Section 3

Characterization of Current Conditions

The foundation for the *City Beautiful H_2O Program Plan* (Program Plan) is an accurate and up-to-date understanding of existing conditions within the Capital Region Water (CRW) service area and the configuration and operation of the sewer collection, conveyance, and treatment systems. CRW developed and implemented a series of data collection and analysis programs, and incorporated the data and analysis results into a hydrologic and hydraulic (H&H) model of the CRW system. The model was used as a tool to quantify and characterize existing system configurations and flows, and establish a baseline condition on which to develop alternative combined sewer overflow (CSO) and sanitary sewer overflow (SSO) control measures.

3.1 Overview of Characterization of Current Conditions

Located along the east shore of the Susquehanna River, CRW is a municipal authority that provides wastewater and stormwater collection, conveyance and treatment services to over 17,200 customers in the City of Harrisburg (City). CRW also provides wastewater conveyance and treatment services to six suburban communities as wholesale customers. CRW owns, operates, and maintains the wastewater and stormwater infrastructure within the City and receives wastewater flow from the suburban communities served by separate sanitary sewer systems through four gravity points of connection. Flow from Steelton Borough, served by a combined sewer system, is received via the Trewick Pump Station that conveys wastewater directly to the advanced wastewater treatment facility (AWTF). This overview section is intended to provide a concise executive summary of the information provided in the more detailed report sections that follow. A map of the CRW service area, including the service area of the suburban community collection systems, is provided in **Figure 3-1**.

Section 3.2 characterizes CRW's wastewater and stormwater collection and conveyance systems, consisting of a 45 MGD capacity AWTF, two major pumping stations, 1.3 miles of force mains, 13.8 miles of interceptor sewer, 59 CSO regulators and 58 CSO outfalls (two share a common outfall), approximately 160 miles of separate and/or combined collection system sewers, and approximately 4,300 storm inlets and catch basins. A map of the CRW conveyance and collection systems within the City limits is provided in Figure 3-1. Comprehensive inspection programs were successfully conducted for the CSO regulator structures, the interceptor system (both prior to and after cleaning), the pump stations, and the force mains. These inspections provided the necessary information to properly understand the configuration, critical elevations, and maintenance conditions along the CRW sewer system infrastructure. A Rapid Assessment Inspection was conducted at every known manhole and connecting pipe within the sewer collection system to quickly update the geographic information system (GIS) database and mapping, and to identify sewer segments with immediate structural or maintenance needs. These rapid assessment inspections are also being used to prioritize areas for systematic CCTV inspections to better define and prioritize remedial maintenance and repair needs.

Figure 3-1: CRW Service Area Including Service Area of Suburban Community Systems

Section 3.3 describes the monitoring and analysis of precipitation data that was conducted to quantify and characterize current precipitation patterns within the CRW service area and long-term trends. A gauge adjusted radar rainfall (GARR) system combined Doppler radar technology with a regional gauge network to develop high resolution, spatially distributed precipitation to support the development and validation of the H&H models. The long-term gauge records from the Capital City and Harrisburg International Airports were analyzed statistically to develop a "typical year" precipitation dataset. This typical year precipitation was applied to the H&H models of the CRW system to establish the frequency, duration, and volume of CSO discharges and develop and assess alternative control strategies. To assess the capacity and levels of service provided by the separate sanitary collection/conveyance system and the combined sewer collection system, a set of synthetic design storms was developed to represent conditions during the 2-year, 5-year and 10-year, 24-hour storm events.

Section 3.4 describes the updated hydrologic and hydraulic (H&H) model and the monitoring data used to validate it. CRW incorporated the sewer system information obtained through its completed facility inspection programs to update and refine its H&H model of the CRW conveyance system. CRW also performed extensive precipitation monitoring and flow monitoring to properly calibrate and validate its H&H model as shown in **Table 3-1**. The CRW hydrologic model simulates dry and wet weather flow and represents all catchment areas within the City of Harrisburg contributing to the conveyance system, for both separate and combined sewer systems. As required by the 2015 Partial Consent Decree (PCD), the hydraulic model was extended to major trunk sewers within the collection system. The model was used to develop a thorough understanding of the wastewater and stormwater flows characteristics of its sewer system in response to precipitation events of varying duration and intensity; to characterize hydraulic capacity, sewer system overflows, and unauthorized combined sewer system discharges; and to support the development of the Program Plan.

Table 3-1: Monitoring Site Summary

Monitoring Category	Number of Monitoring Sites
Satellite Community	4
Interceptor System	9
Combined Sewer	13
Separate Sewer Area	7

These modelling assessment results indicate that a comprehensive rainfall dependent infiltration/inflow (RDII) reduction program would not be cost-effective for CRW, since the completed wastewater flow monitoring and analysis activities showed the existing sewer collection systems are relatively "tight," and allow a minimal amount of extraneous RDII flow to enter. However, the high ground water infiltration flows monitored along Industrial Road, adjacent to Paxton Creek and Wildwood Lake, indicate that the trunk sewer could be a cost-effective candidate for a sewer lining project.

3.2 Treatment, Conveyance, and Collection System Characteristics

Section V-E, paragraph 21 of the PCD requires CRW to prepare and submit a characterization of its existing collection and conveyance systems, providing all the information required by the National CSO Policy. This requirement was successfully met in CRW's revised *Combined Sewer System Characterization Report* [1]and *Separate Sanitary Sewer Capacity Assessment Report*,[2] as summarized in this Section.

A map of the CRW service area collection sewer system is provided in **Figure 3-2**. The map shows the locations of the six interceptor sewers that convey wastewater from the collection sewers to the advanced wastewater treatment facility. The map also shows the delineations and extents of the sewershed areas that discharge into each of the interceptors (the six colored areas).

The map shows the delineations and names of each of the individual catchment areas that discharge to the distinct points of connection to the interceptors. Most of these connection points have regulator structures that divert a controlled flow rate to the interceptor, and allow excess combined wastewater to be discharged to receiving waters.

Approximately 60 percent of contributing area within the City of Harrisburg is served by combined sewers that carry wastewater and stormwater in the same pipe. Approximately 40 percent of contributing area within the City is served by separate sanitary sewers, where stormwater is conveyed by CRW and other public (e.g. PennDOT, other State properties) MS4 systems which discharge to a stream. Approximately 12 percent of the City does not contribute wastewater or stormwater to CRW's system (e.g. railroad corridors, areas adjacent to streams).

In the CRW service area, there are five categories of catchment area types, distinguished by where the sanitary wastewater flows and the stormwater runoff flows are ultimately conveyed. There also are areas not served by CRW sewers. Tributary areas for each of the five categories of catchment types shown in **Figure 3-2** are provided in **Table 3-2**.

CRW's wastewater and stormwater collection and conveyance systems consist of the following components described and characterized in this report section.

- An advanced wastewater treatment facility (AWTF), with a permitted monthly average daily design capacity of 45 million gallons per day (mgd), that treats wastewater from the City of Harrisburg and the suburban communities

AWTF Hydraulic Capacity	
Headworks	80 MGD
Primary Clarifiers	80 MGD
Secondary Treatment	45 MGD
BNR	45 MGD
Disinfection	80 MGD
2017 Influent Flow to AWTF	
Average Daily Flow	20.9 MGD
Max Avg. Daily Flow	51.9 MGD
Max Monthly ADF	25.8 MGD
Peak Flow	74.1 MGD

[1] *Combined Sewer System Characterization Report, Version 2.0*, February 2018, available at **https://capitalregionwater.com/cbh2o**.

[2] *Separate Sanitary Sewer Capacity Assessment Report, Version 2.0*, February 2018, available at **https://capitalregionwater.com/cbh2o**.

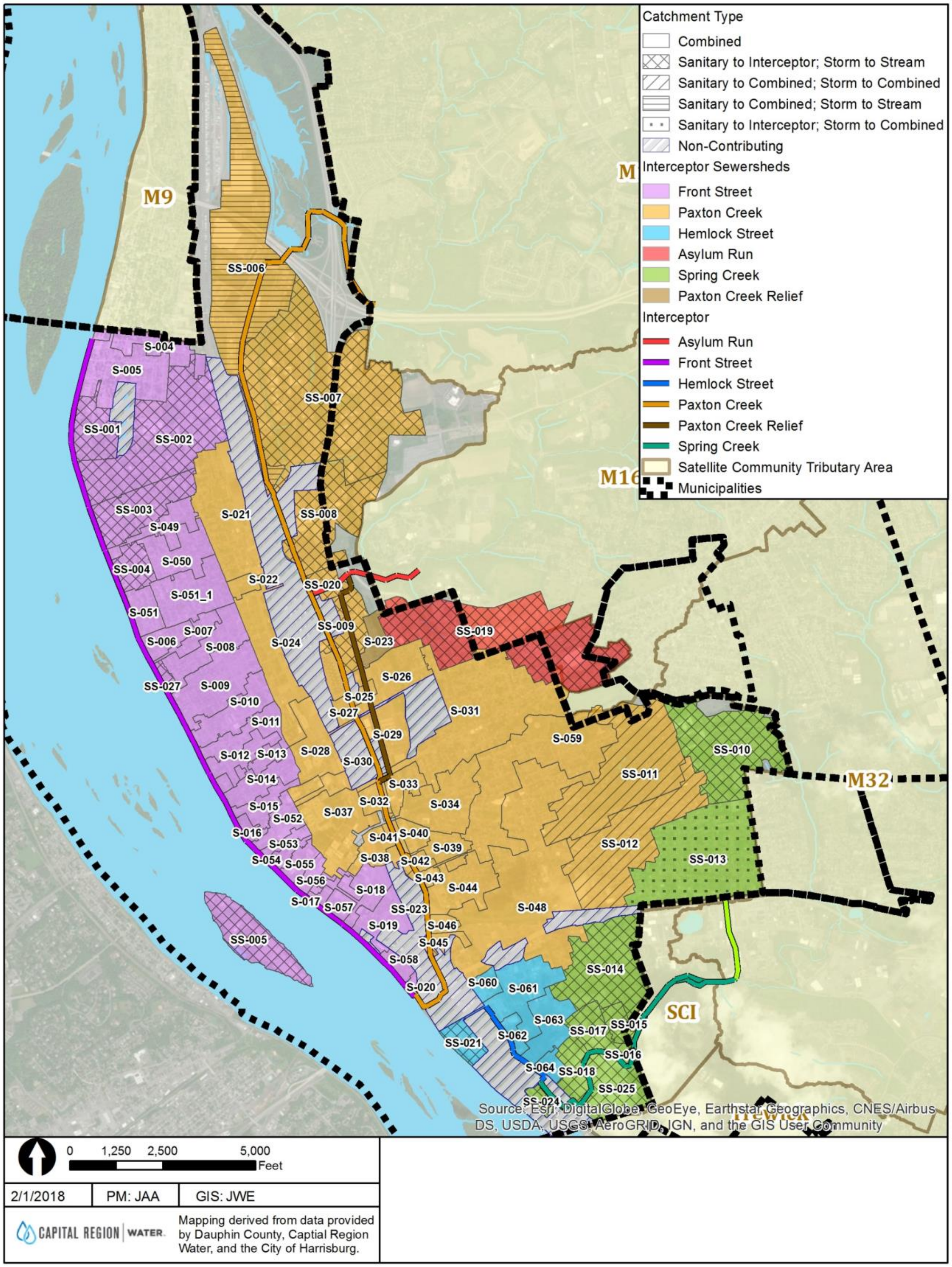

Figure 3-2: CRW Service Area Collection Sewer System and Catchment Areas

- A conveyance system consisting of:
    - 13.8 miles of interceptor sewer
    - Two major pumping stations and 1.3 miles of force mains that convey flow from the interceptors to the AWTF
    - 59 CSO regulator and 58 outfall structures (two regulators share a common outfall) that divert a controlled flow rate to the interceptor, and allow excess combined wastewater to be discharged to receiving waters
- A collection system consisting of:
    - Approximately 160 miles of separate and/or combined collection system sewers
    - Approximately 4,300 storm inlets and catch basins

Table 3-2: Catchment Area Types and Tributary Area Statistics

Sewershed	Combined Sewer System		Separate Sewer System					Non-Contributing Area (ac)	Separate Sanitary Outside City* (ac)
	[1] Combined Sewer Catchments (ac)	[2] Sanitary / Storm to Combined (ac)	[3] Sanitary to Combined; Storm to River		Sanitary to Interceptor				
					[4] Storm to Combined (ac)	[5] Storm to River			
			CRW MS4 (ac)	Other MS4 (ac)		CRW MS4 (ac)	Other MS4 (ac)		
Front Street	723	0	0	0	0	366	0	-	1
Paxton Creek	1,223	301	184	55	0	66	262	-	211
Hemlock Street	124	0	0	0	0	19	0	-	0
Paxton Creek Relief	16	0	0	0	0	0	0	-	0
Asylum Run	0	0	0	0	0	58	34	-	137
Spring Creek	0	0	0	0	169	367	0	-	5
Total	**2,086**	**301**	**184**	**55**	**169**	**876**	**295**	**561**	**354**
Percent of City	**46%**	**7%**	**4%**	**1%**	**4%**	**19%**	**7%**	**12%**	**-**
Percent of Contributing Area	**53%**	**8%**	**5%**	**1%**	**4%**	**22%**	**7%**	**-**	**-**

*Contributing area not tributary to a point of connection meter

Comprehensive inspection programs were successfully conducted for the CSO regulator structures, the interceptor system (both prior to and after cleaning), the pump stations and the force mains. These inspections provided the necessary information to properly understand the configuration, critical elevations, and maintenance conditions along the CRW Conveyance system. For the collection system, a Rapid Assessment Inspection was conducted at every known manhole and connecting pipe to quickly update the geographic information system (GIS) database and mapping, and to identify sewer segments with immediate structural or maintenance needs. These rapid assessment inspections are also being used to prioritize areas for systematic CCTV inspections to better define and prioritize remedial maintenance and repair needs. Summary information is provided in the following report sections.

3.2.1 Advanced Wastewater Treatment Facility

CRW owns and operates the AWTF located at 1662 South Cameron Street in Harrisburg, PA. The AWTF is one of the largest publicly owned treatment facilities in the Commonwealth and currently the largest in Pennsylvania within the Chesapeake Bay Watershed. The AWTF employs biological nutrient removal technology in a High Purity Oxygen Activated Sludge (HPOAS) plant to achieve nitrogen and ammonia requirements. CRW's AWTF treats wastewater from the City of Harrisburg and the six suburban communities located within its service area. The 5-year average annual wastewater flow at the AWTF during 2013 to 2017 was 21.4 million gallons per day (MGD). The permitted design hydraulic capacity of the AWTF is 45 MGD. More detailed descriptions of the treatment facility, the treatment processes, and the individual process units are provided in Sections 3.3 and 3.4 of the March 2017 Combined Sewer System Characterization Report and Section 3.3 of the March 2017 CRW Wastewater Division, *Operations and Maintenance Manual*[3], which is updated annually. The wastewater and solids handling processes for the current AWTF are summarized below and illustrated on **Figure 3-3**.

In March 2014, CRW began upgrading its AWTF with biological nutrient removal to comply with the Chesapeake Bay Tributary Strategy and meet associated new NPDES permit discharge requirements. This $50 million project at the AWTF consisted of adding biological nutrient removal technology to the existing processes to achieve nitrogen and ammonia removal requirements. The process involved adding side stream treatment (nitrification) for the filtrate from the sludge dewatering process that, when returned to the main treatment process, will bolster performance. Multiple tanks and processes were modified to complete integration of the new process. The project was completed in 2016.

Influent Flows: The AWTF receives the wastewater flows from Front Street Pump Station and the Spring Creek Pump Station in a common force main, while flows from the Borough of Steelton are pumped directly to the AWTF. Wastewater flows are screened at the pump stations by mechanically-cleaned bar screens.


Figure 3-4: Vortex Grit Chambers at CRW AWTF

Headworks Facilities: Wastewater flow passes through the influent channel to four vortex grit removal units, shown in **Figure 3-4**. Effluent from the grit removal units flows through a venturi flow meter located in the 54-inch pipe in the Control Building which is used to measure total plant flow. Improvements to the headworks facility, which will increase the wet weather treatment capacity, have been designed and construction will continue through 2018.

[3] *CRW Operation & Maintenance Manual, Version 2.0*, March 2017, available at **https://capitalregionwater.com/cbh2o**.

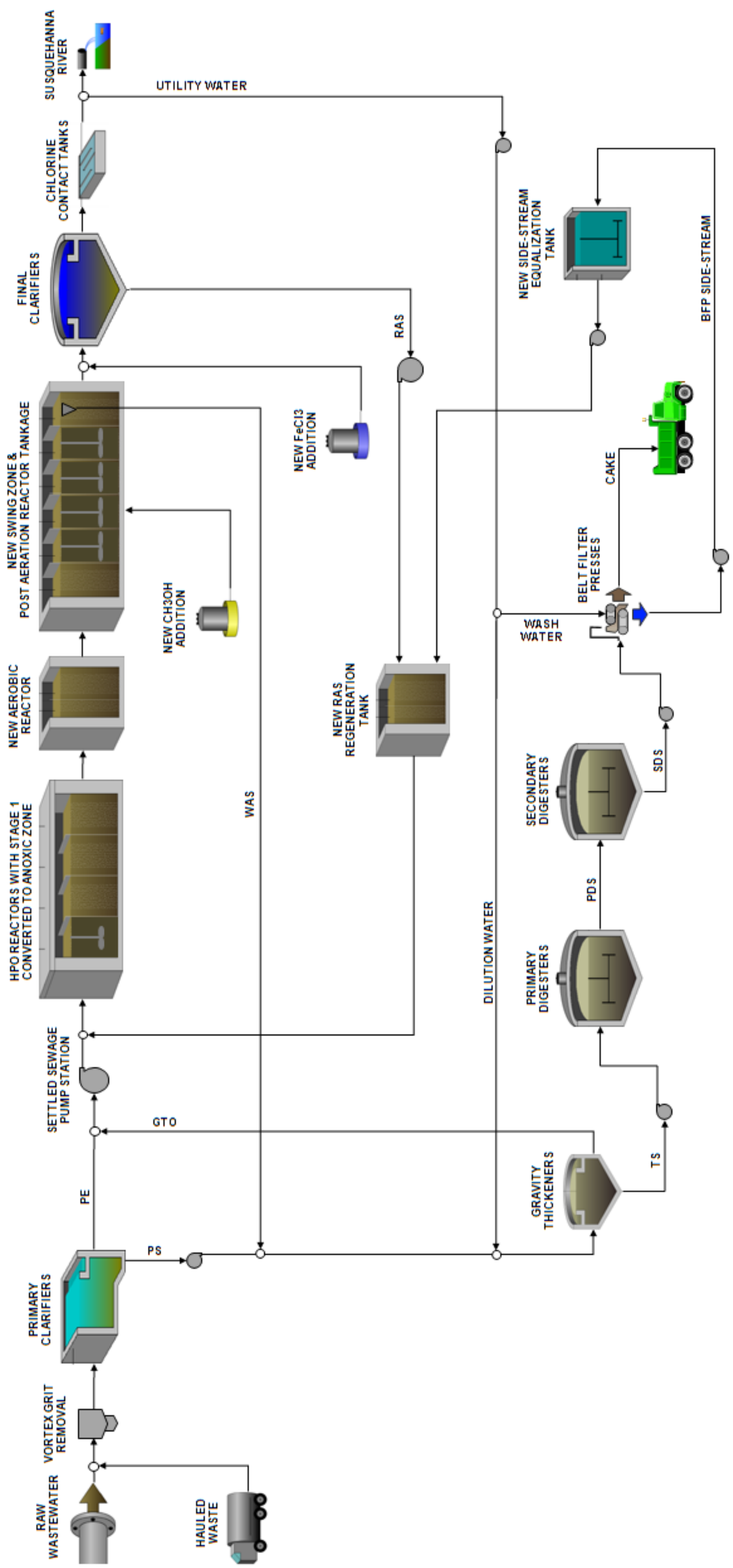

Figure 3-3: Process Flow Diagram for CRW AWTF Current Conditions
Source: Harrisburg Advanced Wastewater Treatment Facility Improvements Project. Basis of Design Report. Prepared by AECOM, February 2012

Primary Treatment Facilities: After the flow meter, wastewater is conveyed to the four primary clarifiers. Primary sludge is combined with waste activated sludge, and conveyed to the gravity thickeners. Stress testing was recently conducted to quantify the wet weather treatment capacity of the newly renovated and expanded facilities. The AWTF now has provisions for Chemically Enhanced Primary Treatment (CEPT). CEPT is used to improve total suspended solids (TSS) and biochemical oxygen demand (BOD) removal during peak loading periods.

Advanced Treatment Facilities**:** Settled wastewater overflows the primary clarifiers' weirs to the Settled Wastewater Pump Station. All settled wastewater flow, up to 45 mgd, is pumped to the advanced process. Peak flows above 45 mgd are bypassed around the advanced process and directed to the chlorine contact tank for disinfection. The advanced treatment process is based on High Purity Oxygen Activated Sludge (HPOAS) technology wherein the Oxygenation Tanks are covered and aeration is achieved by high purity oxygen produced by the on-site cryogenic facility. The AWTF improvements project currently provides additional nitrogen removal capability by the conversion of the first stage of the HPOAS to a pre-anoxic zone and the addition of a Bioreactor between the HPOAS and final settling tanks.

Figure 3-5: Chlorine Contact Tank at CRW AWTF

The Bioreactor has the capability to alternate between aerobic and anoxic zones with methanol addition to complete the nitrogen removal process. Following the Bioreactor, there is a post-aeration channel to increase the dissolved oxygen concentration in the effluent to meet NPDES discharge permit conditions. Flow from the Bioreactor enters a mix tank where polymer can be added for Chemically Enhanced Secondary Treatment (CEST) to improve solids settling in the final settling tanks. Flow is equally distributed to the six, 102-feet square final settling tanks using weir gates and flow meters. Effluent from the final clarifiers is conveyed to the chlorine contact tanks, shown in **Figure 3-5**, where it is disinfected using chlorine gas and chlorinators prior to discharge to the Susquehanna River.

Sludge and Solids Handling Facilities: Return Activated Sludge (RAS) collected in the final settling tanks flows to the RAS pump station wet well where it is pumped to the RAS regeneration tank. This new side stream treatment process combines the filtrate from the sludge dewatering belt filter presses with RAS for nitrification treatment in the covered RAS regeneration tank using high purity oxygen. The overflow from the RAS regeneration tank is then distributed between the Oxygenation Tanks.

The gravity thickened primary and waste activated sludges are pumped to the two-stage anaerobic digesters. The thickened sludge is heated and gas mixed in the primary digester to reduce volatile solids content and stabilize the sludge for disposal. Sludge overflows the primary digesters to the secondary digesters which function as sludge storage tanks. The digested sludge is then dewatered by belt filter presses and disposed of via landfill or land application.

Table 3-3: CRW AWTF NPDES Discharge Limits

Discharge Parameter	Unit	Minimum Value	Monthly Average Value	Weekly Average Value	Instantaneous Maximum Value
pH	-	6.0	-	-	9.0
Dissolved Oxygen	mg/L	5.0	-	-	-
Total Residual Chlorine	mg/L	-	0.5	-	1.6
Total Suspended Solids	mg/L	-	30	45	60
$CBOD_5$	mg/L	-	25	45	50
Ammonia-Nitrogen (May 1 – October 31)	mg/L	-	11	-	22
Total Phosphorus	mg/L	-	2.0	-	4.0
Fecal Coliform (May 1 – September 30)	Counts/100mL	-	200	-	-
Fecal Coliform (November 1 – April 30)	Counts/100 mL	-	2000	-	-

The AWTF discharges treated effluent to the Susquehanna River under a National Discharge Elimination System (NPDES) permit issued by the Pennsylvania Department of Environmental Protection (PA-DEP). The AWTF discharge limits under the NPDES Permit Number PA 0027197 are summarized in **Table 3-3**.

3.2.2 Interceptor System Characteristics and Inspections

For the early development of the Program Plan, an accurate and up-to-date understanding was needed of the existing CRW interceptor system. Comprehensive inspection programs were successfully conducted to obtain the necessary information to properly understand the alignment and conditions of the network of interceptor pipes, obtain the configurations and critical elevations of the regulator structures, develop the H&H model, and meet PCD requirements.

The CRW interceptor system consists of 13.8 miles of sewer pipe ranging in size and shape from 24-inch circular to 60-inch by 72-inch arch or rectangular pipe. Two of the interceptors, Asylum Run and Spring Creek convey separate sanitary flow. The other four interceptors are combined sewers. A map of the CRW interceptor sewers is provided in **Figure 3-6**. Pertinent information on the interceptor sewers is summarized in **Table 3-4**.

In 2014, CRW hired a contractor to inspect and assess the Asylum Run, Front Street, Hemlock Creek, Paxton Creek, Paxton Creek Relief, and Spring Creek Interceptor sewers. The technologies utilized to implement the inspections included closed circuit television (CCTV), sonar profiling, and laser profiling, which allowed full inspection of the pipes while maintaining full operation of the interceptor system and conveyance of the wastewater flow. Approximately 200 interceptor manholes were inspected, providing pan and tilt inspection images.

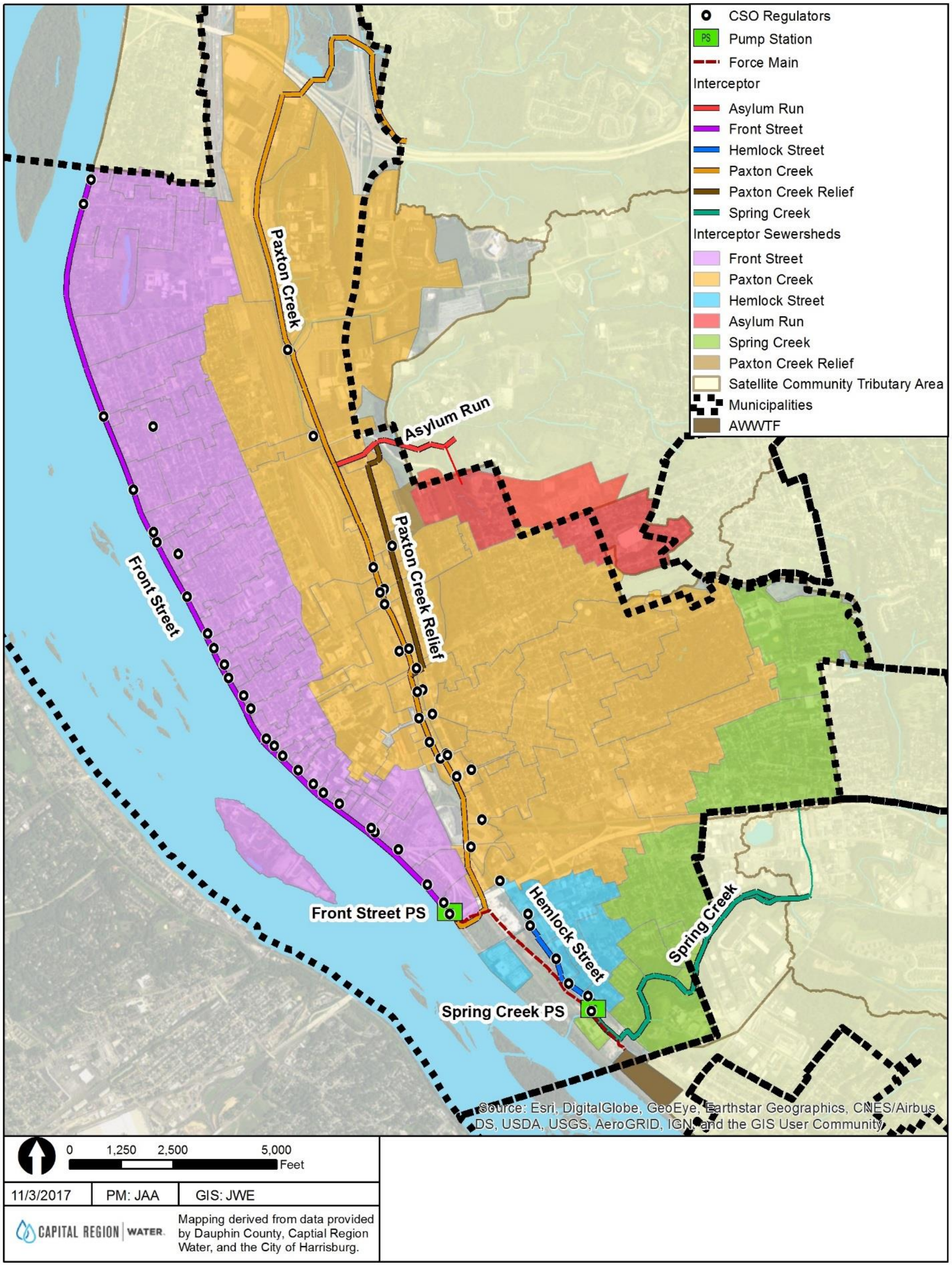

Figure 3-6: The CRW Interceptor Sewer System

Table 3-4: Key Characteristics of Interceptors in the CRW Conveyance System

Interceptor	Type	Typical Cross-Section	Length (miles)	Slope %	Material	Number of CSO Outfalls
Asylum Run (ARI)	Separate	24" Round	0.67	0.61	Concrete, VCP	0
Front Street (FSI)	Combined	39"H x 36"	3.95	0.07	Concrete, VCP	28
Hemlock Street (HSI)	Combined	24" Round	0.52	0.18	Concrete, VCP	5
Paxton Creek (PCI)	Combined	59"H x 48"W; 60"H x 72"W	5.53	0.09	Concrete	25
Paxton Creek Relief (PCRI)	Combined	48" Round	1.15	0.11	Concrete	1
Spring Creek (SCI)	Separate	24"-30" Round, 34"H x 32"W, 39"H x 36"W	2.03	0.37	Concrete, CMP, DIP	0

The observations and results from the completed interceptor pipe inspections were documented digitally using the standardized protocols of the National Association of Sewer Service Companies (NASSCO) Pipeline Assessment Certification Program (PACP). The observations and results were also documented in a February 2015 memorandum.[4] The goal of using PACP standards is for CRW to organize the inspection data to create a comprehensive database to properly identify, plan, prioritize, manage and renovate their pipelines based on condition evaluation. The inspection results were reviewed and recommendations were developed for additional cleaning, further inspection, and anticipated rehabilitation requirements.

Plans and specifications were developed for the interceptor cleaning project, which was bid during September and October 2015, awarded in January 2016, and completed in early March 2017. A total of 35,700 linear feet of interceptor pipes were cleaned and approximately 1,500 cubic yards (1,800 tons) of debris were removed.

As the cleaning contractor completed its cleaning operations, each cleaned section of the interceptor was re-inspected using sonar and CCTV technologies, and the findings documented in a May 2017 memorandum[5], which superseded the February 2015 memorandum. The re-inspections verified that the pipes were sufficiently cleaned, documented the location and quantity of any residual solids depositions, and revealed hidden structural and/or maintenance defects and incorrect pipe cross sections.

Table 3-5 provides a summary of heavy cleaning that was completed during 2016 and 2017 (recommendations per the 2014 inspections) and the length of recommended rehabilitation for each interceptor.

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[4] Technical Memorandum, *Summary and Recommendations for Cleaning and Rehabilitation of CRW Sewer Interceptors from the Review of Redzone CCTV, Laser and Sonar Data*, February 2015.

[5] Technical Memorandum, *CRW Interceptor Cleaning and Rehab Improvements Update Report,* May 2017.

Table 3-5: Summary of Recommended Interceptor Cleaning and Rehabilitation

Interceptor	Length of Heavy Cleaning Completed (feet)	Length of Recommended Rehabilitation (feet)
Asylum Run (ARI)	0	2,504
Front Street (FSI)	11,973	12,581
Hemlock Street (HSI)	1,143	0
Paxton Creek (PCI)	15,651	13,499
Paxton Creek Relief (PCRI)	6,312	0
Spring Creek (SCI)	655	5,117
Total:	**35,734**	**33,701**

3.2.3 Major Pump Station and Force Main Characteristics

Two sewage pump stations convey flow to CRW's AWTF. The Front Street Pump Station receives flow from the Front Street and Paxton Creek interceptors, while the Spring Street Pump Station conveys interceptor flow from the Hemlock Street and Spring Creek Interceptors. The Front Street Pump Station discharges to a 48-inch force main; the Spring Creek discharges to a 24-inch force main, which then discharges to the Front Street Pump Station force main. Immediately before reaching the AWTF, the force main expands to a 54-inch diameter. The Front Street pump station has four pumps, each pump is 10,000 gpm (two pumps are variable speed, and two pumps are constant speed). **Table 3-6** presents the operating level of each of these pumps. The Spring Creek pump station has three pumps; each pump is 8,350 GPM and all are variable speed. **Table 3-7** presents the operating level of each of these pumps. According to CRW's Nine Minimum Control Plan[6], both the Front Street and Spring Creek pump stations are over 50-years old, are nearing the end of their useful lives, and are in need of significant remedial maintenance and reconstruction within their existing buildings. A recent inspection of CRW's force main, however, did not identify any leaks, stable gas pockets, or priority anomalies.

Table 3-6: Front Street Pump Station Wet Well Operating Levels

Operating Condition	Rising Wet Well Levels (feet)	Dropping Wet Well Levels (feet)
Lead Variable Speed Pump	Start @ 294.0	Stop @ 291.0
1st Lag Variable Speed Pump	Start @ 295.0	Stop @ 292.0
2nd Lag Constant Speed Pump	Start @ 297.0	Stop @ 292.0
3rd Lag Constant Speed Pump	Start @ 297.1	Stop @ 295.0

Notes: 1. High Water Alarm = 297.0
2. Low Water Alarm = 291.5
3. Bottom of Wet Well = 286.0

[6] *CRW Nine Minimum Control Plan, Version 3.0*, August 2017, available at **https://capitalregionwater.com/cbh2o**.

Table 3-7: Spring Creek Wet Well Operating Levels

Wet Well Parameters	Rising Wet Well Levels (feet)	Dropping Wet Well Levels (feet)
Lead Pump	Start @ 3.5	Stop @ 1.5
1st Lag Pump	Start @ 5.0	Stop @ 3.0

Notes: 1. High Water Alarm = 5.5
2. Low Water Alarm = 1.0
3. Levels referenced to bottom of wet well
4. The third pump must be placed into service manually

3.2.4 CSO Regulator Structure and Outfall Characteristics and Inspections

The CRW conveyance system includes 59 CSOs distributed along the four interceptor sewers plus an emergency overflow outfall at each of the two pumping stations. The locations of these CSO regulator structures are provided in **Figure 3-7**. To obtain the needed information for the Program Plan, CRW contracted for an inspection of every CSO regulator structure within the CRW interceptor system[7]. The systematic inspections were critical to documenting the configuration of each regulator, confirming key dimensions and elevations, and identifying potential structural or functional deficiencies. The inspection observation and measurement information and data for each individual regulator structure were documented in a five-page inspection form.

The configuration of a typical CSO diversion structure in the CRW system is provided in **Figure 3-8**. Combined wastewater enters the diversion chamber and under dry weather conditions, all the flow is diverted away from the trunk sewer and towards the interceptor sewer by a concrete diversion weir (also called a diversion dam). An example of a typical diversion weir is provided in **Figure 3-9**. During wet weather, the rate and volume of stormwater flow from the combined catchments increases significantly and can exceed the capacity of the regulators, downstream interceptor sewers and/or the treatment facility. When this occurs, the CSO regulator structures (sometimes called diversion structures) divert a controlled flow rate to the interceptor, while untreated excess combined wastewater is discharged to receiving waters.

There are two main categories of CSO regulator structures in the CRW system: regulators with variable control orifices and those with fixed orifice openings. Most of the CSO regulator structures in the CRW system have variable control orifices where the sizes of the control openings from the diversion chamber to the regulator chamber can increase and decrease under differing flow conditions, as determined by the mechanical Brown and Brown (B&B) type regulators. For most structures, under wet weather conditions, when the influent flow from the trunk line is high enough to approach the crest of the diversion weir, the wastewater level in the float chamber raises the float mechanism, triggering the control orifice to close. When the storm is over and the water level in the trunk sewer recedes, the float mechanism reopens the orifice to its fully open position. An example of a typical B&B mechanism is provided in **Figure 3-10**.

[7] *Regulator Infrastructure Inspection Report,* October 2013

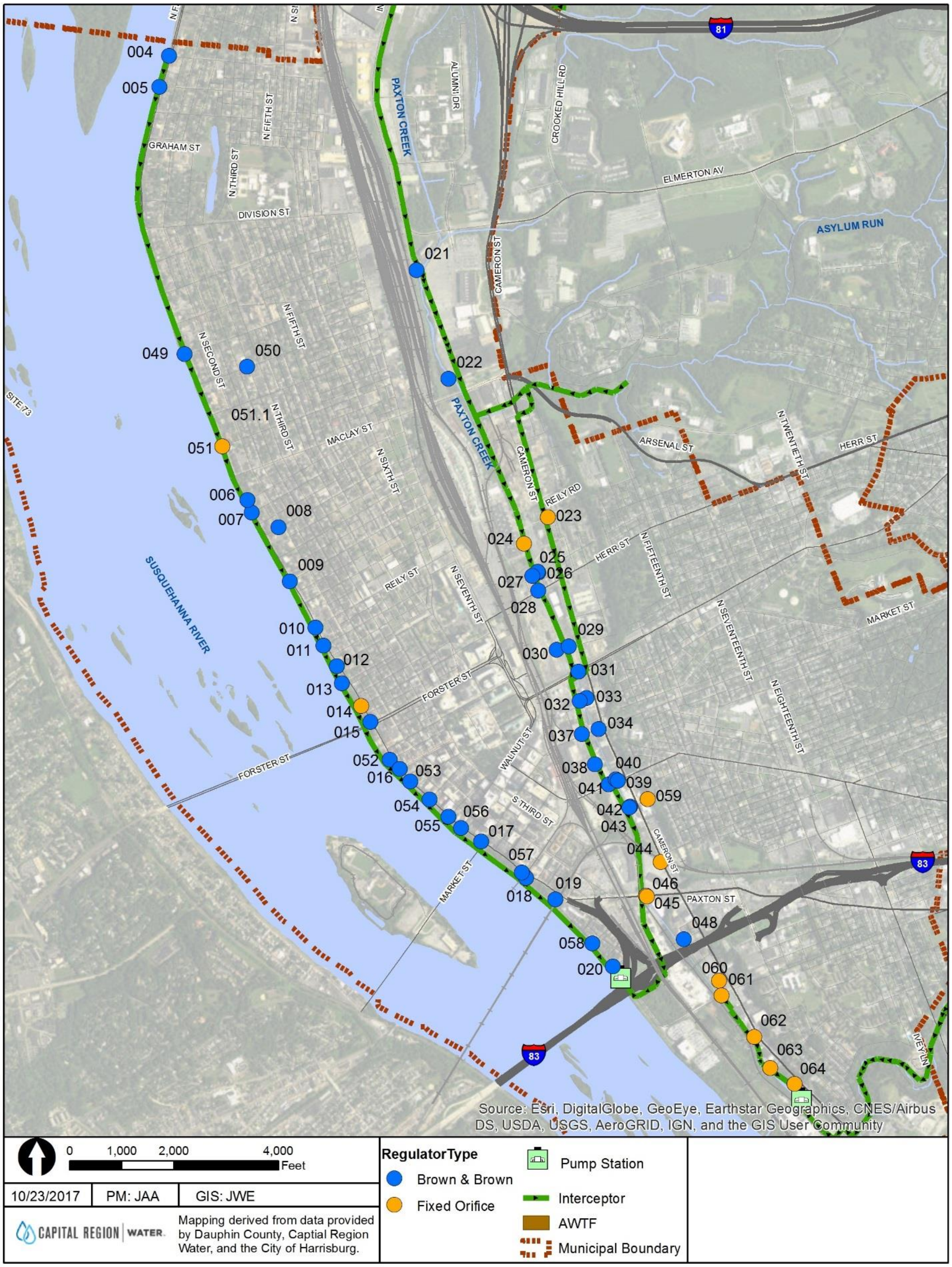

Figure 3-7: Locations of CSO Regulator Structures within the CRW System

Thirteen of the CSO regulator structures have fixed control orifices and the size of the opening does not change under dry and wet weather conditions. The fixed orifice structures are similar to the variable orifice structures except that the size of control orifice openings are fixed and do not change. There is no float chamber in the structure and there is no B&B mechanical equipment. Some of the structures have a V-notch weir to control water surfaces in the chamber. Examples of fixed orifice controls are provided in **Figure 3-11**.

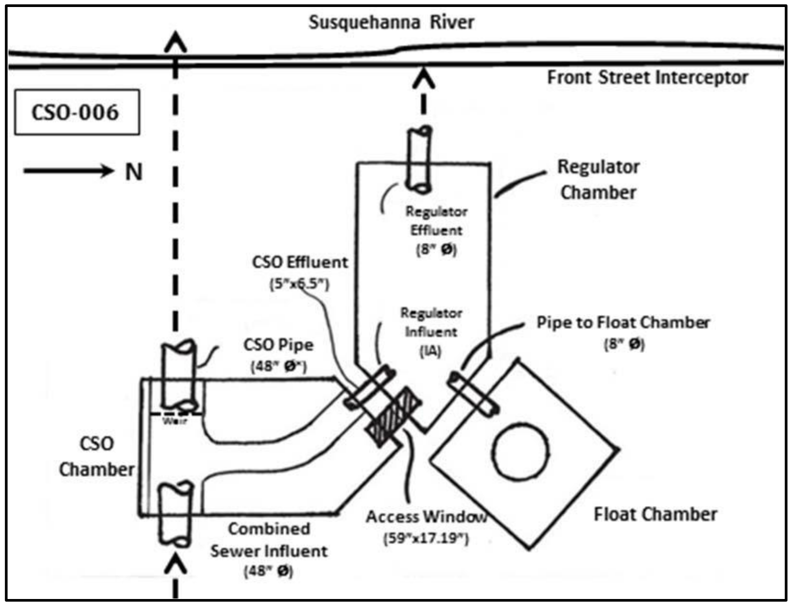

Figure 3-8: Configuration of a Typical CRW CSO Regulator Structure

Figure 3-9: Example of a Diversion Dam

Figure 3-10: Brown and Brown Control Equipment

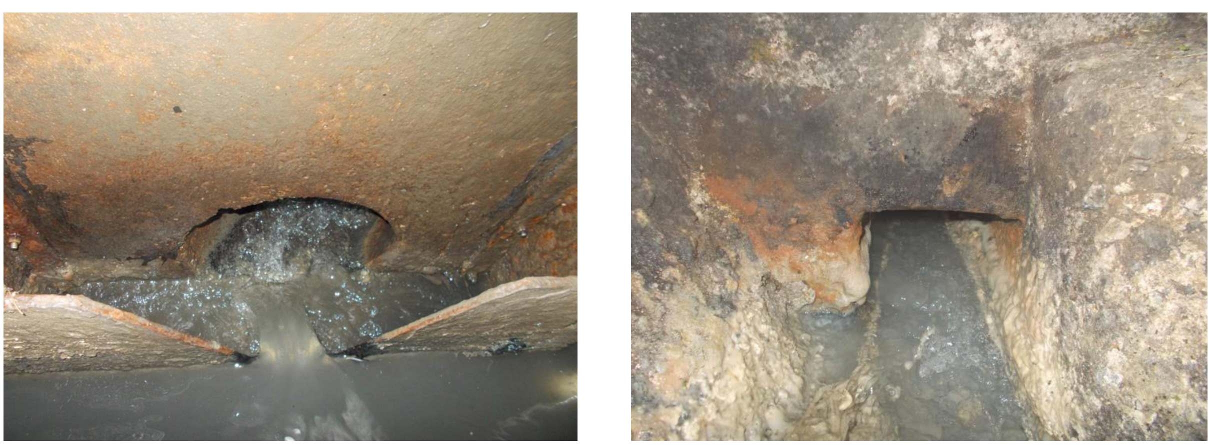

Figure 3-11: Examples of Fixed Orifice Controls

An emergency overflow structure and outfall serves each of the Front Street and Spring Creek Interceptors. They allow CSO discharges to occur if there were to be a mechanical failure at the pump station.

3.2.5 Collection System Characteristics and Inspections

In the initial stages of the City Beautiful H_2O Program Plan, CRW needed to quickly update its original GIS mapping of the configuration of the combined and separate sanitary sewer collection systems within the service area. It would not be possible to meet the PCD schedule and milestone deadlines by televising the entire system. Therefore, CRW elected to implement a Rapid Assessment Inspection Program, conducted via a pole camera inspection of every known manhole and connecting pipe within the collection system. The information gathered through the Rapid Assessment Inspection Program was successfully used to delineate the combined and separate sewer catchment areas within the CRW collection system. A map of the CRW collection system showing the catchment areas was previously provided in **Figure 3-3**.

CRW retained a contractor to perform the collection system Rapid Assessment Inspection Program in 2015 and 2016. **Table 3-8** provides a summary of the miles of pipe and the number of manholes and outfalls that were inspected. The inspection observations were divided between operations and maintenance (O&M) findings and structural findings.

Table 3-8: CRW Rapid Assessment Inspection Summary

Combined/Separate Sewer System	Miles of Pipe	Number of Manholes/Outfalls	Inspection Period
Collection System Trunk Sewers	31	713	2015-2016
Collection System Branch Sewers	92	2,087	2015-2016
Separate Storm Sewers	16	302	2016
Total	**139**	**3,102**	-

O&M findings consist of defects related to the operation of the sewer system. Defects such as root intrusions and debris and grease deposits are examples of O&M defects. Structural defects pertain to any issue that may jeopardize the structural integrity of the pipe or manhole. Cracks, fractures, holes, exposed rebar, and missing bricks are examples of structural defects. The rapid assessment inspections are being followed by an ongoing program of closed circuit television (CCTV) inspections that are described later in this Program Plan.

The zoom camera inspections allowed for a rapid assessment of the condition of the pipes within CRW's collection system. Since inspections were conducted from the manhole access points only, each pipe has an upstream and downstream video that was captured. By analyzing both the upstream and downstream videos, a general condition assessment was performed for the viewable portion of each pipe, and preliminary rehabilitation recommendations were made. If nothing was preventing visibility within the pipe, fifty feet or more of the pipe length was viewable from videos taken at both the upstream and downstream manholes, which was generally sufficient for providing a preliminary characterization of the pipe. However, for pipes with bends, partial obstructions, or long distances between manholes, the assessment was more limited.

Ongoing CCTV Inspections and Assessments: While the collected Rapid Assessment Inspection data were essential in meeting the PCD schedule, there were understood limitations to the information provided because conditions within the pipe segments beyond the manhole inspection limits could not be observed. Subsequently, CRW developed and is implementing a prioritized CCTV inspection program to fill in the information gaps at a pace within their capabilities.

CRW is in the process of conducting a prioritized remedial CCTV inspection of the entire collection system within the next five to seven years to eliminate risk associated with unknown defects, especially for critical sewers which have a high consequence of failure. To expedite the process, CRW has committed to purchasing a second CCTV truck and hiring additional staff to operate it. Outside contractors may also be used, as necessary, to supplement in-house CCTV capabilities. It is important to note that the CCTV inspection program is likely to identify additional defects not seen by the rapid assessment inspections which will elevate the condition score, and thus the recommendation priority, of many pipes. CRW is utilizing its Cityworks Asset Management System to document completed CCTV inspections, prioritize future CCTV inspections, and manage the pace at which inspections are conducted. Once the remedial CCTV inspections are completed on a system-wide basis. CRW will be able to transform its CCTV inspections from a remedial program to a preventative O&M program.

Updating of the GIS Database: The observations, findings, and relevant data from the completed Rapid Inspection Program were entered into the CRW geographic information system (GIS) database. The database updates included information such as pipe location, pipe size, and pipe condition, including the type and severity of any observed defects. The updated information facilitated the refinement of GIS-based maps of the CRW collection system. The GIS database is updated as new information is obtained through the ongoing CCTV inspections.

Ongoing Catch Basin Inspection and Repair: CRW is also in the process of conducting a comprehensive program of inspection, cleaning, and repair of its catch basins and storm inlets. The CRW collection system includes approximately 4,300 catch basins and inlets. CRW is utilizing its Cityworks Asset Management System to document completed inspections, prioritize and schedule any required remediation work, track completed rehabilitation activities, and manage the pace at which the activities are completed.

3.2.6 Prioritized Asset Management Program

Asset management is a systematic process of operating, maintaining, and upgrading assets cost-effectively. A Cityworks asset management and work order system has been successfully implemented to assist CRW in fulfilling its responsibility to provide sustainable services to their customers while maintaining their assets in a cost-effective manner. For quality assurance, sewer system inspections were conducted and documented using the criteria, standards and methodology of the National Association of Sewer Service Companies (NASSCO).

Cityworks Asset and Work Order Management: Cityworks provides CRW with a comprehensive public asset and work management tool for the operation and maintenance of infrastructure facilities and other location-focused activities. The asset management program manages infrastructure capital assets to minimize the total cost of owning, operating, and maintaining assets at acceptable levels of service. Maintenance management involves two fundamental practices – reactive and scheduled maintenance. Cityworks logs and manages reactive maintenance activities such as when CRW crews conduct regulator structure inspections after a storm event, or respond to a citizen call reporting a sinkhole or clogged storm inlet. Cityworks manages scheduled maintenance or preventive maintenance activities to ensure the performance of CRW assets either individually or as a part of a larger system.

NASSCO Documentation Standards: The CRW conveyance and collection system inspections were conducted and documented using the criteria, standards and methodology of the National Association of Sewer Service Companies (NASSCO). Using the NASSCO protocols, and NASSCO-certified inspection supervisors, a standardized condition assessment score was assigned for each observed pipe or manhole defect to establish an overall level of severity. The protocols for the Pipeline Assessment Certification Program (PACP) were used for the sewer inspections. The standardization certification ensures that an assigned defect label and severity rating is consistent whether the inspection is conducted in Los Angeles or Harrisburg. The protocols for the Manhole Assessment Certification Program (MACP) were applied to the manhole inspections.

3.3 Regional Precipitation Characteristics

The Partial Consent Decree, in Section V-E, paragraph 15 requires CRW to develop and implement an *Initial Flow Metering and Monitoring Program Plan* (IFMMPP)[8]. The plan included a regional rain gauge network, and a gauge adjusted radar rainfall (GARR) system to collect precipitation data. The PCD also requires CRW to use the collected data to characterize precipitation over its service area. The long-term record data at the airport gauges were analyzed to develop a typical year rainfall dataset and a set of synthetic design storms for the CRW service area. The collected and analyzed precipitation data were sufficient to refine and validate the hydrologic and hydraulic (H&H) model.

3.3.1 Characterization of Precipitation Statistics and Patterns

The combined record from the two airport gauges provided a long-term historical record of 57 years. The average annual precipitation volume and the average annual number of storm events were determined, along with the associated standard deviations, for the extended precipitation record. The median annual rainfall for the Greater Harrisburg region for the 57-year record was 39.8 inches, and the standard deviation was 8.1 inches. The 68 percent confidence interval extends from 31.7 inches to 47.9 inches.

Figure 3-12 shows the average monthly distribution of precipitation volumes based upon the long-term precipitation record. Also shown on the figure are the plus and minus one standard deviation values, a measure of the statistical spread in the observed dataset. **Table 3-9** provides the information in tabular form.

[8] *Initial Flow Metering and Monitoring Program Plan,* July 2013.

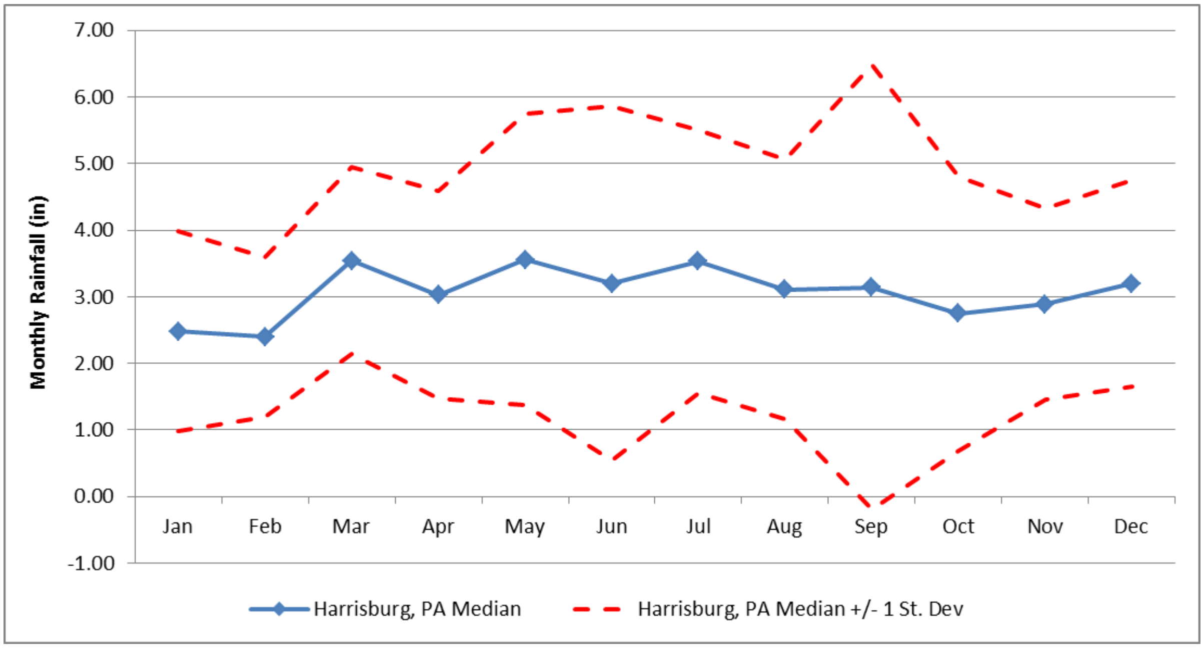

Figure 3-12: Median Monthly Precipitation Volumes in Harrisburg

Table 3-9: Median Monthly Precipitation Volumes in Harrisburg

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	2.48	2.40	3.54	3.03	3.56	3.20	3.53	3.11	3.14	2.75	2.89	3.20
Standard. Deviation	1.50	1.20	1.40	1.56	2.19	2.65	1.97	1.95	3.34	2.05	1.44	1.55
Standard. Deviation. as %[2]	61%	50%	40%	51%	62%	83%	56%	63%	106%	75%	50%	49%
Median + 1 SD	3.98	3.60	4.94	4.59	5.75	5.85	5.50	5.06	6.48	4.79	4.33	4.75
Median – 1 SD	0.98	1.20	2.14	1.47	1.37	0.55	1.56	1.16	-0.20	0.70	1.45	1.65

(1)Note: All precipitation volumes are given in inches
(2)Note: Standard deviation as a percent of the median value

The analysis of the airport rainfall records indicated that the median annual number of significant precipitation events, events greater than 0.05 inches, over the long-term record was 86, and the standard deviation was 12.3 events. A minimum inter-event period of 6 hours was used for the analysis. The 68 percent confidence interval extends from 73.7 events to 98.3 events.

Figure 3-13 shows the average distribution of precipitation event frequency. Also shown on the figure are the plus and minus one standard deviation values to show the statistical spread in the observed dataset. The figure shows that the number of precipitation events in the greater Harrisburg area tend to be distributed evenly throughout the year, averaging from 6 to 9 events per month. **Table 3-10** provides the information in tabular form.

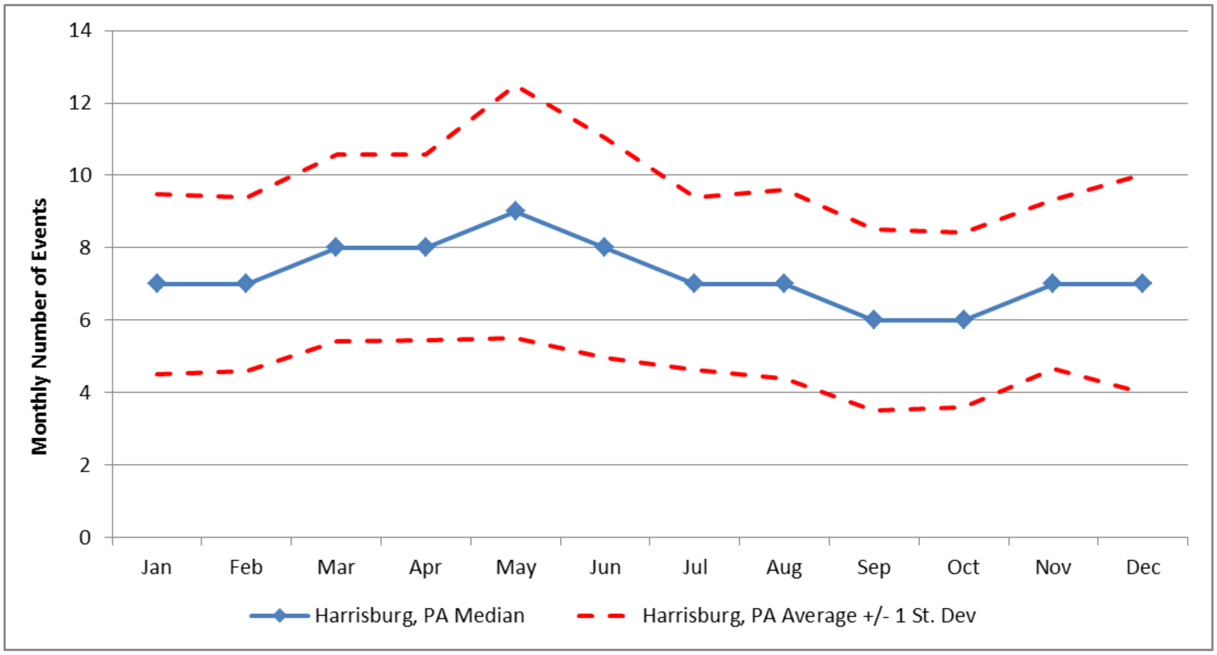

Figure 3-13 Median Number of Monthly Precipitation Events for Harrisburg

Table 3-10: Median Monthly Precipitation Events in Harrisburg

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	7.0	7.0	8.0	8.0	9.0	8.0	7.0	7.0	6.0	6.0	7.0	7.0
Stand. Deviation	2.5	2.5	2.7	2.5	3.6	3.1	2.4	2.6	2.5	2.4	2.4	3.0
Stand. Dev. as %*	36%	35%	33%	32%	40%	38%	34%	37%	42%	40%	34%	43%
Median + 1 SD	9.5	9.5	10.7	10.5	12.6	11.1	9.4	9.6	8.5	8.4	9.4	10.0
Median – 1 SD	4.5	4.5	5.3	5.5	5.4	4.9	4.6	4.4	3.5	3.6	4.6	4.0

*Note: Standard deviation as a percent of the median value

3.3.2 Catchment Area Rainfall for H&H Modeling

To quantify and characterize precipitation patterns within the CRW service area, and support the development of the Program Plan, CRW successfully developed and implemented a precipitation gauge network consisting of eight tipping bucket rain gauges located throughout the service area. The gauge network recorded rainfall depths in 5-minute intervals with a minimum recorded depth of 0.01 inches. All the gauges are heated to allow for accurate measurement of frozen precipitation events during winter. Hourly rainfall data were also collected from the two National Weather Service gauges located at the Capital City Airport and at the Harrisburg International Airport. **Table 3-11** summarizes the rain gauge network and the respective gauge period of record while **Figure 3-14** shows the rain gauge network locations in relation to the City of Harrisburg and the communities receiving wholesale conveyance and treatment services from CRW.

Table 3-11: Precipitation Monitoring Site Summary

Gauge Name /Number	Gauge Location	Period of Record	Data Collection Status	Data Analysis Status
ID COOP 363699	Capital City Airport	5/1/1948 - 1991	Completed	Completed
FAA_ Hourly-KCXY	Capital City Airport	1996 – Present	Ongoing	Ongoing
Harrisburg Int. Airport	Harrisburg Int. Airport	10/1/1991 – Present	Ongoing	Ongoing
RG1	Koons Park	9/3/2014 – Present	Ongoing	Ongoing
RG2	Market Street	8/1/2014 - Present	Ongoing	Ongoing
RG3	CRW AWTP	8/1/2014- Present	Ongoing	Ongoing
RG4	Swatara	9/5/2014 - Present	Ongoing	Ongoing
RG5	United Water	9/12/2014 - Present	Ongoing	Ongoing
RG6	Lower Paxton	9/9/2014 - Present	Ongoing	Ongoing
RG7	East Pennsboro	9/6/2014 – Present	Ongoing	Ongoing
RG8	Steelton	9/5/2014 - Present	Ongoing	Ongoing

Like any rain gauge network, the CRW system cannot quantify and characterize precipitation volumes, intensities, and patterns that occur between the gauge locations. To characterize the spatial variability of rainfall events over the CRW service area, gauge adjusted radar rainfall (GARR) data were obtained and used along with the gauge network data. GARR precipitation data were provided in 5-minute intervals within a high-resolution pixel grid comprised of 1-km by 1-km (0.6-mi by 0.6-mi) cells. A total of 586 pixel cells define precipitation patterns over the CRW service area, including the City of Harrisburg and the collection systems serving the suburban communities. **Figure 3-14** shows the GARR pixel grid in relation to the rain gauge network and municipal boundaries.

Radar reflectivity data were produced by the National Weather Service (NWS) Next Generation Radar (NEXRAD) system and were obtained from the KCCX radar site located near State College, Pennsylvania, approximately 62 miles from the City of Harrisburg. In the production of GARR, radar rainfall data were bias corrected through comparison with rain gauge accumulations. The high-resolution, spatially distributed GARR data over the entire CRW service area were used to characterize the response of combined and separate sanitary sewer collection systems to wet weather, support the calibration of the H/H models, and provide rainfall data for future system performance evaluations.

The radar rainfall data was applied to the delineated catchment areas within the CRW service area. This was done by intersecting the catchment area with the GARR pixel grid to determine the area from each pixel cell that falls within each tributary area. Once these areas are derived, an area-weighted precipitation value was calculated for each time step for each tributary drainage area. By doing this, a precipitation data set unique to each point of interest's tributary drainage area was produced.

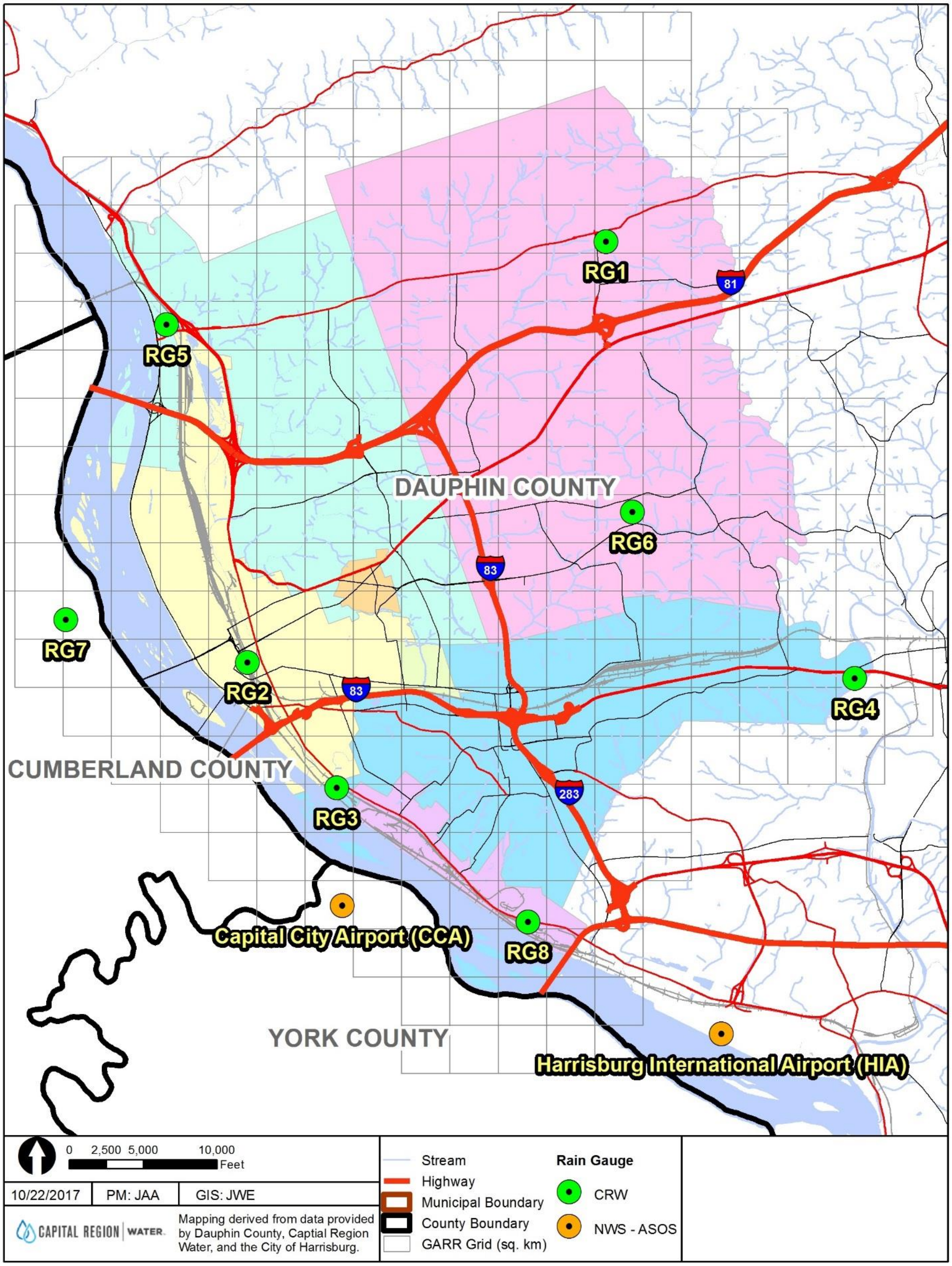

Figure 3-14 Precipitation Monitoring Sites and GARR Grid

3.3.3 Development of the Typical Year Rainfall

A representative or typical year precipitation dataset for the CRW service area was created[9] for use with the H&H Model of CRW's conveyance system to establish the frequency, duration, and volume of CSO discharges; characterize their potential water quality impacts; and develop and assess alternative control strategies.

Point Precipitation Frequencies: The National Oceanic and Atmospheric Administration (NOAA) has conducted statistical analyses for long-term record precipitation record gauges across the country, and distributes the results on their internet site as NOAA Atlas 14. The Atlas provides precipitation frequency estimates for Harrisburg, based upon a partial duration frequency analysis of the long-term record. **Table 3-12** provides the analysis results for a one-year recurrence interval, including upper and lower bounds of the 90 percent confidence interval.

The completed analyses of the long-term precipitation record for the Harrisburg area established the following specific statistical criteria for the typical year rainfall.

- The average annual rainfall is 39.8 inches, and there is a 90 percent statistical confidence that the annual rainfall for the typical year should lie within a range extending from 31.7 inches to 47.9 inches.
- The average annual precipitation event frequency is 86 storms, and there is a 90 percent statistical confidence that the annual number of storms for the typical year should lie within a range extending from 74 to 98 events. A threshold value of 0.10 inches and an inter-event of six hours were used to define significant precipitation events.
- The desired monthly distribution of rainfall depths and event frequencies for the typical year, along with their associated confidence ranges, are shown on **Table 3-10.**
- The peak storm intensities for the typical year, along with their associated confidence ranges, are provided on **Table 3-12.**

Table 3-12: Point Precipitation Frequency Estimates* for Harrisburg for a 1-Year Recurrence Interval

Duration	Precipitation for 1 Year Recurrence Interval	Lower Bound 90% Confidence Interval	Upper Bound 90% confidence Interval
5-min	0.321	0.289	0.356
10-min	0.511	0.46	0.567
15-min	0.639	0.575	0.709
30-min	0.874	0.786	0.969
60-min	1.09	0.979	1.21

*Note: all precipitation frequency estimates are given in inches

The representative typical year precipitation record, developed for the Program Plan and input into the validated H&H model, meets these criteria. Therefore, the dataset should accurately

[9] Technical Memorandum, *Typical Year Report,* July 2015.

represent the long-term precipitation record for the CRW service area. When the typical year precipitation dataset is input into the existing condition H&H models, the simulated annual CSO statistics for annual event frequency, volume, and duration should closely match corresponding statistical averages of the long-term historical record, establish existing baseline conditions, and facilitate the development and evaluation of wet weather control alternatives.

Impacts of Climate Change: Both the National CSO Policy and the US-EPA guidance for the preparation of a LTCP clearly states that control alternatives are to be developed based upon an "average annual basis." Therefore, rainfall analyses are implemented from the typical long-term rainfall record. CRW implemented written US-EPA guidance when developing and assessing alternatives, and utilized the typical year precipitation analysis approach. Sensitivity runs were subsequently conducted and considered to quantify performance under a range of precipitation conditions, including those imposed by climate change trends. While CRW could consider climate change in sizing facilities, the level of control (and the associated sizing of facilities) provided by the CRW Program Plan is guided by the financial capability constraints of the service area rate payers (see Section 8.0). The impacts of climate change would require a significant extension to the implementation schedule for the Program Plan, well beyond that of a traditional Consent Decree timeframe. Therefore, the possible long-term effects of climate change will potentially impact the level of service provided by the Program Plan, but not impact the recommended control facilities.

3.3.4 Development of Synthetic Design Storm Rainfall

The Program Plan is intended to prevent separate sanitary sewer overflows (SSOs) and control unauthorized releases from the combined sewer system, along with controlling CSO discharges. To quantify and characterize specific locations with the potential for SSOs and unauthorized combined sewer releases to occur within the CRW service area, a series of synthetic design storms were developed and applied to the H&H models. The analyses complied with the requirements specified in the PCD that require CRW to conduct a capacity assessment study of the Harrisburg sewer system under current conditions during peak dry weather flow conditions and the 2-year, 5-year, and 10-year 24-hour storm events[10].

CRW obtained and utilized rainfall intensity-duration-frequency statistics for Harrisburg published in NOAA Atlas 14 to define 24-hour rainfall volumes for the recurrence interval storm events. Design rainfall hyetographs were developed by fitting these volumes to the SCS-Type II distribution, which embeds the intensity of storms with durations less than 24 hours, allowing the calculation of runoff statistics across drainage areas of varying size, slope, and storage characteristics. This distribution properly estimates peak flows from drainage catchments over a range of times of concentration shorter than 24-hours.

The SCS-Type II distribution is considered a stacked distribution, where approximations of the 5-minute, 10-minute, 15-minute, 30-minute, 1-hour, 2-hour, 6-hour, and 12-hour storm volumes are superimposed roughly symmetrical around the twelfth hour of the synthetic storm. This temporal distribution has been widely implemented by water resources professionals to calculate frequency duration volumes and peak intensities applicable to a wide range of catchment and

[10] *Separate Sanitary Sewer Capacity Assessment Report, Version 2.0,* Section 4, February 2018, available at **https://capitalregionwater.com/cbh2o**.

sewershed areas and times of concentration. Hyetographs, or graphical bar-chart representations, of the resulting design storm rainfall distributions are provided in **Figure 3-15** through **Figure 3-17**.

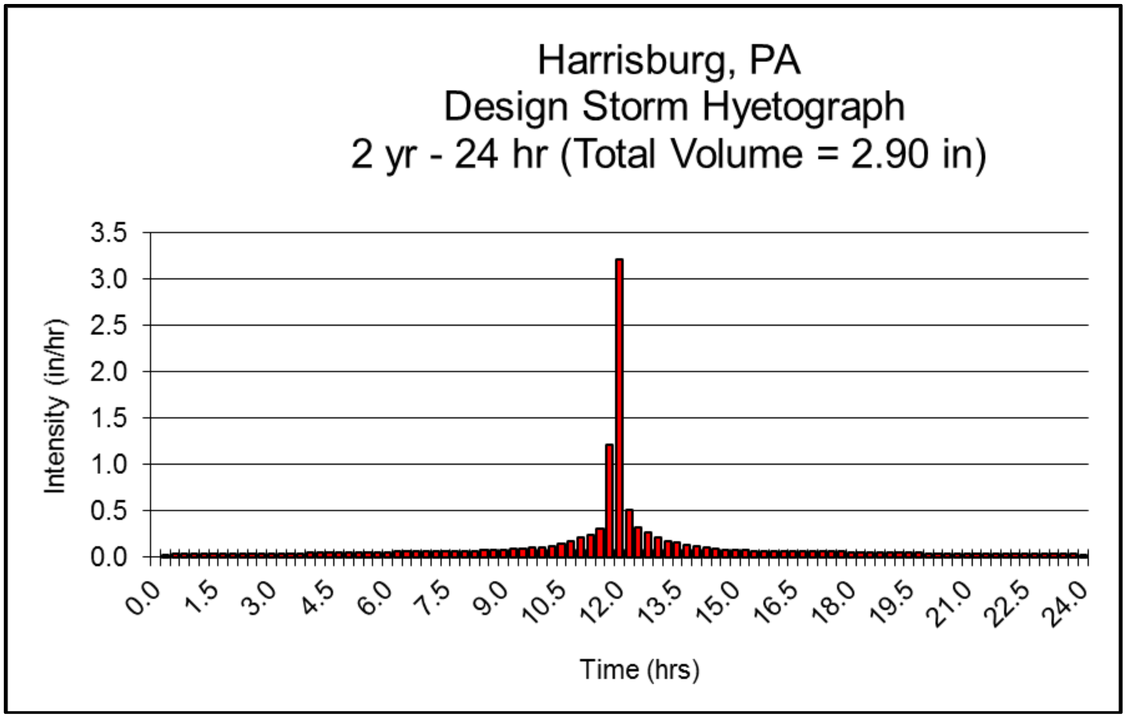

Figure 3-15: Hyetograph for a 2-Year, 24-Hour Synthetic Design Storm

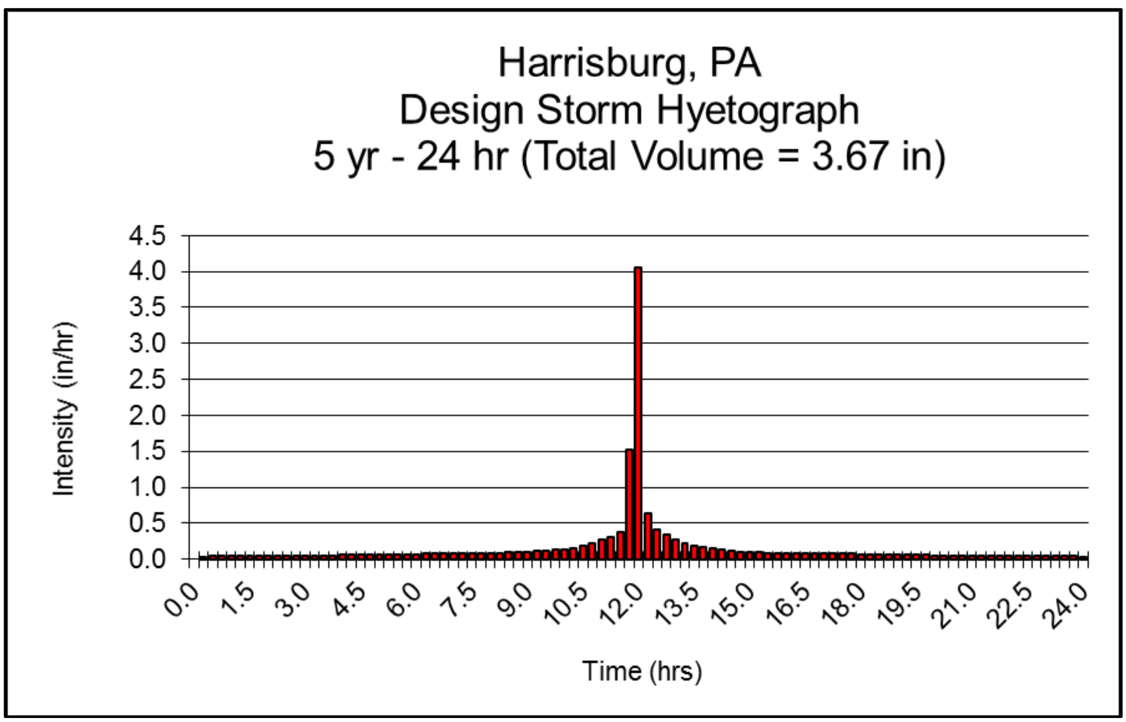

Figure 3-16: Hyetograph for a 5-Year, 24-Hour Synthetic Design Storm

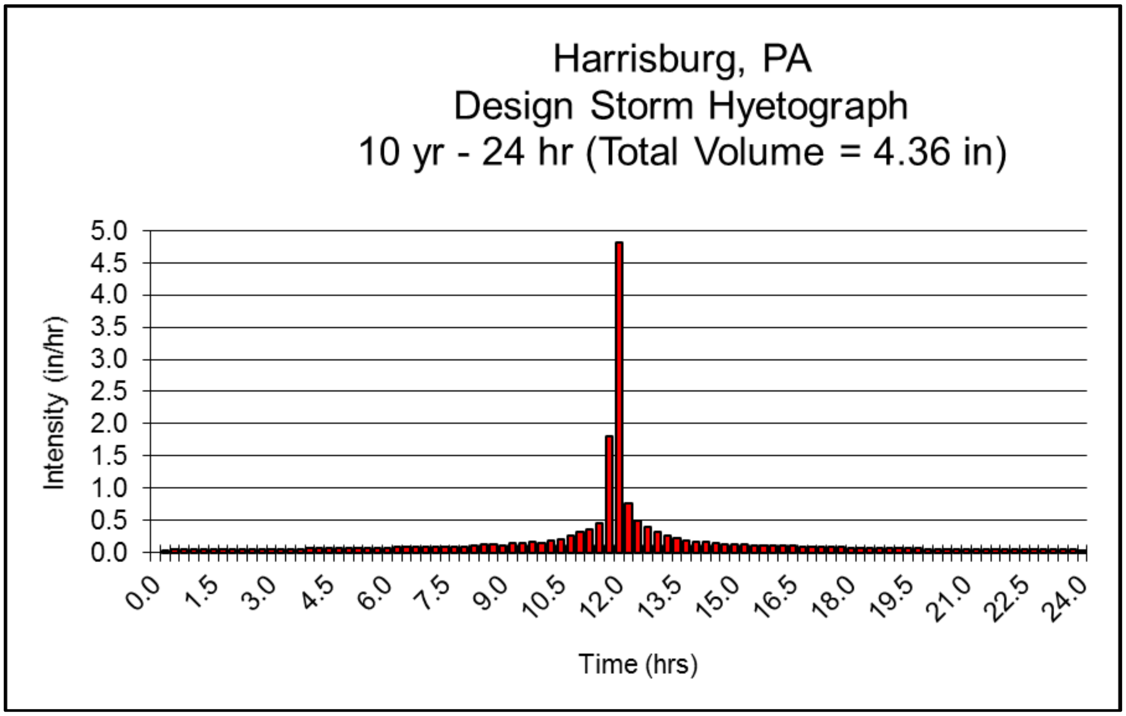

Figure 3-17: Hyetograph for a 10-Year, 24-Hour Synthetic Design Storm

NOAA Atlas 14 includes figures that show the analysis results for monthly precipitation exceedance values for the 60-minute and 24-hour duration storms. A copy of these figures is provided in **Figure 3-18** and **Figure 3-19**. The results indicate that 60-minute duration design storms, typically associated with intense thunderstorm activity, are most likely to occur during the months of July and August (with the highest probability bar values in the graph). The 24-hour duration design storms, typically associated with large frontal systems, are most likely to occur during the months of August and September (again, with the highest probability bar values in the graph). The analysis figures indicate it would be unlikely that these design storms would occur during the winter season or during times of high seasonal ground water that occur during the months of February, March and April. The probability bar values in the NOAA Atlas 14 graph are much smaller during these months, indicating a much lower probability of occurrence. Artificially imposing these design storms on spring time hydrologic conditions would invoke statistical joint probability principles that would result in unrealistically low joint probabilities and unrealistically high return interval estimates.

The CRW analyses match the design storms to the seasonal hydraulic conditions that would most likely be encountered. For the 60-minute and 24-hour durations, the design storms would most likely occur during the month of August. Therefore, GWI values and RDII values for the month of August were selected for the model simulations.

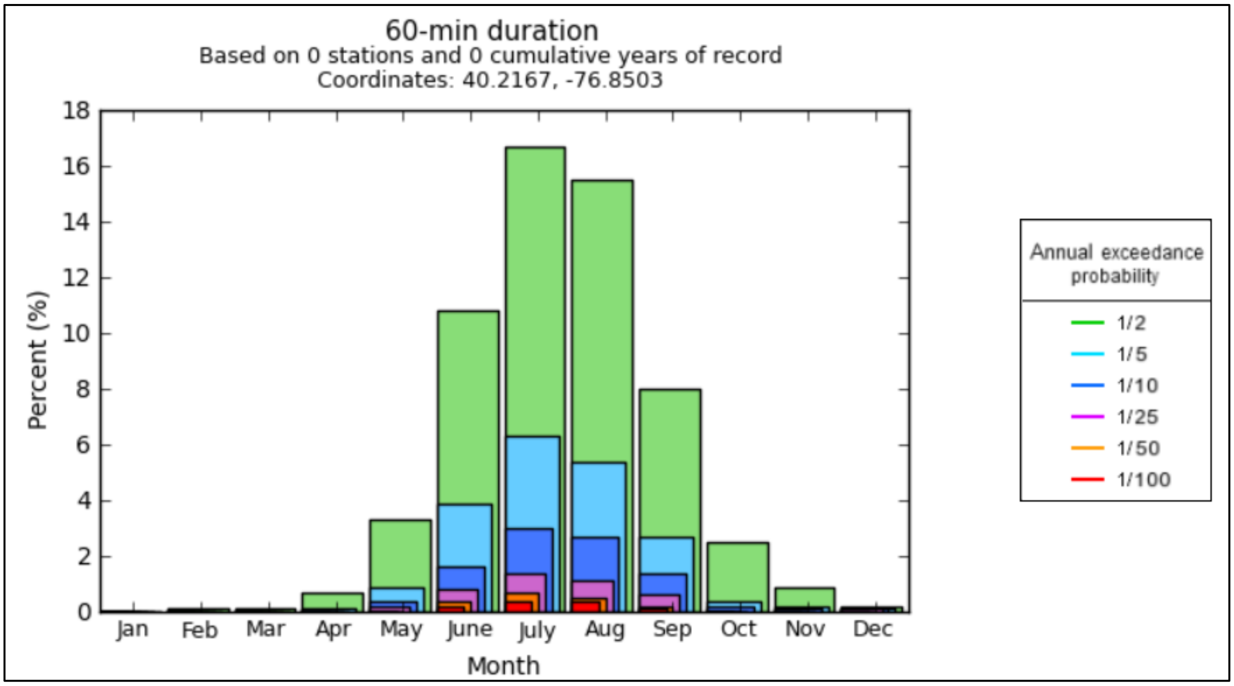

Figure 3-18: Monthly Storm Probability for 60-Minute Rain Durations from NOAA Atlas 14

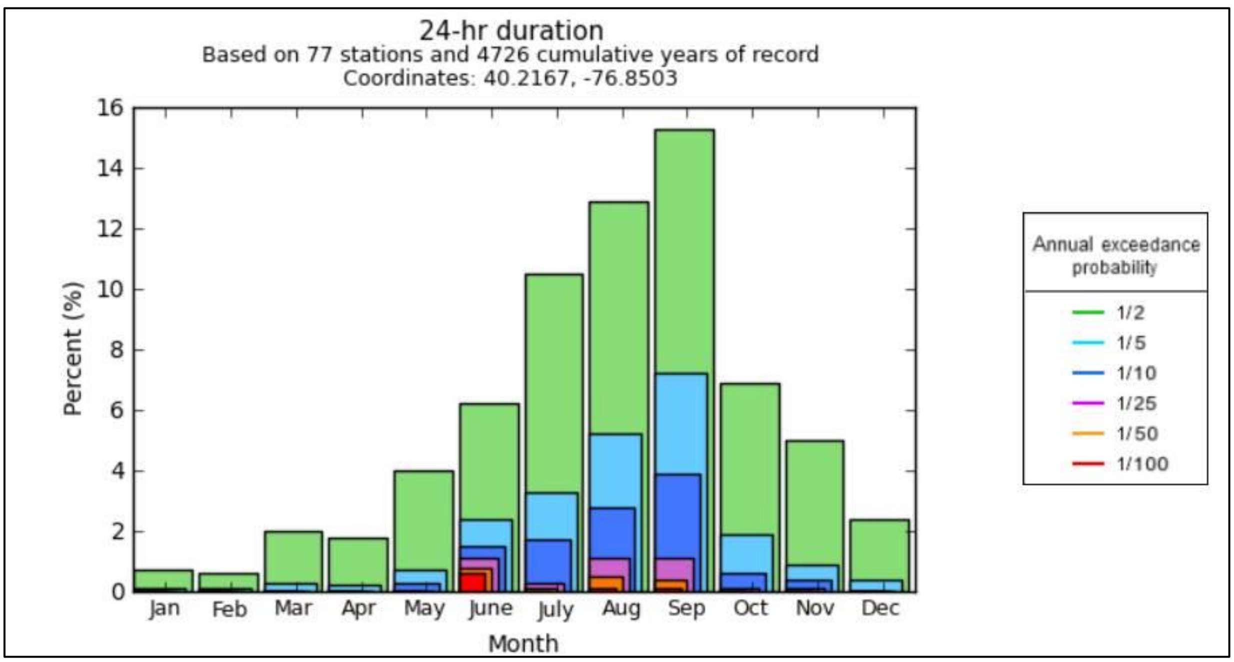

Figure 3-19: Monthly Storm Probability for 24-Hour Rain Durations from NOAA Atlas 14

3.4 Wastewater and Stormwater Flow Characteristics

CRW incorporated the sewer system information obtained through its completed facility inspection programs (Section 3.2) to update and refine its hydrologic and hydraulic (H&H) model of the CRW conveyance system. CRW also performed extensive precipitation monitoring (see Section 3.3) and flow monitoring to properly calibrate and validate its H&H model. The model was used to develop a thorough understanding of the wastewater and stormwater flow characteristics of its sewer system in response to precipitation events of varying duration and intensity; to characterize hydraulic capacity, sewer system overflows, and unauthorized combined sewer system discharges; and to support the development of the Program Plan.

3.4.1 Regulatory Context and Requirements

The Partial Consent Decree, in Section V-E, paragraph 15 requires CRW to develop and implement an *Initial Flow Metering and Monitoring Program Plan* (IFMMPP) [11]. The IFMMPP defined a precipitation and flow monitoring program to collect the data needed to characterize the CRW system and to refine and validate the hydrologic and hydraulic (H&H) model, as described in this Section.

Section V-E, paragraphs 15g and h of the Partial Consent Decree (PCD) require CRW to prepare, calibrate, and verify a hydrologic and hydraulic (H&H) model of the CRW conveyance system. CRW developed and calibrated an updated model and on April 1, 2016, CRW submitted a *Sewer System H&H Model Report*[12] to US-EPA and PA-DEP documenting the completed model. The collected and analyzed precipitation data were sufficient to refine and validate the hydrologic and hydraulic (H&H) model[13], [14].

PCD Section V-C, paragraph g-vi requires CRW to utilize the calibrated H&H model to characterize the frequency, duration, and volume of CSO discharges from the CRW sewer system under existing condition Typical Year precipitation conditions and under existing condition, actual monitored precipitation conditions. CRW has successfully utilized the H&H model for quantifying CSO discharges under typical year precipitation, and the results are documented in Program Plan Section 4.3. On a six-month frequency schedule, CRW applies high-resolution, spatially-distributed GARR precipitation data to the H&H model to quantify existing condition CSO discharges. Semiannual CSO discharge reports are submitted to US-EPA and PA-DEP.

3.4.2 Summary of the Hydrologic and Hydraulic Model

The CRW hydrologic model simulates dry and wet weather flow and represents all catchment areas within the City of Harrisburg contributing to the conveyance system, and trunk sewers within the collection system, for both separate and combined sewer systems. The hydraulic model simulates how the flows are conveyed through the sewer system and represents the CRW

[11] *Initial Flow Metering and Monitoring Program Plan,* July 2013.

[12] *Sewer System H&H Model Report*, Sections 2.4 and 2.5, April 2016.

[13] *Combined Sewer System Characterization Report Version 2.0,* Sections 2.0 and 5.3, February 2018, available at **https://capitalregionwater.com/cbh2o**.

[14] *Separate Sanitary Sewer Capacity Assessment Report Version 2.0,* Section 3.1.3, February 2018, available at **https://capitalregionwater.com/cbh2o**.

conveyance and trunk sewer systems.

The XP-SWMM hydraulic model developed to support preparation of the CSO LTCP in 2005 was converted into SWMM5 and used as the starting point to update and refine the conveyance system model. This model was then calibrated with the flow and rainfall data collected between September 2014 and November 2015 using the WaPUG[15] calibration criteria. The calibrated conveyance system/trunk sewer model was used to develop the typical year overflow statistics reported in **Section 4.3** of this Report.

Model of CRW's Conveyance System: The hydraulic model of the conveyance system consists of the following components:

- ***Interceptor system***: upstream and downstream inverts, diameter or size, shape, and depth of sediment were refined using data collected for CRW's GIS development program.
- ***Regulator and CSOs***: physical parameters and the operational schedules were collected from field inspection and interviews with CRW Field Operations personnel.
- ***Pump Stations***: Pump capacity, pump curves, wet well level time series and operational schedules were collected during preparation of CRW's Operation & Maintenance Manual.

Model of CRW Trunk Sewers: According to the requirements of the Partial Consent Decree (PCD) Paragraphs E(15)(g) and E(30)(b)(i), the hydraulic model was extended into the collection system trunk sewers, defined as 15 to 20 percent of the pipes within CRW's collection system meeting the following criteria:

- All combined sewers 42" or greater,
- All separate sanitary sewers 18" or greater that drain into the combined sewer system, and
- Additional sewers necessary to represent the downstream portion of the collection system, including major flow split manholes within the collection system.

Table 3-13 provides a summary of the CRW interceptor and collection systems included in the H&H model, while **Figure 3-20** provides a map of the modeled sewers.

Table 3-13: Characteristics of CRW's Collection/Trunk Sewer Model

Features	Characteristics
Number of Catchments	482
Number of Pipes	2,148
Number of CSOs	59
Number of Wastewater Pumping	2 (Front Street and Spring Creek Pump Stations)
Inflow from Suburban Communities	4 (M9, M13, M32, M167)
Six Interceptor Systems: (1) Front Street Interceptor; (2) Paxton Creek Interceptor; (3) Paxton Relief Interceptor; (4) Spring Creek Interceptor; (5) Hemlock Creek Interceptor; (6) Asylum Run Interceptor	

[15] Wastewater Planning Users Group, a not-for-profit organization established to promote best practice in the wastewater industry.

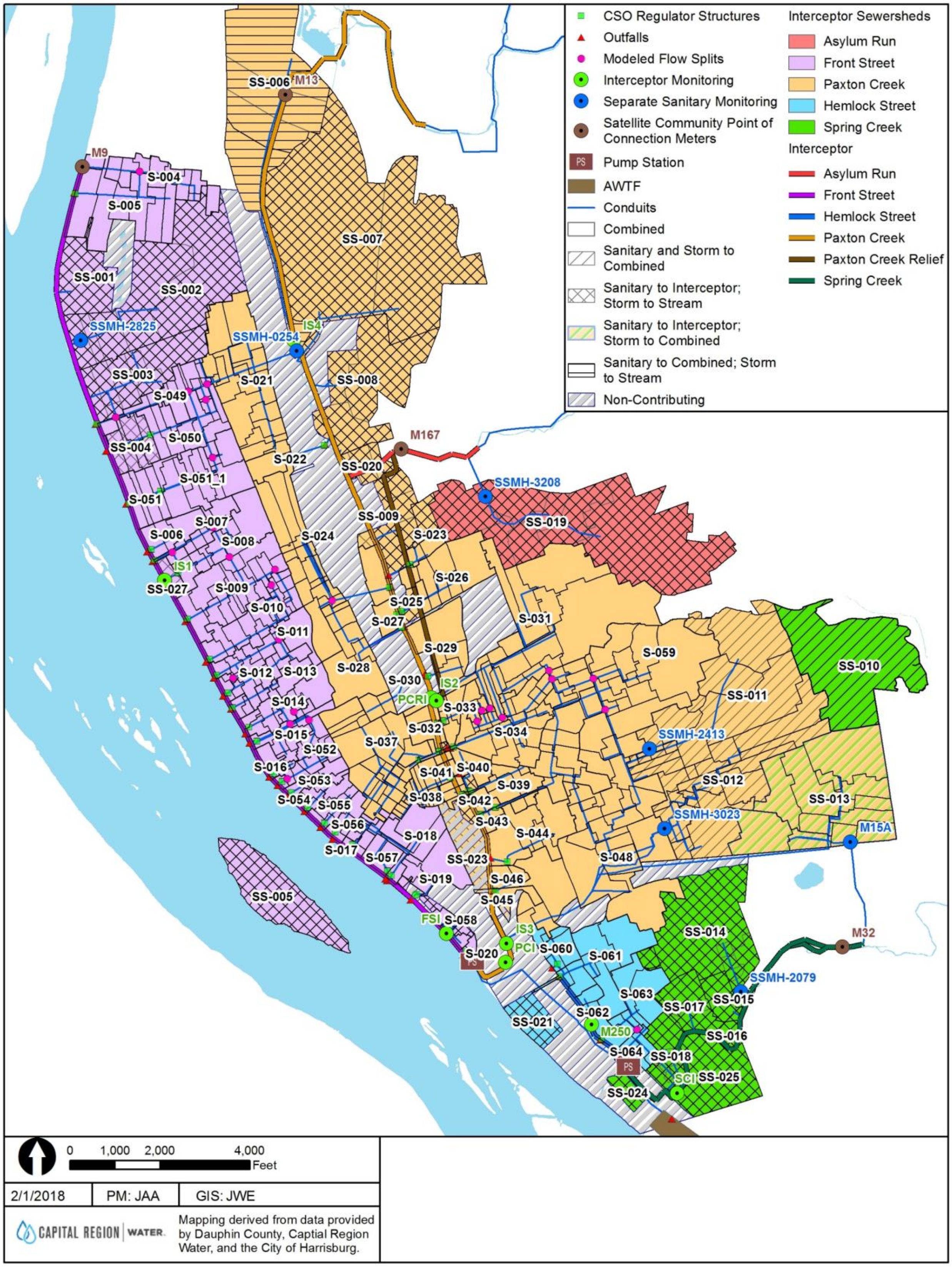

Figure 3-20: Interceptor and Major Trunk Sewers Represented by the H&H Models

Hydrologic Model: The hydrologic model uses data about each catchment and internal calculations to determine the amount of flow entering the major trunk sewer system:

- ***Sewershed / catchment delineation*** was refined using collection system data recently collected in the field and from record drawings as part of CRW's GIS development program.
- ***Catchment Base Wastewater Flow (BWF)*** consists of average existing dry weather flows with the appropriate diurnal pattern, derived from the flow monitoring data.
- ***Catchment Seasonal Groundwater Infiltration (GWI)*** was estimated from long-term flow monitoring data and distributed to model catchments representing specific geographic areas tributary to the modeled sewers.
- ***Separate/Combined Stormwater Catchment hydrologic properties***: Aerial photographs collected in 2013 were used to refine the impervious area of each catchment. Other hydrologic parameters (e.g., width, slope, infiltration parameters) were established through standard hydrologic protocol and refined through model calibration, as described later in this section.
- ***Separate Sanitary Catchment Rainfall-Dependent Infiltration/Inflow (RDII)*** is characterized by a set of unit hydrograph parameters that relate precipitation to infiltration/inflow to separate sanitary sewers, derived from analysis of precipitation and flow monitoring data for a wide range of wet weather events.

The hydrologic model developed to support calibration of the conveyance system model[16] used a single catchment to represent flow draining to each CSO regulator. Following model calibration, these catchments were further divided to properly allocate flow to the trunk sewers in the model. The hydrologic parameters and dry weather flows defined for each CSO catchment in the calibrated model were distributed and/or assigned to its subdivided catchments in the trunk sewer model, and model results were checked for consistency with the calibrated model[17][18].

3.4.3 Summary of Monitoring Data used to Support the H&H Model

An accurate and up-to-date understanding was needed of existing wastewater flow along the CRW sewer conveyance and generated within CRW's separate and combined catchments under dry and wet weather conditions. An *Initial Flow Metering and Monitoring Program Plan* (IFMMPP)[19] was developed and implemented to collect the precipitation and flow monitoring data needed to characterize the CRW system and to refine and validate the hydrologic and hydraulic (H&H) model. Flow monitoring was performed at the following locations:

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[16] *Sewer System H&H Modeling Report*, April 2016.

[17] *Combined Sewer System Characterization Report Version 2.0,* Sections 2.0 and 5.3, February 2018, available at **https://capitalregionwater.com/cbh2o**.

[18] *Separate Sanitary Sewer Capacity Assessment Report Version 2.0,* Section 3.1.3, February 2018, available at **https://capitalregionwater.com/cbh2o**.

[19] *Initial Flow Metering and Monitoring Program Plan,* July 2013.

- At the four major points of connection (POCs) where wastewater flows from the suburban community collection systems are conveyed to the CRW system.
- At selected City separate sanitary sewer catchment areas to characterize base wastewater flow (BWF), groundwater infiltration (GWI), and rainfall dependent infiltration/inflow (RDII),
- At selected CSO regulator structures to characterize the hydrology of their tributary catchment areas, and
- Along selected points along the CRW interceptor system to calibrate/validate hydraulic model of the conveyance system.

Comprehensive protocols and standards for field activities were implemented to execute the flow monitoring program to maximize the collection of high quality data. CRW successfully implemented quality assurance and quality control (QA/QC) measures necessary to confirm that the network of flow monitoring equipment provided representative, accurate and reliable data, and that the data quality is sufficient for use in the development of the H&H models for the Program Plan.

3.4.3.1 Interceptor Flow Monitoring and Characterization

The IFMMPP identified nine critical monitoring locations along the CRW interceptor system. CRW successfully installed and maintained flow monitors at these sites to provide the necessary data to successfully quantify and characterize the distribution of wastewater flow along the CRW interceptor sewer system, provide the necessary data to calibrate and verify the H&H model, and meet PCD requirements. The monitors collected and recorded redundantly monitored wastewater depth, monitored velocity, and calculated flow in 5-minute time-step increments. The monitoring site information and status are summarized in **Table 3-14** and the monitoring locations are provided in **Figure 3-21**.

Table 3-14: Interceptor System Monitoring Site Summary

Monitor ID	Interceptor System	Pipe Diameter (inches)	Data Collection Initiated	Data Collection Status	Data Analysis Status
IS1	Front Street	35.5 H x 30.5 W	8/01/2014	Ongoing	Ongoing
FSI	Front Street	41 H x 42.5 W	8/01/2014	Ongoing	Ongoing
PCI	Paxton Creek	60 diameter	8/01/2014	Ongoing	Ongoing
PCRI	Paxton Creek	48 diameter	8/13/2014	Ongoing	Ongoing
IS2	Paxton Creek	48 H x 59 W (arch)	8/21/2014	Ongoing	Ongoing
IS3	Paxton Creek	60 diameter	8/22/2014	Ongoing	Ongoing
IS4	Paxton Creek	42 diameter	8/18/2014	Ongoing	Ongoing
M250	Hemlock Street	24 diameter	8/01/2014	Ongoing	Ongoing
SCI	Spring Creek	34 H x 32.5 W	8/13/2014	Ongoing	Ongoing

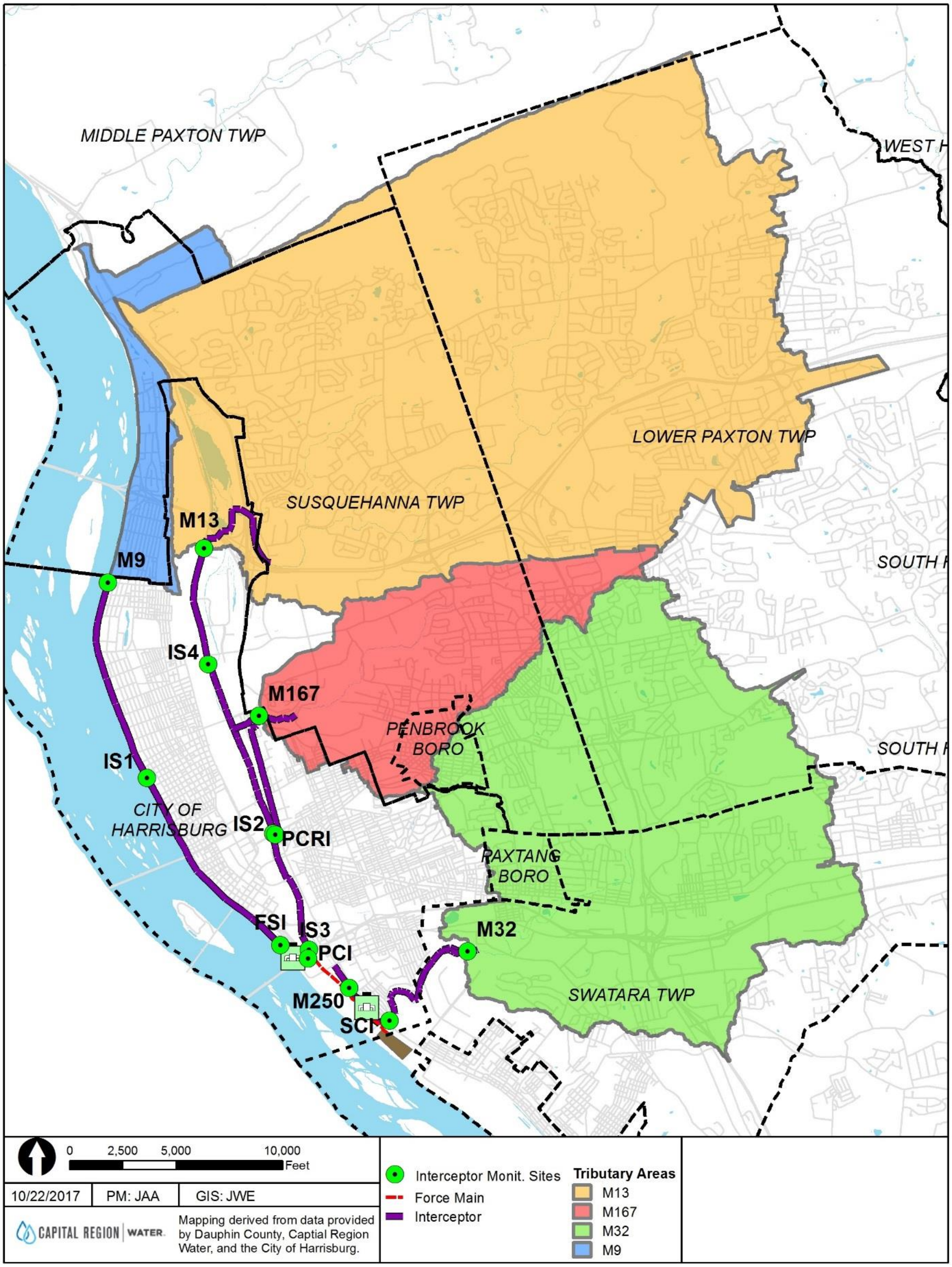

Figure 3-21: Interceptor and Suburban Community Point of Connection Monitoring Sites

3.4.3.2 Suburban Community Flow Monitoring and Characterization

The IFMMPP also identified the four points of connection (POCs) where wastewater flows from the suburban community collection systems are conveyed to the CRW system. CRW installed and maintained flow monitors at each of these POC sites to quantify and characterize dry and wet weather flow from the suburban community separate sanitary sewer systems. The monitors collected and recorded redundantly monitored wastewater depth, monitored velocity, and calculated flow in 5-minute time-step increments. The monitoring site information and status are summarized in **Table 3-15** and the monitoring locations are provided in **Figure 3-21**.

Table 3-15: Suburban Community POC Monitoring Site Summary

Monitor ID	Pipe Diameter	Catchment Area (acres)	Data Collection Initiated	Data Collection Status	Data Analysis Status
M9	24 inches	847	8/01/2014	Ongoing	Ongoing
M13	42 inches	12,602	8/15/2014	Ongoing	Ongoing
M32	34 inches	6,716	8/14/2014	Ongoing	Ongoing
M167	24 inches	2,334	8/14/2014	Ongoing	Ongoing

3.4.3.3 Combined Collection System Flow Monitoring and Characterization

CRW successfully characterized flows generated within 13 selected catchments of CRW's combined sewer system. This was done by monitoring depth and velocity at the influent to each associated combined sewer overflow (CSO) regulator structure. Detailed analyses in Addendum #3 to the IFMMPP[20] identified these sites as providing a representative sampling of the types of combined sewershed areas within the City of Harrisburg. Monitoring at each CSO regulator site had a duration of 12 months to quantify and characterize seasonal variations in wastewater and stormwater flow and monitor a sufficient number of storm events throughout the year. The monitoring equipment recorded data in 5-minute time-step increments. Two categories of monitoring sensors were installed and two categories of data were collected:

- The first category was the monitored wastewater depth and flow from the influent trunk sewer to the regulator structure. The data were used to successfully quantify and characterize wastewater flow from each tributary catchment for use in calibrating the hydrologic parameters of CRW's H&H model.
- The second category was the monitored depths of CSO discharges over the diversion weirs. The diversion weirs and the regulator structures direct all the dry weather wastewater and a portion of the wet weather flow to the interceptor system for conveyance and treatment. The data, along with the daily observations of CSO activation by CRW maintenance staff, were used to calibrate the H&H model representation of regulator hydraulics and Brown and Brown regulator operational rules.

The collection system characterization monitoring sites, characteristics, and status are summarized in **Table 3-16** and illustrated in **Figure 3-22**, along with their respective catchments.

[20] *Initial Flow Metering and Monitoring Program Plan,* Addendum #3, December 2014.

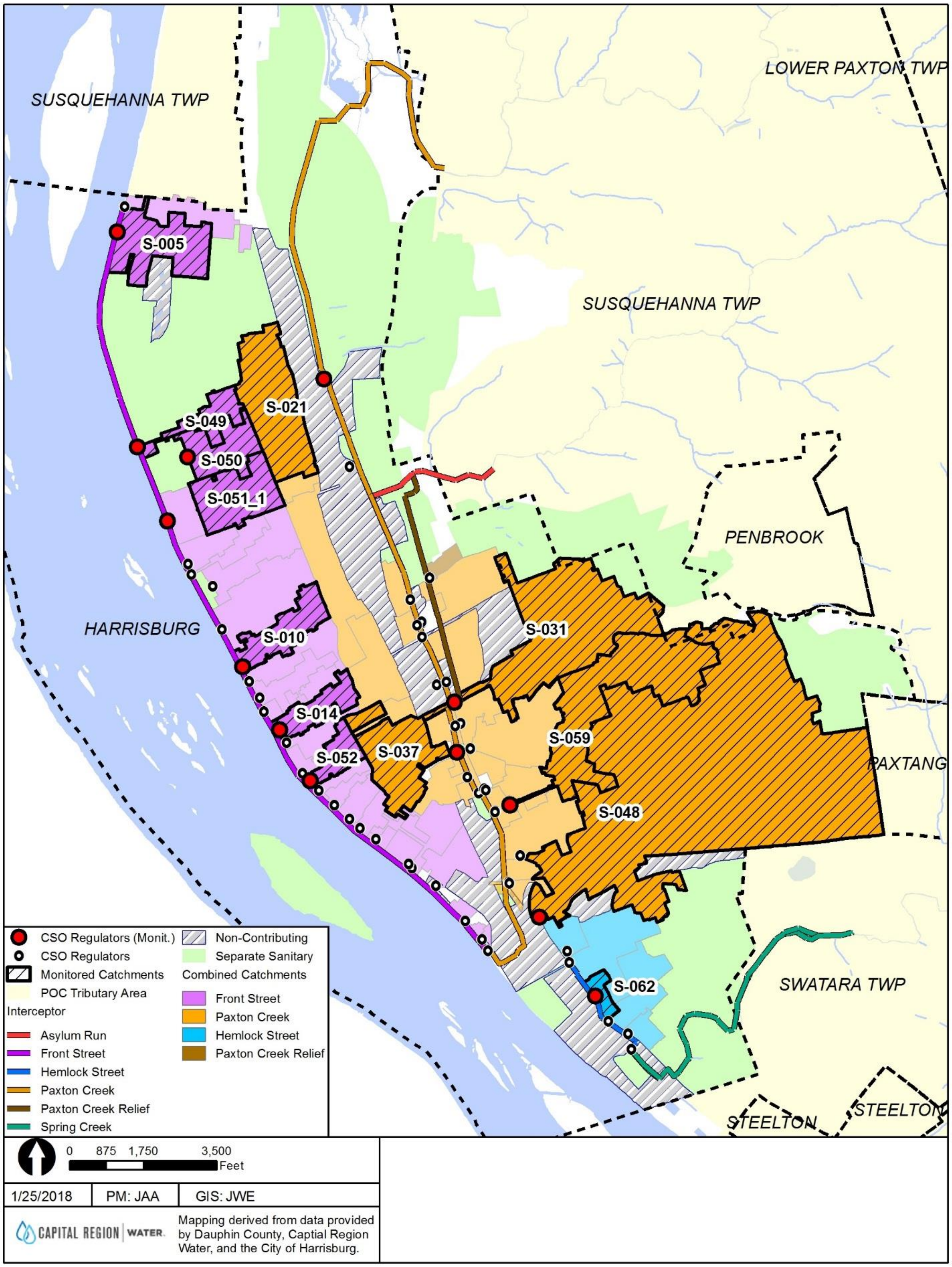

Figure 3-22: Combined Trunk Sewer and CSO Regulator Monitoring Sites

Table 3-16: Combined Collection System Flow Characterization Monitoring Site Summary

Monitored Catchment ID	Catchment Area (acres)	Monitored CSO Regulator ID	Pipe Size H x W or Diameter (inches)	Data Collection Initiated	Data Collection Status	Data Analysis Status
S-005	69.5	CSO-005	61 H x 48 W	7/31/2014	Completed	Completed
S-010	41.8	CSO-010	36	8/04/2014	Completed	Completed
S-014	29.9	CSO-014	34.5	8/05/2014	Completed	Completed
S-021	149.3	CSO-021	51 and 24	7/31/2014	Completed	Completed
S-031	220.0	CSO-031	60 H x 48 W	7/23/2014	Completed	Completed
S-037	74.2	CSO-037	66 H x 48 W	9/25/2014	Completed	Completed
S-048	766.5	CSO-048	66 H x 60 W	7/22/2014	Completed	Completed
S-049	27.8	CSO-049	54	7/22/2014	Completed	Completed
S-050	41.8	CSO-050	48	8/01/2014	Completed	Completed
S-051.1	57.0	CSO-051.1	54 H x 44 W	9/30/2014	Completed	Completed
S-052	21.9	CSO-052	30 H x 36 W	8/06/2014	Completed	Completed
S-059	149.7	CSO-059	54 H x 45 W	8/28/2014	Completed	Completed
S-062	10.4	CSO-062	15	8/05/2014	Completed	Completed

3.4.3.4 Separate Sanitary Collection System Flow Monitoring

CRW successfully monitored seven key separate sanitary catchments within the City of Harrisburg collection system. Two of these seven catchment monitoring sites, SSMH-2413 and SSMH 3023, monitor flow from separate sanitary catchments that discharge into a CRW combined sewer upstream of the CSO 048 regulator, and are thus considered to be part of CRW's combined sewer system. The remaining five metering sites monitor flow from separate sanitary catchments that discharge directly to the interceptor system, and are thus considered to be part of CRW's separate sanitary sewer system.

All seven monitoring sites provided the necessary data to successfully quantify and characterize dry and wet weather flow from CRW's separate sanitary catchments. The monitors collected and recorded redundantly monitored wastewater depth, monitored velocity, and calculated flow in 5-minute time-step increments. Over 12 months of data were collected and utilized for the analyses, which permitted the model to account for seasonal variability of ground water and the response of the separate sanitary catchments to wet weather. Separate sanitary sewer catchment monitoring locations are provided in **Figure 3-23** and the monitoring site and status information are summarized in **Table 3-17**.

Figure 3-23 and **Table 3-17** depict and include two separate sanitary catchments (SSMH-2413 and SSMH-3023) that discharge into a downstream combined sewershed area (S-048). The catchments were monitored and modeled as separate sewers, but classified as being part of the combined collection system to be consistent with Partial Consent Decree definitions.

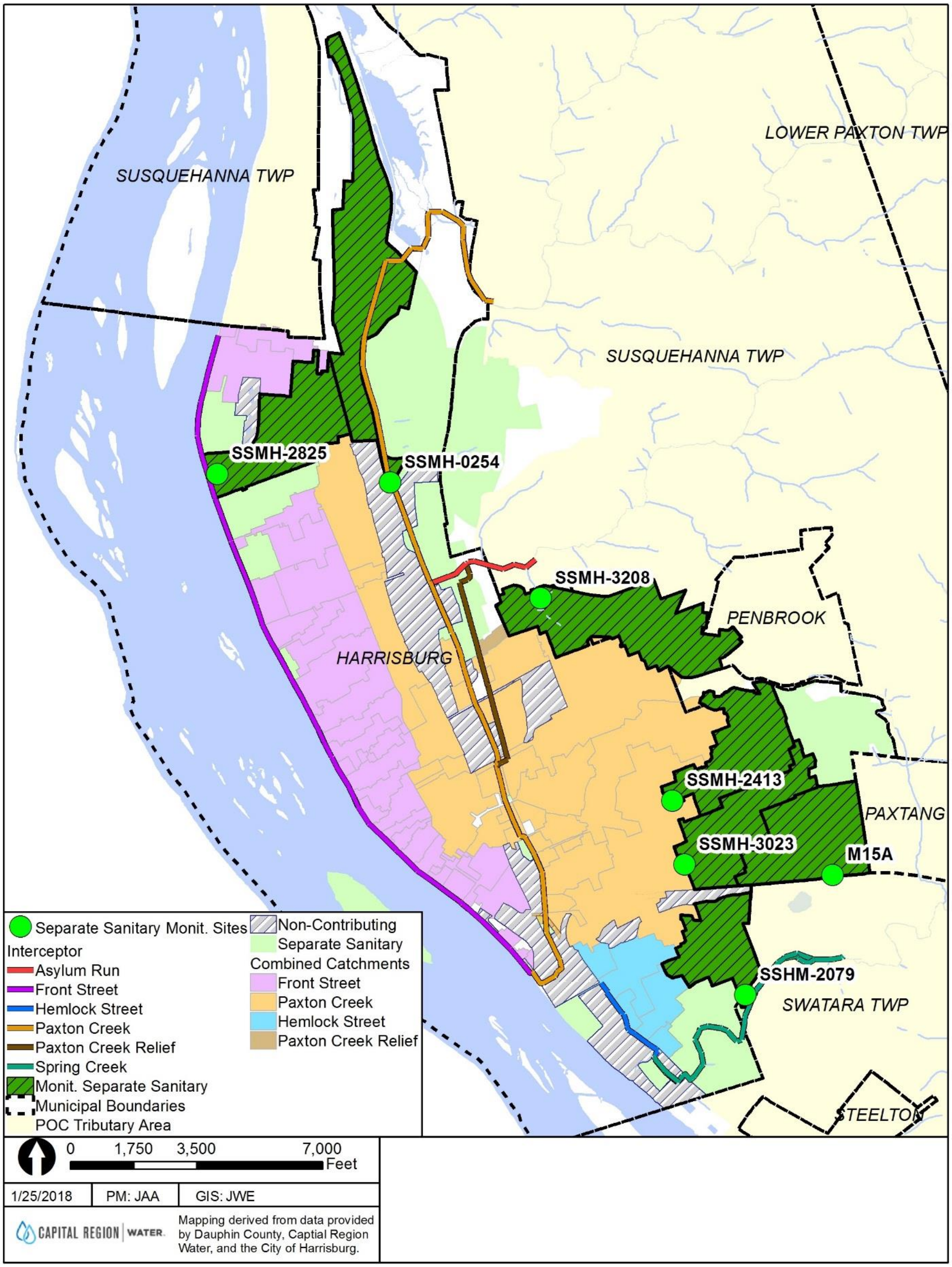

Figure 3-23: Separate Sanitary Catchment Monitoring Sites

Table 3-17: City of Harrisburg Separate Sanitary Sewer Data Collection Site Summary

Monitored Catchment ID	Catchment Area (acres)	Monitor Location	Pipe Diameter (inches)	Interceptor	Data Collection and Analysis Status
M15A	169	South 26th Street	18 dia.	Spring Creek	Completed
SSMH-0254	276	Industrial Road	15 dia.	Paxton Creek	Completed
SSMH-2079	109	South 19th Street	14 dia.	Spring Creek	Completed
SSMH-2413	156	Darlington and 19th	20 dia.	Paxton Creek	Completed
SSMH-2825	166	Front and Shamokin	18 dia.	Front Street	Completed
SSMH-3023	139	Brookwood and 17th	48 dia.	Paxton Creek	Completed
SSMH-3208	229	Arsenal Boulevard	24 dia.	Asylum Run	Completed

3.4.3.5 Characterization of Dry Weather Flow (DWF)

For each of the selected suburban community and City separate sanitary sewer system monitoring sites, monitored storm flows were analyzed to characterize wet weather hydrology within separate sanitary sewer systems. The flow quantification analyses were conducted using the Environmental Protection Agency (EPA) Sanitary Sewer Overflow Analysis Program (SSOAP). The SSOAP program divided the total monitored wastewater flow into its three components, base wastewater flow (BWF), ground water infiltration (GWI), and rainfall dependent infiltration and inflow (RDII). These components of wastewater flow are depicted in **Figure 3-24**.

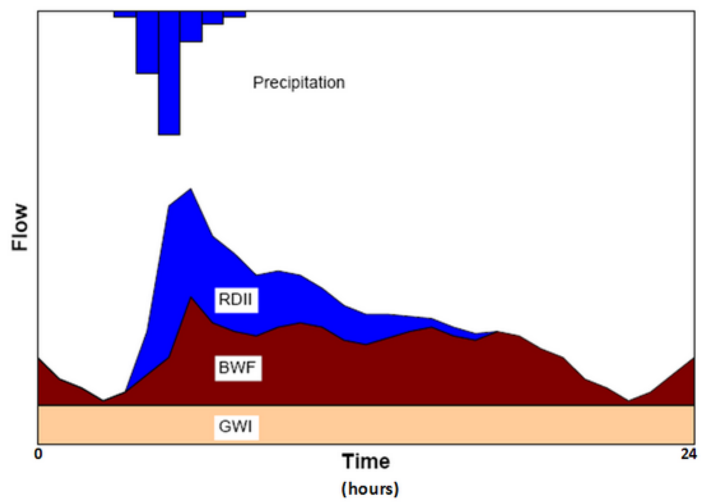

Figure 3-24: Typical Flow Characterization in a Separate Sanitary Sewer System

The quantified BWF represents the monitored residential, commercial, institutional, and industrial flow that was discharged to the sanitary sewer system for collection and treatment. The quantified GWI represents the monitored infiltration of ground water that entered the collection system through leaking pipes, pipe joints, and manhole walls. Dry weather flow (DWF) is the sum of BWF and GWI.

A suitable DWF characterization period is preceded by at least three days without rainfall of 0.1 inches or larger. During the monitoring period from September 2014 through August 2015, the longest period of DWF meeting these criteria occurred between November 7, 2014 and November 15, 2014. The calibration of DWF involved was performed in the following manner.

- ***Establish Boundary Conditions***: The boundary condition of the model was established by determining average DWF and diurnal hydrographs from the suburban communities at monitoring sites M9, M13, M167 and M32.

- ***DWF from CRW's Service Area***: Average DWF (per acre) and diurnal patterns measured with the 13 meters located at the influent to the CSO regulators and seven meters characterizing flow from CRW's separate sanitary sewers were used to determine the representative DWF for the catchments within CRW's service area.
- ***Calibrate at Interceptor Monitoring Stations:*** DWF calibration was performed by comparing DWF generated with the H&H model with measured flow data at interceptor monitoring stations IS1, FSI, IS4, IS2, PCRI, PCI and SCI.

Table 3-18 summarizes the DWF calibration findings obtained using this methodology, the average DWF generated within each major sewershed of CRW's service area, and monthly variability of DWF.

Table 3-18: Estimated Dry Weather Flow Measured Within CRW's Conveyance System.

Condition	Estimated Flow at Flow Meters in the Interceptor (MGD)													Total To AWTF
	Front Street			Asylum/ PCRI		Paxton Creek				Hemlock	Spring Creek			
	M9	IS1	FSI	M167	PCRI	M13	IS4	IS2	IS3	M250	M32	M15A	SCI	
Average Dry Weather Flow (DWF)	0.37	1.24	2.37	2.12	2.28	4.16	4.43	9.96	11.89	0.17	0.25	4.59	5.19	19.62
Minimum Nighttime Flow (MNF)	0.10	0.42	0.53	1.06	1.19	1.17	1.48	2.71	3.18	0.03	0.06	1.92	2.23	5.97
Groundwater Infiltration (GWI)	0.09	0.38	0.48	0.95	1.07	1.05	1.34	2.44	2.86	0.02	0.05	1.73	2.00	5.36
Base Wastewater Flow (BWF)	0.28	0.86	1.89	1.17	1.21	3.11	3.09	7.52	9.03	0.14	0.20	2.86	3.19	14.25

3.4.3.6 Characterization of Rainfall-Dependent Infiltration/Inflow

The inflow component of RDII is the water that entered the sanitary sewer system directly via leaky manhole lids and frames, roof drain connections, sump pumps, foundation drains, and cross connections. The infiltration portion of RDII refers to rainfall runoff that filters through the soil before entering a sanitary sewer system through damaged pipe sections, leaky joints, etc. These defects can occur in both the public right-of-way portions of the sewer system or in individual service laterals on private property.

The SSOAP program was used to quantify the RDII associated with each successfully monitored storm and develop a series of input values for use by the H&H models. The calculated volume of RDII for each monitored storm was divided by the corresponding volume of rainfall over the catchment or sewershed area and expressed as a percentage or R-value. This R-value represents the fraction of monitored rainfall that fell over the tributary catchment/sewershed area that entered the sanitary sewer system. The SSOAP program was used to distribute the calculated RDII volumes and develop a series of three triangular unit hydrographs to represent the fast, medium and slow responses of the catchment/sewershed collection systems to each of the monitored storms, as depicted in **Figure 3-25**.

These hydrographs represent the magnitude and timing of the RDII hydrology of the monitored separate sanitary catchment areas. Selected individual storm hydrographs were averaged together on a monthly basis to represent seasonal variability. These monthly unit hydrographs were used as input into the H&H model for monitored areas, and extrapolated values were derived for unmonitored areas. For each storm within each separate sanitary catchment area, the model applied the appropriate monthly-average unit hydrographs to the monitored rainfall so that the model-simulated sewer system responses correlated well to the monitored RDII flow.

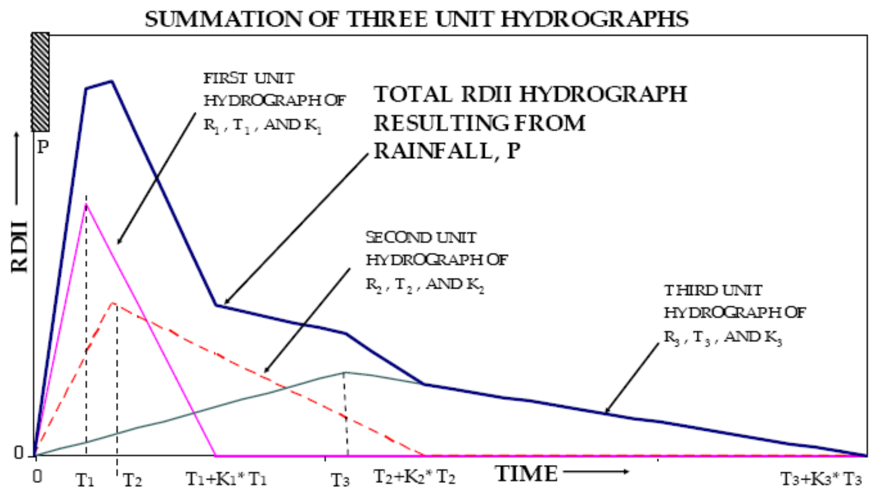

Figure 3-25: Unit Hydrograph Parameters Derived from SSOAP Toolbox

Representative analysis results are illustrated in **Figure 3-26** and **Figure 3-27**. The short-term (R1) RDII responses, medium-term (R2), and long-term (R3) responses are depicted for the monitored SSMH-2079 and SSMH-0254 catchment areas. The analysis results revealed that the SSMH-2079 catchment area demonstrated significant seasonal variability, and total RDII flows during the winter and early spring seasons are more than twice those experienced during the summer and fall. Conversely, the SSMH-0254 catchment area demonstrated minimal seasonal variability where RDII flows were consistent throughout the year, except for an observed 20 percent reduction during the fall season. Both catchment areas had relatively low total R-values, indicative of a "tight" collection system, despite the differences in the seasonality of the RDII responses.

Individual RDII analysis results for each of the monitored and analyzed City separate sanitary sewer catchment areas are provided in **Table 3-19**. The seven selected City catchment areas were previously shown in **Figure 3-23**. The short-term (R1), medium-term (R2), and long-term (R3) RDII responses, along with the total RDII response are provided. Also included is the GWI ratio, which reflects the magnitude of observed GWI component of the monitored average daily dry weather flow. The total R-values ranged from 0.99 percent to 4.19 percent, indicating the fraction of monitored rainfall over the catchment area that entered the sanitary sewer system.

Low values typically indicate a tighter sewer system with minimal extraneous flow. On the contrary, high values indicate high quantities of extraneous flow. Low total R-values are generally below 2 percent, while average total R-values range from 2 percent to 6 percent. Moderately high total R-values range from 6 percent to 10 percent, and high values are generally over 10 percent. These assessment results indicate that a comprehensive RDII reduction program would not be cost-effective for CRW, since the existing sewer collection systems are relatively tight. However, the high GWI ratio monitored at site SSMH-0254, located along Industrial Road and adjacent to Paxton Creek and Wildwood Lake, indicate that the trunk sewer could be a cost-effective candidate for a sewer lining project.

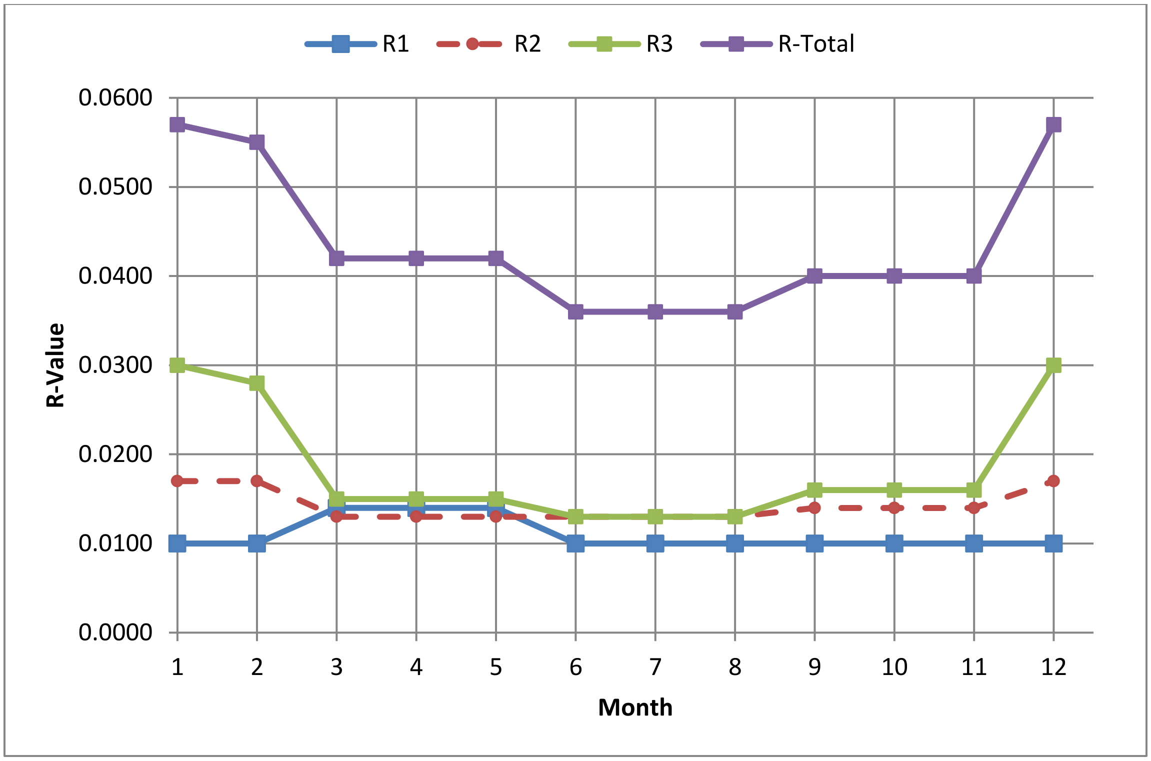

Figure 3-26: Monthly Varied R Values at SSMH-2079 (Significant Seasonal Variation)

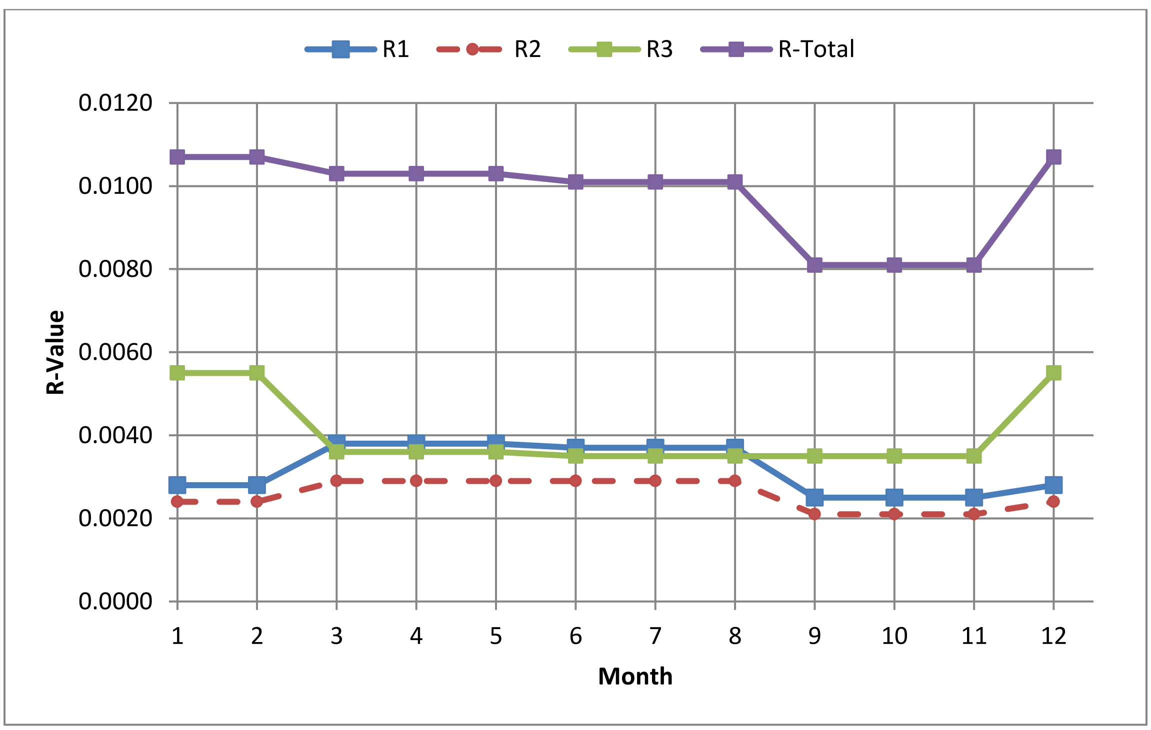

Figure 3-27: Monthly Varied R Values at SSMH-0254 (Minimal Seasonal Variation)

Table 3-19: Summary RDII Analysis Results for CRW Separate Sanitary Sewer Catchment Areas

Monitoring Site	R1	R2	R3	Total R	GWI Ratio
SSMH-0254	0.0033	0.0026	0.0040	0.0099	0.93
SSMH-2079	0.0095	0.0137	.0187	0.0419	0.63
SSMH-2413	0.0093	0.0073	0.0071	0.0236	0.77
SSMH-2825	0.0117	0.0070	0.0055	0.0242	0.72
SSMH-3023	0.0108	0.0074	0.0087	0.0270	0.82
SSMH-3208	0.0105	0.0098	0.0130	0.0333	0.78
SSMH-M15A	0.0144	0.0118	0.0115	0.0376	0.64

Individual RDII analysis results for each of the monitored and analyzed suburban community separate sanitary sewer catchment areas are provided in **Table 3-20**. The four point of connection catchment areas were previously shown in **Figure 3-21**. The total R-values ranged from 0.87 percent to 2.16 percent, indicating the fraction of monitored rainfall over the catchment area that entered the sanitary sewer system. These assessment results indicate that a comprehensive RDII reduction program would not be cost-effective for the suburban communities, since the existing sewer collection systems are relatively tight.

3.4.3.7 Wet Weather Flow Calibration

The CRW model was calibrated during wet weather conditions using the monitored precipitation and flows for the selected calibration periods and events. To calibrate and verify the CRW H&H model, four events were selected: three for calibration and one for validation. **Table 3-21** summarizes the four selected events. Two events were selected for model calibration from the top ten storm events; one representing a high intensity storm event (i.e., July 26, 2015), and one representing a large volume, medium intensity event (i.e., June 1, 2015). The remaining calibration event (i.e., March 13, 2015) represents hydrologic conditions during small to moderate storm events. This last event was selected in order to properly represent average annual and seasonal conditions and CSO statistics, as well as be appropriate for evaluation of green infrastructure alternatives that promote infiltration and evapotranspiration. This third calibration event also represents springtime conditions when soils are more saturated. The validation event (November 23, 2014) represents average conditions, as well as conditions during a third season (autumn). Review of the flow monitoring data during these events indicates that they are accompanied by flow monitoring data of good quality to support calibration/validation.

Table 3-20: Summary RDII Analysis Results for Suburban Separate Sanitary Sewer Catchment Areas

Monitoring Site	R1	R2	R3	Total R	GWI Ratio
POC M9	0.0018	0.0018	0.0051	0.0087	0.63
POC M13	0.0018	0.0023	0.0068	0.0109	0.54
POC M32	0.0022	0.0022	0.0094	0.0138	0.72
POOC M167	0.0039	0.0039	0.0138	0.0216	0.78

Table 3-21: Selected Storm Events for H&H Model Calibration and Validation

No.	Storm Event Date	Averaged Total Rainfall Volume (in.)	Average Peak Rainfall Intensity (in./hr.)	Rainfall Duration (hr.)	Purpose
1	June 1, 2015	1.35	0.36	8.92	Calibration – Large Volume
2	July 26, 2015	0.91	0.81	4.42	Calibration – High Intensity
3	March 13, 2015	0.63	0.11	10.42	Calibration – Moderate Event
4	November 23, 2014	0.58	0.24	6.92	Validation– Moderate Event

Monitored flow during three calibration events were compared with modeled flow at the sites of the meters along the interceptor system to demonstrate that CRW's H&H Model provides accurate and reliable estimates of conveyance system performance over a range of events representative of CSOs and the likely range of CSO control. While the goal is to meet WaPUG[21] criteria at every meter during each calibration event, occasional outliers may occur that are attributable to one or more of the following situations:

- ***Event-specific monitoring excursions***. If model and monitor results align well for other events and/or adjacent meters, an event specific excursion in measured flow may be attributable to potential short-term blockages or hydraulic transients during the event. Severe levels of debris exist in the interceptor and are known to periodically but temporarily affect flow monitor accuracy.
- ***Uncertainty in pump operating rules***. Both the Front Street and Spring Creek pump stations are over 50 years old and scheduled for major overhauls in the next few years. Review of flow data indicates some uncertainty in pump station operation which, when coupled with backwater conditions in the interceptor, are difficult to model. Modeling in support of the Program Plan focuses on new pump stations / operating rules, since station replacement/repair is expected to occur before implementation begins.
- ***Uncertainty in wet weather response from suburban communities.*** Wet weather flows from suburban communities estimated using the RTK parameters derived from flow monitoring data and US-EPA SSOAP analysis represent large upstream areas and local phenomena within suburban systems that may influence monitored flows in CRW's system.

Detailed information on the development, calibration, and verification of the H&H model, as well as a series of plots depicting simulated versus observed wastewater total volume, peak flow, and maximum depth are provided in the 2016 *Sewer System H&H Model Report*[22].

[21] Wastewater Planning Users Group – Code of Practice for the Hydraulic Modeling of Sewer Systems, Version 3.001, December 2002, http://www.ciwem.org/wp-content/uploads/2016/05/Code-of-Practice-for-the-Hydraulic-Modelling-of-Sewer-Systems.pdf

[22] *Sewer System H&H Model Report*, Sections 2.4 and 2.5, April 2016.