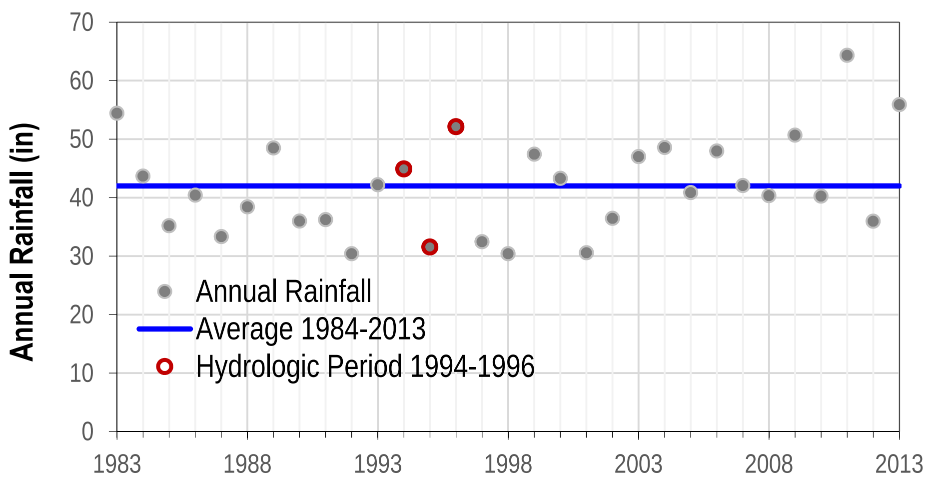
Table 7-4: Rank of Hydrologic Period 1994-1996 from Various Rainfall Data Set

	30-year Rainfall Records, 1984-2013	50-year Rainfall Records, 1964-2013	100-year Rainfall Records, 1914-2013
Rank of 1994-1996	1	1	2 (1925-1927 as Rank 1)

7.2.6 Additional Information on Statistical Analysis of Rainfall Data

Figure 7-3 shows annual rainfall and average annual rainfall for years 1983-2013. The hydrologic period 1994-1996 contains a relatively wet year (1996 with 52.1 inches), a dry year (1995 with 31.6 inches) and a year close to average conditions (1994 with 44.9 inches).

Figure 7-3: Annual Rainfall 1983 - 2013



Characteristics of the top 10 storms (by rainfall depth) in each year of the hydrologic period 1994-1996 are shown in Tables 7-5, 7-6 and 7-7.

Table 7-5: Ten Largest Storms and Return Frequencies in 1994

Top 10 Rainfall Event	Rainfall Start Date and Time	Rainfall Volume (in)	Rainfall Duration (hr)	Max Rainfall Intensity (in/hr)	Rainfall Return Period
1	7/18/1994 7:00	3.45	4	1.5	25-yr
2	7/14/1994 15:00	2.89	7	1.41	10-yr
3	3/9/1994 11:00	2.00	27	0.37	< 1 year
4	8/21/1994 19:00	1.76	18	0.49	< 1 year
5	3/28/1994 0:00	1.41	37	0.14	< 1 year
6	5/7/1994 15:00	1.37	15	0.25	< 1 year
7	3/2/1994 9:00	1.32	22	0.14	< 1 year
8	1/27/1994 19:00	1.15	20	0.2	< 1 year
9	7/27/1994 17:00	1.11	8	0.49	< 1 year
10	1/17/1994 10:00	1.07	18	0.18	< 1 year

Table 7-6: Ten Largest Storms and Return Frequencies in 1995

Top 10 Rainfall Event	Rainfall Start Date and Time	Rainfall Volume (in)	Rainfall Duration (hr)	Max Rainfall Intensity (in/hr)	Rainfall Return Period
1	10/4/1995 18:00	1.82	33	0.54	< 1 year
2	10/27/1995 20:00	1.81	13	0.5	< 1 year
3	9/16/1995 22:00	1.6	13	0.24	< 1 year
4	1/6/1995 18:00	1.43	11	0.27	< 1 year
5	1/20/1995 0:00	1.25	10	1	< 1 year
6	10/20/1995 21:00	1.21	16	0.52	< 1 year
7	3/8/1995 17:00	1.16	8	0.29	< 1 year
8	10/14/1995 7:00	1.12	21	0.25	< 1 year
9	2/3/1995 22:00	1.04	15	0.2	< 1 year
10	7/17/1995 22:00	1.00	4	0.48	< 1 year

Table 7-7: Ten Largest Storms and Return Frequencies in 1996

Top 10 Rainfall Event	Rainfall Start Date and Time	Rainfall Volume (in)	Rainfall Duration (hr)	Max Rainfall Intensity (in/hr)	Rainfall Return Period
1	12/13/1996 13:00	3.03	33	0.27	1-yr
2	8/12/1996 19:00	2.34	13	0.52	1-yr
3	9/16/1996 14:00	2.26	16	0.38	< 1 year
4	10/18/1996 16:00	2.22	19	0.54	1-yr
5	7/12/1996 15:00	2.11	22	0.4	< 1 year
6	12/1/1996 7:00	1.62	23	0.56	< 1 year
7	6/29/1996 22:00	1.61	17	0.26	< 1 year
8	11/25/1996 23:00	1.58	10	0.38	< 1 year
9	7/31/1996 20:00	1.48	4	1.03	< 1 year
10	10/8/1996 10:00	1.32	11	0.24	< 1 year

Section 8 Hydrologic and Hydraulic Modeling

This section describes the development and application of the Hydrologic and Hydraulic Model for DELCORA's combined sewer system. This model will aid in the identification and evaluation of a range of potential water pollution treatment/control alternatives for use as part of DELCORA's Combined Sewer Overflow Long-Term Control Plan Update (CSO LTCPU).

8.1 Background

Since 1997, DELCORA has conducted annual modeling of the CSS using the USEPA's Storm Water Management Model (SWMM) to estimate overflows to its receiving waters. SWMM is a dynamic rainfall-runoff simulation model that can simulate single-event or continuous runoff quantity and quality from primarily urban areas. The model simulates the time-varying process of rainfall onto land surfaces, the conversion of rainfall to infiltration, evaporation, or surface runoff, and the routing of mixed stormwater runoff and sanitary sewage through the collection system. This model is also referred to as DELCORA's Hydrologic and Hydraulic (H&H) model.

The original DELCORA H&H model was developed and calibrated for the 1999 LTCP, but it did not include the entirety of DELCORA's service areas. The original model included one (1) rain gage located at the WRTP, 67 subcatchment areas, 29 outfall nodes (CSO outfalls), 736 storage nodes (sewer manholes), 735 conduit links (sewer mains) and 34 orifice links (CSO regulators), but no pump stations and force mains were included.

The model was set up to simulate monthly CSO discharges with reasonable continuity error in EPASWMM 5.0. The model had been updated and expanded over the years to account for changes in the combined sewer system, but it had not been re-calibrated during the development of the 2012 revisions to the LTCP.

Monthly CSO overflow estimates using the model are reported to the PADEP as part of DELCORA's Annual Municipal Wasteload Management Report (Chapter 94 Report) and monthly with the PADEP electronic Discharge Monitoring Report (e-DMR). The H & H Model is also used as a scenario model to evaluate potential upgrades to the CSO system.

The original DELCORA H&H model was developed and calibrated for the 1999 LTCP. The model was updated and expanded over the years to account for changes in the CSO system, but it was not re-calibrated during the development of the 2012 LTCP (Weston, 2012). Section V.A.14 of the 2015 Consent Decree requires DELCORA to update and calibrate the H&H Model to include hydrologic representations of all areas tributary to the Model Area. The project team reviewed the 2012 model in order to:

- Assess adequacy of the original model for use in DELCORA's LTCPU.
- Identify gaps with the original model in meeting the requirements in the Consent Decree.
- Identify updates required to reflect current hydrologic and hydraulic conditions of DELCORA's collection system.
- Determine refinements needed for the model update.

Results from the review of the 2012 H&H Model were presented in the *Hydrologic and Hydraulic Model Update and Calibration Plan* (Greeley and Hansen, 2015). DELCORA completed the expansion and revisions to the H&H model in the summer of 2017, and it now includes all of Model Area and more accurately reflects the current collection system conditions. .

The revised H&H model uses Gauge Adjusted Radar Rainfall (GARR) data to estimate the frequency and volume of CSO overflows and to evaluate long-term strategies for minimizing CSO overflows. Precipitation breaks of at least 12 hours are used to establish separate storm events.

8.2 H & H Modeling Capabilities

The H & H Model simulates runoff from the CSO service areas into the sewers and then routes the flow through the major trunk sewers, CSO regulator structures, and the interceptors to the Western Regional Treatment Plant. A number of hydraulic modeling software packages are available, including EPA SWMM5, InfoSWMM, InfoWorks, Mike Urban and PCSWMM. For this H&H Model update, EPA SWMM, Version 5.0, Build 5.0.022 and Innovyze InfoSWMM Version 14.5 Update 4 were selected as the modeling software. EPA SWMM5 is a fully dynamic model and has been used extensively throughout the United States and abroad to assess CSO, flooding and water quality issues. It can be applied to simulate single events or long periods of time in a continuous mode. It can estimate runoff flow from several subcatchment basins and route the flow through the sewer system to treatment facilities or to the receiving waters. InfoSWMM uses the current EPA SWMM 5 engine as its computational solution and is fully integrated with ArcGIS which provides greater flexibility of importing model network from existing GIS database and preparing initial model inputs from existing datasheets. InfoSWMM was used during the model development and the calibration phase.

8.2.1 Combined Sewer System Model

The InfoSWMM model has the following capabilities for modeling DELCORA’s combined sewer system:

- A user-friendly, ArcGIS integrated graphical interface for cost-effective use and updating.
- A physical based model with model formulations explicitly linked to actual conditions in the field as input by the user.
- Simulates the hydraulic conditions of the modeled trunk sewers, interceptors, gravity sewers, force mains, pump stations, and treatment plant during dry and wet weather.
- Evaluates CSO control alternatives and interceptor capacities.
- Can be periodically updated to reflect the implementation of the CSO control plan and increased development within the service areas.
- Estimates of Run-off from combined sewer areas.
- Estimates wet weather flows from separate sewered areas (rainfall derived inflow and infiltration (RDII)).
- Real-Time Control operations.
- Technical and regulatory credibility (developed from U.S. EPA SWMM software).

8.3 Data Collected

The data requirements needed for the sewer system model include

- Physical characteristics of the sewer system, which are used to configure the model specifically for DELCORA's collection system. (The physical characteristics of the sewer system are described in Section 3 of this report)
- Land use data, which influences the amount of runoff delivered to the sewer system. (See information presented in Section 3 of this report)
- Rainfall data, which are used as inputs to the model. (The collection of rainfall data is for validation and calibration is described in Section 4 of this report. Rainfall data for use as the typical hydrologic period is described in Section 7 of this Report)
- Flow monitoring data, which are used to calibrate and validate the collection system model output. (The collection of flow monitoring data is described in Section 4 of this report)

The model update is based on information obtained from a variety of sources including DELCORA's input, GIS, record drawings and field survey. Other documents pertaining to standard/actual operating procedures for CSO regulators, pump stations and the WRTP were also used to set up real time controls in the model. The model network consists of all major interceptors and force mains and extends to all active overflow points. The datum for the model is NGVD 29.

8.4 H & H Model Development

The development of a sewer system model is complicated and includes many components. The following paragraphs describe how the data described in the previous section are used in the model development.

8.4.1 H & H Model Inputs

Inputs to the Model include rainfall data and the hydrologic watershed parameters. The watershed parameters pertains to the combined sewer service areas only and were as follows:

- Subcatchment areas
- Percent imperviousness (pavement, rooftops, and structures impervious to rainfall infiltration)
- Subcatchment widths
- Overland slope within the subcatchments
- Depression storage within the subcatchments
- Manning's roughness coefficient for overland flow
- Soil infiltration of rainfall in pervious areas
- Base flow

The rainfall data and watershed parameters are described in the following subsections.

8.4.2 Rainfall Data

Rainfall data within the model represent the average precipitation that falls on an area within a defined time interval. Rainfall data was entered in the model as total rainfall or rainfall intensity occurring within a time interval. The rainfall time interval can be as short as a minute or as long as an hour. Generally, the model results satisfactorily match observed flow monitor data when the rainfall input time interval is at a minimum of 15 minutes. Actual rainfall data recorded at 5-minute frequency were entered into the model for model calibration.

8.4.3 Subcatchment Areas

Subcatchment areas are the discrete surface areas that contribute runoff and overland flow to the combined sewers. Delineation of subcatchments was described in Section 3 of this Report. The model represents a subcatchment as a polygon area with the overland slope perpendicular to the subcatchment width. The point where the runoff enters the sewer is called the point of concentration (receiving node). The major trunk sewers from each CSO service area along with all interceptor sewers and CSO regulators were incorporated into the model.

8.4.4 Percent Imperviousness

The initial percent imperviousness for the combined area was calculated as described in Section 3 of this Report. Then, the impervious percentage values were adjusted during the model calibration process to best simulate the observed hydrologic response over the selection of precipitation events. All open areas not tributary to the sewer system were measured from the aerial photographs and subtracted from the subcatchment areas. The open areas are considered non-point sources, which drain directly to the receiving waters.

8.4.5 Subcatchment Widths

Subcatchment width affects the shape of the runoff hydrograph and is generally an H&H model calibration parameter. Higher peak flow rates and more immediate response to a storm event are simulated when the subcatchment width is increased for the same subcatchment. The initial inputs for the subcatchment width were determined by dividing the total area of the subcatchment by the representative overland flow length in the subcatchment. These initial inputs were adjusted based on model calibration comparisons to data.

8.4.6 Overland Slope

Overland slope is a measure of the steepness of the land in the subcatchments. It is a model input and affects the travel time of overland flow, peak runoff rate, and runoff volume. Steeper slope decreases the travel time, increases the peak runoff rate and increases the runoff volume. The slope of a subcatchment should reflect the average slope along the pathway of overland flow to inlet locations. For the combined sewer subcatchments, slopes from the 2012 H&H model were retained for use in the updated model.

8.4.7 Depression Storage

Some rainfall on the pervious and impervious areas is held in small depressions rather than becoming part of the overland flow. It is defined as the amount of incidental surface depressions that must be filled before runoff typically begins. Initial values for depression storage were described in Section 3 of this Report. For all practical purposes, depression storage is difficult to measure and is typically adjusted during the calibration process.

8.4.8 Manning's “n” Roughness Coefficient

Overland flow travels slower or faster depending on the roughness of the surface in the subcatchment. The higher the roughness coefficient, the greater the friction and the slower the flow travels. Again, this is a model parameter that cannot be practically measured. A typical range of Manning’s “n” suggested by the SWMM is 0.011-0.024 for impervious area and 0.06-0.80 for pervious area. The initial values were set to 0.013 for impervious surfaces and 0.15 for pervious surfaces. Roughness is an empirical value and may be treated as a calibration parameter if necessary.

8.4.9 Separate Sewer Areas

The DWF for each separate sewer service area was determined as described in Section 4 and input into the model at the appropriate combined sewer node. To estimate the wet weather impacts on the separate sewer service areas, the flow monitoring data collected during the monitoring program was evaluated.

8.4.9.1 Rainfall Derived Infiltration and Inflow (RDII)

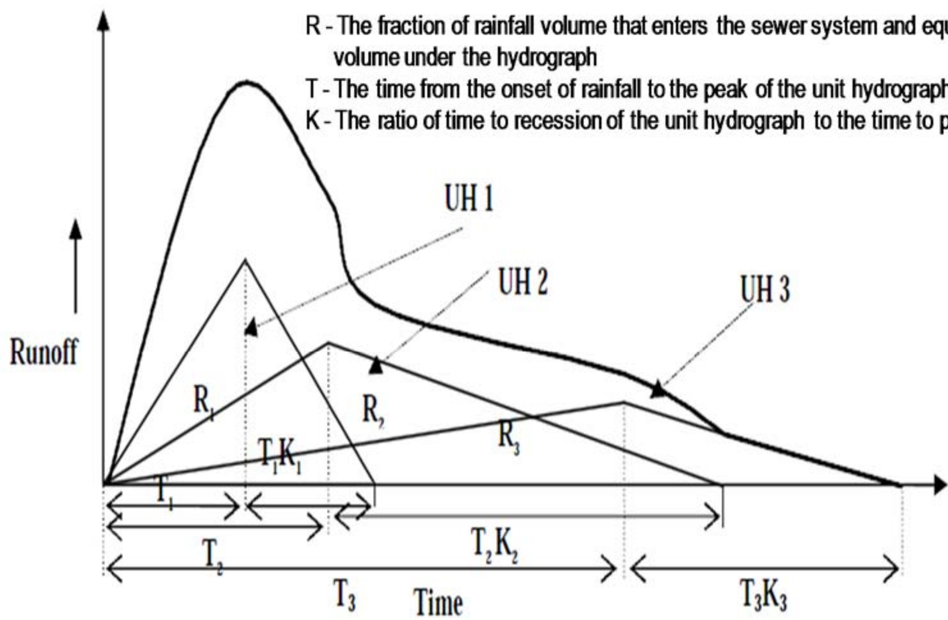
The model uses the RTK unit hydrograph (UH) to estimate RDII into the separated area sewer systems. As shown in Figure 8-1 (Muleta & Boulos, 2008), a RTK UH set contains up to three hydrographs: one for a short-term response (UH1), one for an intermediate-term response (UH2), and one for a long-term response (UH3). UH1 represents the most rapidly responding inflow component and has a short T value, UH2 includes both inflow and infiltration and has a longer T value, and UH3 includes infiltration that may continue long after the storm event has ended and has the longest T value. The unit hydrograph is defined by the following three parameters:

- R: the fraction of rainfall volume that enters the sewer system and equals to the volume under the hydrograph,
- T: the time from the onset of rainfall event to the peak of the unit hydrograph in hours, and
- K: the ratio of time to recession of the unit hydrograph to the time to peak.

The same set of RDII parameters were applied in the same metershed because of the availability of the flow hydrograph for model calibration. The initial values of RTK were estimated using the RDII Analyst tool in the InfoSWMM. The RTK values are calibration parameters to be refined during model calibration.

Rainfall and sewershed area information was needed for RDII calibration. Subcatchment areas were estimated as described in Section 3. Rainfall and flow data from the monitoring program (see Section 4) were used for the calibration.

Figure 8-1: RTK Unit Hydrographs



Source: M.K. Muleta and P.F. Boulos, Analysis and Calibration of RDII and Design of Sewer Collection Systems, ASCE Conference Proceedings 316, 642 (2008)

8.4.10 Soil Infiltration

Infiltration parameters modestly influence the runoff hydrograph from the combined sewer system subcatchments by reflecting rainfall absorption into the soil. The H&H model uses the Horton method with infiltration parameters determined based on evaluation of soil types as described in Section 3.

8.4.11 Sewer Mains

Sewer mains are the conveyance element and were simulated as conduits in the model. The following input information was entered into the H&H model:

- Conduit ID
- Shape
- Number of barrels
- Upstream and downstream nodes
- Upstream and downstream offset
- Dimension (length, diameter/depth)
- Manning's roughness coefficient
- Minor loss coefficient (entry loss, exit loss, average loss)
- Flap gate installed or not (set at no flap gate for most of the sewer mains)

Most of the pipe input parameters, including upstream and downstream nodes, dimension, shape, number of barrels, and flap gate information, were found or estimated from record drawings, design drawings and sewer gravity main GIS shapefiles. For pipes that do not begin or end at the invert of the upstream or downstream node, an offset value was provided to describe the difference from the invert of the pipe to the invert of the upstream or downstream node.

Manning's roughness coefficient is related to the pipe material. The initial input of the Manning's n for different materials is summarized in Table 8-1.   The Manning's n may be changed during calibration to account for minor loss or additional sediment depositions in the pipe.

The initial minor loss for pipe will be set at zero for most pipes. For those pipes with sharp turns, a higher minor loss was applied.

Table 8-1: Manning's Roughness Coefficient for Sewer Mains

Pipe Material	Manning's N
Polyvinyl Chloride (PVC)	0.011
Reinforced Concrete Pipe (RCP)	0.013
Ductile Iron (DI)	0.013
Cast Iron (CI)	0.013
Corrugated Metal Pipe (CMP)	0.020
Masonry	0.025
Unknown	0.013

8.4.12 Manholes

Sewer manholes were simulated as junction nodes in the model. The following information was entered into the H&H model:

- Node ID
- Invert
- Maximum Depth (approximated as the difference from manhole rim and manhole invert)
- Surcharge Depth

8.4.13 CSO Outfalls

CSO outfalls will be simulated as outfall nodes in the model. The following information was entered into the model:

- Outfall ID
- Type (free, normal, fixed stage, tidal stage, time series, stage-flow, flap gate)
- Invert
- Boundary conditions

Outfall characteristics were described in Section 3.

8.4.14 Flow Diversion Structure

As described in Section 3, most of the flow diversion structures are similar to Brown and Brown type regulators. The key components required for modeling these structures were described in Section 3.

Regulator Gates

Regulator gates will be simulated as orifices in the updated model. The following information was entered into the model:

- Regulator Gate ID
- Upstream and downstream nodes
- Type
- Shape (two shapes: circle, rectangular)
- Dimension (Height, Width)
- Discharge Coefficient

Characteristics of the regulator gates were described in Section 3. All regulator gates are modeled as rectangular except for REG_004_Gate which is modeled as a circular orifice. The updated model includes real time control rules for opening and closing of the gates based on levels in the float chamber and regulator limit settings

Orifices

Characteristics of the orifice plates are described in Section 3. The following information was entered into the model:

- Orifice ID
- Upstream and downstream nodes
- Type (two types: side, bottom)
- Shape (two shapes: circle, rectangular)
- Dimension (Height, Width, Crest Height)
- Discharge Coefficient

8.4.15 Weirs

Diversion weirs will be simulated as weirs in the model. Characteristics of the weirs are described in Section 3. The following information was entered into the model:

- Weir ID
- Upstream and downstream nodes
- Type (four potential weir types: transverse, sideflow, V-notch, trapezoidal)
- Dimension (Height, Weir Length, Weir Crest Height)
- Coefficient of Discharge
- Number of End Contractions

8.5 Summary

The 2012 H&H model was updated as described above. A summary of the key revisions is presented in Table 8-2. The detailed layout of the updated model is shown in Figure 8-2 and Figure 8-3.

Table 8-2: Summary of Revised H&H Model

Review Item	2012 Model Review Observation	Comments	Updated Model
Model Software	- EPA SWMM 5.0		Innovyze InfoSWMM version 14.5
Vertical Datum	- NAVD 88	- To be verified	- NGVD29
General Sub Models	- EPASWMM for the runoff model - Horton Equation for the infiltration model - Hydrodynamic wave for the flow routing model	- All these choices are commonly seen in collection system modeling practices	
Rain Gauge	- One (1) rain gage, located at the Western Regional Treatment Plant (WRTP)	- One rain gauge is not sufficient for the entire service area in the model	- Seven (7) rain gauges, as shown in Section 2 - Additional GARR analysis performed
Service Area	- 67 subcatchments, all for combined area - One set of Horton infiltration parameters are applied to most of the subcatchments (66 out of 67 subcatchments) - The infiltration parameters applied in the model is equivalent to infiltration parameters for soil type C/D	- All service area including separated area that contribute flow to the DELCORA collection system should be included in the model - Combined area delineation will be checked to include any changes along the years - Soil type need to be checked to verify Horton infiltration parameters in all subcatchments	- 114 subcatchments, 53 for combined area and 61 for separated areas - Combined area was modified to include newly separated areas. - Horton infiltration parameters applied to 56 out of 114 subcatchments - Horton infiltration parameters varied based on identified soil types -

Review Item	2012 Model Review Observation	Comments	Updated Model
Sewer Manhole	- 736 storage nodes. - All sewer manholes are simulated as storage units in the model. - The majority of the storage units (732 out of the 736) have a diameter of 4-ft, and the rest (4 units) have a surface area of 100 square feet (sf.) (equivalent to 10'x10'). - All storage units are set-up with a ponding area of 9,999 sf. to allow excess water to collect atop of the nodes and be re-introduced into the system as conditions permit.	- Sewer manholes will be simulated as common junction node - This will help with SSO evaluation in the collection system	- 860 common junction nodes. - The majority of the common junction nodes (836 out of the 860) have a diameter of 4-ft, and the rest (4 units) have a surface area of 100 square feet (sf.) (equivalent to 10'x10'). - There are 35 imaginary junctions created to receive flow from the subcatchments gravity network not included in the model network
CSO Outfall	- 29 outfall nodes - All CSO outfalls are free outfall	- All outfalls are located in the Delaware River in the tidal reach, a tidal stage instead of free outfall should be assigned to the outfalls - Outfall ID 101 has dry weather input of 1.76 cfs, it represents WRTP in the model	- 24 CSO outfall nodes - Tidal data is assigned to 24 outfalls using time series - Wherever tide gates are installed, a real time control is applied

Review Item	2012 Model Review Observation	Comments	Updated Model
Sewer Mains	- 735 conduit links. - Negative slopes at Nodes 73803 and 70709 not matching the GIS. - Pipe connectivity is not consistent with the GIS in Subcatchment EA1, 25A. - Pipe size and connectivity is not consistent with the GIS around Node: 5201242, 5201234. - Pipe size is not consistent with the GIS around Node: 52018-52015. - Pipe size is not consistent with the GIS around Node: 531-527, 522-517, 516-513, 510020301-5100202, 403-NCPS, 40801-40801A, 32405-32404, and 1110402-11103. - Pipe size and slope are not consistent with the GIS around Node: 422-4140. - NREG06 outfall pipe direction is opposite.	- All the negative slopes and inconsistencies need to be checked with the most updated GIS and record drawings during the model update	- 817 conduit links. - 45 imaginary conduit links created to receive flows from subcatchment gravity network not included in the model

Review Item	2012 Model Review Observation	Comments	Updated Model
CSO Regulators	- 34 orifice links. - All CSO regulators are simulated using orifices to intercept dry weather flows and partial wet weather flows to the collection system, and with elevated conduits to convey extra flows to the CSO outfalls. - Approximately 75% of the orifices (25 out of 34) are modeled with Real Time Control (RTC) to mimic regulator gate opening based on level. - None of the regulator diverting weir structures is simulated in the model.	- Diverting weir structures need to be added in the model - The slopes of all overflow pipes connected to the CSO outfalls need to verified - All orifice opening dimensions verified will be verified - All the RTC rules regulating orifice opening will be verified with actual operation	- 44 orifice links. - CSO regulators are simulated using orifices and float-operated gates to intercept dry weather flows and partial wet weather flows to the collection system, and with conduits set a verified inverts to convey extra flows to the CSO outfalls. Exceptions occur at several regulators where orifices have been removed and at one regulator where the float and gate have been removed. - Approximately 57% of the orifices (25 out of 45) are modeled with Real Time Control (RTC) to mimic regulator gate opening based on level. - Regulator diverting weir structures added to the model. - All regulator characteristics were verified using record drawings excepting Regulator 17 which was field verified.
Pump Station	- No pump station is included in the model	- All pump stations that contribute flow to the DELCORA collection system should be added to the model, with related force mains	- Pump stations added to model. - Related force mains added to model

Review Item	2012 Model Review Observation	Comments	Updated Model
Dry Weather Flow	- 94 dry weather flow (DWF) inputs - Total DWF is 7.01 MGD - No diurnal curve - DWF does not include all the separated service areas that contribute to the DELCORA system -	- DWF should be updated to include all the service areas that contribute to the DELCORA system - Weekday and weekend diurnal curve should be included in the model to effectively simulate dry weather diurnal pattern	- 114 dry weather flow (DWF) inputs - Total DWF is 29.57 MGD - DWF analysis was performed on all flow meters in separated and combined areas as well as pump stations - Weekday and weekend diurnal curves were generated as well as overall, weekday, weekend and monthly DWF factors.
RDII	- No rainfall-derived infiltration/inflow (RDII) element was found in the model	- RDII should be included in the model to estimate reasonable wet weather inflow from RDII	- RDII was included in the model to estimate reasonable wet weather inflow from RDII

8.6 H & H Model Calibration

Model credibility is developed through model calibration and validation. Model calibration involves application of the model to known external inputs (e.g., rainfall), evaluation of the model's ability to replicate monitored conditions (e.g., flow and volume), and adjustment of key model parameters as needed until an acceptable level of agreement is reached between simulated and monitored conditions.

The collection system H&H Model was calibrated in conjunction with the flow monitoring and sampling program. The H & H Model was calibrated by running the model with rainfall data collected from selected storms and then comparing the calculated results to the actual flow monitoring data collected. The model parameters were adjusted and the process repeated until the calculated results approximated the actual flow monitor measurements. Goals for the model calibration included:

- To match visually the shape of the curve between model and flow monitor.
- To match model runoff volumes (volume under curve) to actual runoff volumes.
- To match model runoff peak flow rates to actual runoff peak flow rates.

Once the model was calibrated to the selected storms, at least one additional storm was run through the model to validate that the model was sufficiently calibrated.

Figure 8-2: Updated H&H Model Layout

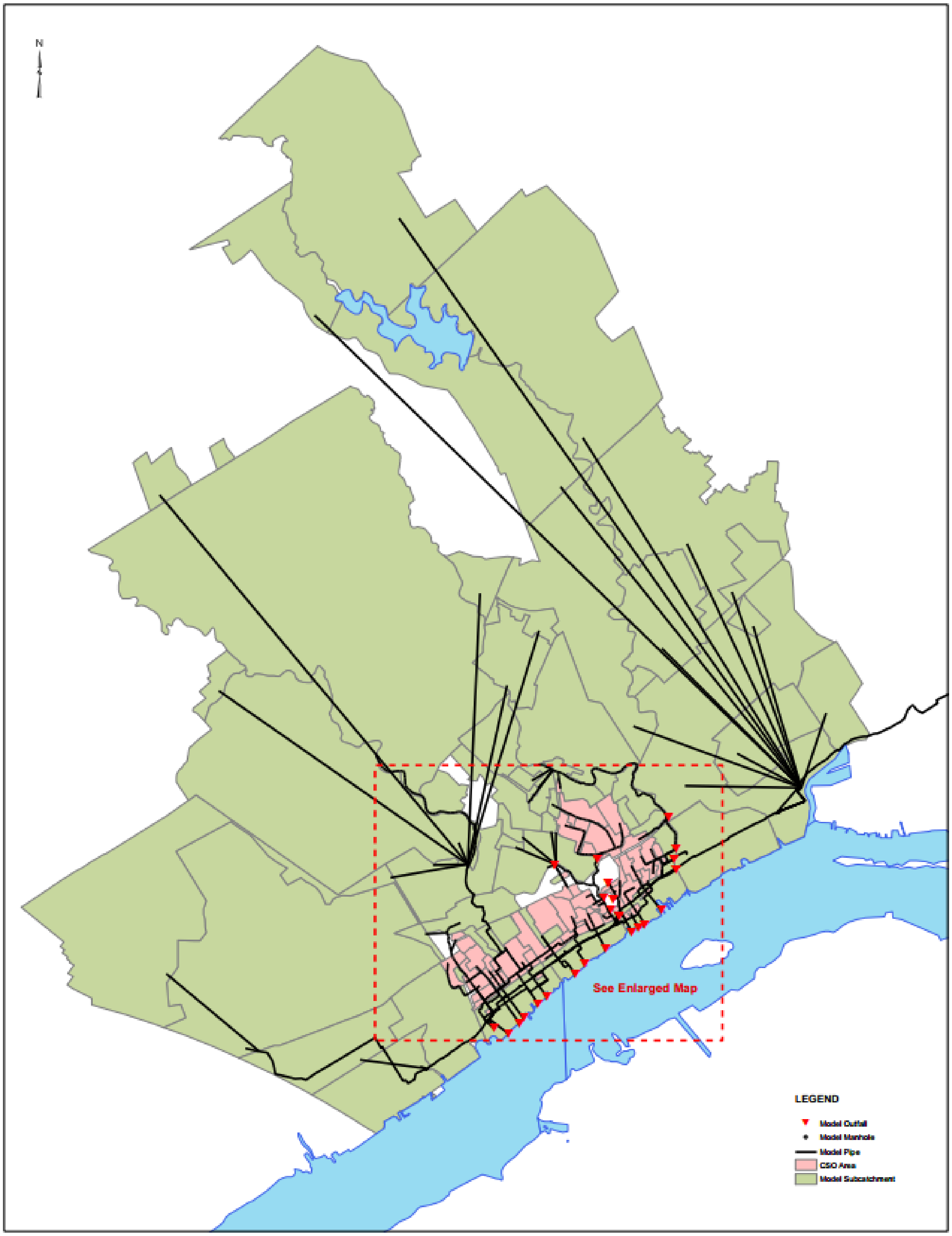
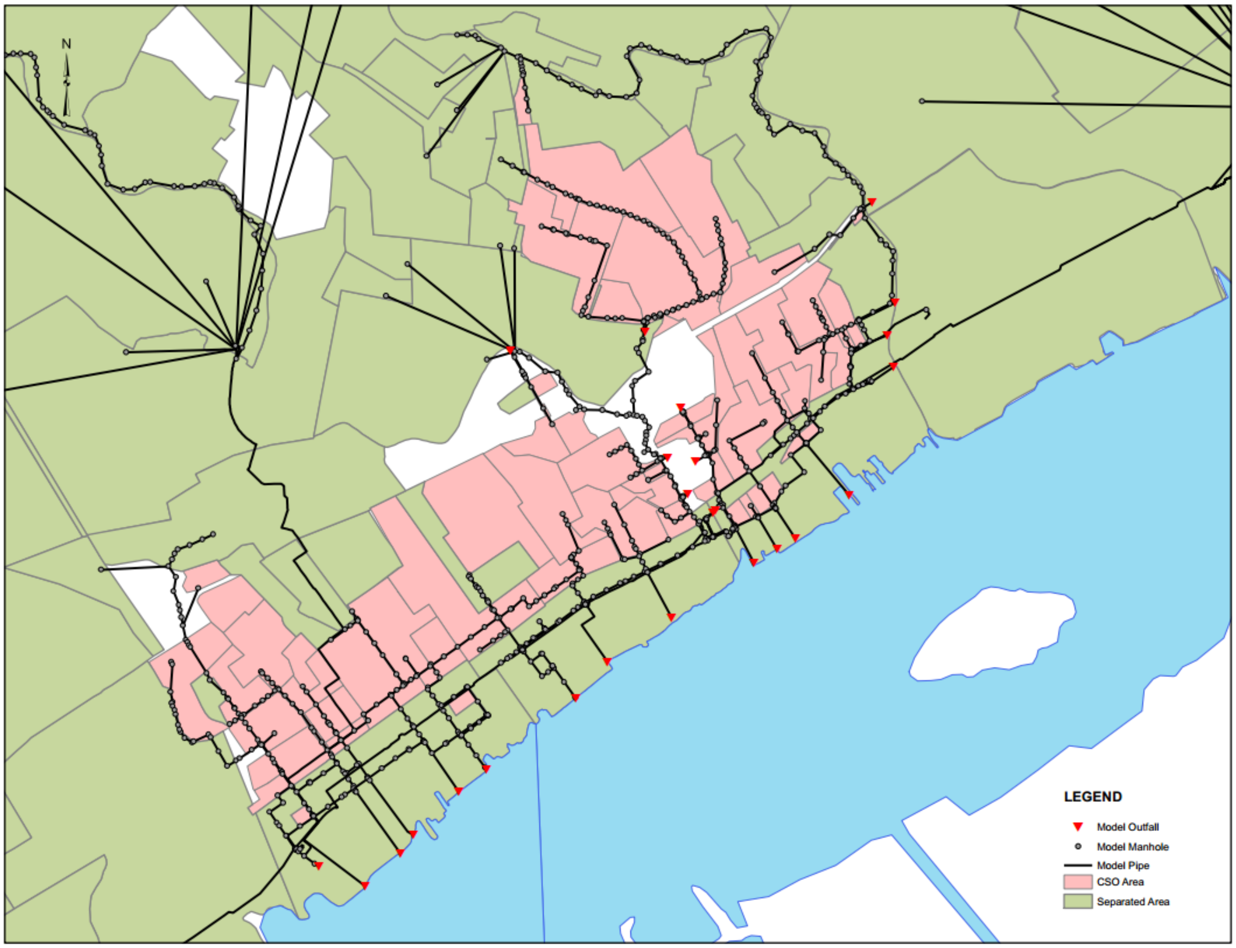


Figure 8-3: Updated H&H Model Layout – CSS Area



8.6.1 Dry Weather Flow Calibration

Dry weather flow (DWF) analysis was based on the rainfall and flow monitoring results. DWF distribution in the collection system was based on land use data. Weekday, weekend and monthly diurnal factors from the DWF analysis were applied for each flow meter service area. Upstream meters in the system were calibrated first, then flows through the system to the pumps stations and to the WRTP were balanced. Figure 4-4 shows the arrangement of the meters in the system and meter identification.

DWF calibration will adhere to industry standards and the criteria below:

- The simulated hydrograph should match the general observed hydrograph shape,
- The simulated time of peaks and troughs will be within 1 hour of the observed,
- The simulated peak flow will be within 10% of the observed flow, and
- The simulated flow volume over 24 hours will be within 10% of observed flow.

The dry weather calibration shows that model and the flow monitors are not all within the goal of ten percent. There are a number of reasons for the differences. The accuracy of flow monitors in large pipes is reduced as the flows get smaller. The dry weather flows are very small, especially in comparison to the wet weather flows. Dry weather flow also has a diurnal curve. The model does not replicate the dry weather flow diurnal curve, but takes the average of the diurnal curve and uses that as a constant dry weather flow. This could cause some discrepancy between the model and metered flows.

After the dry weather calibration was considered to be satisfactory, the model was calibrated for wet weather periods as described below.

8.6.2 Wet Weather Calibration

Wet weather flow (WWF) includes surface runoff from the combined area, RDII from the entire service area, and connected rooftops, if any, from the separated area. RDII parameters will be developed based on the separated area, and surface runoff parameters will be adjusted for the combined area to calibrate the system response to the wet weather conditions.

Four (4) wet weather events were selected for wet weather calibration. Final selections include wet weather events with various rainfall intensities and volume. Larger storm events will have more weighting factor in the calibration process because the large events are the ones that dominate the total overflow volume.

WWF calibration will adhere to industry standards and the criteria below:

- The simulated hydrograph should match the general observed hydrograph shape,
- The simulated time of peaks and troughs will be similar having regard to the duration of the event,
- The simulated peak flow for significant peaks will be within the range of -10% to +10%,
- The simulated flow volume will be within the range of -10% to +10%,

The four storms were selected for calibration of the collection system model met all the desired storm characteristics as describe in Section 4 of this Report. The May 29, 2016 storm was a 1.82-inch storm with a duration of approximately 11 hours and a maximum intensity of 0.78 in/hr. The September 28, 2016 storm was a 2.36-inch storm with a duration of 47 hours and a maximum intensity of 0.37 inches/hour. The November 29, 2016 storm was a 1.08 inch storm with a duration of 14 hours and a maximum intensity of 0.21 in/hr. The July 28, 2016 rain event was a 1.26-inch storm with a duration on 19 hours and a maximum intensity of 0.74 in/hr. Data on these storms is in shown in Table 8-3.

Table 8-3: Wet Weather Events for Model Calibration and Validation

Event ID	Start Time	Stop Time	Rainfall Duration (hr)	Rainfall Depth* (inches)	Max. Intensity (in/hr)	Used in Calibration	Used in Validation
E1	5/29/16 19:00	5/30/16 5:00	11.00	1.82	0.78	C	
E2	9/28/16 12:00	9/30/16 10:00	47.00	2.36	0.37	C	
E3	11/29/16 7:00	11/29/16 20:00	14.00	1.08	0.21	C	
E4	3/30/17 21:00	4/1/17 3:00	31.00	1.83	0.25		V
E5	5/21/16 11:00	5/22/16 21:00	35.00	1.71	0.33		V
E6	7/28/16 15:00	7/29/16 9:00	19.00	1.26	0.74	C	
*At Chester PS rain gauge							

The figures in Appendix B show the observed and simulated flow for the model calibration. Also included in Appendix B are plots of modeled versus monitored (i.e., observed) volumes and peak flows. A well calibrated model will result in plotted values that are close to a one-to-one relationship. These one-to-one plots can be found in Appendix B.

8.7 H & H Model Validation

According to USEPA's Guidance on Monitoring and Modeling (1999), "validation is the process of testing the calibrated model using one or more independent data set(s) of rainfall data." DELCORA's sewer system model was validated with rainfall from two rain events (May 21, 2016 and March 30, 2017). The May 21, 2016 rain event was a 1.71-inch storm with a duration of 35 hours and a maximum intensity of 0.33 in/hr. The March 30, 2017 storm was a 1.83 inch storm with a duration of 31 hours and a maximum intensity of 0.25 in/hr. The rainfall data for these storms is shown on Table 8-3 above. These storms were chosen for their size, intensity and because there were no rain events for five days before the storm. The figures in Appendix B show the observed and simulated flows for the model validation.

Also included in Appendix B are plots of modeled versus monitored (i.e., observed) volumes and peak flows. A well-calibrated model will result in plotted values that are close to a one to one relationship. These one-to-one plots can be found in Appendix B.

8.8 H & H Model Results

Following calibration, the typical hydrologic period (1994 to 1996) was used as the rainfall input to the H&H model. The hourly rainfall for the period 1994 to 1996 had been previously determined to be representative of annual average conditions with respect to rainfall amount (volume), number of rainfall events per year, rainfall duration, and rainfall intensity and has been discussed in Section 7.

A summary of estimated volume, frequency and duration of CSO discharge events based from the calibrated H&H model using the typical hydrologic period is presented in Appendix C. The total annual average CSO overflow volume was approximately 300 MG for the typical hydrologic period. The dry weather flows and their monthly factors in the calibration model are based on the flow monitoring period (March 2016 through March 2017). For future model application, the dry weather flows should be based on future flow projections and the monthly factors should be adjusted accordingly.

Section 9 References

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Greeley and Hansen. (2016a). *Typical Hydrologic Period Report.* Report prepared for Delaware County Regional Water Quality Control Authority (DELCORA). This report was approved by USEPA and PADEP on May 23, 2016. See approval letters in this section.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

MAR 01 2016

Mr. Robert Willert, Executive Director
Delaware County Regional Quality Control Authority
100 East Fifth Street
Chester, PA 19013

RE: Civil Action 2:15-cv-04652-RB

Dear Mr. Willert:

The United States Environmental Protection Agency (EPA) has received the Delaware County Regional Quality Control Authority (DELCORA) Hydrologic and Hydraulic Model Update and Calibration Plan. EPA has consulted with the Pennsylvania Department of the Environment (PaDEP).

EPA hereby approves the plan with the understanding that the term "two days" as stated in paragraph 5.1.2.1 (Dry Weather Overflow Analysis) shall mean 48 hours.

Thank you for your continued cooperation with this matter. Please do not hesitate to contact me at (215)814-2097 if you have any questions.

Sincerely,

Andrew F. Seligman, Environmental Scientist
Water Enforcement Branch

cc: R. Smolski, EPA
P. Yeany, EPA
M. DeSantis, DELCORA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

MAY 23 2016

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Mr. Michael J. DiSantis, Director
Operations & Maintenance
Delaware County Regional Quality Control Authority
100 East Fifth Street
Chester, PA 19013

RE: Civil Action 2:15-cv-04652-RB

Dear Mr. Disantis:

The United States Environmental Protection Agency (EPA) has received the Delaware County Regional Quality Control Authority (DELCORA) Typical Hydrologic Period Report (Updated April 2016). EPA has consulted with the Pennsylvania Department of the Environment (PaDEP). EPA hereby approves the subject plan.

Thank you for your continued cooperation with this matter. Please do not hesitate to contact me at (215) 814-2097 if you have any questions.

Sincerely,

Andrew F. Seligman, Environmental Scientist
Water Enforcement Branch

cc: R. Smolski, EPA
P. Yeany, EPA
M. DiSantis, DELCORA
S. O'Neil, PaDEP SERO
J. Fields, PaDEP SERO

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Consent Order

OCT 2 5 2016
2016-1211

cc: 2 tcp group

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

OCT 1 3 2016

Mr. Robert Willert, Executive Director
Delaware County Regional Quality Control Authority
100 East Fifth Street
Chester, PA 19013

RE: Civil Action 2:15-cv-04652-RB

Dear Mr. Willert:

The United States Environmental Protection Agency (EPA) has received the Delaware County Regional Quality Control Authority (DELCORA) Alternatives Evaluation Approach Report (AEAR) dated April 27, 2016. EPA understands DELCORA has chosen the "Demonstration Approach" and hereby approves the AEAR.

Sincerely,

Andrew F. Seligman, Environmental Scientist
Water Enforcement Branch

cc: R. Smolski, EPA
P. Yeany, EPA
M. DeSantis, DELCORA

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

Mr. Robert Willert, Executive Director
Delaware County Regional Quality Control Authority
100 East Fifth Street
Chester, PA 19013

OCT 13 2016

RE: Civil Action 2:15-cv-04652-RB

Dear Mr. Willert:

The United States Environmental Protection Agency (EPA) has received the Delaware County Regional Quality Control Authority (DELCORA) Revised Identification of Sensitive Area Analysis (RISAA) dated May 13, 2016. EPA has consulted with the Pennsylvania Department of the Environment (PaDEP). EPA hereby approves the RISAA.

Sincerely,

Andrew F. Seligman, Environmental Scientist
Water Enforcement Branch

cc: R. Smolski, EPA
P. Yeany, EPA
M. DeSantis, DELCORA

DELAWARE COUNTY REGIONAL WATER QUALITY CONTROL AUTHORITY
P.O. Box 999 • Chester, PA 19016-0999

DELCORA

June 30, 2017

FED EX – NEXT DAY

Chief, Environmental Enforcement Section
Environment and Natural Resources Division
U.S. Department of Justice
601 D Street NW
Washington, DC 20004
Re: DOJ No. 90-5-1-1-10972

Philip Yeany
Office of Regional Counsel (3RC20)
U.S. EPA, Region 3
1650 Arch Street
Philadelphia, PA 19103-2029

Chief
NPDES Enforcement Branch (3WP42)
Water Protection Division
U.S. EPA, Region 3
1650 Arch Street
Philadelphia, PA 19103-2029

Program Manager – Clean Water Program
PA DEP
Southeast Regional Office
2 East Main Street
Norristown, PA 19401

RE: Civil Action Number Case 2:15-cv-04652-RB
& DOJ Case Number 90-5-1-1-10972
Sewer System Hydrologic and Hydraulic Model Report

Dear Sir/Madam:

By this letter, the Delaware County Regional Water Quality Control Authority is enclosing a copy of the above mentioned report in accordance with the requirements of the Consent Decree.

If there are any questions, please contact me. Thank you.

Sincerely,

Michael J. DiSantis
Director of Operations & Maintenance

MJD:bab
enclosure

ADMINISTRATION
☐610-876-5523
☐FAX: 610-876-2728

CUSTOMER SERVICE/BILLING
☐610-876-5526
☐FAX: 610-876-1460

PURCHASING & STORES
☐610-876-5523
☐FAX: 610-497-7959

PLANT & MAINTENANCE
☐610-876-5523
☐FAX: 610-497-7950

X:\Consent Decree 2015\Phase 1 - FCA\9 - Task 5 - Hydrologic-Hydraulic Model\DOJ-EPA-PADEP-Hydrologic & Hydraulic Model Report - 6-30-2017.doc

cc: via email
Margaret Hill, Blank Rome
Marlene Finizio, Greeley and Hansen
Michael Hope, Greeley and Hansen
Ed Bothwell, DELCORA
Michael DiSantis, DELCORA
John Pileggi, DELCORA
Robert Willert, DELCORA
Charles Hurst, DELCORA
File – Consent Order – LTCP CSO

Section 10 Abbreviations

BGEPA:	Bald and Golden Eagle Protection Act
CDCA:	Central Delaware County Authority
CDPS:	Central Delaware Pump Station
CPS:	Chester Pump Station
CRPS:	Chester Ridley Pump Station
CSO:	Combined Sewer Overflow
CSS:	Combined Sewer System
CWA:	Clean Water Act
DCJA:	Darby Creek Joint Authority
DELCORA:	Delaware County Municipal Utilities Authority
DEP:	Pennsylvania Department of Environmental Protection
DRBC:	Delaware River Basin Commission
e-DMR:	electronic Discharge Monitoring Report
EDPS:	Eddystone Pump Station
EPS:	Existing Pump Station
ESI:	Environmental Sensitivity Index
GIS:	Geographic Information System
H&H:	Hydrologic and Hydraulic
KCPS:	Kimberly Clark Pump Station
LTCP:	Long Term Control Plan
LTCPU:	Long-Term Control Plan Update
MBTA:	Migratory Bird Treaty Act
MDL:	Method Detection Limit
MF:	Migratory Fishes
MGD:	Million Gallons per Day
MHPS:	Marcus Hook Pump Station
NCPS:	Naamans Creek Pump Station
NPDES	National Pollutant Discharge Elimination System
NRCS:	Natural Resources Conservation Service
NTU:	Nephelometric Turbidity Units
PA Integrated Report:	PA Integrated Water Quality Monitoring and Assessment Report
PADEP:	Pennsylvania Department of Environmental Protection
PCBs:	Polychlorinated Biphenyls
PCCP:	Prestressed Concrete Cylinder Pipe
POC:	Pollutant of Concern
POPC:	Parameter of Potential Concern
PSWPCP:	Philadelphia Water Department's Southwest Water Pollution Control Plant
QA/QC:	Quality Assurance/Quality Control
QAPP:	Quality Assurance Project Plan
R.M.:	River Mile
RHM:	Radnor Haverford Marple Authority
SPS:	Sunoco Pump Station
STORET:	Storage and Retrieval for Water Quality Data
TMDL:	Total Maximum Daily Load

TSF:	Trout Stocking
UH:	Unit Hydrograph
USEPA or EPA:	United States Environmental Protection Agency
WQMP:	Water Quality Monitoring Program
WQR:	Water Quality Regulations
WQS:	Water Quality Standards
WRTP:	Western Regional Treatment Plant
WWF:	Warm Water Fishes

Appendix A CSO Regulator Structure Characteristics

Table A-1: CSO Outfall Characteristics Summary

Outfall No.	CSO Receiving Water	Invert at Regulator	Invert at Receiving Stream
002	Delaware River	7.00	-3.5
003	Delaware River	7.98	-3.5
004	Delaware River	8.80	-3.5
005	Delaware River	4.74	-4.5
007	Delaware River	0.81	0.21
008	Delaware River	2.79	0.01
009	Delaware River	2.61	-4
010*	Delaware River	22.5	*
011	Delaware River	7.09	-4
012	Chester Creek	1.46	-2
013	Delaware River	1.86	-4
014	Delaware River	-1.09	-4
015	Ridley Creek	0.52	-3
016	Ridley Creek	0.11	-5
017	Ridley Creek	0.09	0.09
018	Ridley Creek	6.28	-5.0
019	Chester Creek	18.00	12.28
020	Chester Creek	8.78	-4
021	Chester Creek	5.78	-1.5
022	Chester Creek	11.5	-3.5
023	Chester Creek	1.33	-3.0
024	Chester Creek	1.21	-4.0
025	Chester Creek	-1.08	-4.0
026	Chester Creek	9.00	-4.0
032	Delaware River	1.00	-4.0
033	Ridley Creek	N/A	N/A

Notes:
*CSO regulator 010 discharges at Outfall 009.
N/A: Not Applicable

Table A-2: Regulator Gates Characteristics

Regulator Gate ID No.	Dimensions		Invert EL (ft.)
	Height	Width	
002	5.0 in.	7.5 in.	6.29
003	7.5 in.	7.75 in	7.18
004	8.0 in. dia.	N/A	7.89
005	12.0 in.	12.0 in.	3.99
007	5.0 in.	6.00 in.	0.50
008	7.5 in.	12.375 in.	2.63
009	5.0 in.	7.5 in.	2.45
010*	7.5 in.	15.375 in.	21.50
011	5.0 in.	9.25 in.	6.99
012	2.50	9.25 in.	0.50
013	7.5 in.	7.75 in.	0.84
014	12.0 in.	15.00 in.	-2.50
015	5.0 in.	6.00 in.	0.46
016	7.5 in.	12.375 in.	-0.55
017	5.0 in.	6.00 in.	0.09
018	5.0 in.	6.00 in.	6.06
019	7.5 in.	15.38 in.	16.89
020	7.5 in.	7.75 in.	8.06
021	7.5 in.	7.75 in.	4.56
022	5.00 in.	6.00 in.	10.47
023	7.5 in.	7.75 in.	0.50
024	5.0 in.	9.25 in.	0.50
025	5.0 in.	6.00 in	-2.25
026	7.5 in.	12.375 in.	7.91
032	*	*	-0.20
033	N/A	N/A	N/A
*Gate removed; no data for gate opening dimensions. Regulator modeled as pipe with same diameter as upstream sewer			

Table A-3: Orifice Characteristics

Orifice ID No.	Orifice Type	Dimensions		Invert EL (ft.)
		Height	Width	
002	Side	4 5/8 in.	6 in.	5.78
003	Side	6 ¼ in.	7 in.	6.68
004	None	N/A No Orifice Plate		N/A
005	Side	7 ½ in.	12 in.	3.49
007	Side	3 ½ in.	5 in.	0
008	Side	6 7/8 in.	18 in.	2.13
009	Side	3 ½ in.	8 in.	1.95
010*	Side	10.563 in.	15 in.	21.09
011	Side	5 7/8 in.	8 in.	6.49
012	Side	4 5/8 in.	14 in.	0.00
013	Side	4 ½ in.	16 in.	0.34
014	Side	7 ½ in.	16 in	-3
015	None	N/A No Orifice Plate		N/A
016	Side	9 1/8 in.	30 in.	-1.05
017	None	N/A No Orifice Plate		N/A
018	None	N/A No Orifice Plate		N/A
019	None	N/A No Orifice Plate		N/A
020	Side	12.15 in.	8 in.	7.41
021	Side	11.33 in.	15 in.	4.47
022	Side	2.9 in.	8 in.	9.97
023	Side	5.75 in.	14 in.	0.00
024	Side	7.5 in.	16 in.	-2.75
025	Side	4.61 in.	5 in.	7.41
026	Side	7.69 in.	30 in.	
032	None	N/A No Orifice Plate		N/A

Orifice ID No.	Orifice Type	Dimensions	Invert EL
033	N/A	N/A No longer connected to CSS	N/A

Table A-4: Weir Characteristics

Weir ID No.	Dimensions		
	Height	Length	Crest Height
002	2.50 ft.	2.24 ft.	1.21 in.
003	2.50 ft.	2.24 ft.	1.30 in.
004	2.74 ft.	1.69 ft.	1.17 in.
005	3.50 ft.	2.65 ft.	1.25 in.
007	3.50 ft.	2.65 ft.	0.81 in.
008	4.98 ft.	3.54 ft.	1.23 in.
009	3.25 ft.	3.12 ft.	0.94 in.
010*	2.50 ft.	2.24 ft.	1.50 in.
011	2.44 ft.	3.9 ft.	1.76 in.
012	1.58 ft.	1.73 ft.	1.46 in.
013	3.40 ft.	2.65 ft.	1.62 in.
014	2.75 ft.	2.52 ft.	2.33 in.
015	2.79 ft.	1.53 ft.	0.27 in.
016	3.58 ft.	4.51 ft.	2.08 in.
017	2.17 ft.	2.63 ft.	0.96 in.
018	4.33 ft.	2.58 ft.	0.25 in.
019	3.17 ft.	2.05 ft.	1.44 in.
020	2.50 ft.	2.24 ft.	1.44 in.
021	0.63 ft.	1.48 ft.	1.72 in.
022	2.53 ft.	2.24 ft.	1.53 in.
023	1.50 ft.	2.24 ft.	1.25 in.
024	3.00 ft.	2.45 ft.	1.13 in
025	2.50 ft.	2.24 ft.	1.67 in.
026	0.95 ft.	2.43 ft.	2.64 in.
032	2.75 ft.	1.66 ft.	1.54 in.
033	N/A	N/A	N/A

*Height (H) measured from weir crest to pipe crown; Crest Height (H) measured from invert of upstream node to weir crest

Table A-5: Permitted CSOs in the City of Chester

Name of Receiving Stream	CSO Regulator/Outfall	Interceptor/CSO Regulator Location	Latitude	Longitude
Delaware River	002	Front and Booth	39°49'30"N	75°23'31"W
Delaware River	003	Front and Highland	39°49'34"N	75°23'11"W
Delaware River	004	Front and Haves	39°50'36"N	75°23'07"W
Delaware River	005	Front and Townsend	39°49'46"N	75°22'53"W
Delaware River	007	Delaware and Reaney	39°49'51"N	75°22'45"W
Delaware River	008	2nd and Tilghman	39°50'05"N	75°22'22"W
Delaware River	009	2nd and Lloyd	39°50'14"N	75°22'10"W
Delaware River(1)	010	5th and Pusey	39°50'26"N	75°22'19"W
Delaware River	011	2nd and Parker	39°50'26"N	75°21'54"W
Delaware River	013	2nd and Welsh	39°50'37"N	75°21'17"W
Delaware River	014	3rd and Upland	39°50'50"N	75°21'05"W
Delaware River(2)	032	2nd and Avenue of The States	39°50'34"N	75°21'25"W
Chester Creek	012	2nd and Edgmont	39°50'42"N	75°21'38"W
Chester Creek	019	14th and Crozer Hospital	39°51'24"N	75°21'54"W
Chester Creek	020	Kerlin and Finland	39°51'24"N	75°22'27"W
Chester Creek	021	9th and Sproul	39°51'08"N	75°21'49"W
Chester Creek	022	6th and Sproul	39°50'56"N	75°21'47"W
Chester Creek	023	3rd and Edgmont	39°50'45"N	75°21'42"W
Chester Creek	024	3rd and Dock	39°50'44"N	75°21'43"W
Chester Creek	025	5th and Penn	39°50'49"N	75°21'50"W
Chester Creek	026	7th and Penn	39°50'58"N	75°21'55"W
Ridley Creek	015	4th and Melrose	39°51'03"N	75°20'48"W
Ridley Creek	016	8th and McDowell	39°51'15"N	75°20'53"W
Ridley Creek	017	9th and Campbell	39°51'16"N	75°20'51"W
Ridley Creek	018	Sun Drive and Hancock Street	39°51'47"N	75°20'57"W

Name of Receiving Stream	CSO Regulator/Outfall	Interceptor/CSO Regulator Location	Latitude	Longitude
Ridley Creek(2)	033	Elkington Boulevard and Ridley Creek	39°52'22"N	75°22'29"W
Notes: (1) CSO Regulator #010 discharges to the Delaware River through CSO Outfall #009. (2) No mechanical regulator used for this outfall.				

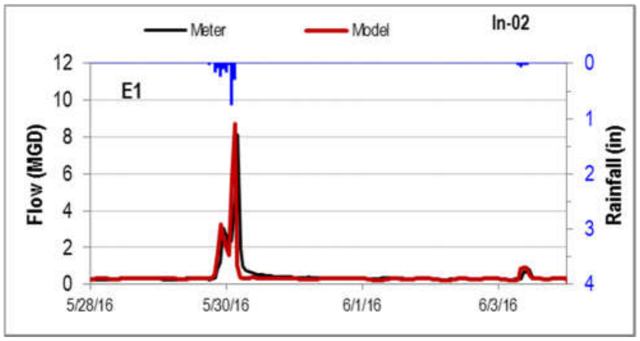
Appendix B H&H Model Calibration and Validation Results

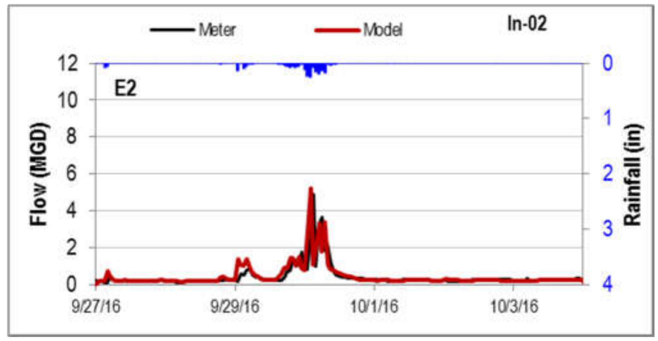
H&H MODEL CALIBRATION AND VALIDATION RESULTS
APPENDIX B TABLE OF CONTENTS

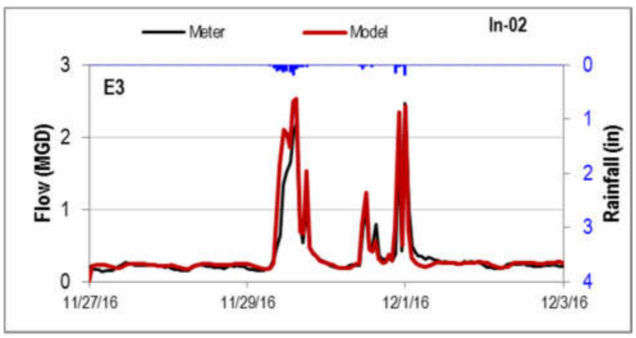
Flow Meter No.	Page No.

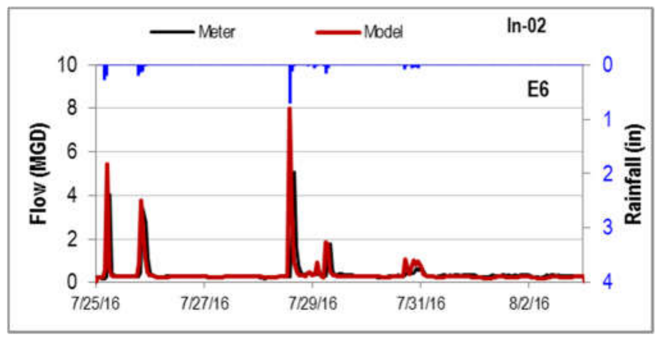
FLOW METER IN-02 MODEL CALIBRATION AND VALIDATION RESULTS

In-02 Model Calibration Results (Metered and Modeled Flow)

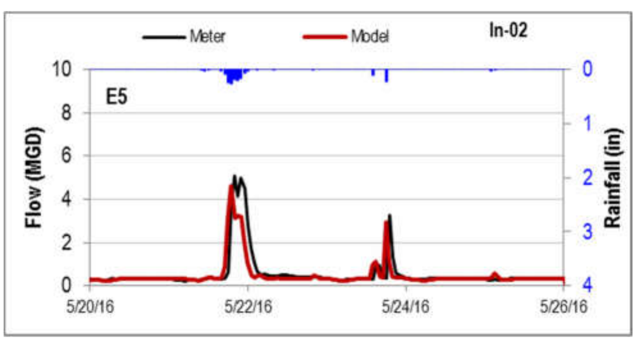


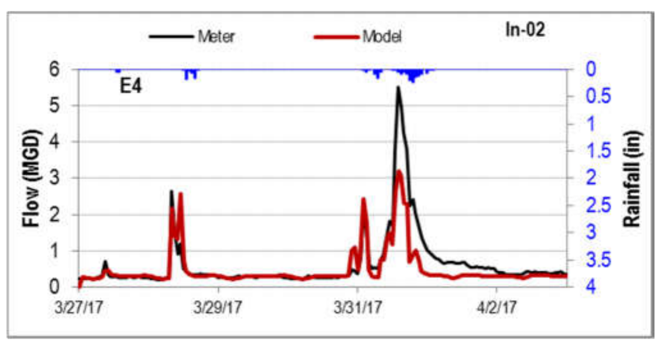




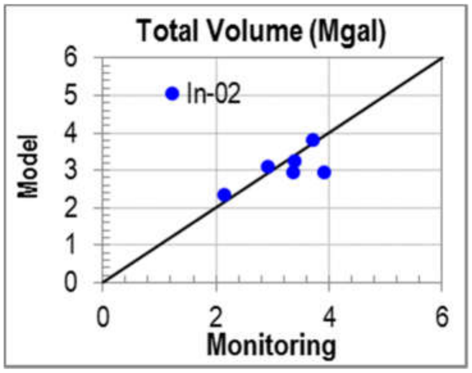


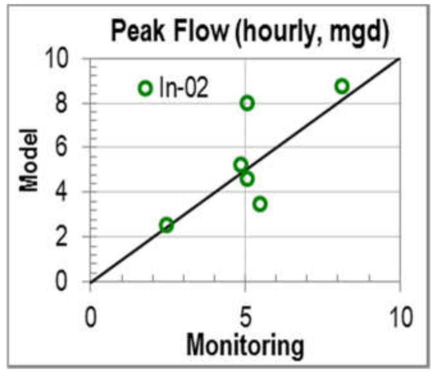
In-02 Model Validation Results (Metered and Modeled Flow)





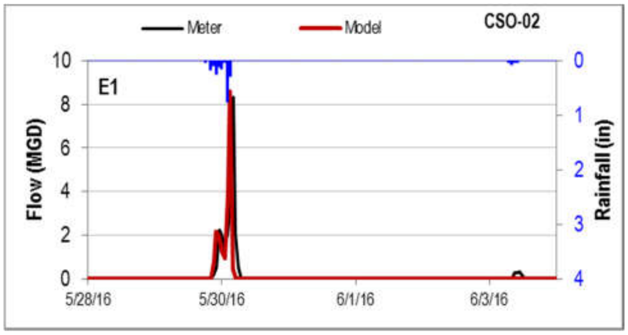
In-02 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

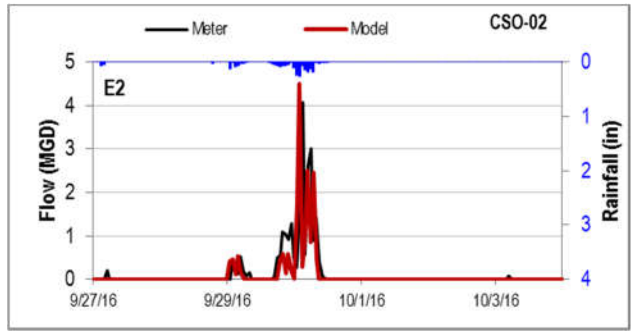


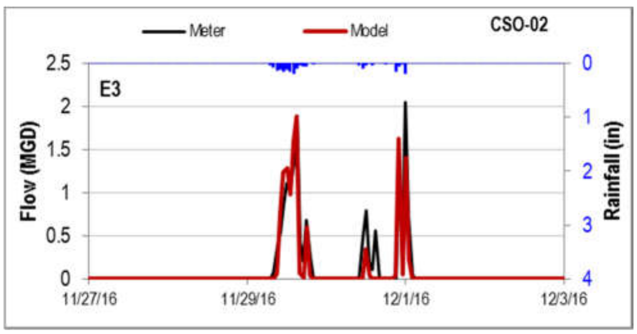


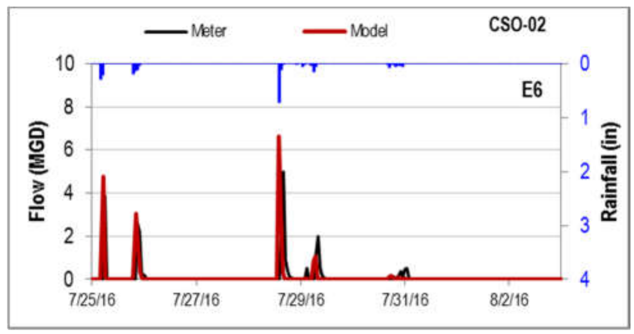
FLOW METER CSO-02 MODEL CALIBRATION AND VALIDATION RESULTS

CSO-02 Model Calibration Results (Metered and Modeled Flow)

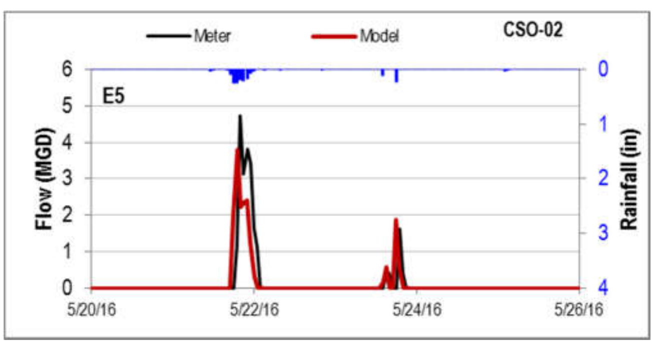


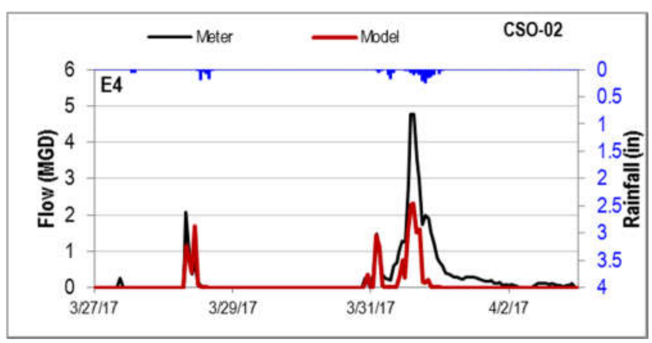




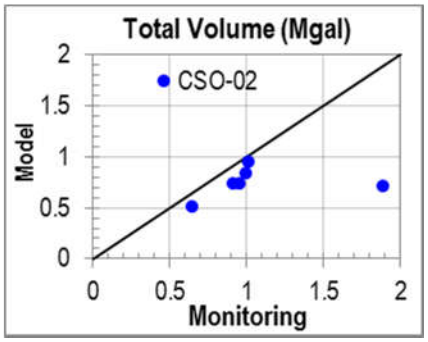


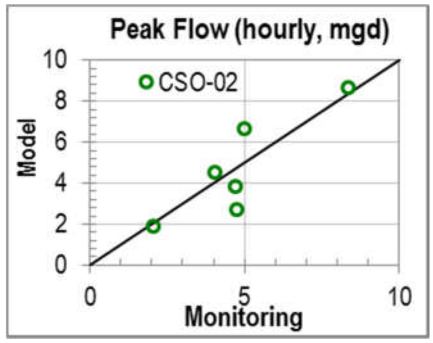
CSO-02 Model Validation Results (Metered and Modeled Flow)





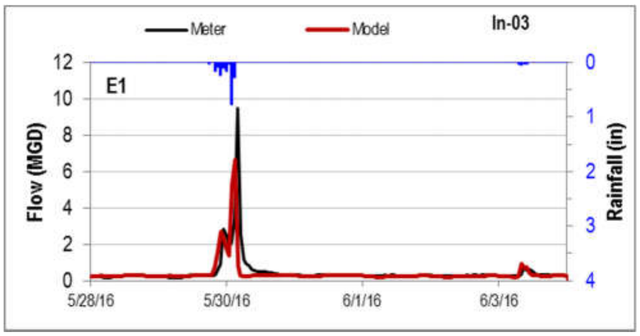
CSO-02 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

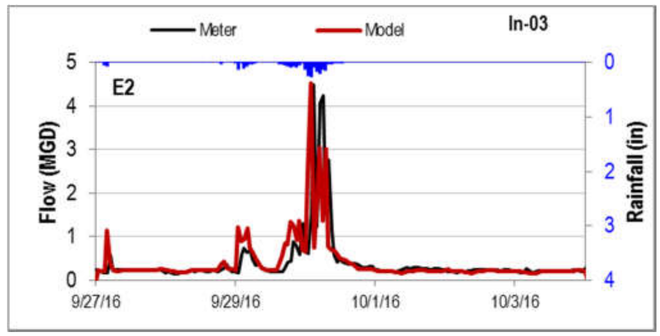


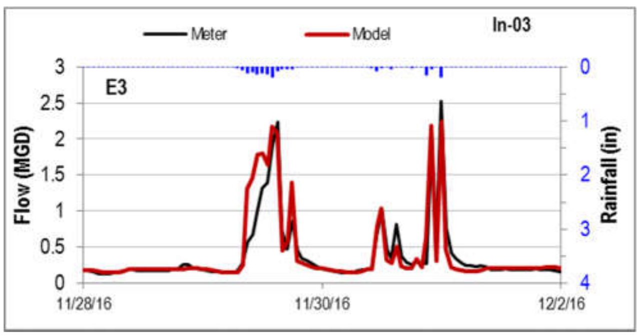


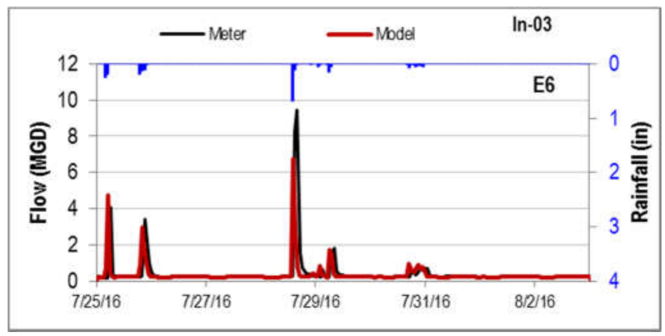
FLOW METER IN-03 MODEL CALIBRATION AND VALIDATION RESULTS

In-03 Model Calibration Results (Metered and Modeled Flow)

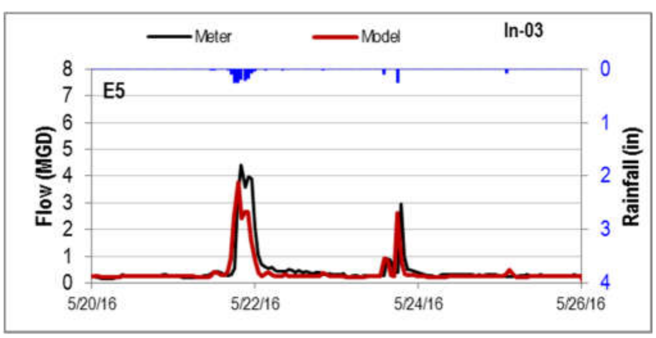


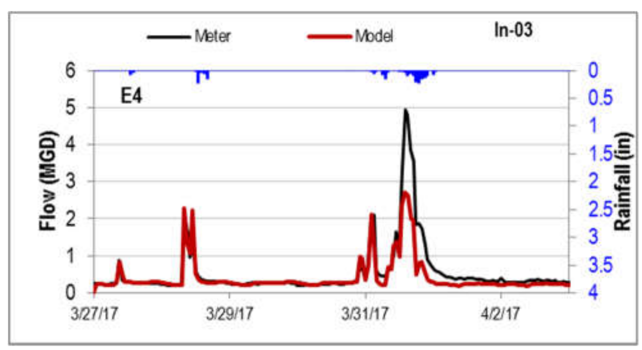




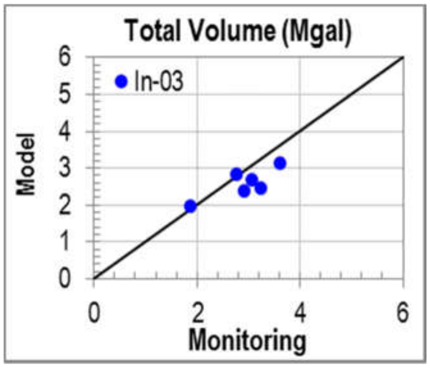


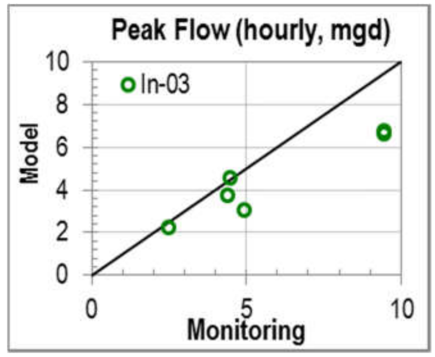
In-03 Model Validation Results (Metered and Modeled Flow)





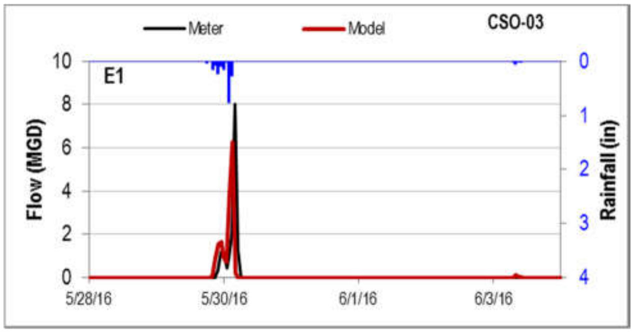
In-03 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

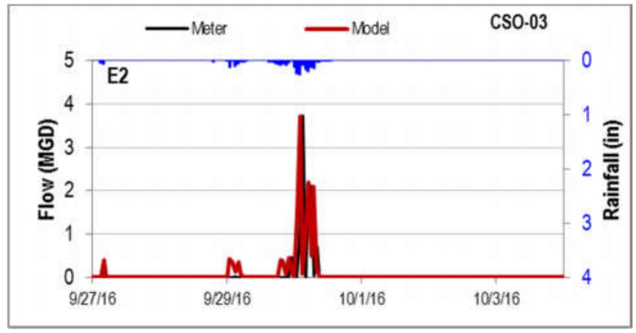


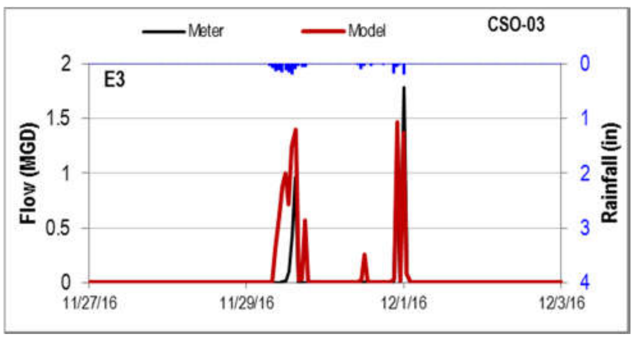


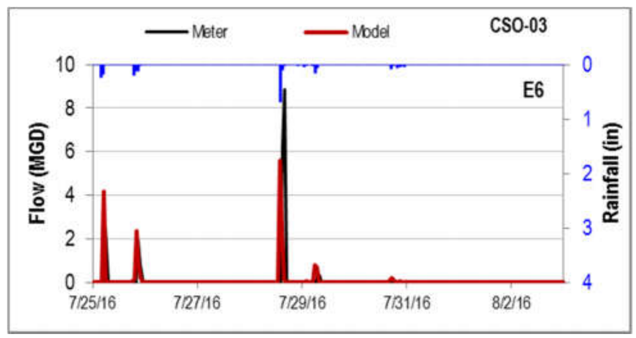
FLOW METER CSO-03 MODEL CALIBRATION AND VALIDATION RESULTS

CSO-03 Model Calibration Results (Metered and Modeled Flow)

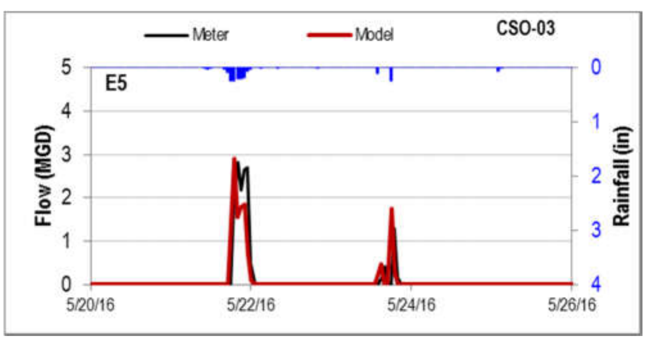


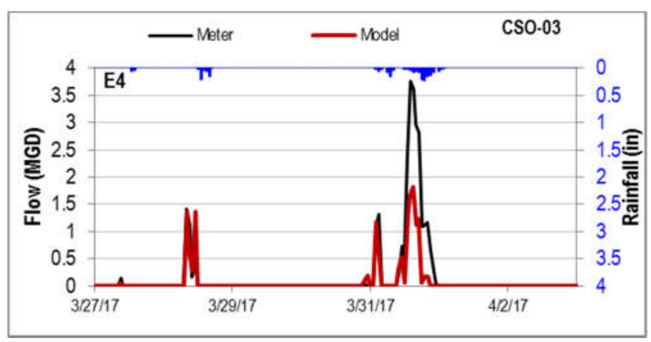




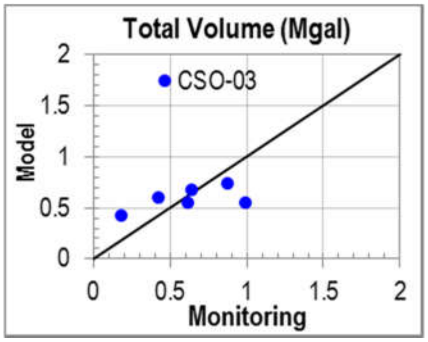


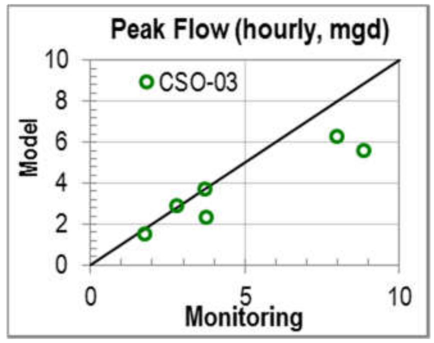
CSO-03 Model Validation Results (Metered and Modeled Flow)





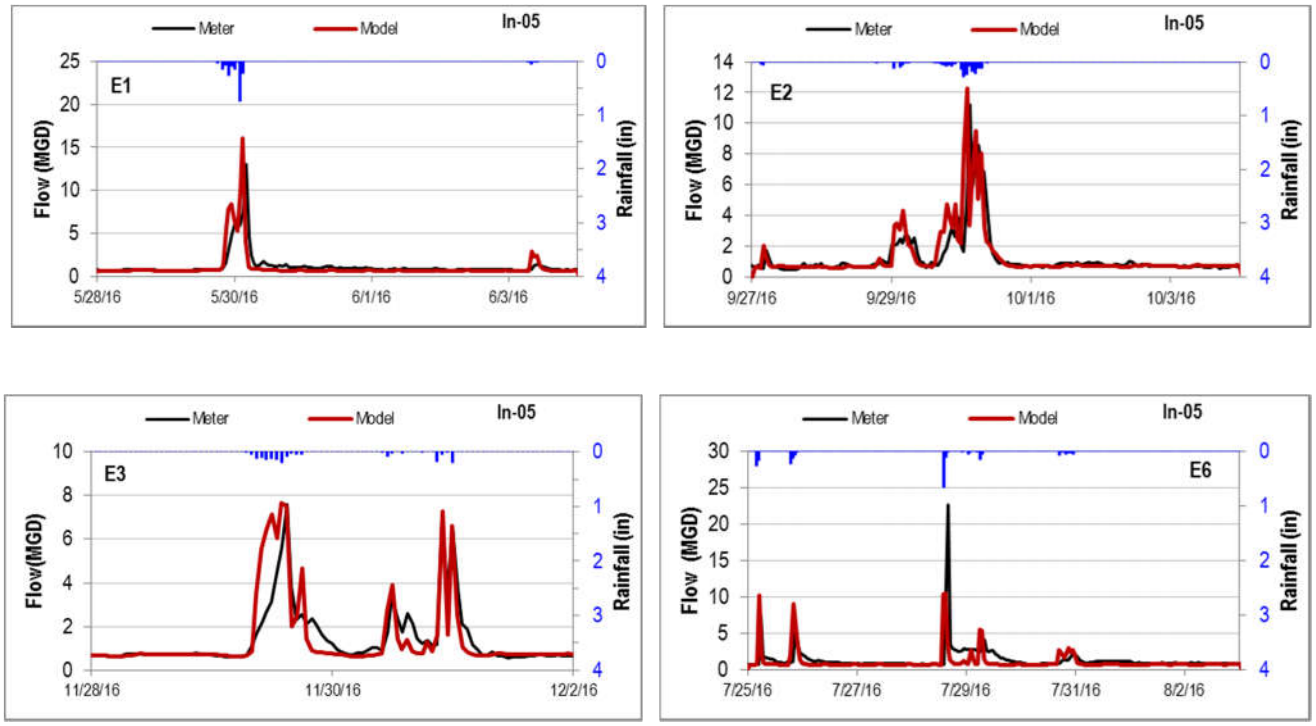
CSO-03 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



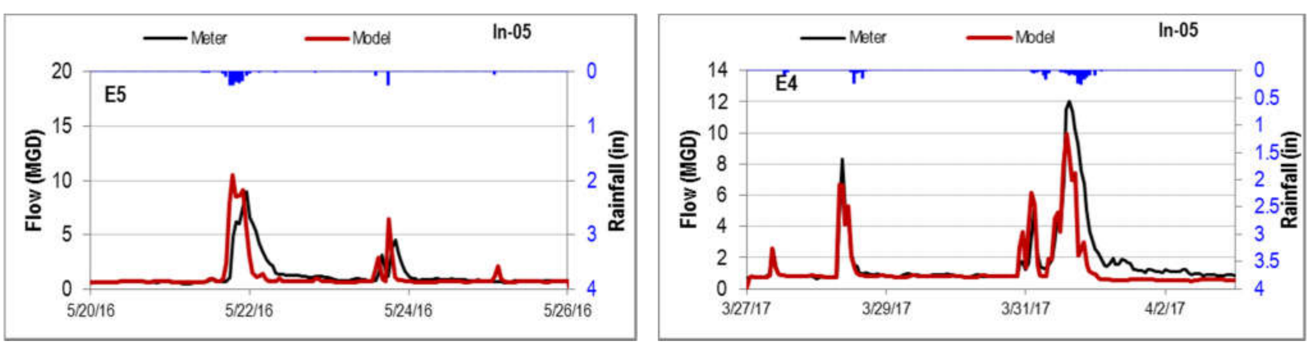


FLOW METER IN-05 MODEL CALIBRATION AND VALIDATION RESULTS

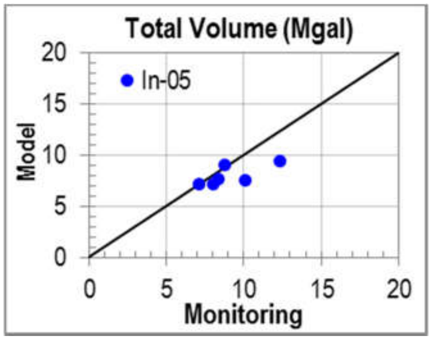
In-05 Model Calibration Results (Metered and Modeled Flow)

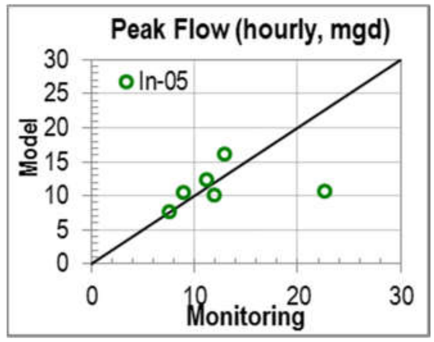


In-05 Model Validation Results (Metered and Modeled Flow)



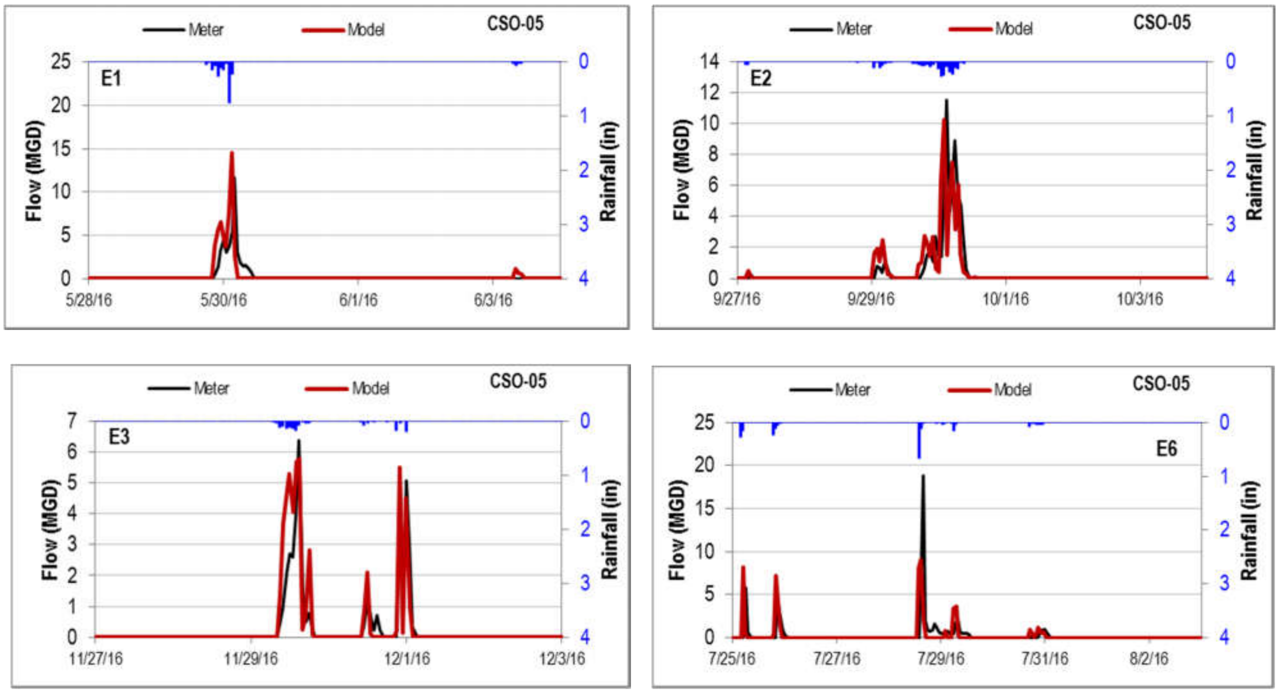
In-05 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



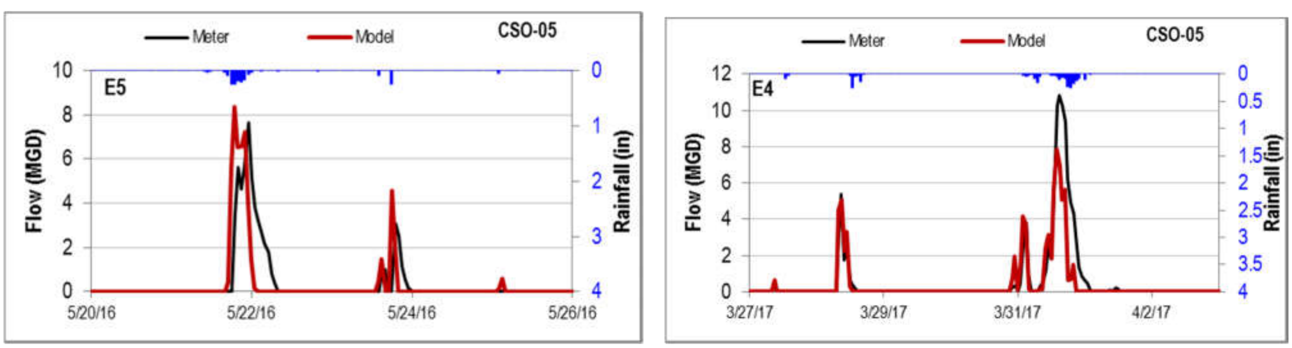


FLOW METER CSO-05 MODEL CALIBRATION AND VALIDATION RESULTS

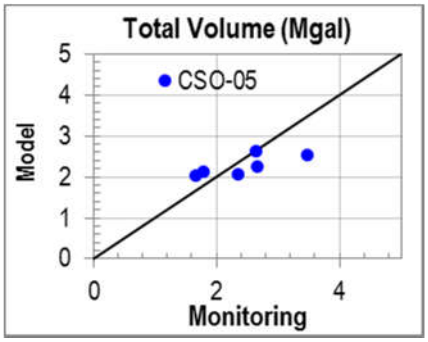
CSO-05 Model Calibration Results (Metered and Modeled Flow)

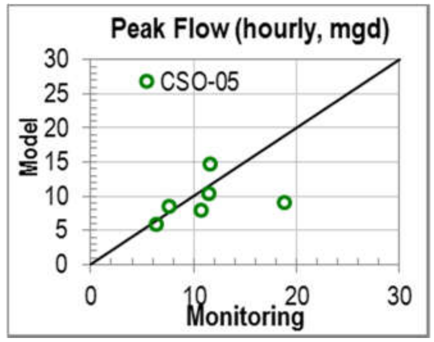


CSO-05 Model Validation Results (Metered and Modeled Flow)



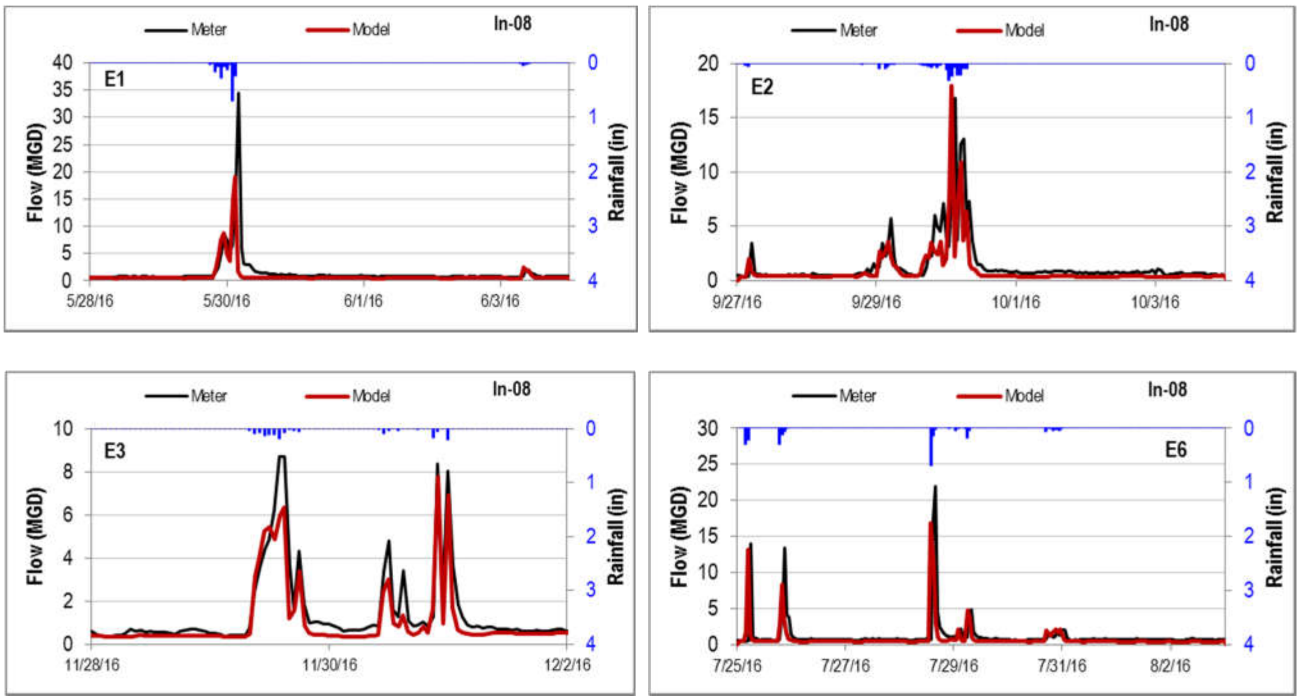
CSO-05 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



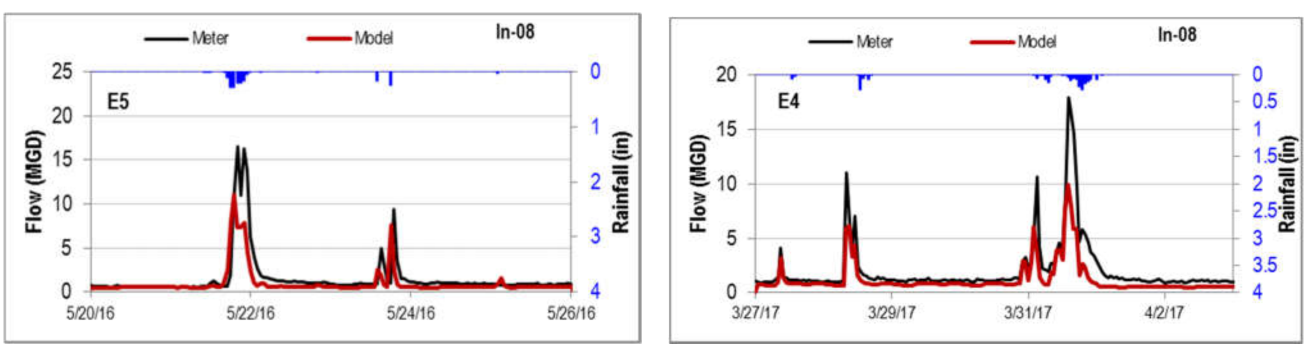


FLOW METER IN-08 MODEL CALIBRATION AND VALIDATION RESULTS

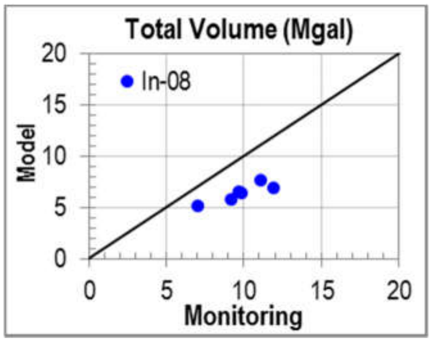
In-08 Model Calibration Results (Metered and Modeled Flow)

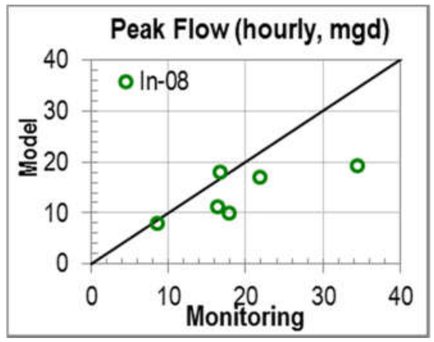


In-08 Model Validation Results (Metered and Modeled Flow)



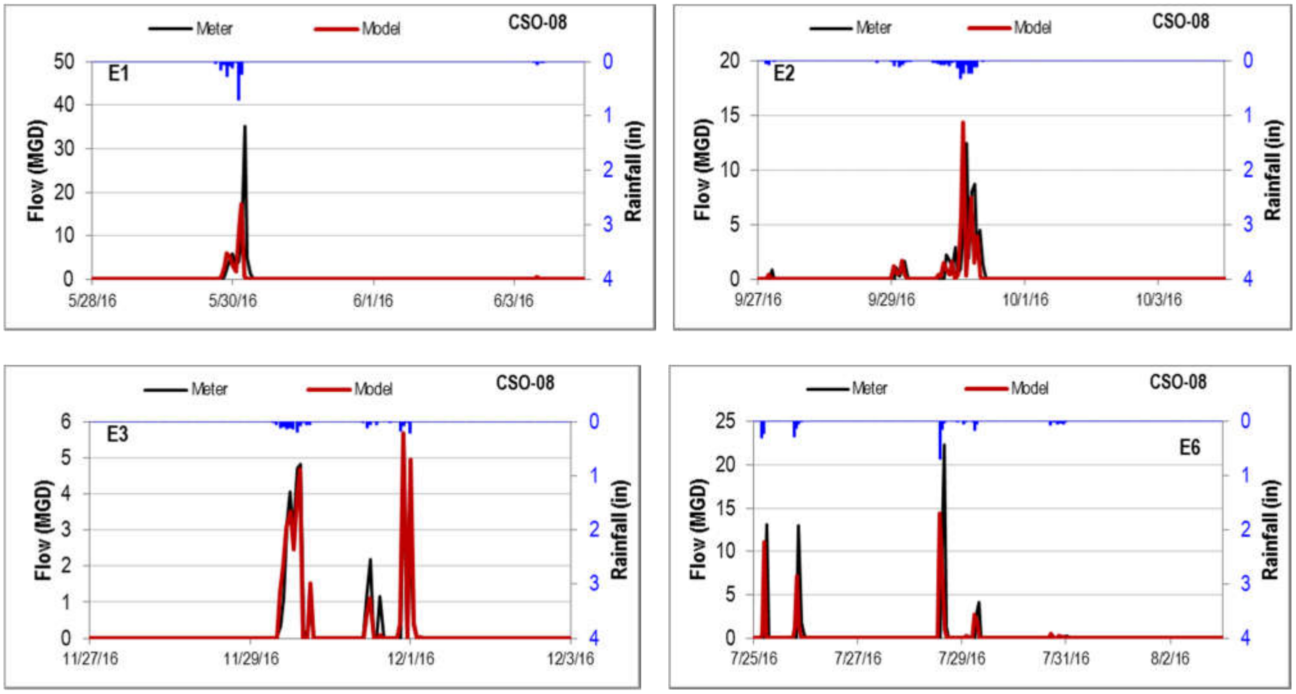
In-08 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



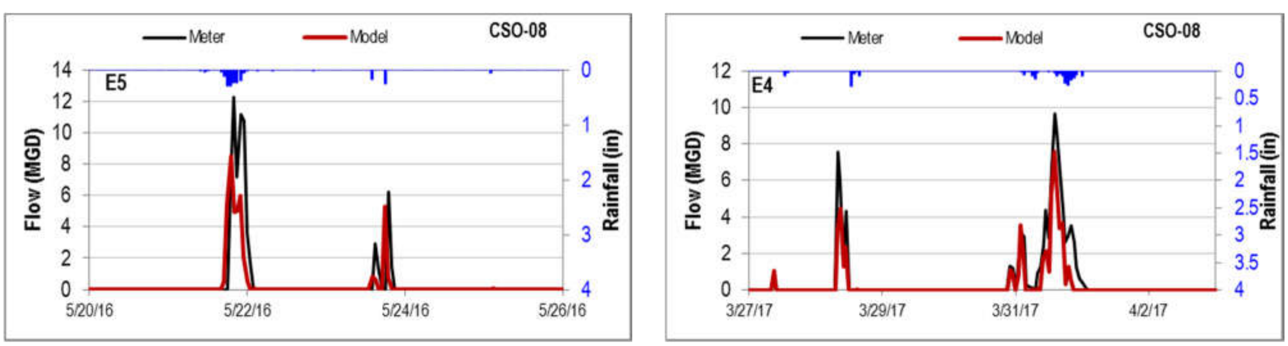


FLOW METER CSO-08 MODEL CALIBRATION AND VALIDATION RESULTS

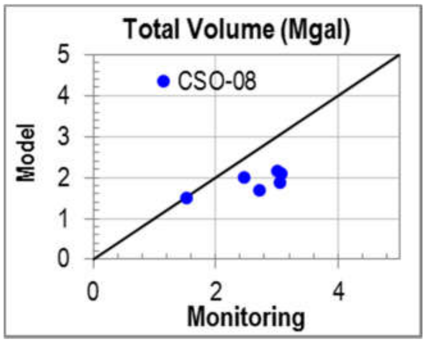
CSO-08 Model Calibration Results (Metered and Modeled Flow)

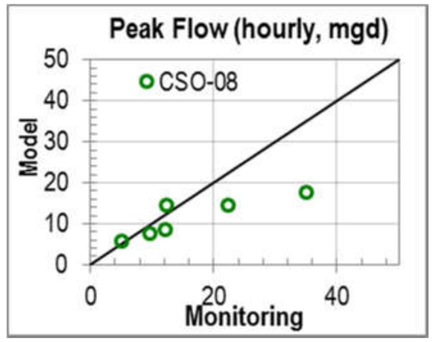


CSO-08 Model Validation Results (Metered and Modeled Flow)



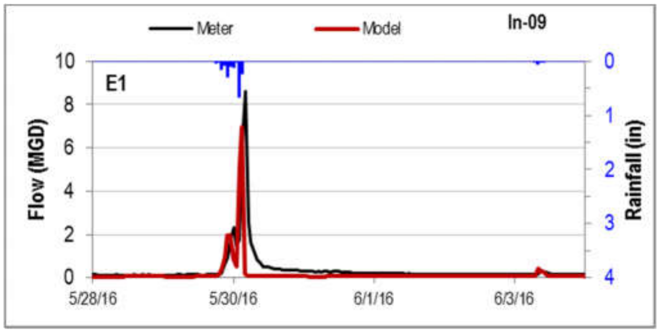
CSO-08 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

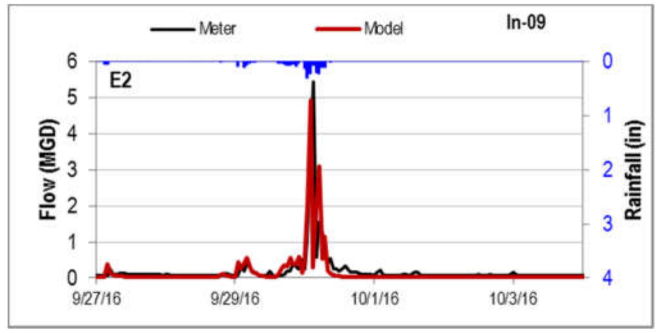


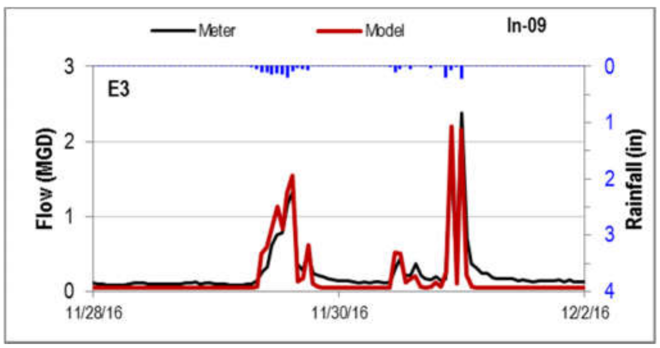


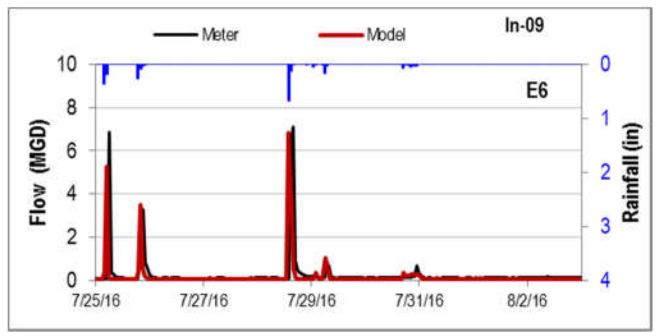
FLOW METER IN-09 MODEL CALIBRATION AND VALIDATION RESULTS

In-09 Model Calibration Results (Metered and Modeled Flow)

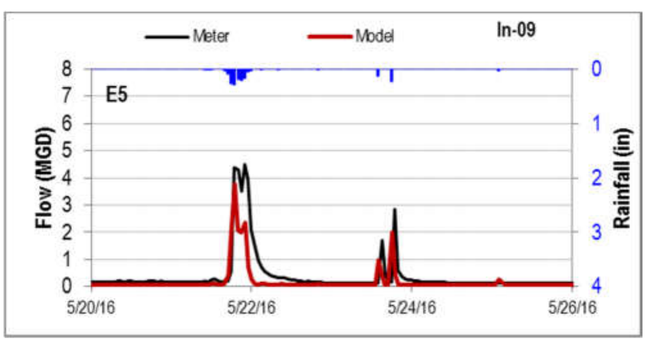


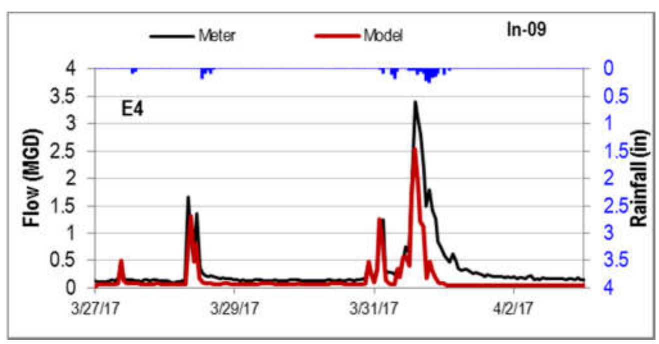




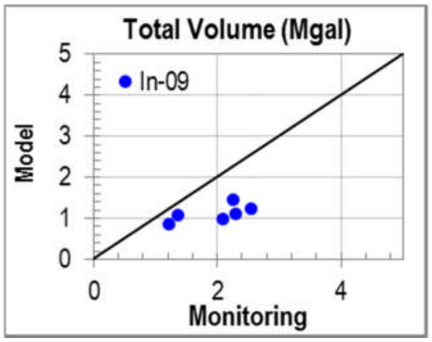


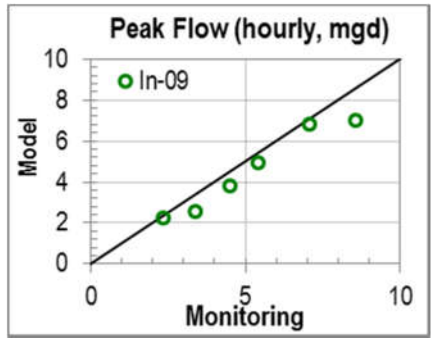
In-09 Model Validation Results (Metered and Modeled Flow)





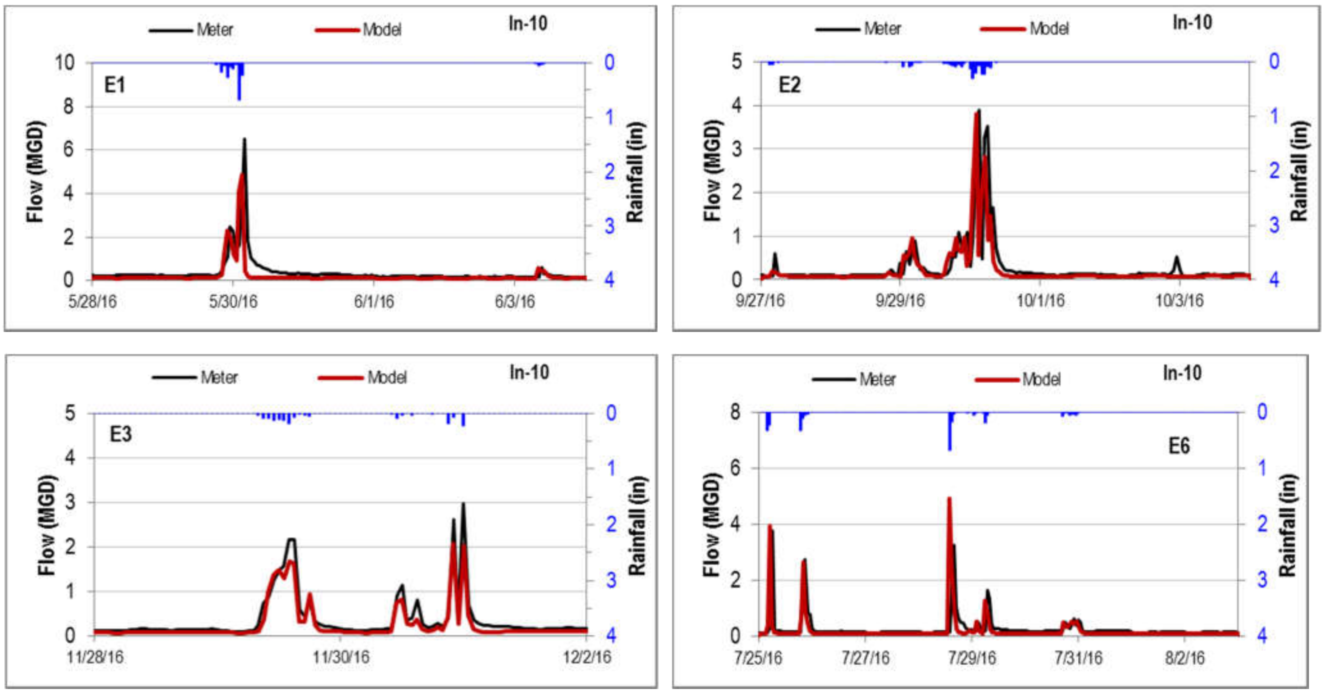
In-09 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



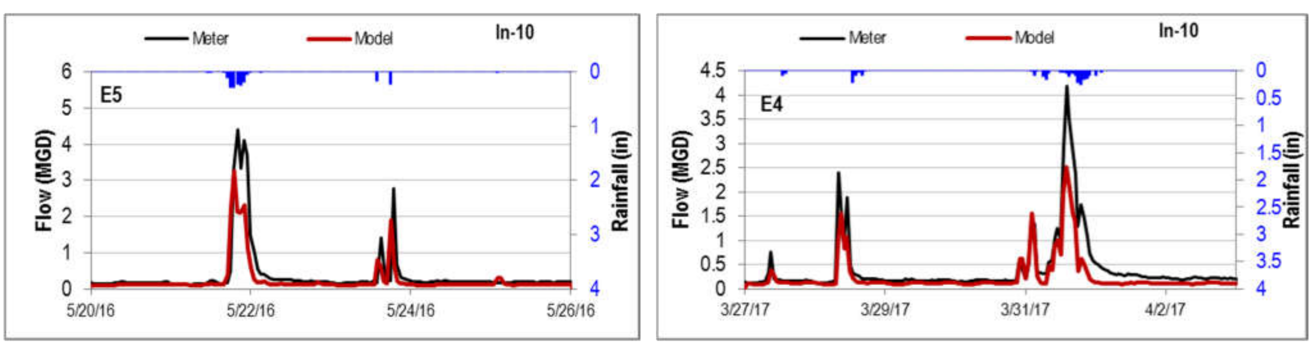


FLOW METER IN-10 MODEL CALIBRATION AND VALIDATION RESULTS

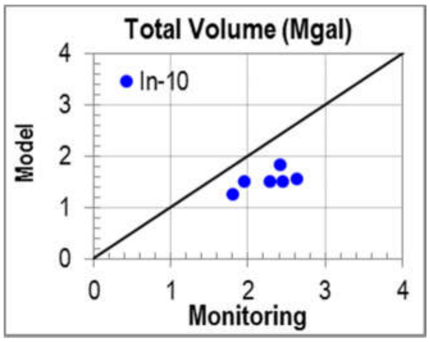
In-10 Model Calibration Results (Metered and Modeled Flow)

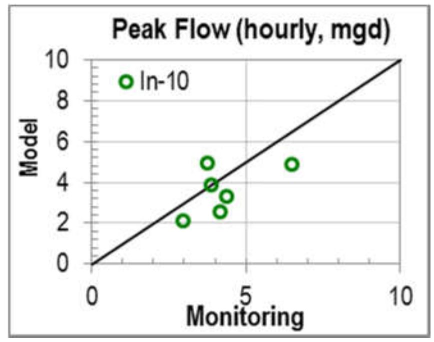


In-10 Model Validation Results (Metered and Modeled Flow)



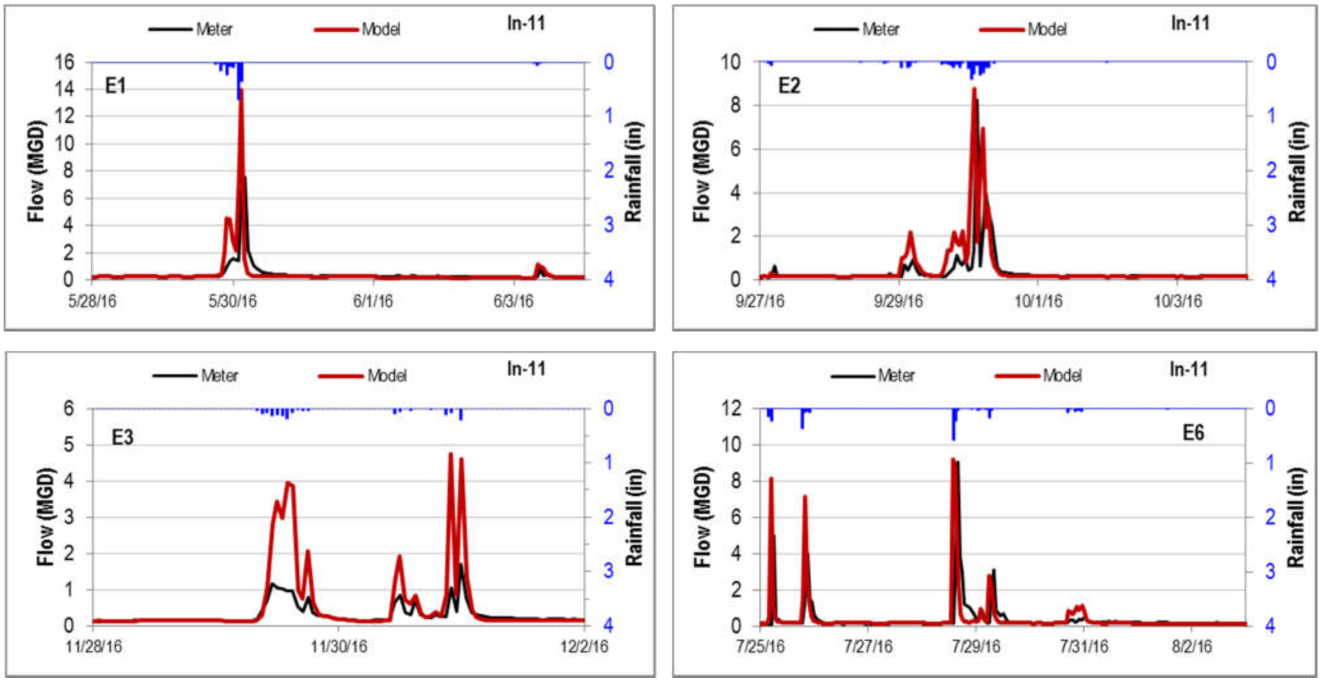
In-10 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



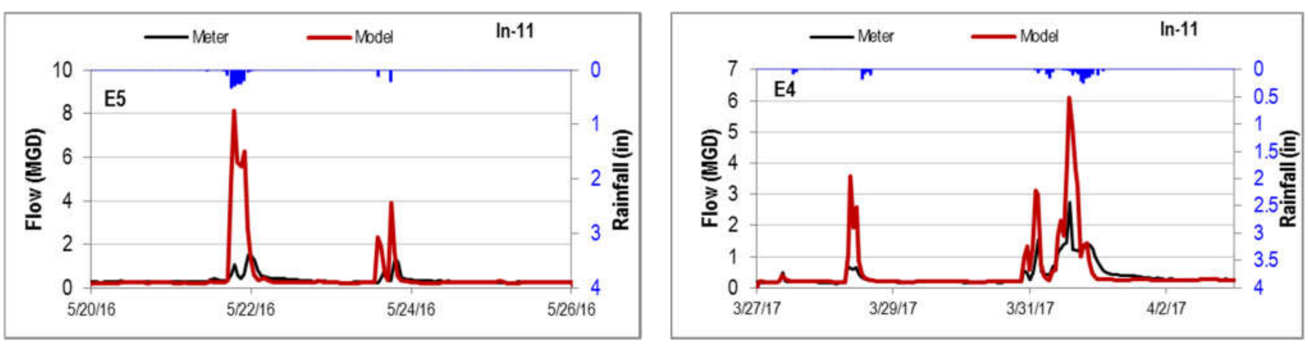


FLOW METER IN-11 MODEL CALIBRATION AND VALIDATION RESULTS

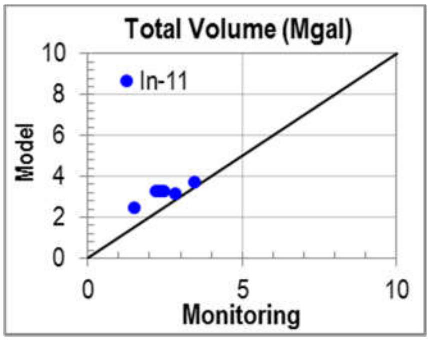
In-11 Model Calibration Results (Metered and Modeled Flow)

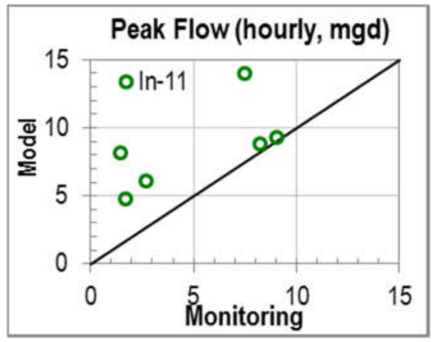


In-11 Model Validation Results (Metered and Modeled Flow)



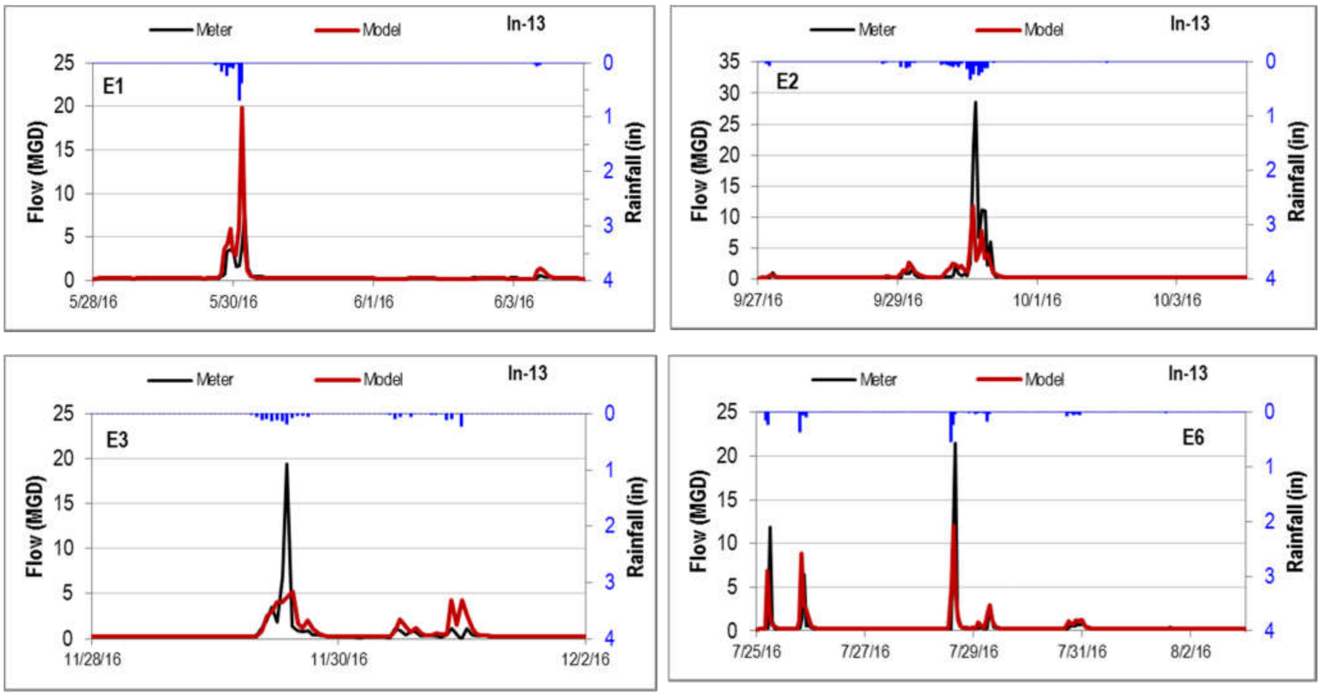
In-11 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



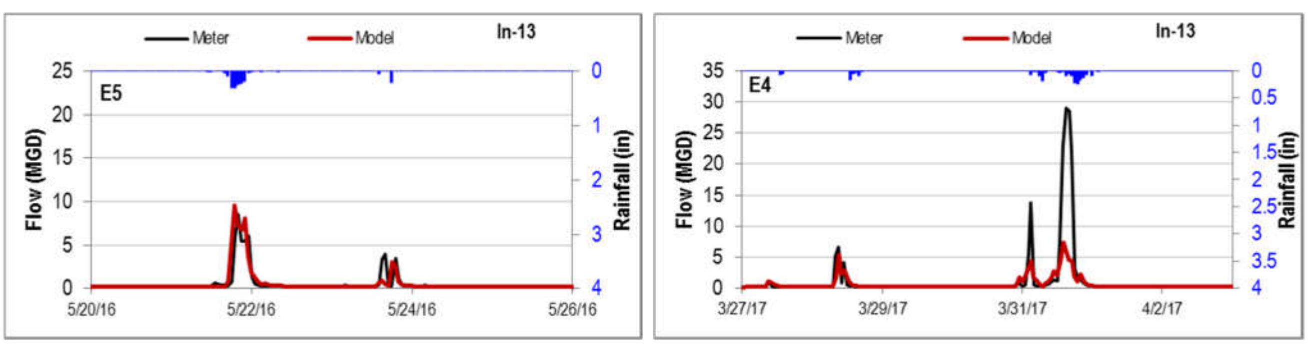


FLOW METER IN-13 MODEL CALIBRATION AND VALIDATION RESULTS

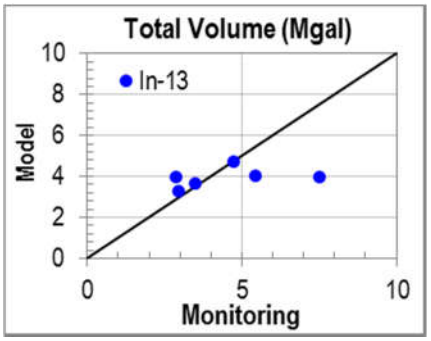
In-13 Model Calibration Results (Metered and Modeled Flow)

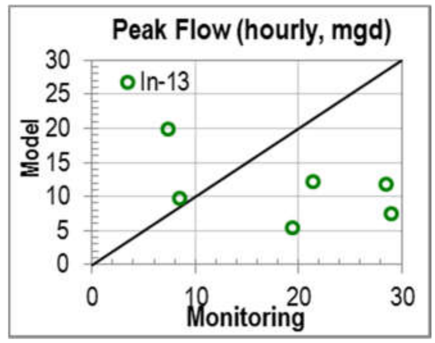


In-13 Model Validation Results (Metered and Modeled Flow)



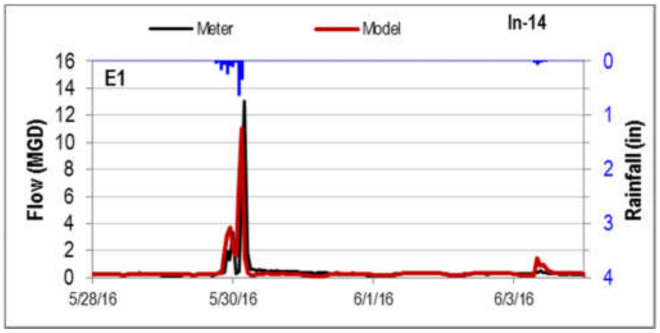
In-13 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

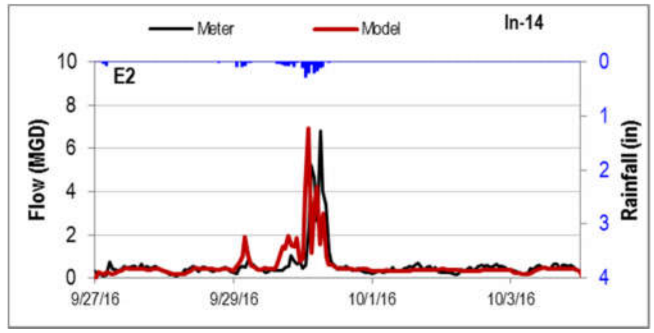


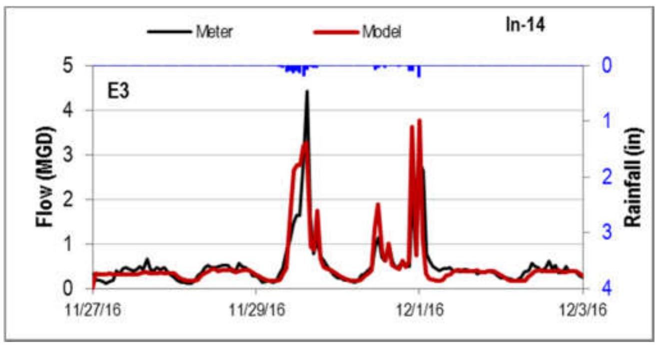


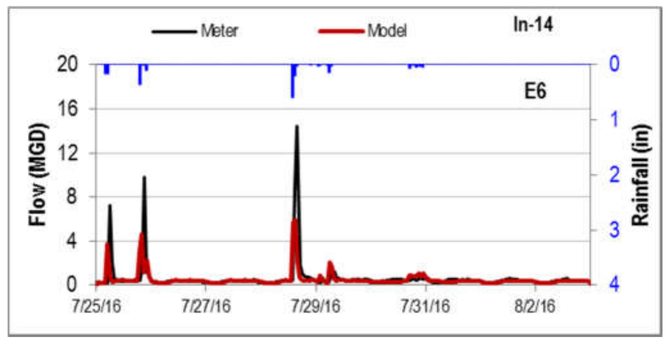
FLOW METER IN-14 MODEL CALIBRATION AND VALIDATION RESULTS

In-14 Model Calibration Results (Metered and Modeled Flow)

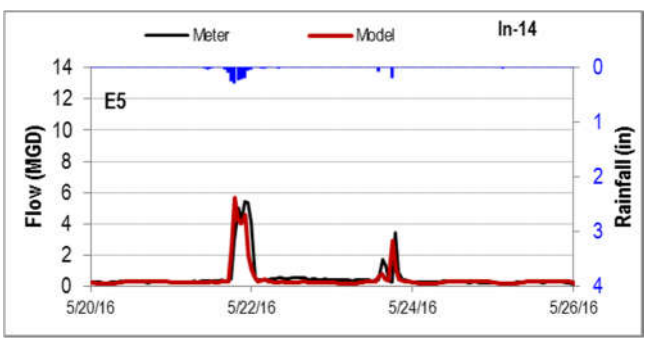


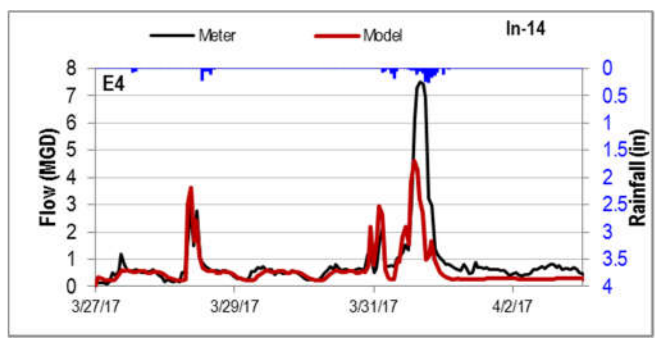




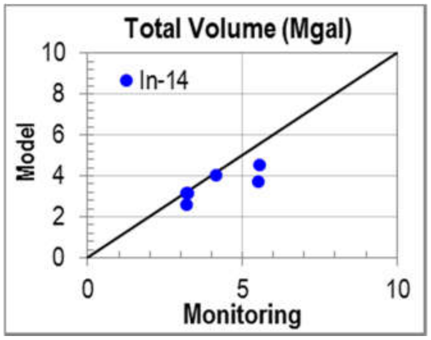


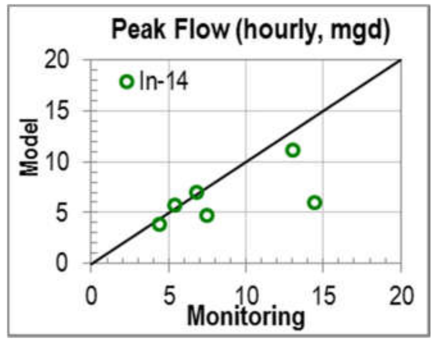
In-14 Model Validation Results (Metered and Modeled Flow)





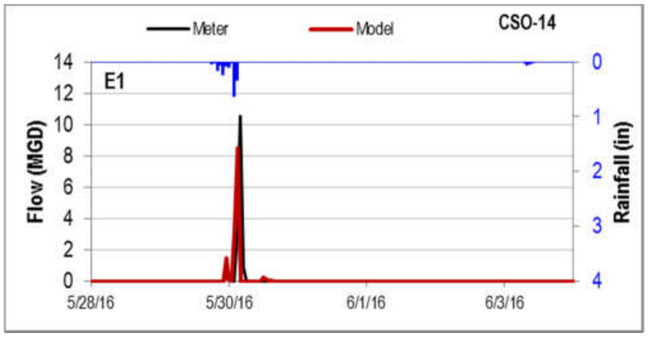
In-14 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

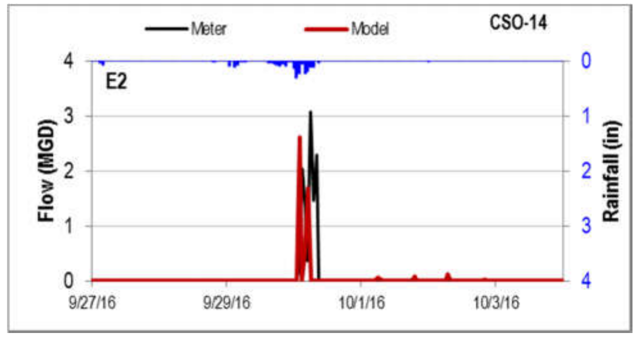


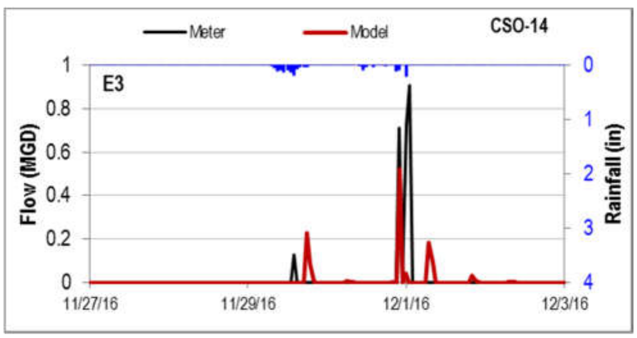


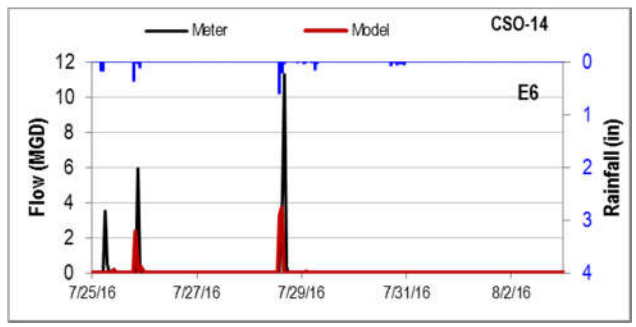
FLOW METER CSO-14 MODEL CALIBRATION AND VALIDATION RESULTS

CSO-14 Model Calibration Results (Metered and Modeled Flow)

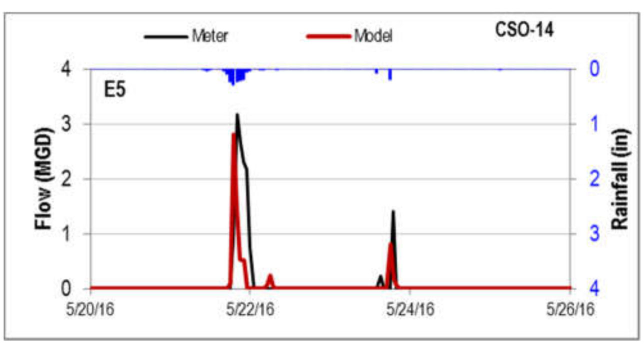


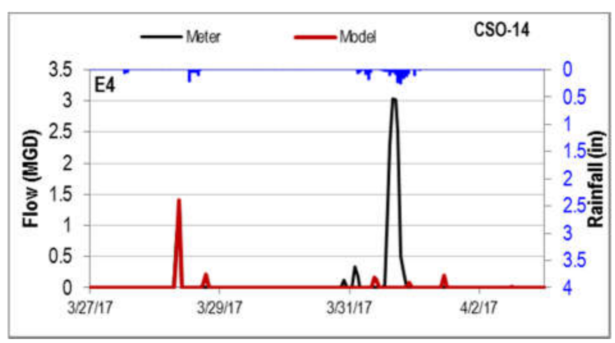




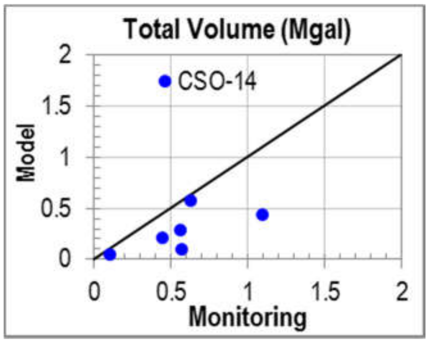


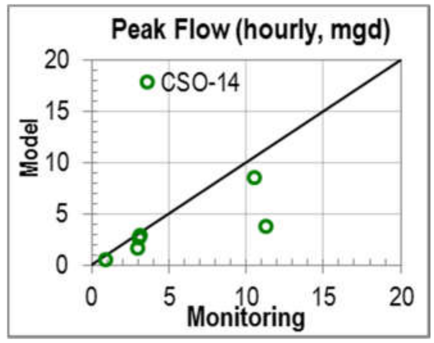
CSO-14 Model Validation Results (Metered and Modeled Flow)





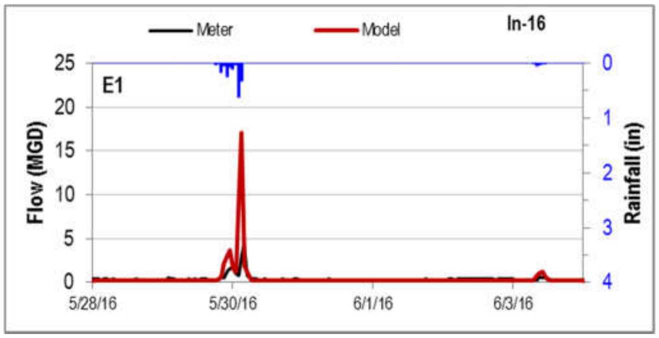
CSO-14 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

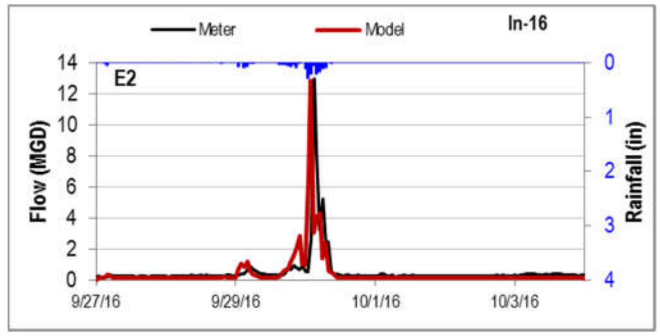


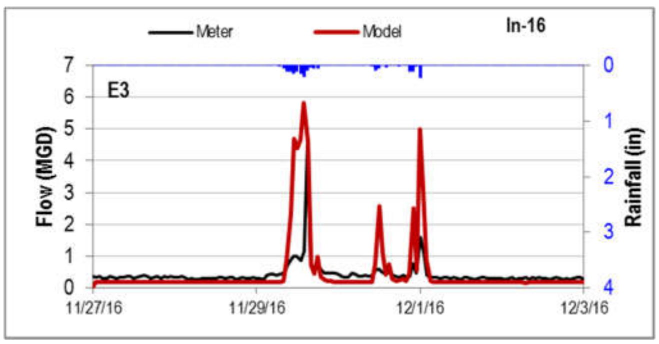


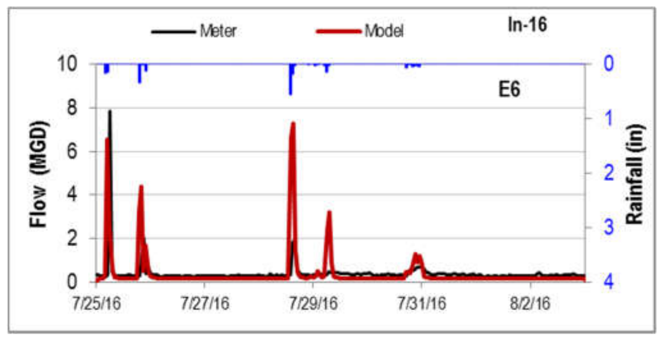
FLOW METER IN-16 MODEL CALIBRATION AND VALIDATION RESULTS

In-16 Model Calibration Results (Metered and Modeled Flow)

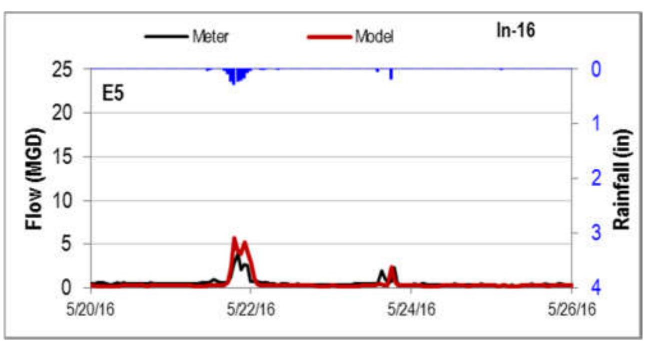


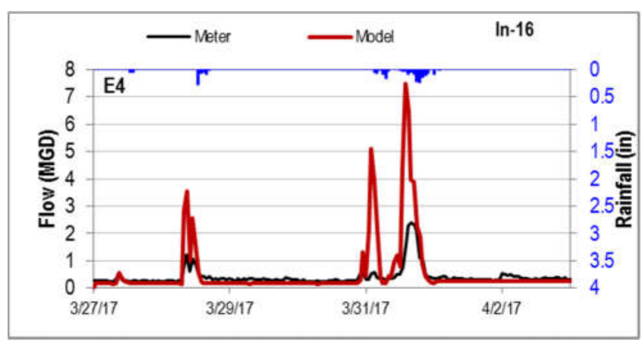




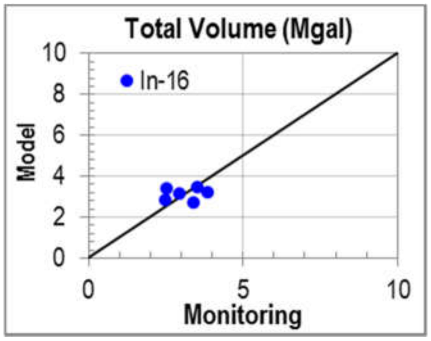


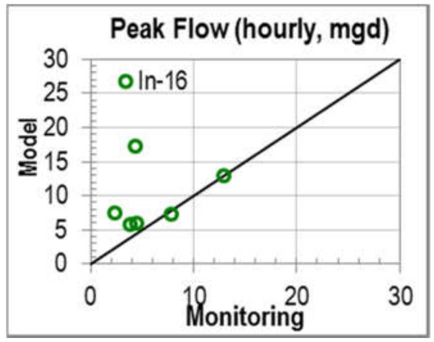
In-16 Model Validation Results (Metered and Modeled Flow)





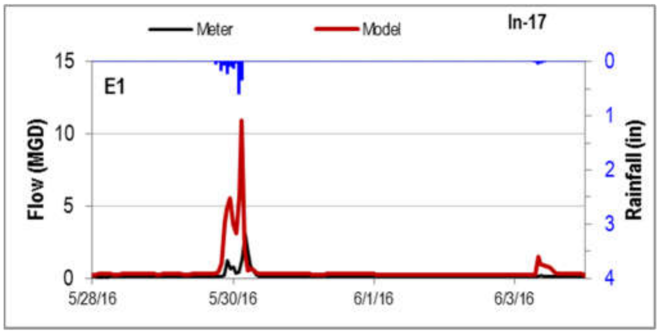
In-16 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

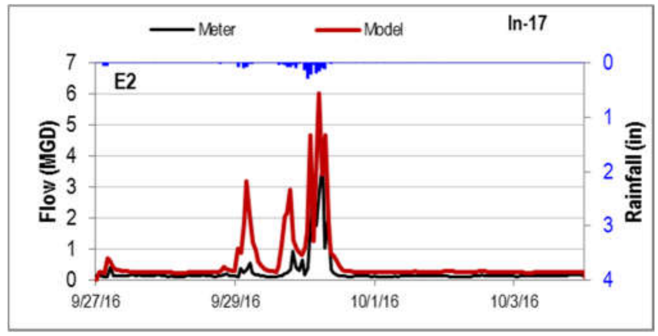


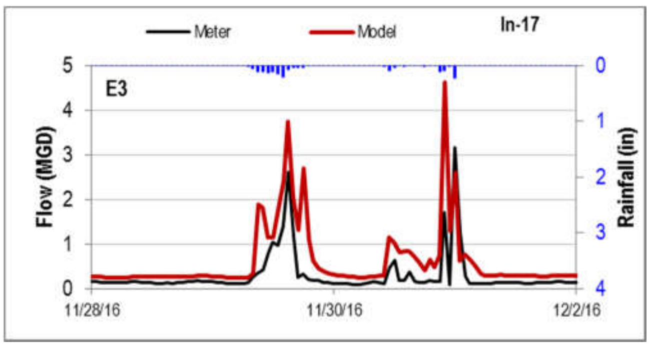


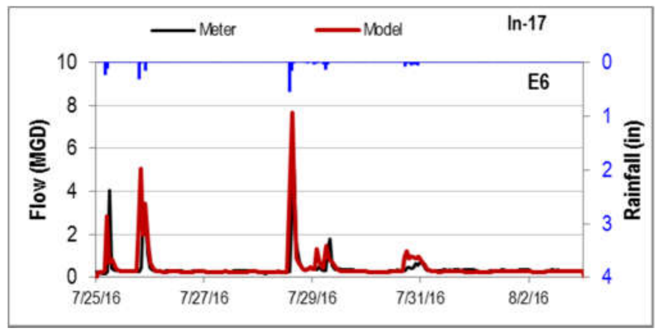
FLOW METER IN-17 MODEL CALIBRATION AND VALIDATION RESULTS

In-17 Model Calibration Results (Metered and Modeled Flow)

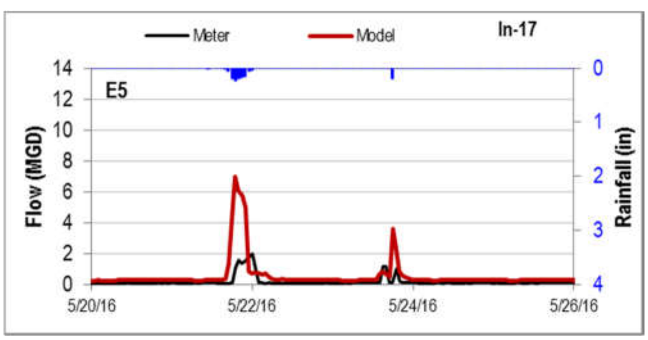


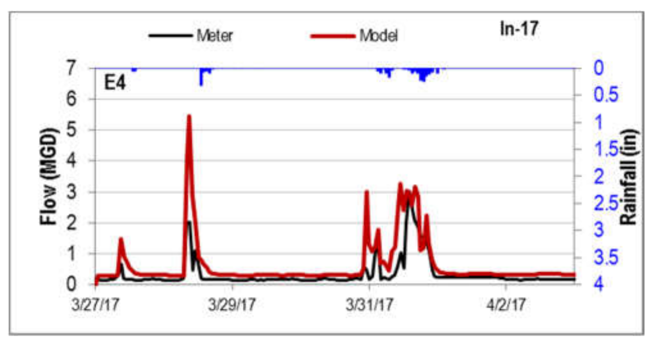




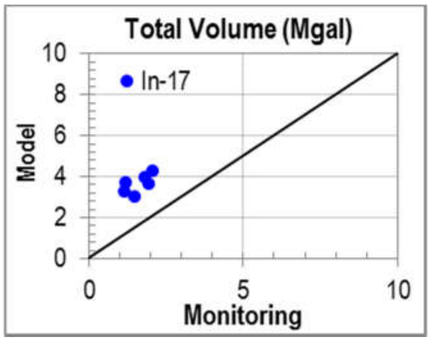


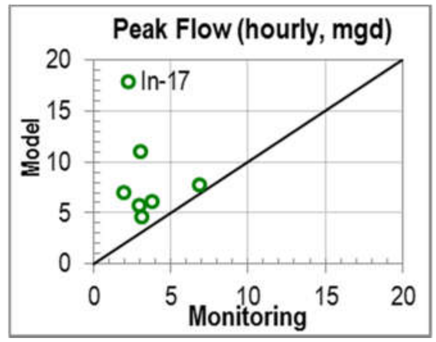
In-17 Model Validation Results (Metered and Modeled Flow)





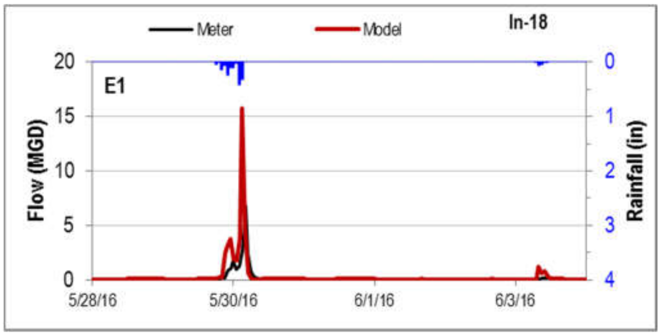
In-17 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

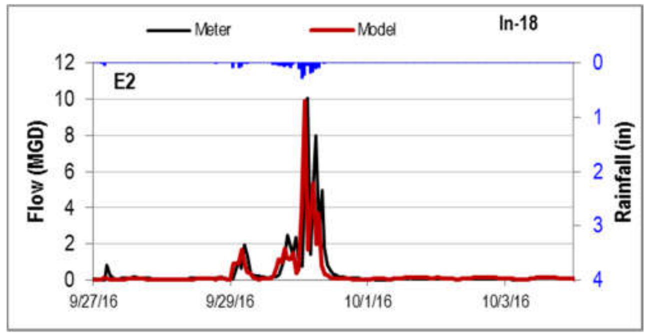


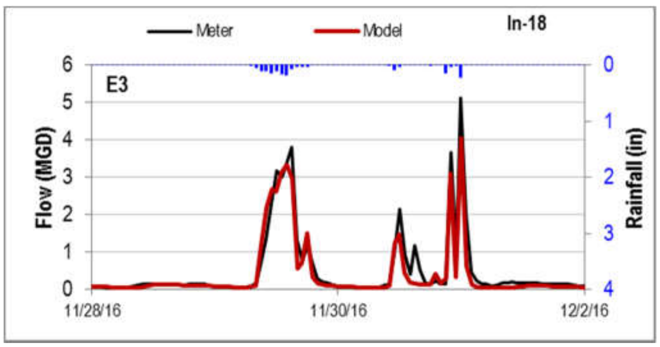


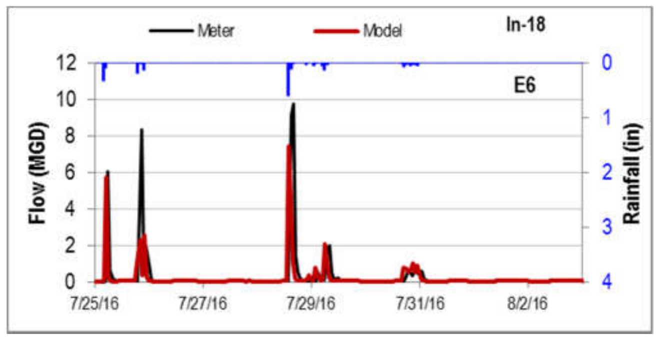
FLOW METER IN-18 MODEL CALIBRATION AND VALIDATION RESULTS

In-18 Model Calibration Results (Metered and Modeled Flow)

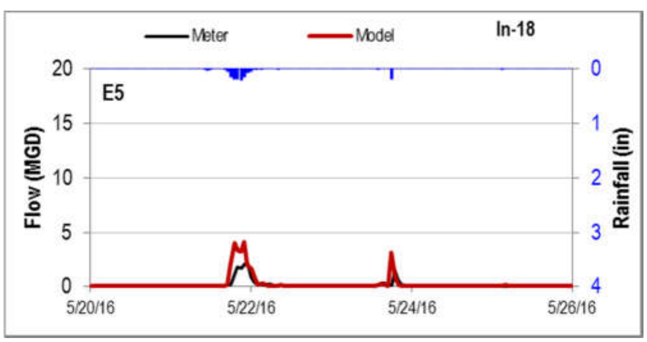


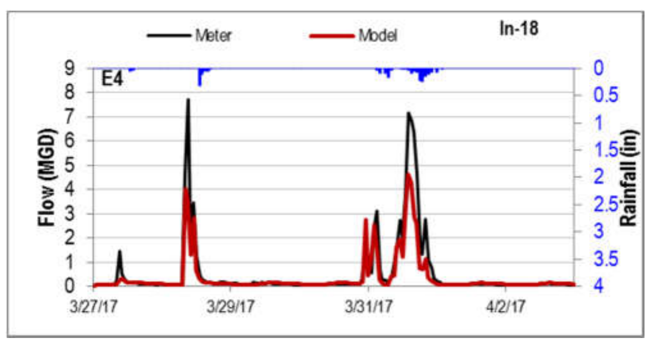




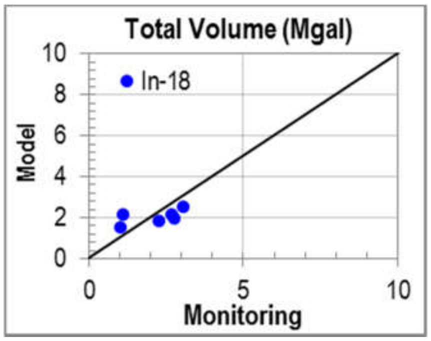


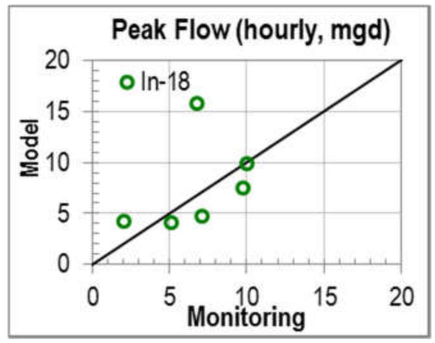
In-18 Model Validation Results (Metered and Modeled Flow)





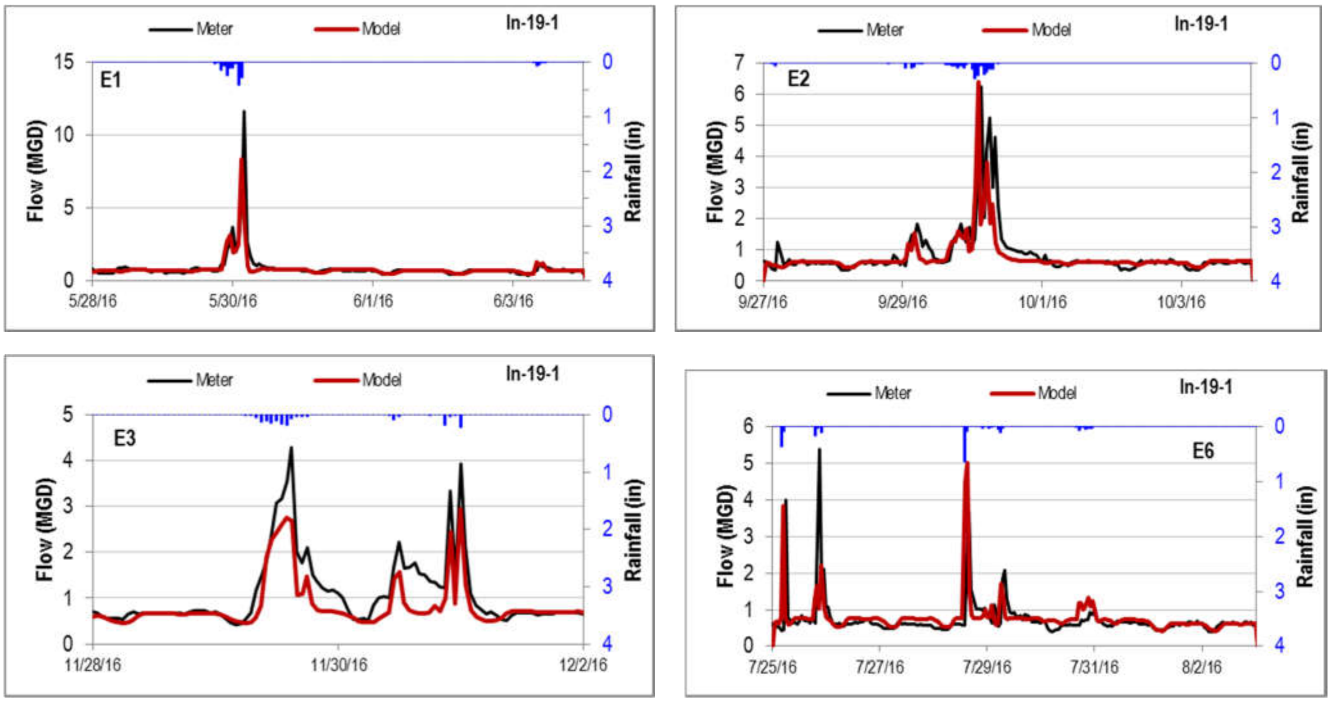
In-18 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



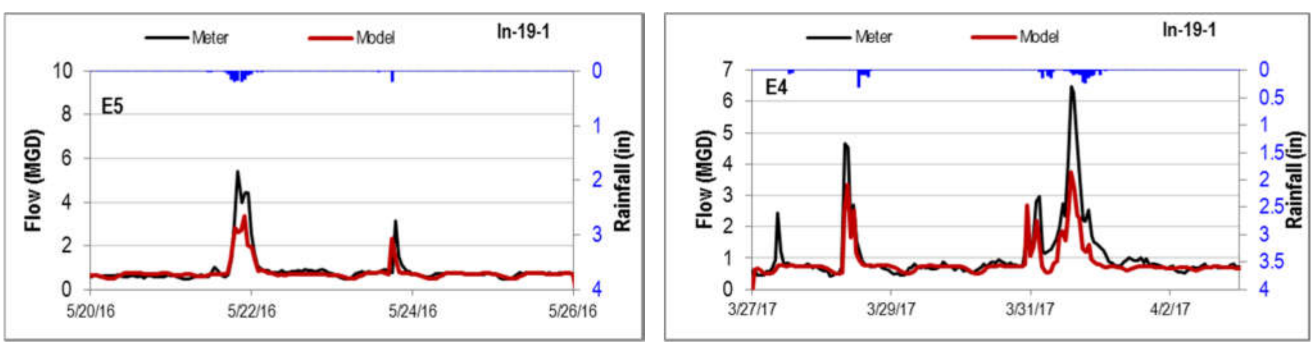


FLOW METER IN-19-1 MODEL CALIBRATION AND VALIDATION RESULTS

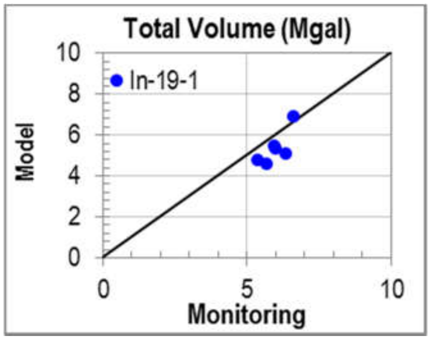
In-19-1 Model Calibration Results (Metered and Modeled Flow)

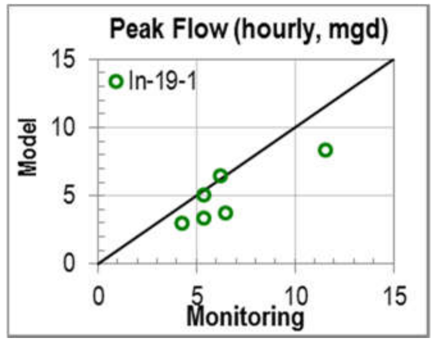


In-19-1 Model Validation Results (Metered and Modeled Flow)



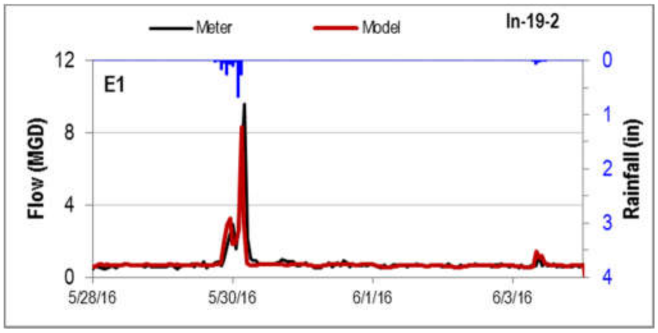
In-19-1 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

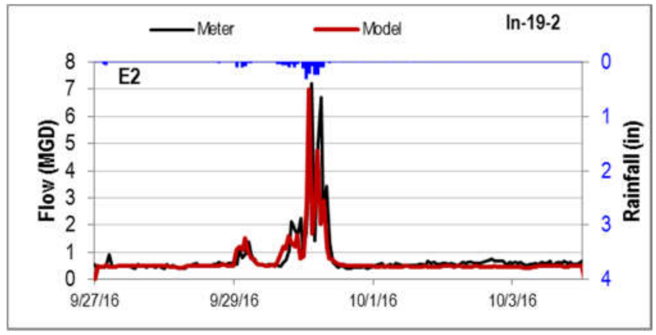


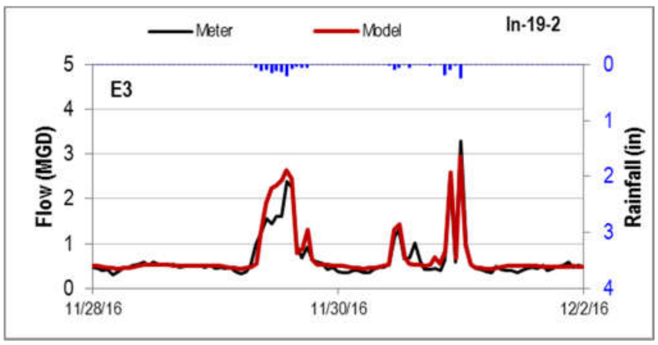


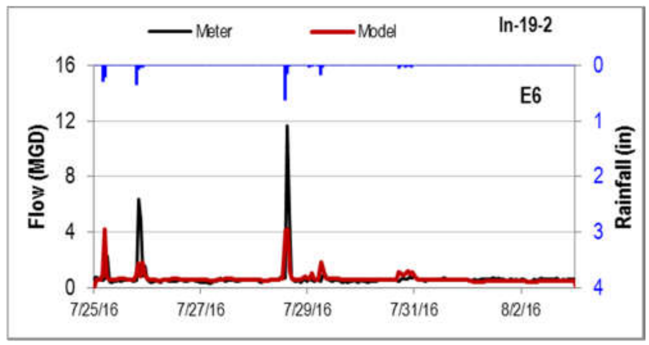
FLOW METER IN-19-2 MODEL CALIBRATION AND VALIDATION RESULTS

In-19-2 Model Calibration Results (Metered and Modeled Flow)

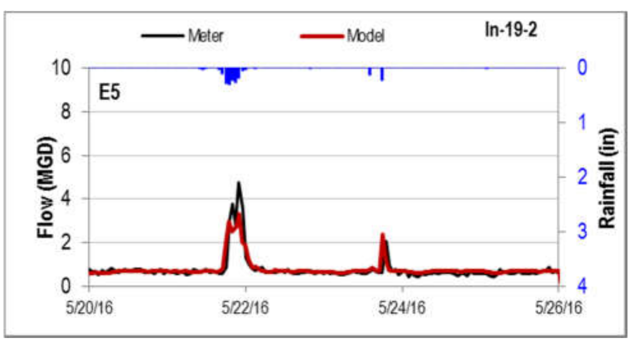


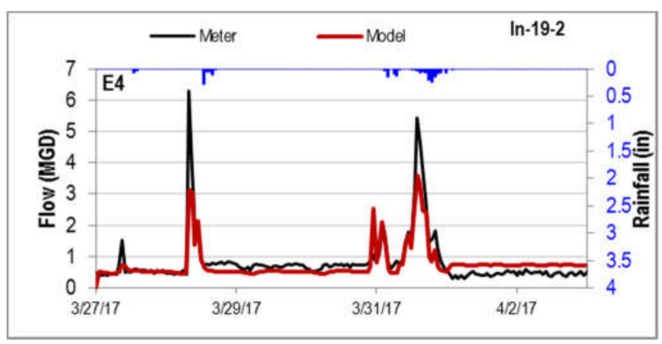




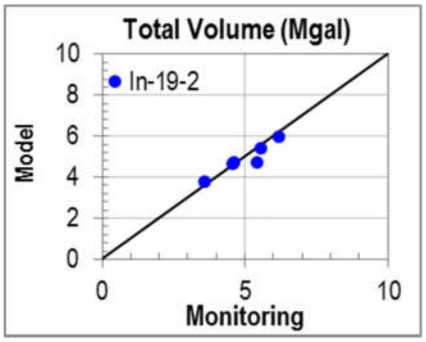


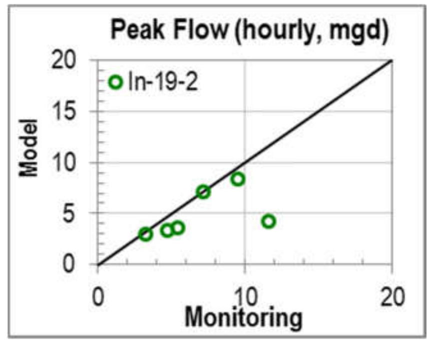
In-19-2 Model Validation Results (Metered and Modeled Flow)





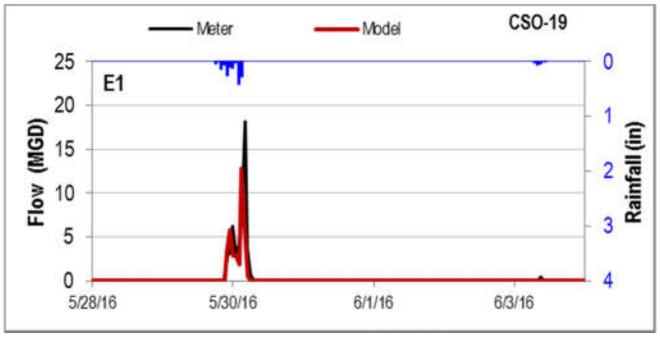
In-19-2 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

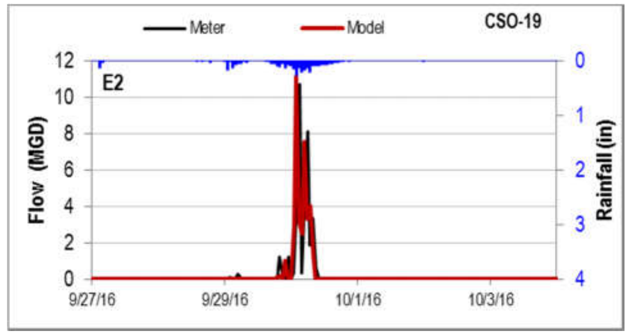


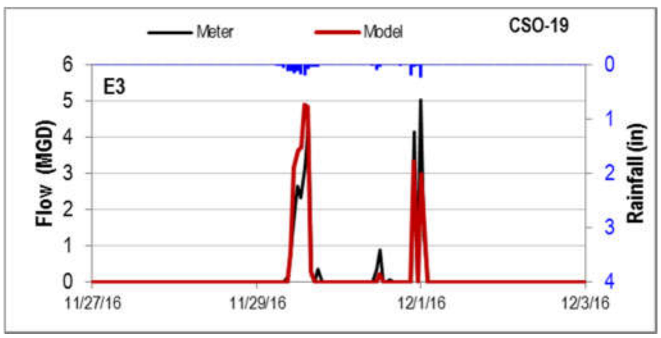


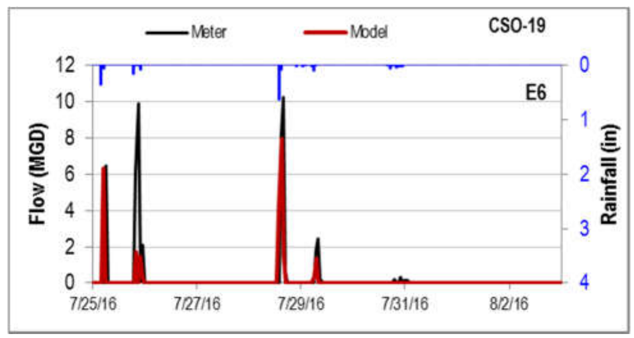
FLOW METER CSO-19 MODEL CALIBRATION AND VALIDATION RESULTS

CSO-19 Model Calibration Results (Metered and Modeled Flow)

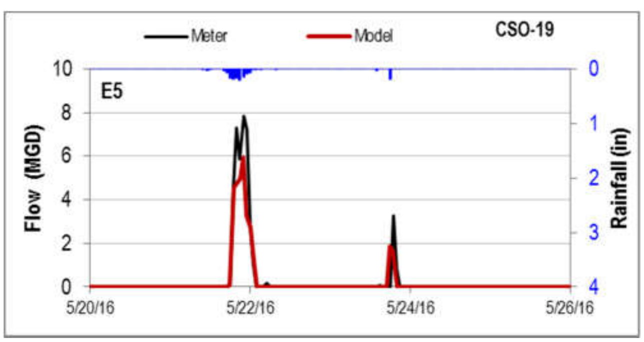


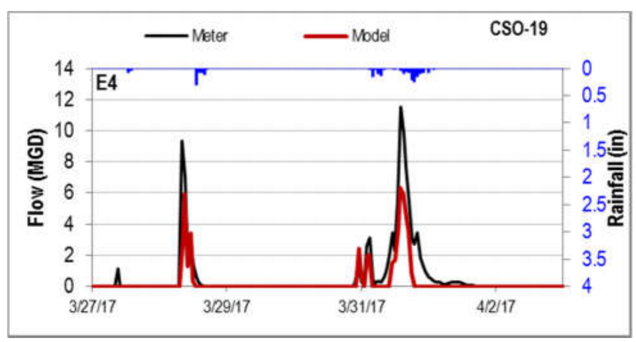




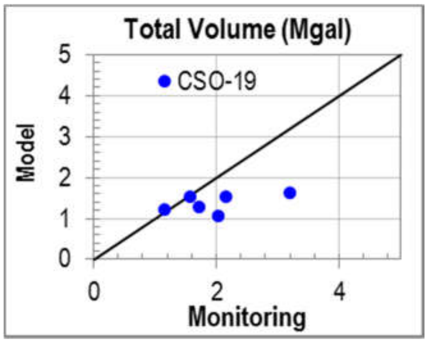


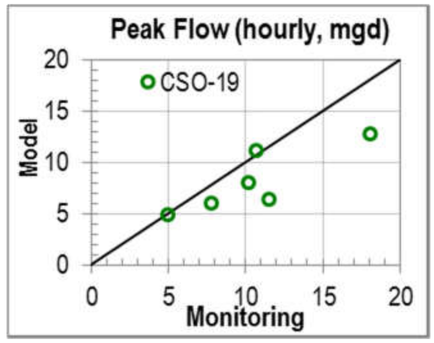
CSO-19 Model Validation Results (Metered and Modeled Flow)





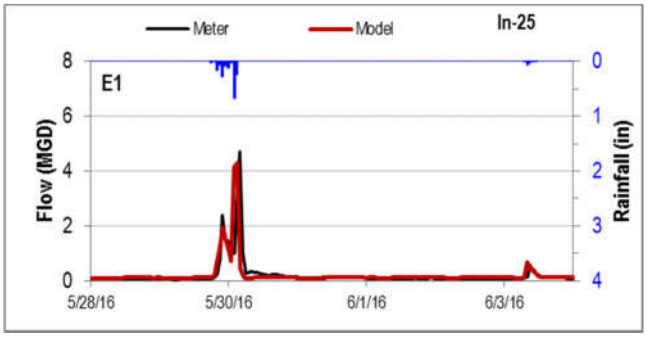
CSO-19 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

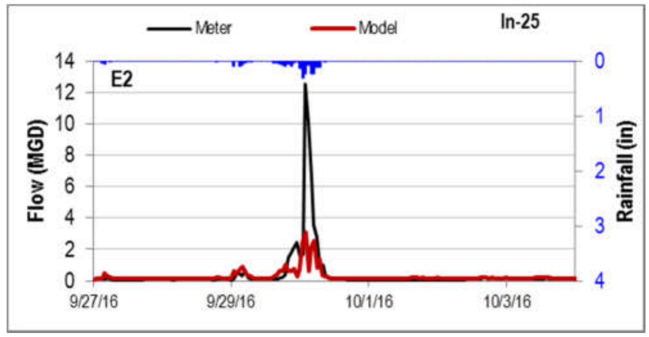


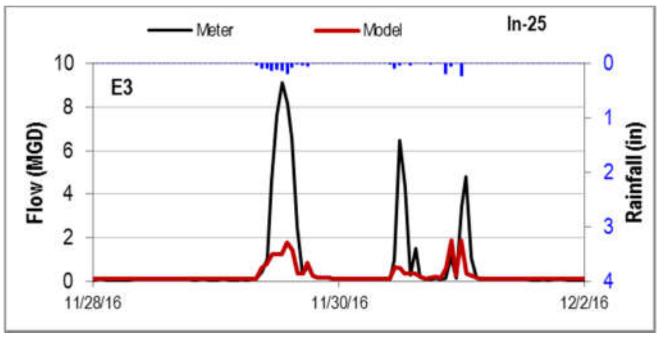


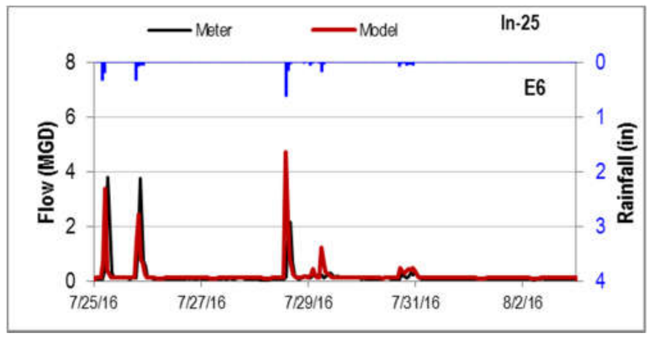
FLOW METER IN-25 MODEL CALIBRATION AND VALIDATION RESULTS

In-25 Model Calibration Results (Metered and Modeled Flow)

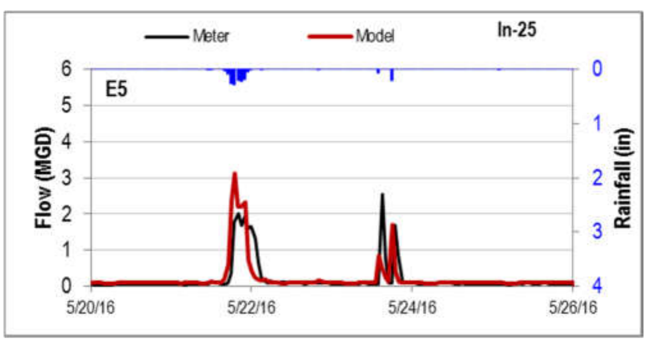


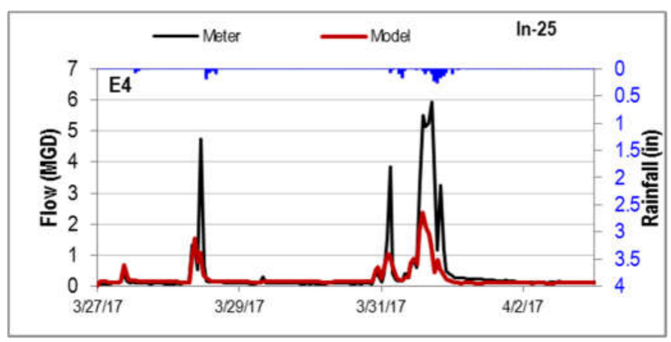




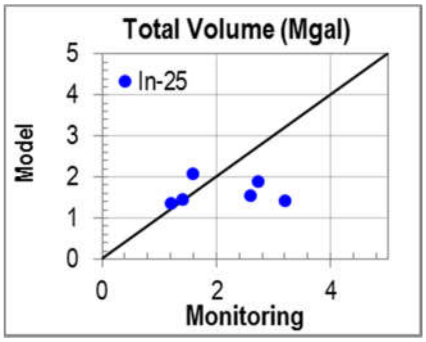


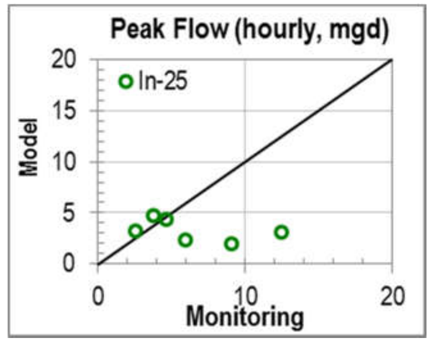
In-25 Model Validation Results (Metered and Modeled Flow)





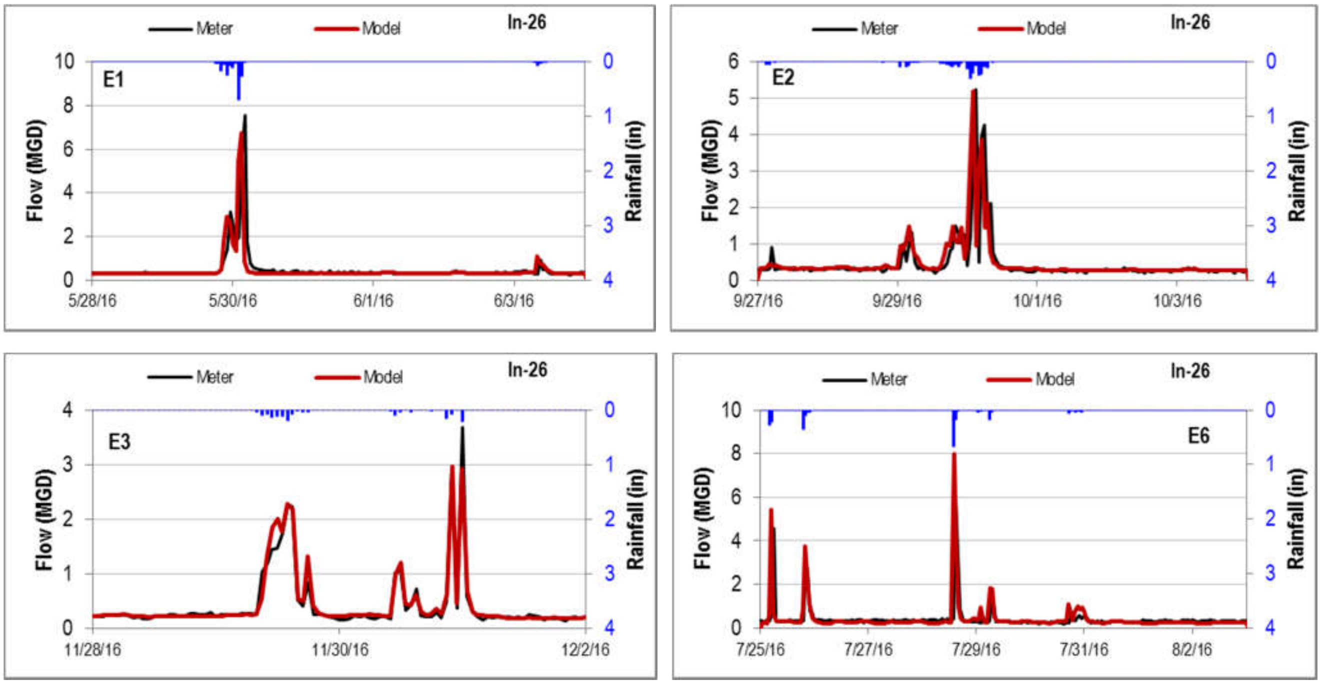
In-25 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



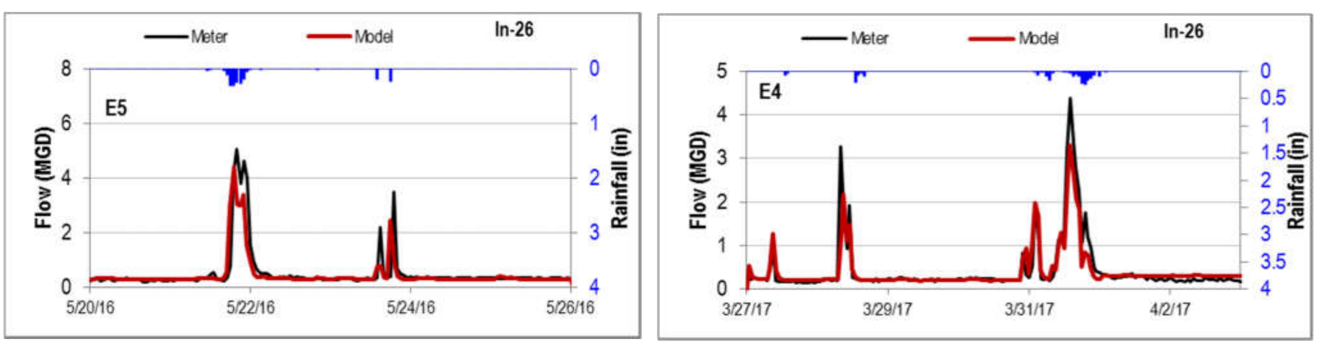


FLOW METER IN-26 MODEL CALIBRATION AND VALIDATION RESULTS

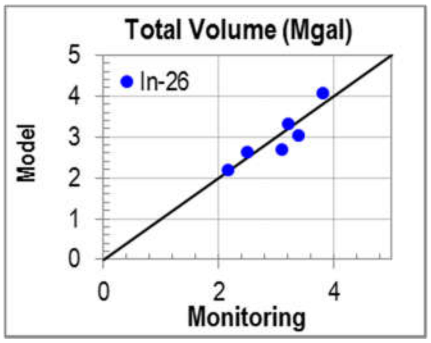
In-26 Model Calibration Results (Metered and Modeled Flow)

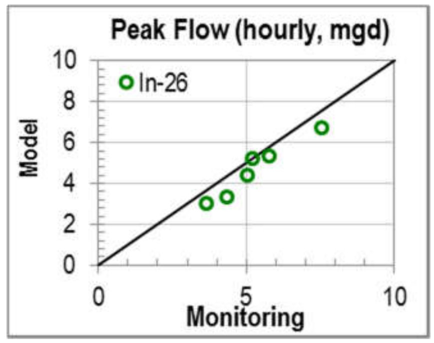


In-26 Model Validation Results (Metered and Modeled Flow)



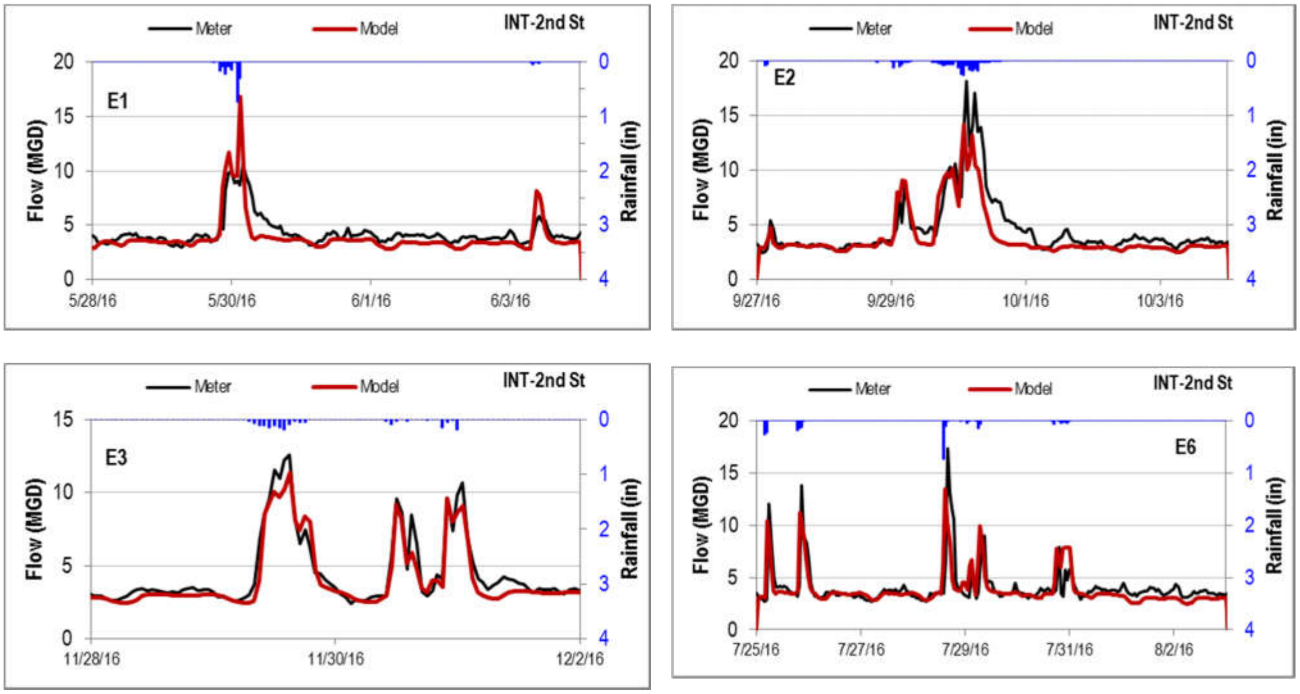
In-26 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



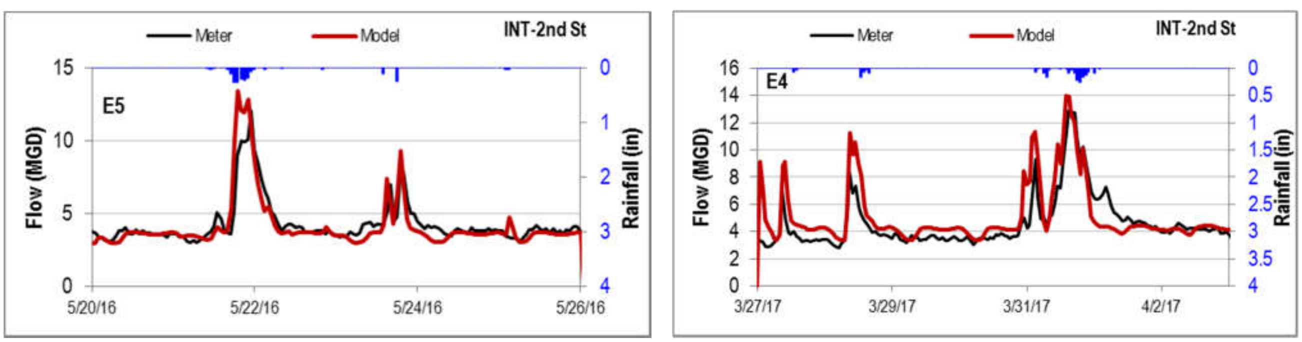


FLOW METER INT-2nd St MODEL CALIBRATION AND VALIDATION RESULTS

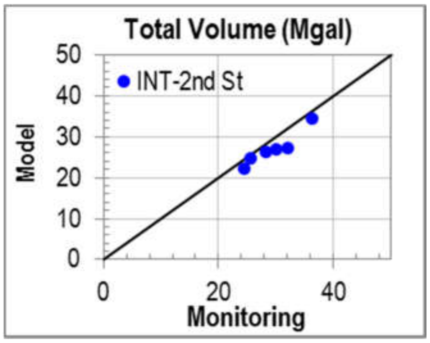
INT-2nd St Model Calibration Results (Metered and Modeled Flow)

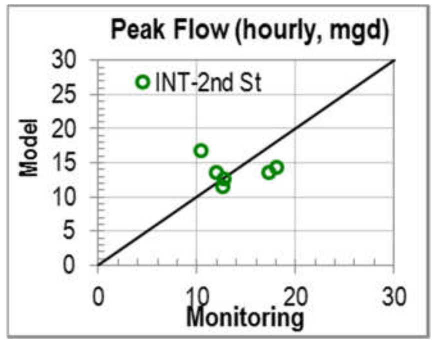


INT-2nd St Model Validation Results (Metered and Modeled Flow)



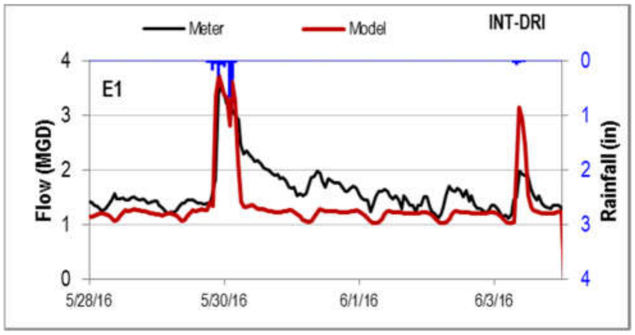
INT-2nd St Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

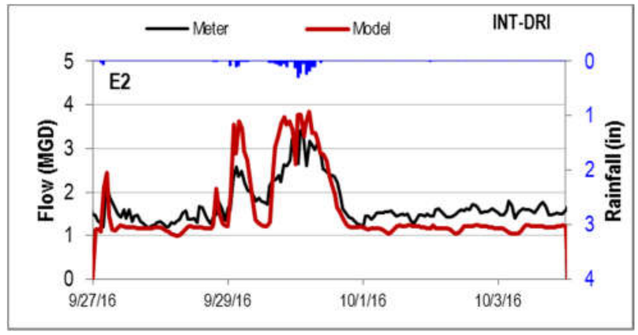


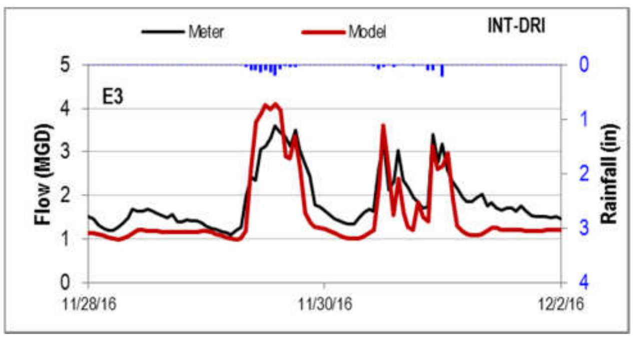


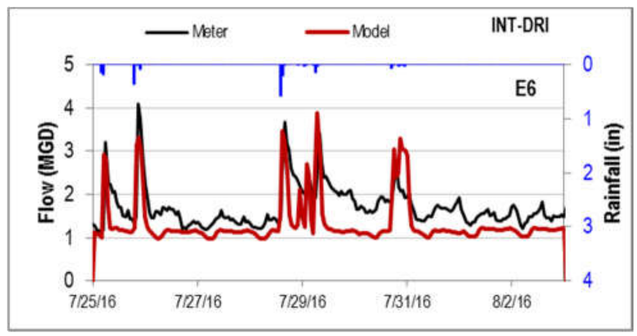
FLOW METER INT-DRI MODEL CALIBRATION AND VALIDATION RESULTS

INT-DRI Model Calibration Results (Metered and Modeled Flow)

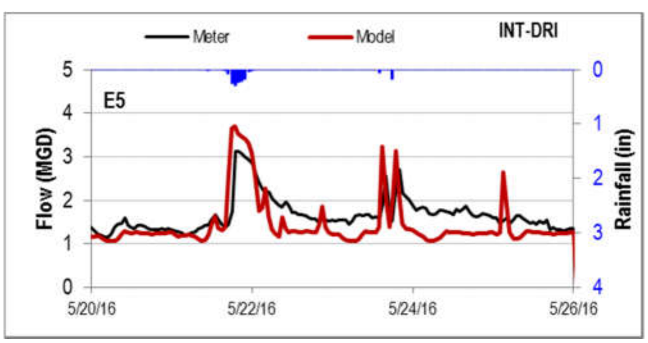


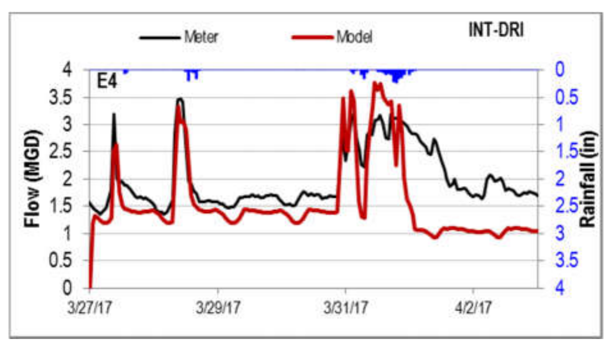




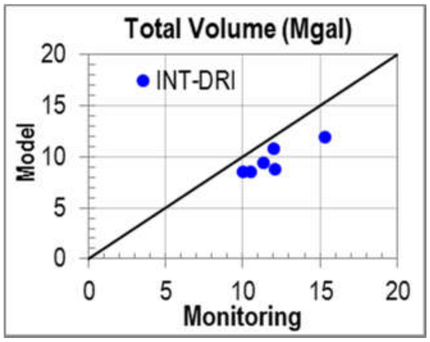


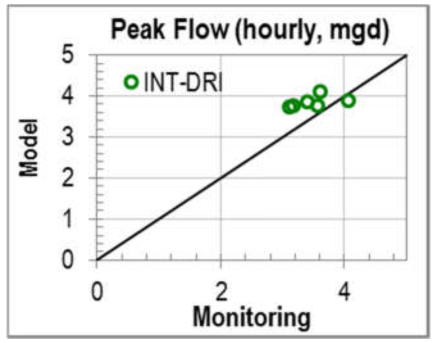
INT-DRI Model Validation Results (Metered and Modeled Flow)





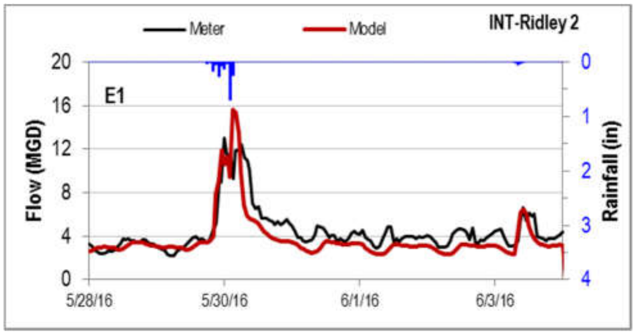
INT-DRI Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

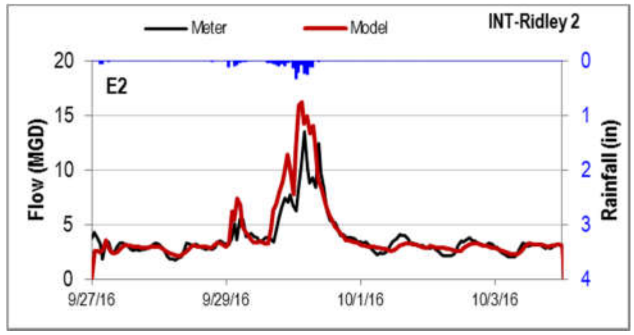


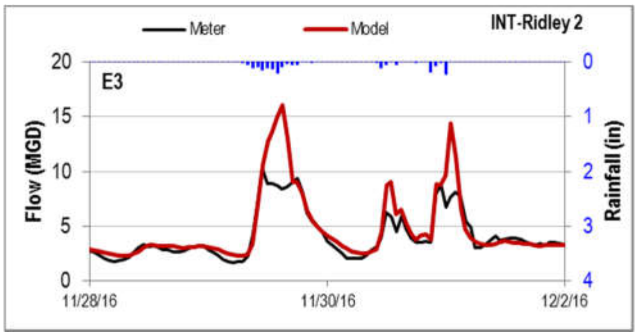


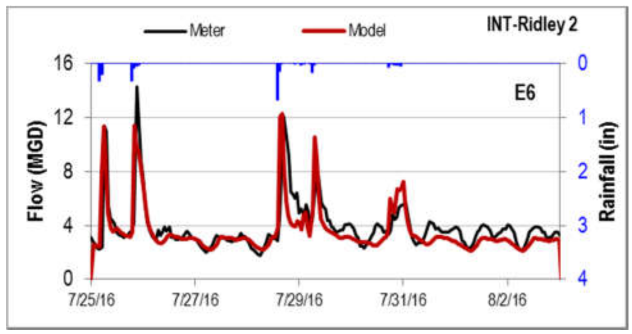
FLOW METER INT-Ridley 2 MODEL CALIBRATION AND VALIDATION RESULTS

INT-Ridley 2 Model Calibration Results (Metered and Modeled Flow)

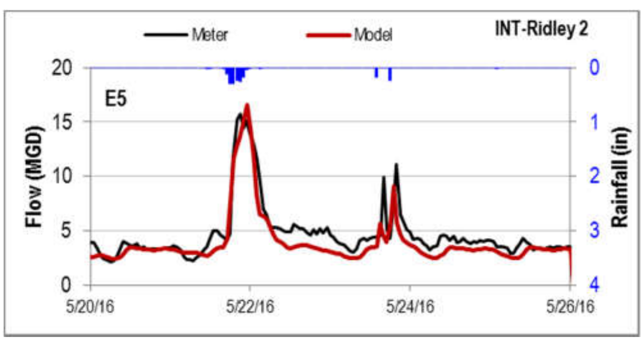


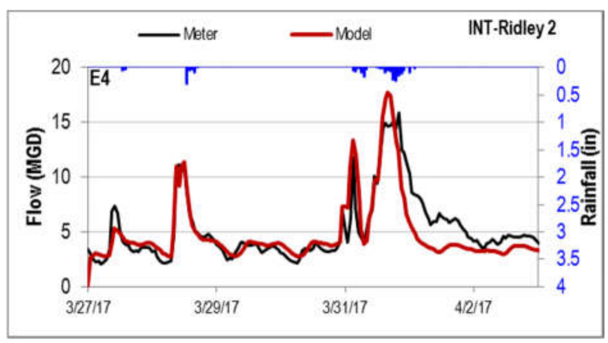




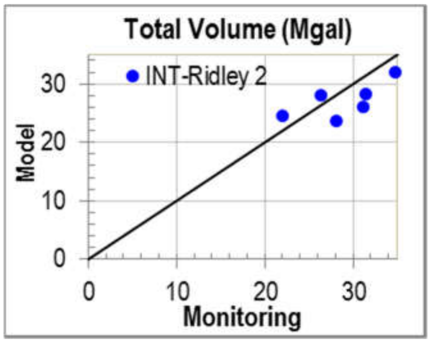


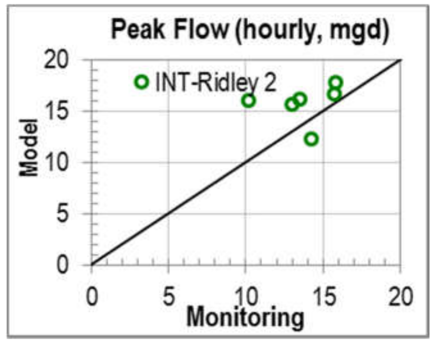
INT-Ridley 2 Model Validation Results (Metered and Modeled Flow)





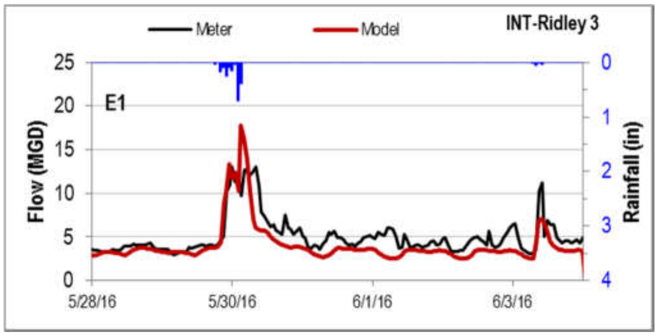
INT-Ridley-2 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

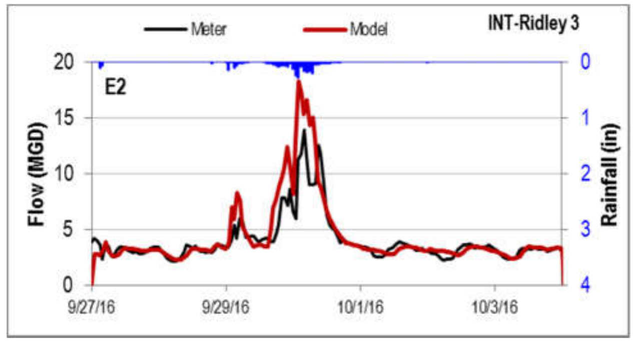


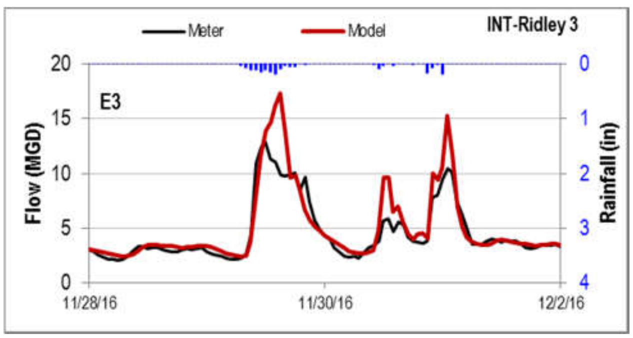


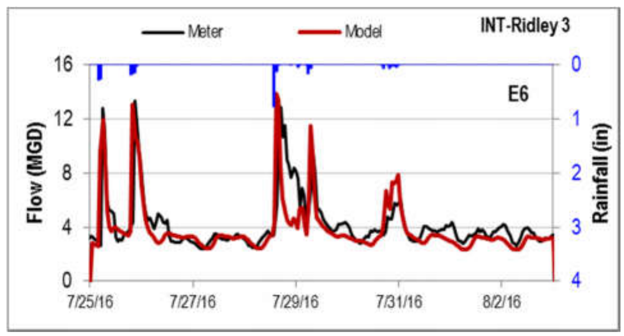
FLOW METER INT-Ridley 3 MODEL CALIBRATION AND VALIDATION RESULTS

INT-Ridley 3 Model Calibration Results (Metered and Modeled Flow)

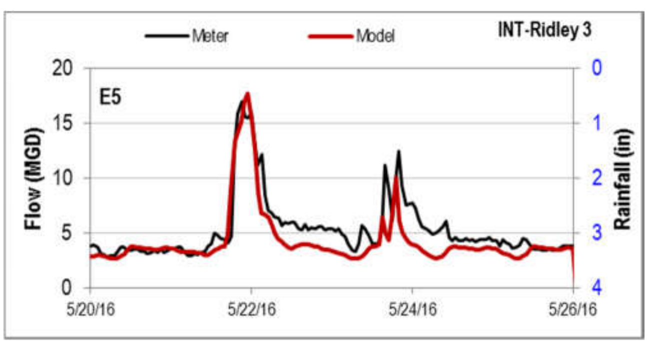


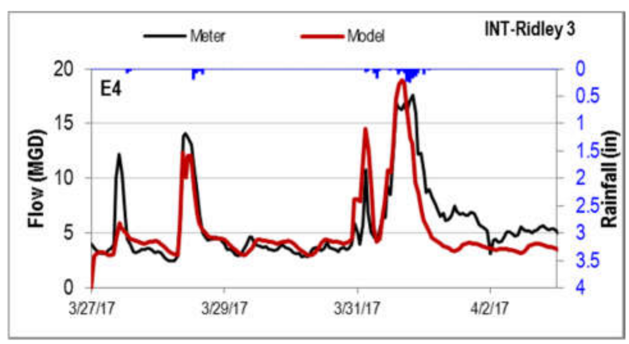




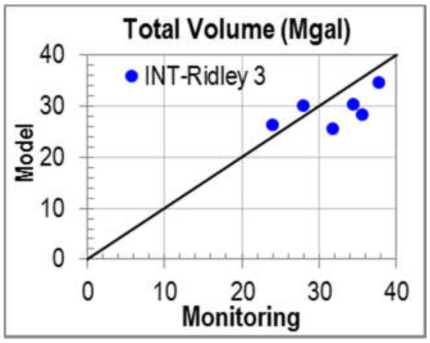


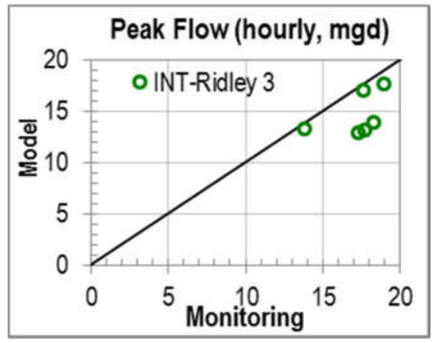
INT-Ridley 3 Model Validation Results (Metered and Modeled Flow)





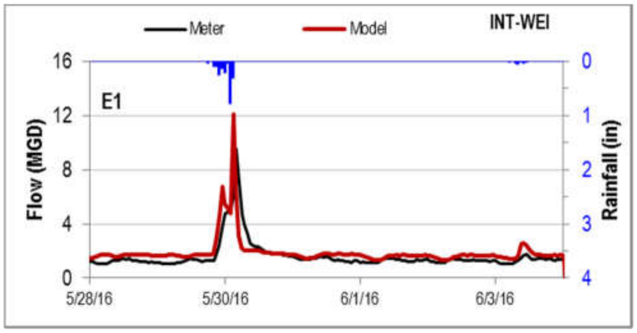
INT-Ridley 3 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

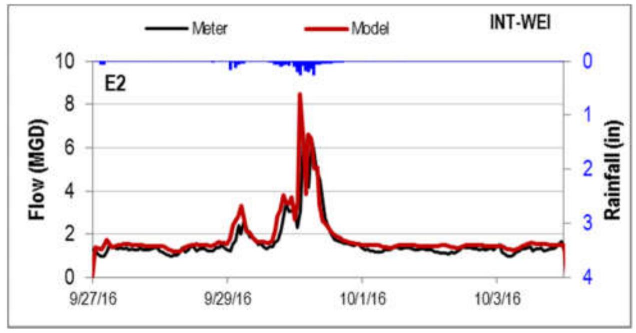


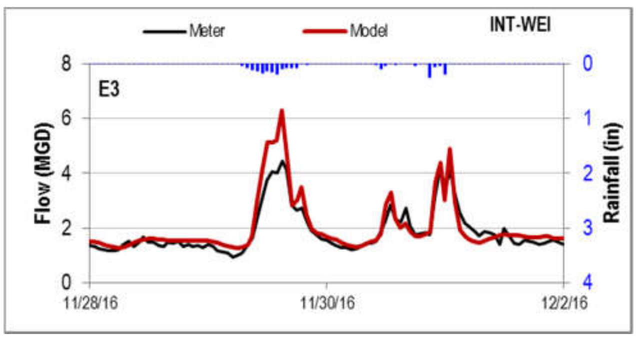


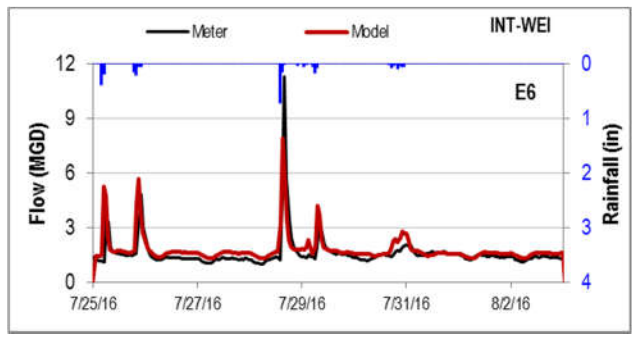
FLOW METER INT-WEI MODEL CALIBRATION AND VALIDATION RESULTS

INT-WEI Model Calibration Results (Metered and Modeled Flow)

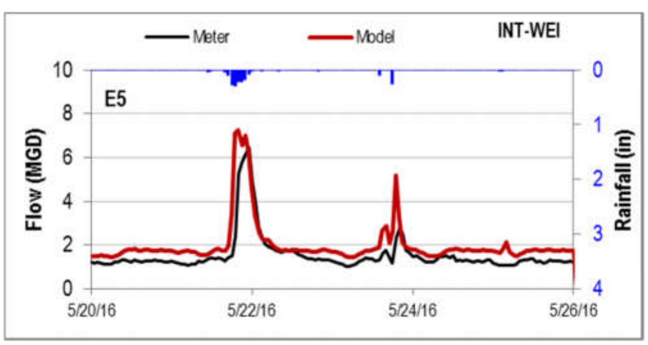


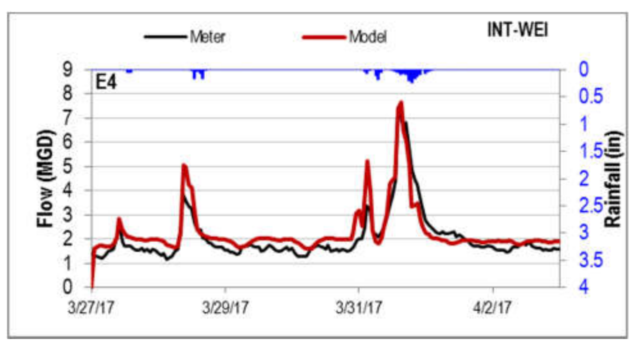




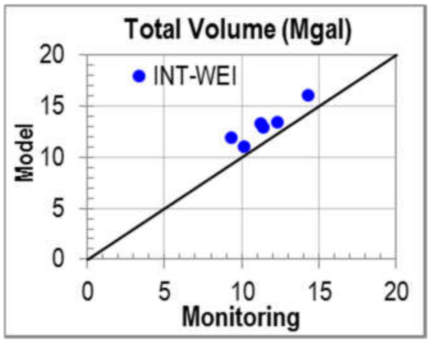


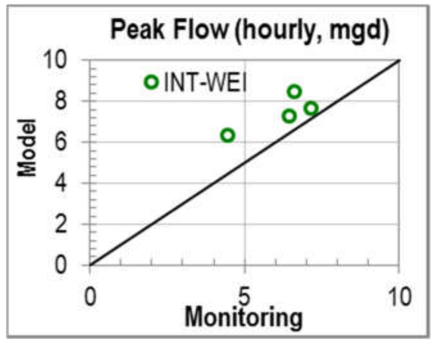
INT-WEI Model Validation Results (Metered and Modeled Flow)





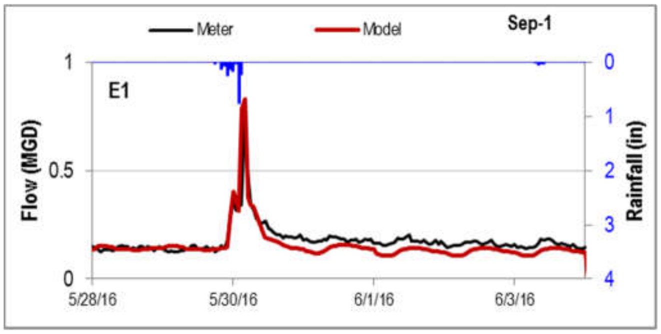
INT-WEI Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

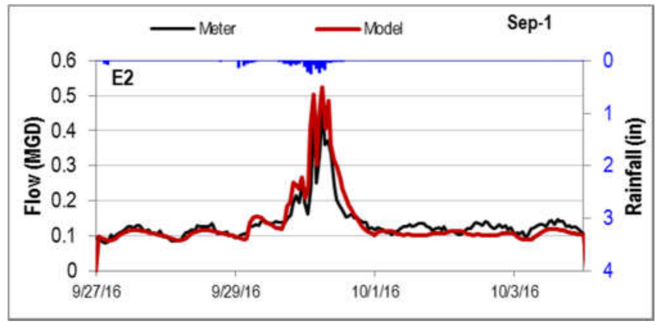


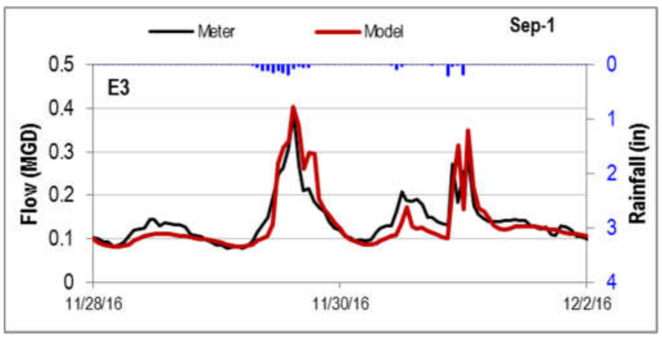


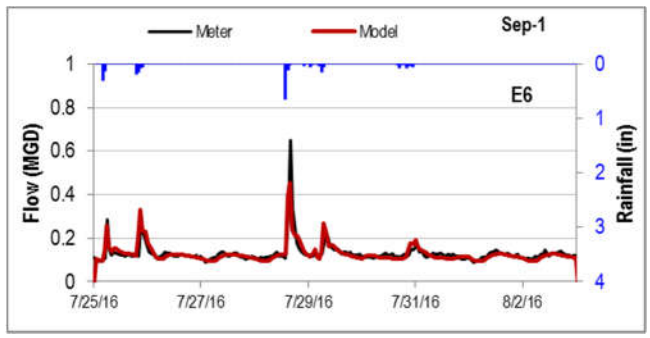
FLOW METER Sep-1 MODEL CALIBRATION AND VALIDATION RESULTS

Sep-1 Model Calibration Results (Metered and Modeled Flow)

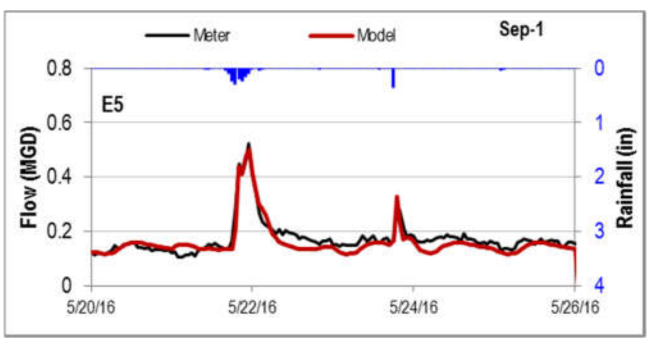


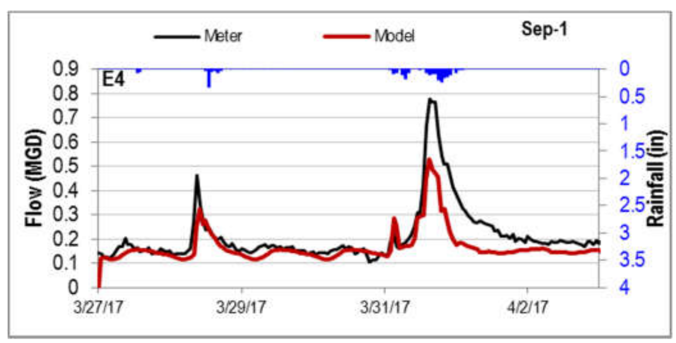




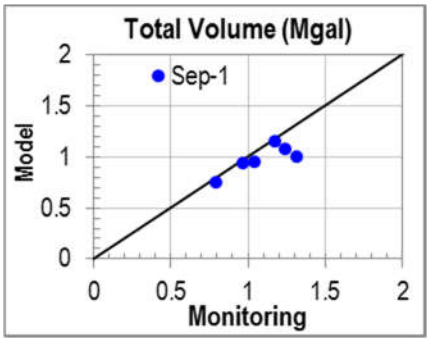


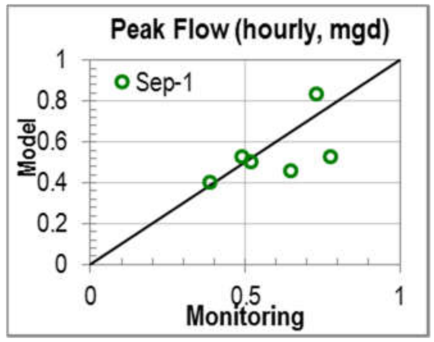
Sep-1 Model Validation Results (Metered and Modeled Flow)





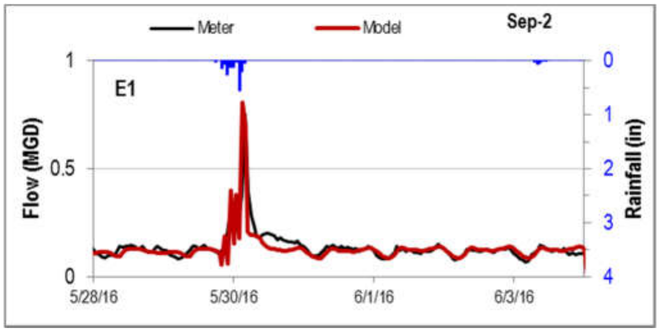
Sep-1 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

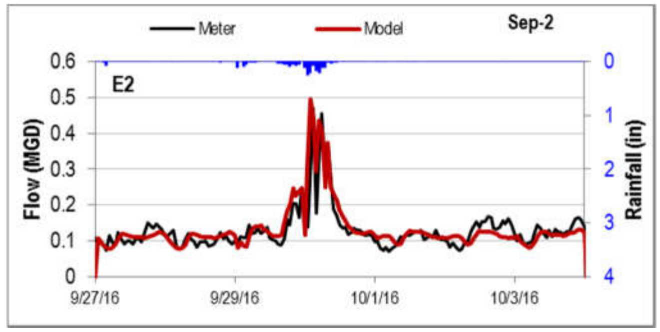


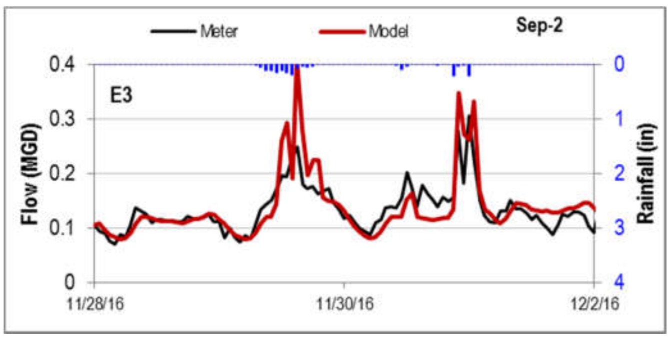


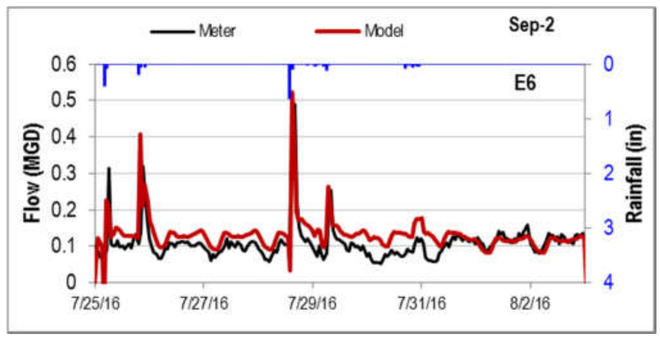
FLOW METER Sep-2 MODEL CALIBRATION AND VALIDATION RESULTS

Sep-2 Model Calibration Results (Metered and Modeled Flow)

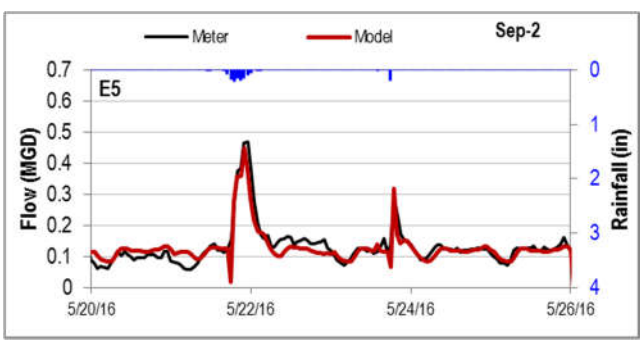


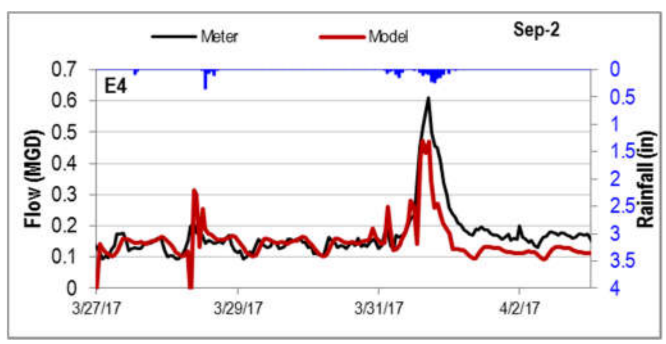




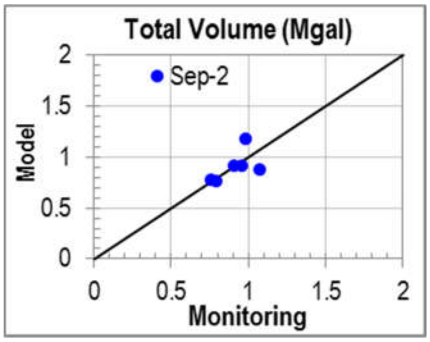


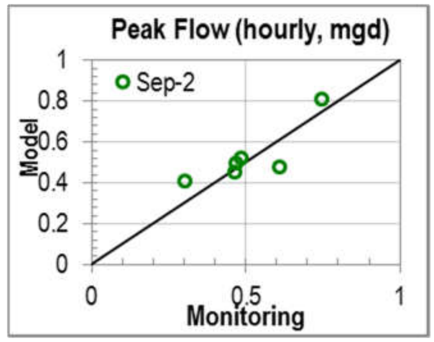
Sep-2 Model Validation Results (Metered and Modeled Flow)





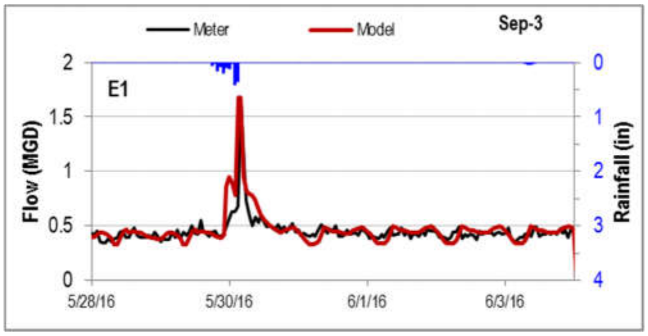
Sep-2 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

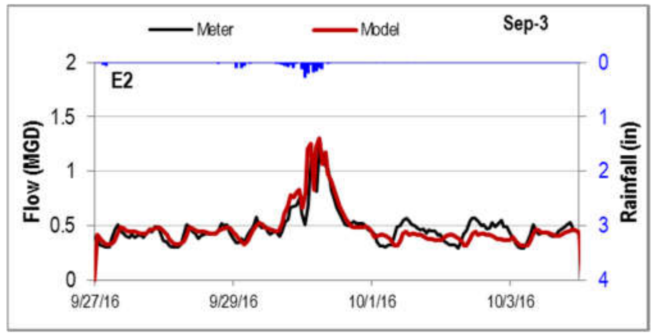


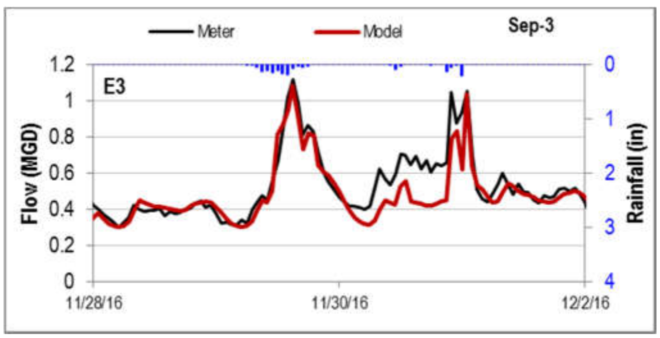


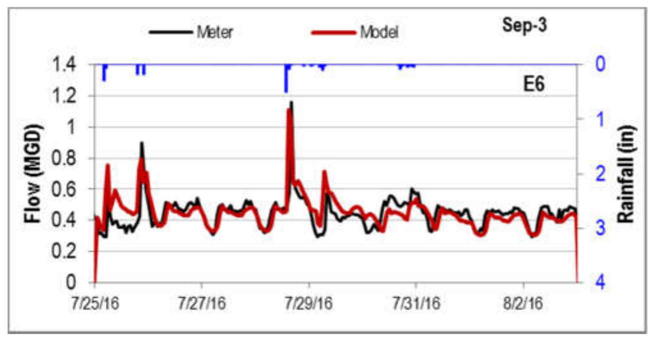
FLOW METER Sep-3 MODEL CALIBRATION AND VALIDATION RESULTS

Sep-3 Model Calibration Results (Metered and Modeled Flow)

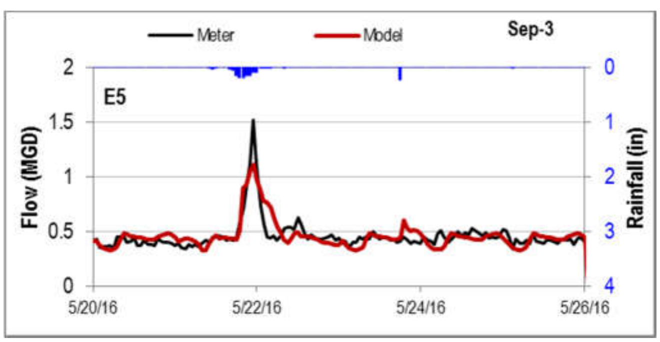


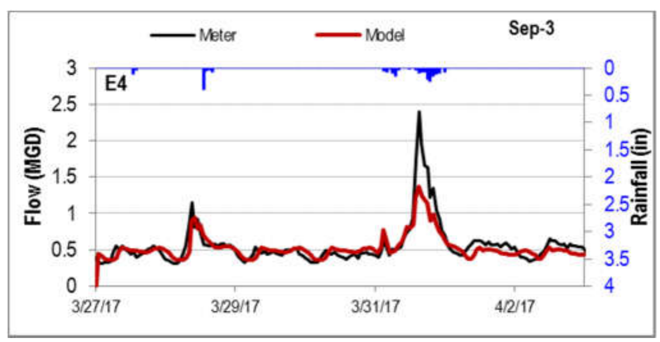




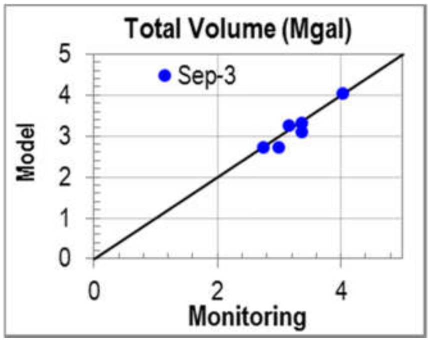


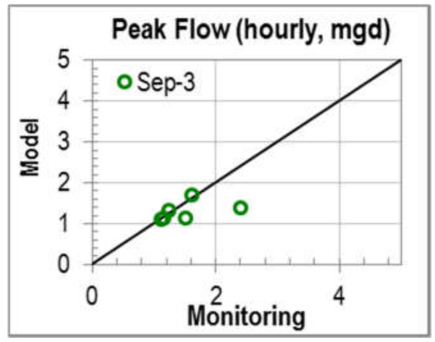
Sep-3 Model Validation Results (Metered and Modeled Flow)





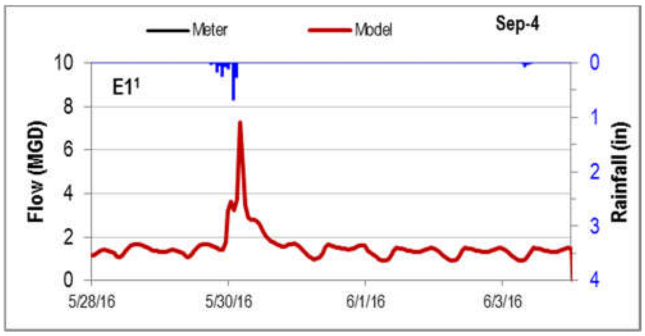
Sep-3 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

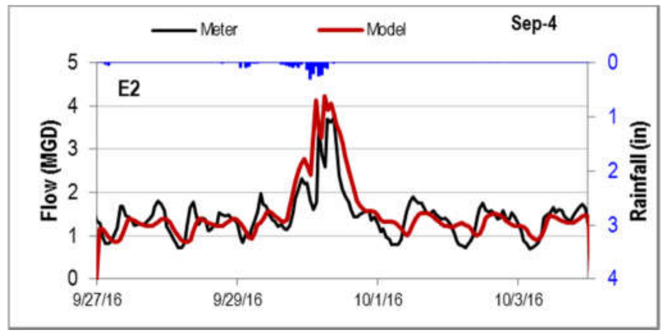


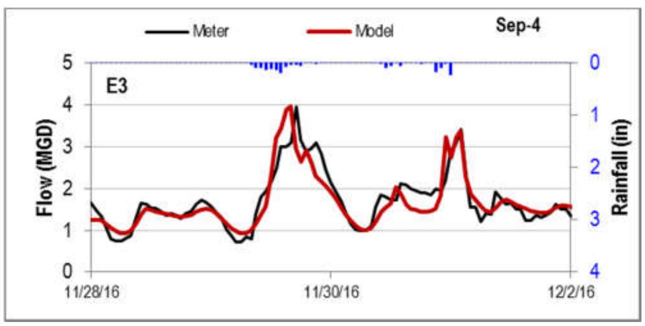


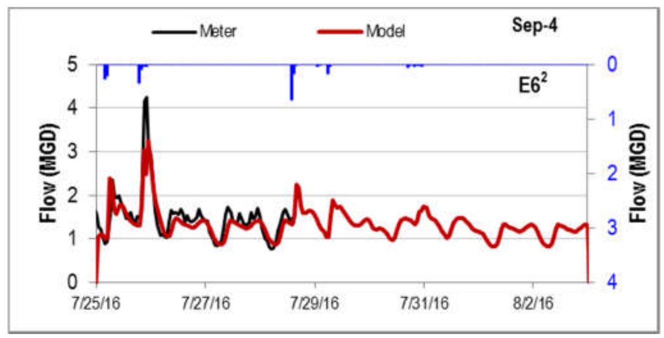
FLOW METER Sep-4 MODEL CALIBRATION AND VALIDATION RESULTS

Sep-4 Model Calibration Results (Metered and Modeled Flow)

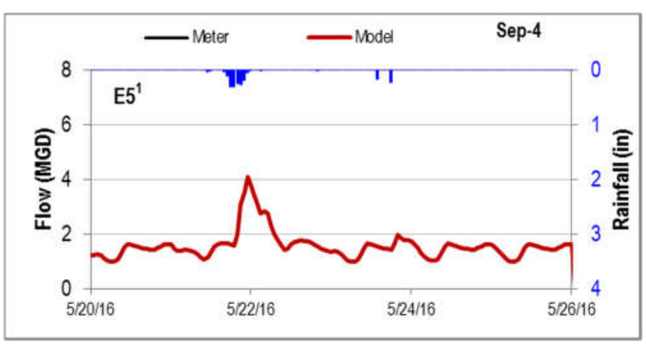


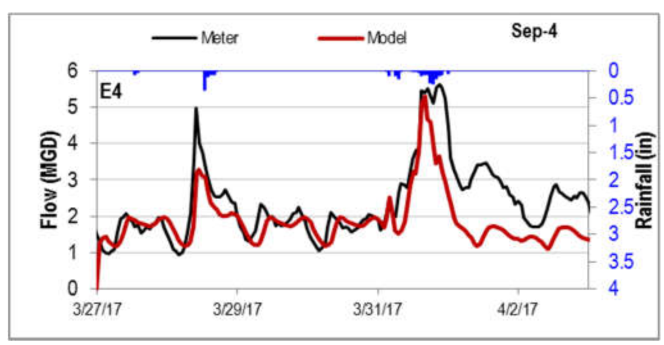






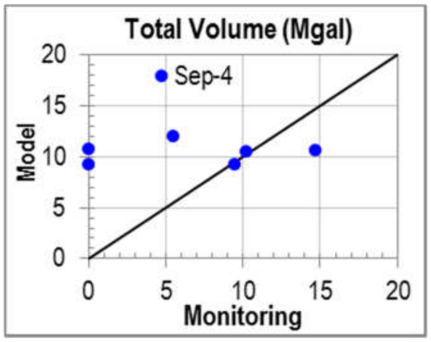
Sep-4 Model Validation Results (Metered and Modeled Flow)

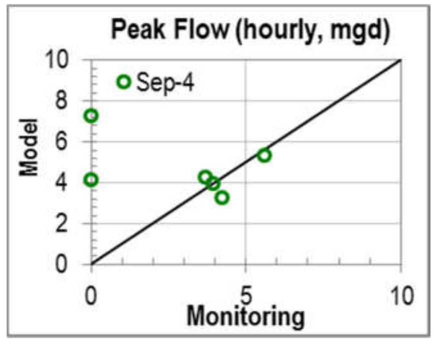




NOTE:
[1] Flow Meter installed June 2016.
[2] Flow Meter was taken out of service for maintenance.

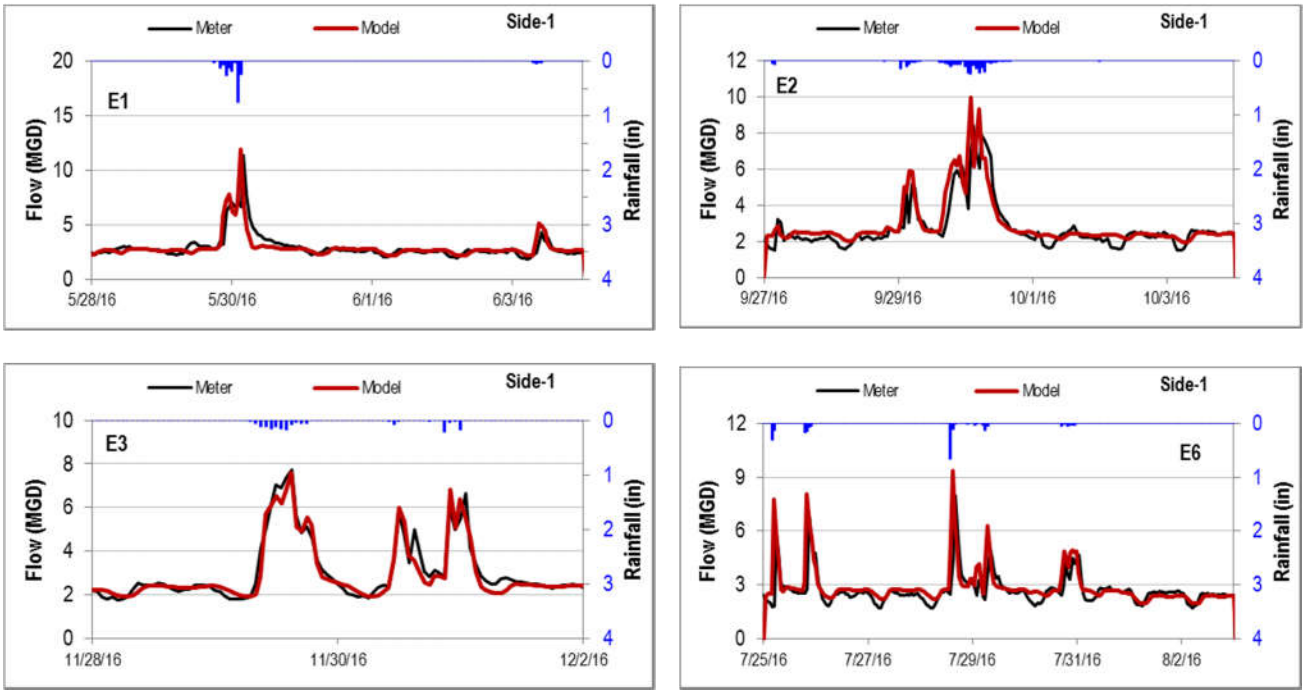
Sep-4 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



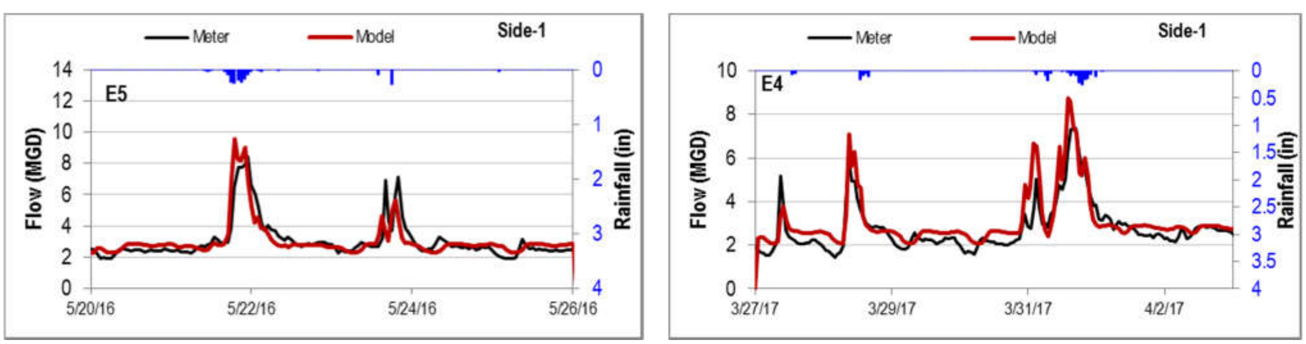


FLOW METER Side-1 MODEL CALIBRATION AND VALIDATION RESULTS

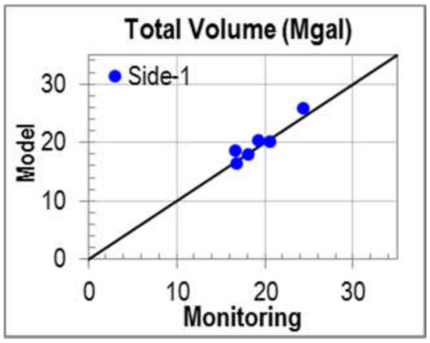
Side-1 Model Calibration Results (Metered and Modeled Flow)

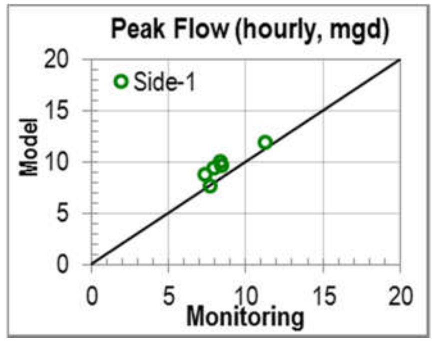


Side-1 Model Validation Results (Metered and Modeled Flow)



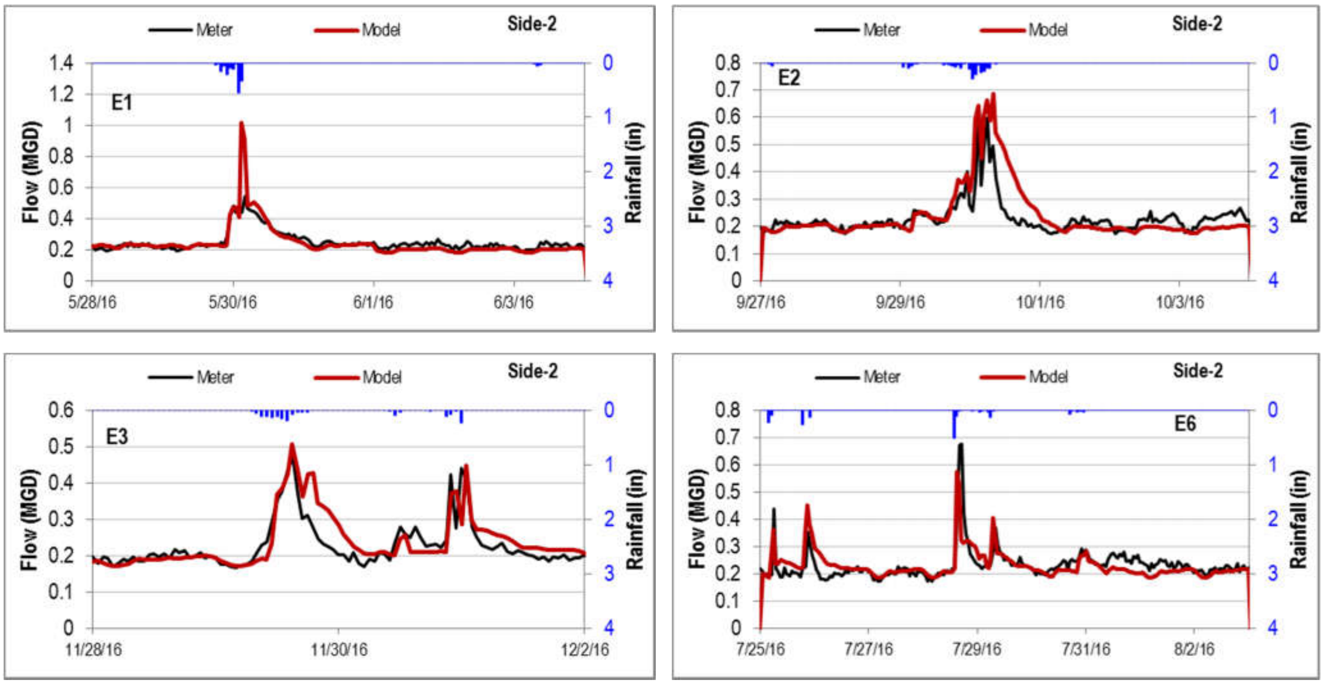
Side-1 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



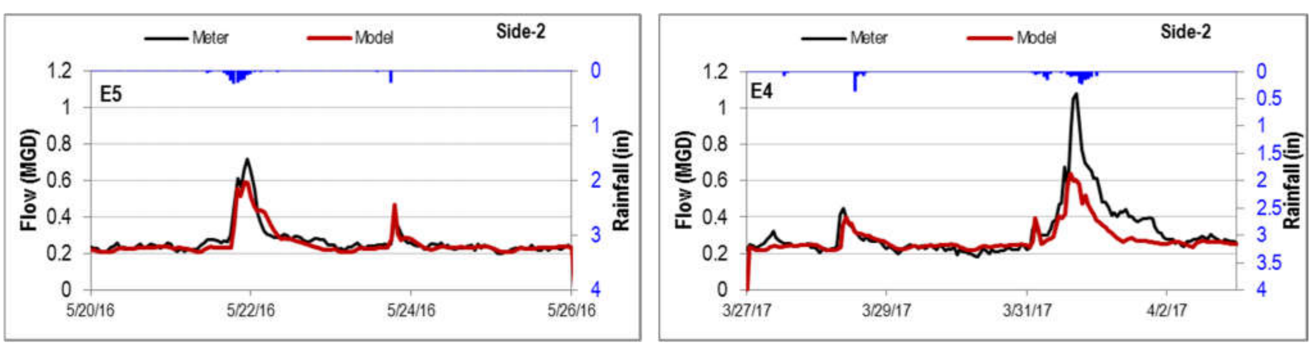


FLOW METER Side-2 MODEL CALIBRATION AND VALIDATION RESULTS

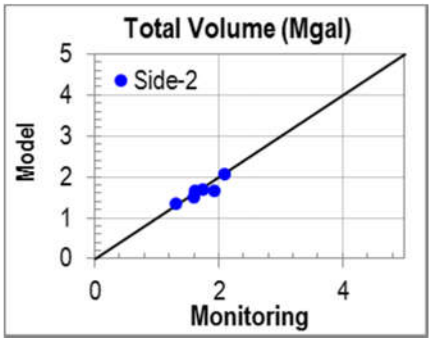
Side-2 Model Calibration Results (Metered and Modeled Flow)

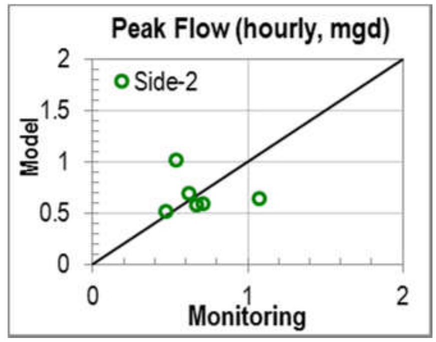


Side-2 Model Validation Results (Metered and Modeled Flow)



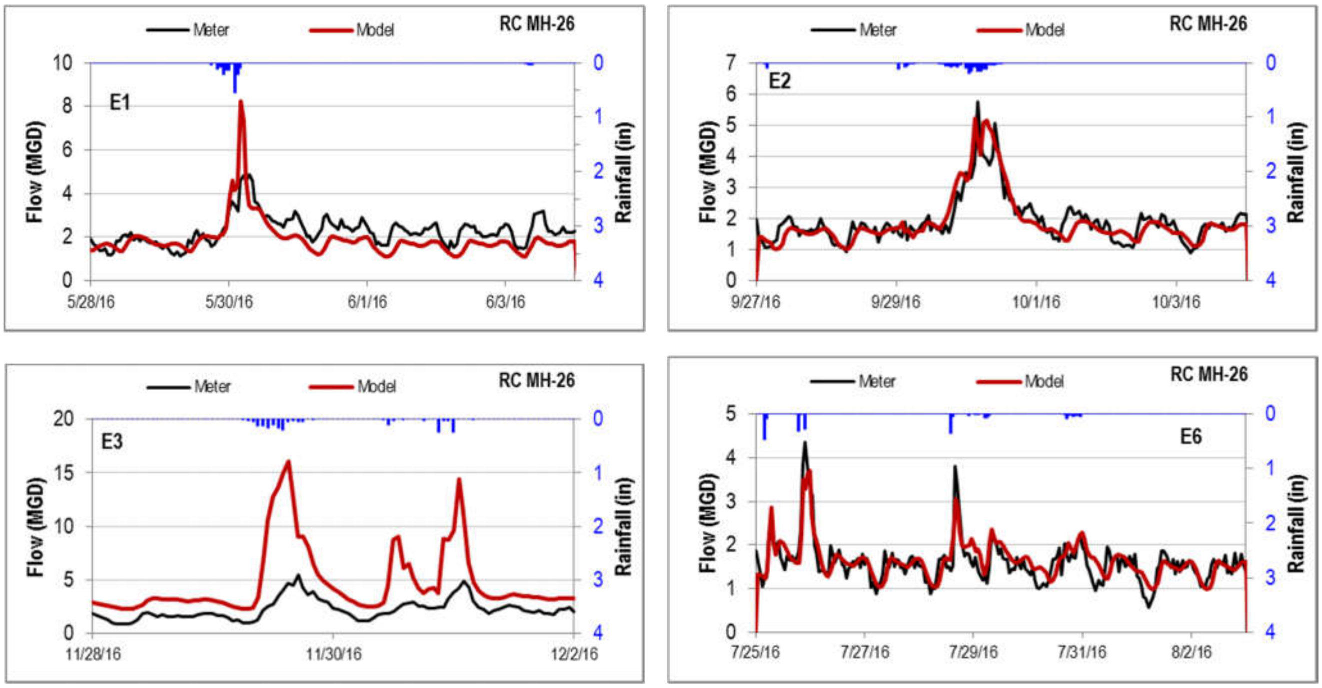
Side-2 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



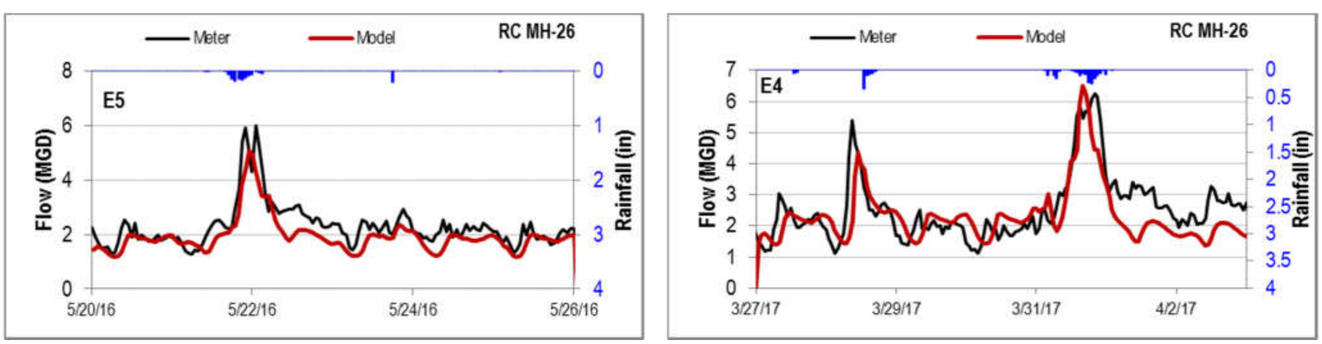


FLOW METER RC MH-26 MODEL CALIBRATION AND VALIDATION RESULTS

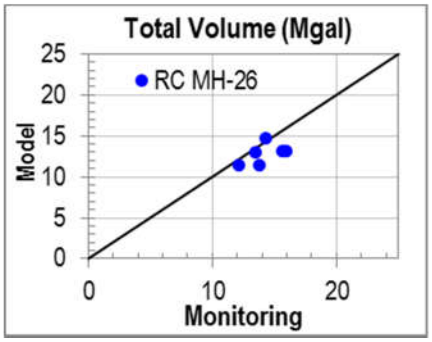
RC MH-26 Model Calibration Results (Metered and Modeled Flow)

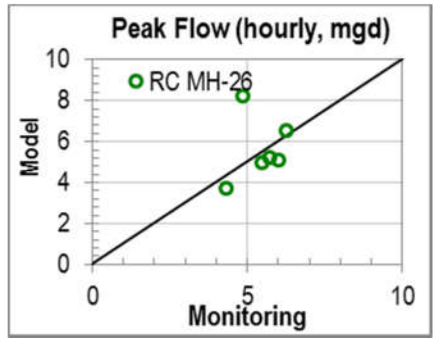


RC MH-26 Model Validation Results (Metered and Modeled Flow)



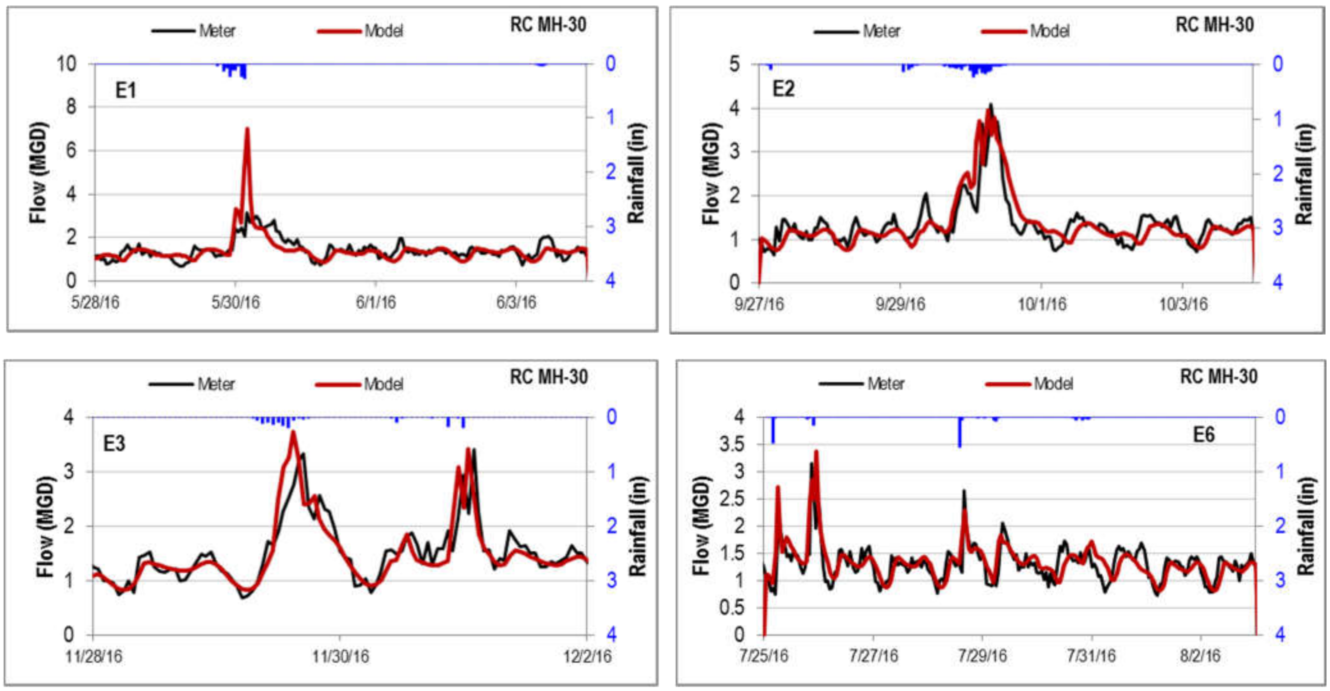
RC MH-26 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



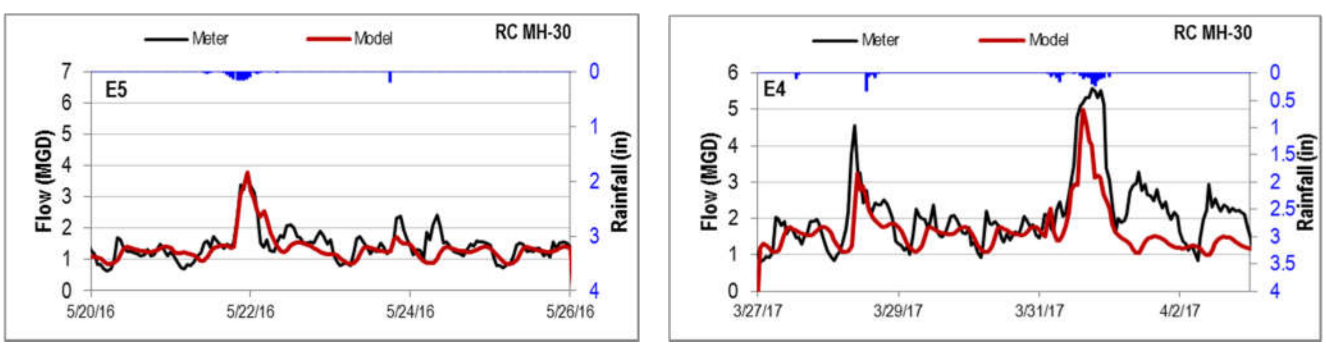


FLOW METER RC MH-30 MODEL CALIBRATION AND VALIDATION RESULTS

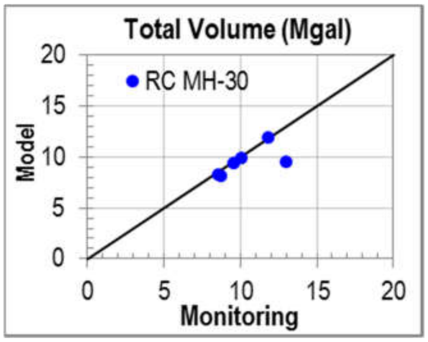
RC MH-30 Model Calibration Results (Metered and Modeled Flow)

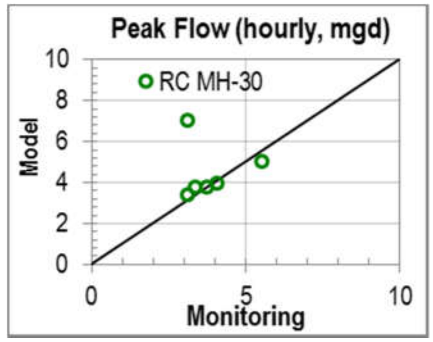


RC MH-30 Model Validation Results (Metered and Modeled Flow)



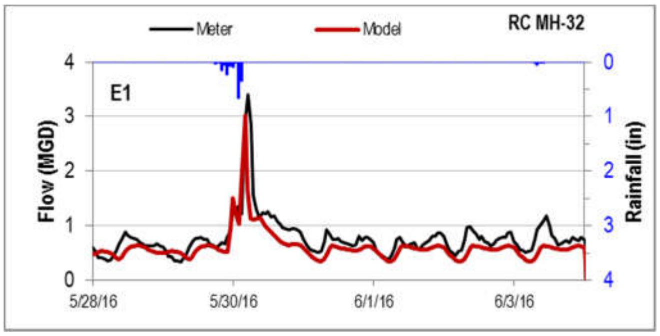
RC MH-30 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

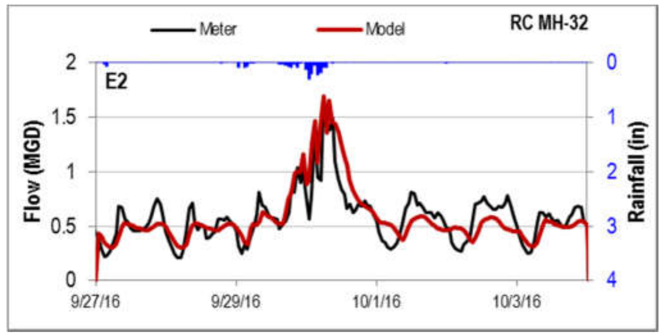


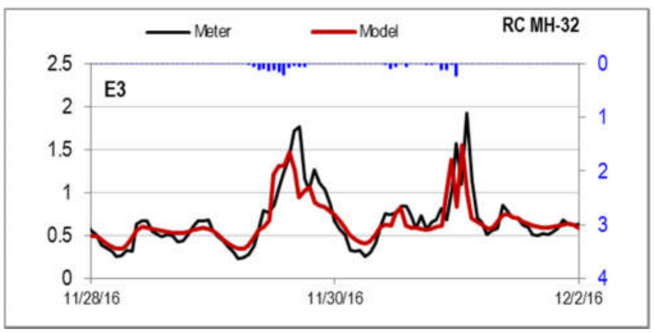


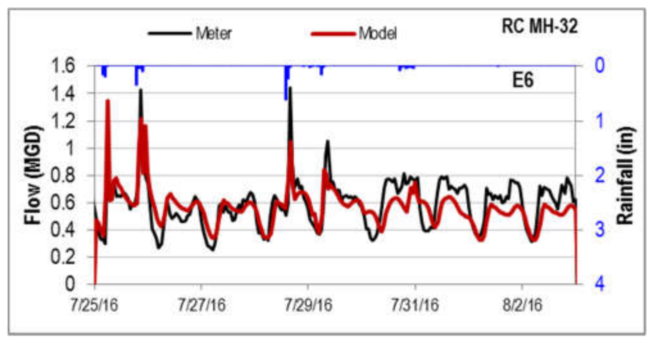
FLOW METER RC MH-32 MODEL CALIBRATION AND VALIDATION RESULTS

RC MH-32 Model Calibration Results (Metered and Modeled Flow)

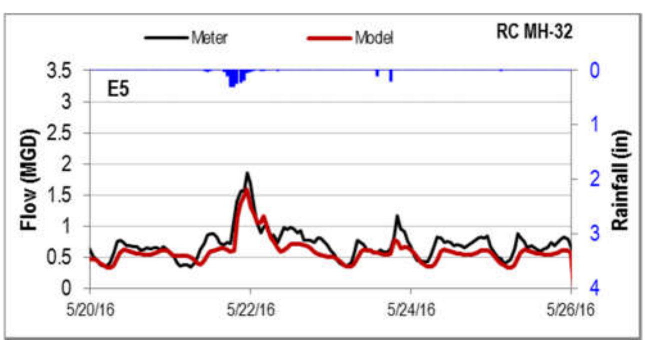


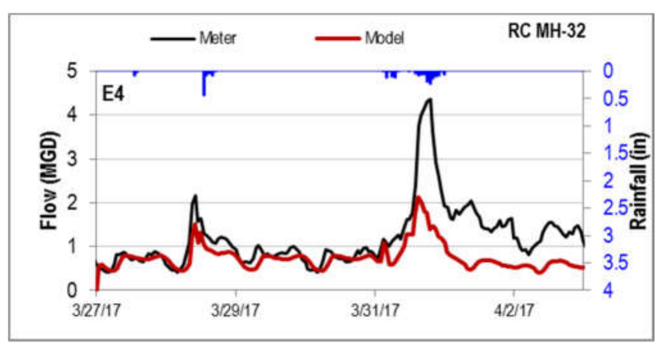




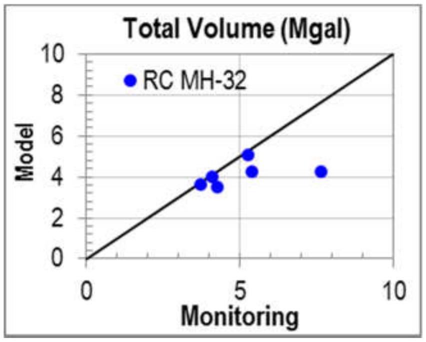


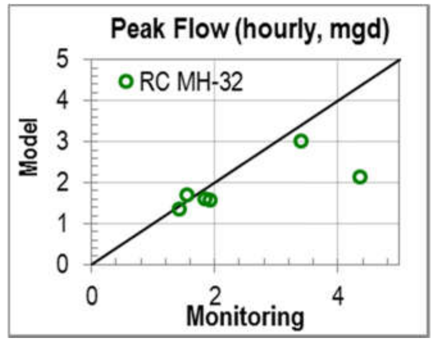
RC MH-32 Model Validation Results (Metered and Modeled Flow)





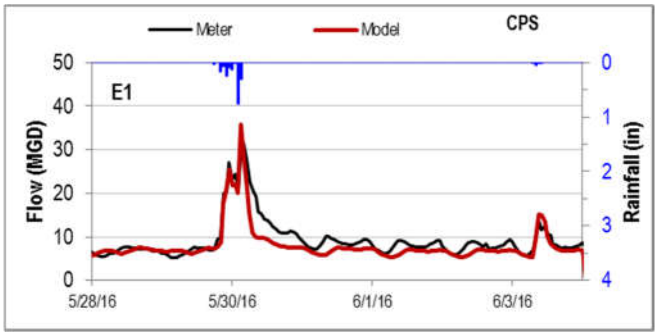
RC MH-32 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

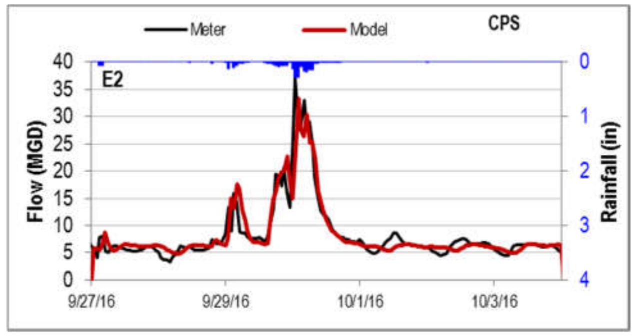


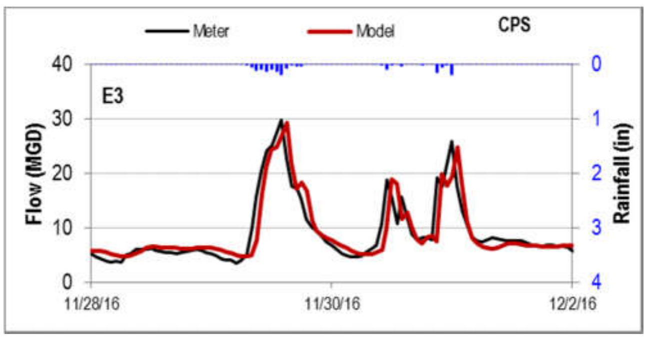


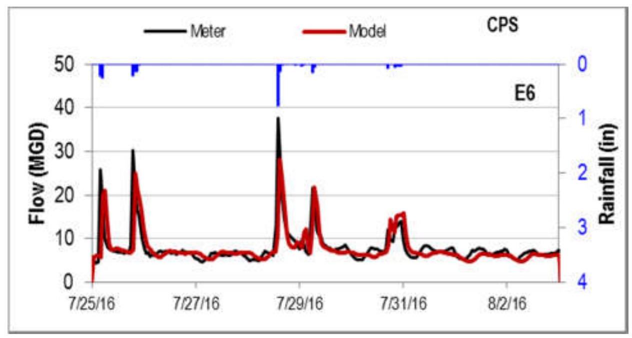
FLOW METER CPS MODEL CALIBRATION AND VALIDATION RESULTS

CPS Model Calibration Results (Metered and Modeled Flow)

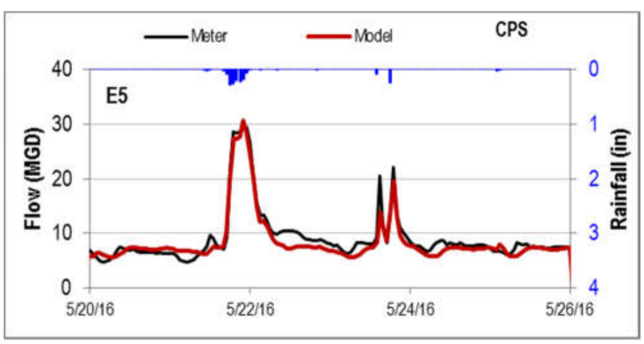


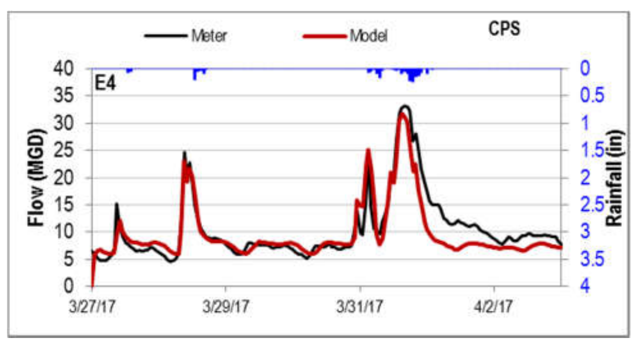




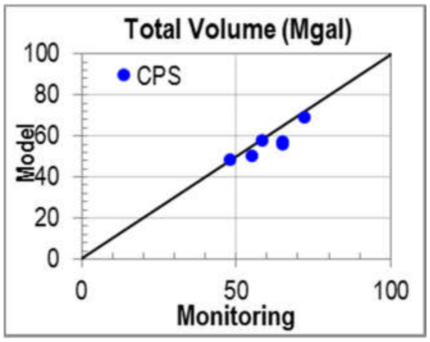


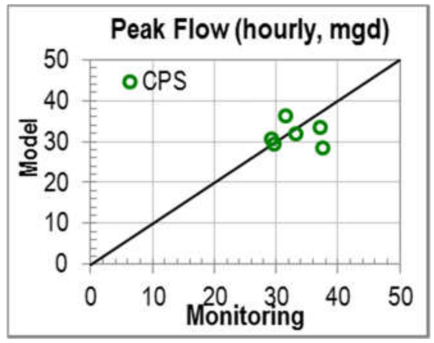
CPS Model Validation Results (Metered and Modeled Flow)





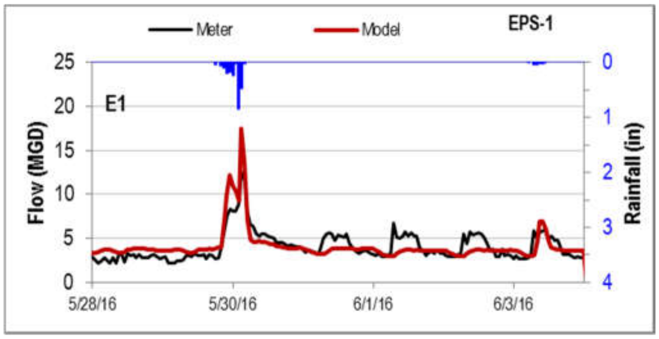
CPS Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

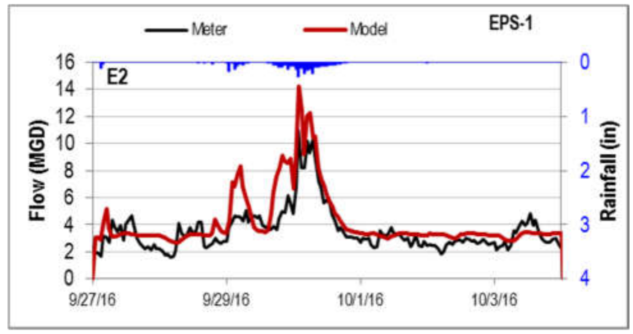


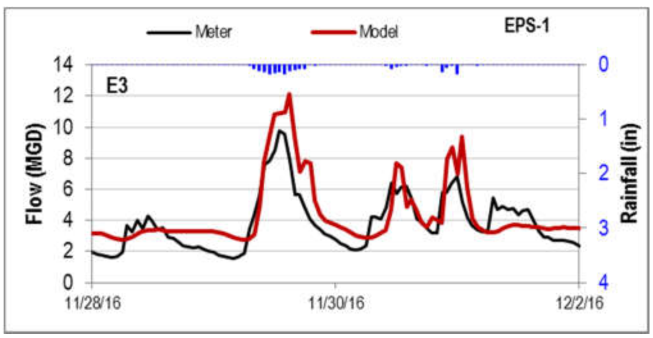


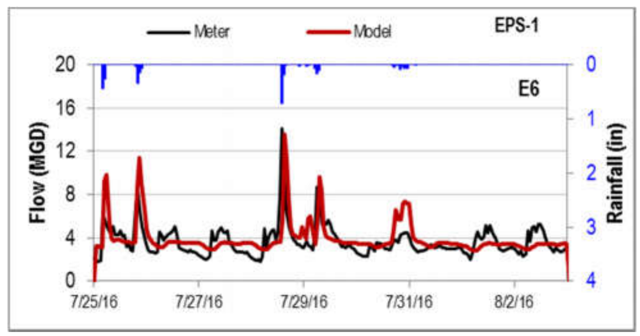
FLOW METER EPS-1 MODEL CALIBRATION AND VALIDATION RESULTS

EPS-1 Model Calibration Results (Metered and Modeled Flow)

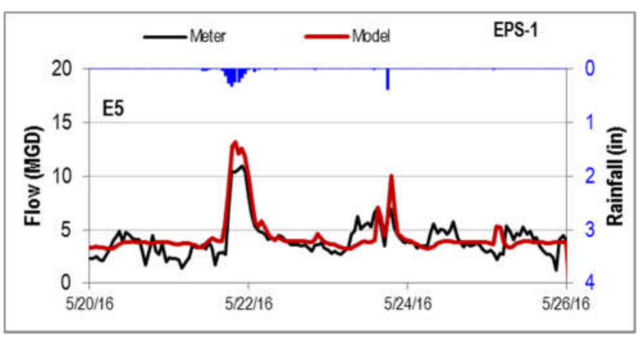


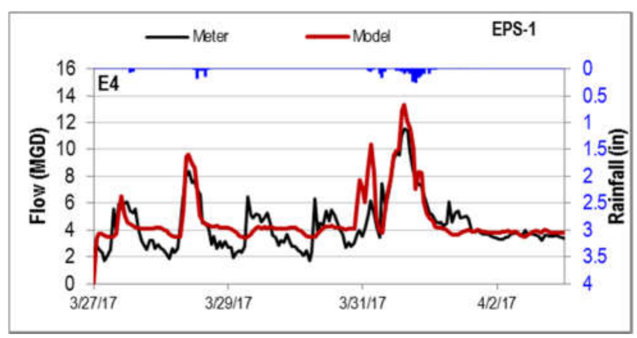




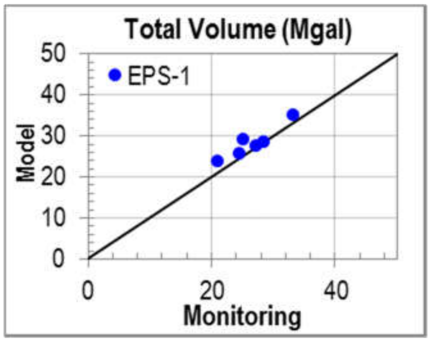


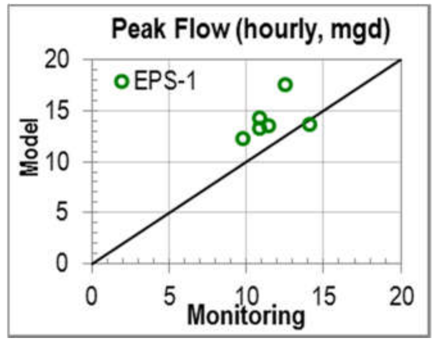
EPS-1 Model Validation Results (Metered and Modeled Flow)





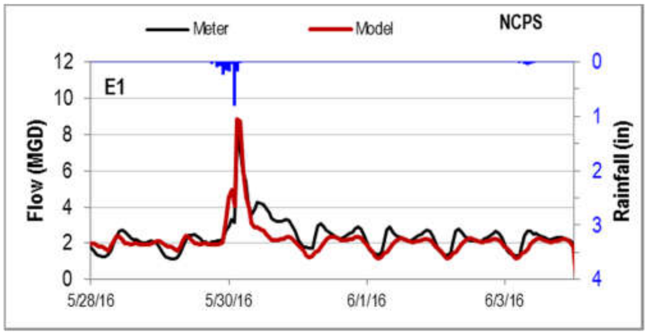
EPS-1 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

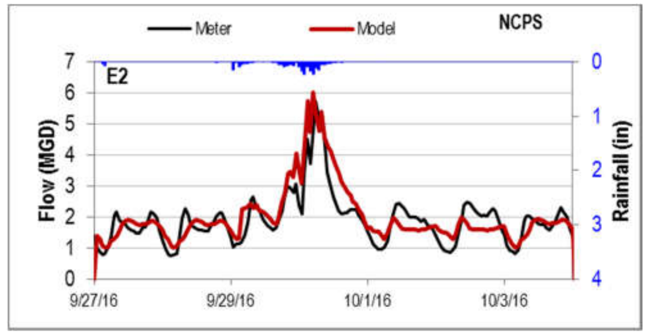


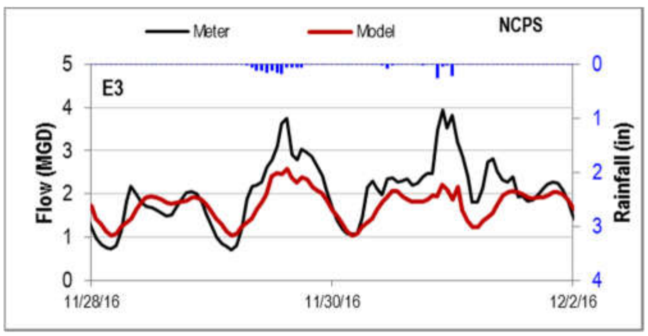


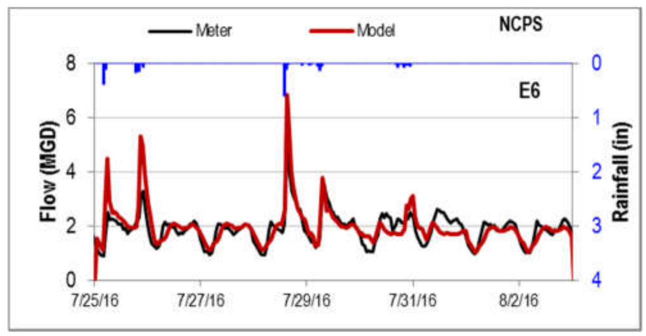
FLOW METER NCPS MODEL CALIBRATION AND VALIDATION RESULTS

NCPS Model Calibration Results (Metered and Modeled Flow)

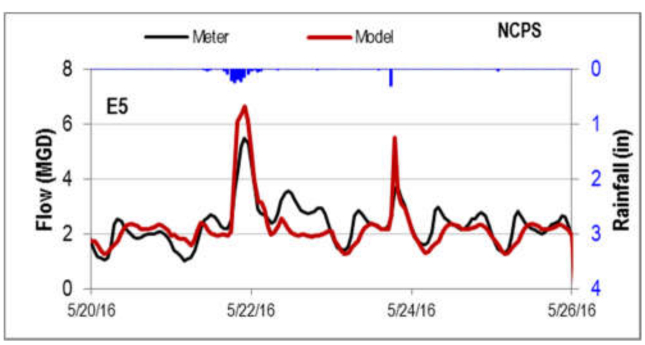


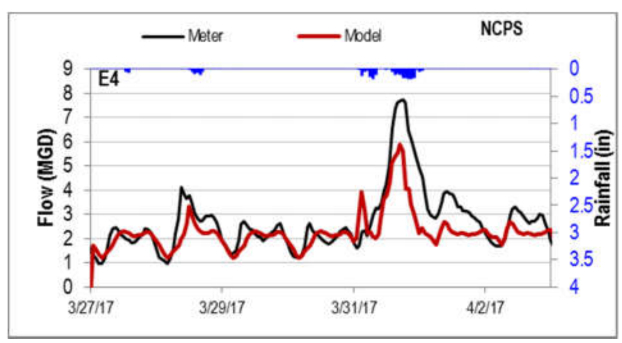




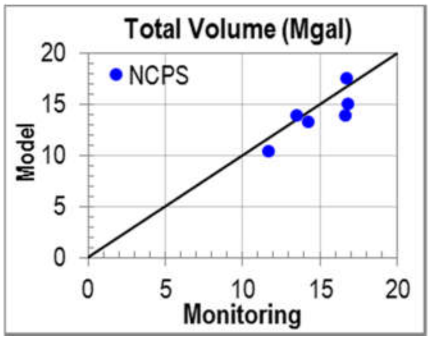


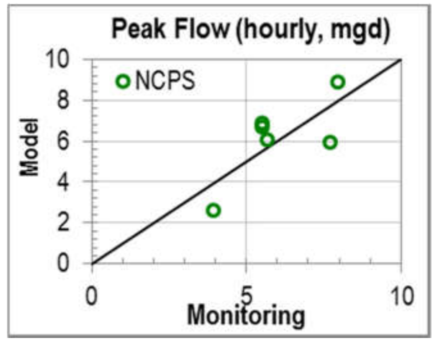
NCPS Model Validation Results (Metered and Modeled Flow)





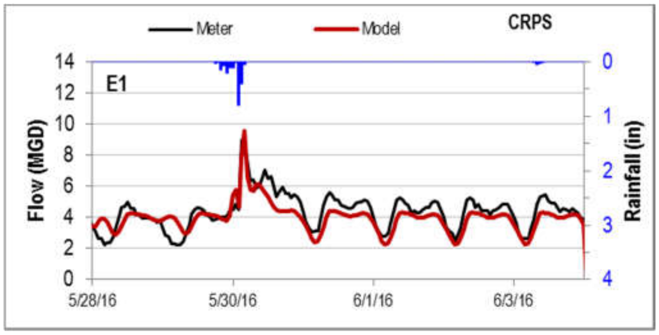
NCPS Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

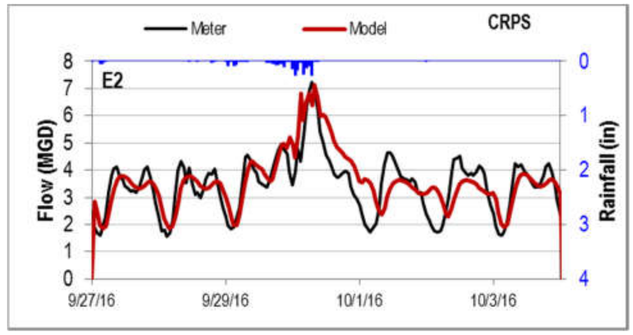


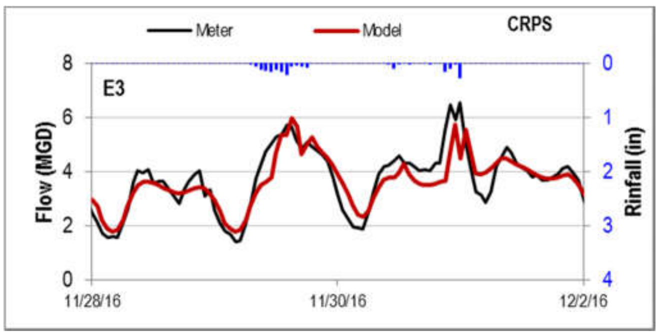


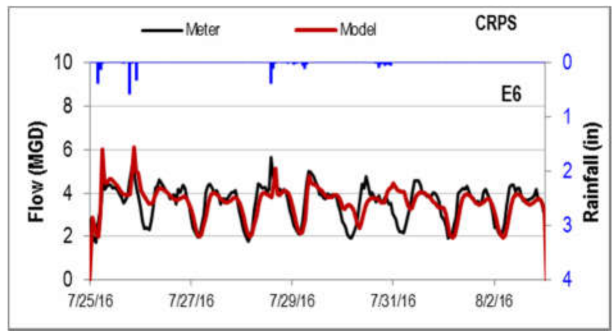
FLOW METER CRPS MODEL CALIBRATION AND VALIDATION RESULTS

CRPS Model Calibration Results (Metered and Modeled Flow)

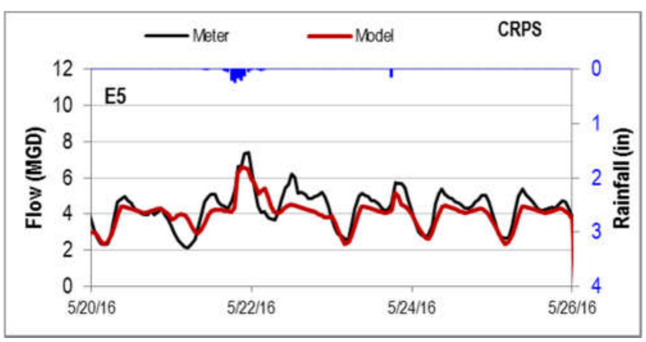


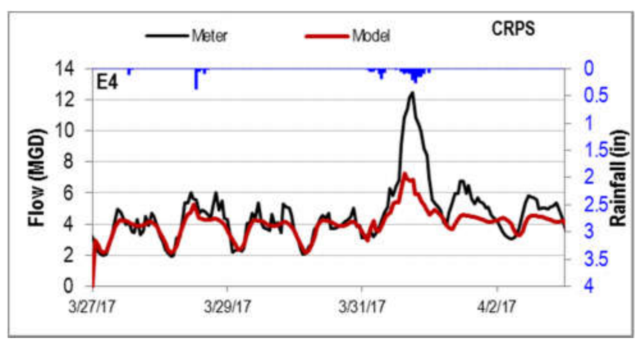




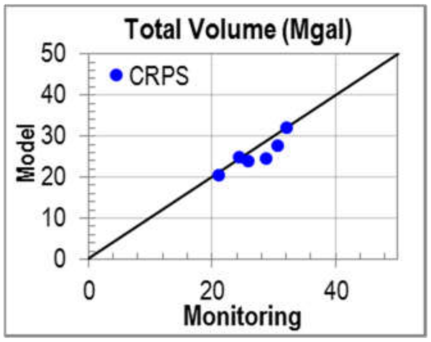


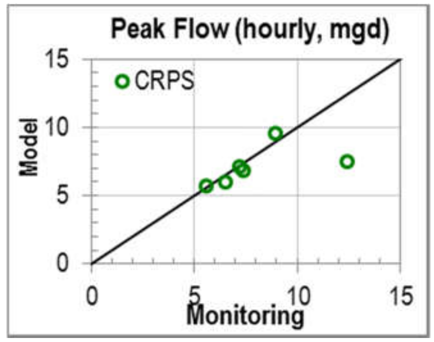
CRPS Model Validation Results (Metered and Modeled Flow)





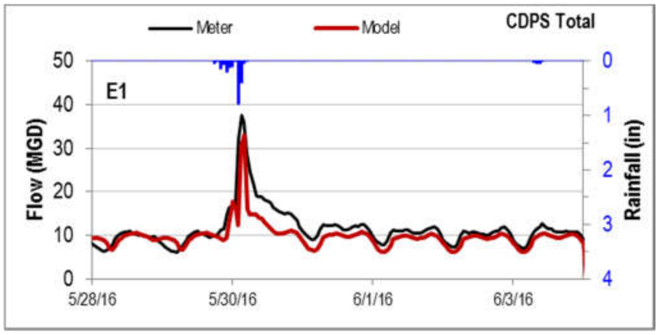
CRPS Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

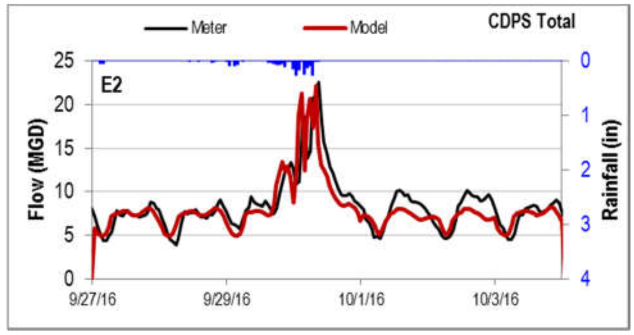


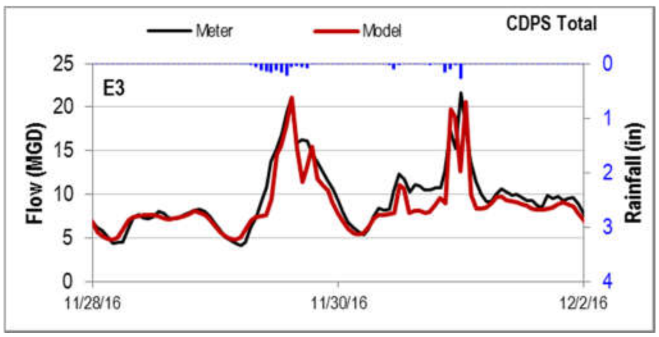


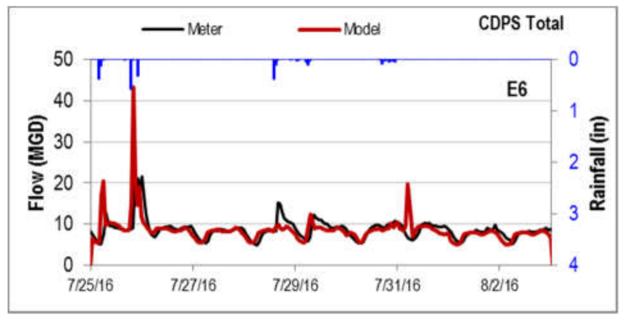
FLOW METER CDPS TOTAL MODEL CALIBRATION AND VALIDATION RESULTS

CDPS Total Model Calibration Results (Metered and Modeled Flow)

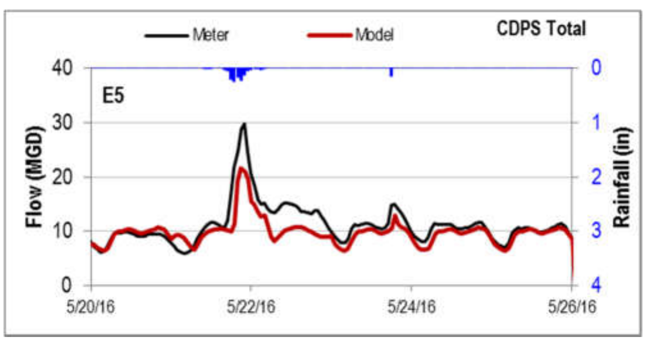


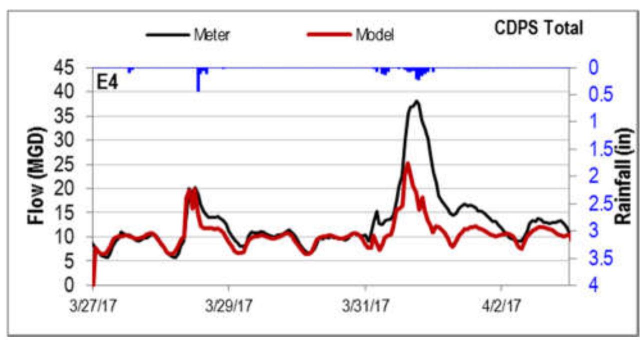




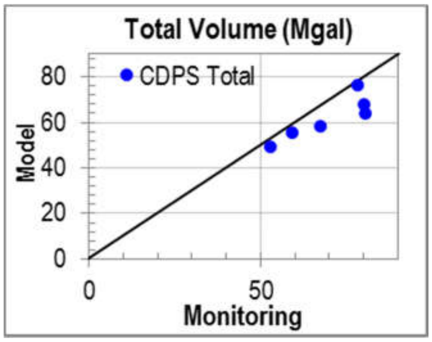


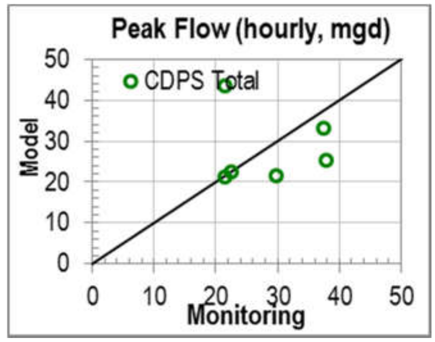
CDPS Total Model Validation Results (Metered and Modeled Flow)





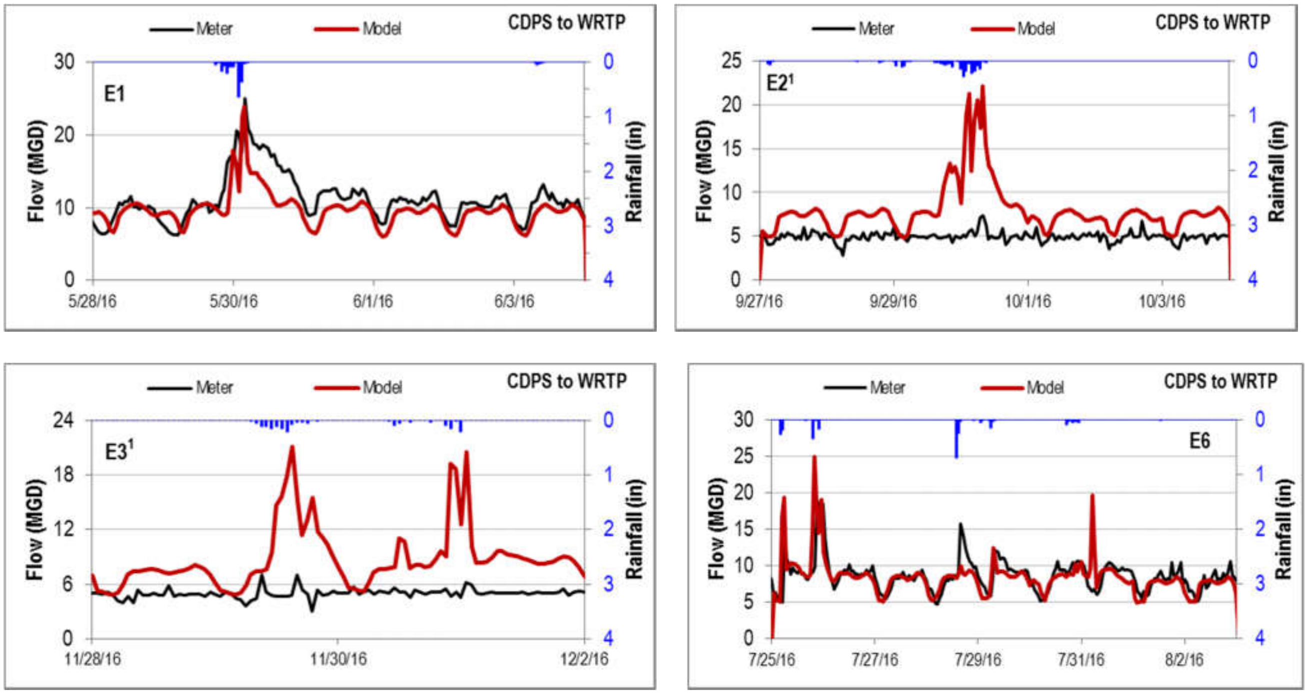
CDPS Total Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



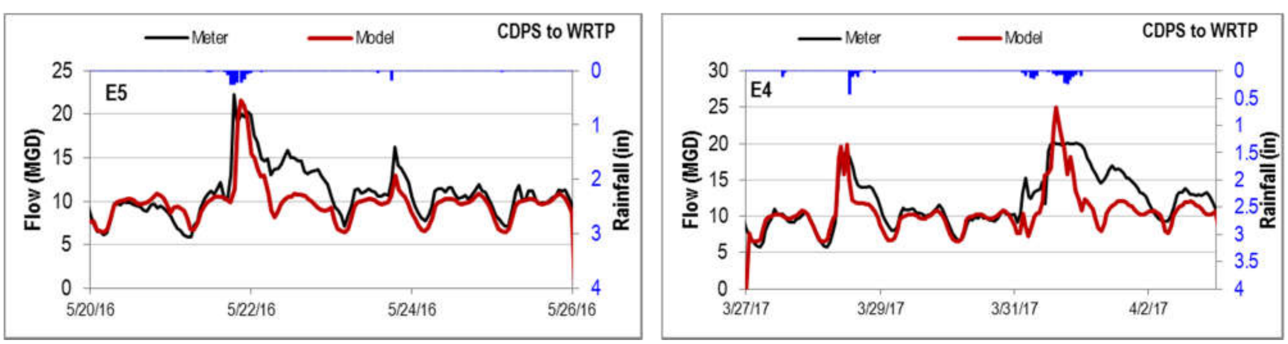


FLOW METER CDPS TO WRTP MODEL CALIBRATION AND VALIDATION RESULTS

CDPS to WRTP Model Calibration Results (Metered and Modeled Flow)



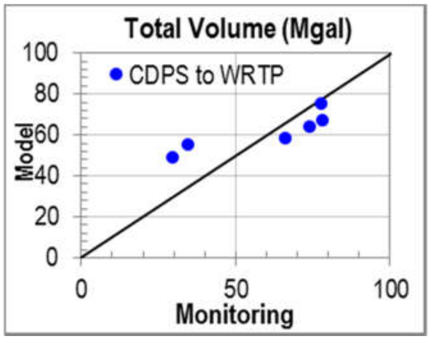
CDPS to WRTP Model Validation Results (Metered and Modeled Flow)

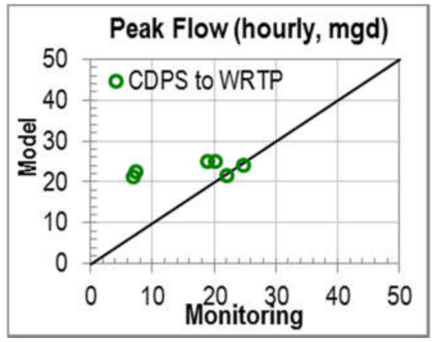


NOTE:

1 During this storm, CDPS Flow to the plant was capped due to the aeration replacement project.

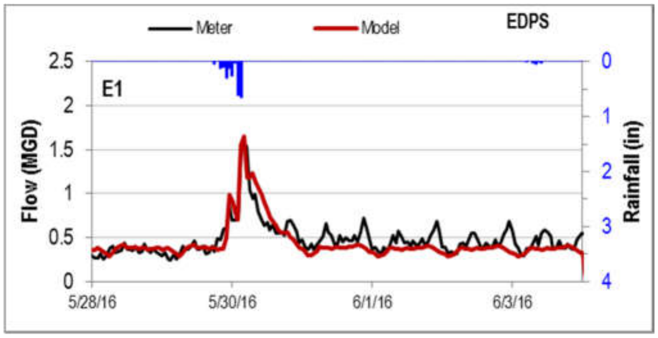
CDPS to WRTP Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

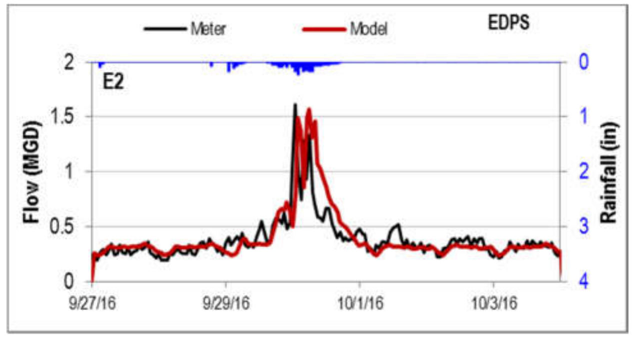


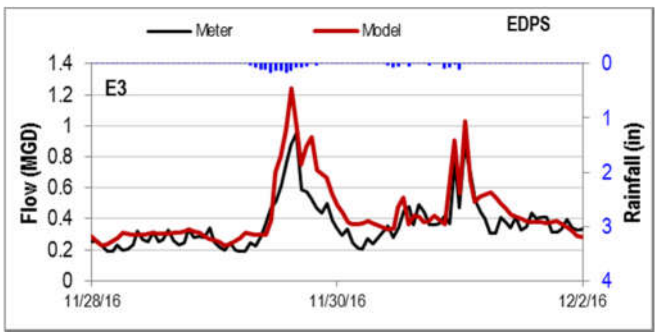


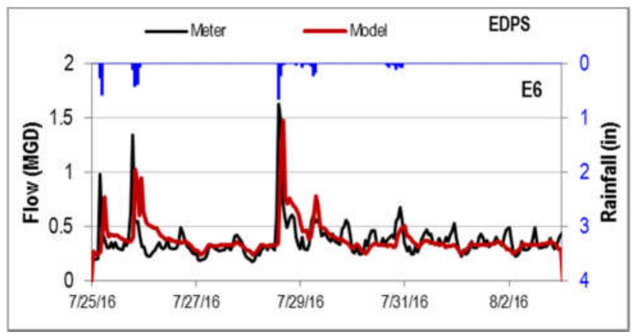
FLOW METER EDPS MODEL CALIBRATION AND VALIDATION RESULTS

EDPS Model Calibration Results (Metered and Modeled Flow)

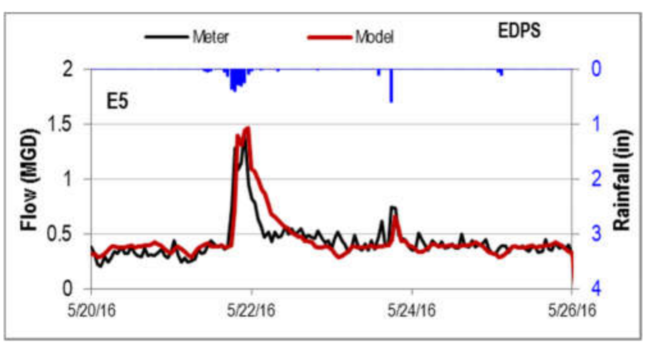


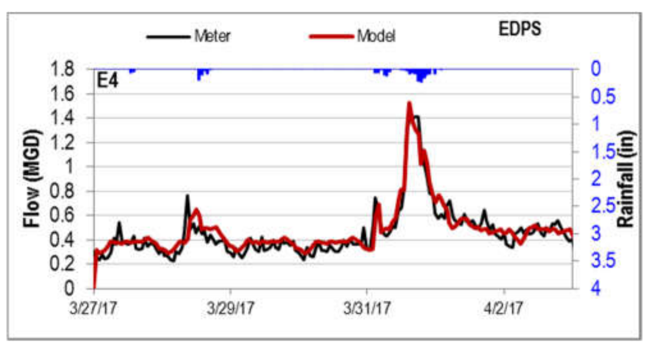




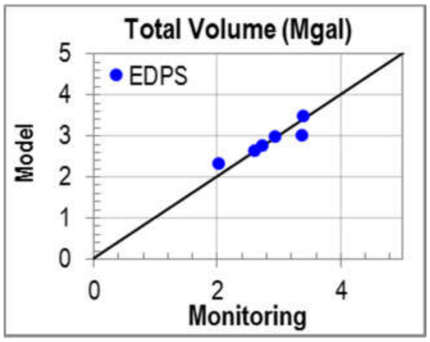


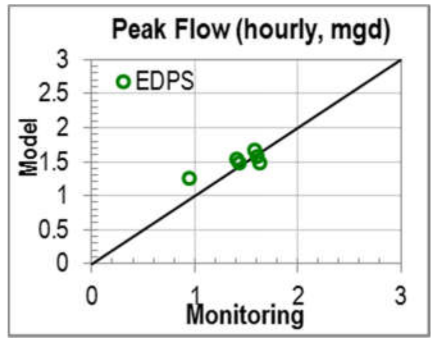
EDPS Model Validation Results (Metered and Modeled Flow)





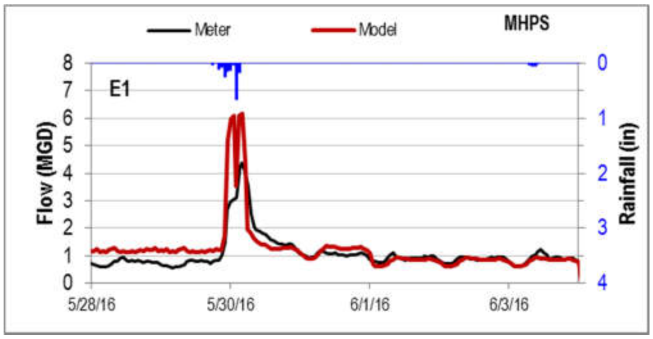
EDPS Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

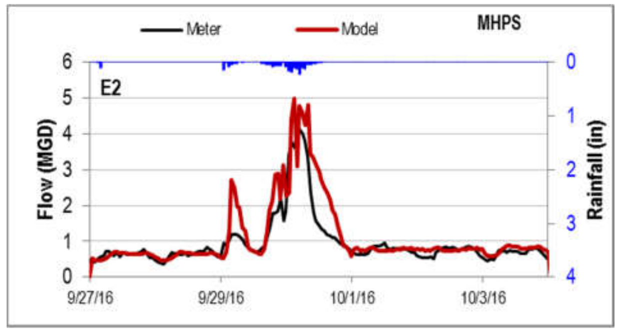


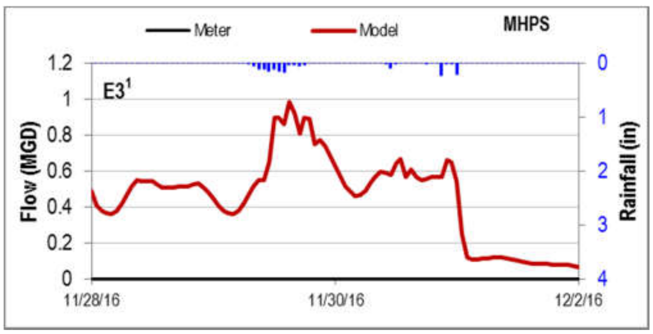


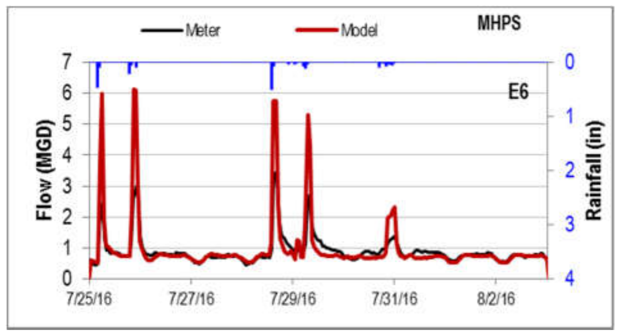
FLOW METER MHPS MODEL CALIBRATION AND VALIDATION RESULTS

MHPS Model Calibration Results (Metered and Modeled Flow)

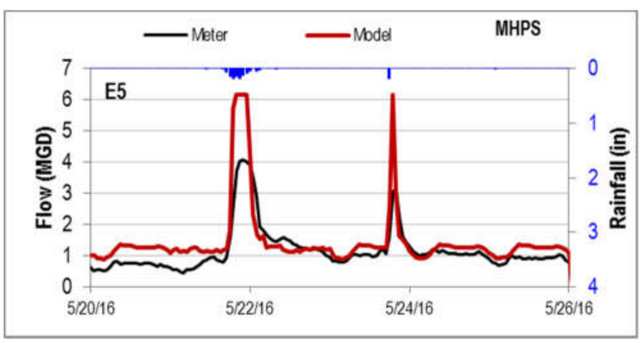


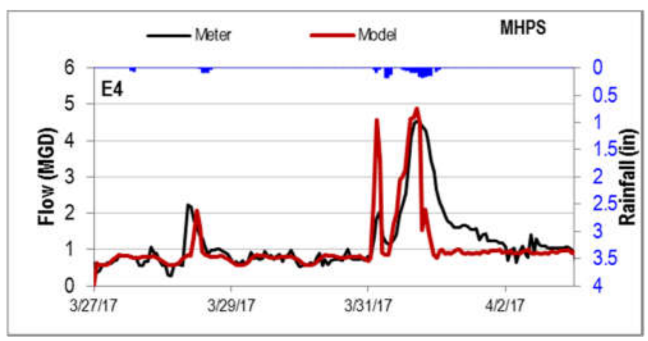






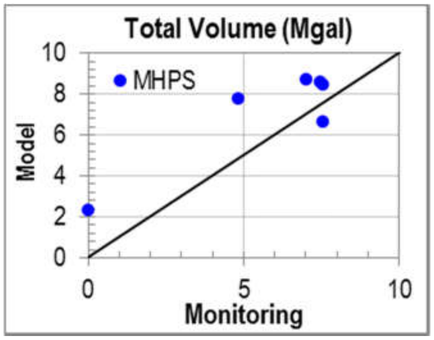
MHPS Model Validation Results (Metered and Modeled Flow)

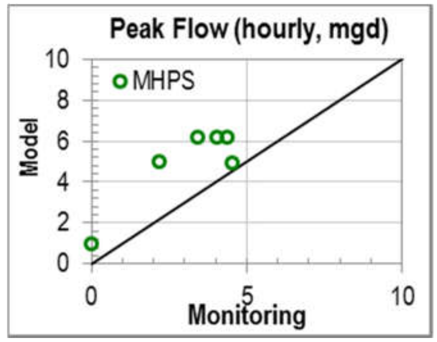




NOTE:
[1] Pump Station Meter data not available from November 22, 2016 to December 22, 2016.

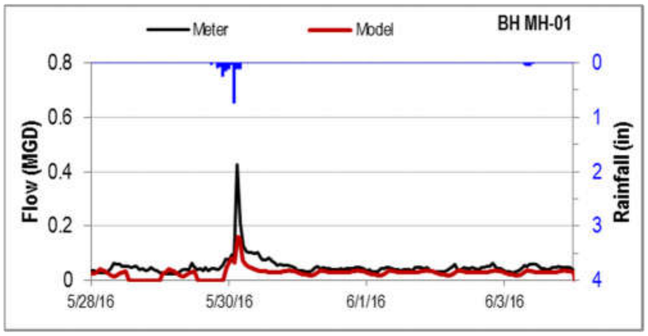
MHPS Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

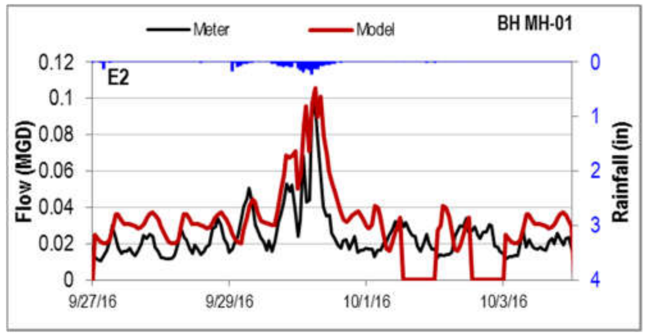


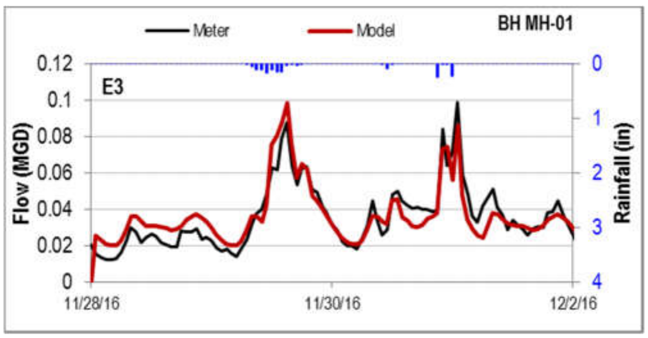


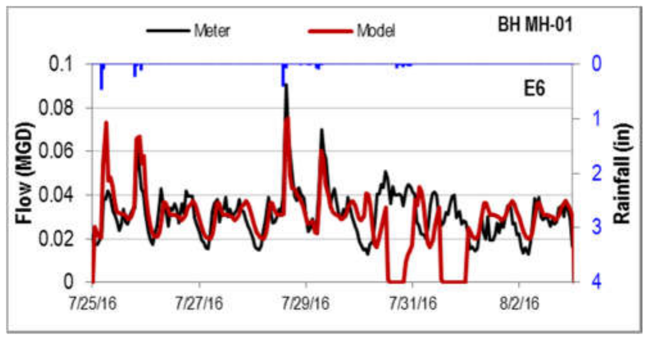
FLOW METER BH MH-01 MODEL CALIBRATION AND VALIDATION RESULTS

BH MH-01 Model Calibration Results (Metered and Modeled Flow)

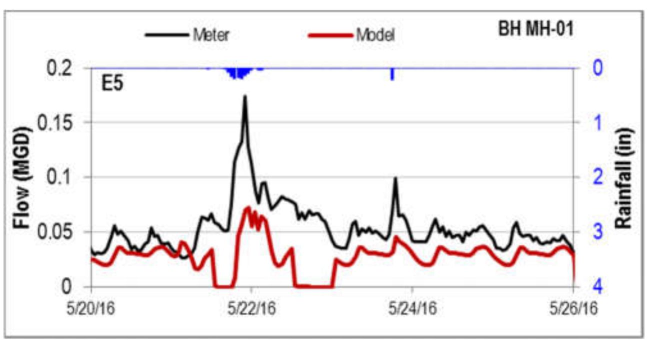


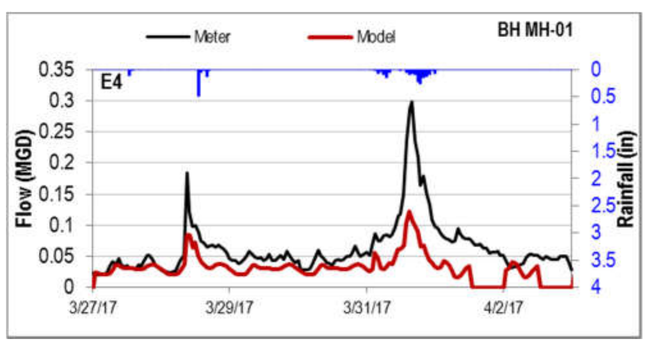




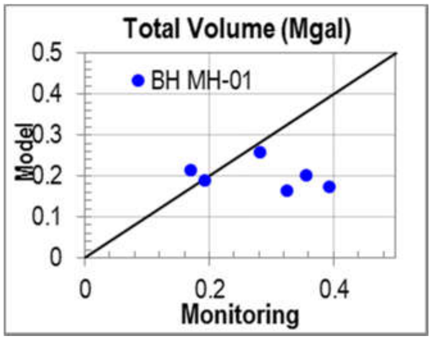


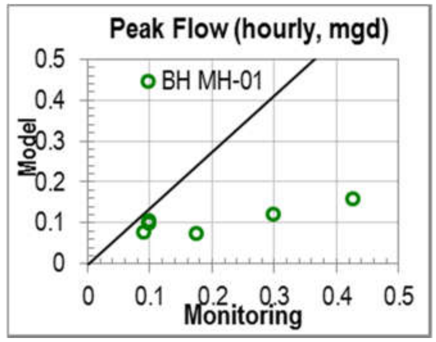
BH MH-01 Model Validation Results (Metered and Modeled Flow)





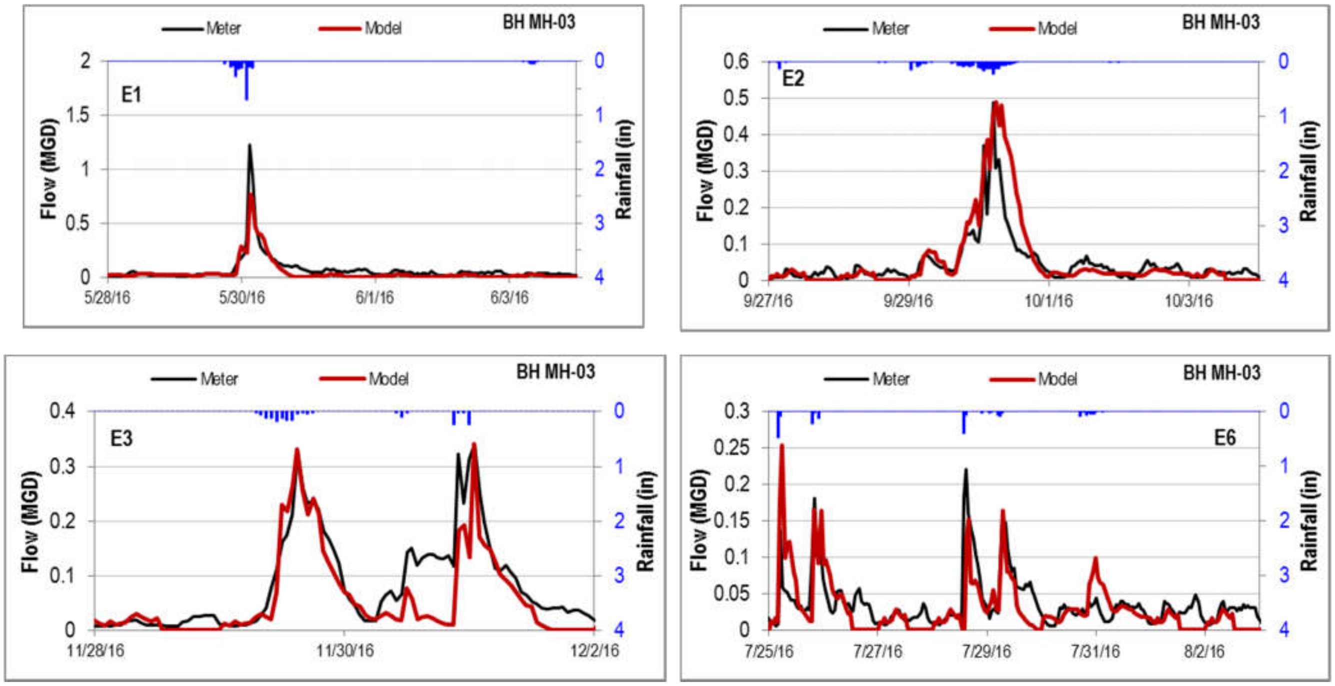
BH MH-01 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



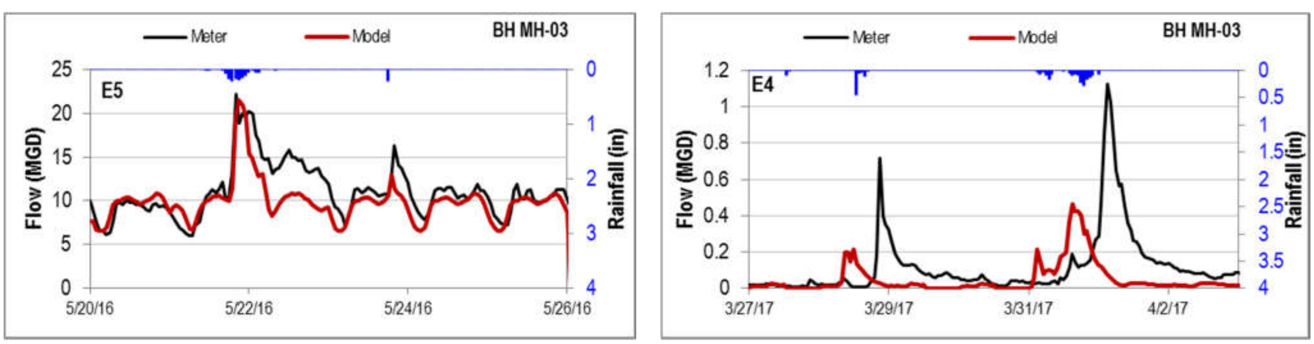


FLOW METER BH MH-03 MODEL CALIBRATION AND VALIDATION RESULTS

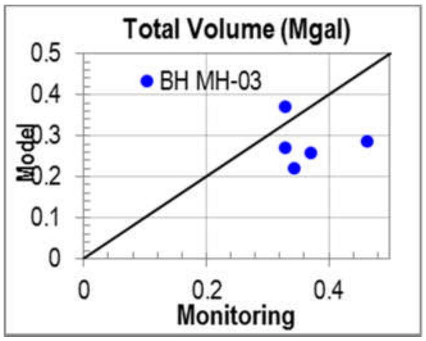
BH MH-03 Model Calibration Results (Metered and Modeled Flow)

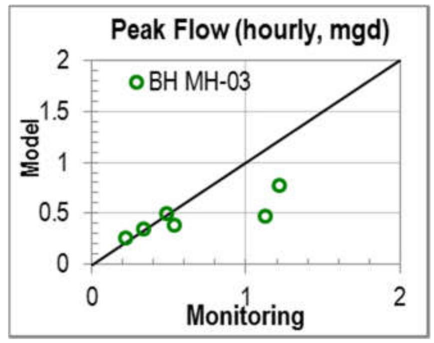


BH MH-03 Model Validation Results (Metered and Modeled Flow)



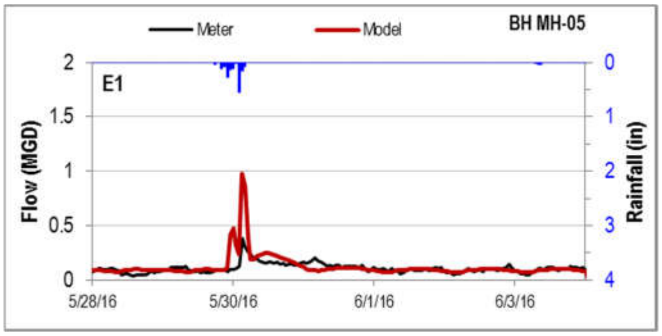
BH MH-03 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

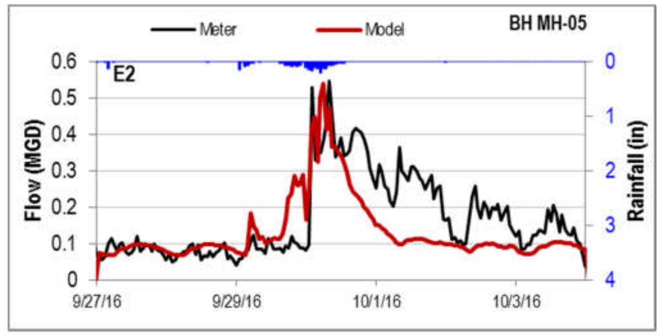


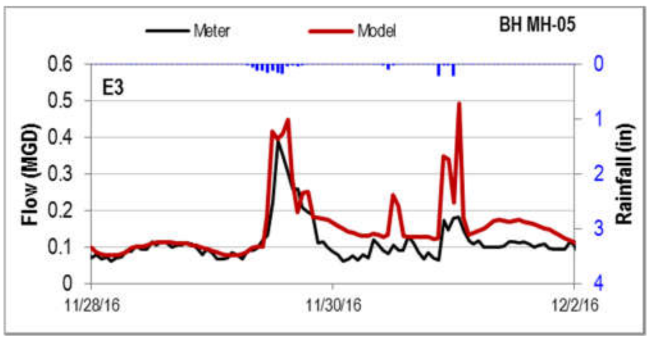


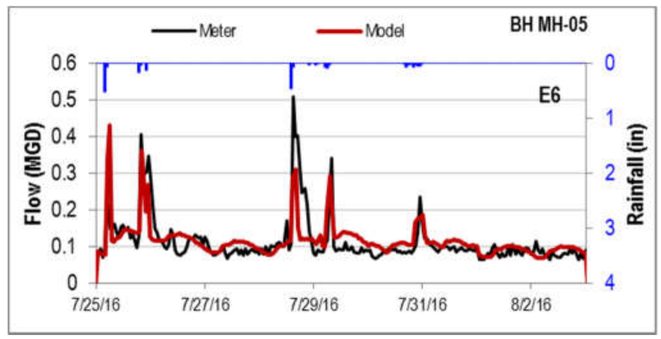
FLOW METER BH MH-05 MODEL CALIBRATION AND VALIDATION RESULTS

BH MH-05 Model Calibration Results (Metered and Modeled Flow)

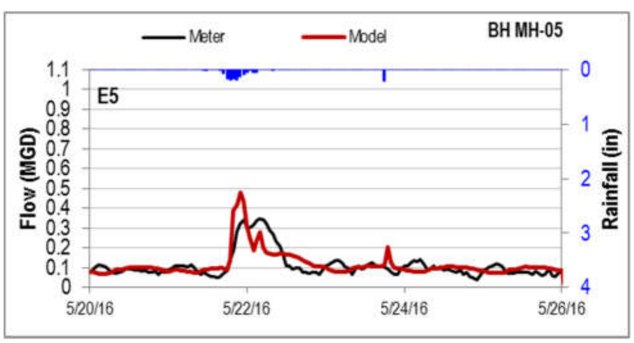


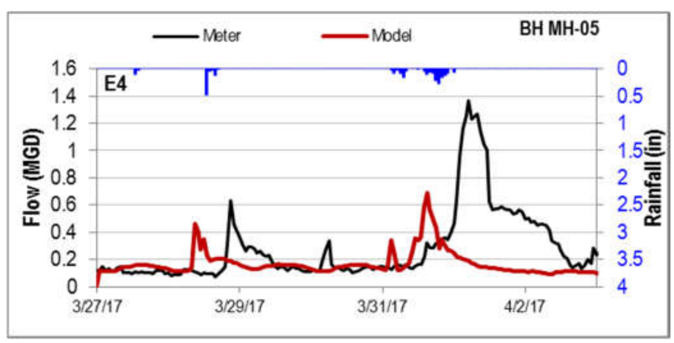




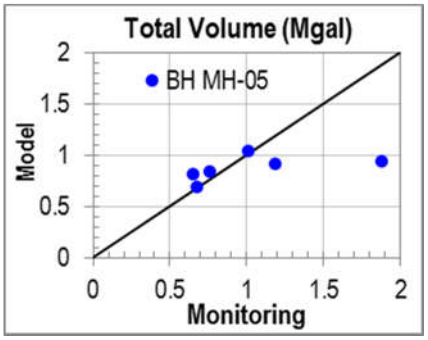


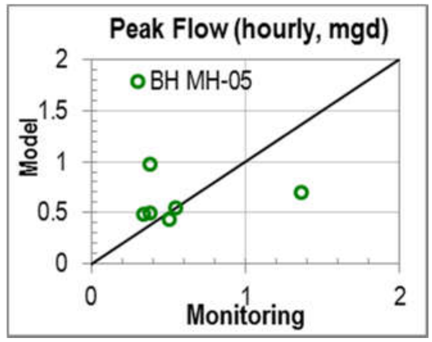
BH MH-05 Model Validation Results (Metered and Modeled Flow)





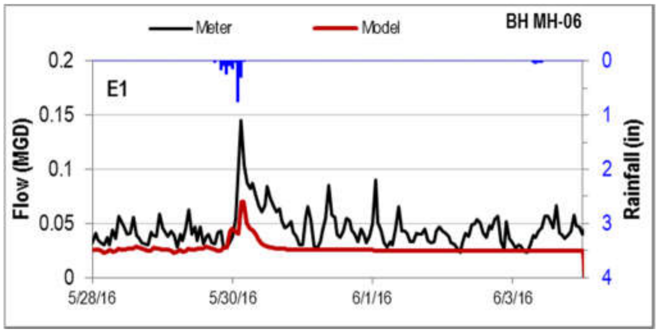
BH MH-05 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)

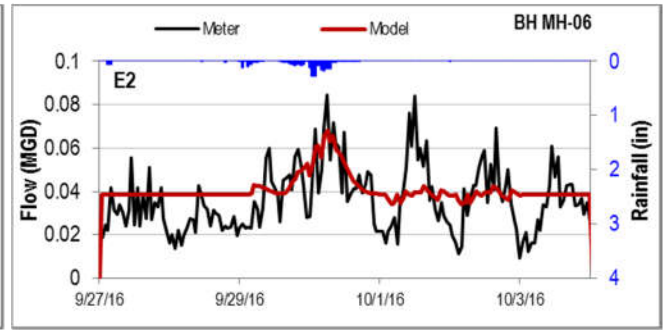


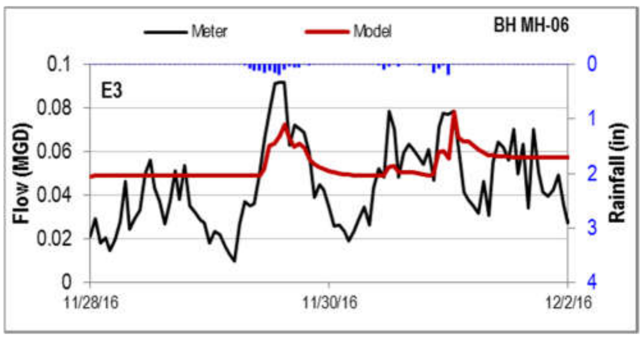


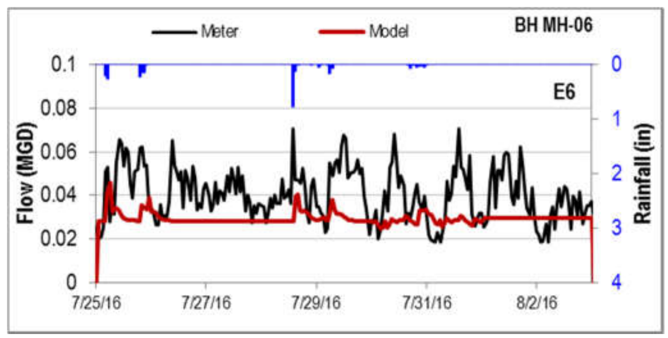
FLOW METER BH MH-06 MODEL CALIBRATION AND VALIDATION RESULTS

BH MH-06 Model Calibration Results (Metered and Modeled Flow)

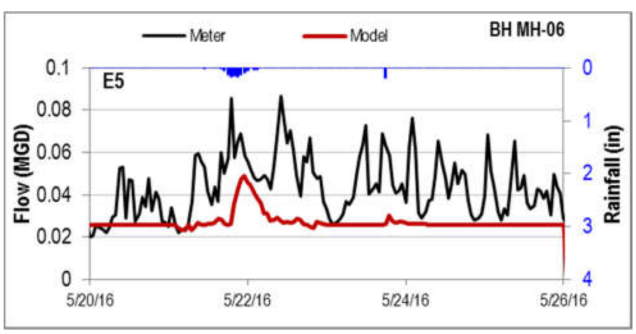


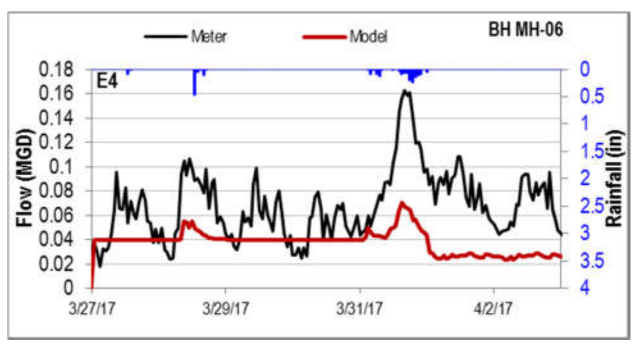




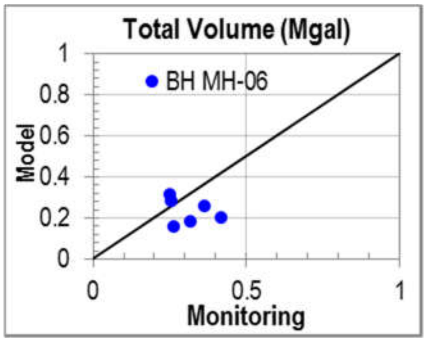


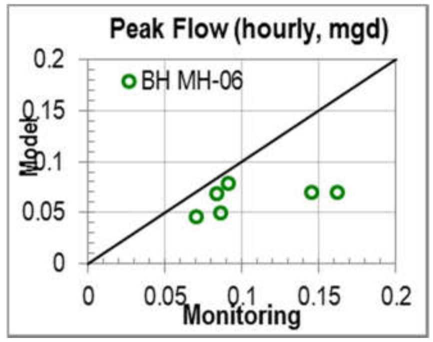
BH MH-06 Model Validation Results (Metered and Modeled Flow)





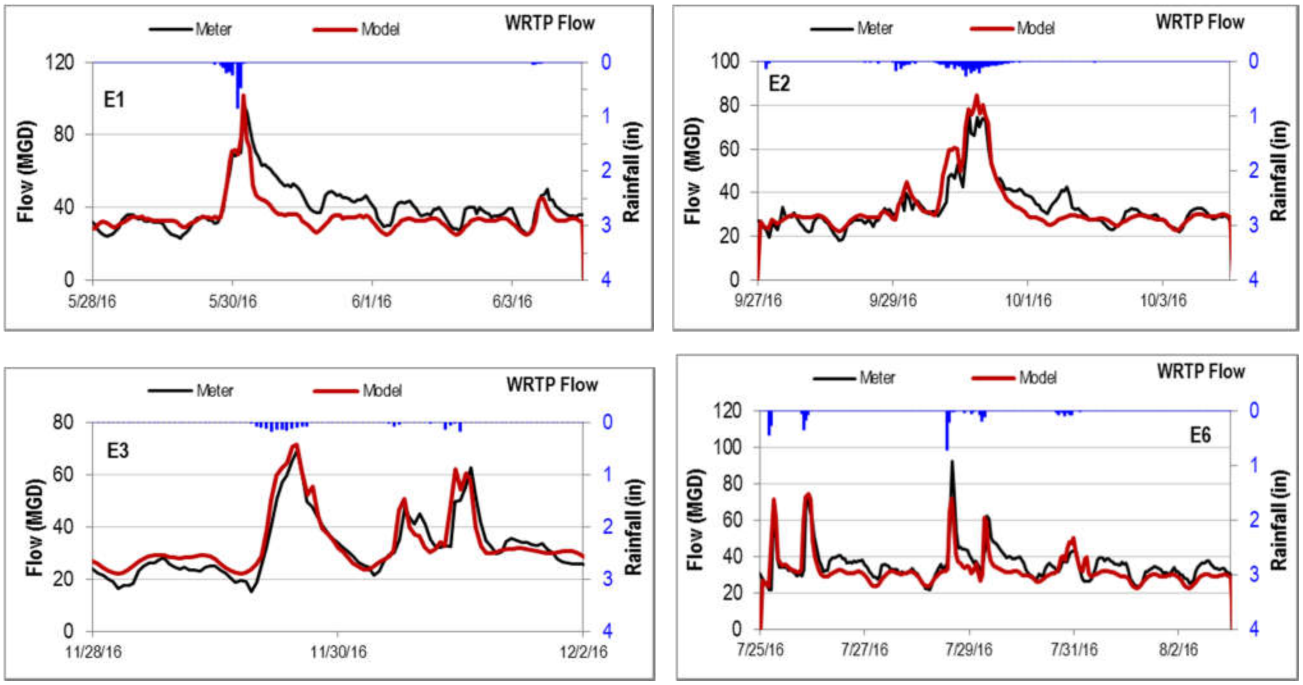
BH MH-06 Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)



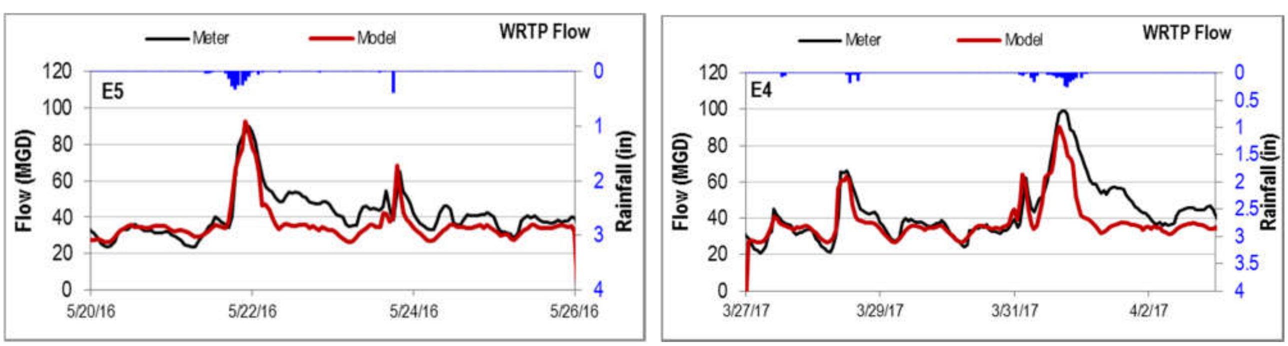


FLOW METER WRTP Flow MODEL CALIBRATION AND VALIDATION RESULTS

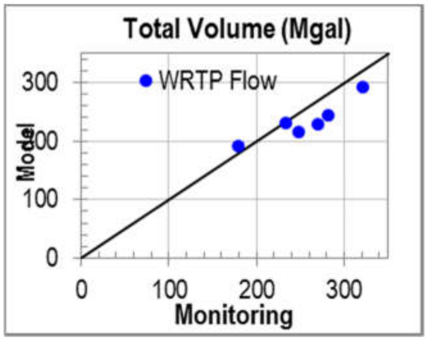
WRTP Flow Model Calibration Results (Metered and Modeled Flow)

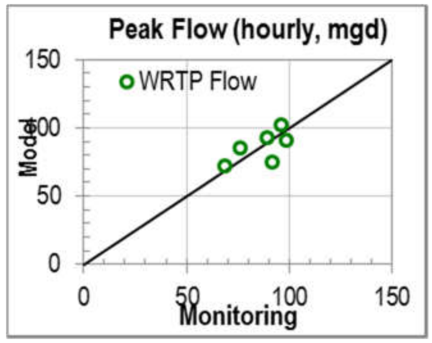


WRTP Flow Model Validation Results (Metered and Modeled Flow)



WRTP Flow Overall Model Calibration and Validation Results (Volume and Flow 1:1 Plots)





Appendix C H&H Model Results for Typical Hydrologic Period

2017 Calibrated and Validated Model Results

Overflow Frequency (occurrence)

	Rainfall	NREG02	NREG03	NREG04	NREG05	NREG07	NREG08	NREG09	NREG11	NREG12	NREG13	NREG14	NREG15	NREG16	NREG17	NREG18	NREG19	NREG20	NREG21	NREG22	NREG23	NREG24	NREG25	NREG26	NREG32
1994	45.0	53	51	21	73	43	63	41	62	2	53	30	64	27	76	90	42	36	36	53	21	0	55	21	0
1995	31.4	47	43	14	61	35	52	34	54	1	47	24	55	20	69	79	35	28	1	46	14	0	49	13	0
1996	52.1	65	61	28	78	54	70	53	70	1	66	37	72	33	88	103	54	45	1	65	26	0	68	26	0
Average	42.8	55	52	21	71	44	62	43	62	1	55	30	64	27	78	91	44	36	13	55	20	0	57	20	0

Overflow Volume (MG)

	Rainfall	NREG02	NREG03	NREG04	NREG05	NREG07	NREG08	NREG09	NREG11	NREG12	NREG13	NREG14	NREG15	NREG16	NREG17	NREG18	NREG19	NREG20	NREG21	NREG22	NREG23	NREG24	NREG25	NREG26	NREG32	TOTAL
1994	45.0	13.1	9.8	3.4	42.3	2.2	35.7	8.5	26.7	0.1	24.5	8.2	2.0	10.8	39.6	37.1	37.1	3.7	3.7	5.4	0.7	0.0	9.5	3.3	0.0	327
1995	31.4	8.3	6.1	2.4	29.9	1.3	22.4	4.5	17.8	0.0	16.4	4.0	1.3	4.2	28.3	20.5	20.9	1.7	0.0	3.4	0.2	0.0	6.2	1.1	0.0	201
1996	52.1	15.4	11.5	4.3	53.6	2.5	41.2	8.7	32.0	0.0	30.3	7.4	2.4	7.7	48.5	38.6	44.0	3.4	0.0	6.3	0.4	0.0	11.2	1.8	0.0	371
Average	42.8	12.3	9.2	3.4	41.9	2.0	33.1	7.3	25.5	0.0	23.8	6.5	1.9	7.6	38.8	32.1	34.0	2.9	1.2	5.0	0.4	0.0	9.0	2.0	0.0	300

Overflow Duration (Hour)

	Rainfall	NREG02	NREG03	NREG04	NREG05	NREG07	NREG08	NREG09	NREG11	NREG12	NREG13	NREG14	NREG15	NREG16	NREG17	NREG18	NREG19	NREG20	NREG21	NREG22	NREG23	NREG24	NREG25	NREG26	NREG32
1994	45.0	359	274	99	553	222	606	226	457	7	352	133	398	84	758	1029	251	127	127	294	51	0	352	51	0
1995	31.4	270	204	82	406	169	449	174	339	2	256	92	299	60	559	820	178	103	2	228	36	0	257	35	0
1996	52.1	441	337	161	605	299	699	306	522	2	437	196	470	127	830	1094	329	194	2	358	74	0	422	74	0
Average	42.8	357	272	114	521	230	585	235	439	4	348	140	389	90	716	981	253	141	44	293	54	0	344	53	0

Year	Total WRTP Flow (MG) during wet conditions (precipitation time+6 hr)[1]	Total Overflow (MG)	Total Wet Weather Flow (MG)	Wet Weather Capture
1994	1,293	327	1,620	80%
1995	962	201	1,163	83%
1996	1,531	371	1,902	80%
Average	**1,262**	**300**	**1,562**	**81%**

[1]Volume of combined sewage captured/treated is based on WRTP flow during precipitation events greater than 0.1 inch (including precipitation duration and 6 hours after precipitation)

Appendix D Water Quality Sampling Results

Water Quality Monitoring Program: Overview of Raw Results[1]

Parameter	Event Type	Location	Minimum Value (#/100ml)	Maximum Value (#/100ml)	Average Value (#/100ml)	No. of Samples
E. COLI	DRY	Chester Creek	10	470	130	18
		Delaware River	1	45	17	27
		Ridley Creek	2	1,900	265	16
	WET	Chester Creek	40	22,000	4,937	45
		Delaware River	2	6,900	207	143
		Ridley Creek	56	87,000	5,690	45
		CSO	25,000	1,780,000	254,403	67
		Stormwater	36	156,000	16,248	38
ENTEROCOCCUS	DRY	Chester Creek	8	190	70	18
		Delaware River	1	320	21	22
		Ridley Creek	6	900	167	16
	WET	Chester Creek	40	41,000	9,584	44
		Delaware River	2	40,000	476	141
		Ridley Creek	20	31,000	8,112	45
		CSO	4,800	3,220,000	193,961	67
		Stormwater	1,091	505,000	72,206	38
FECAL COLIFORM	DRY	Chester Creek	4	1,200	361	17
		Delaware River	2	54	27	30
		Ridley Creek	4	3,800	709	18
	WET	Chester Creek	52	44,000	7,134	45
		Delaware River	2	10,000	250	145
		Ridley Creek	44	103,000	7,646	45
		CSO	15,300	1,630,000	165,486	67
		Stormwater	20	1,480,000	54,081	38

Notes:
1. Sampling results currently undergoing QA/QC, summary statistics may change pending QA/QC results.

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