Clean Water 2020 Program

SEWER SYSTEM HYDRAULIC MODEL REPORT

August 2020

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Section 1 Summary and Intent

1.1 Introduction and Objectives

The City of Columbia (City) developed a calibrated Hydraulic Model of its Sewer System to establish existing hydraulic conditions and plan for future capacity needs of the Sewer System. The City prepared this Sewer System Hydraulic Model Report (HMR) to document the Hydraulic Model development and to establish policies and procedures to maintain the Hydraulic Model.

The calibrated Hydraulic Model will be employed to:

- Develop and implement operation and maintenance procedures that optimize collection and transmission capacity
- Evaluate the impacts which infiltration/inflow (I/I) rehabilitation projects, proposed system modifications, and upgrades and expansion have on collection and transmission capacity and the performance of the City's sewer system
- Prioritize the continuing evaluation of the wastewater collection and transmission system (WCTS) pursuant to the Continuing Sewer Assessment Program (CSAP; approved May 23, 2016)
- Implement the Capacity Assurance Program (CAP)
- Prioritize rehabilitation projects

The Hydraulic Model and HMR were prepared in accordance with Paragraph 17 (Sewer System Hydraulic Model) of the Consent Decree entered by order dated May 21, 2014 (*The United States of America and State of South Carolina by and through the Department of Health and Environmental Control vs. The City of Columbia*, Civil Action No. 3:13 ‑ 2429 ‑ TWL, DOJ Case Number 90-5-1-1-00954), which is referred to herein as the Consent Decree or CD.

The Hydraulic Model was developed in coordination with the CSAP for the initial assessment of the Major components of the Wastewater Collection and Transmission System (WCTS).

The City must submit the HMR within 15 months of the completion of the CSAP of the Major WCTS (submitted on May 23, 2019) in accordance with the CD. In compliance with Paragraph 17, the Hydraulic Model of the Major WCTS is based on system attribute data collected as part of the Sewer Mapping Program of the Major WCTS (completed November 23, 2018; approved December 9, 2014), and on flow and rainfall data collected as part of the flow monitoring program described in the CSAP (Paragraph 14.b.(v) of the CD). Flow monitoring and the data collection methodology and quality control processes used to collect the system data for the calibration of the Hydraulic Model are described in detail in the City's CSAP (Clean Water 2020, revised 2018).

Table 1-1 contains a list of the CD requirements for the HMR and the sections of this document that address each requirement.

Table 1-1: Summary of Consent Decree Requirements for the Hydraulic Model Report

CD Section	CD Requirements	Report Section
17.a.	"Capabilities. At a minimum, the Model shall be capable of: (i). Accurately predicting the flow rate and hydraulic grade line of wastewater in Force Mains from Major Pump Stations and the Major Gravity Sewer Lines under any historical dry or wet weather condition; (ii). Accurately predicting the location and severity of SSOs from the WCTS under any historical dry or wet weather condition; (iii). Fully dynamic temporal analysis, including an accounting of downstream backwater impacts on upstream flows; (iv). Accurately predicting the impacts of changes to Pump Station capacities on upstream and downstream flow rates and hydraulic grade lines, including hydraulic losses which may result from either full or partial Pump Station failures; and (v). Generating hydrographs depicting baseline wastewater flow and I/I for the Subbasins for various storm recurrence intervals. The Model shall include methods for accurately estimating the baseline wastewater flows and I/I components in each Subbasin using quality-controlled flow data obtained for the Sewer System."	Section 2
17.b.	"Implementation. At a minimum, Columbia shall employ the Model to: (i). Assist with the development and implementation of operation and maintenance procedures that optimize collection and transmission capacity; (ii). Evaluate the impacts with Infiltration/Inflow rehabilitation projects, proposed system modifications, and upgrades and expansions have on collection and transmission capacity and the performance of Columbia's Sewer System; (iii). Prioritize the continuing evaluation of the WCTS pursuant to the CSAP in Paragraph 14; (iv). Prioritize rehabilitation projects; and (v). Implement the Capacity Assurance Program described in Paragraph 12.e."	City shall employ Hydraulic Model to address CD requirements in Section 17.b.
17.c.	"Procedures and Protocols. Columbia shall develop and employ written procedures, protocols, and schedules to routinely perform: (i). Calibrations of the Model to account for age-related and other changes to Sewer System hydraulics, and to obtain and manage updated data from physical field observations and measurements for this purpose; (ii). Verification of the Model's accuracy and performance; and (iii). Sensitivity analyses to determine how the Model responds to changes in input parameters and variables."	Section 5
17.d.	"Model Report. Fifteen (15) months after completion of the CSAP for major components of the WCTS described in Paragraph 14 above [in CD], Columbia shall submit a report ("Model Report") to EPA and DHEC which:	
17.d.(i)	"Identifies the functional attributes, characteristics, and limitations specific to the Model's software as compared to other products evaluated by Columbia and explains how the Model meets the capabilities required in Paragraph 17.a."	Section 2
17.d.(ii)	"Identifies the date that the Model was deemed to be calibrated and functional."	Section 5
17.d.(iii)	"Identifies all input and output parameters, constants, and assumed values used by the Model."	Sections 3 and 5
17.d.(iv)	"Explains the basis for the input parameters used in each Subbasin to characterize baseline wastewater flows and I/I, the quality assurance procedures used in acquiring the input data, and the engineering basis for the selections of constants (e.g., friction factors) and assumed values."	Section 3 and Section 4
17.d.(v)	"Provides a brief description of each procedure and protocol developed pursuant to Paragraph 17.c., provides the associated schedules, and identifies the individual(s) with their qualifications who are employed to implement the procedures and protocols."	Section 5
17.e.	"Site Audit. Following receipt of the Model Report in Paragraph 17.d., above, EPA and DHEC may conduct compliance audits of the capabilities of the Model, the implementation of the Model, and the use of written procedures and protocols as required by this Paragraph."	N/A

1.2 Report Layout

Section 1 (Summary and Intent): This section provides an overview of the report and a summary of the CD requirements.

Section 2 (Hydraulic Model Software Capabilities): This section provides a discussion of the capabilities of the modeling software utilized for the Hydraulic Model, as well as comparisons to other modeling software.

Section 3 (Physical Model Development): This section details the procedure for the collection and analysis of the physical system characteristics and the procedure for inputting this data into the modeling software. This section should be referenced for physical model updates.

Section 4 (Hydrologic Input Data): This section details the procedure for collection and analysis of hydrologic data (flow monitoring and rainfall data) and the procedure for inputting this data into the modeling software.

Section 5 (Hydraulic Model Calibration, Verification, and Sensitivity Analysis): This section provides the general procedures for the calibration of the Hydraulic Model, as well as brief descriptions of the verification and sensitivity analysis.

Section 6 (Hydraulic Model Updates and Recalibration): This section provides a recommended schedule and the required personnel for updates to the Hydraulic Model and recalibration.

1.3 Glossary of Terms

- **Average Daily Dry Weather Flow (ADF)** – the average flow recorded throughout the day, excluding any additional flows resulting from rainfall events.
- **Base Wastewater Flow (BWWF)** – domestic wastewater from residential, commercial, and institutional (schools, churches, hospitals, etc.) sources.
- **Calibration** – the adjustment of model parameters to closely match modeled flows to measured flows within an established criteria range.
- **Calibration Criteria** – qualitative and quantitative standards by which modeled flows are compared to measured flows.
- **Groundwater Infiltration (GWI)** – groundwater entering the collection system through defective pipes, pipe joints, and manhole walls. This infiltration component is not directly impacted by rainfall events.
- **Major Gravity Sewer Lines** – pipes that are 15 inches or larger in diameter.
- **Major Pump Stations** – pump stations receiving flow from pipes that are 15-inches or larger in diameter.
- **Meter Basins -** delineated based on the tributary area to the installed flow meters.
- **Minimum Daily Flow (MDF)** – the minimum flow recorded throughout the day.
- **Radar Rainfall Data** (also called gauge adjusted radar rainfall (GARR)) – the refinement of gauge rainfall data using available radar.

- **Rainfall Dependent Inflow/Infiltration (RDI/I)** – rainfall that enters the sanitary sewer system in direct response to the intensity and duration of rainfall events.
- **RTK Unit Hydrograph Method** – a synthetic unit hydrograph method used to model the system's response to rainfall events.
- **Sensitivity Analysis** – an analysis of the Model's sensitivity to the adjustment of model parameters, such as pipe roughness.
- **Sewerbasins** –major drainage areas that are tributary to trunk sewers.
- **Stevens-Schutzbach Method (SSM)** – a method for calculating the groundwater infiltration component of dry weather flow.
- **Subbasins** – defined by the Consent Decree.
- **Subcatchments** – subdivided subbasins. A modeling component that contains dry weather and wet weather flow data parameters, which are applied to a manhole as a load.
- **Trade Flow** – InfoWorks - terminology for large industrial or commercial contributing flows.
- **Verification** – the comparison of the calibrated model against flow data that were not used for the calibration.
- **Wet Weather Flows (WWF)** – increased flows in the system that directly result from rainfall events.

1.4 Acronyms and Abbreviations

- **ADF** – Average Daily Dry Weather Flow
- **BWWF** – Base Wastewater Flow
- **CAP** – Capacity Assurance Program
- **CD** – Consent Decree
- **CIP** – Capital Improvements Program
- **City –** City of Columbia
- **CSAP** – Continuing Sewer Assessment Program
- **CW2020** – City's program, Clean Water 2020, to manage the Consent Decree compliance
- **DHEC** – Department of Health and Environmental Control
- **DWF** – Dry Weather Flow
- **EPA** – United States Environmental Protection Agency
- **GIS** – Geographic Information System
- **GPD** – Gallons per Day
- **GWI** – Groundwater infiltration
- **I/I** – Infiltration and Inflow
- **IMS** – Information Management System
- **IR** – Infrastructure Rehabilitation
- **MDF** – Minimum Daily Flow
- **MGD** – Million Gallons per Day

- **MWWTP** – Metro Wastewater Treatment Plant
- **O&M** – Operations and Maintenance
- **RDI/I** – Rainfall Dependent Infiltration and Inflow
- **SCADA** – Supervisory Control and Data Acquisition
- **SSO** – Sanitary Sewer Overflow
- **WWF** – Wet Weather Flow

Section 2 Hydraulic Model Software Capabilities

Section 2 identifies how the City's Hydraulic Model meets the requirements of the CD related to the selection of Hydraulic Model Software as listed in **Table 2-1**:

Table 2-1: Checklist of Consent Decree Requirements within Section 2

CD Section	CD Requirements	Report Section
17.a.	Capabilities. At a minimum, the Model shall be capable of:	
	(i). Accurately predicting the flow rate and hydraulic grade line of wastewater in Force Mains from Major Pump Stations and the Major Gravity Sewer Lines under any historical dry or wet weather condition;	2.3.1
	(ii). Accurately predicting the location and severity of SSOs from the WCTS under any historical dry or wet weather condition;	2.3.2
	(iii). Fully dynamic temporal analysis, including an accounting of downstream backwater impacts on upstream flows;	2.3.3
	(iv). Accurately predicting the impacts of changes to Pump Station capacities on upstream and downstream flow rates and hydraulic grade lines, including hydraulic losses which may result from either full or partial Pump Station failures; and	2.3.4
	(v). Generating hydrographs depicting baseline wastewater flow and I/I for the Subbasins for various storm recurrence intervals. The Model shall include methods for accurately estimating the baseline wastewater flows and I/I components in each Subbasin using quality-controlled flow data obtained for the Sewer System.	2.3.5
17.d.	Model Report. Fifteen (15) months after completion of the CSAP for major components of the WCTS described in Paragraph 14 above [in CD], Columbia shall submit a report ("Model Report") to EPA and DECH which:	
	(i). Identifies the functional attributes, characteristics, and limitations specific to the Model's software as compared to other products evaluated by Columbia and explains how the Model meets the capabilities required in Paragraph 17.a.	2.2 and 2.3

2.1 Background

In 2012, prior to entering into the CD, the City engaged a professional engineering consultant with sewer modeling experience to develop and calibrate a Hydraulic Model of the Major WCTS to identify system capacity deficiencies and evaluate system improvements to address these deficiencies. The scope for the development of the Hydraulic Model did not specify the sewer modeling software to be used. Based on their prior professional experience in modeling large wastewater collection systems, the City's consultant in coordination with City staff, selected InfoWorks CS Version 13.5, a software package from Innovyze® (Portland, OR, USA), to simulate the WCTS. Fundamental considerations for the selection of this software package included the ability to integrate with the City's GIS and the City's other electronic operations data sources, to develop and update the Hydraulic Model, and simulate complex hydraulic structures and operational control strategies that are implemented at the City's existing pump stations and equalization storage facilities.

Development and calibration of this Hydraulic Model was completed in August 2014 and followed the general protocols discussed in this HMR. Hydraulic Model development relied on available GIS of the collection system and flow metering and rainfall data from a monitoring period in 2012. The calibrated Hydraulic Model was used to develop the initial City of Columbia Wastewater Collection System Master

Plan (July 2018) to begin implementation of system improvements to address system capacity deficiencies.

The City completed the Sewer Mapping Program at the end of 2018 for the Major WCTS, which provided essential and comprehensive information to update the physical system data in the 2012 GIS database. In 2019, in accordance with the City's intention to periodically maintain the Hydraulic Model, the City completed a recalibration of the Hydraulic Model, which was based on updated physical system characteristics and new hydrologic event data. Currently, the Hydraulic Model is updated and recalibrated to flow data from 2015/2016 and it is now being used to develop the WCTS Master Plan for the major components of the system. The 2015/2016 data was collected two months after the City experienced record rainfall and a historical flooding event; however, the data collected from December 2015 thru February 2016 provides valid input for the collection system model calibration with the appropriate adjustments during the capacity analysis. Using the recalibrated Hydraulic Model, major WCTS components are being assessed under typical baseline flow conditions and a 2-Year, 24-Hour representative storm event. It is expected the revised WCTS Master Plan for the Major System will be completed by the end of 2020.

As part of the 2019 Model Recalibration, the City's consultant updated the hydraulic model software to InfoWorks ICM Version 9.0 because the previous version of InfoWorks CS software was retired by the software company in 2016. Sewer models developed using InfoWorks CS are seamlessly migrated to the updated InfoWorks ICM software without data loss, and both have similar capabilities. The InfoWorks ICM software has the same functionality as InfoWorks CS with several upgrades, with the most significant improvement being its ability to run multiple simulations concurrently.

2.2 Hydraulic Model Software Selection

As noted above, the City's consultant selected the City's hydraulic model software based on their professional experience and on an evaluation of the software's ability to meet general industry standards prior to the CD filing. The software, InfoWorks ICM, meets the capabilities expressly required under the Consent Decree (Paragraph 17.a.), as discussed further below. Discussions of software specific modeling components herein reference parameters and capabilities found in InfoWorks ICM Version 9.0.

The following is a brief comparison of InfoWorks ICM to other sewer modeling software packages available in the public domain or on the commercial market.

- InfoWorks ICM: Versions of InfoWorks sewer modeling software have been available since approximately 1980 and used in the United States since the mid-1990s. InfoWorks ICM Version 9.0 has been available since 2018. The software package is used by many large cities around the world. Based on the City consultant's experience, the software has a stable numerical engine, which is required to accurately and efficiently perform complex modeling simulations and can handle complex control strategies, such as simulation of the Saluda River Pump Station Equalization Storage Facility. Based on the City consultant's professional judgment, the software has a well-designed graphical interface and strong data and scenario management capabilities. InfoWorks ICM also has self-diagnosis and de-bugging features, as well as options for simulating the hydrologic cycle such that rainfall can be simulated as Infiltration/Inflow (I/I) into the modeled sewer system. The software also integrates well with GIS, which is the physical data inventory for the City's WCTS.

- InfoSWMM®: InfoSWMM® is another Innovyze® product. InfoSWMM® has been available since 2004. The software is used by many medium to large sized utilities. InfoSWMM® is available as an extension of ArcGIS, or as a stand-alone version (InfoSWMM® SA).
- PCSWMM: PCSWMM is a product marketed by Computational Hydraulics International. This software has been available since 1984 and is used by many large cities around the United States and worldwide. The software has an easy-to-use graphical user interface.
- SewerGEMS®: SewerGEMS® is a product of Bentley Systems, Inc. This software has been available since approximately 1997. SewerGEMS® is available as an extension of ArcMap, AutoCAD, MicroStation, or as a stand-alone version.

The software packages listed above represent the market leaders in the sewer modeling field. All have similar functionality, characteristics, and relevant output, and they meet industry standards for collection system simulation software. However, they may incorporate different computational approaches. Some software packages also have different pre- or post-processing software and graphics that are typically offset by the user's experience or third-party programs.

Simulation of wet weather flow in a wastewater collection system is an important function of modeling software. I/I can be modeled using a variety of techniques, such as unit hydrographs, surfaces, and/or simulation of groundwater levels. InfoWorks ICM has many options for simulating I/I while SewerGEMS® appears to have the least number of options. While each software package has a groundwater model, InfoWorks ICM utilizes a dual reservoir model to simulate inflow from soil and ground store components, whereas the SWMM-based models utilize an aquifer model with a single input. InfoWorks ICM also has an extensive list of built-in hydraulic structures that can be modeled. For those reasons, InfoWorks was selected to develop the City's Hydraulic Model.

Although InfoWorks ICM is a powerful hydraulic modeling software package, it, like any modeling software, has disadvantages and limitations. This software is proprietary and not open source. Licenses are needed to create and run the models; these licenses can be costly. In addition, the user interface for InfoWorks could be considered more complex than other models and, therefore, may require more extensive familiarity to model collection systems and run simulations. However, these disadvantages did not dissuade the City's consultant from recommending the selection of InfoWorks software given the consultant's experience with its robust computational advantages.

The City may periodically re-evaluate available collection system simulation software packages and reserves the option to select a different software package in the future if it meets the capability requirements of Paragraph 17.a of the CD. Any such re-evaluation will be based on user experience and familiarity, common industry practice, and technical criteria, including cost, model calculation, performance, data management, GIS integration, data interchange, user interface, results presentation, technical support, licensing, and other capabilities.

2.3 Hydraulic Model Software Attributes and Characteristics

InfoWorks ICM utilizes a simulation engine that allows the Hydraulic Model to predict flow impacts following a rainfall event by providing fast, accurate, and stable modeling of the key elements of sewer collection systems. The numerical engine provides automatic time-stepping and implicit numerical solutions to optimize runtime and to facilitate mathematical stability. The software incorporates full solution modeling of backwater effects and reverse flows, open channels, trunk sewers, complex pipe connections, and complex ancillary structures. Access to the underlying data is available from graphical and geographical views. Animated presentations of the results in geographical plan, long section, and three-dimensional junction views are standard, together with reporting results and flood frequency analysis using tables and graphs. By using a standard database format, InfoWorks ICM provides the ability to review current and historical model network versions and attribute data (Innovyze, 2018).

The following subsections give a brief overview of the model software's functional attributes, characteristics, and predictive capabilities to show how the City's InfoWorks ICM model meets the CD objectives for the software requirements.

2.3.1 Predictions of Flow Rates and Hydraulic Grade Lines

InfoWorks ICM modeling software can accurately predict flow rates through gravity sewer and force mains and produce hydraulic grade line (HGL) under any historical or projected future dry or wet weather flow conditions. **Figure 2-1** illustrates typical results from the Hydraulic Model. Results are displayed graphically and in tabular form below the graphics. The graphic shows the scaled pipe diameter, manhole locations, ground elevation, and computed HGL. For pressure-flow conditions, the HGL will be above the pipe and show surcharged conditions. Under most gravity dry weather flow conditions, the HGL will be the flow depth within the pipe. SSOs are predicted when the HGL exceeds the manhole rim elevation (where there are unrestricted manhole covers). The tabular data below the graphics includes model assumptions for pipe roughness and other system characteristics to fully understand the basis for the simulation. Predicted flow depth (reported as flow depth above pipe invert), velocity, and flow rate are shown in the tabular information.

2.3.2 Predictions of Location and Severity of Overflows

As noted above, the modeling software can predict the location and severity of SSOs from the WCTS and account for the volume of flow lost from the system from an SSO simulated by the Hydraulic Model (when the hydraulic grade line exceeds the rim elevations of the sewer manholes) under any historical dry and wet weather flow conditions. **Figure 2-1** includes a graphical representation of a predicted overflow location. The software computes the volume of flow that exits (or is "lost" from) the sewer system as overflow. This volume is reported in the output data for each node with an overflow.

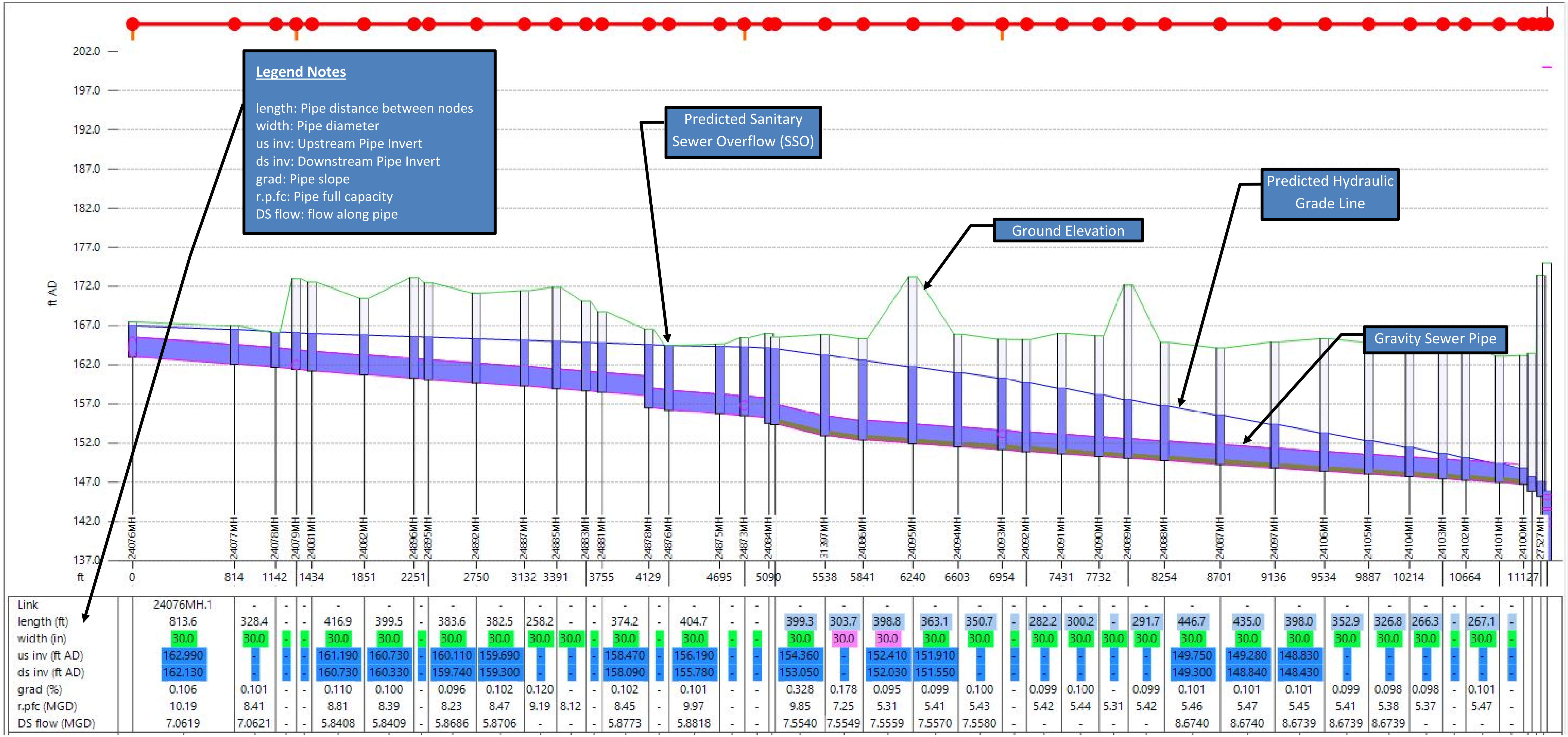

Figure 2-1: Example of Hydraulic Profile Model Results from InfoWorks ICM

2.3.3 Dynamic Temporal Analysis

InfoWorks ICM utilizes the fully dynamic Saint-Venant equations to represent the hydraulic behavior of sewer systems. This software uses a system of integrated relational databases to store and apply data describing the collection system and can represent non-uniform, non-steady flow behavior, including surcharged pipes, looped networks, bi-directional flow, split flows, and backwater impacts. The calculations can transition between gravity and pressurized flow at any point during the simulation while maintaining stable output.

2.3.4 Predictions of Impacts Caused by Changes to Pump Station Capacities

InfoWorks ICM allows the physical and operational characteristics of sewer pump stations to be input into the Hydraulic Model to predict changes in flow rates and upstream/downstream hydraulic grade lines with changes in pump station capacity. **Figure 2-2** shows an example predicted model output for various flows (and levels) being generated by various pump combinations operating simultaneously in a pump station. This capability includes the ability to replicate hydraulic conditions resulting from full or partial pump station failures by graphically depicting the changes in the HGL and pipe flow (zero flow from pump shut-offs or failures).

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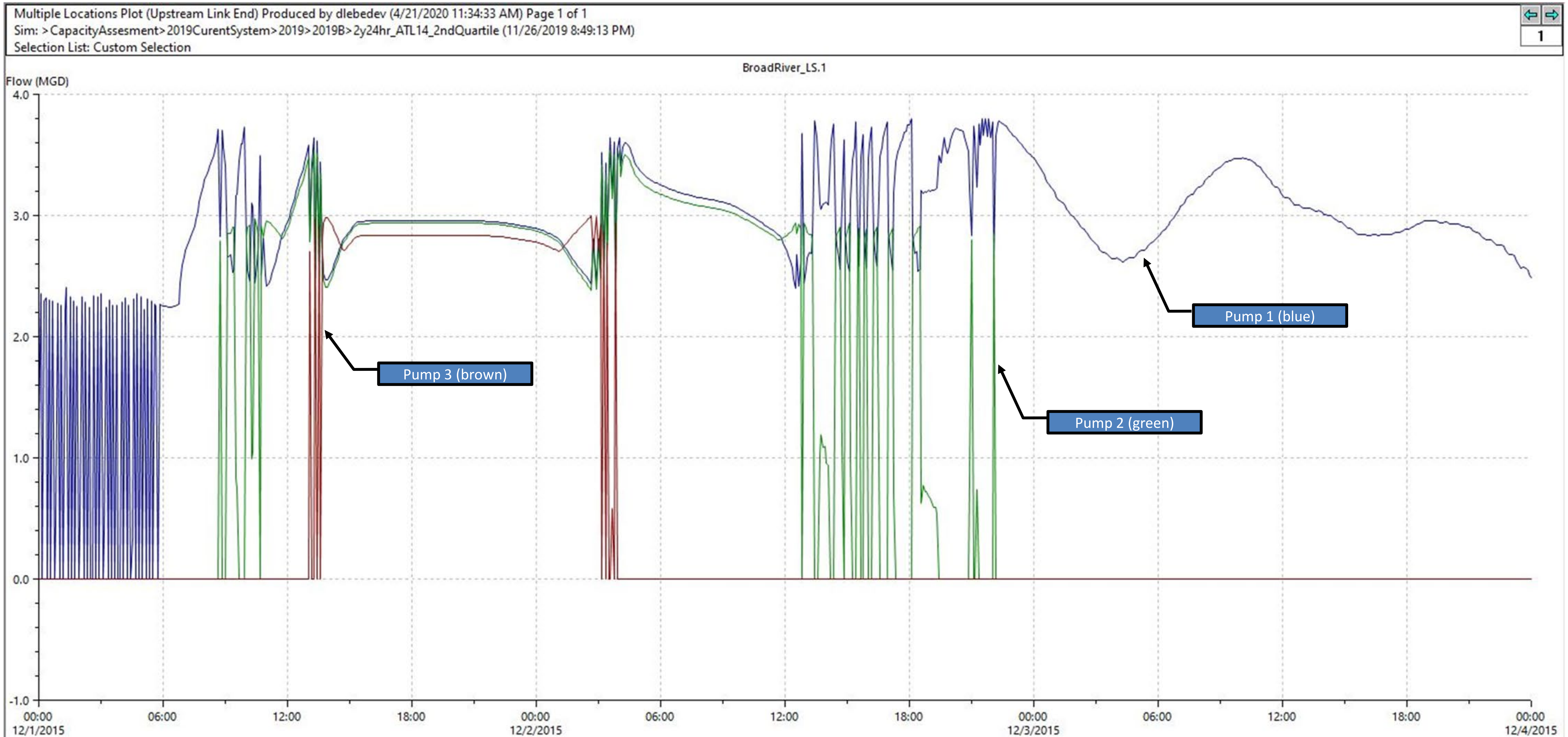

	Flow (MGD) Min	Flow (MGD) Max	Volume (US Mgal)
BroadRiver_LS.1	-0.000	3.802	8.637
BroadRiver_LS.2	-0.000	3.537	3.695
BroadRiver_LS.3	-0.000	2.998	1.651

Figure 2-2: Example of Flows and Levels from Broad River Pump Station Output in the Hydraulic Model (InfoWorks ICM Output) with Different Pumps in Operation

2.3.5 Generation of Hydrographs Depicting Baseline Wastewater Flow and I/I

The Hydraulic Model also generates hydrographs depicting temporal changes in baseline wastewater flow and I/I. The Hydraulic Model is capable of simulating dry weather and wet weather flow based on the calibrated model usage patterns and parameters to represent the measured flow data. The wastewater flow is often divided into three components: Groundwater Infiltration (GWI), Base Wastewater Flow (BWWF), and Rainfall Dependent Inflow/Infiltration (RDI/I).

Figure 2-3 displays the wet weather flow (WWF), average dry weather flow (ADF, and GWI, along with their relationship to BWWF and RDI/I. Infiltration and inflow is depicted in the Hydraulic Model as GWI, which is typically baseline groundwater coming in through pipes and manholes, and RDI/I, which is the higher amounts of I/I through pipes/manholes and possibly stormwater inlet connections from flow generated by rainfall. Areas in **Figure 2-3** that are shaded indicate periods of time when the system has a rainfall response. **Section 4.5.2** discusses how these flows are developed for the Hydraulic Model.

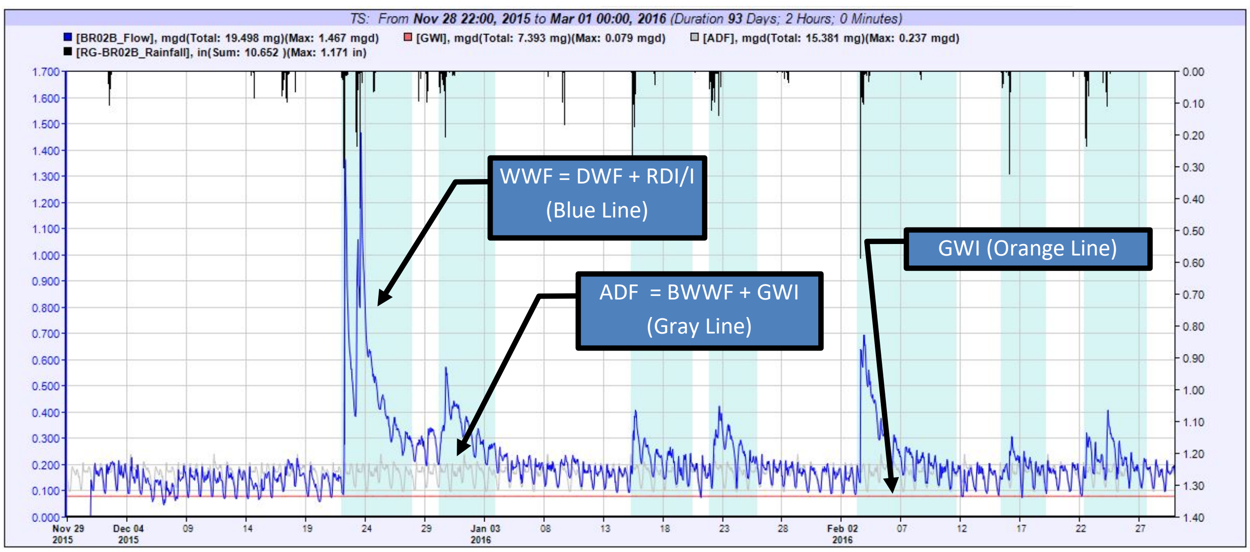

Figure 2-3: Example of Temporal Changes in Wastewater Flows

Section 3 Physical Model Development

Section 3 identifies how the Hydraulic Model meets the requirements of the CD related to the development of the Hydraulic Model to represent the physical features in the WCTS, as listed in **Table 3-1**.

Table 3-1: Checklist of Consent Decree Requirements within Section 3

CD Section	CD Requirements	Report Section
17.d.	Model Report. Fifteen (15) months after completion of the CSAP for major components of the WCTS described in Paragraph 14 above [in CD], Columbia shall submit a report ("Model Report") to EPA and DECH which:	
	(iii). Identifies all input and output parameters, constants, and assumed values used by the Model."	3.2, 3.3, and 5.2.1
	(iv). Explains the bases for the input parameters used in each Subbasin to characterize baseline wastewater flows and I/I, the quality assurance procedures used in acquiring the input data, and the engineering bases for the selections of constants (e.g., friction factors) and assumed values."	3.2

Output parameters describe the results of the Hydraulic Model computations and summarize the software generated pipe flow rates velocities and hydraulic grade lines based on the input to the Model. This is discussed more in Section 5.2.1.

3.1 Hydraulic Model Overview

3.1.1 Existing Sewer Collection System

The City owns and operates a sanitary sewer collection and conveyance system that serves approximately 63,000 customers (a service population of approximately 250,000) in the metropolitan Columbia area. The collection system consists of over 1,000 miles of sewer piping and 57 active sewer pump stations. The flow from the collection system ultimately discharges to the City's Metropolitan Wastewater Treatment Plant (MWWTP). The MWWTP has a treatment capacity of 60 million gallons per day (mgd). An overview of the existing sewer collection system is shown in **Figure 3-1**.

The WCTS serves the City of Columbia, portions of Richland County, and portions of Lexington County, including portions of the East Richland County Public Service District and the City of West Columbia. The Fort Jackson area is also within the City of Columbia boundaries and contributes flow to the City's system, but the City does not operate the satellite sewer system. There are also smaller private satellite sewer systems that contribute flow to the City's WCTS, such as Blue Granite Water Company.

The Ni America (n/k/a Ni Pacolet Milliken Utilities, LLC) area was previously connected to the system and was included in the original system network for calibration to the 2015-2016 flow monitoring data. Since October 2017, Ni America was removed from the system and does not contribute flow to the WCTS. In addition, Richland County took ownership and operation of a small portion of the southwestern collection system in 2020, which drains to the Mill Creek Pump Station. This asset transfer included five pump stations (Green Lakes, Quail Creek, Garners Ferry Road, Meyers Creek, and Swandale), which lowers the number of active sewer pump stations operated by the City to 52 and slightly reduces the total number of City sewer miles.

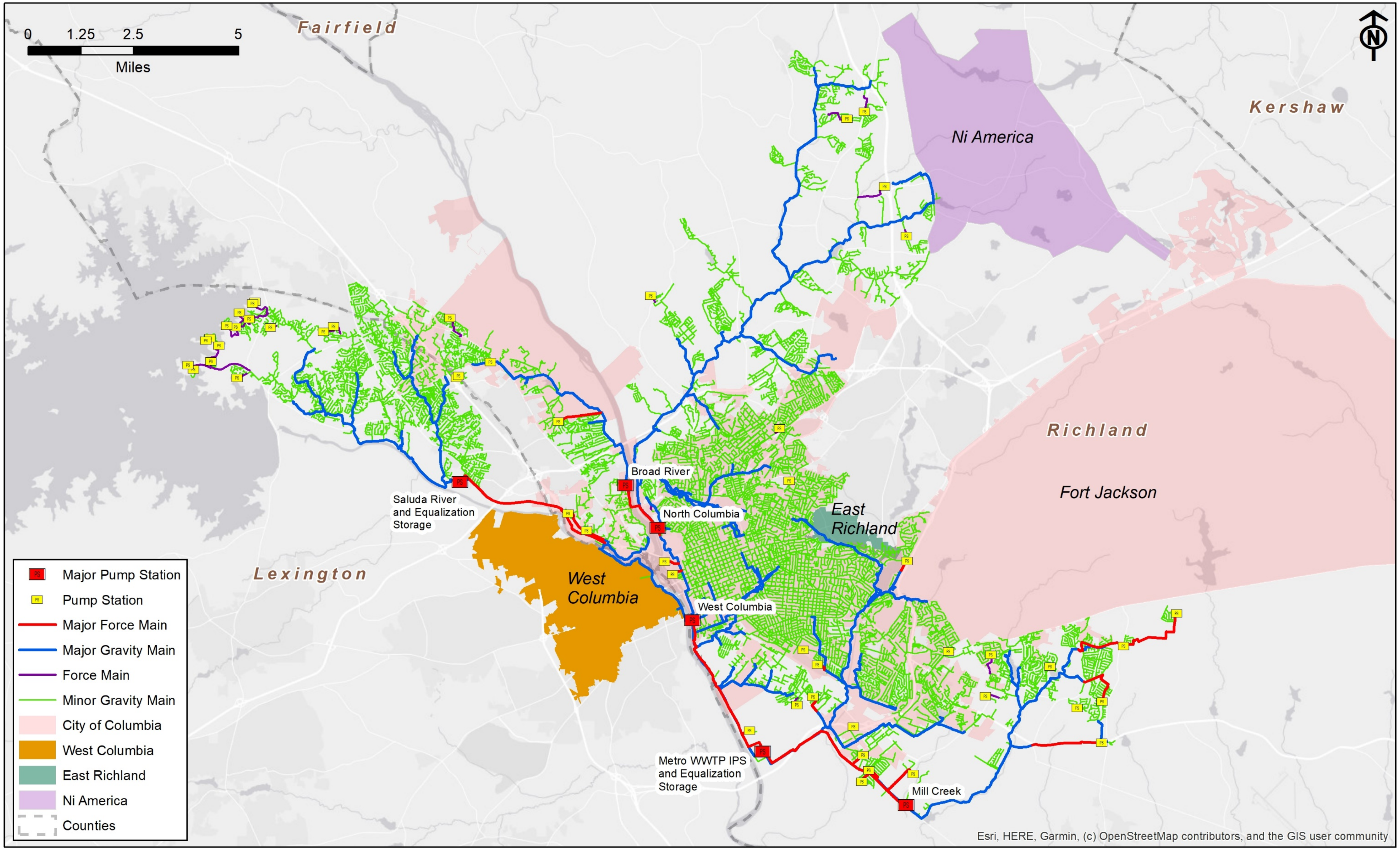

Figure 3-1: Columbia Water's Existing Sewer Collection System

The system is divided into eight sewer service basins and multiple sewer sub-basins defined in Appendix C of the CD. These are discussed in more detail in Section 4.

The Major WCTS, which is simulated in the Hydraulic Model, consists of about 119 miles of pipes equal to or larger than 15 inches in diameter (about 11 percent of the system). These pipes are shown in blue in Figure 3-1. There are five major WCTS pump stations (with pump capacities greater than 1,000 gallons per minute, as shown in red squares in Figure 3-1), which convey flow downstream to the MWWTP. Most of the major pump stations pump directly to the MWWTP either by direct force mains or by discharge into a gravity system that drains into the MWWTP. One station (the Saluda River Pump Station) conveys flow to a downstream station (West Columbia Pump Station). There are two large flow equalization storage facilities in the system to capture wet weather flow and avoid discharges - one is adjacent to the Saluda River Pump Station and the other one is at the MWWTP.

The 10 million gallon (MG) equalization storage facility at the Saluda River Pump Station is comprised of two tanks. There is a dedicated pump station onsite (with four pumps) that conveys excess wet weather flow into the storage tanks. This storage is used to temporarily store wet weather flow to reduce the hydraulic impacts downstream. Storage volume is drained by gravity back into the system after flow generated by a storm event has subsided, and the flow is eventually treated at the MWWTP.

The MWWTP is also an important component of the WCTS. The plant treats sanitary flow and the wet weather flow that is conveyed to it during storms. The Influent Pump Station (IPS) pumps most of the flow into the plant (the Mill Creek and West Columbia Pump Stations pump directly to the grit handling facility). After grit removal, when capacity at the plant is exceeded, excess flow is diverted to the adjacent flow equalization storage lagoon (approximately 160 MG open surface impoundment). When storm flow subsides, this stored flow is drained back into the plant for treatment.

Equalization storage and operations controls at the Saluda River Pump Station and at the MWWTP are dynamically simulated in the Hydraulic Model, as discussed in Section 3.2. The MWWTP Influent Pump Station is also included in the Hydraulic Model, as discussed in Section 3.2.

Figure 3-2 provides a schematic of how the system is linked with the five largest pump stations and piping system. Hydraulically, the five Major Pump Stations provide good hydraulic breaks in the system for simulation and calibration.

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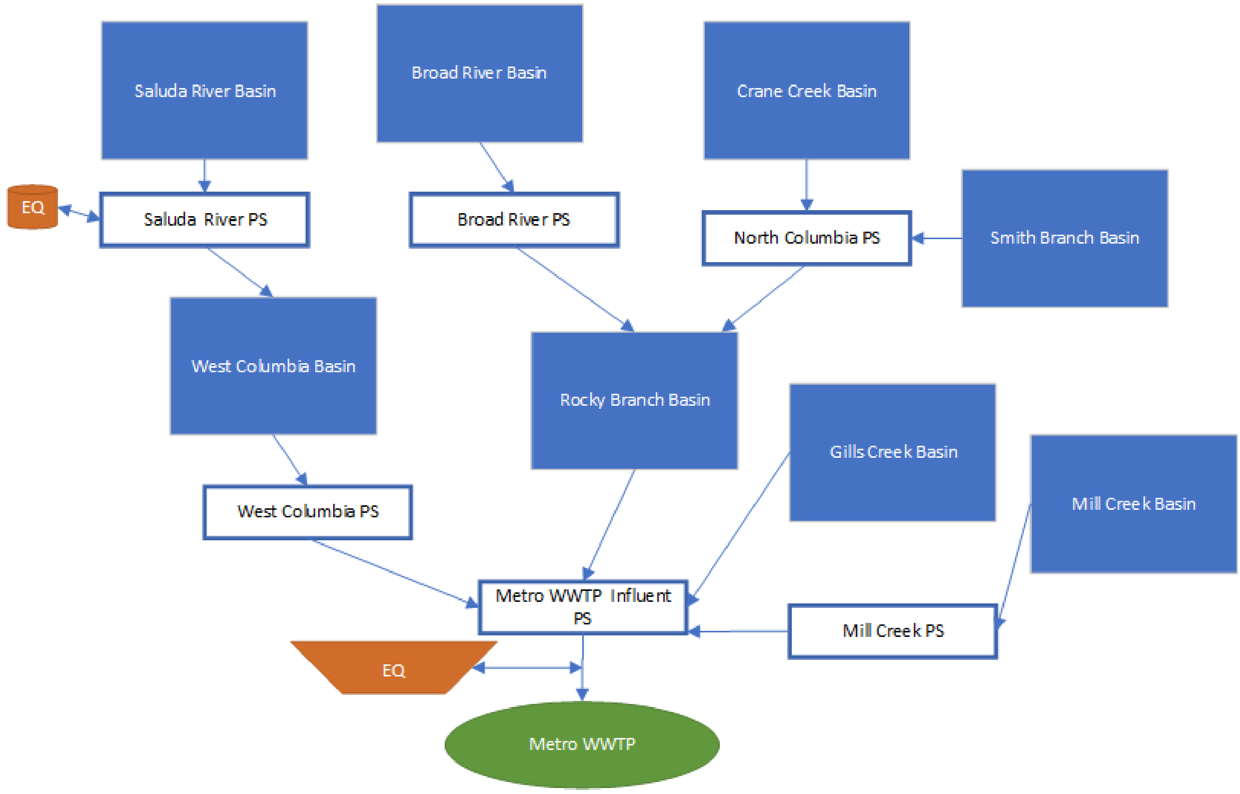

Figure 3-2: Schematic of Columbia Water's Existing Sewer Collection System

3.1.2 Model Extents

As required by Paragraph 17.a.(i). of the CD, the Hydraulic Model was developed to represent the Major WCTS, which is defined in the CSAP as all pipes 15-inches in diameter and larger (Major Gravity Sewer Lines or Force Mains) and all pump stations that receive flow from gravity lines 15-inches or larger or that discharge into force mains larger than 15-inches in diameter (Major Pump Stations). Appendix H of the CD lists five pump stations that have pump capacities greater than 1,000 gpm and would be considered major components based on the criteria above:

- Broad River Pump Station
- Saluda River Pump Station
- North Columbia Pump Station
- West Columbia Pump Station
- Mill Creek Pump Station

Using the 15-inch diameter pipe criteria above, the CSAP included two additional major pump stations - Edventure Pump Station and Garners Ferry Pump Station. For the development of the Hydraulic Model, 20 additional pump stations (pumps, wet wells, and force mains) were added to the Hydraulic Model due to their pumping capacity, the size of the upstream service area, and/or interconnections in the WCTS. These additional stations are referred to as “Minor” pump stations.

3.1.3 Summary

Figure 3-3 summarizes the pipe, pumping station, equalization storage, and treatment system components included in the Hydraulic Model.

3.2 Physical System Data Collection and Analysis

The Hydraulic Model was initially created from the City’s GIS as the primary inventory for permanent physical system asset data for the collection and transport of sewer flow to the Metro WWTP, including data on pipes, manholes, pump stations, force mains, and storage facilities. The GIS is continually being updated by City staff based on available data (field surveys, record drawings, and ongoing system assessment activities such as the CSAP, etc.). The physical system data is critical information for the Hydraulic Model’s computational engines to derive the system capacity and headloss via open channel, gravity pipe, and closed conduit (pressure flow) equations, along with the transition between these hydraulic conditions.

GIS information is also typically supplemented, where practical, by field inspections of assets to determine the general condition of system facilities and to confirm physical conditions where practical, to identify appropriate modeling constants to define the system hydraulic losses. The City’s Sewer Mapping Program (CD Paragraph 12.f.), completed in November 2018 for the Major WCTS, provided substantial verification of the City’s existing assets and their physical condition based on field topographic surveys, internal video or multi-sensor pipe inspections, manhole inspections, and general reconnaissance. This data was used to develop input characterization data for the 2019 Hydraulic Model Recalibration.

Physical characteristics of major facilities like the pump stations and storage facilities may not be fully characterized in GIS for hydraulic simulations. Accordingly, data for these facilities is supplemented by available as-built or construction record drawings. In addition, documented operating controls and logic were programmed in the Hydraulic Model to replicate actual control functionality for pumps and storage facilities.

Finally, for the development of this Hydraulic Model, the five Major Pump Stations (with capacity greater than 1,000 gpm) were also assessed to confirm dimensions and piping connections, hydraulic restrictions, and pump data. Pump tests were also performed at each of the five Major Stations to confirm pump capacity and identify any hydraulic issues. Some of the less hydraulically significant pump stations were also tested and modeled. Pumps tests may not be required at all pump stations depending on the hydraulic significance of each station; for stations with lower flow rates, the use of drawdown tests or published data may be adequate for simulation purposes.

All model input data is analyzed for consistency and accuracy to identify any data anomalies that could be readily confirmed by further research or field investigations. This level of effort may not be required for all model recalibration efforts unless significant system improvements have been implemented or there are continuing system investigations that improve the GIS database.

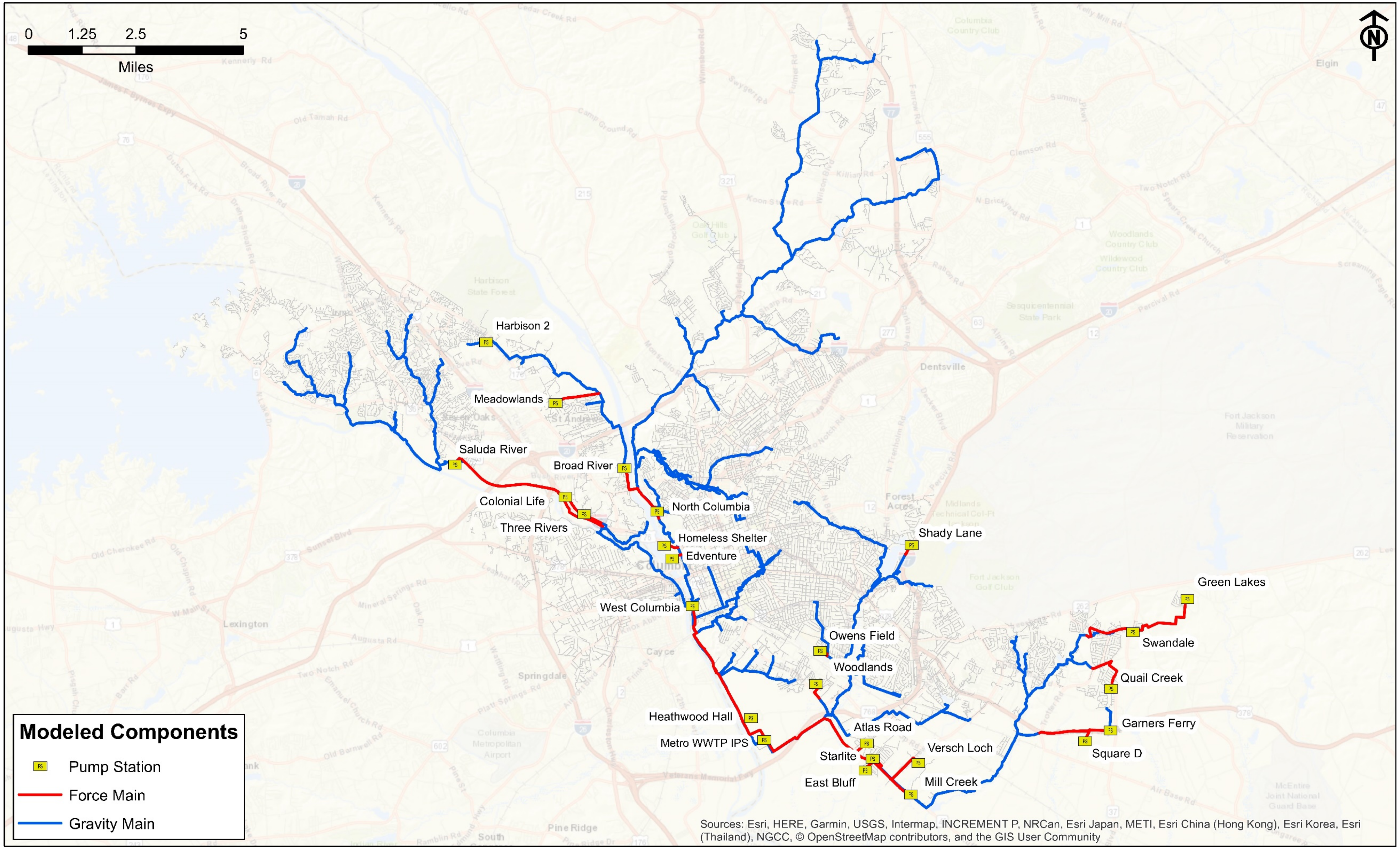

Figure 3-3: Modeled Hydraulic Network (2019 Model)

Part of the consistency review of each data set was to confirm datum/units including:

Datum/Units	Standard
• Projected Coordinate System	• NAD_1983_HARN_StatePlane_South_Carolina_FIPS_3900_Feet_Intl
• Linear Unit	• Foot
• Geographic Coordinate System	• GCS_North_American_1983_HARN
• Datum	• D_North_American_1983_HARN
• Angular Unit	• Degree

Model input data quality control procedures are discussed in each section below describing how the data is cross-checked and input to the InfoWorks ICM Hydraulic Model.

3.3 Hydraulic Model Input Parameters

Most sewer collection system hydraulic models combine the physical system data that describe the pipes, manholes, storage facilities, and pump stations with flow inputs, including groundwater contribution, to simulate the conveyance of wastewater from upstream loading points to the end of the collection system. The modeled network consists of three major components: nodes, links, and subcatchments. Modeling software includes many different model parameters to simulate these components in closed conduit and open channel conveyance systems, but all have the three basic components.

Nodes and links represent the physical components of the collection system. Nodes represent a specific point in the network and typically represent manholes, wet wells or storage facilities. Nodes are connected by links, which are typically conduits or pipes in a sewer system but also represent control points like pumps. Nodes and links of different types are incorporated, as necessary, to model complex structures such as pump stations. Wastewater flow is loaded into the Hydraulic Model via model subcatchments. Subcatchments are discussed in Section 4. A detailed discussion of these major components is provided below based on the InfoWorks ICM modeling software.

The Metro WWTP was partially simulated at the end of the collection system. The influent pump station (IPS) wet well and screw pumps were included in the model network, which pumps most of the flow into the WWTP. The West Columbia Pump Station and Mill Creek Pump Station typically pump via force mains directly to the preliminary treatment facilities (screening and grit removal), which are located downstream of the screw pumps. After preliminary treatment, flow is either directed to primary treatment (not simulated) or to the 160 MG equalization storage facility, which was simulated. The equalization storage facility is drained into the IPS.

3.3.1 Nodes

The four node types used in InfoWorks ICM to model the City's collection system include break, manhole, outfall, and storage. Detailed descriptions of each type are outlined below.

3.3.1.1 Break

Break nodes are used to model pipe alignment changes where there is no manhole or storage. Break nodes are commonly used to connect force main piping that vary in size or slope. When modeling the collection system for the City of Columbia, break nodes were also used to connect the pumps to the force main.

3.3.1.2 Manhole

Manholes are defined in InfoWorks ICM by their ground level, chamber floor elevation, chamber and shaft areas, and flood type. The Hydraulic Model uses these parameters to dynamically simulate temporary storage in the manhole.

The following provides an overview of each parameter:

- **Ground Level** – represents the topographic elevation or the rim elevation (but rim elevations can be higher than the ground elevation in Columbia) obtained from GIS or USGS mapping;
- **Chamber Floor Elevation** – represents the elevation of the invert of the manhole; data is obtained from record drawings;
- **Chamber and Shaft Areas** – represent the cross-sectional area of both the chamber, which is the area from the manhole invert to the crown of the top-most pipe connecting to the manhole, and the shaft, which is the area of the manhole from the top of the chamber to the manhole rim. The default area value of 12.566 ft^2 is assigned to each shaft and chamber, which represents the area of a 4-ft diameter cylindrical manhole (unless record drawings are available to suggest that the manholes are bigger or structures or vaults exist and that their depiction in the Hydraulic Model would be hydraulically significant, which is typically an engineering decision). The chamber and shaft for each manhole is assumed to be 4-foot in diameter when placed in the Hydraulic Model unless there are record drawings or GIS information that indicate otherwise;
- **Flood Type** – defines the modeling characteristics associated with manhole overflows (when flow depth exceeds the rim elevation). The flood types used in this model include lost, sealed, and stored to simulate the actual field conditions, as summarized below:

Flood Type	Description	Model Logic
Lost	Sewer flow depth exceeds the manhole rim and water is lost from the system as an SSO	[Surcharge Depth] = 0 ***most common***
Sealed	The manhole cover is fixed to the chamber and shaft and the sewer flow can rise indefinitely without lost flow	[Surcharge Depth] > 0 ***if reported in the City's GIS data***
Stored	Sewer flow can exceed the rim elevation, but flow is retained on a catchment surface, which returns to the system as conditions allow	[Surcharge Depth] > 0 and [Ponded Area] > 0

Figure 3-4 illustrates the typical model input parameters used for manhole nodes in the InfoWorks ICM Model. "AD" in Figure 3-4 stands for "Above Datum".

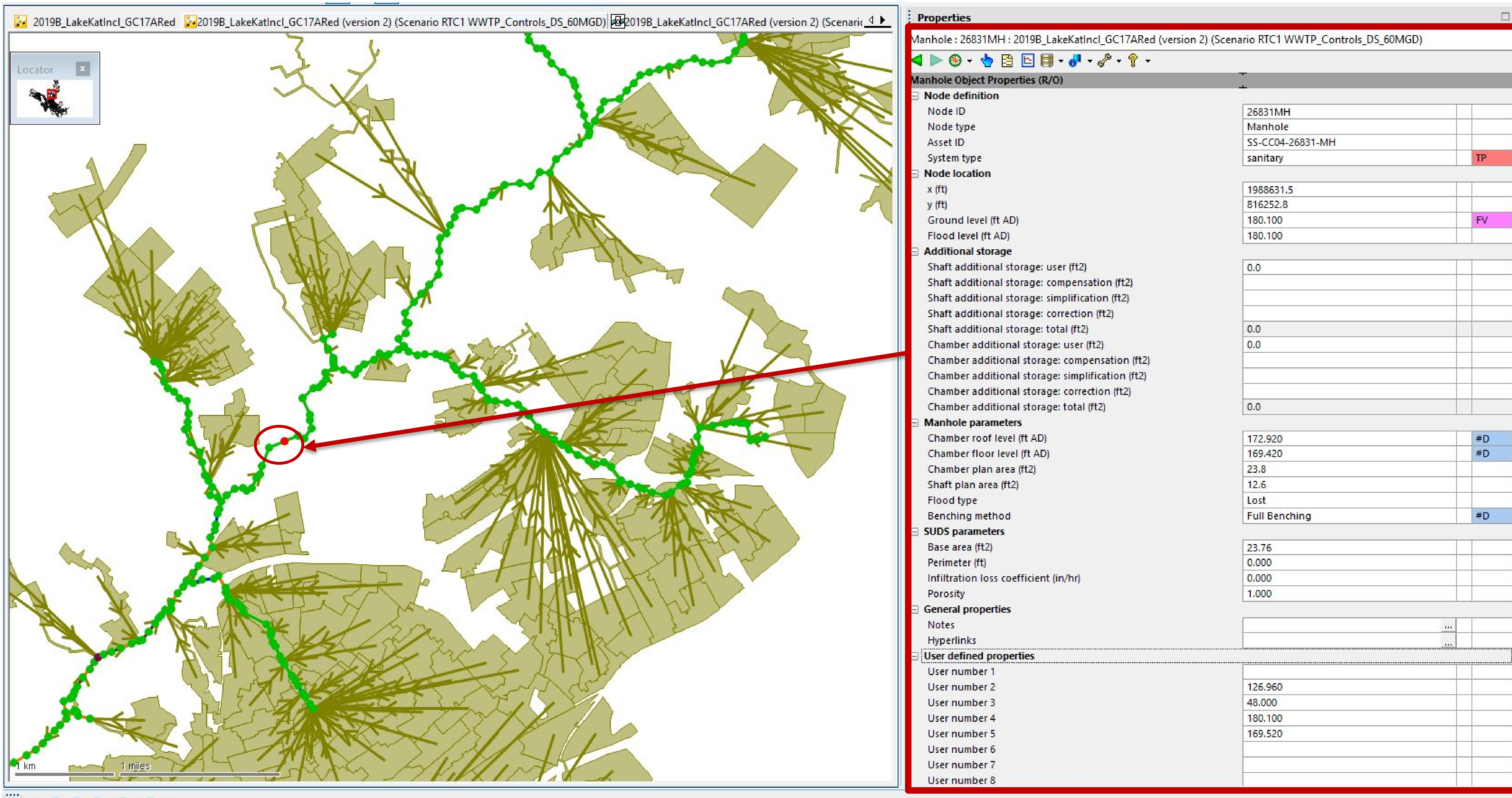

Figure 3-4: Example of Manhole Node Parameters in the Hydraulic Model

3.3.1.3 Outfall

An outfall represents a location where wastewater flow leaves the modeled system. For a sanitary sewer collection system model, an outfall is typically located at a wastewater treatment plant, which is the last discharge point in the system. One outfall was used at the City's MWWTP to simulate the end of the collection system.

3.3.1.4 Storage

System storage facilities are characterized as storage nodes in the InfoWorks ICM model. Storage nodes define storage geometry for non-conveyance storage elements, such as pump station wet wells and equalization tanks. Data to define the representation of storage is developed based on record drawings of the facilities. The wet wells for the five larger and 20 smaller pump stations were simulated using storage nodes.

The Hydraulic Model also has two storage facilities:

- Saluda Pump Station Storage (10 MG) – Saluda Storage Pump Station
- Columbia Metro WWTP (160 MG) – Influent Pump Station

Physical characteristics, obtained from record drawings or field investigations, describe the configurations and operating conditions of the storage facilities. These facilities operate in conjunction with pump station controls. The Saluda River Storage facility has a dedicated pump station that conveys excess wet weather flow into the two storage tanks (one 3 MG and one 7 MG storage tank). The operational controls in each of these facilities, whether automatic or manual, are critical to simulate as these conditions dictate when storage is used and dewatered, which helps curb peak flows in the system. Both storage facilities have drains that have modulated valves to control the flow rate, which are dynamically simulated in the Hydraulic Model.

The volumetric properties of a storage node are described by a function or table of surface area versus level. **Figure 3-5** provides an example of how storage data (in a level/area storage curve) for a wet well is input to the InfoWorks ICM model.

Major attributes of a storage object in the Model include:

- **Ground Elevation** – topographic grade or top of storage chamber/wet well roof
- **Storage Volume and/or Parameters** – wet well dimensions or level-area table (shown in Figure 3-4)
- **Wet Well Invert** – bottom elevation of wet well/storage tank
- **Flood Level** – first floor elevation or bottom of the wet well roof

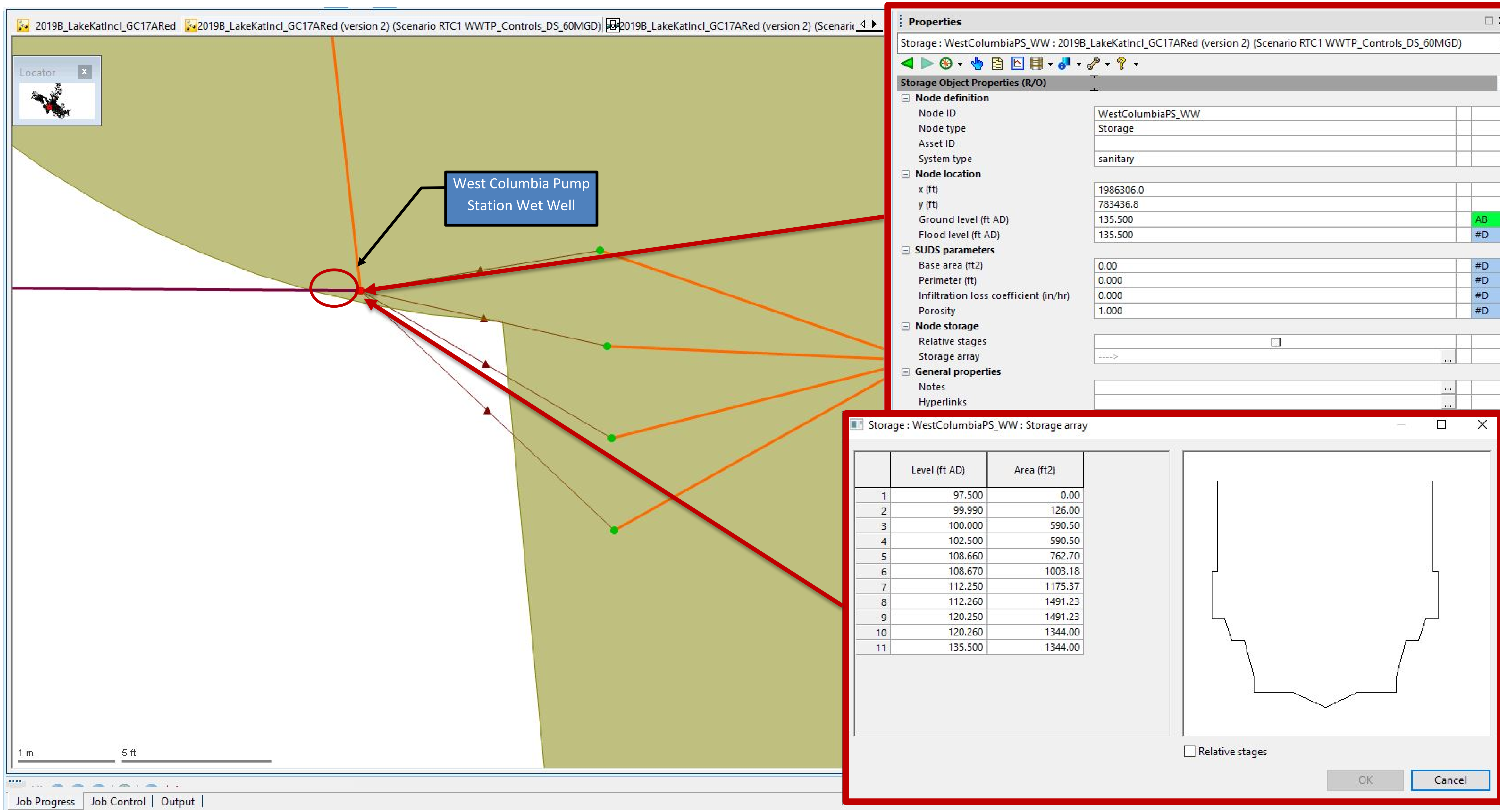

Figure 3-5: Example of Storage Parameters for a wet well at the West Columbia Pump Station in the Hydraulic Model

3.3.2 Links

A link represents the physical connection between two nodes and may be one of the following:

- *Conduit* – denotes a gravity sewer pipe or force main connecting two nodes
- *Pump* – denotes each pump and its connection between the wet well and force main

Force mains as conduits are discussed in Section 3.3.2.2 Pump Stations

3.3.2.1 Conduits (Gravity Sewer Pipes)

Most links in the Hydraulic Model are gravity sewer pipes, which are simulated as conduits. The hydraulic condition associated with each conduit is initially defined using a roughness type and a computational solution model to reflect the type of hydraulic condition the pipe is under. The InfoWorks ICM solution models include full, pressure, and force main. The gravity system utilizes the full solution model, which applies the Saint-Venant equations to surcharged and non-surcharged pipes. **Figure 3-6** shows an example of the model parameters that are input to simulate a conduit.

3.3.2.1.1 Data Sources and Quality Checking

The City's GIS database, dated October 29, 2019, was used to develop the Hydraulic Model. The GIS database contained the most recent physical system characteristics of the piping system based on the Sewer Mapping Program (which was used to update the 2012 physical system data set used for the 2014 Hydraulic Model development). The Hydraulic Model was utilized to review pipe profiles. The analysis included a review of various attribute fields, such as Rim Elevation, Depth, and GPS attributes (where available) for manholes, along with nominal size, length, material, and upstream (U/S) and downstream (D/S) inverts for pipes. Conflicting data was updated, as necessary, based on additional field investigations to develop a robust database for model simulations. The Hydraulic Model includes notations for each pipe regarding its data source and field confirmation.

3.3.2.1.2 Pipe Roughness and Constants

Pipe roughness is used to describe the friction headloss in piping systems. Pipe roughness coefficients for gravity sewer pipe are based on Manning's roughness values. These values are initially selected based on the known material and physical condition of the pipe. There are numerus references available for guidance in selecting the various coefficients, e.g., Handbook of Hydraulics (Brater and King, 1976) as referenced in "Computer Tools for Sanitary Sewer System Capacity Analysis and Planning" (Vallabhaneni, P.E., BCEE, Chan, P.E., & Burgess, 2007).

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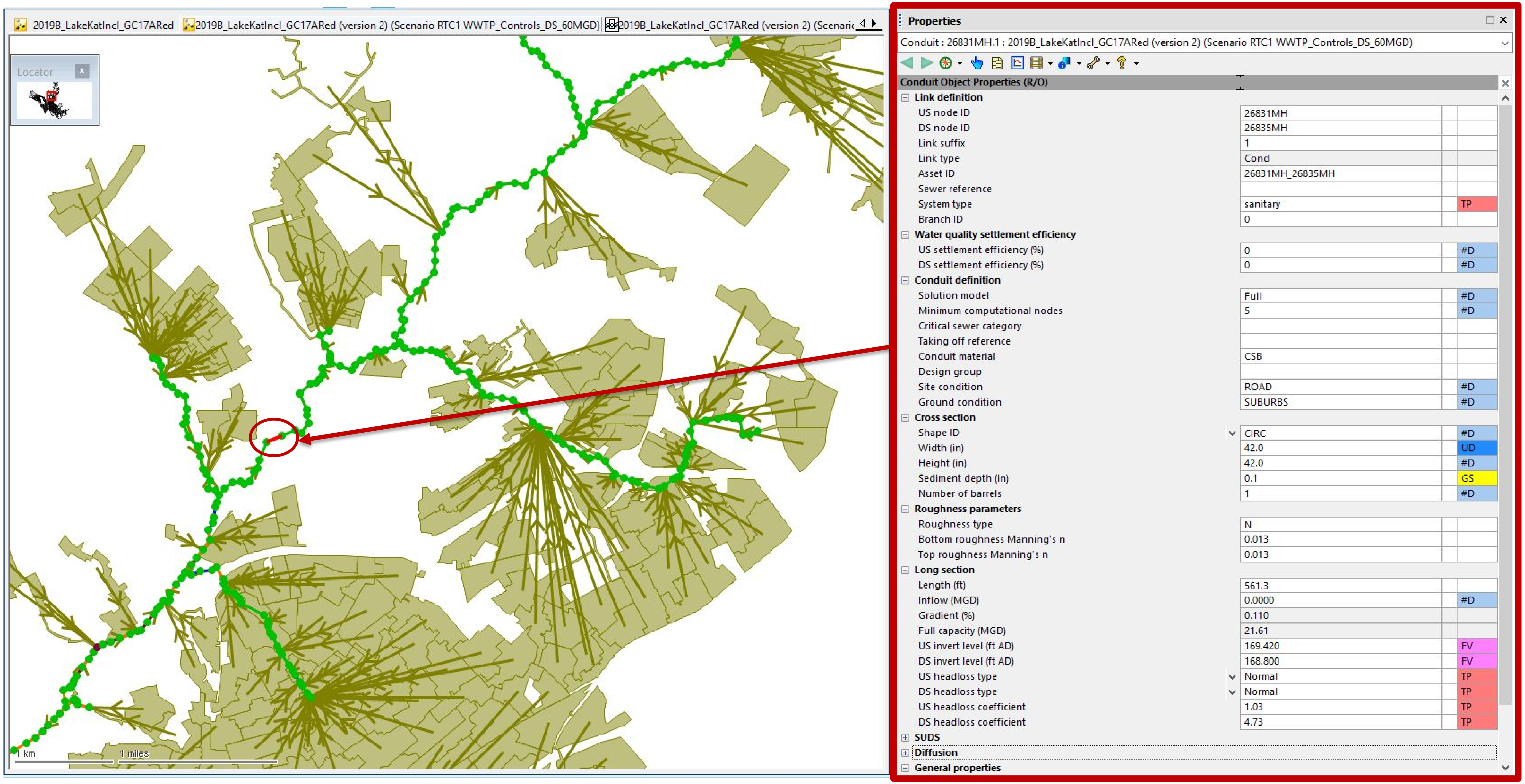

Figure 3-6: Example of Link Parameters in the Hydraulic Model

Table 3-2 summarizes the initial roughness values that are typically used for each material type. Roughness values may initially be adjusted higher for gravity sewer (adding more roughness) if the physical condition of the pipe is poor (cracking, off set joints, etc. that might increase friction headloss) or if there is sediment in the pipe (documented by field inspections or CCTV). Older pipes that have been rehabbed by lining may have assumed friction factors that are closer to the initial values of new pipe. During the calibration process, pipe roughness values may be adjusted to match simulated flow depth to the actual depth of flow at a monitoring location (calibration adjustments are discussed further in **Section 5**).

Table 3-2: Initial Pipe Roughness Values

Pipe Material	Abbreviation	Roughness Coefficients Manning's N	 HW C-Factor
Asbestos Cement	AC	0.011	140
Cast Iron	CAS	0.012	130
Concrete Pipe (non-reinforced)	CP	0.012	100 – 140
Clay Tile	CT	0.014	100
Ductile Iron Pipe	DIP	0.012	140
Fiberglass Reinforced Pipe	FRP	0.013	150
Polyethylene Pipe	PE	0.009 – 0.015	140
Polyvinyl chloride	PVC	0.009 – 0.011	150
Reinforced Concrete	RCP	0.011	140
Steel Pipe	SP	0.012	140
Vitrified Clay Pipe	VCP	0.011	110

NOTE: [1] Final roughness values in individual model segments are based on calibration adjustments and/or engineering judgment.

InfoWorks ICM, also allows the simulation of minor headlosses (flow direction changes in manhole, entrance and exit losses, and bends) to consider the potential hydraulic impacts of the pipe connection to each manhole and/or pipe transitions (if there is no manhole). These minor headloss constants are assumed based on industry standard literature values. Headloss is calculated from the manhole to the pipe to account for energy lost due to turbulent transitions between manholes and pipes. Initial minor head loss values are automatically assigned within InfoWorks ICM. These values may be modified with engineering judgment based on field data during the calibration process.

3.3.2.1.3 Gravity Pipe Sediment Data

Pipe sediment accumulation can be added to the links. The City provided pipe sediment data within the collection system that was compiled based on field investigations and internal pipe inspection records. The data was provided with the City's GIS database and included the average depth and maximum depth of sediment measured in gravity mains. Depth of sediment in the flow meter manholes was obtained from the flow meter installation reports.

Sediment in a sewer system is typically a variable condition. The Columbia wastewater collection system is impacted by peak flows during wet weather conditions and this additional flow often moves sediment downstream. Accordingly, the sediment conditions measured during these field investigations may not be the same as the conditions during the flow monitoring period. As a result, the data would be used as necessary to match field conditions during the calibration process.

3.3.2.2 Pump Stations and Force Mains

The pump stations and force mains define the physical characteristics of the pump and pressure conveyance system in the Hydraulic Model. These physical characteristics describe the configurations and operating conditions of the pump stations and the force mains that convey sewer flows from the pump stations. The operational controls in each pump station, whether automatic or manual, are critical to simulate as these conditions dictate when pumps are operated, which creates variable flow conditions in the system.

Pump stations and force mains are typically simulated in hydraulic models as a combination of links and nodes: a storage node for the wet well, a link for each pump, a break node to connect the pumps to the force main, and a link for the force main. The following discussion is how these components are developed together in the Hydraulic Model to represent pump station facilities.

The physical characteristics of the pump stations and force mains were identified using available as-built or construction record drawings. Hydraulic Model input parameters for the pump stations include:

- Pump Stations
  - Geographic Location
  - Wet Well Dimensions
  - Top of Wet Well Roof Elevation
  - Wet Well Invert Elevation
  - Pump and Pipe Configurations
  - Pump Performance Data (Testing Data or Manufacturer’s Pump Curve Data)
  - Operating Controls
    - Including information on pump operating sequence as a function of wet well level and pump alternation, pump vs. wet well designations (if more than one wet well), pump speed control (for variable speed pumps), downstream pump control (if a downstream manhole is used to control an upstream pump station), standby pump operation (if available), and detailed pump characterization (flow as a function of head and drive speed).
- Force Mains
  - Geographic Location
  - Force Main Material
  - Force Main Diameter
  - Force Main Length
  - Force Main Profile
  - Force Main Roughness (Hazen-Williams C-Factor)

Piping connectivity, pump station connectivity, and system operating schemes (e.g., pump station logic) were checked with City staff to confirm that the physical description of the Model and the operating strategies within pump stations were consistent with the actual collection and transmission system.

Pump performance field tests are sometimes used to confirm existing conditions. In Columbia, as part of the hydraulic modeling effort, pump performance tests were conducted for the five major pump stations. Visual observation of pipe connectivity and wet well dimensions was completed during the pump performance testing of the five stations. The remaining 20 minor pump stations, included in the Hydraulic Model, were modeled using available drawdown data from testing performed by City or a subcontractor This effort is discussed further below.

3.3.2.2.1 Pump Station Wet Wells (Nodes)

Pump station wet wells are represented in InfoWorks ICM using the storage nodes. Storage geometry is defined by the chamber area and shaft area. Complex wet well geometries can be represented in the Hydraulic Model by using the storage type element and an area-level table representing the cross-sectional area per unit of depth (see **Section 3.3.1.4** and **Figure 3-3**).

3.3.2.2.2 Pumps (Links)

The operating characteristics of the pumps within the pump station require model inputs that include the following:

- Number of pumps
- Pump operation logic including Pump On / Pump Off levels for each pump
- Capacity of the pumps and pump curves showing head/discharge relationships

Within InfoWorks ICM, pump links are used to link the wet well model node to the downstream model node. Four different types of pump links can be simulated in the Hydraulic Model: Fixed Pumps, Rotodynamic Pumps, Variable Speed Pumps, and Screw Pumps. Most of these pump types are found in the Columbia system.

Pump curves for each station for the simulation of pumping capacity were developed by shifting the manufacturer's curve, using pump affinity laws, to align with performance test duty points or drawdown test results. System curves were developed using the wet well water levels from start-up or drawdown testing results, station discharge piping, force main piping, and force main discharge elevation. Then, the force main roughness was adjusted until the system curve passed through a best fit of the performance test duty points or drawdown test results.

Field test results provide the operating conditions for the pump station simulations in the Hydraulic Model. Both the force main headloss parameters (Hazen-Williams C-factors and minor losses) and pump curves were adjusted in the Hydraulic Model to achieve the field-observed pumping conditions.

Figure **37** shows an example of the development of the pump and system curves.

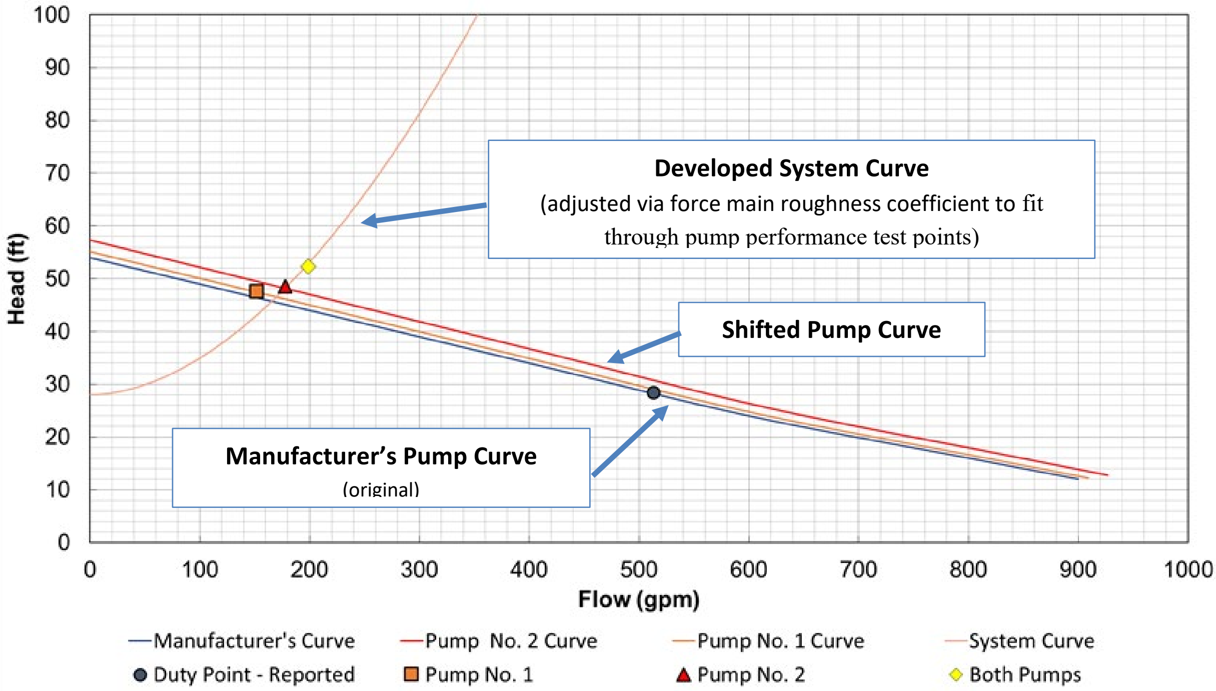

Figure 3-7: Example of Pump and System Curve Development

A comprehensive understanding of pump station operations is necessary to simulate the facility in the Hydraulic Model. Sometimes this means creating diagrams, as shown in **Figure 3-8,** to show a schematic representation of the flow and operating conditions for more sophisticated operations.

Current operating controls and logic were also programmed in the Hydraulic Model to replicate actual pump and wet well control functionality. This data is used to confirm simulation results correlated with actual system operation. **Table 3-3** shows an example of the pump station control logic input to the Hydraulic Model for the wet well levels and pump operation at the Saluda River Export Pump Station.

3.3.2.2.3 Force Mains (Links/Conduits)

In addition to gravity sewer pipes, force mains are also modeled as conduits under pressure. The hydraulic conditions associated with these conduits are defined using an appropriate solution model and roughness coefficient. The force main solution is designed to conduct hydraulic calculations on pump station discharge conduits. Hazen-Williams C is specified as the roughness coefficient (see Table 3-2) for conduits using the force main solution model. For the Hazen-Williams C roughness type, the roughness coefficients are calculated based on pump station performance testing or drawdown testing results and the diameter, length, and static head of the force mains. These coefficients are verified by comparing the pumping rate in the Hydraulic Model to the drawdown pumping rate.

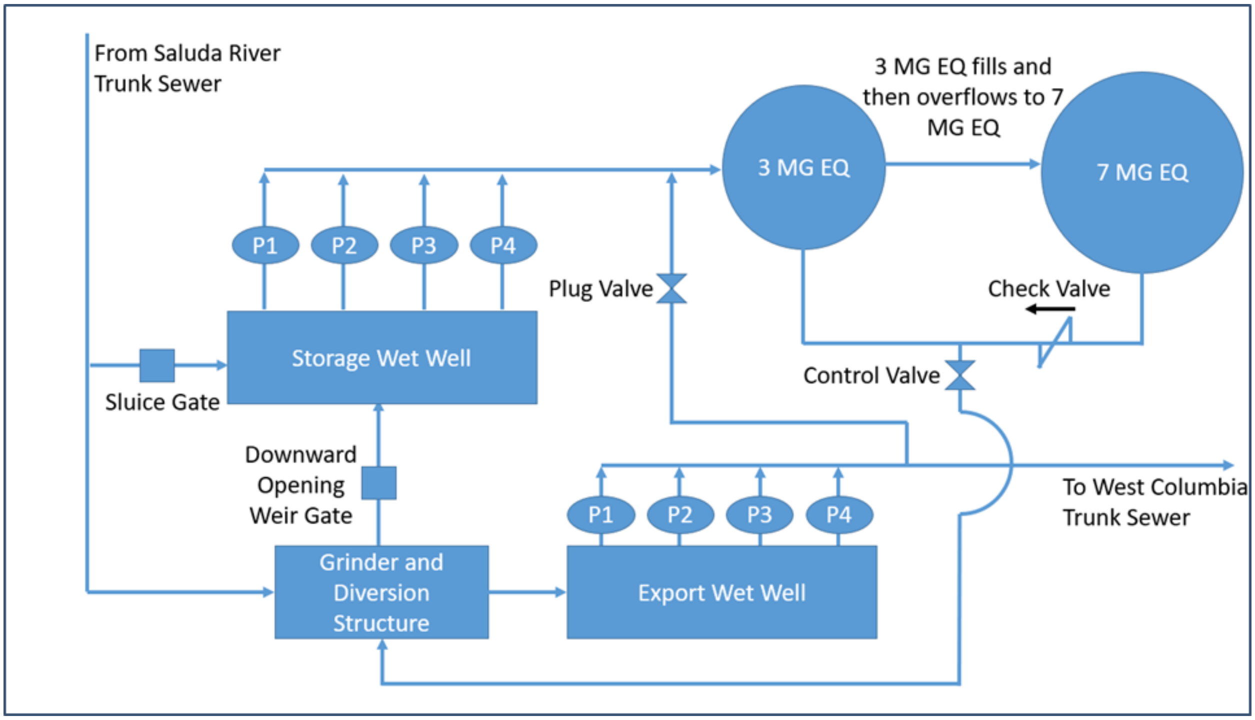

Figure 3-8 Saluda River Pump Station Operations and Controls

Table 3-3: SRPS Export Pump Operational Settings – Rising Wet Well Levels

Level Above Invert (ft)	Operation
15.0	Lead Pump Starts Lead Pump 's Speed Set to 948 rpm
15.0 – 16.0	Lead Pump's Speed Linearly Varied from 948 rpm to 1,185 rpm
16.0	Lag Pump Starts Lead Pump On Both Pumps' Speeds Set to 948 rpm
16.0 – 17.0	Both Pumps' Speeds Linearly Varied from 948 rpm to 1,185 rpm
18.0	Lag Lag Pump Starts Lag Pump On Lead Pump On Three Pumps' Speeds Set to 948 rpm
18.0 – 24.0	Three Pumps' Speeds Linearly Varied from 948 rpm to 1,185 rpm
18.5 High Level Alarm	Lag Lag Pump On Lag Pump On Lead Pump On
20.0 High High-Level Alarm	Wet Well High High Alarm

3.3.2.2.4 Summary

Table 3-4 lists all the pump stations included in the 2019 Hydraulic Model and the assumed Firm Pump Capacity based on field tests and available data.

Table 3-4: Collection System Pump Stations Included in the Hydraulic Model

Pump Station Name	Category	Firm Capacity (gpm)
Atlas Road Pump Station (PS)	Minor	300
Broad River PS	**Major**	**6,700**
Colonial Life PS	Minor	225
East Bluff PS	Minor	443
Edventure PS	**Major** (CSAP)	**50**
Garners Ferry PS	**Major** (CSAP)	**184**
Green Lakes PS	Minor	550
Harbison 2 PS	Minor	150
Heathwood Hall PS	Minor	288
Homeless Shelter PS	Minor	80
Metro WWTP IPS	**Major**	**41,600**
Meadowlands PS	Minor	700
Mill Creek PS	**Major**	**10,600**
North Columbia PS	**Major**	**21,600**
Owens Field PS	Minor	152
Quail Creek PS	Minor	240
Saluda River PS	**Major**	**10,700**
Shady Lane PS	Minor	300
Square D PS	Minor	N/A
Starlite PS	Minor	420
Swandale PS	Minor	300
Three Rivers PS	Minor	300
Versch Loch PS	Minor	190
West Columbia PS	**Major**	**16,000**
Woodlands PS	Minor	525

Section 4 Hydrologic Model Input Data

Section 4 identifies how system hydrologic data is compiled and represented in the Hydraulic Model. Table 4-1 list the CD requirements of the CD for this report section.

Table 4-1: Checklist of Consent Decree Requirements within Section 4

CD Section	CD Requirements	Report Section
17.d.(iv)	"Explains the bases for the input parameters used in each Subbasin to characterize baseline wastewater flows and I/I, the quality assurance procedures used in acquiring the input data, and the engineering bases for the selections of constants (e.g., friction factors) and assumed values."	Section 4

Section 4.1 provides a description of wastewater flow components. Section 4.2 discusses the basins and subbasins defined by the CD that help to represent the distribution of flow in the sewer system and identifies subcatchments, which are modeling component of subbasins used to further refine the characterization of the hydrologic data in the sewer system. Section 4.3 discusses how hydrologic data is compiled, verified, and integrated into the Hydraulic Model to characterize wastewater flow in each basin. Section 4.4 explains how the data is incorporated in the Hydraulic Model, including any constants and assumed values for simulations.

4.1 Overview of Wastewater Flow Components

As discussed in Section 2.3, wastewater flow can be divided into three components: GWI, BWWF, and RDI/I. GWI is the base groundwater flow in the system. ADF is represented by a combination of BWWF and GWI. BWWF is the sanitary flow component and GWI is the groundwater component. WWF is the combination of ADF and RDI/I, which represents the rainfall related contribution of flow into the system.

Figure 4-1 shows a graphical representation of these components.

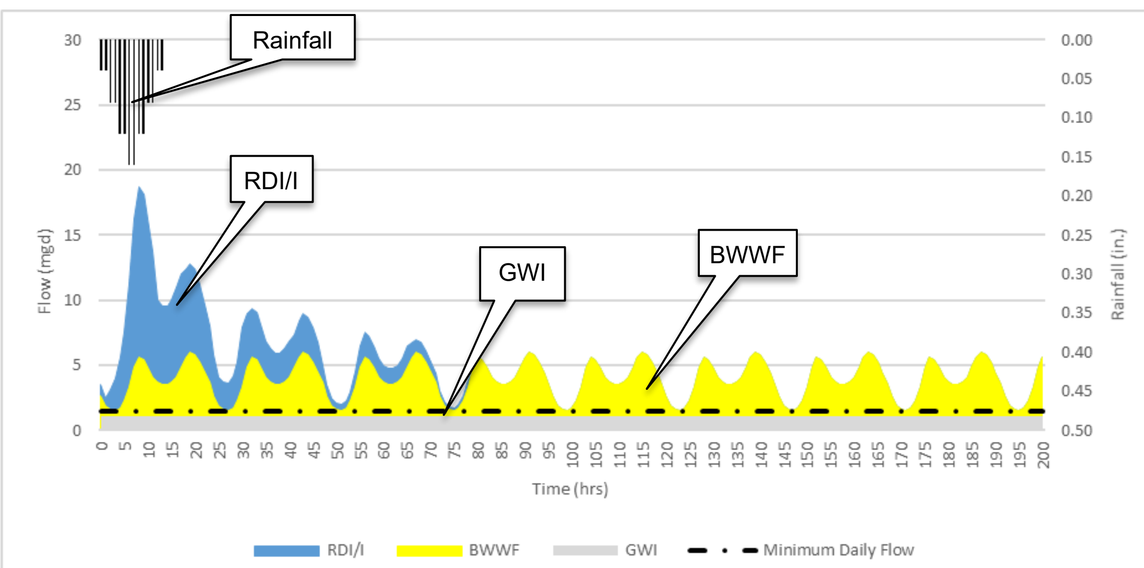

Figure 4-1: Wastewater Flow Components

4.1.1 Dry Weather Flow

Dry weather flow is defined by the days when there is no rainfall and no rainfall influence in the sewer system from previous wet weather events. Typically, representative dry-weather flow is adopted from at least 2- to 7-day periods depending on the frequency of rainfall events.

Figure 4-2 shows examples of dry-weather flow periods and periods when rainfall could be considered as contributing to the total system flow (shaded areas in the figure show the periods when the system has a wet weather response). Daily variations of the BWWF flow rate (blue line in **Figure 4-2**) follow the diurnal sanitary flows of the day, where nighttime flows are the lowest and daytime demands typical peak twice a day during the morning and evening.

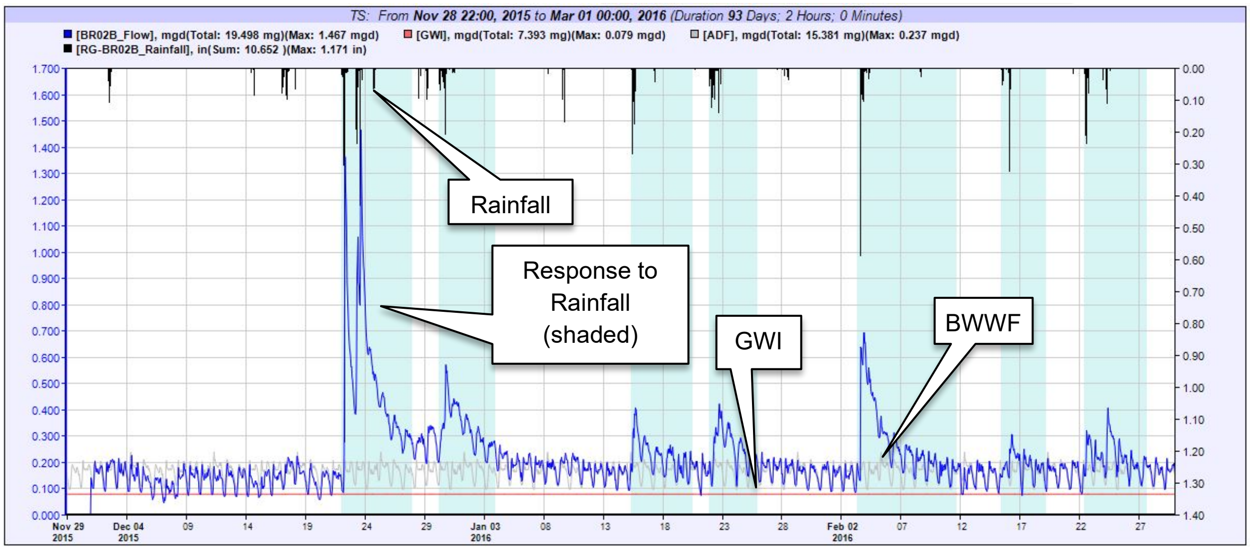

Figure 4-2: Example of Dry Weather Flow Components

4.1.1.1 Groundwater Infiltration (GWI)

GWI is defined as groundwater infiltration entering the collection system through defects in pipes, pipe joints, and manhole walls. The magnitude of GWI depends on the depth of the groundwater table above the pipelines, the percentage of the system that is submerged, and the physical condition of the sewer system. Groundwater flow contributions in the Hydraulic Model are derived from flow metering data and are usually held constant for short-term metering periods. Seasonal variations of groundwater in the Hydraulic Model may be adjusted if the calibration period extends over different seasons. GWI is also affected by rainfall but this response is typically gradual and is not directly related to any individual rainfall event. Groundwater flow contribution changes are typically exhibited in flow at the WWTP that persists for periods of many days or weeks. From a practical standpoint, it is often not possible to differentiate infiltration of groundwater (saturated zone) from infiltration due to long-term drainage of unsaturated soils, and the term GWI is used in this report to describe both types of flow.

The GWI component of the flow data was estimated using the Stevens-Schutzbach Method (SSM) (Mitchell, P.E., Stevens, P.E., & Nazaroff, P.E., 2007). The SSM is one approach that is reported to provide more predictable results than other comparable methods. SSM uses the minimum daily flow (MDF), as depicted in **Figure 4-1**, which is usually recorded during the late night/early morning hours when most residents are asleep and businesses are closed. MDF includes GWI. ADF is the average dry weather flow recorded throughout the day, excluding any direct inflow resulting from rainfall events. The SSM calculates the GWI portion of the ADF according to **Equation 4-1** (Mitchell, P.E., Stevens, P.E., & Nazaroff, P.E., 2007).

$$GWI = \frac{0.4(MDF)}{1 - 0.6(MDF / ADF)^{ADF^{0.7}}} \tag{4-1}$$

GWI can be calculated on a subbasin basis using the flow meter data collected for that subbasin.

4.1.1.2 Base Wastewater Flow (BWWF)

BWWF is the combination of domestic wastewater from residential, commercial, and institutional (schools, churches, hospitals, etc.) sources, as well as industrial wastewater sources. It is affected by population and land use and varies throughout the day in response to personal habits and business operations (diurnal). BWWF is not impacted by rainfall. Using the calculated GWI, the BWWF portion of the total dry weather flow can be calculated using **Equation 4-2**.

$$BWWF = ADF - GWI \tag{4-2}$$

4.1.2 Wet Weather Flow

4.1.2.1 Rainfall Dependent Inflow/Infiltration (RDI/I)

RDI/I refers to rainfall that enters the sanitary sewer system in direct response to rainfall events. RDI/I can be further broken down into inflow and rainfall-dependent infiltration, based upon the pathways through which the flow enters the sewers or manholes. Inflow reaches the collection system by direct connections rather than by first percolating through the soil. Inflow sources may include roof downspouts connected to the sanitary sewers, yard and area drains, holes in manhole covers, and cross-connections with storm drains or catch basins. Rainfall-dependent infiltration includes all other rainfall dependent flow that enters the collection system, including rainfall that enters through defective pipes, pipe joints, and manhole walls after percolating through the soil.

4.2 Delineation of Sewer Service Area

Hydrologic data in a hydraulic model is developed on a basin, subbasin, and subcatchment basis, which are explained further below. The CD (Appendix C) delineates the City's Major WCTS into eight major sewer basins, which all have a downstream pump station, as shown schematically on Figure 3-2 (Page 20). The CD also further divides the larger basins into subbasins based on their hydraulic connectivity developed on the existing GIS at the time of the CD. Since the development of the CD, some boundaries of the subbasins may have changed slightly as more field inspection confirmed connectivity in the system.

For the purposes of model development, the basin/subbasin delineations were maintained in the Hydraulic Model but were modified slightly to match the boundaries/tributary sewer areas to each temporary flow meter (based on the most recent GIS showing pipe connectivity) since this data was used to verify the model response. The meters were named for the subbasins they were located in. Not every subbasin was monitored and each meter basin may include portions of upstream subbasins.

The meter basins were further delineated into subcatchments to facilitate the wastewater loading into the Hydraulic Model. The meter basins and subcatchments were developed solely for model recalibration and do not conflict with any information provided in the CD.

4.2.1 Sewer Basins

As shown on **Figure 4-3**, the City's sewer service area encompasses the incorporated city limits as well as adjacent areas beyond the city limits. The City's sewer system collects and conveys wastewater from several major topographic drainage areas in the central region of South Carolina. These areas include the eastern portion of the Saluda River basin upstream of the confluence of the Broad River and the Saluda River; the western portion of the Broad River upstream of the confluence of the Broad River and the Saluda River; the eastern and western (West Columbia) portion of the Congaree River basin upstream of Interstate 77; and several other smaller, naturally-drained basins including Mill Creek, Gills Creek, Crane Creek, Smith Branch, and Rocky Branch (all of which are in the Broad River and Congaree River Basins).

Figure 4-3 also shows the service area delineation based on the regional "208" planning study. Section 208 of the Federal Clean Water Act identifies planning actions required to maintain water quality standards of rivers, lakes, and estuaries within major drainage basins across the state. The Central Midlands Council of Governments (CMCOG) is the designated planning agency for the compliance of Section 208 in the Columbia area. The boundaries of the service area have been influenced over time by other private and public sewer providers. Adjacent sewer providers (during the model calibration period) include Richland County, East Richland County Public Service District, Ni America, Alpine Utilities, Bush River Utilities, West Columbia, Cayce, Lexington, and Fort Jackson. The City transports and treats sewer flows from Fort Jackson, West Columbia, and portions of the East Richland County Public Service District.

These eight City sewer basins, shown in **Figure 4-3**, include:

- Broad River (BR) basin
- Saluda River (SR) basin
- Crane Creek (CC) basin
- Mill Creek (MC) basin
- Rocky Branch (RB) basin
- Smith Branch (SB) basin
- West Columbia (WC) basin
- Gills Creek (GC) basin

A large portion of the City's Crane Creek basin east of Highway 21 was transferred to Ni America in October 2017. This change occurred after the 2016 monitoring period used for the 2019 recalibration effort (discussed later). Therefore, flows from this area were considered during calibration but excluded for current (2020) and future system capacity analyses.

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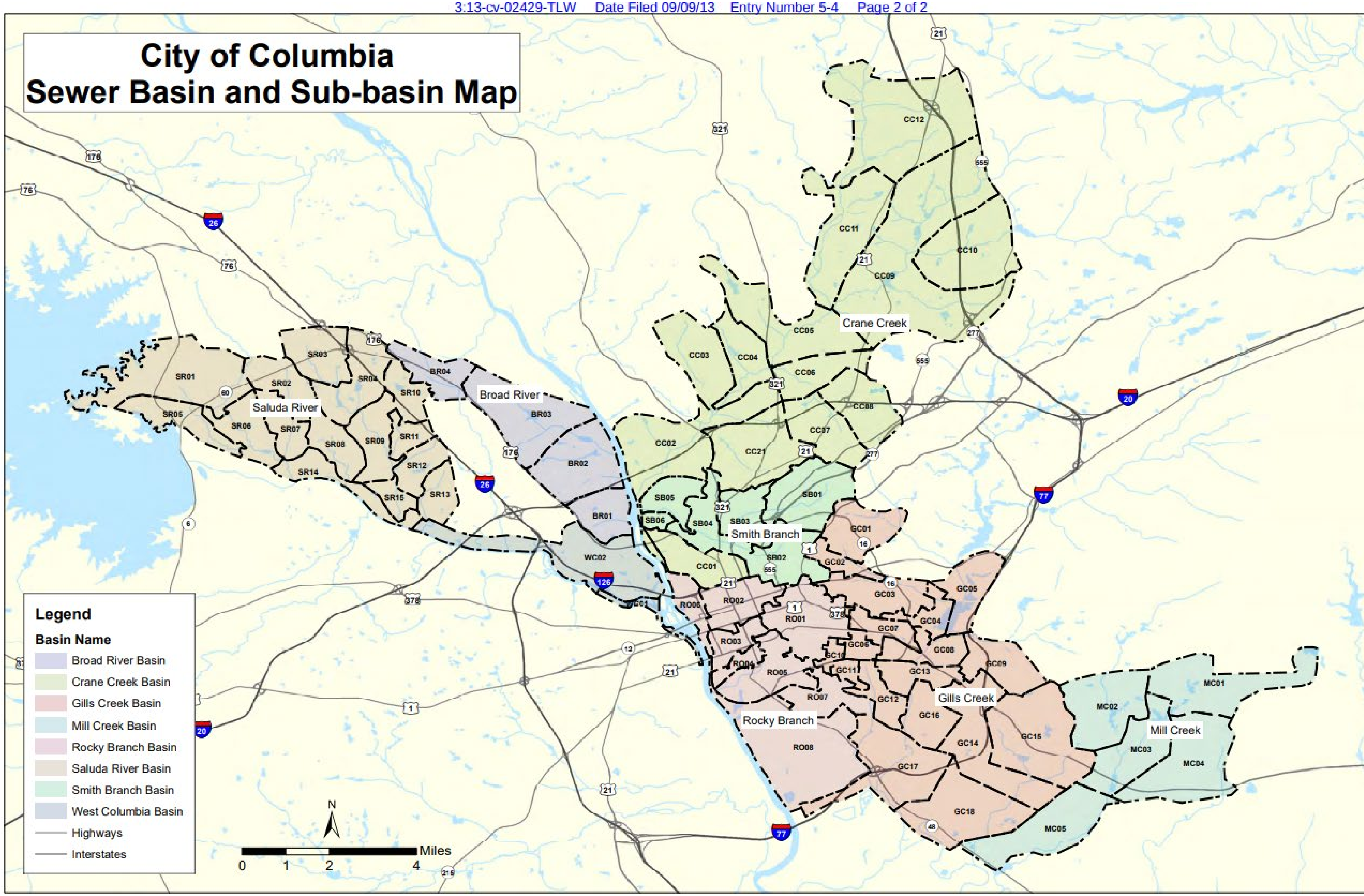

Figure 4-3: CD Sewer Basins and Sub-basins in the Columbia Service Area

4.2.2 Subbasins

Figure 4-3 also shows the subbasins for the City's Major WCTS defined in the CD. Subbasins in the CD do not represent the boundaries of the existing sewer lines as numerous parcels in the CD subbasins are undeveloped.

To develop the Hydraulic Model, the actual sewered service area must be identified to assign flows to the model nodes. Delineation of the meter basin is more important than the actual CD boundaries for a subbasin because the Hydraulic Model uses existing contributing sewer areas. Accordingly, the CD subbasins were refined using the flow meter locations, the Sewer Mapping Program GIS showing connectivity, property parcel data and orthophotography in GIS. The refined delineations used in the Hydraulic Model are referred to as "meter basins".

A meter basin is defined as the actual sewer tributary to that meter. These meter basins represent "clusters" of upstream pipes that all converge to a downstream flow meter located on a trunk line. Large undeveloped parcels were subtracted from the upstream tributary area in each subbasin to identify the direct sewer service tributary area. Trunk lines and other wastewater piping that passed through undeveloped parcels or undeveloped areas inside of a parcel were given a 30-foot buffer (15 feet on each side of pipe) to capture potential infiltration/inflow (I/I) contributions from undeveloped areas in and around the sewer rights-of-way/easements that are susceptible to traffic and maintenance activities. This buffer was not added to force mains inside the system. Based on GIS, parcels adjacent to the pipes, parcels containing sewer customer identification points, impermeable areas, and buffer areas were selected and merged together to create one polygon.

Areas in the East Richland Public Sewer District, the City of West Columbia, and Fort Jackson that had sewer pipes that flow to the City's collection system were also included in the meter basins identification. The Ni America service area was also included, which was monitored by Meter PFM10.

Figure 4-4 shows the subbasins that were delineated for the Hydraulic Model compared to the subbasins provided in the CD for reference. The model subbasins are based on, but generally more refined than, the CD subbasins. It is expected that as future growth occurs in each subbasin, the sewer flow will stay within each of these subbasin boundaries for modeling purposes (but this doesn't necessarily have to happen).

Figure 4-5 shows a flow diagram that was developed to show how each meter/sub basins connect within the system.

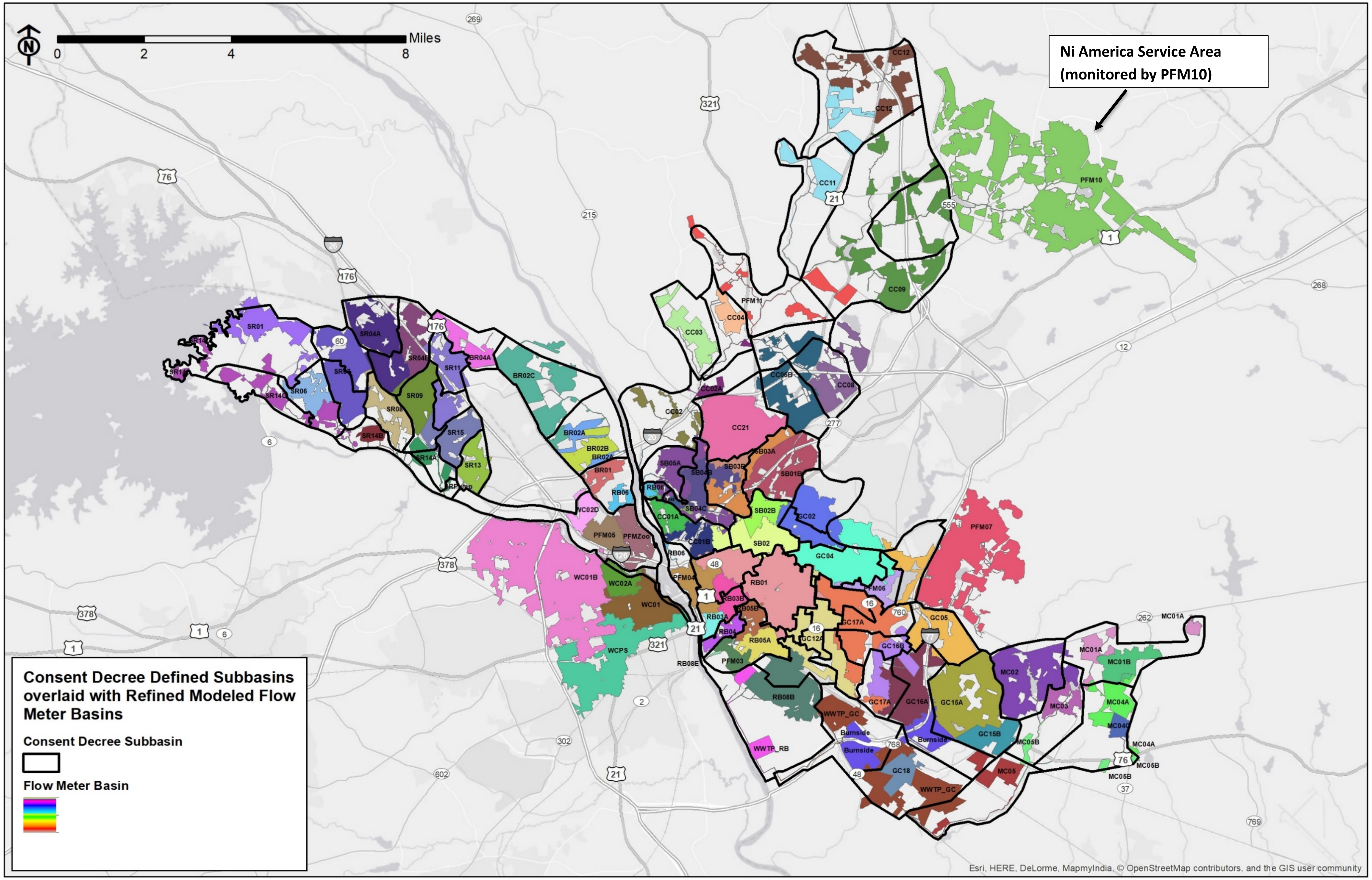

Figure 4-4: Comparison of Subbasins defined by CD and Meter Basins defined for Model Development

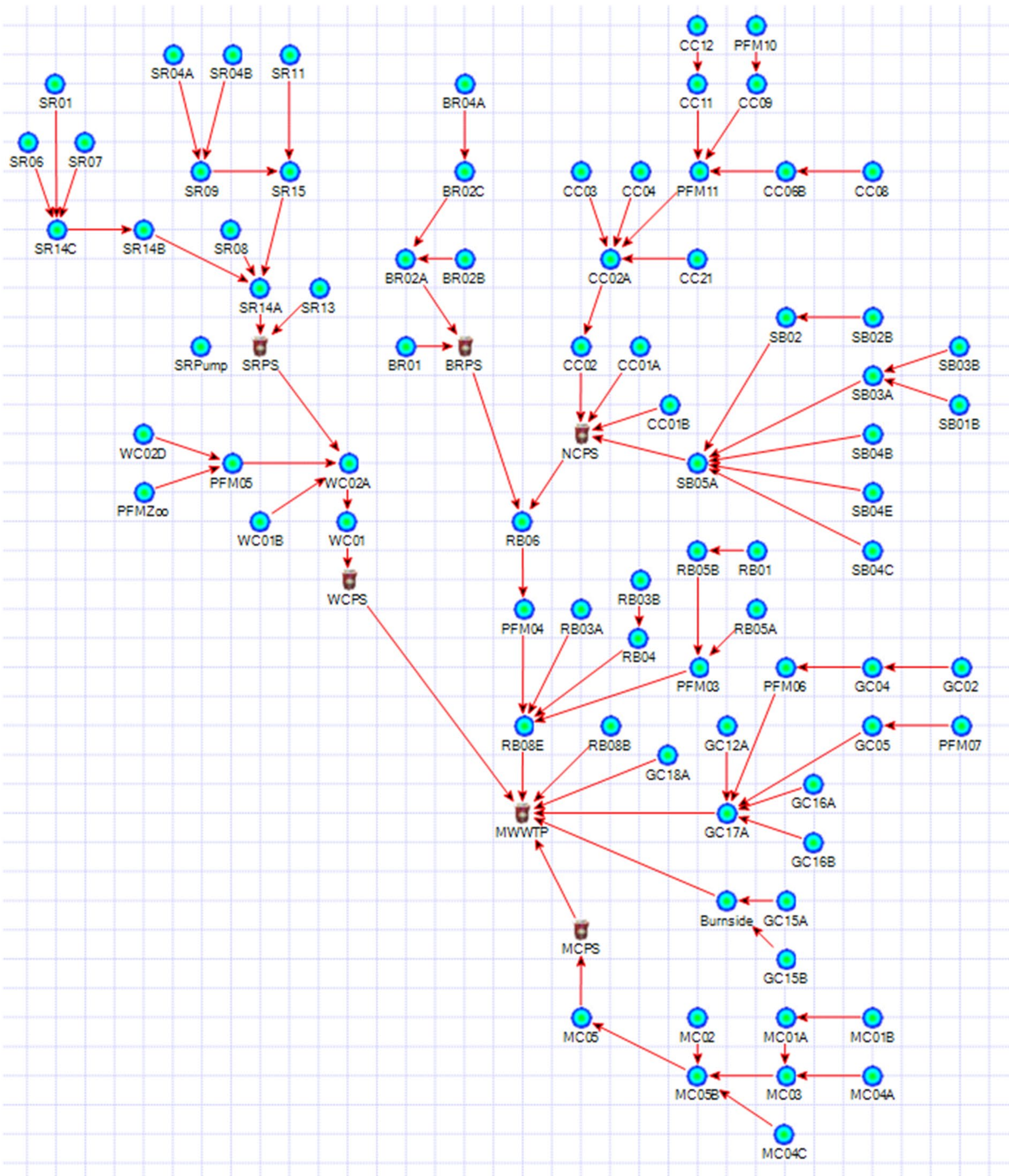

Figure 4-5: Flow Schematic of Meter Basins in the City's Wastewater Service Area

4.2.3 Subcatchments

Meter/Subbasins were further divided into subcatchments to facilitate model development and accuracy. In each meter basins, clusters of pipes converging to a single manhole along a trunk line are used to delineate the subcatchments based on tributary area.

Subcatchments are model components. Delineated subcatchments are added as objects in the Hydraulic Model to represent the physical area from which baseline wastewater flows and I/I are collected. Since the Hydraulic Model only includes sewer pipes with diameters 15-inches and larger; the subcatchment areas are also used to represent the wastewater flow from tributary areas upstream of the modeled pipes (i.e., those areas with pipes and laterals smaller than 15-inches in diameter).

Subcatchments are defined by the following parameters:

- General:
    - Subcatchment Name
    - Node Name (Drainage Node)
    - Total Area
    - Rainfall Profile ID (reference to spatially varying rainfall for the subcatchment)

- Dry Weather Flow (described in Section 3):
    - Base Flow (constant groundwater infiltration)
    - Population
    - Unit Wastewater Loading (i.e., Per Capita Loading)
    - Wastewater Profile

- Wet Weather Flow:
    - Groundwater Infiltration Module (GIM) parameters (described in section 4.5.2)
    - Wet weather flow parameters (RTK parameters described in Section 4.5.1)

A target size of 30 acres was used for the Hydraulic Model development to provide a high resolution and allow for expansion of the Hydraulic Model (if desired). Parcels and buffered areas that discharged to the identified manhole served as the boundaries for the subcatchments. Areas that discharged directly to a pump station were delineated as separate subcatchments. Each subcatchment is given a unique identification (ID), which is created using the flow meter ID plus a subsequent number (e.g., CC12-02). Flow meter used the subbasin IDs to be consistent. Pump station subcatchments were uniquely identified within GIS with the pump station name. Undeveloped or uninhabited areas, such as lakes, baseball fields, or parks that did not contribute to the sewer network, were removed from the subcatchments.

Figure 4-6 shows an example of the subcatchments delineated in subbasin CC12.

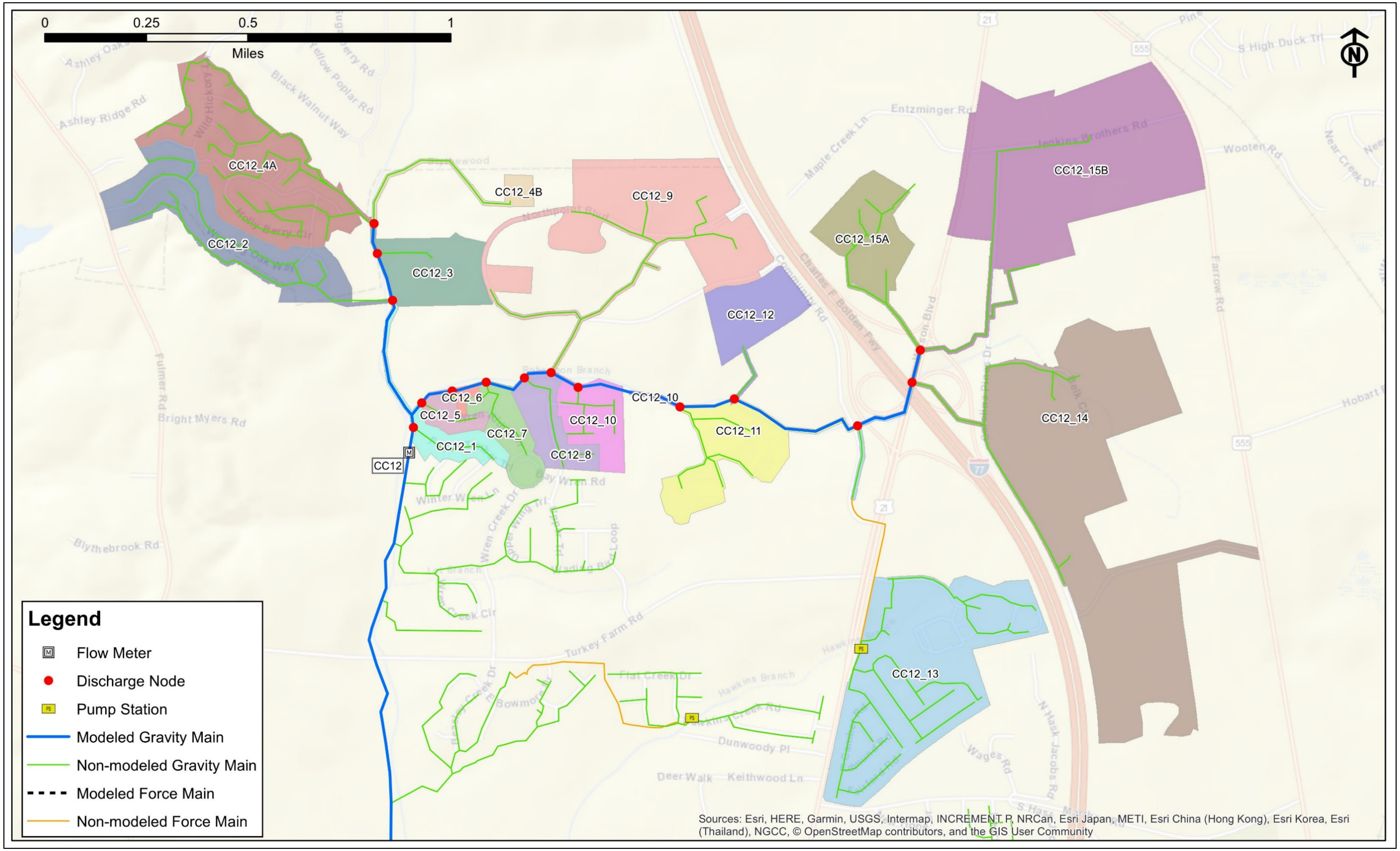

Figure 4-6: Subcatchment Delineation Example

4.3 Hydrologic Data Collection and Analysis

To properly characterize dry- and wet- weather sewer flows, the baseline sewer flow and I/I contribution must be determined. To meet this objective, flow meters and rain gauges are installed throughout the system to monitor actual sewer flows and the rainfall response over an extended period. The following is an overview of the data collection and analysis procedures and quality control review process. A thorough description of the data collection procedures and quality control review process can be found in the CSAP report (Clean Water 2020, 2018).

4.3.1 Flow Monitoring Data

Flow monitoring programs to develop hydraulic models to simulate existing conditions are established using a combination of temporary and permanent flow meters. Temporary meters provide "a 'snapshot' of the sewer system flows over a short duration" and permanent meters allow for an analysis of long-term and seasonal trends. The City currently has eight permanent flow meters installed throughout its system.

The City completed several temporary flow monitoring programs. These programs were performed as part of the CSAP and meter locations were identified to capture the dry- and wet-weather flows for each program to evaluate system conditions. **Table 4-2** provides a summary of the available temporary flow monitoring data that was considered for the 2019 Hydraulic Model development.

Table 4-2: Summary of the Available Flow Metering Data for Model Development

Flow Monitoring Program Year	Period	Description
2012	February 20, 2012 through June 20, 2012	○ 65 flow meters providing full system coverage ○ Utilized for the 2014 hydraulic modeling effort
2014	March 7, 2014 through June 14, 2014	○ 26 flow meters providing coverage for specific subbasins
2015	April 13, 2015 through June 13, 2015	○ 83 flow meters providing full system coverage
2016	December 1, 2015 through February 29, 2016	○ 70 flow meters providing full system coverage

The 2012 data was used for the 2014 Hydraulic Model calibration. The operation and condition of the WCTS has improved since this flow data period. Data collected in 2014 was at a limited number of locations and was not considered sufficient for a full model characterization and recalibration. Data collected in 2015 was during a seasonal low-groundwater period and there were only a limited number of representative storm events (with low rainfall and high frequencies) available for recalibration. The 2016 data set, which ran from late 2015 to early 2016, provided more comprehensive data for recalibration of the Hydraulic Model because it had a sufficient number of meters to reflect wide-spread system response, had multiple representative storm events for recalibration (with higher and more intense rainfall than the 2015 dataset), and the 2016 data was collected during an elevated seasonal groundwater contribution period (winter). While the 2015/2016 data was collected two months after the City experienced record rainfall and a historical flooding event, this data provides valid input for the collection system model calibration with the appropriate adjustments to be made during the capacity analysis.

The locations of the meters used for the 2016 flow monitoring program are included in **Figure 4-7**.

Future monitoring periods could be selected to capture the seasonal variations in antecedent moisture conditions, additional rainfall events, and changes in the collection system resulting from system improvements related to capital projects, operations and maintenance, and other changes in the WCTS.

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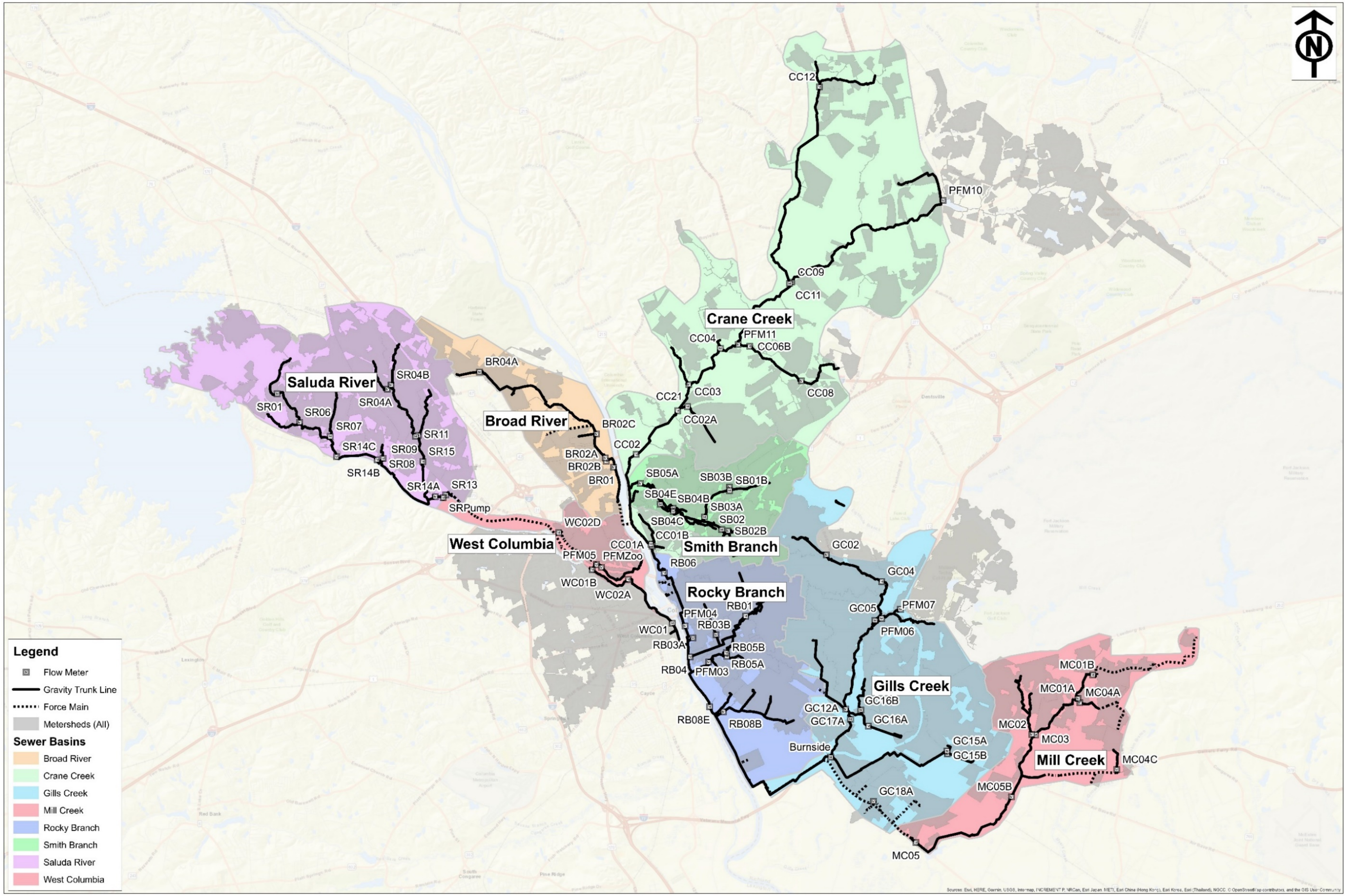

Figure 4-7: 2016 Flow Meter Locations

4.3.2 Rainfall Data

In addition to sewer flow data, rainfall data is gathered during flow monitoring periods to calibrate the simulated RDI/I to observed wet weather flows. This rainfall data is typically collected with multiple existing or new rain gauges located throughout the WCTS. For the 2016 monitoring period, 5 permanent rain gauges and 15 temporary rain gauges collected rainfall depths throughout the system. The locations of these gauges can be found in **Figure 4-8**.

Spatial distribution and density of rain gauges are important considerations when selecting gauge locations. The gauges should be equally distributed to provide adequate coverage across all basins. Once data is collected, rain gauge locations and data should be analyzed to determine if the rainfall data will be sufficient to properly characterize RDI/I in the system. This analysis should include the characterization of captured storm events (i.e. variability of rainfall across service area). Rainfall data is applied to each subbasin during the model calibration process. If this rainfall does not accurately represent the actual rainfall within the subbasin, effective calibration will be difficult. In many cases, it will be necessary to supplement the rain gauge data with radar data to accurately fill in the gaps between rain gauge locations. Supplemental rain gauge calibrated radar data was used for the 2019 hydraulic modeling efforts to enhance the calibration results.

4.3.3 Flow Monitoring and Rainfall Data Quality Review

Flow monitoring data and rainfall data were analyzed for accuracy, consistency, and completeness, as described in Section 5.1. Flow monitoring data was evaluated as part of the City's Flow Monitoring Program in compliance with the Consent Decree. Prior to incorporation within the Hydraulic Model, flow balances across upstream and downstream meters were used to identify potential locations where loss in meter accuracy could have occurred. Rain gauge data was compared to, and supplemented by, radar rainfall data to assure quality within the wet weather flow evaluation. A detailed description of the quality review procedures can be found in the CSAP report.

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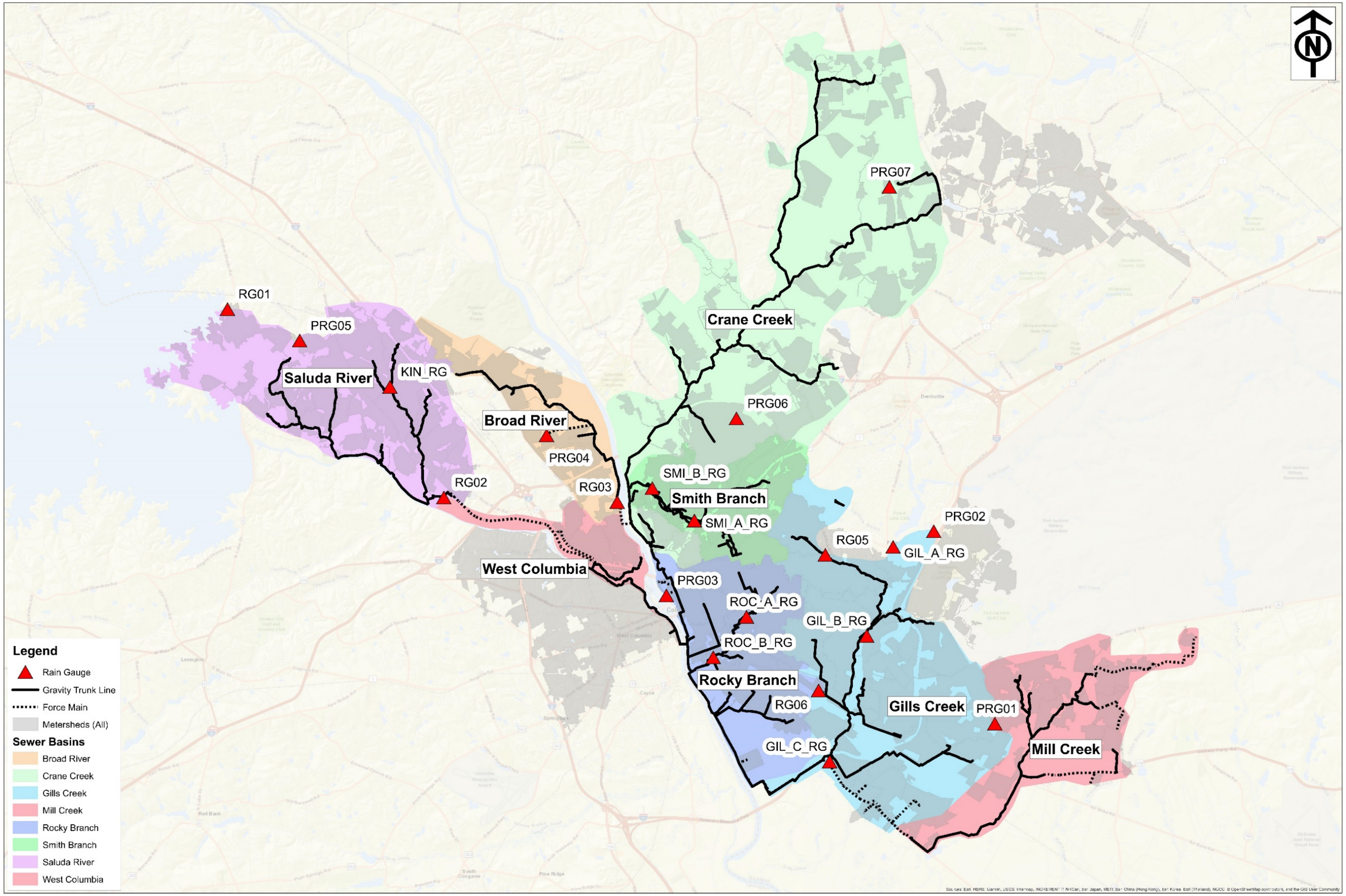

Figure 4-8: 2016 Rain Gauge Locations

4.3.4 Sanitary Sewer Overflow Data

Data regarding wet weather-related sanitary sewer overflows (SSOs) is maintained by the City. This data contains the location and date of reported SSOs within the WCTS. Model verification included confirmation that SSOs produced by monitored storm events match those produced by the Hydraulic Model.

4.3.5 Level Sensing Data

During the monitoring period use for the 2019 Hydraulic Model development, level sensing devices (in addition to flow meters) were installed in several manholes throughout the collection system. Though not required, when this data is available, it can help inform model calibration through confirmation of surcharge locations.

4.3.6 Pump Station Data

If available, pump station flow data, run time data, level data, (e.g. from SCADA) and flow and drawdown testing data should be used to assist with the calibration of the modeled pump stations and flows entering the pump station. For the Hydraulic Model development, detailed data from the City's SCADA system was used to evaluate flows through major pump stations.

4.4 Dry Weather Flow Development

Flow in the collection system is input into the Hydraulic Model by subcatchment (described in **Section 4.3.3**) as a load to a modeled manhole. The hydrologic input data is used to generate flow in the modeled sewer system during both dry and wet weather conditions. During dry weather, meter data is used to quantify GWI and BWWF in the collection system.

The type of hydrologic input data is similar among most hydraulic modeling software packages. In InfoWorks ICM, the dry weather flow is described in the Hydraulic Model as follows:

- GWI

  The GWI value is entered in the subcatchment "Base flow" parameter tab (see **Figure 4-9**). GWI is calculated from the observed data (as described in **Section 4.1.1.1**) and distributed from the subbasin to the individual subcatchments based on the acreage contributing to that subcatchment as a fraction of total acreage of the subbasin.

- BWWF

  Average day BWWF is calculated as described in **Section 4.1.1.2.** The temporal variation for the BWWF can then be described in the model using hourly flow factors, population, and a per capita flow rate based on quality-controlled flow data from the sewer system. The modeling software allows for multiple patterns for these temporal variations in flow. The BWWF can be entered directly in the parameter tab or can be represented by an equivalent population and a unit per capita flow rate (i.e. person x gpcd). The unit per capita flow and the diurnal patterns are stored in InfoWorks ICM as wastewater profiles.

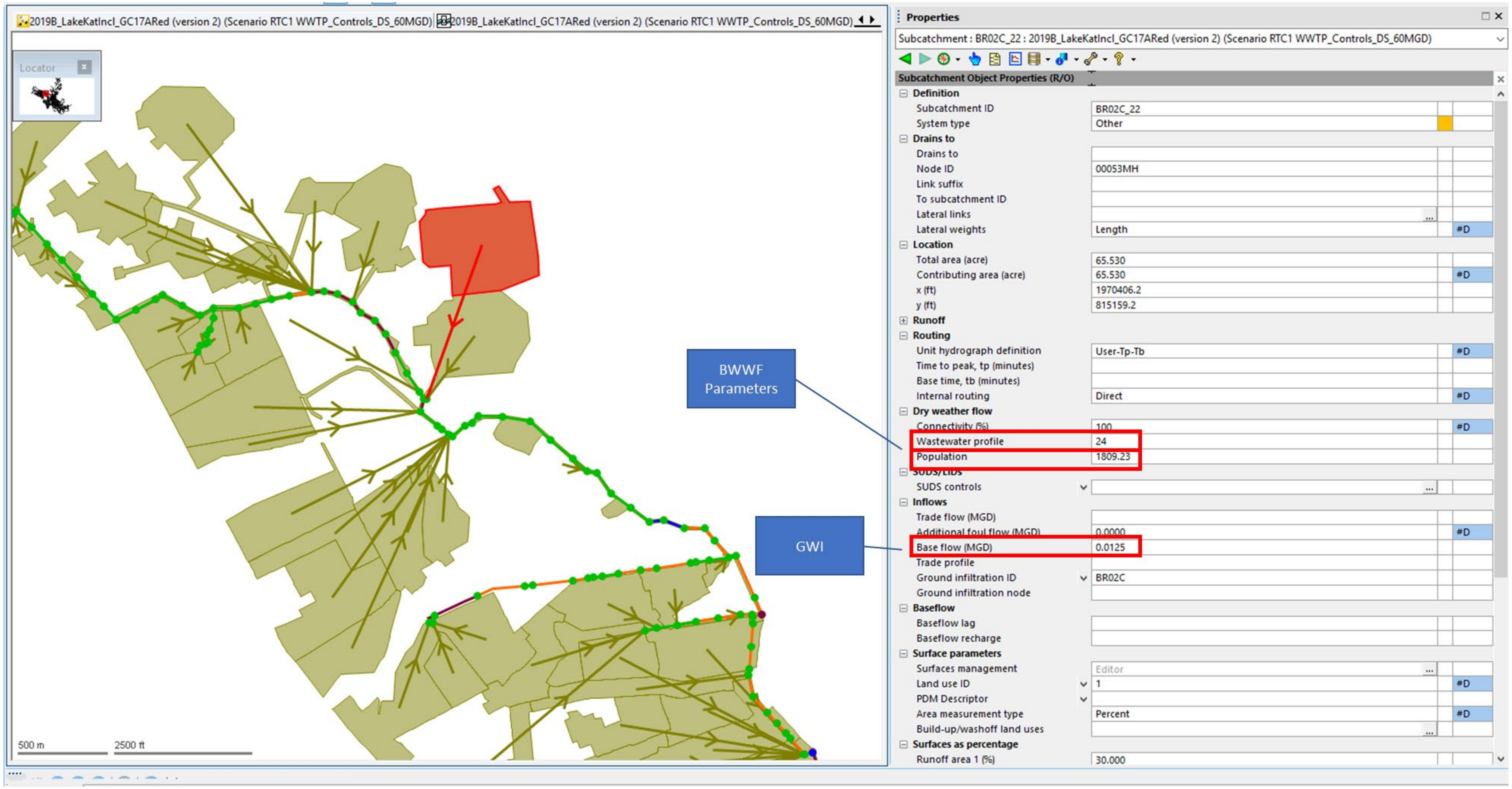

Figure 4-9: Dry Weather Flow Data Entry Example in InfoWorks

For the City's Hydraulic Model, the BWWF is represented by equivalent served population in the contributing subcatchment and the per capita unit flow for that subcatchment. Population values are entered directly into the model software along with a wastewater profile that represents the diurnal curve (described below) for the flow in that subcatchment.

Table 4-3 shows an example of the flow parameters developed for a few subcatchments within the 2019 Hydraulic Model. **Figure 4-9** shows an example of the data entry form. Large industrial and commercial flows can be modeled separately using an average flow (trade flow) and trade profile (diurnal curve). **Sections 4.4.1, 4.4.2, and 4.4.3** describe the BWWF components (population, per capita flow, and wastewater profile) in greater detail. **Section 4.4.4** describes the process for representing large industrial and commercial flows.

Table 4-3: Example of Dry Weather Flow Parameters (2019 Model Recalibration)

Subcatchment	Flow Equivalent Population	Per Capita Flow (gpcd)	Base Flow (GWI) (mgd)
BR01_1	876	61.3	0.0218
CC01A_1	134	108.4	0.0204
MC01B_100	62	61.9	0.0038

4.4.1 Population

The equivalent population input value for the City's InfoWorks ICM model was determined using metered water consumption data. The average water consumption (in gpd) was identified for each subcatchment using the City's water billing data system. Water billing records for larger irrigation users were subtracted from these water consumption billing records. Since some water use does not enter the sewer system (i.e. irrigation for residential and businesses or livestock watering), a fraction of the water consumption was assumed to contribute to sewer flow. For initial estimates, a return-to-sewer fraction of 0.93 was assumed for each subbasin based on analysis of historical City sewer flows and water consumption uses.

The equivalent population for the subcatchment was determined by assuming a per capita flow rate and calculating the population that would produce the average sewer flow using the water consumption data.

Table 4-4 shows an example of the population calculations.

Table 4-4: Example of Population Calculations (2019 Model Recalibration)

Water Consumption (gpd)	Fraction to Enter the Sewer (%)	Sewer Consumption (gpd)	Assumed per Capita Flow Rate (gpcd)	Equivalent Population
93,994	93	87,414	65	1,345

4.4.2 Per Capita Flow

The per capita flow is refined in the Hydraulic Model using the calculated BWWF (reference **Section 4.1.1.2**) and the equivalent population described in the previous section. The following is an example of the Per Capita Flow calculation for subcatchment CC21:

$$Per\ Capita\ Flow = \frac{BWWF}{Population} = \frac{53{,}699}{876} = 61.3$$

4.4.3 Wastewater Profile

Diurnal curves are established based on hourly flow factors using the equation:

$$factor_{t=n} = \frac{ADF_{t=n} - GWI_{t=n}}{BWWF} \tag{4-3}$$

In this equation, the subscript "t=n" represents an hourly time increment, such that hourly flow monitoring data is used to produce an hourly diurnal flow factor. This hourly factor can then be multiplied by the average BWWF to generate the profile of flow in that subbasin over the day. The result is a "wastewater profile" that reflects the hourly change in sanitary flows over a day. An example of a wastewater profile and the individual factors, as represented in InfoWorks ICM, is shown in **Figure 4-10**.

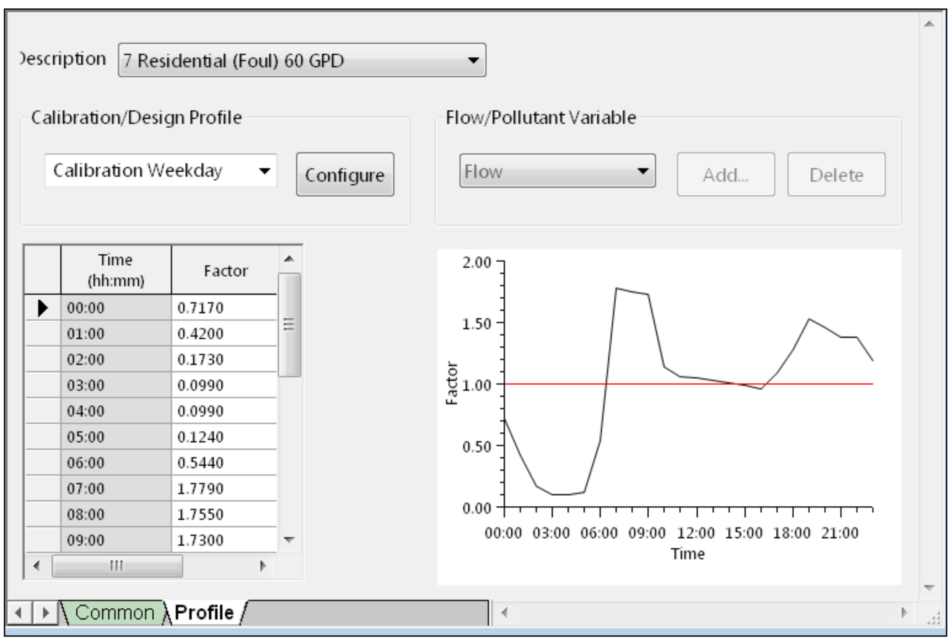

Figure 4-10: Wastewater Profile Example

4.4.4 Trade Flow and Trade Profile

In InfoWorks ICM, the term "Trade Flow" is used to represent large industrial or commercial customers whose flow is separated out from BWWF. A trade flow pattern is created for each large industrial or commercial user with a distinct discharge pattern, and the multiplier (average flow) is calculated based on the water consumption or discharge records. The trade profile consists of the normalized diurnal pattern and the average discharge flow, which in InfoWorks ICM is called the trade flow multiplier.

For the Hydraulic Model, the top industrial/commercial dischargers were selected by the City based on billing records and/or the City's Industrial Pretreatment Program. The discharge location was identified within GIS, and the hourly and daily discharge records, if available, were examined. If a separate flow pattern was able to be identified from nearby flow monitors, then a trade profile is created within the Hydraulic Model. If not, the discharge was incorporated into the sanitary flow for the subcatchment.

4.5 Wet Weather Flow Input Parameters

During precipitation events, the flow in the collection system increases as a result of RDI/I. To model the collection system's response to rainfall events, the RTK Unit Hydrograph method was employed to simulate the wet weather flow response experienced by the wastewater collection system. The RTK model allows the user to input the time of the peak flow and total runoff time, as well as the percentage of total rainfall that becomes runoff. Each meter basin is associated with its own unit hydrograph to represent its RDII response timing and volume.

The RTK Unit Hydrograph method, a version of the synthetic unit hydrograph method, was used to model wet weather flows for the City's Hydraulic Model. This method is approved by the EPA for use in sewer system modeling (Vallabhaneni, P.E., BCEE, Chan, P.E., & Burgess, 2007). The RTK Unit Hydrograph method includes the use of three triangular unit hydrographs to characterize the extent and timing of RDI/I entering the sanitary sewer system.

The Groundwater Infiltration Module (GIM) was also used to assist in achieving the proper volumetric groundwater responses in instances where the RTK method alone does not accurately simulate the collection system response to rainfall. The GIM adds groundwater infiltration to sewer flows during wet weather simulations and is typically used where lagging infiltration is present. The groundwater infiltration component can add volume to the peak and/or tail of a hydrograph. The GIM is typically used in cases where active infiltration is present.

Active groundwater infiltration is different than GWI (baseflow) in that it can vary temporally based on the amount and duration of rainfall. As was mentioned in **Section 2**, InfoWorks ICM utilizes a dual reservoir model to simulate inflow from soil and ground store components.

To perform the wet weather calibration for the Hydraulic Model, the RTK values are combined with the GIM to achieve the proper volumetric responses of storms throughout the calibration period. The RTK Unit Hydrograph method and the GIM are explained in further detail in the following sections.

4.5.1 RTK Unit Hydrograph Method

The RTK unit hydrograph method utilizes up to three-unit hydrographs to represent the RDI/I response to rainfall. **Figure 4-11** illustrates this unit hydrograph approach. Each of the three-unit hydrographs is characterized by the R, T, and K parameters, which are defined as:

- R = the fraction of rainfall volume that enters the sanitary sewer system

- T = the time to peak in hours
- K = the ratio of time to recession to the time to peak (recession limb description)

The first unit hydrograph represents the quick system response to rainfall, which is attributed primarily to inflow. The second unit hydrograph is attributed to a mix of inflow and infiltration. The third unit hydrograph represents the extended system response to rain and is attributed predominantly to infiltration. When all three-unit hydrographs are used to characterize a response, a matrix of nine RTK parameters is derived as follows:

- R1, T1, K1 (first unit hydrograph parameters)
- R2, T2, K2 (second unit hydrograph parameters)
- R3, T3, K3 (third unit hydrograph parameters)

Based on guidance from the United States Environmental Protection Agency (USEPA, 2007), typical ranges for T-values are as follows: $0.5 \leq T1 \leq 2$; $3 \leq T2 \leq 5$; and $5 \leq T3 \leq 10$; in some cases, the T-values may need to be different than the typical ranges to match the observed flow data. The sum of the R-values is the total R-value, which represents the fraction of rainfall volume that enters the sanitary sewer system for a particular rainfall event; $R1 + R2 + R3 = R_{Total}$.

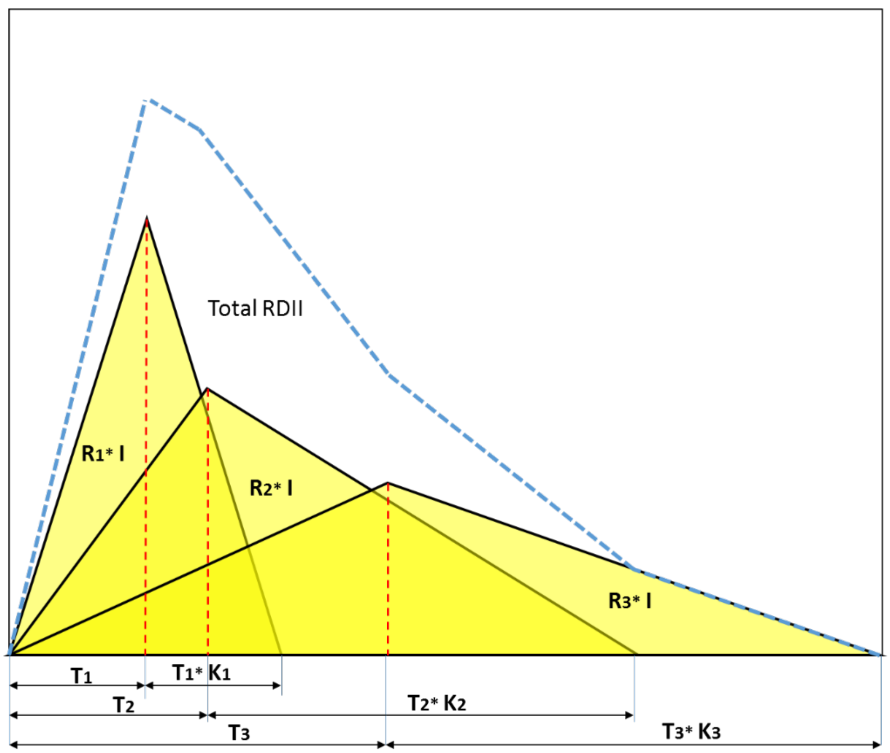

Figure 4-11: RTK Unit Hydrographs

The unit hydrographs are added together to render a composite response that is calibrated to closely match the response observed in the system as measured by the flow and rainfall monitoring data. RTK values were derived from a series of rainfall events at each of the sanitary sewer flow meters.

Table 4-5 shows an example of the resulting RTK values by subbasin from the 2019 Hydraulic Model development effort.

Table 4-5: Example of Wet Weather RTK Parameters

Subbasin	R1	T1 (hrs)	K1	R2	T2 (hrs)	K2	R3	T3 (hrs)	K3	Total R
BR01	0.8	0.5	8	1.5	3	8	1.5	5	10	3.8
CC01B	0.5	0.4	2	1.0	2	6	1.0	8	12	2.5
GC02	0.5	0.5	6	0.5	2	3	1.2	5	10	2.2
MC05	0.1	0.5	2	0.2	2	6	3.0	5	8	3.3

4.5.2 Groundwater Infiltration Module

The Groundwater Infiltration Model (GIM) was used to compensate and achieve missing volume in the system when the flow could not be accurately represented using the RTK unit hydrographs alone. The GIM adds groundwater infiltration to sewer flows during wet weather simulations. The groundwater infiltration component can add volume to the peak and/or tail of a hydrograph. The GIM is typically used in cases where lagging infiltration is present. **Figure 4-12** shows the amount of wet weather that is predicted using the RTK method and the amount that is predicted using the GIM.

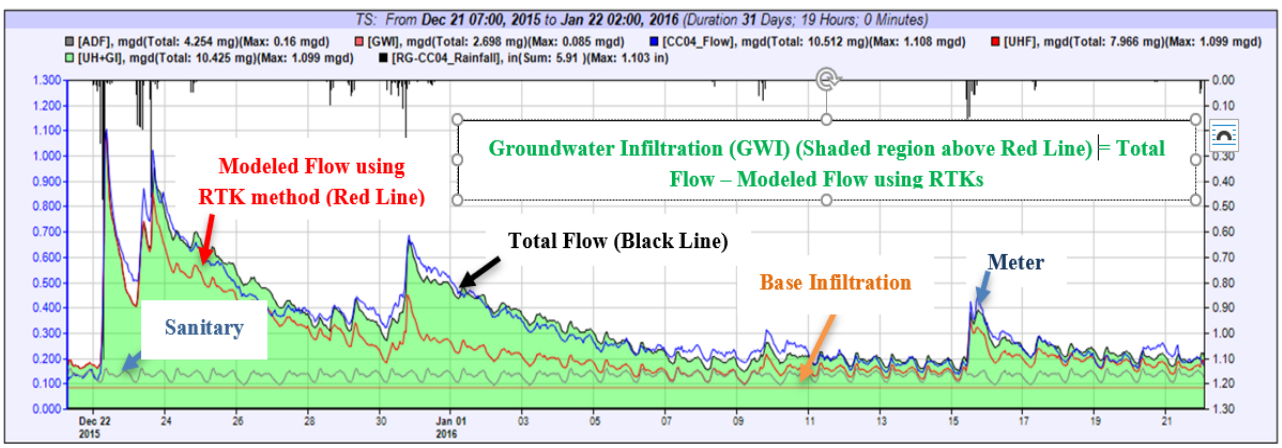

Figure 4-12: Example of Flow Contributions from RTK values and GIM

Rainfall feeds the GIM from runoff surface areas associated with existing subcatchment. To simplify the calibration process and to quantify groundwater contribution from the specific subcatchment, the groundwater contribution was assigned to the separate surface with the “constant infiltration” type.

InfoWorks ICM divides the GIM into two parts: Soil Store infiltration (faster) and Ground Store infiltration (slower). **Figure 4-13** shows how the GIM works in InfoWorks ICM. The volume of runoff from contributing runoff surfaces that does not enter the sewer as runoff enters the Soil Store. A portion of the volume that enters the Soil Store enters the sewer. The remainder enters the Ground Store. A portion of this water enters the sewer, and the remainder is lost.

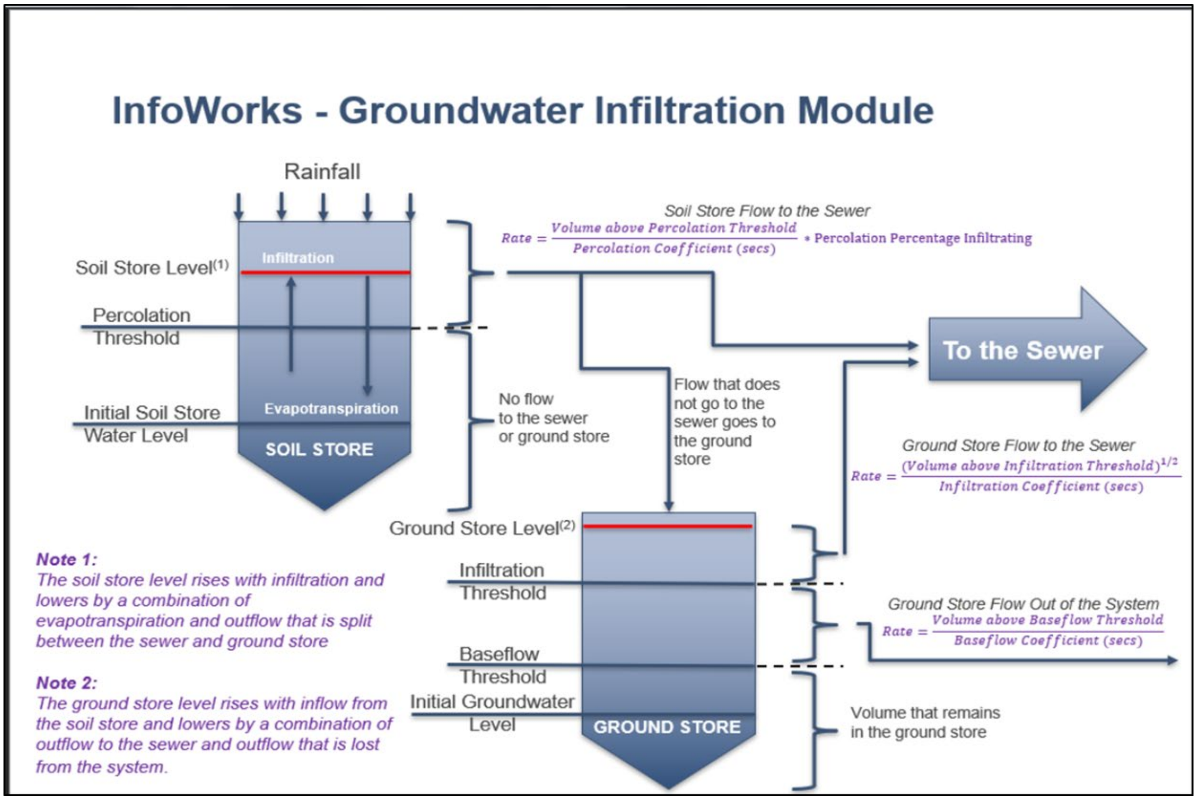

Figure 4-13: The Groundwater Infiltration Model in InfoWorks ICM

To calibrate the GIM to rainfall events, Innovyze® suggests a two-phase approach. The first phase is to calibrate the RDII by finding the percolation percentage infiltrating, the percolation threshold, and the percolation coefficient. This phase must be performed on storms where no groundwater infiltration occurs and can be conducted using the following steps:

1. Provide initial values for the percolation percentage infiltrating, the percolation threshold, and the percolation coefficient.

2. Run the model simulation and compare the modeled flow to the observed data.

3. Adjust these parameters to match modeled flows to observed data by noting the following:

    a. An increase in the percolation percentage infiltrating will result in an increase in the amount of volume infiltrating.

    b. An increase in the percolation threshold will result in an increase in the lag between when the storm begins and when the infiltration begins.

    c. An increase in the percolation coefficient will result in an increase in the duration of the infiltration flow.

The second phase is to calibrate the groundwater infiltration by finding the infiltration coefficient, the baseflow coefficient, the infiltration threshold level, and the baseflow threshold level. Innovyze® recommends that this calibration be performed on a portion of the rainfall event where a minimum of two

(2) spikes in infiltration flow are observed in the flow data. This phase can be conducted using the following steps:

1. Use the values found in the first phase of the calibration and enter initial values for the infiltration coefficient, the baseflow coefficient, the infiltration threshold level, and the baseflow threshold level.

2. Run the model simulation and compare the modeled flow to the observed data.

3. Adjust these parameters to match modeled flows to observed data by noting the following:

   a. An increase in the infiltration coefficient will result in an increase in the duration of groundwater infiltration.

   b. An increase in both the baseflow coefficient and the difference between the baseflow threshold level and the infiltration threshold level will result in an increase in the time between groundwater infiltration events.

The City's consultant utilized the two-phase approach suggested by Innovyze® to incorporate the GIM into the wet weather calibration. **Table 4-6** provides a description of the parameters for Soil Store and Ground Store used to develop the GIM, along with initial values and the range of values used to calibrate the Hydraulic Model.

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Table 4-6: GIM Parameters used in Model Calibration

GIM Component	Parameter	Description	Initial Value	Range for Calibration
Soil Store	Soil Depth (ft)	Depth of soil considered for soil storage, which is typically the depth of soil above the sewer	3	0.5 – 9
	Percolation Coefficient (s)	Time used to calculate inflow rate of flow from the soil store to the sewer.	4	0.04 – 24
	Percolation Threshold (%)	The percent of the soil depth that must be wet to cause inflow to the sewer.	85	78 – 98
	Percolation Percentage Infiltrating (%)	The percent of water in the soil above the percolation threshold that can enter the sewer	50	1 – 75
	Porosity of Soil (%)	Percent of void space in the soil volume	40	N/A[1]
Ground Store	Baseflow Coefficient (s)	Time used to calculate the rate of flow that is lost from the system	500	1 – 750
	Infiltration Coefficient (s)	Time used to calculate inflow rate of flow from the ground store to the sewer	75	10 – 250
	Porosity of Ground (%)	The percent of void spaces in the ground volume	40	N/A[1]
	Baseflow Threshold Level (ft)	The level at which flow exits the ground store and is lost	2.5	1.9 – 2.2
	Baseflow Threshold Type	Absolute level or relative to the upstream invert of the pipe to which the subcatchment is attached	Absolute	N/A[1]
	Infiltration Threshold Level (ft)	The level at which flow enters the sewer	3	2.01 – 2.5
	Infiltration Threshold Type	Absolute level or relative to the upstream invert of the pipe to which the subcatchment is attached	Absolute	N/A[1]
Ground Infiltration Event	Initial Soil Saturation (%)	The percent of the soil depth that is already wet	75	N/A[1]
	Initial Groundwater Level (ft)	Initial ground store water level	2	N/A[1]
	Groundwater Level Type	Absolute level or relative to the upstream invert of the pipe to which the subcatchment is attached	Absolute	N/A[1]

[1]These initial values for these parameters were not adjusted during the model calibration.

In addition, evaporation plays a key role in emptying the Soil Store. The evaporation rate is defined in the rainfall event in units of inches per day. When the Soil Store is 100 percent full, the evaporation rate is defined by the rainfall event. When the Soil Store is 0 percent full, the evaporation rate is zero. For all soil store values between 0 and 100, the evaporation rate is linearly interpolated.

4.6 Summary

Development of the sewer model hydrologic input data is not as straightforward as the development of the physical input data. Hydrologic flows have vastly different mechanisms for entering the WCTS. Thus, hydrologic data comes from different and varying sources and are subject to climate conditions. Sewer system hydraulic models have complex approaches to simulate these varying field conditions and significant engineering judgement is used to develop the proper approach for these simulations to take advantage of the hydraulic model features.

Three (3) basic flow components and factors that are used to develop the complex and dynamic WCTS flows:

- Sanitary Flow:
  - Population
  - Until Flow Rates (i.e. Per Capita Flow)
  - Wastewater Profile (Diurnal pattern)
- Base Groundwater Infiltration
  - Constant groundwater infiltration
- Wet Weather Flow:
  - Groundwater Infiltration Module (GIM parameters)
  - Wet weather flow parameters (RTK parameters)

Field monitoring of system flows and climate conditions is critical to adjust the model to mimic these field conditions and to maintain a model with a robust predictive capacity for future analyses. Calibrated baseline flow conditions will be adjusted during system capacity analysis to match typical annual average conditions.

Section 5 describes the calibration approach that is used to develop the Hydraulic Model to replicate dry and wet weather conditions.

Appendix A includes the hydrologic input parameters for each subbasin in the City's 2019 InfoWorks ICM model.

Section 5 Hydraulic Model Calibration, Verification, and Sensitivity Analysis

Section 5 discussed the Hydraulic Model Calibration, Verification, and Sensitivity Analysis requirements of the CD related to the development of the Hydraulic Model as listed in **Table 5-1.**

Table 5-1: Checklist of Consent Decree Requirements covered in Section 5

CD Section	CD Requirements	Report Section
17.c.	"Procedures and Protocols. Columbia shall develop and employ written procedures, protocols, and schedules to routinely perform: (i). Calibrations of the Model to account for age-related and other changes to Sewer System hydraulics, and to obtain and manage updated data from physical field observations and measurements for this purpose; (ii). Verification of the Model's accuracy and performance; and (iii). Sensitivity analyses to determine how the Model responds to changes in input parameters and variables."	Section 5
17.d.(ii)	"Identifies the date that the Model was deemed to be calibrated and functional."	Section 5.4
17.d.(iii)	"Identifies all input and output parameters, constants, and assumed values used by the Model."	Section 5.2
17.d.(v)	"Provides a brief description of each procedure and protocol developed pursuant to Paragraph 17.c., provides the associated schedules, and identifies the individual(s) with their qualifications who are employed to implement the procedures and protocols."	Section 5

5.1 General Procedures and Protocols

Section 3 of this report discussed the physical model development, including the collection and analysis of physical data, input data quality control, and the process to input this data into the modeling software. A GIS database of the physical model components should be maintained by the City and updated as new data becomes available (e.g., from additional field observations, surveys, or measurements). When this new data is incorporated into the Hydraulic Model, the changes should be described using tags and attributes to properly manage and track revisions to the data. **Section 4** focused on the collection of hydrologic data (primarily flow and rainfall data) and the process by which this data is analyzed and input into the Hydraulic Model. Updating the hydrologic data in the Hydraulic Model may require recalibration as described below.

The following sections discuss the calibration process, defined as the adjustment of model parameters to closely match measured flows within an established criteria range. These adjustments will account for age- and condition-related changes within the system as well as changes to contributing flows. This section will also provide a brief description of the verification and sensitivity analysis procedures. The following is a brief description of the calibration process. Additional detail is provided in **Section 5.3**.

The hydraulic model calibration process generally consists of the following steps:

- Determine the time period to which the Hydraulic Model will be calibrated.

- Compile flow monitoring data and rainfall data for the selected time period. The flow monitoring data should be analyzed for both accuracy and completeness, as described in **Section 4.2**. The data should also be examined based on historical data to determine if it is typical for the time period (e.g., an atypically dry year, excessively wet year, etc.). This qualitative evaluation helps put the model results in context of potentially over-predicting or under-predicting future system performance. Baseline assumptions used in the Hydraulic Model for the calibration period will require adjustment during future system capacity analyses to represent typical baseline conditions that might not have existed during the calibration period.
- Specify dry weather and wet weather calibration criteria, which can consist of both qualitative and quantitative model performance. Examples of criteria are provided in the next sections.
- **Dry Weather Calibration Procedure:**
  - Select time period(s) without direct wet weather influence from the flow monitoring data.
  - Compare output flows produced by the model simulation using dry weather input hydrographs to the flows measured by the monitors.
  - Adjust model parameters as necessary, including those related to friction coefficients (i.e., Manning's n-coefficient), pipeline sediment buildup or similar partial blockages, pump station operation, system equalization operation, and other real-time controls with the goal of creating simulated flows and depths comparable to observed data.
  - Complete qualitative and quantitative comparisons of model predictions to the flow measurements expressed in terms of percent deviation and report results. Compare these results to the pre-determined calibration criteria. If spatial areas of the Hydraulic Model are not within specified criteria, reiterate adjustments and/or document why criteria were not met (e.g., inconsistent performance of flow monitor during data collection, insufficient number of dry weather days during monitoring period, etc.)
- **Wet Weather Calibration Procedure:**
  - Select the wet weather event(s) within the flow monitoring period to which the Hydraulic Model will be calibrated. Compile necessary rainfall data and simulate the antecedent period and appropriate hydrograph(s) to match the storm intensities and volumes. Sometimes, the storms will be simulated discretely with the antecedent dry-weather period or as a continuous calibration period as representative for the monitoring program (this is an engineering judgement based on the available data and the model simulation times).
    - Wet weather events should be selected to best match the target rainfall event return period (e.g., a 2-year, 24-hour event).
    - The quality of both the flow and corresponding rainfall data to be used for calibration must be evaluated using the quality assurance process for the data (**Section 4.2.3** and CSAP). Appropriate data should be consistent across the area and show system responses that corresponds to rainfall events (typical ADF pattern that peaks after initiation of heavy rainfall followed by return to ADF pattern). Metering data that is not robust may be discounted in the calibration process.

        - Representative calibration periods should have at least one rainfall event causing surcharging where problem areas are known to exist.
    - Compare modeled system response and output flows to the selected wet weather events. Also consider the shape and timing for wet weather response.
        - The shape of the modeled and metered curves and the timing of the peaks, troughs, and recessions of the modeled and metered curves should be similar for flow and depth.
        - Confirm known areas of overflows in the system are predicted within the Hydraulic Model.
    - Refine the values of RTKs and the effects of the groundwater model to achieve the proper volumetric responses and achieve seasonal variation and delayed responses of storms throughout the year.
    - Complete qualitative and quantitative comparisons of model predictions with the flow measurements expressed in terms of percent deviation and report results. Compare to the pre-determined calibration criteria (reference **Figure 5-3** and **Figure 5-4**). If spatial areas of the Hydraulic Model are not within specified criteria, reiterate adjustments and/or document why criteria were not met (e.g., inconsistent performance of flow monitor during data collection, insufficient wet weather response, etc.)

Following calibration, model verification and a sensitivity analysis should be completed. These processes are detailed in **Sections 5.3** and **5.4**, respectively.

5.2 Hydraulic Model Calibration Procedure

The objective of the hydraulic modeling effort is to accurately characterize the collection system under existing conditions and predict performance under future conditions and to identify and evaluate system improvements to address any deficiencies. Accordingly, the Hydraulic Model must be calibrated to existing system conditions, sewer flow, and system operations. The Hydraulic Model simulates both dry and wet weather conditions and, thus, both dry and wet weather calibration comparison procedures are performed.

5.2.1 Typical Modeling Output Parameters

Simulation runs of the Hydraulic Model produce results that represent the hydraulic conditions through the transmission and collection system at defined or prescribed time steps, including flow rate, water depth in pipes, wet wells, storage facilities, and manholes, and the hydraulic grade line (HGL) for gravity pipe, pressure pipe, and model nodes.

Table 5-2 shows the key output parameters for the various modeled components.

The Hydraulic Model output data is used for the comparison of model output data with measured data discussed in the following sections and is used for predictive system behavior under simulated system conditions. This data can be viewed is static and temporally varied conditions. Example figures of the Hydraulic Model's output were provided in **Section 2**. This data can be viewed graphically and/or within data tables.

Table 5-2: Typical Modeling Output Parameters

Component (Reference Section 3)	Output Parameter
Gravity Sewer Pipe Force Main Pumps	Flow Rate (e.g., million gallons per day, mgd)
Gravity Sewer Pipe Force Main Pumps	Flow Volume (e.g., million gallons, MG)
Manhole Pump Station Equalization Storage	System Losses (Overflow Volume - MG)
Gravity Sewer Pipe Force Main	Velocity (feet per second, ft/s)
Gravity Sewer Pipe Manhole Pump Station Storage Facilities Force Main Manhole (surcharge) Pump Station Wet Well	Hydraulic Grade Line (feet)
Equalization Storage	Equalization Storage Used (Depth and Volume)

5.2.2 Dry Weather Calibration

The first step of the calibration process is to calibrate the Hydraulic Model to dry weather conditions: the output flow produced by the model simulation using dry weather input hydrographs are compared to the flow measured by the flow meters. Adjustments are made to the input data to match the field conditions, as necessary. During this process, it may be determined that there were extraordinary field conditions in discrete areas; engineering judgement is used to replicate these field conditions in the Hydraulic Model.

5.2.2.1 Dry Weather Calibration Period

It is recommended that at least a three-day dry weather period (days without direct wet weather influence) be selected from the monitoring period to compare to the modeled dry weather flow patterns. The overall compatibility of the Hydraulic Model with dry weather conditions can be verified through long-term graphs and flow volume compared to MWWTP and Major Pump Station flow. For meter locations where there appears to be a significant difference in flow patterns between weekdays and weekends, individual patterns are generated, input to the Hydaulic Model, and used to represent weekend and weekday variations in the Hydraulic Model.

5.2.2.2 Dry Weather Calibration Criteria

Hydraulic Model calibration is evaluated based on qualitative and quantitative comparisons of model predictions to the existing field measurements and is expressed in terms of percent deviation. This approach assumes a confidence in the observed flow, depth, and rainfall data. Calibration criteria selected for the City's model are mostly based on the standards outlined in the Code of Practice for the Hydraulic Modelling of Urban Drainage Systems (CIWEM Urban Drainage Group, 2017) as summarized in **Table 5-3**. The City may choose to refine these criteria for future model calibration.

Table 5-3: Dry Weather Calibration Criteria

Hydraulic Characteristic	Criteria for Calibration[1]
Flow Rate	-10% to +10% of measured[1], or ±0.1 mgd
Flow Volume	-10% to +10% of measured[1], or ±0.1 MG
Maximum, Average, and Minimum Depth	-15% to +15% of measured or within 0.3 ft.
Shape	The shape of modeled and metered curves should be similar for flow and depth.
Timing	The timing of the peaks, troughs and recessions of modeled and metered curves should be similar for flow and depth.
[1] *In compliance with Code of Practice for the Hydraulic Modelling of Urban Drainage Systems* (CIWEM Urban Drainage Group, 2017)*, previously known as WaPUG standards.*	

These standards are not used for the validation of the modeled depth of flow. According to the standards, the calibration for the depth of surcharge should be within +1.6 feet (above) to -0.3 feet (below) the observed depth, and, for important points in the system, modeled values for non-surcharged depths should be within 0.33 feet (plus or minus) of the observed data. However, these standards do not account for the size of the pipe. For example, the allowable error in a non-surcharged 18 inch-diameter pipe is 22%, while the allowable error is 5.5% for a non-surcharged 72 inch-diameter pipe. As such, the selected depth criterion is to allow an error of ±15% of the observed depth. If the depth deviation exceeds ±15% but the absolute difference is within 0.3ft the Hydraulic Model could be considered calibrated.

Because the modeled depth depends on the accuracy of the calculated flow and the assumed hydraulic conditions, the modeled depth is not expected to consistently match the observed depth exactly. The observed hydraulic conditions may also change because of deposition and resuspension of sediment and debris, changes in operations, weir flow, and/or other variables.

5.2.2.3 Typical Model Adjustments for Dry Weather Calibration

Dry weather calibration is achieved by adjusting, as necessary, dry weather loads, model parameters related to friction coefficients (i.e., Manning's n-coefficient), pipeline sediment buildup or similar partial blockages, pump station operation, system equalization operation, and other real-time controls with the goal of creating simulated flows and depths comparable to observed data.

The dry weather calibration process potentially includes a review of the Hydraulic Model input data to perform additional quality control checks of the data for consistency and accuracy. It is possible that a review of the targeted dry weather period will identify anomalies in the data that were not readily apparent when the data was first input to the model, especially for simulation of groundwater infiltration. All final adjustments to the data to match the measured flow period is based on engineering judgement and industry standards. Final Manning's n values should range between 0.10 and 0.15, unless it can be documented that there may have been extraordinary conditions during the monitoring/calibration period.

As noted above, data consistency and completeness is important. During dry weather calibration, there may be instances where meters do not provide useful information, data may be missing, or may conflict with nearby meters due to unanticipated conditions such as poor meter calibration, meter fouling, or unique and/or temporary hydraulic field conditions, etc. Meters that have suspect full or partial datasets should be evaluated and the data discounted for model calibration purposes. Depending on circumstances, upstream and/or downstream meter can be used to help augment the calibration.

5.2.3 Wet Weather Calibration

Once the Hydraulic Model is calibrated for dry weather conditions, wet weather calibration is undertaken with the goal of reproducing measured flows and depths during storm events. Initially, wet weather calibration is focused on individual storm events. This is done by simulating several storms that occurred during the flow monitoring period. RTK unit hydrographs are used to simulate the volume and timing responses to best represent the actual system response to rainfall. As discussed in **Section 4**, for the Columbia InfoWorks ICM model, the GIM module was also used to supplement the RTK wet weather model response, which helps to simulate GWI during high antecedent moisture conditions.

5.2.3.1 Wet Weather Events

Rainfall events are typically analyzed based on the intensity and volume, with a target minimum volume of at least 0.5 inches. Rainfall data is also analyzed to obtain a return period for each event. The return period of a storm is related to the probability that a storm of a given size or larger will occur in any given year.

Selection of storm events for wet weather calibration is based primarily on professional engineering judgment, though there are some general guidelines that should be followed. The determination of whether sufficient storm events have been captured to adequately support the modeling effort is guided by the following criteria:

- The quality of both the flow and corresponding rainfall data must be reliable, with data that is consistent across the area, no obvious malfunction of monitors/gauges, etc. and system response that corresponds to rainfall events;
- At least one rainfall event causing surcharging where problem areas are known to exist must be captured;
- There should be a range of durations and intensities.

5.2.3.2 Wet Weather Calibration Criteria

The wet weather calibration criteria used for the City's Hydraulic Model is described in **Table 5-4**. Similar to the dry weather flow criteria, these criteria are based largely on the CIWEM standards, with the exception of the depth criteria. The City may choose to refine these criteria for future Hydraulic Model recalibrations.

Table 5-4: Wet Weather Calibration Criteria

Hydraulic Characteristic	Criteria for Calibration
Peak Flow Rate	-15% to + 25% of measured[1], or ±0.1 mgd
Flow Volume	-10% to +20% of measured[1], or ±0.1 MG
Maximum, Average, and Minimum Depth	-15% to +15% of measured or within 0.3 feet
Shape	The shape of modeled and metered curves should be similar for flow and depth.
Timing	The timing of the peaks, troughs and recessions of modeled and metered curves should be similar for flow and depth.
Flooding	Predicted flooding will be corroborated using customer complaints, flooding/overflow records, City feedback, and other historical records.
[1] *In compliance with Code of Practice for the Hydraulic Modelling of Urban Drainage Systems* (CIWEM Urban Drainage Group, 2017), *previously known as WaPUG standards.*	

5.2.3.3 Typical Model Adjustments for Wet Weather Calibration

Wet weather calibration is completed by adjusting the RTK parameters to match the modeled event response with the measured flows. If modeled flows do not meet the wet weather criteria after the adjustment of RTK parameters, adjustment to the groundwater model will be made to accommodate missed volumes.

As noted above, data consistency and completeness is important. During wet weather calibration, there may be instances where meters do not provide useful information, data may be missing, or may conflict with nearby meters similar due to unanticipated conditions such as poor meter calibration, meter fouling, or unique and/or temporary hydraulic field conditions, etc. This potential issue is even more sensitive during a wet-weather calibration. Accordingly, meters that have suspect full or partial datasets should be evaluated and the data discounted for model calibration purposes. Depending on circumstances, upstream and/or downstream meter can be used to help augment the calibration.

5.2.4 Model Calibration Results

All calibration results are tabulated and include wet and dry weather calibration reports for each subbasin. Each calibration report contains the following:

- Name of the subbasin
- Designation of the report as for wet weather or dry weather calibration results
- A graphic displaying the shape and timing fit between observed and modeled flows and depths, as illustrated in **Figure 5-1.**
- A table of calibration statistics that lists for each identified event the characteristics of that event, the modeled flow peak, the observed (monitored) flow peak, the relative error between the modeled and observed flow peak, the modeled flow volume, the observed flow volume, and relative error between the modeled and observed flow volume.

- Scatter plots showing the comparison of observed versus modeled data for peak flow, flow volume, and peak depth. As illustrated in **Figure 5-2**, these plots also show the upper and lower limits of the calibration criteria and whether the modeled depth-flow relationship resembles the observed relationship.
- Confirmation of whether calibration criteria were met for the subbasin.
- Comments on the results as necessary to identify challenges or anomalies.

The goal for Hydraulic Model calibration for the City was for a minimum of two out of every three events to meet the calibration criteria established for dry and wet weather flows defined in **Table 5-1** and **Table 5-2**, respectively. The number of events used for calibration for each sewershed varied depending on the number of observed events available in the flow record as well as the quality of the collected data. For any locations at which calibration goals were not met, the reason(s) believed to cause the discrepancy was identified and reported with the data. Possible reasons for not meeting calibration goals include meter malfunction and accuracy, interruption in system operation (e.g., bypass pumping), or system blockage. Flow balances across upstream and downstream meters were used to identify potential locations where loss in meter accuracy could have occurred.

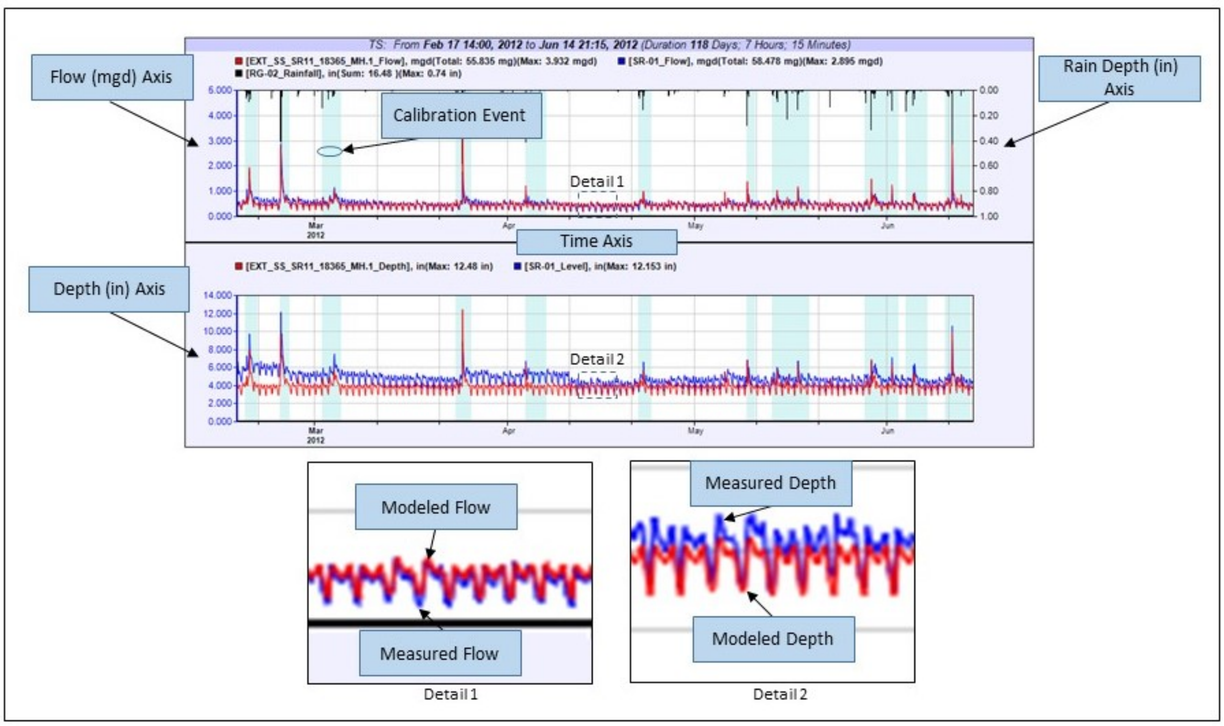

Figure 5-1: Example of Shape and Timing Calibration Results

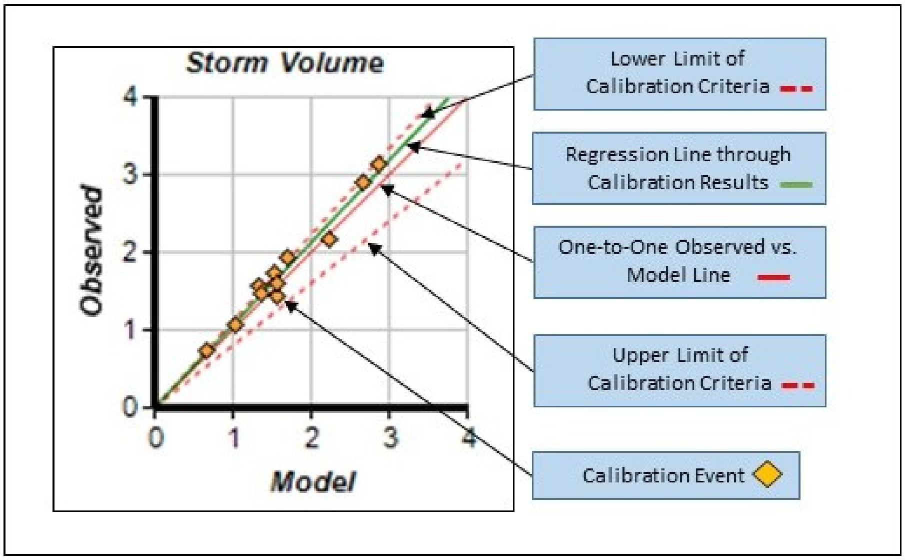

Figure 5-2: Example of Scatter Plot Comparisons for Modeled vs. Observed Data

The Hydraulic Model's results are also calibrated using the shape and timing for wet weather response. The shape of the modeled and metered curves and the timing of the peaks, troughs, and recessions of the modeled and metered curves should be similar for flow and depth.

To help summarize the results of the calibration process for each meter/model location, a table such as **Table 5-5** could be created to show the overall status of the calibrated point. In this example, although there appears to be some deviation for separate parameters, such as flow (Q), the overall calibration may be acceptable to industry standards (Tables 5-1 and 5-2 from the CIWEM standards).

Table 5-5: Example of Calibration Statistics for Modeled vs. Observed Data

Date	Q Max Error	Q Vol Error	Peak Level Error	Level Within CIWEM Threshold
12/17/2015	-5%	16%	-4%	TRUE
12/22/2015	38%	23%	0%	TRUE
12/28/2015	32%	17%	3%	TRUE
1/15/2016	16%	-10%	-4%	TRUE
1/21/2016	3%	-3%	-8%	TRUE
2/3/2016	26%	-5%	-4%	TRUE
2/15/2016	9%	10%	-15%	TRUE
2/22/2016	-16%	-7%	-11%	TRUE
Total	**88%**	**88%**	**100%**	**100%**

5.3 Hydraulic Model Verification Procedure

After calibration has been completed, the Hydraulic Model should be verified "against measured data and historical observations [to indicate] whether the Hydraulic Model is replicating known performance" (CIWEM Urban Drainage Group, 2017). This verification should be made against a different set of data than was used during the calibration process. Long term flow monitoring data from permanent flow meters, SSO data, level sensing data, and WWTP and pump station flow data are examples of information that can be used for the verification process. Verification is a qualitative process, and "any changes to the Hydraulic Model should be made only where this reflects the physical state of the sewer system and not solely to make the Hydraulic Model fit the verification data" (CIWEM Urban Drainage Group, 2017).

5.4 Hydraulic Model Sensitivity Analysis Procedure

A sensitivity analysis should be completed in areas where there may be levels or flow conditions that approach a critical capacity limit. The sensitivity analysis can be used to determine how model results change when specific parameters, such as friction factors, sediment, and hydrologic parameters are modified. The sensitivity analysis is a qualitative procedure and the analysis should consider the overall program goals and the priority for any resulting system capacity recommendations. The result of this type of analysis can provide insight to the level of conservatism attained in the Hydraulic Model.

5.5 Current Hydraulic Model Calibration Data and Conclusions

Based on professional engineering judgment, the input data consistency review, hydraulic mass balance evaluation, dry and wet weather calibration criteria, and feedback from City staff on system operation, the Hydraulic Model was considered calibrated in December 2019 to flow metering and precipitation data in a continuous time-series for the period from December 2015-February 2016. Hydraulic Model simulations were calibrated to more than eighty (80) meter locations, including temporary and permanent flow meters locations and to metered flow and operations at the five largest pump stations. The calibration results show generally good correlation between the flow data and model results over the calibration period.

As an additional verification, rainfall data from a more recent storm event on December 13, 2019 was simulated to compare to recorded smart cover data, permanent flow meter data and SSOs. The Hydraulic Model correlated well with the actual field conditions, which increased relative confidence in the Hydraulic Model's ability to predict system response.

During model calibration using the 2015/2016 data, a few anomalies from flow meter data were observed. The anomalies affected a minority of the system and reflected what could be typically experienced with a significant flow monitoring program for a system the size of the City's system. If future validation efforts suggest that such inconsistencies warrant further investigation, the City may undertake future flow monitoring in certain portions of the system to obtain new flow data to recalibrate and enhance the simulation of those portions of the WCTS.

Section 6 Hydraulic Model Updates and Recalibration

6.1 Schedule and Personnel

Physical updates to the City GIS systems should be implemented as needed based on professional judgment and should account for new data derived from physical field observations and measurements. The procedures discussed in **Section 3** should be followed for physical model updates.

Hydraulic Model recalibration requires a more intensive process than simple physical model updates. For long-term model maintenance, it is recommended that the Hydraulic Model be recalibrated approximately every five years with the timeframe to be determined based on professional engineering judgment. If physical and hydrologic system characteristics do not change substantially, a less frequent model recalibration may be appropriate.

If significant individual basin rehabilitation work is completed, the Hydraulic Model could be recalibrated more frequently and at the basin level to reflect improvements made to the system. The Columbia system has five Major Pumps Stations that provide definitive hydraulic boundaries to recalibrate basins separately. These basin recalibrations should be well documented and performed to the same standards as the original system-wide Hydraulic Model calibration. The basin recalibration process should include verification of the Hydraulic Model's accuracy and performance, as well as, analysis of model sensitivity to changes in input parameters and variables.

The City may elect to conduct basin-level model recalibration if there are significant changes to:

- Flow - for example larger industrial, commercial, or residential developments connecting to the system that are greater than 15,000 GPD);
- Major sewer infrastructure capacity improvements or system extensions (15-inches and larger); and
- Modified pump stations where capacity or significant operating conditions affecting capacity have changed due to the modifications.

The Hydraulic Model's maintenance will include coordination among the necessary resources (engineering, GIS, operations, etc.) for timely and accurate changes to the Hydraulic Model. A summary of model update procedures and personnel is shown in **Table 6-1**.

Table 6-1: Model Update Summary

Procedure/Protocol	Schedule	Lead Contacts*
Physical System Revisions	As Determined by Professional Engineering Judgment Based on a Quarterly Review of GIS Data	City GIS Representative
Flow Input Revisions	As Determined by Professional Engineering Judgement Based on a Review of Flow Data Every 2 years	City Operations Representative City Hydraulic Model Representative
Hydraulic Model Review and Recalibration	As Determined by Professional Engineering Judgement Based on a Review of System Changes Every 5 years	City Hydraulic Model Representative
Partial Model Updates and Recalibration	Triggers: Significant Changes in Collection System Layout (e.g., flow rerouting) Subbasin Level Changes (Significant SSES rehabilitation and/or major CIP investment analysis)	City Engineering Representative City Hydraulic Model Representative

* *Hydraulic Model Representative shall be familiar with model inputs (physical infrastructure, flow data) and model outputs, including interpretation of predicted flows and hydraulic grade lines.*

GIS Representative shall be familiar with the system's physical infrastructure and the representation of that infrastructure within a GIS environment, including the necessary attributes to be maintained and the source(s) of this data. This representative shall also be able to perform quality control and technical verification of the existing and all new data within the GIS.

Engineering Representative shall be familiar with the Capacity Assurance Program and how the Hydraulic Model informs the CAP reviews. This individual shall also be familiar with ongoing City initiatives in terms of RDI/I reduction, infrastructure repairs, flow monitoring updates, etc.

Operations Representative shall be familiar with the interconnectedness of the collection, transmission, and treatment systems, including all operational strategies at pump stations and equalization facilities, control points, critical manholes, and current system status.

References

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APPENDICES

Appendix A

Table A-1: Summary of Dry Weather Flow Parameters by Meter Basin

Subcatchment	Wastewater Profile	Equivalent Population	Per Capita Flow	Base Flow[1,2] (GWI)
BR01	70	196	61.3	0.0000
BR02A	25	1084	35.0	0.0000
BR02B	22	1451	50.7	0.0000
BR02C	24	4926	35.6	0.0000
BR04A	23 or 24[1]	862	92.7	0.1095
Burnside	48	2743	14.0	0.2176
CC01A	11	1383	108.4	0.1107
CC01B	12	1154	70.8	0.0212
CC02	10	2607	62.6	0.0000
CC02A	10	931	62.6	0.0000
CC03	9	3293	47.2	0.0851
CC04	8	938	63.7	0.0440
CC06B	6	3615	58.7	0.0824
CC08	5	3410	97.7	0.1463
CC09	1	5886	76.7	0.0000
CC11	3	1670	64.0	0.2662
CC12	2	957	36.4	0.0501
CC21	1	5211	76.7	0.8190
GC02	50	7787	62.2	0.4460
GC04	51	8267	45.5	0.3157
GC05	51 or 53[1]	4104	45.5 or 118.3[2]	0.3871
GC12A	57	17019	52.0	0.3737
GC15A	46	4979	74.5	0.1005
GC15B	47	1404	29.1	0.0418
GC16A	55	7301	52.6 or 104.9[2]	0.2296
GC16B	56	3491	32.7	0.2245
GC17A	54	6072	104.9	0.2712
GC18	4 or 49[1]	655	65 or 127.6[2]	0.0237
MC01A	40	1602	97.9	0.0454
MC01B	38 or 40[1]	2650	61.9 or 97.9[2]	0.1245
MC02	44	3585	96.3	0.1817
MC03	41	1730	130.3	0.0248
MC04A	39	1367	87.2	0.0101
MC04C	42	164	101.0	0.0259
MC05	75	1280	43.7	0.1856
MC05B	4 or 75[1]	598	43.7 or 65[2]	0.0686
PFM03	63	1801	59.8	0.1242
PFM04	59	2450	76.9	0.1703
PFM05	67	1387	51.3	0.1056
PFM06	52	1404	151.8	0.0850
PFM07	76	8829	85.0	0.2868
PFM10	74	26153	65.0	0.8292
PFM11	7	1967	61.8	0.2237
PFMZoo	66	1842	77.2	0.2256
RB01	60	13013	60.2	0.9954
RB03A	71	597	16.2	0.0725
RB03B	64	2376	58.3	0.2134
RB04	65	1830	22.9	0.1368
RB05A	62	1601	30.3	0.0925
RB05B	61	1988	38.0	0.1142
RB06	4	2257	65.0	0.0000
RB08B	58	6363	55.7	0.5651

RB08E	1	6310	76.7	0.0000
SB01B	14	5487	48.1	0.3239
SB02	16	6833	47.3	0.1965
SB02B	15	1167	64.7	0.0608
SB03A	17	1760	69.3	0.0701
SB03B	13	161	110.8	0.0069
SB04B	18	3465	21.5	0.1386
SB04C	19	52	74.6	0.0071
SB04E	20	422	132.5	0.0147
SB05A	21	3553	188.5	0.3335
SR01	32	5300	62.4	0.4838
SR04A	26	4053	65.5	0.2995
SR04B	27	2194	70.6	0.1328
SR06	31	5531	81.0	0.1994
SR07	33	9688	46.9	0.3199
SR08	35	5404	67.9	0.1861
SR09	29	3746	17.1	0.0000
SR11	28	11865	70.0	0.7120
SR13	37	5366	93.8	0.1762
SR14A	36	2354	40.6	0.2031
SR14B	34	1188	27.1	0.0000
SR14C	31	3426	81.0	0.4105
SR15	30	11035	83.0	0.1765
SRPump	1	23	76.7	0.0000
WC01	69	2802	103.6	0.1805
WC01B	69	41492	103.6	1.4894
WC02A	72	5487	38.4	0.1188
WC02D	68	10717	72.0	0.3543
WWTP_GC	77	8779	65.0	0.0271
WWTP_RB	77	602	65.0	0.0000

Notes:

[1]This meter basin utilized multiple wastewater profiles to meet the calibration criteria for the model.

[2]This meter basin utilized multiple per capita flow values to meet the calibration criteria for the model.

Table A-2: Dry Weather Flow Parameters by Subcatchment

Subcatchment	Wastewater Profile	Equivalent Population	Per Capita Flow	Base Flow[1,2] (GWI)
BR01_1	70	876	61.3	0.0218
BR01_2	70	95	61.3	0.0241
BR01_3	70	166	61.3	0.0192
BR01_4	70	555	61.3	0.0199
BR01_5	70	311	61.3	0.0162
BR01_6	70	767	61.3	0.0180
BR01_7	70	348	61.3	0.0116
BR02A_1	25	117	35.0	0.0000
BR02A_10	25	31	35.0	0.0000
BR02A_2	25	141	35.0	0.0000
BR02A_3	25	153	35.0	0.0000
BR02A_4	25	1	35.0	0.0000
BR02A_5	25	136	35.0	0.0000
BR02A_6	25	88	35.0	0.0000
BR02A_7	25	280	35.0	0.0000
BR02A_8	25	306	35.0	0.0000
BR02A_9	25	90	35.0	0.0000
BR02B_1	22	38	50.7	0.0057
BR02B_10	22	63	50.7	0.0036
BR02B_11	22	171	50.7	0.0080
BR02B_12	22	71	50.7	0.0049
BR02B_2	22	113	50.7	0.0042
BR02B_3	22	195	50.7	0.0071
BR02B_4	22	135	50.7	0.0089
BR02B_5	22	246	50.7	0.0049
BR02B_6	22	101	50.7	0.0060
BR02B_7	22	114	50.7	0.0063
BR02B_8	22	80	50.7	0.0043
BR02B_9	22	98	50.7	0.0046
BR02C_1	24	0	35.6	0.0045
BR02C_10	24	185	35.6	0.0060
BR02C_11	24	112	35.6	0.0061
BR02C_12	24	1	35.6	0.0041
BR02C_13	24	25	35.6	0.0024
BR02C_14	24	30	35.6	0.0057
BR02C_15	24	1	35.6	0.0006
BR02C_16	24	415	35.6	0.0024
BR02C_17	24	986	35.6	0.0090
BR02C_18	24	77	35.6	0.0075
BR02C_19	24	153	35.6	0.0070
BR02C_2	24	2	35.6	0.0005
BR02C_20	24	63	35.6	0.0017
BR02C_21	24	152	35.6	0.0027
BR02C_22	24	1809	35.6	0.0125
BR02C_23	24	6	35.6	0.0034
BR02C_24	24	8	35.6	0.0020
BR02C_25	24	115	35.6	0.0013
BR02C_26	24	2245	35.6	0.0106
BR02C_27	24	6782	35.6	0.0041
BR02C_28	24	8	35.6	0.0041
BR02C_29	24	0	35.6	0.0009

BR02C_3	24	213	35.6	0.0106
BR02C_30	24	7	35.6	0.0035
BR02C_31	24	355	35.6	0.0046
BR02C_32	24	54	35.6	0.0024
BR02C_33	24	2	35.6	0.0025
BR02C_4	24	272	35.6	0.0099
BR02C_5	24	371	35.6	0.0080
BR02C_6	24	0	35.6	0.0008
BR02C_7	24	1021	35.6	0.0081
BR02C_8	24	341	35.6	0.0104
BR02C_9	24	331	35.6	0.0033
BR04A_1	23	237	92.7	0.0141
BR04A_10	23	143	92.7	0.0062
BR04A_11	23	89	92.7	0.0140
BR04A_12	24	17	35.6	0.0055
BR04A_2	23	41	92.7	0.0015
BR04A_3	23	154	92.7	0.0085
BR04A_4	23	51	92.7	0.0039
BR04A_5	24	266	35.6	0.0077
BR04A_6	23	277	92.7	0.0179
BR04A_7	23	225	92.7	0.0129
BR04A_8	23	179	92.7	0.0122
BR04A_9	23	231	92.7	0.0182
Burnside_10	48	182	14.0	0.0022
Burnside_11	48	67	14.0	0.0018
Burnside_12	48	15	14.0	0.0028
Burnside_13	48	56	14.0	0.0007
Burnside_14	48	128	14.0	0.0009
Burnside_15	48	75	14.0	0.0024
Burnside_16	48	9	14.0	0.0020
Burnside_17	48	0	14.0	0.0001
Burnside_18	48	10	14.0	0.0014
Burnside_19	48	0	14.0	0.0009
Burnside_1_1	48	40	14.0	0.0005
Burnside_2	48	14	14.0	0.0022
Burnside_3	48	75	14.0	0.0034
Burnside_4	48	1	14.0	0.0021
Burnside_5	48	1	14.0	0.0024
Burnside_6	48	87	14.0	0.0009
Burnside_7	48	684	14.0	0.0027
Burnside_8	48	0	14.0	0.0006
Burnside_9	48	42	14.0	0.0019
CC01A_1	11	134	108.4	0.0204
CC01A_10	11	9	108.4	0.0013
CC01A_11	11	6	108.4	0.0011
CC01A_12	11	2	108.4	0.0134
CC01A_13	11	16	108.4	0.0043
CC01A_14	11	153	108.4	0.0157
CC01A_15	11	191	108.4	0.0188
CC01A_16	11	152	108.4	0.0177
CC01A_17	11	158	108.4	0.0148
CC01A_2	11	193	108.4	0.0274
CC01A_3	11	24	108.4	0.0141
CC01A_4	11	89	108.4	0.0131
CC01A_5	11	4	108.4	0.0019
CC01A_6	11	156	108.4	0.0211

CC01A_7	11	3	108.4	0.0017
CC01A_8	11	14	108.4	0.0012
CC01A_9	11	8	108.4	0.0009
CC01B_1	12	290	70.8	0.0609
CC01B_10	12	195	70.8	0.0450
CC01B_11	12	295	70.8	0.0465
CC01B_12	12	57	70.8	0.0168
CC01B_13	12	163	70.8	0.0355
CC01B_2	12	305	70.8	0.0077
CC01B_3	12	41	70.8	0.0128
CC01B_4	12	51	70.8	0.0034
CC01B_5	12	21	70.8	0.0047
CC01B_6	12	40	70.8	0.0097
CC01B_7	12	344	70.8	0.0591
CC01B_8	12	201	70.8	0.0468
CC01B_9	12	160	70.8	0.0312
CC02_1	10	32	62.6	0.0000
CC02_10	10	0	62.6	0.0000
CC02_11	10	40	62.6	0.0000
CC02_12	10	15	62.6	0.0000
CC02_13	10	15	62.6	0.0000
CC02_14	10	5	62.6	0.0000
CC02_2	10	0	62.6	0.0000
CC02_3	10	144	62.6	0.0000
CC02_4	10	153	62.6	0.0000
CC02_5	10	85	62.6	0.0000
CC02_6	10	2	62.6	0.0000
CC02_7	10	2	62.6	0.0000
CC02_8	10	150	62.6	0.0000
CC02_9	10	2	62.6	0.0000
CC02A_1	10	29	62.6	0.0000
CC02A_2	10	0	62.6	0.0000
CC02A_3	10	14	62.6	0.0000
CC02A_4	10	19	62.6	0.0000
CC02A_5	10	2	62.6	0.0000
CC02A_6	10	0	62.6	0.0000
CC02A_7	10	34	62.6	0.0000
CC02A_8	10	18	62.6	0.0000
CC02A_9	10	31	62.6	0.0000
CC03_1	9	111	47.2	0.0105
CC03_10	9	65	47.2	0.0067
CC03_11	9	43	47.2	0.0084
CC03_12	9	29	47.2	0.0085
CC03_13	9	87	47.2	0.0066
CC03_16	9	84	47.2	0.0070
CC03_17	9	4	47.2	0.0049
CC03_18	9	5	47.2	0.0044
CC03_19	9	19	47.2	0.0067
CC03_2	9	70	47.2	0.0110
CC03_20	9	26	47.2	0.0111
CC03_3	9	2	47.2	0.0034
CC03_32	9	9	47.2	0.0005
CC03_4	9	0	47.2	0.0004
CC03_40	9	10	47.2	0.0011
CC03_41	9	26	47.2	0.0013
CC03_42	9	12	47.2	0.0006

CC03_43	9	1	47.2	0.0018
CC03_44	9	9	47.2	0.0021
CC03_45	9	20	47.2	0.0024
CC03_46	9	5	47.2	0.0030
CC03_47	9	6	47.2	0.0004
CC03_48	9	12	47.2	0.0034
CC03_49	9	17	47.2	0.0018
CC03_5	9	0	47.2	0.0004
CC03_50	9	53	47.2	0.0069
CC03_6	9	1	47.2	0.0018
CC03_7	9	28	47.2	0.0085
CC03_8	9	60	47.2	0.0148
CC03_9	9	0	47.2	0.0009
CC04_1	8	20	63.7	0.0038
CC04_10	8	113	63.7	0.0096
CC04_11	8	30	63.7	0.0042
CC04_12	8	15	63.7	0.0032
CC04_2	8	119	63.7	0.0119
CC04_3	8	0	63.7	0.0006
CC04_4	8	76	63.7	0.0103
CC04_5	8	75	63.7	0.0116
CC04_6	8	92	63.7	0.0107
CC04_7	8	88	63.7	0.0062
CC04_8	8	67	63.7	0.0067
CC04_9	8	67	63.7	0.0060
CC06B_1	6	89	58.7	0.0052
CC06B_10	6	40	58.7	0.0044
CC06B_11	6	71	58.7	0.0051
CC06B_12	6	72	58.7	0.0074
CC06B_13	6	113	58.7	0.0055
CC06B_14	6	150	58.7	0.0062
CC06B_16	6	143	58.7	0.0052
CC06B_17	6	174	58.7	0.0054
CC06B_18	6	113	58.7	0.0036
CC06B_19	6	37	58.7	0.0046
CC06B_2	6	140	58.7	0.0024
CC06B_20	6	97	58.7	0.0042
CC06B_21	6	140	58.7	0.0061
CC06B_22	6	70	58.7	0.0030
CC06B_23	6	101	58.7	0.0067
CC06B_24	6	57	58.7	0.0038
CC06B_25	6	120	58.7	0.0036
CC06B_26	6	41	58.7	0.0030
CC06B_27	6	57	58.7	0.0031
CC06B_28	6	0	58.7	0.0007
CC06B_29	6	109	58.7	0.0032
CC06B_3	6	1	58.7	0.0012
CC06B_30	6	110	58.7	0.0025
CC06B_31	6	139	58.7	0.0051
CC06B_32	6	124	58.7	0.0070
CC06B_33	6	158	58.7	0.0050
CC06B_34	6	75	58.7	0.0027
CC06B_35	6	126	58.7	0.0046
CC06B_36	6	147	58.7	0.0052
CC06B_37	6	0	58.7	0.0005
CC06B_38	6	97	58.7	0.0024

CC06B_39	6	13	58.7	0.0019
CC06B_4	6	189	58.7	0.0037
CC06B_40	6	14	58.7	0.0010
CC06B_5	6	143	58.7	0.0048
CC06B_6	6	58	58.7	0.0016
CC06B_7	6	185	58.7	0.0045
CC06B_8	6	3	58.7	0.0005
CC06B_9	6	0	58.7	0.0003
CC08_1	5	191	97.7	0.0094
CC08_10	5	10	97.7	0.0024
CC08_11	5	19	97.7	0.0028
CC08_12	5	109	97.7	0.0154
CC08_13	5	93	97.7	0.0085
CC08_14	5	88	97.7	0.0141
CC08_15	5	180	97.7	0.0190
CC08_16	5	164	97.7	0.0145
CC08_17	5	1105	97.7	0.0140
CC08_18	5	0	97.7	0.0147
CC08_19	5	228	97.7	0.0141
CC08_2	5	1	97.7	0.0174
CC08_20	5	386	97.7	0.0121
CC08_21	5	89	97.7	0.0127
CC08_22	5	93	97.7	0.0084
CC08_23	5	240	97.7	0.0107
CC08_24	5	200	97.7	0.0139
CC08_3	5	12	97.7	0.0007
CC08_4	5	131	97.7	0.0165
CC08_5	5	14	97.7	0.0038
CC08_6	5	283	97.7	0.0198
CC08_7	5	269	97.7	0.0061
CC08_8	5	25	97.7	0.0035
CC08_9	5	7	97.7	0.0034
CC09_10	1	72	76.7	0.0000
CC09_11	1	1	76.7	0.0000
CC09_12	1	0	76.7	0.0000
CC09_13	1	1	76.7	0.0000
CC09_14	1	30	76.7	0.0000
CC09_15	1	26	76.7	0.0000
CC09_16	1	66	76.7	0.0000
CC09_17	1	21	76.7	0.0000
CC09_18	1	14	76.7	0.0000
CC09_19	1	204	76.7	0.0000
GC04_4	51	7	45.5	0.0006
GC04_5	51	90	45.5	0.0108
GC04_6	51	9	45.5	0.0006
GC04_7	51	155	45.5	0.0106
GC04_8	51	122	45.5	0.0047
GC04_9	51	30	45.5	0.0018
GC05_1	53	127	118.3	0.0153
GC05_10	53	41	118.3	0.0031
GC05_11	53	179	118.3	0.0216
GC05_12	53	152	118.3	0.0115
GC05_13	53	263	118.3	0.0200
MC01B_100	38	62	61.9	0.0038
MC01B_101	38	124	61.9	0.0062
MC01B_2	38	252	61.9	0.0140

MC01B_3	38	43	61.9	0.0028
MC01B_3_1	38	44	61.9	0.0019
MC01B_3_1_1	38	23	61.9	0.0010
MC01B_3_2	38	13	61.9	0.0015
MC01B_4	38	29	61.9	0.0025
MC01B_4_1	38	50	61.9	0.0034
MC01B_4_2	38	7	61.9	0.0009
CC09_2	1	108	76.7	0.0000
CC09_20	1	0	76.7	0.0000
CC09_21	1	41	76.7	0.0000
CC09_22	1	187	76.7	0.0000
CC09_23	1	15	76.7	0.0000
CC09_24	1	185	76.7	0.0000
CC09_25	1	309	76.7	0.0000
CC09_26	1	153	76.7	0.0000
CC09_27	1	255	76.7	0.0000
CC09_28	1	137	76.7	0.0000
CC09_29	1	118	76.7	0.0000
CC09_3	1	273	76.7	0.0000
CC09_30	1	75	76.7	0.0000
CC09_31	1	17	76.7	0.0000
CC09_32	1	17	76.7	0.0000
CC09_33	1	107	76.7	0.0000
CC09_34	1	80	76.7	0.0000
CC09_35	1	14	76.7	0.0000
CC09_36	1	0	76.7	0.0000
CC09_37	1	185	76.7	0.0000
CC09_38	1	0	76.7	0.0000
CC09_39	1	5	76.7	0.0000
CC09_3_Trane	1	205	76.7	0.0000
CC09_4	1	35	76.7	0.0000
CC09_40	1	270	76.7	0.0000
CC09_41	1	59	76.7	0.0000
CC09_42	1	815	76.7	0.0000
CC09_43	1	2	76.7	0.0000
CC09_44	1	548	76.7	0.0000
CC09_45	1	23	76.7	0.0000
CC09_46	1	39	76.7	0.0000
CC09_47	1	16	76.7	0.0000
CC09_48	1	378	76.7	0.0000
CC09_49	1	86	76.7	0.0000
CC09_5	1	37	76.7	0.0000
CC09_50	1	20	76.7	0.0000
CC09_51	1	25	76.7	0.0000
CC09_52	1	119	76.7	0.0000
CC09_53	1	252	76.7	0.0000
CC09_54	1	218	76.7	0.0000
CC09_55	1	413	76.7	0.0000
CC09_56	1	2	76.7	0.0000
CC09_57	1	3	76.7	0.0000
CC09_58	1	63	76.7	0.0000
CC09_59	1	86	76.7	0.0000
CC09_6	1	149	76.7	0.0000
CC09_60	1	0	76.7	0.0000
CC09_61	1	264	76.7	0.0000
CC09_62	1	201	76.7	0.0000

CC09_7	1	295	76.7	0.0000
CC09_8	1	201	76.7	0.0000
CC09_9	1	117	76.7	0.0000
CC11_1	3	271	64.0	0.0030
CC11_11	3	0	64.0	0.0001
CC11_12	3	6	64.0	0.0015
CC11_13	3	48	64.0	0.0008
CC11_14	3	340	64.0	0.0037
CC11_15	3	114	64.0	0.0023
CC11_16	3	105	64.0	0.0021
CC11_17	3	106	64.0	0.0028
CC11_18	3	163	64.0	0.0017
CC11_19	3	0	64.0	0.0002
CC11_2	3	2	64.0	0.0015
CC11_20	3	46	64.0	0.0020
CC11_22	3	23	64.0	0.0011
CC11_23	3	31	64.0	0.0013
CC11_24	3	54	64.0	0.0019
CC11_25	3	54	64.0	0.0019
CC11_26	3	77	64.0	0.0012
CC11_27	3	26	64.0	0.0012
CC11_28	3	21	64.0	0.0013
CC11_29	3	33	64.0	0.0018
CC11_3	3	371	64.0	0.0049
CC11_30	3	149	64.0	0.0022
CC11_31	3	122	64.0	0.0017
CC11_32	3	173	64.0	0.0023
CC11_33	3	0	64.0	0.0002
CC11_34	3	58	64.0	0.0014
CC11_35	3	48	64.0	0.0003
CC11_36	3	94	64.0	0.0018
CC11_4	3	98	64.0	0.0032
CC11_5	3	59	64.0	0.0020
CC11_6	3	51	64.0	0.0034
CC11_7	3	101	64.0	0.0019
CC11_8	3	158	64.0	0.0030
CC11_9	3	3	64.0	0.0005
CC12_1	2	273	36.4	0.0108
CC12_10	2	123	36.4	0.0052
CC12_11	2	162	36.4	0.0058
CC12_12	2	21	36.4	0.0011
CC12_13	2	1	36.4	0.0003
CC12_14	2	60	36.4	0.0022
CC12_15	2	36	36.4	0.0024
CC12_16	2	101	36.4	0.0027
CC12_17	2	9	36.4	0.0004
CC12_18	2	19	36.4	0.0054
CC12_19	2	36	36.4	0.0110
CC12_2	2	101	36.4	0.0050
CC12_20	2	109	36.4	0.0056
CC12_21	2	10	36.4	0.0062
CC12_22	2	9	36.4	0.0023
CC12_23	2	75	36.4	0.0087
CC12_24	2	306	36.4	0.0044
CC12_25	2	365	36.4	0.0030
CC12_26	2	167	36.4	0.0026

CC12_27	2	223	36.4	0.0065
CC12_28	2	1	36.4	0.0013
CC12_29	2	63	36.4	0.0004
CC12_3	2	25	36.4	0.0066
CC12_30	2	110	36.4	0.0037
CC12_31	2	112	36.4	0.0030
CC12_32	2	50	36.4	0.0026
CC12_33	2	1	36.4	0.0020
CC12_4	2	13	36.4	0.0030
CC12_5	2	301	36.4	0.0037
CC12_6	2	1	36.4	0.0055
CC12_7	2	38	36.4	0.0057
CC12_8	2	97	36.4	0.0011
CC12_9	2	59	36.4	0.0044
CC21_1	1	65	76.7	0.0058
CC21_10	1	84	76.7	0.0068
CC21_11	1	26	76.7	0.0043
CC21_12	1	17	76.7	0.0042
CC21_13	1	6	76.7	0.0118
CC21_14	1	11	76.7	0.0089
CC21_15	1	25	76.7	0.0067
CC21_16	1	36	76.7	0.0119
CC21_17	1	1	76.7	0.0066
CC21_18	1	494	76.7	0.0156
CC21_19	1	95	76.7	0.0123
CC21_2	1	2	76.7	0.0146
CC21_20	1	146	76.7	0.0134
CC21_21	1	296	76.7	0.0136
CC21_22	1	45	76.7	0.0156
CC21_23	1	122	76.7	0.0137
CC21_24	1	12	76.7	0.0052
CC21_25	1	60	76.7	0.0086
CC21_26	1	97	76.7	0.0143
CC21_27	1	136	76.7	0.0152
CC21_28	1	72	76.7	0.0096
CC21_29	1	389	76.7	0.0119
CC21_3	1	104	76.7	0.0104
CC21_30	1	91	76.7	0.0085
CC21_31	1	146	76.7	0.0113
CC21_32	1	160	76.7	0.0162
CC21_33	1	163	76.7	0.0061
CC21_34	1	56	76.7	0.0065
CC21_35	1	461	76.7	0.0146
CC21_36	1	185	76.7	0.0130
CC21_37	1	2	76.7	0.0099
CC21_38	1	72	76.7	0.0088
CC21_39	1	5	76.7	0.0059
CC21_4	1	646	76.7	0.0131
CC21_40	1	7	76.7	0.0112
CC21_41	1	1	76.7	0.0068
CC21_42	1	504	76.7	0.0114
CC21_43	1	30	76.7	0.0115
CC21_44	1	10	76.7	0.0049
CC21_45	1	2	76.7	0.0061
CC21_46	1	2	76.7	0.0012
CC21_47	1	2	76.7	0.0005

CC21_48	1	35	76.7	0.0061
CC21_49	1	5	76.7	0.0011
CC21_5	1	10	76.7	0.0013
CC21_50	1	4	76.7	0.0015
CC21_51	1	2	76.7	0.0042
CC21_6	1	46	76.7	0.0151
CC21_7	1	8	76.7	0.0097
CC21_8	1	2	76.7	0.0085
CC21_9	1	42	76.7	0.0030
GC02_1	50	42	62.2	0.0158
GC02_10	50	38	62.2	0.0048
GC02_11	50	72	62.2	0.0110
GC02_12	50	83	62.2	0.0103
GC02_13	50	17	62.2	0.0048
GC02_14	50	115	62.2	0.0149
GC02_15	50	305	62.2	0.0285
GC02_16	50	19	62.2	0.0019
GC02_17	50	7	62.2	0.0007
GC02_18	50	14	62.2	0.0026
GC02_19	50	385	62.2	0.0164
GC02_2	50	167	62.2	0.0166
GC02_20	50	18	62.2	0.0021
GC02_21	50	65	62.2	0.0075
GC02_22	50	108	62.2	0.0160
GC02_23	50	2	62.2	0.0030
GC02_24	50	85	62.2	0.0110
GC02_25	50	15	62.2	0.0015
GC02_26	50	15	62.2	0.0028
GC02_27	50	13	62.2	0.0033
GC02_28	50	346	62.2	0.0372
GC02_29	50	121	62.2	0.0137
GC02_3	50	75	62.2	0.0163
GC02_30	50	25	62.2	0.0041
GC02_31	50	6	62.2	0.0091
GC02_32	50	46	62.2	0.0068
GC02_33	50	2	62.2	0.0009
GC02_34	50	30	62.2	0.0046
GC02_35	50	96	62.2	0.0115
GC02_36	50	204	62.2	0.0210
GC02_37	50	664	62.2	0.0130
GC02_38	50	83	62.2	0.0123
GC02_39	50	211	62.2	0.0220
GC02_4	50	120	62.2	0.0156
GC02_40	50	237	62.2	0.0332
GC02_41	50	436	62.2	0.0319
GC02_5	50	141	62.2	0.0111
GC02_6	50	159	62.2	0.0130
GC02_7	50	93	62.2	0.0134
GC02_8	50	183	62.2	0.0231
GC02_9	50	179	62.2	0.0130
GC04_1	51	130	45.5	0.0084
GC04_10	51	167	45.5	0.0092
GC04_11	51	126	45.5	0.0063
GC04_12	51	0	45.5	0.0001
GC04_13	51	0	45.5	0.0048
GC04_14	51	33	45.5	0.0074

GC04_15	51	199	45.5	0.0078
GC04_16	51	142	45.5	0.0081
GC04_17	51	245	45.5	0.0121
GC04_18	51	154	45.5	0.0081
GC04_19	51	20	45.5	0.0020
GC04_2	51	72	45.5	0.0105
GC04_20	51	108	45.5	0.0048
GC04_21	51	65	45.5	0.0041
GC04_22	51	98	45.5	0.0043
GC04_23	51	58	45.5	0.0078
GC04_24	51	73	45.5	0.0047
GC04_25	51	135	45.5	0.0062
GC04_26	51	141	45.5	0.0053
GC04_27	51	311	45.5	0.0180
GC04_28	51	274	45.5	0.0128
GC04_29	51	266	45.5	0.0140
GC04_3	51	302	45.5	0.0154
GC04_30	51	110	45.5	0.0065
GC04_31	51	44	45.5	0.0131
GC04_32	51	85	45.5	0.0069
GC04_33	51	94	45.5	0.0083
GC04_34	51	378	45.5	0.0117
GC04_35	51	286	45.5	0.0118
GC04_36	51	77	45.5	0.0038
GC04_37	51	199	45.5	0.0076
GC05_14	53	238	118.3	0.0275
GC05_15	53	162	118.3	0.0113
GC05_16	51	135	45.5	0.0103
GC05_17	53	6	118.3	0.0018
GC05_18	53	0	118.3	0.0020
GC05_19	53	0	118.3	0.0021
GC05_2	53	89	118.3	0.0061
GC05_20	53	0	118.3	0.0005
GC05_21	53	258	118.3	0.0217
GC05_22	53	107	118.3	0.0313
GC05_23	53	175	118.3	0.0157
GC05_24	53	142	118.3	0.0088
GC05_24_1	53	96	118.3	0.0067
GC05_25	53	99	118.3	0.0097
GC05_26	53	144	118.3	0.0115
GC05_27	53	497	118.3	0.0266
GC05_28	53	514	118.3	0.0351
GC05_29	53	264	118.3	0.0203
GC05_3	53	148	118.3	0.0200
GC05_30	53	481	118.3	0.0256
GC05_31	53	201	118.3	0.0307
GC05_32	53	305	118.3	0.0315
GC05_33	51	127	45.5	0.0103
GC05_34	51	282	45.5	0.0095
GC05_35	51	221	45.5	0.0105
GC05_36	51	261	45.5	0.0067
GC05_37	51	117	45.5	0.0067
GC05_38	51	131	45.5	0.0118
GC05_39	51	106	45.5	0.0086
GC05_4	53	164	118.3	0.0138
GC05_5	53	313	118.3	0.0152

GC05_6	53	125	118.3	0.0139
GC05_7	53	62	118.3	0.0112
GC05_8	53	114	118.3	0.0196
GC05_9	53	203	118.3	0.0238
GC12A_1	57	339	52.0	0.0115
GC12A_10	57	63	52.0	0.0032
GC12A_11	57	176	52.0	0.0070
GC12A_12	57	62	52.0	0.0021
GC12A_13	57	413	52.0	0.0150
GC12A_14	57	65	52.0	0.0037
GC12A_15	57	46	52.0	0.0022
GC12A_16	57	49	52.0	0.0023
GC12A_17	57	41	52.0	0.0026
GC12A_18	57	31	52.0	0.0011
GC12A_19	57	48	52.0	0.0039
GC12A_2	57	248	52.0	0.0153
GC12A_20	57	49	52.0	0.0015
GC12A_21	57	78	52.0	0.0013
GC12A_22	57	171	52.0	0.0012
GC12A_23	57	53	52.0	0.0007
GC12A_24	57	30	52.0	0.0006
GC12A_25	57	20	52.0	0.0015
GC12A_26	57	38	52.0	0.0014
GC12A_27	57	26	52.0	0.0007
GC12A_28	57	2	52.0	0.0007
GC12A_29	57	51	52.0	0.0021
GC12A_3	57	129	52.0	0.0057
GC12A_30	57	3	52.0	0.0003
GC12A_31	57	3	52.0	0.0003
GC12A_32	57	26	52.0	0.0006
GC12A_33	57	407	52.0	0.0126
GC12A_34	57	100	52.0	0.0055
GC12A_35	57	181	52.0	0.0080
GC12A_36	57	324	52.0	0.0137
GC12A_37	57	101	52.0	0.0057
GC12A_38	57	119	52.0	0.0058
GC12A_39	57	52	52.0	0.0036
GC12A_4	57	170	52.0	0.0065
GC12A_40	57	95	52.0	0.0040
GC12A_41	57	81	52.0	0.0036
GC12A_42	57	146	52.0	0.0041
GC12A_43	57	126	52.0	0.0046
GC12A_44	57	253	52.0	0.0070
GC12A_45	57	384	52.0	0.0125
GC12A_46	57	317	52.0	0.0147
GC12A_47	57	177	52.0	0.0102
GC12A_48	57	198	52.0	0.0073
GC12A_49	57	65	52.0	0.0030
GC12A_5	57	26	52.0	0.0010
GC12A_50	57	143	52.0	0.0052
GC12A_51	57	178	52.0	0.0076
GC12A_52	57	202	52.0	0.0064
GC12A_53	57	220	52.0	0.0083
GC12A_54	57	479	52.0	0.0149
GC12A_55	57	279	52.0	0.0087
GC12A_6	57	217	52.0	0.0076

GC12A_7	57	21	52.0	0.0007
GC12A_8	57	203	52.0	0.0089
GC12A_9	57	74	52.0	0.0028
GC15A_1	46	100	74.5	0.0056
GC15A_10	46	210	74.5	0.0297
GC15A_11	46	981	74.5	0.0303
GC15A_12	46	450	74.5	0.0173
GC15A_13	46	748	74.5	0.0271
GC15A_14	46	269	74.5	0.0254
GC15A_15	46	529	74.5	0.0140
GC15A_16	46	101	74.5	0.0191
GC15A_17	46	94	74.5	0.0132
GC15A_18	46	113	74.5	0.0190
GC15A_19	46	134	74.5	0.0201
GC15A_2	46	79	74.5	0.0247
GC15A_20	46	81	74.5	0.0287
GC15A_21	46	29	74.5	0.0201
GC15A_22	46	489	74.5	0.0200
GC15A_23	46	146	74.5	0.0271
GC15A_24	46	280	74.5	0.0135
GC15A_25	46	191	74.5	0.0108
GC15A_26	46	80	74.5	0.0060
GC15A_27	46	154	74.5	0.0125
GC15A_28	46	286	74.5	0.0188
GC15A_29	46	182	74.5	0.0128
GC15A_3	46	649	74.5	0.0179
GC15A_4	46	195	74.5	0.0153
GC15A_5	46	123	74.5	0.0097
GC15A_6	46	202	74.5	0.0131
GC15A_7	46	352	74.5	0.0115
GC15A_8	46	142	74.5	0.0252
GC15A_9	46	80	74.5	0.0254
GC15B_1	47	229	29.1	0.0097
GC15B_2	47	46	29.1	0.0025
GC15B_3	47	144	29.1	0.0049
GC15B_4	47	72	29.1	0.0039
GC15B_5	47	121	29.1	0.0033
GC15B_6	47	202	29.1	0.0023
GC15B_7	47	0	29.1	0.0007
GC15B_8	47	139	29.1	0.0016
GC16A_1	55	118	52.6	0.0049
GC16A_10	55	348	52.6	0.0103
GC16A_11	55	162	52.6	0.0095
GC16A_12	55	96	52.6	0.0076
GC16A_13	55	405	52.6	0.0038
GC16A_14	55	101	52.6	0.0065
GC16A_15	55	235	52.6	0.0076
GC16A_16	55	246	52.6	0.0101
GC16A_17	55	393	52.6	0.0076
GC16A_18	55	160	52.6	0.0021
GC16A_19	55	18	52.6	0.0032
GC16A_2	55	85	52.6	0.0030
GC16A_20	55	250	52.6	0.0105
GC16A_21	55	143	52.6	0.0068
GC16A_22	55	293	52.6	0.0073
GC16A_23	55	124	52.6	0.0035

GC16A_24	55	182	52.6	0.0095
GC16A_25	55	288	52.6	0.0092
GC16A_26	55	226	52.6	0.0088
GC16A_27	55	93	52.6	0.0034
GC16A_28	55	56	52.6	0.0027
GC16A_29	55	58	52.6	0.0034
GC16A_3	55	71	52.6	0.0037
GC16A_30	55	178	52.6	0.0054
GC16A_4	55	95	52.6	0.0041
GC16A_5	55	31	52.6	0.0019
GC16A_6	55	155	52.6	0.0062
GC16A_7	54	25	104.9	0.0015
GC16A_8	55	76	52.6	0.0019
GC16A_9	55	89	52.6	0.0029
GC16B_1	56	115	32.7	0.0085
GC16B_10	56	2675	32.7	0.0327
GC16B_11	56	362	32.7	0.0112
GC16B_12	56	110	32.7	0.0113
GC16B_13	56	215	32.7	0.0086
GC16B_14	56	461	32.7	0.0069
GC16B_15	56	39	32.7	0.0072
GC16B_16	56	232	32.7	0.0103
GC16B_17	56	216	32.7	0.0086
GC16B_18	56	40	32.7	0.0049
GC16B_2	56	35	32.7	0.0016
GC16B_3	56	99	32.7	0.0057
GC16B_4	56	76	32.7	0.0061
GC16B_5	56	20	32.7	0.0019
GC16B_6	56	62	32.7	0.0027
GC16B_7	56	110	32.7	0.0045
GC16B_8	56	244	32.7	0.0110
GC16B_9	56	142	32.7	0.0109
GC17A_1	54	67	104.9	0.0106
GC17A_10	54	45	104.9	0.0073
GC17A_11	54	26	104.9	0.0010
GC17A_12	54	3	104.9	0.0014
GC17A_13	54	421	104.9	0.0150
GC17A_14	54	62	104.9	0.0200
GC17A_15	54	182	104.9	0.0228
GC17A_16	54	46	104.9	0.0155
GC17A_17	54	184	104.9	0.0221
GC17A_18	54	16	104.9	0.0009
GC17A_19	54	208	104.9	0.0114
GC17A_2	54	260	104.9	0.0159
GC17A_20	54	19	104.9	0.0010
GC17A_21	54	44	104.9	0.0027
GC17A_22	54	150	104.9	0.0109
GC17A_23	54	5	104.9	0.0009
GC17A_24	54	64	104.9	0.0068
GC17A_25	54	34	104.9	0.0094
GC17A_26	54	174	104.9	0.0143
GC17A_27	54	431	104.9	0.0280
GC17A_28	54	43	104.9	0.0043
GC17A_29	54	440	104.9	0.0088
GC17A_3	54	39	104.9	0.0032
GC17A_30	54	463	104.9	0.0184

GC17A_31	54	366	104.9	0.0281
GC17A_32	54	87	104.9	0.0152
GC17A_33	54	42	104.9	0.0065
GC17A_34	54	109	104.9	0.0122
GC17A_35	54	226	104.9	0.0192
GC17A_36	54	197	104.9	0.0141
GC17A_37	54	94	104.9	0.0176
GC17A_38	54	77	104.9	0.0122
GC17A_39	54	422	104.9	0.0139
GC17A_4	54	289	104.9	0.0147
GC17A_40	54	147	104.9	0.0112
GC17A_41	54	31	104.9	0.0075
GC17A_42	54	34	104.9	0.0110
GC17A_43	54	88	104.9	0.0126
GC17A_44	54	171	104.9	0.0105
GC17A_45	54	162	104.9	0.0113
GC17A_46	54	60	104.9	0.0075
GC17A_47	54	195	104.9	0.0169
GC17A_48	54	242	104.9	0.0320
GC17A_49	54	162	104.9	0.0129
GC17A_5	54	8	104.9	0.0010
GC17A_50	54	312	104.9	0.0237
GC17A_51	54	335	104.9	0.0128
GC17A_52	54	385	104.9	0.0250
GC17A_53	54	233	104.9	0.0278
GC17A_54	54	254	104.9	0.0231
GC17A_55	54	17	104.9	0.0056
GC17A_6	54	63	104.9	0.0012
GC17A_7	54	209	104.9	0.0138
GC17A_8	54	171	104.9	0.0141
GC17A_9	54	474	104.9	0.0303
GC18_1	49	31	127.6	0.0058
GC18_2	49	118	127.6	0.0097
GC18_3	4	96	65.0	0.0031
GC18_4	49	156	127.6	0.0207
GC18_5	49	34	127.6	0.0041
GC18_6	4	73	65.0	0.0024
GC18_7	49	11	127.6	0.0108
GC18_8	49	77	127.6	0.0253
MC01A_1	40	0	97.9	0.0001
MC01A_10	40	233	97.9	0.0101
MC01A_11	40	147	97.9	0.0056
MC01A_12	40	78	97.9	0.0030
MC01A_13	40	137	97.9	0.0026
MC01A_14	40	137	97.9	0.0041
MC01A_2	40	44	97.9	0.0061
MC01A_3	40	0	97.9	0.0012
MC01A_4	40	210	97.9	0.0075
MC01A_5	40	131	97.9	0.0043
MC01A_6	40	13	97.9	0.0076
MC01A_7	40	146	97.9	0.0059
MC01A_8	40	3	97.9	0.0004
MC01A_9	40	163	97.9	0.0088
MC01B_1	40	219	97.9	0.0100
MC01B_4_3	38	19	61.9	0.0007
MC01B_4_4	38	56	61.9	0.0031

MC01B_5	38	48	61.9	0.0084
MC01B_6	38	89	61.9	0.0162
MC01B_7	38	256	61.9	0.0141
MC01B_8	38	226	61.9	0.0108
MC01B_9	38	176	61.9	0.0098
MC02_1	44	71	96.3	0.0171
MC02_10	44	204	96.3	0.0234
MC02_11	44	0	96.3	0.0025
MC02_12	44	77	96.3	0.0125
MC02_13	44	120	96.3	0.0173
MC02_14	44	137	96.3	0.0151
MC02_15	44	82	96.3	0.0121
MC02_16	44	196	96.3	0.0185
MC02_17	44	81	96.3	0.0180
MC02_18	44	84	96.3	0.0135
MC02_19	44	24	96.3	0.0130
MC02_2	44	81	96.3	0.0226
MC02_20	44	286	96.3	0.0110
MC02_21	44	125	96.3	0.0238
MC02_22	44	46	96.3	0.0115
MC02_23	44	89	96.3	0.0145
MC02_24	44	35	96.3	0.0101
MC02_25	44	33	96.3	0.0095
MC02_26	44	83	96.3	0.0082
MC02_27	44	207	96.3	0.0160
MC02_28	44	220	96.3	0.0126
MC02_29	44	170	96.3	0.0107
MC02_3	44	134	96.3	0.0111
MC02_30	44	87	96.3	0.0137
MC02_31	44	129	96.3	0.0173
MC02_32	44	199	96.3	0.0229
MC02_4	44	226	96.3	0.0297
MC02_5	44	57	96.3	0.0096
MC02_6	44	190	96.3	0.0250
MC02_7	44	61	96.3	0.0111
MC02_8	44	84	96.3	0.0203
MC02_9	44	56	96.3	0.0097
MC03_1	41	121	130.3	0.0197
MC03_10	41	2	130.3	0.0038
MC03_11	41	106	130.3	0.0193
MC03_12	41	79	130.3	0.0097
MC03_2	41	169	130.3	0.0127
MC03_3	41	134	130.3	0.0109
MC03_4	41	3	130.3	0.0020
MC03_5	41	148	130.3	0.0148
MC03_6	41	184	130.3	0.0176
MC03_7	41	3	130.3	0.0095
MC03_8	41	35	130.3	0.0078
MC03_9	41	62	130.3	0.0075
MC04A_1	39	413	87.2	0.0290
MC04A_10	39	58	87.2	0.0047
MC04A_100	39	119	87.2	0.0071
MC04A_11	39	90	87.2	0.0051
MC04A_2	39	302	87.2	0.0166
MC04A_3	39	13	87.2	0.0105
MC04A_4	39	264	87.2	0.0218

MC04A_5	39	29	87.2	0.0097
MC04A_6	39	175	87.2	0.0116
MC04A_7	39	136	87.2	0.0138
MC04A_8	39	220	87.2	0.0168
MC04A_9	39	134	87.2	0.0126
MC04A_9_1	39	49	87.2	0.0035
MC04C_1	42	266	101.0	0.0184
MC04C_2	42	116	101.0	0.0160
MC04C_3	42	0	101.0	0.0015
MC04C_4	42	238	101.0	0.0171
MC05_1	75	56	43.7	0.0350
MC05_10	75	6	43.7	0.0182
MC05_10_McEntireProduce	75	3585	43.7	0.0090
MC05_11	75	4	43.7	0.0182
MC05_2	75	8	43.7	0.0030
MC05_3	75	0	43.7	0.0002
MC05_4	75	254	43.7	0.0194
MC05_5	75	1574	43.7	0.0092
MC05_6	75	0	43.7	0.0015
MC05_7	75	0	43.7	0.0051
MC05_8	75	452	43.7	0.0247
MC05_9	75	986	43.7	0.0111
MC05B_1	75	0	43.7	0.0012
MC05B_2	75	0	43.7	0.0012
MC05B_3	75	4	43.7	0.0048
MC05B_4	4	285	65.0	0.0092
MC05B_5	75	41	43.7	0.0057
MC05B_6	75	404	43.7	0.0077
MC05B_7	75	1	43.7	0.0094
MC05B_8	75	0	43.7	0.0017
PFM03_1	63	177	59.8	0.0415
PFM03_10	63	67	59.8	0.0482
RB08B_37	58	45	55.7	0.0134
RB08B_38	58	60	55.7	0.0167
RB08B_39	58	501	55.7	0.0105
RB08B_4	58	245	55.7	0.0078
RB08B_40	58	20	55.7	0.0083
RB08B_5	58	359	55.7	0.0232
RB08B_6	58	358	55.7	0.0080
RB08B_7	58	387	55.7	0.0158
RB08B_8	58	43	55.7	0.0082
RB08B_9	58	0	55.7	0.0022
RB08E_1	1	66	76.7	0.0000
RB08E_10	1	58	76.7	0.0000
RB08E_11	1	175	76.7	0.0000
RB08E_12	1	223	76.7	0.0000
RB08E_13	1	65	76.7	0.0000
RB08E_14	1	137	76.7	0.0000
RB08E_15	1	130	76.7	0.0000
RB08E_16	1	7	76.7	0.0000
RB08E_17	1	135	76.7	0.0000
RB08E_18	1	106	76.7	0.0000
RB08E_19	1	242	76.7	0.0000
RB08E_2	1	231	76.7	0.0000
RB08E_20	1	173	76.7	0.0000
RB08E_21	1	149	76.7	0.0000

RB08E_22	1	79	76.7	0.0000
RB08E_23	1	91	76.7	0.0000
RB08E_24	1	19	76.7	0.0000
RB08E_25	1	15	76.7	0.0000
RB08E_26	1	135	76.7	0.0000
RB08E_27	1	91	76.7	0.0000
RB08E_28	1	149	76.7	0.0000
RB08E_29	1	264	76.7	0.0000
RB08E_3	1	36	76.7	0.0000
RB08E_30	1	2	76.7	0.0000
RB08E_31	1	7	76.7	0.0000
RB08E_32	1	142	76.7	0.0000
RB08E_33	1	127	76.7	0.0000
RB08E_34	1	98	76.7	0.0000
RB08E_35	1	353	76.7	0.0000
RB08E_36	1	74	76.7	0.0000
RB08E_37	1	96	76.7	0.0000
RB08E_38	1	27	76.7	0.0000
RB08E_39	1	7	76.7	0.0000
RB08E_4	1	181	76.7	0.0000
RB08E_40	1	70	76.7	0.0000
RB08E_41	1	219	76.7	0.0000
RB08E_42	1	143	76.7	0.0000
RB08E_42_LindauChemicals	1	292	76.7	0.0000
RB08E_5	1	111	76.7	0.0000
RB08E_6	1	55	76.7	0.0000
RB08E_7	1	125	76.7	0.0000
RB08E_8	1	67	76.7	0.0000
RB08E_9	1	24	76.7	0.0000
SB01B_1	14	141	48.1	0.0109
SR08_11	35	91	67.9	0.0147
SR08_12	35	200	67.9	0.0190
SR08_13	35	18	67.9	0.0224
SR08_14	35	143	67.9	0.0253
SR08_15	35	185	67.9	0.0218
SR08_2	35	140	67.9	0.0231
SR08_3	35	0	67.9	0.0012
SR08_4	35	74	67.9	0.0089
SR08_5	35	171	67.9	0.0204
SR08_6	35	49	67.9	0.0083
SR08_7	35	132	67.9	0.0091
SR08_8	35	77	67.9	0.0114
SR08_9	35	190	67.9	0.0300
SR09_1	29	252	17.1	0.0000
SR09_10	29	213	17.1	0.0000
SR09_11	29	37	17.1	0.0000
SR09_12	29	136	17.1	0.0000
SR09_13	29	119	17.1	0.0000
SR09_14	29	78	17.1	0.0000
SR09_15	29	97	17.1	0.0000
PFM03_11	63	134	59.8	0.0399
PFM03_12	63	113	59.8	0.0314
PFM03_2	63	167	59.8	0.0330
PFM03_3	63	21	59.8	0.0087
PFM03_4	63	18	59.8	0.0205
PFM03_5	63	388	59.8	0.0213

PFM03_6	63	912	59.8	0.0297
PFM03_7	63	30	59.8	0.0113
PFM03_8	63	45	59.8	0.0137
PFM03_9	63	145	59.8	0.0468
PFM04_1	59	490	76.9	0.0249
PFM04_10	59	0	76.9	0.0031
PFM04_11	59	1	76.9	0.0064
PFM04_12	59	382	76.9	0.0425
PFM04_13	59	588	76.9	0.0197
PFM04_14	59	246	76.9	0.0324
PFM04_15	59	419	76.9	0.0377
PFM04_16	59	125	76.9	0.0295
PFM04_17	59	149	76.9	0.0273
PFM04_18	59	163	76.9	0.0278
PFM04_19	59	89	76.9	0.0277
PFM04_2	59	319	76.9	0.0318
PFM04_20	59	252	76.9	0.0308
PFM04_21	59	58	76.9	0.0181
PFM04_22	59	1	76.9	0.0100
PFM04_3	59	218	76.9	0.0305
PFM04_4	59	103	76.9	0.0234
PFM04_5	59	0	76.9	0.0012
PFM04_6	59	8	76.9	0.0374
PFM04_7	59	2	76.9	0.0055
PFM04_8	59	2	76.9	0.0012
PFM04_9	59	15	76.9	0.0027
PFM05_1	67	145	51.3	0.0250
PFM05_10	67	601	51.3	0.0229
PFM05_11	67	261	51.3	0.0218
PFM05_12	67	53	51.3	0.0128
PFM05_3	67	6	51.3	0.0070
PFM05_4	67	167	51.3	0.0131
PFM05_5	67	145	51.3	0.0265
PFM05_7	67	99	51.3	0.0173
PFM05_8	67	35	51.3	0.0197
PFM05_9	67	185	51.3	0.0134
PFM06_1	52	385	151.8	0.0264
PFM06_10	52	137	151.8	0.0159
PFM06_11	52	247	151.8	0.0257
PFM06_12	52	108	151.8	0.0102
PFM06_13	52	216	151.8	0.0182
PFM06_14	52	124	151.8	0.0084
PFM06_2	52	103	151.8	0.0115
PFM06_3	52	70	151.8	0.0087
PFM06_4	52	211	151.8	0.0183
PFM06_5	52	53	151.8	0.0089
PFM06_6	52	11	151.8	0.0023
PFM06_7	52	159	151.8	0.0098
PFM06_8	52	44	151.8	0.0037
PFM06_9	52	20	151.8	0.0032
PFM07_1	76	8829	85.0	0.2868
PFM10_1	74	26153	65.0	0.8292
PFM11_1	7	97	61.8	0.0222
PFM11_10	7	55	61.8	0.0130
PFM11_11	7	0	61.8	0.0025
PFM11_12	7	75	61.8	0.0123

PFM11_13	7	54	61.8	0.0078
PFM11_14	7	0	61.8	0.0121
PFM11_15	7	0	61.8	0.0017
PFM11_16	7	83	61.8	0.0092
PFM11_17	7	160	61.8	0.0072
PFM11_18	7	95	61.8	0.0116
PFM11_2	7	2	61.8	0.0034
PFM11_3	7	11	61.8	0.0070
PFM11_4	7	0	61.8	0.0037
PFM11_5	7	84	61.8	0.0131
PFM11_6	7	82	61.8	0.0352
PFM11_7	7	68	61.8	0.0108
PFM11_8	7	79	61.8	0.0198
PFM11_9	7	31	61.8	0.0076
PMFZoo_1	66	969	77.2	0.0495
PMFZoo_10	66	182	77.2	0.0323
PMFZoo_11	66	308	77.2	0.0312
PMFZoo_12	66	551	77.2	0.0301
PMFZoo_13	66	88	77.2	0.0360
PMFZoo_14	66	23	77.2	0.0403
PMFZoo_15	66	389	77.2	0.0309
PMFZoo_16	66	0	77.2	0.0020
PMFZoo_17	66	0	77.2	0.0037
PMFZoo_2	66	688	77.2	0.0493
PMFZoo_4	66	38	77.2	0.0032
PMFZoo_5	66	35	77.2	0.0259
PMFZoo_6	66	202	77.2	0.0369
PMFZoo_7	66	181	77.2	0.0261
PMFZoo_8	66	370	77.2	0.0328
PMFZoo_9	66	22	77.2	0.0344
RB01_1	60	415	60.2	0.0079
RB01_10	60	56	60.2	0.0021
RB01_11	60	68	60.2	0.0013
RB01_12	60	5	60.2	0.0035
RB01_13	60	11	60.2	0.0009
RB01_14	60	4	60.2	0.0021
RB01_15	60	28	60.2	0.0021
RB01_16	60	325	60.2	0.0178
RB01_17	60	227	60.2	0.0142
RB01_18	60	177	60.2	0.0175
RB01_19	60	352	60.2	0.0152
RB01_2	60	256	60.2	0.0070
RB01_20	60	201	60.2	0.0209
RB01_21	60	535	60.2	0.0190
RB01_22	60	262	60.2	0.0127
RB01_23	60	268	60.2	0.0175
RB01_24	60	242	60.2	0.0158
RB01_25	60	114	60.2	0.0111
RB01_26	60	64	60.2	0.0077
RB01_27	60	95	60.2	0.0013
RB01_28	60	37	60.2	0.0011
RB01_29	60	262	60.2	0.0097
RB01_3	60	414	60.2	0.0228
RB01_30	60	88	60.2	0.0055
RB01_31	60	230	60.2	0.0168
RB01_32	60	257	60.2	0.0178

RB01_33	60	85	60.2	0.0047
RB01_34	60	108	60.2	0.0031
RB01_35	60	6	60.2	0.0011
RB01_36	60	1	60.2	0.0019
RB01_37	60	28	60.2	0.0028
RB01_38	60	2	60.2	0.0016
RB01_39	60	42	60.2	0.0051
RB01_4	60	516	60.2	0.0275
RB01_40	60	118	60.2	0.0113
RB01_41	60	237	60.2	0.0180
RB01_42	60	176	60.2	0.0178
RB01_43	60	220	60.2	0.0170
RB01_44	60	125	60.2	0.0110
RB01_45	60	188	60.2	0.0118
RB01_46	60	1577	60.2	0.0192
RB01_47	60	1654	60.2	0.0185
RB01_48	60	393	60.2	0.0168
RB01_49	60	299	60.2	0.0198
RB01_5	60	185	60.2	0.0120
RB01_50	60	306	60.2	0.0194
RB01_51	60	171	60.2	0.0181
RB01_52	60	566	60.2	0.0189
RB01_53	60	206	60.2	0.0192
RB01_54	60	343	60.2	0.0192
RB01_55	60	253	60.2	0.0215
RB01_56	60	747	60.2	0.0276
RB01_57	60	23	60.2	0.0045
RB01_58	60	39	60.2	0.0037
RB01_59	60	42	60.2	0.0015
RB01_6	60	229	60.2	0.0145
RB01_60	60	251	60.2	0.0226
RB01_61	60	217	60.2	0.0126
RB01_62	60	167	60.2	0.0018
RB01_63	60	382	60.2	0.0168
RB01_64	60	2086	60.2	0.0145
RB01_65	60	1048	60.2	0.0111
RB01_66	60	410	60.2	0.0118
RB01_67	60	16	60.2	0.0011
RB01_68	60	364	60.2	0.0009
RB01_69	60	4	60.2	0.0017
RB01_7	60	217	60.2	0.0110
RB01_70	60	3	60.2	0.0034
RB01_71	60	90	60.2	0.0012
RB01_72	60	2	60.2	0.0010
RB01_73	60	4	60.2	0.0008
RB01_74	60	17	60.2	0.0019
RB01_75	60	35	60.2	0.0025
RB01_76	60	35	60.2	0.0029
RB01_77	60	55	60.2	0.0025
RB01_78	60	84	60.2	0.0035
RB01_79	60	85	60.2	0.0112
RB01_8	60	268	60.2	0.0148
RB01_80	60	935	60.2	0.0092
RB01_81	60	385	60.2	0.0144
RB01_82	60	80	60.2	0.0141
RB01_83	60	533	60.2	0.0118

RB01_84	60	151	60.2	0.0148
RB01_85	60	49	60.2	0.0162
RB01_86	60	208	60.2	0.0152
RB01_87	60	142	60.2	0.0158
RB01_9	60	30	60.2	0.0014
RB03A_1	71	1190	16.2	0.0290
RB03A_2	71	12	16.2	0.0019
RB03A_3	71	78	16.2	0.0163
RB03A_4	71	319	16.2	0.0228
RB03A_5	71	701	16.2	0.0257
RB03A_6	71	700	16.2	0.0242
RB03A_7	71	63	16.2	0.0241
RB03B_1	64	454	58.3	0.0288
RB03B_10	64	325	58.3	0.0353
RB03B_11	64	137	58.3	0.0094
RB03B_12	64	696	58.3	0.0116
RB03B_13	64	1984	58.3	0.0414
RB03B_14	64	674	58.3	0.0363
RB03B_15	64	521	58.3	0.0398
RB03B_2	64	59	58.3	0.0055
RB03B_3	64	625	58.3	0.0319
RB03B_4	64	942	58.3	0.0084
RB03B_5_USC_ColonialLifeCenter	64	353	58.3	0.0062
RB03B_6	64	186	58.3	0.0167
RB03B_7	64	511	58.3	0.0208
RB03B_8	64	402	58.3	0.0434
RB03B_9	64	1877	58.3	0.0336
RB04_1	65	79	22.9	0.0384
RB04_10	65	59	22.9	0.0158
RB04_11	65	53	22.9	0.0070
RB04_12	65	82	22.9	0.0177
RB04_13	65	266	22.9	0.0275
RB04_14	65	280	22.9	0.0277
RB04_15	65	4452	22.9	0.0419
RB04_2	65	66	22.9	0.0194
RB04_3	65	44	22.9	0.0051
RB04_4	65	1	22.9	0.0031
RB04_5	65	19	22.9	0.0037
RB04_6	65	21	22.9	0.0025
RB04_7	65	23	22.9	0.0048
RB04_8	65	221	22.9	0.0323
RB04_9	65	123	22.9	0.0277
RB05A_1	62	81	30.3	0.0372
RB05A_10	62	11	30.3	0.0064
RB05A_11	62	115	30.3	0.0011
RB05A_2	62	10	30.3	0.0290
RB05A_3	62	294	30.3	0.0411
RB05A_4	62	366	30.3	0.0321
RB05A_5	62	390	30.3	0.0352
RB05A_6	62	96	30.3	0.0242
RB05A_7	62	11	30.3	0.0317
RB05A_8	62	16	30.3	0.0232
RB05A_9	62	247	30.3	0.0370
RB05B_1	61	1	38.0	0.0097
RB05B_10	61	567	38.0	0.0076
RB05B_11	61	859	38.0	0.0157

RB05B_12	61	61	38.0	0.0062
RB05B_13	61	429	38.0	0.0358
RB05B_14	61	20	38.0	0.0055
RB05B_15	61	265	38.0	0.0033
RB05B_2	61	1437	38.0	0.0189
RB05B_3	61	652	38.0	0.0082
RB05B_4	61	1023	38.0	0.0071
RB05B_5	61	8	38.0	0.0017
RB05B_6	61	393	38.0	0.0253
RB05B_7	61	506	38.0	0.0045
RB05B_8	61	1	38.0	0.0029
RB05B_9	61	1	38.0	0.0027
RB06_1	4	262	65.0	0.0000
RB06_10	4	4	65.0	0.0000
RB06_11	4	0	65.0	0.0000
RB06_12	4	60	65.0	0.0000
RB06_2	4	344	65.0	0.0000
RB06_3	4	23	65.0	0.0000
RB06_4	4	252	65.0	0.0000
RB06_5	4	166	65.0	0.0000
RB06_6	4	43	65.0	0.0000
RB06_7	4	24	65.0	0.0000
RB06_8	4	26	65.0	0.0000
RB06_9	4	18	65.0	0.0000
RB08B_1	58	23	55.7	0.0143
RB08B_10	58	406	55.7	0.0149
RB08B_11	58	123	55.7	0.0029
RB08B_12	58	99	55.7	0.0021
RB08B_13	58	62	55.7	0.0017
RB08B_14	58	193	55.7	0.0072
RB08B_15	58	44	55.7	0.0107
RB08B_16	58	15	55.7	0.0034
RB08B_17	58	30	55.7	0.0111
RB08B_18	58	18	55.7	0.0068
RB08B_19	58	9	55.7	0.0020
RB08B_2	58	131	55.7	0.0148
RB08B_20	58	14	55.7	0.0033
RB08B_21	58	2	55.7	0.0014
RB08B_22	58	114	55.7	0.0081
RB08B_23	58	144	55.7	0.0075
RB08B_24	58	58	55.7	0.0106
RB08B_25	58	138	55.7	0.0140
RB08B_26	58	1	55.7	0.0184
RB08B_27	58	40	55.7	0.0152
RB08B_28	58	1	55.7	0.0168
RB08B_29	58	230	55.7	0.0151
RB08B_3	58	2	55.7	0.0036
RB08B_30	58	14	55.7	0.0122
RB08B_31	58	35	55.7	0.0093
RB08B_32	58	231	55.7	0.0126
RB08B_33	58	14	55.7	0.0089
RB08B_34	58	37	55.7	0.0167
RB08B_35	58	17	55.7	0.0141
RB08B_36	58	35	55.7	0.0102
SB01B_10	14	89	48.1	0.0069
SB01B_11	14	53	48.1	0.0061

SB01B_12	14	94	48.1	0.0139
SB01B_13	14	17	48.1	0.0133
SB01B_14	14	152	48.1	0.0142
SB01B_15	14	81	48.1	0.0134
SB01B_16	14	146	48.1	0.0133
SB01B_17	14	27	48.1	0.0063
SB01B_18	14	91	48.1	0.0068
SB01B_19	14	14	48.1	0.0059
SB01B_2	14	194	48.1	0.0182
SB01B_20	14	46	48.1	0.0055
SB01B_21	14	206	48.1	0.0062
SB01B_22	14	38	48.1	0.0114
SB01B_23	14	12	48.1	0.0096
SB01B_24	14	117	48.1	0.0102
SB01B_25	14	436	48.1	0.0083
SB01B_26	14	9	48.1	0.0023
SB01B_27	14	184	48.1	0.0114
SB01B_3	14	19	48.1	0.0082
SB01B_4	14	206	48.1	0.0086
SB01B_5	14	232	48.1	0.0137
SB01B_6	14	116	48.1	0.0104
SB01B_7	14	399	48.1	0.0050
SB01B_8	14	99	48.1	0.0070
SB01B_9	14	0	48.1	0.0003
SB02_1	16	1382	47.3	0.0131
SB02_10	16	322	47.3	0.0061
SB02_11	16	5	47.3	0.0107
SB02_12	16	19	47.3	0.0106
SB02_13	16	628	47.3	0.0052
SB02_14	16	6	47.3	0.0167
SB02_15	16	122	47.3	0.0079
SB02_16	16	250	47.3	0.0071
SB02_17	16	420	47.3	0.0086
SB02_18	16	210	47.3	0.0079
SB02_19	16	50	47.3	0.0047
SB02_2	16	39	47.3	0.0015
SB02_20	16	137	47.3	0.0097
SB02_21	16	271	47.3	0.0109
SB02_22	16	3	47.3	0.0088
SB02_23	16	50	47.3	0.0080
SB02_24	16	31	47.3	0.0030
SB02_25	16	82	47.3	0.0046
SB02_26	16	3	47.3	0.0084
SB02_3	16	19	47.3	0.0018
SB02_4	16	25	47.3	0.0043
SB02_5	16	145	47.3	0.0067
SB02_6	16	159	47.3	0.0066
SB02_7	16	39	47.3	0.0120
SB02_8	16	251	47.3	0.0111
SB02_9	16	110	47.3	0.0091
SB02B_1	15	123	64.7	0.0201
SB02B_10	15	239	64.7	0.0200
SB02B_2	15	165	64.7	0.0283
SB02B_3	15	3	64.7	0.0084
SB02B_4	15	136	64.7	0.0199
SB02B_5	15	181	64.7	0.0223

SB02B_6	15	269	64.7	0.0150
SB02B_7	15	333	64.7	0.0190
SB02B_8	15	167	64.7	0.0199
SB02B_9	15	138	64.7	0.0175
SB03A_1	17	10	69.3	0.0018
SB03A_10	17	23	69.3	0.0112
SB03A_11	17	155	69.3	0.0131
SB03A_12	17	54	69.3	0.0109
SB03A_13	17	60	69.3	0.0114
SB03A_14	17	168	69.3	0.0154
SB03A_15	17	74	69.3	0.0096
SB03A_16	17	147	69.3	0.0146
SB03A_17	17	143	69.3	0.0162
SB03A_18	17	81	69.3	0.0093
SB03A_19	17	288	69.3	0.0070
SB03A_2	17	54	69.3	0.0080
SB03A_20	17	45	69.3	0.0035
SB03A_3	17	621	69.3	0.0044
SB03A_4	17	72	69.3	0.0270
SB03A_4_RichlandHospital	17	3687	69.3	0.0000
SB03A_5	17	146	69.3	0.0104
SB03A_6	17	124	69.3	0.0045
SB03A_7	17	16	69.3	0.0136
SB03A_8	17	379	69.3	0.0114
SB03A_9	17	276	69.3	0.0077
SB03B_1	13	43	110.8	0.0211
SB03B_2	13	185	110.8	0.0376
SB03B_3	13	147	110.8	0.0307
SB03B_4	13	177	110.8	0.0314
SB04B_1	18	140	21.5	0.0074
SB04B_10	18	107	21.5	0.0056
SB04B_11	18	153	21.5	0.0054
SB04B_12	18	31	21.5	0.0062
SB04B_13	18	219	21.5	0.0064
SB04B_14	18	130	21.5	0.0061
SB04B_15	18	139	21.5	0.0071
SB04B_16	18	75	21.5	0.0060
SB04B_17	18	108	21.5	0.0063
SB04B_18	18	190	21.5	0.0091
SB04B_19	18	128	21.5	0.0059
SB04B_2	18	67	21.5	0.0042
SB04B_20	18	2	21.5	0.0007
SB04B_3	18	133	21.5	0.0068
SB04B_4	18	25	21.5	0.0014
SB04B_5	18	35	21.5	0.0010
SB04B_6	18	179	21.5	0.0098
SB04B_7	18	27	21.5	0.0009
SB04B_8	18	176	21.5	0.0068
SB04B_9	18	310	21.5	0.0072
SB04C_1	19	52	74.6	0.0071
SB04E_1	20	124	132.5	0.0210
SB04E_2	20	22	132.5	0.0036
SB05A_1	21	128	188.5	0.0104
SB05A_10	21	80	188.5	0.0140
SB05A_11	21	123	188.5	0.0169
SB05A_12	21	5	188.5	0.0085

SB05A_13	21	68	188.5	0.0087
SB05A_14	21	467	188.5	0.0123
SB05A_15	21	8	188.5	0.0189
SB05A_16	21	61	188.5	0.0162
SB05A_17	21	99	188.5	0.0143
SB05A_18	21	328	188.5	0.0199
SB05A_19	21	66	188.5	0.0157
SB05A_2	21	21	188.5	0.0024
SB05A_20	21	7	188.5	0.0142
SB05A_21	21	27	188.5	0.0094
SB05A_22	21	36	188.5	0.0047
SB05A_23	21	40	188.5	0.0052
SB05A_24	21	32	188.5	0.0039
SB05A_25	21	128	188.5	0.0154
SB05A_26	21	200	188.5	0.0166
SB05A_27	21	92	188.5	0.0135
SB05A_28	21	148	188.5	0.0176
SB05A_29	21	126	188.5	0.0183
SB05A_3	21	22	188.5	0.0052
SB05A_30	21	103	188.5	0.0119
SB05A_31	21	49	188.5	0.0139
SB05A_32	21	86	188.5	0.0025
SB05A_33	21	10	188.5	0.0013
SB05A_34	21	14	188.5	0.0037
SB05A_35	21	17	188.5	0.0054
SB05A_36	21	262	188.5	0.0173
SB05A_4	21	25	188.5	0.0042
SB05A_5	21	41	188.5	0.0084
SB05A_6	21	42	188.5	0.0048
SB05A_7	21	15	188.5	0.0048
SB05A_8	21	41	188.5	0.0131
SB05A_9	21	95	188.5	0.0104
SR01_1	32	254	62.4	0.0057
SR01_10	32	181	62.4	0.0118
SR01_11	32	161	62.4	0.0158
SR01_12	32	69	62.4	0.0118
SR01_13	32	417	62.4	0.0228
SR01_14	32	230	62.4	0.0163
SR01_15	32	45	62.4	0.0022
SR01_16	32	193	62.4	0.0146
SR01_17	32	163	62.4	0.0132
SR01_18	32	146	62.4	0.0102
SR01_19	32	80	62.4	0.0064
SR01_2	32	12	62.4	0.0074
SR01_20	32	98	62.4	0.0061
SR01_21	32	190	62.4	0.0145
SR01_22	32	193	62.4	0.0108
SR01_23	32	248	62.4	0.0171
SR01_24	32	111	62.4	0.0089
SR01_25	32	26	62.4	0.0046
SR01_3	32	7	62.4	0.0017
SR01_4	32	95	62.4	0.0044
SR01_5	32	29	62.4	0.0034
SR01_6	32	22	62.4	0.0014
SR01_7	32	11	62.4	0.0055
SR01_8	32	159	62.4	0.0083

SR01_9	32	202	62.4	0.0154
SR04A_1	26	158	65.5	0.0085
SR04A_10	26	58	65.5	0.0042
SR04A_11	26	69	65.5	0.0028
SR04A_12	26	93	65.5	0.0027
SR04A_13	26	211	65.5	0.0071
SR04A_14	26	282	65.5	0.0063
SR04A_15	26	159	65.5	0.0062
SR04A_16	26	174	65.5	0.0040
SR04A_17	26	192	65.5	0.0059
SR04A_18	26	181	65.5	0.0043
SR04A_19	26	161	65.5	0.0047
SR04A_2	26	44	65.5	0.0033
SR04A_20	26	244	65.5	0.0047
SR04A_21	26	141	65.5	0.0037
SR04A_22	26	198	65.5	0.0060
SR04A_23	26	77	65.5	0.0035
SR04A_24	26	71	65.5	0.0030
SR04A_25	26	108	65.5	0.0054
SR04A_26	26	99	65.5	0.0031
SR04A_27	26	152	65.5	0.0048
SR04A_3	26	98	65.5	0.0039
SR04A_4	26	112	65.5	0.0049
SR04A_5	26	23	65.5	0.0010
SR04A_6	26	91	65.5	0.0031
SR04A_7	26	70	65.5	0.0026
SR04A_8	26	242	65.5	0.0080
SR04A_9	26	88	65.5	0.0024
SR04B_1	27	580	70.6	0.0163
SR04B_10	27	160	70.6	0.0113
SR04B_11	27	31	70.6	0.0123
SR04B_12	27	906	70.6	0.0139
SR04B_13	27	141	70.6	0.0150
SR04B_14	27	61	70.6	0.0101
SR04B_15	27	35	70.6	0.0064
SR04B_2	27	4	70.6	0.0158
SR04B_3	27	1205	70.6	0.0171
SR04B_4	27	260	70.6	0.0092
SR04B_5	27	269	70.6	0.0041
SR04B_6	27	34	70.6	0.0050
SR04B_7	27	806	70.6	0.0170
SR04B_8	27	221	70.6	0.0024
SR04B_9	27	774	70.6	0.0136
SR06_1	31	185	81.0	0.0066
SR06_10	31	144	81.0	0.0041
SR06_11	31	76	81.0	0.0028
SR06_12	31	150	81.0	0.0052
SR06_2	31	135	81.0	0.0044
SR06_3	31	116	81.0	0.0039
SR06_4	31	103	81.0	0.0036
SR06_5	31	87	81.0	0.0033
SR06_6	31	57	81.0	0.0031
SR06_7	31	184	81.0	0.0048
SR06_8	31	90	81.0	0.0043
SR06_9	31	110	81.0	0.0031
SR07_1	33	83	46.9	0.0023

SR07_10	33	115	46.9	0.0024
SR07_11	33	4	46.9	0.0001
SR07_12	33	154	46.9	0.0024
SR07_13	33	13	46.9	0.0002
SR07_14	33	161	46.9	0.0026
SR07_15	33	87	46.9	0.0015
SR07_16	33	153	46.9	0.0021
SR07_17	33	220	46.9	0.0032
SR07_18	33	131	46.9	0.0024
SR07_19	33	147	46.9	0.0013
SR07_2	33	137	46.9	0.0020
SR07_20	33	150	46.9	0.0031
SR07_21	33	91	46.9	0.0011
SR07_22	33	140	46.9	0.0015
SR07_23	33	225	46.9	0.0024
SR07_24	33	225	46.9	0.0033
SR07_25	33	13	46.9	0.0021
SR07_26	33	172	46.9	0.0020
SR07_27	33	252	46.9	0.0036
SR07_28	33	117	46.9	0.0029
SR07_29	33	87	46.9	0.0015
SR07_3	33	206	46.9	0.0014
SR07_30	33	81	46.9	0.0012
SR07_31	33	121	46.9	0.0018
SR07_32	33	300	46.9	0.0020
SR07_33	33	140	46.9	0.0026
SR07_34	33	69	46.9	0.0014
SR07_4	33	32	46.9	0.0005
SR07_5	33	1	46.9	0.0001
SR07_6	33	210	46.9	0.0023
SR07_7	33	4	46.9	0.0001
SR07_8	33	62	46.9	0.0009
SR07_9	33	21	46.9	0.0002
SR08_1	35	129	67.9	0.0200
SR08_10	35	35	67.9	0.0059
SR09_16	29	244	17.1	0.0000
SR09_17	29	130	17.1	0.0000
SR09_18	29	259	17.1	0.0000
SR09_2	29	41	17.1	0.0000
SR09_3	29	143	17.1	0.0000
SR09_4	29	171	17.1	0.0000
SR09_5	29	203	17.1	0.0000
SR09_6	29	219	17.1	0.0000
SR09_7	29	30	17.1	0.0000
SR09_8	29	12	17.1	0.0000
SR09_9	29	102	17.1	0.0000
SR11_1	28	469	70.0	0.0127
SR11_10	28	44	70.0	0.0064
SR11_11	28	172	70.0	0.0035
SR11_12	28	3	70.0	0.0007
SR11_13	28	85	70.0	0.0092
SR11_14	28	8	70.0	0.0038
SR11_15	28	161	70.0	0.0071
SR11_16	28	66	70.0	0.0086
SR11_17	28	126	70.0	0.0125
SR11_18	28	65	70.0	0.0086

SR11_19	28	219	70.0	0.0240
SR11_2	28	43	70.0	0.0054
SR11_20	28	331	70.0	0.0287
SR11_21	28	451	70.0	0.0131
SR11_22	28	142	70.0	0.0121
SR11_23	28	685	70.0	0.0218
SR11_24	28	178	70.0	0.0275
SR11_25	28	243	70.0	0.0188
SR11_26	28	139	70.0	0.0090
SR11_27	28	20	70.0	0.0103
SR11_3	28	115	70.0	0.0127
SR11_4	28	29	70.0	0.0052
SR11_5	28	146	70.0	0.0118
SR11_6	28	12	70.0	0.0019
SR11_7	28	15	70.0	0.0023
SR11_8	28	181	70.0	0.0181
SR11_9	28	97	70.0	0.0123
SR13_1	37	219	93.8	0.0235
SR13_10	37	96	93.8	0.0106
SR13_11	37	79	93.8	0.0108
SR13_12	37	384	93.8	0.0110
SR13_2	37	312	93.8	0.0000
SR13_3	37	0	93.8	0.0000
SR13_4	37	86	93.8	0.0080
SR13_5	37	189	93.8	0.0163
SR13_6	37	138	93.8	0.0171
SR13_7	37	165	93.8	0.0143
SR13_8	37	153	93.8	0.0161
SR13_9	37	137	93.8	0.0162
SR14A_1	36	47	40.6	0.0096
SR14A_2	36	5	40.6	0.0003
SR14A_3	36	137	40.6	0.0030
SR14A_4	36	0	40.6	0.0002
SR14A_5	36	0	40.6	0.0011
SR14A_6	36	0	40.6	0.0009
SR14B_1	34	129	27.1	0.0000
SR14B_2	34	0	27.1	0.0000
SR14B_3	34	258	27.1	0.0000
SR14B_4	34	141	27.1	0.0000
SR14B_5	34	0	27.1	0.0000
SR14B_6	34	0	27.1	0.0000
SR14C_1	31	15	81.0	0.0009
SR14C_10	31	9	81.0	0.0006
SR14C_11	31	4	81.0	0.0002
SR14C_12	31	19	81.0	0.0011
SR14C_13	31	193	81.0	0.0052
SR14C_14	31	65	81.0	0.0030
SR14C_15	31	154	81.0	0.0041
SR14C_16	31	10	81.0	0.0008
SR14C_17	31	89	81.0	0.0049
SR14C_18	31	108	81.0	0.0043
SR14C_19	31	146	81.0	0.0055
SR14C_2	31	5	81.0	0.0006
SR14C_20	31	94	81.0	0.0030
SR14C_21	31	67	81.0	0.0027
SR14C_22	31	14	81.0	0.0017

SR14C_23	31	634	81.0	0.0083
SR14C_24	31	79	81.0	0.0040
SR14C_25	31	221	81.0	0.0084
SR14C_26	31	398	81.0	0.0056
SR14C_27	31	221	81.0	0.0062
SR14C_28	31	50	81.0	0.0020
SR14C_3	31	0	81.0	0.0003
SR14C_4	31	112	81.0	0.0039
SR14C_5	31	26	81.0	0.0011
SR14C_6	31	0	81.0	0.0006
SR14C_7	31	87	81.0	0.0020
SR14C_8	31	141	81.0	0.0057
SR14C_9	31	3	81.0	0.0005
SR15_1	30	222	83.0	0.0137
SR15_10	30	18	83.0	0.0016
SR15_11	30	107	83.0	0.0075
SR15_12	30	52	83.0	0.0044
SR15_13	30	47	83.0	0.0080
SR15_14	30	135	83.0	0.0088
SR15_15	30	101	83.0	0.0117
SR15_16	30	52	83.0	0.0046
SR15_17	30	120	83.0	0.0079
SR15_18	30	184	83.0	0.0127
SR15_19	30	163	83.0	0.0109
SR15_2	30	2	83.0	0.0011
SR15_20	30	108	83.0	0.0103
SR15_21	30	28	83.0	0.0033
SR15_22	30	27	83.0	0.0044
SR15_3	30	308	83.0	0.0097
SR15_4	30	45	83.0	0.0071
SR15_5	30	129	83.0	0.0101
SR15_6	30	0	83.0	0.0002
SR15_7	30	18	83.0	0.0063
SR15_8	30	37	83.0	0.0046
SR15_9	30	123	83.0	0.0117
SRPump_1	1	23	76.7	0.0000
WC01_1	69	56	103.6	0.0066
WC01_10	69	17	103.6	0.0080
WC01_11	69	5	103.6	0.0008
WC01_12	69	12	103.6	0.0070
WC01_13	69	37	103.6	0.0131
WC01_14	69	168	103.6	0.0115
WC01_15	69	171	103.6	0.0081
WC01_16	69	133	103.6	0.0127
WC01_17	69	16	103.6	0.0103
WC01_18	69	78	103.6	0.0102
WC01_19	69	56	103.6	0.0094
WC01_2	69	462	103.6	0.0008
WC01_20	69	4	103.6	0.0077
WC01_21	69	794	103.6	0.0134
WC01_22	69	58	103.6	0.0093
WC01_23	69	74	103.6	0.0085
WC01_24	69	64	103.6	0.0078
WC01_25	69	62	103.6	0.0094
WC01_26	69	154	103.6	0.0077
WC01_27	69	88	103.6	0.0082

WC01_28	69	4	103.6	0.0070
WC01_29	69	76	103.6	0.0107
WC01_3	69	0	103.6	0.0024
WC01_30	69	37	103.6	0.0085
WC01_31	69	250	103.6	0.0103
WC01_32	69	12	103.6	0.0116
WC01_3_HouseOfRaeford	69	8519	103.6	0.0005
WC01_4	69	62	103.6	0.0075
WC01_5	69	9	103.6	0.0082
WC01_6	69	8	103.6	0.0015
WC01_7	69	2	103.6	0.0003
WC01_8	69	2	103.6	0.0003
WC01_9	69	45	103.6	0.0075
WC01B_1	69	252	103.6	0.0099
WC01B_10	69	132	103.6	0.0036
WC01B_11	69	221	103.6	0.0071
WC01B_12	69	2	103.6	0.0061
WC01B_13	69	185	103.6	0.0048
WC01B_14	69	40	103.6	0.0038
WC01B_15	69	56	103.6	0.0053
WC01B_16	69	62	103.6	0.0057
WC01B_17	69	76	103.6	0.0061
WC01B_18	69	60	103.6	0.0055
WC01B_19	69	48	103.6	0.0027
WC01B_2	69	6	103.6	0.0055
WC01B_20	69	62	103.6	0.0064
WC01B_21	69	28	103.6	0.0066
WC01B_22	69	267	103.6	0.0044
WC01B_23	69	40	103.6	0.0014
WC01B_24	69	26	103.6	0.0019
WC01B_25	69	197	103.6	0.0067
WC01B_26	72	1	38.4	0.0004
WC01B_27	69	56	103.6	0.0059
WC01B_28	69	99	103.6	0.0079
WC01B_29	69	133	103.6	0.0078
WC01B_3	69	31	103.6	0.0024
WC01B_30	69	32	103.6	0.0051
WC01B_31	69	158	103.6	0.0056
WC01B_32	69	143	103.6	0.0051
WC01B_33	69	116	103.6	0.0051
WC01B_34	69	149	103.6	0.0081
WC01B_35	69	139	103.6	0.0055
WC01B_36	69	88	103.6	0.0064
WC01B_37	69	122	103.6	0.0044
WC01B_38	69	69	103.6	0.0041
WC01B_39	69	167	103.6	0.0099
WC01B_4	69	0	103.6	0.0023
WC01B_40	69	775	103.6	0.0104
WC01B_41	69	221	103.6	0.0089
WC01B_42	69	207	103.6	0.0077
WC01B_43	69	923	103.6	0.0061
WC01B_44	69	2	103.6	0.0069
WC01B_45	69	90	103.6	0.0050
WC01B_46	69	72	103.6	0.0039
WC01B_47	69	20	103.6	0.0050
WC01B_48	69	30	103.6	0.0046

WC01B_49	69	42	103.6	0.0057
WC01B_5	69	265	103.6	0.0071
WC01B_50	69	143	103.6	0.0089
WC01B_51	69	153	103.6	0.0107
WC01B_52	69	64	103.6	0.0068
WC01B_53	69	241	103.6	0.0063
WC01B_54	69	113	103.6	0.0099
WC01B_55	69	48	103.6	0.0046
WC01B_56	69	206	103.6	0.0083
WC01B_57	69	202	103.6	0.0080
WC01B_58	69	279	103.6	0.0090
WC01B_59	69	97	103.6	0.0042
WC01B_6	69	144	103.6	0.0050
WC01B_60	69	50	103.6	0.0074
WC01B_61	69	17	103.6	0.0088
WC01B_62	69	14	103.6	0.0082
WC01B_63	69	7	103.6	0.0094
WC01B_64	69	84	103.6	0.0058
WC01B_65	69	43	103.6	0.0056
WC01B_66	69	113	103.6	0.0060
WC01B_67	69	105	103.6	0.0046
WC01B_68	69	21	103.6	0.0060
WC01B_69	69	17	103.6	0.0037
WC01B_7	69	115	103.6	0.0026
WC01B_70	69	46	103.6	0.0060
WC01B_71	69	274	103.6	0.0056
WC01B_72	69	209	103.6	0.0079
WC01B_73	69	53	103.6	0.0090
WC01B_74	69	156	103.6	0.0052
WC01B_75	69	29	103.6	0.0070
WC01B_76	69	130	103.6	0.0048
WC01B_77	69	197	103.6	0.0078
WC01B_78	69	274	103.6	0.0085
WC01B_79	69	106	103.6	0.0039
WC01B_8	69	5	103.6	0.0003
WC01B_80	69	175	103.6	0.0074
WC01B_81	69	439	103.6	0.0094
WC01B_82	69	199	103.6	0.0059
WC01B_83	69	156	103.6	0.0055
WC01B_9	69	42	103.6	0.0041
WC02A_1	72	130	38.4	0.0029
WC02A_10	72	237	38.4	0.0035
WC02A_2	72	2	38.4	0.0002
WC02A_3	72	14	38.4	0.0014
WC02A_4	72	0	38.4	0.0003
WC02A_5	72	93	38.4	0.0015
WC02A_6	72	140	38.4	0.0020
WC02A_7	72	142	38.4	0.0021
WC02A_8	72	124	38.4	0.0025
WC02A_9	72	12	38.4	0.0034
WC02D_1	68	263	72.0	0.0044
WC02D_10	68	120	72.0	0.0101
WC02D_2	68	14	72.0	0.0046
WC02D_3	68	9	72.0	0.0075
WC02D_4	68	19	72.0	0.0011
WC02D_5	68	55	72.0	0.0073

WC02D_6	68	0	72.0	0.0050
WC02D_7	68	119	72.0	0.0071
WC02D_8	68	195	72.0	0.0048
WC02D_9	68	14	72.0	0.0052
WWTP_GC_1	77	129	65.0	0.0042
WWTP_GC_10	77	151	65.0	0.0000
WWTP_GC_11	77	2	65.0	0.0000
WWTP_GC_12	77	0	65.0	0.0000
WWTP_GC_13	77	3	65.0	0.0001
WWTP_GC_14	77	12	65.0	0.0004
WWTP_GC_15	77	226	65.0	0.0073
WWTP_GC_17	77	12	65.0	0.0004
WWTP_GC_18	77	22	65.0	0.0007
WWTP_GC_19	77	265	65.0	0.0000
WWTP_GC_2	77	133	65.0	0.0043
WWTP_GC_20	77	973	65.0	0.0000
WWTP_GC_21	77	102	65.0	0.0033
WWTP_GC_22	77	39	65.0	0.0013
WWTP_GC_23	77	7	65.0	0.0002
WWTP_GC_24	77	31	65.0	0.0010
WWTP_GC_25	77	36	65.0	0.0000
WWTP_GC_26	77	7	65.0	0.0002
WWTP_GC_27	77	43	65.0	0.0014
WWTP_GC_3	77	135	65.0	0.0044
WWTP_GC_4	77	18	65.0	0.0006
WWTP_GC_5	77	29	65.0	0.0000
WWTP_GC_6	77	79	65.0	0.0000
WWTP_GC_7	77	46	65.0	0.0015
WWTP_GC_8	77	223	65.0	0.0000
WWTP_GC_8_1	77	644	65.0	0.0000
WWTP_GC_8_1_1	77	532	65.0	0.0000
WWTP_GC_9	77	69	65.0	0.0000
WWTP_GC_9_Tyson	77	4811	65.0	0.0000
WWTP_RB_1	77	93	65.0	0.0000
WWTP_RB_2	77	130	65.0	0.0000
WWTP_RB_3	77	0	65.0	0.0000
WWTP_RB_4	77	0	65.0	0.0000
WWTP_RB_5	77	379	65.0	0.0000

[1]Base Flow values were calculated for the calibration period.
[2]Values of “0.0000” represent negligible amounts of base flow.

Table A-3: Wet Weather RTK Parameters

Meter Basin ID	R1 (%)	T1 (hrs)	K1	R2 (%)	T2 (hrs)	K2	R3 (%)	T3 (hrs)	K3	Total R (%)
BR01	0.8	0.5	8	1.5	3	8	1.5	5	10	3.8
BR02A	0.3	0.5	6	0.3	2	8	0.5	3	10	1.1
BR02B	0.4	0.5	10	0.4	3	8	0.4	5	8	1.2
BR02C	0.5	0.5	6	0.6	2	7	0.8	5	5	1.9
BR04A	0.8	0.25	8	1.5	2.5	8	2.0	5	10	4.3
Burnside	0.1	0.5	4	0.4	2	4	2.0	12	15	2.5
CC01A_Flow	0.7	0.4	3	0.8	2	6	3.0	12	8	4.5
CC01B_Flow	0.5	0.4	2	1.0	2	6	1.0	8	12	2.5
CC03_Flow	0.2	0.6	2	0.2	2	4	1.5	5	12	1.9
CC04_Flow	0.5	0.7	4	1.2	3	4	7.5	12	15	9.2
CC06B_net	0.4	0.8	2.5	0.2	2	3	1.8	7	15	2.4
CC08_Flow	0.3	1	2	0.4	2	4	3.2	15	16	3.9
CC09_net	0.1	0.5	2	0.2	2	6	0.2	8	6	0.5
CC11_net	0.2	1	2	0.5	2	8	1.8	12	11	2.5
CC12_Flow	0.1	0.5	3	0.2	2	8	0.3	15	15	0.6
CC21_Flow	0.1	0.4	2	0.1	1.5	3	0.4	5	12	0.6
GC02	0.5	0.5	6	0.5	2	3	1.2	5	10	2.2
GC04	0.5	0.5	5	1.0	5	5	5.0	20	20	6.5
GC05	0.2	0.5	6	0.2	2	8	0.2	5	10	0.6
GC12A	0.4	0.5	5	0.5	3	8	0.3	6	8	1.2
GC15A	0.2	0.5	5	0.3	1.5	6	2.5	8	15	3.0
GC15B	0.2	0.5	5	0.2	2	7	0.0	5	5	0.4
GC16A	0.2	0.5	4	0.4	2	8	2.0	10	15	2.6
GC16B	0.3	0.5	8	0.8	4	4	5.5	20	20	6.6
GC17A	0.3	0.5	5	0.3	2	6	0.5	8	15	1.1
GC18A	0.5	0.5	3	0.8	2	8	8.0	15	20	9.3
GC18A_Flow	0.4	0.8	1	0.9	2	8	7.0	15	17	8.3
MC01A_net	0.1	0.5	3	0.1	4	4	0.1	5	8	0.3
MC01B_Flow	0.1	0.4	5	0.1	2	10	0.5	8	15	0.7
MC02_Flow	0.1	0.6	2	0.2	2	6	1.0	8	12	1.3
MC03_net	0.1	0.5	2	0.2	2	6	0.3	8	12	0.6
MC04A_Flow	0.1	0.5	6	0.1	2	4	0.1	5	10	0.3
MC04C_Flow	2.0	3	3	1.0	5	4	7.0	8	15	10.0
MC05_net	0.1	0.5	2	0.2	2	6	3.0	5	8	3.3
PFM03	0.7	0.5	4	1.0	2	4	2.0	5	10	3.7
PFM05	0.1	0.5	5	0.2	1.5	8	0.5	7	5	0.8
PFM06	0.1	0.5	5	0.2	2	6	0.3	5	10	0.6
PFM07	0.2	0.25	6	0.6	2	4	2.5	8	20	3.3

Meter Basin ID	R1 (%)	T1 (hrs)	K1	R2 (%)	T2 (hrs)	K2	R3 (%)	T3 (hrs)	K3	Total R (%)
PFM10_Flow	0.1	2	2	0.1	2	6	1.2	12	19	1.4
PFM11_net	1.0	1	2	1.0	3	4	3.0	3	5	5.0
PFMZoo	0.3	0.5	4	0.3	1.5	6	0.3	4	5	0.9
RB01	0.2	0.25	2	0.2	0.5	3	0.6	5	10	1.0
RB03A	0.1	0.25	4	0.0	2	4	0.0	3	5	0.1
RB03B	0.6	0.25	2	0.3	1	2	0.0	5	10	0.9
RB04	0.1	1	2	0.2	2	4	0.0	5	10	0.3
RB05A	0.1	0.25	3	0.2	1	3	0.0	3	5	0.3
RB05B	1.0	0.5	2	1.5	1	4	0.0	2	5	2.5
RB08B	0.2	0.5	4	0.2	2	2	1.0	8	25	1.4
SB01B_Flow	0.2	0.6	2	0.3	2	4	1.3	12	5	1.8
SB02_net	0.4	0.6	2.5	0.2	2	4	0.7	12	10	1.3
SB02B_Flow	0.2	0.4	2	0.6	2	4.5	2.1	15	10	2.9
SB03A_net	0.3	1.5	2	0.5	2	6	2.3	12	5	3.1
SB03B_Flow	0.3	0.5	1	0.2	2	4	0.3	3	5	0.8
SB04B_Flow	0.3	0.6	1.4	0.2	2	4	0.1	12	15	0.6
SB04C_Flow	0.5	0.3	2	0.6	2	4	0.3	3	5	1.4
SB04E_Flow	0.4	0.3	2	0.8	1	4	2.0	6	5	3.2
SB05A_net	0.6	0.3	1.5	0.2	2	4	0.3	3	5	1.1
SR01	0.2	0.5	3	0.2	2	4	0.5	3	5	0.9
SR04A	0.1	0.5	2	0.2	1	4	0.0	4	6	0.3
SR04B	0.5	0.5	3	0.3	1	8	1.0	6	8	1.8
SR07	0.1	0.5	3	0.1	1	4	0.5	5	10	0.7
SR08	0.2	0.5	2	0.2	1	4	0.3	5	5	0.7
SR09	0.1	0.5	3	0.1	2	4	0.2	5	5	0.4
SR11	0.5	0.5	3	0.6	1	6	1.5	5	8	2.6
SR13	0.6	0.5	4	1.3	2	6	8.0	12	30	9.9
SR14A	0.1	0.5	5	0.2	1.5	4	0.3	5	15	0.6
SR14C	0.1	0.25	8	0.5	1.5	6	3.0	8	15	3.6
SR15	0.5	1	2	0.7	2	4	2.0	5	15	3.2
WC01	0.2	0.5	4	0.3	2	5	0.5	5	10	1.0
WC01B	0.1	0.5	5	0.2	1.5	4	3.0	8	20	3.3
WC02A	0.1	0.5	5	0.1	2	4	0.2	5	5	0.4
WC02D	0.1	0.3	4	0.2	1	8	0.3	5	15	0.6

Table A-4: Groundwater Infiltration Module (GIM) Parameters

GIM ID	Soil Depth (ft.)	Percolation Coefficient	Baseflow Coefficient	Percolation Percentage Infiltrating	Infiltration Coefficient	Percolation Threshold	Porosity of Soil	Porosity of Ground	Baseflow Threshold Level (ft.)	Baseflow Threshold Type	Infiltration Threshold Level (ft.)	Infiltration Threshold Type
BR02A	3	0.4	50	50	50	85	40	40	2	Absolute	2.1	Absolute
BR02B	3.3	0.4	30	15	50	85	40	40	2	Absolute	2.1	Absolute
BR02C	9	1	100	20	70	81	40	40	1.9	Absolute	2.1	Absolute
BR04A	3	1	500	5	120	85	40	40	2	Absolute	2.1	Absolute
CC01A_Flow	3	3	550	6	180	84	40	40	2.02	Absolute	2.15	Absolute
CC01B_Flow	3	3	250	18	120	89	40	40	2.02	Absolute	2.15	Absolute
CC03_Flow	4	0.1	55	10	25	78	40	40	2.02	Absolute	2.11	Absolute
CC04_Flow	2.4	12	350	45	180	98	40	40	2.02	Absolute	2.02	Absolute
CC06B_net	3	0.5	20	15	55	89	40	40	2.1	Absolute	2.15	Absolute
CC08_Flow	3	0.8	750	35	59	93	40	40	2.2	Absolute	2.15	Absolute
CC09_net	3	4	500	50	75	85	40	40	2.2	Absolute	2.5	Absolute
CC11_net	3	12	250	75	250	97	40	40	2.1	Absolute	2.2	Absolute
CC12_Flow	3	0.5	500	25	75	89	40	40	2.2	Absolute	2.5	Absolute
CC21_Flow	3	0.09	250	5	20	82	40	40	2.02	Absolute	2.09	Absolute
GC02	5	1	100	25	50	82	40	40	2	Absolute	2.1	Absolute
GC12A	8	2	200	20	40	80	40	40	2	Absolute	2.1	Absolute
GC15B	4	3	1	20	120	85	40	40	2	Absolute	2.1	Absolute
GC16A	4.5	2	200	20	40	82	40	40	2	Absolute	2.1	Absolute
GC17A	2	2.5	100	30	120	80	40	40	2	Absolute	2.1	Absolute
GC18A_Flow	4	24	100	75	120	92	40	40	2	Absolute	2.2	Absolute
MC01A_net	2	5	250	5	120	92	40	40	2.01	Absolute	2.1	Absolute
MC02_Flow	2	4	100	45	120	87	40	40	2	Absolute	2.1	Absolute
MC03_net	2	4	100	45	120	87	40	40	2	Absolute	2.1	Absolute
MC04A_Flow	2.5	2.5	100	9	120	80	40	40	2	Absolute	2.1	Absolute
MC04C_Flow	3	22	100	45	120	82	40	40	2	Absolute	2.01	Absolute
MC05_net	4	24	100	52	120	86	40	40	2	Absolute	2.2	Absolute
PFM10_Flow	3	12	500	50	75	85	40	40	2.2	Absolute	2.5	Absolute
PFM11_net	3	11	250	75	250	87	40	40	2.1	Absolute	2.2	Absolute
RB01	3	0.1	200	10	20	85	40	40	2	Absolute	2.1	Absolute
RB05A	0.5	0.08	30	5	75	95	40	40	1.9	Absolute	2.2	Absolute
SB01B_Flow	4	0.04	200	5	120	81	40	40	2.05	Absolute	2.06	Absolute
SB02_net	3	0.6	80	12	120	92	40	40	2.05	Absolute	2.1	Absolute
SB02B_Flow	3	0.7	15	6	250	84	40	40	2.05	Absolute	2.14	Absolute
SB03A_net	2	12	200	55	250	89	40	40	2.05	Absolute	2.26	Absolute
SB04B_Flow	3	0.4	130	12	52	86	40	40	2.01	Absolute	2.1	Absolute
SB04E_Flow	3	0.4	130	3	120	89	40	40	2.01	Absolute	2.1	Absolute
SB05A_net	2	5	130	65	120	89	40	40	2.01	Absolute	2.1	Absolute
SR04A	2.5	0.15	200	18	20	78	40	40	2	Absolute	2.1	Absolute

GIM ID	Soil Depth (ft.)	Percolation Coefficient	Baseflow Coefficient	Percolation Percentage Infiltrating	Infiltration Coefficient	Percolation Threshold	Porosity of Soil	Porosity of Ground	Baseflow Threshold Level (ft.)	Baseflow Threshold Type	Infiltration Threshold Level (ft.)	Infiltration Threshold Type
SR04B	2	1	200	1	80	80	40	40	2	Absolute	2.1	Absolute
SR07	6	1	500	3	80	90	40	40	2	Absolute	2.1	Absolute
SR08	5	0.3	500	50	30	95	40	40	2	Absolute	2.1	Absolute
SR09	1	0.07	1	30	20	90	40	40	2	Absolute	2.2	Absolute
SR11	3	0.05	200	10	20	85	40	40	2	Absolute	2.2	Absolute
SR14A	2	0.5	200	30	10	80	40	40	2	Absolute	2.2	Absolute
SR14C	4	0.5	200	18	40	80	40	40	2	Absolute	2.2	Absolute
WC01B	4	0.25	100	10	60	80	40	40	1.9	Absolute	2.4	Absolute